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The Bluffer's Guide to Hydrogen

This note is intended as a background briefing on the clean hydrogen industry. More details are available on request from HydrogenOne Capital LLP. HydrogenOne Capital LLP was founded in 2020 by JJ Traynor and Richard Hulf, as a specialist investment manager in clean hydrogen, carbon capture and grid scale energy storage. The founders have a combined 60 years of experience in the global energy sector and capital markets.

hydrogenonecapital.com

Table of Contents

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Hydrogen – the elevator speech

- The Paris Agreement and ‘beyond diesel’ mean that everyone is talking about clean hydrogen.
- This clean hydrogen can be used to clean up heavy industry and displace fossil fuels more generally.
- Paris Agreement means a Net Zero economy – clean hydrogen expected to be a $1tn market in that.
- ‘Beyond diesel’ means installing hydrogen fuel in heavy vehicles like trucks, trains and ships
- You can use carbon capture and storage or renewable electricity to make clean hydrogen. This technology is proven and underway today.
- Over 30 countries have hydrogen policies in place, with $70bn of funding.
- In the UK, for example, there is already £3.5bn of low carbon government funding including hydrogen, and further policy announcements coming before November 2021’s COP 26 meeting.
- There are $300bn of clean hydrogen projects on the drawing board today.
- If you’re into energy, this is all pretty hard to ignore. The sector has $1tn market potential in 2040. A 20x increase in clean hydrogen supply is anticipated to 2030, and 500x to 2050…potentially 10% of the primary energy mix by then.

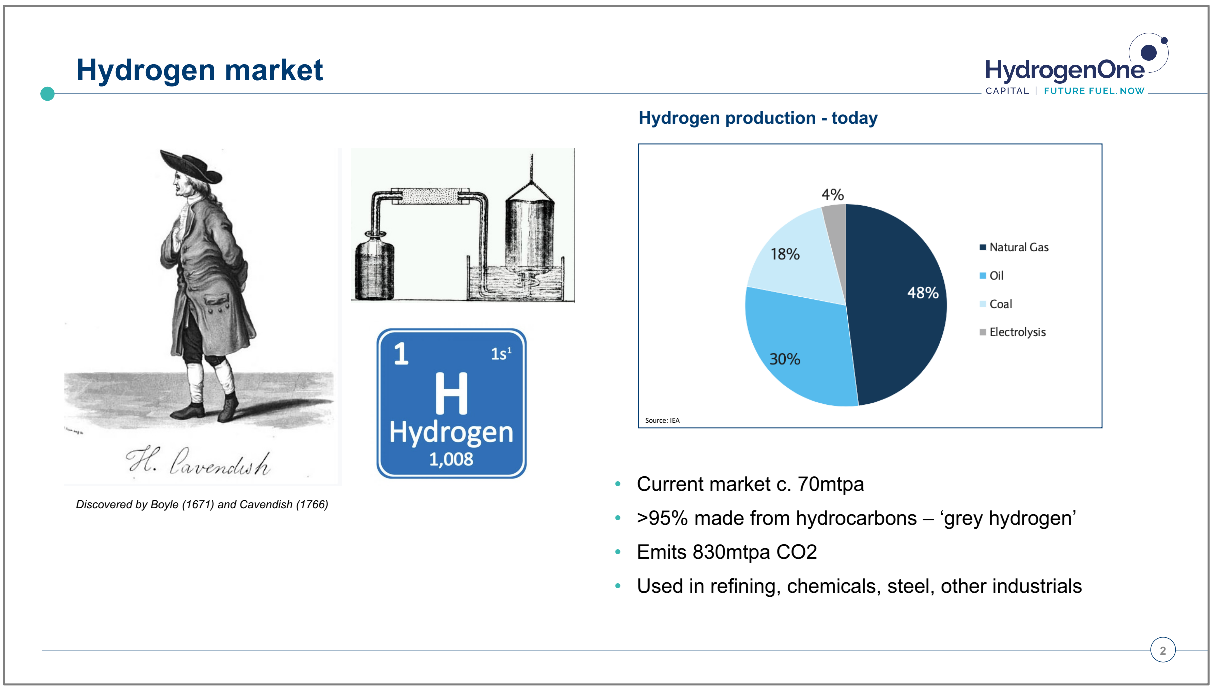
Key jargon

Jargon	Explained	Key players examples
Electrolysers	Decades-old technology going through a renaissance. Car to shipping container-sized units. Electricity enters/leaves via an anode/cathode, and passes through an electrolyte to release heat, hydrogen and oxygen. There are various types of electrolysers, reflecting innovation and the specific purpose of the installation	
…..Alkaline electrolysers	The original. Uses potassium and sodium hydroxide electrolyte. Slower response time to the 'ups and downs' of renewable power, but technology improvements are addressing this. MW Scale, and relatively low cost	Cummins, McPhy, NEL
…..PEM electrolysers	Newer tech – uses a proton exchange membrane. Faster response times and work off a low power load. Popular for green hydrogen systems. Below MW scale but upscaling fast	Cummins, ITM, NEL
….Solid oxide electrolysers	Solid ceramic electrolyte. Uses heat by-product to warm up the electrolyte, meaning it will run with less electricity. A technology that runs hot (700 degrees)	Elcogen, Haldor Topseo
Fuel cells	Anode/cathode system that mixes air (O_2) with hydrogen to release electricity, heat and water. As in electrolysers, the system uses an electrolyte hence there are PEM, solid oxide and other types. Brick to cooker-sized units. Used in trucks, trains, planes, and large buildings as an electricity source	Ballard, Toshiba, Plug Power
CCUS	Carbon capture, use and storage. CO_2 'streams' are extracted from refineries, power plants etc., and piped to wells that have been drilled into geological reservoirs, where the CO_2 is injected and stored. Some systems use the CO_2 for other manufacturing processes	Large oil & gas companies e.g., Exxon, Shell, BP, Equinor, industrial gas companies e.g. Linde, Air Liquide
Grey hydrogen (aka 'brown' and 'black')	Today's 70mtpa industry. Hydrogen made by reforming coal, gas, oil, with consequent greenhouse gas (GHG) emissions (2X UK annually). Steam methane reforming (SMR) is the main process used as well as Autothermal Reforming (ATR)	Air Liquide, Air Products, Linde
Blue Hydrogen	Takes grey hydrogen, but captures and stores the GHG in geological reservoirs (CCS). Matches the skill-sets of integrated oil companies	Shell, Valero, Equinor, Aramco, BP
Green hydrogen	Uses green electricity from wind or solar to power electrolysers, which split water into oxygen and hydrogen. A rapidly-emerging technology that is on the cusp of large scale roll out.	Air Products, Iberdrola, Shell, Engie, Gasunie, ERM, multiple smaller players
Other colours of hydrogen	*Yellow* – takes excess nuclear electricity into electrolysis. *Turquoise* – splits natural gas into hydrogen and solid carbon.	Early stage / experimental
Power-to-X	Conversion of excess electricity supply to storable fuel eg hydrogen and ammonia	Everyone in electrolysis is interested in this

History lesson

Hydrogen was discovered by Boyle in 1671 and identified as an element by Cavendish in 1766 “inflammable air”, which makes water when burnt.

The hydrogen market is today is pretty big, at some 70 million tonnes per year, and the hydrogen is made by industrial gas companies such as Air Liquide, Linde and Air Products.



This hydrogen, known variously as “grey” or sometimes “black”, is made by splitting fossil fuels like natural gas and coal, and releasing greenhouse gases.

The global CO_2 emissions from this are high, roughly 2X UK total GHG emissions annually.

Today, **hydrogen is widely used** in high temperature processes and as a feedstock for ammonia and oil refining, mainly as a desulphurization agent and as a reducing agent in the steel and cement industries . It is also used as a coolant in the power sector.

Hydrogen can also be used to make electricity and heat, using **fuel cells**. Hydrogen fuel cells have been around for a while as well – a fuel cell is similar to a battery, with an anode and a cathode, sandwiched around an electrolyte. The hydrogen goes in, and heat, electricity and water by-product come out. This is an **emissions-free** reaction, and of course attractive in the transport and power sectors, compared to the emissions that come with fossil fuels.

Hydrogen fuel cells have been around since the 1960s, when hydrogen fuel cells were used for electricity supply in space by NASA, and GM made the first fuel cell vehicle.

The prospect of manufacturing **clean hydrogen** – with no GHG emissions – is enormously attractive to the industries that use grey hydrogen today – they are under substantial pressure to clean up, to play their part in Net Zero. More broadly, clean hydrogen has the potential to displace fossil fuels in the energy mix, particularly in the heat, power and transport sectors.

Like other clean energy sources, spending and innovation on clean hydrogen has fluctuated with oil prices and government policy.

It's a little-talked about fact that modern renewables like wind and solar are about 3% of the global energy mix, despite massive investment and commercial deployment since the mid-1970s.

Clean hydrogen has been developing on a similar time scale, against the backdrop of low cost and abundant fossil fuels.

Hydrogen timescales typical of new energy roll-out commercial deployment underway

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- **1960s** – NASA fuel cells on Gemini and Apollo
- **1966** – GM makes first the first FCV
- **1970s** – oil crisis stimulates renewables + hydrogen R&D. First commercial wind farm 1975
- **1980s** – hydrogen used in distributed powergen
- **1990s** – PEM fuel cells emerge for vehicles
- **Early 2000s** oil spikes and climate change stimulate renewables and hydrogen funding (US/EU)
- **2011-14** onwards – China and Japan hydrogen strategies
- **2014-15** – Toyota and Hyundai launch commercial FCVs
- **2015-present**
  - Modern renewables reach c.3% of primary energy supply
  - >50,000 FCV and fuel cell forklifts
  - Germany launches first hydrogen trains
  - 5X increase in fuel cell sales
  - Blue and green hydrogen pilots successfully deployed for 'next-gen' supplies
  - **Wide uptake of hydrogen in country and corporate 'Net Zero' strategies**

4

What drives demand for clean hydrogen?

Policy makers and industry are converging on clean hydrogen as a core technology to deliver Net Zero and improved air quality.

The Paris Agreement has led >30 countries to set out hydrogen policies and $70bn of funding as part of Net Zero targets to deliver the Energy Transition to a low carbon economy.

Burning fossil fuels for energy releases green-house gas and poisonous particulates. More than 20 countries have announced sales bans on internal combustion engine vehicles before 2035, and over 25 cities have pledged to buy only zero-emission buses from 2025 onwards. This is driven by Net Zero agendas, plus the imperative to reduce poisonous emissions from diesel in urban environments.

What is driving the hydrogen economy?
Paris Agreement and Net Zero + urban air quality agenda

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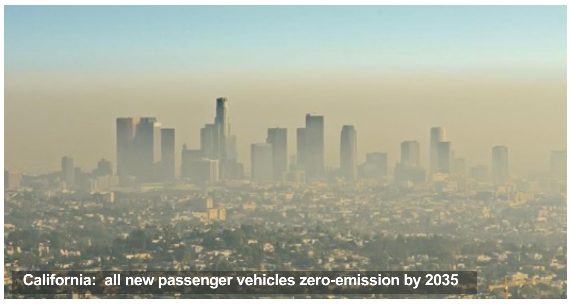
- **75 countries announced Net Zero strategies**
- **>30 countries have hydrogen strategies**

- >90 membership of Hydrogen Council

- **4.2 million deaths/year from air pollution**
- **91% of population live in places exceeding WHO air quality guidelines**


California: all new passenger vehicles zero-emission by 2035

- Battery electric (BEV) and fuel cell vehicles (FCV) are zero-emission 'tailpipe'
- FCV advantaged over BEV in heavy and long distance applications: trucks, buses, trains, forklift

13

According to the World Health Authority (the "WHO"), some 4.2 million deaths per year are caused by poor ambient air quality, and 91% of the world's population live in places exceeding the WHO's air quality guidelines. Much of this pollution is as a result of emissions from internal combustion engines ("ICE") and fossil fuel power plants.

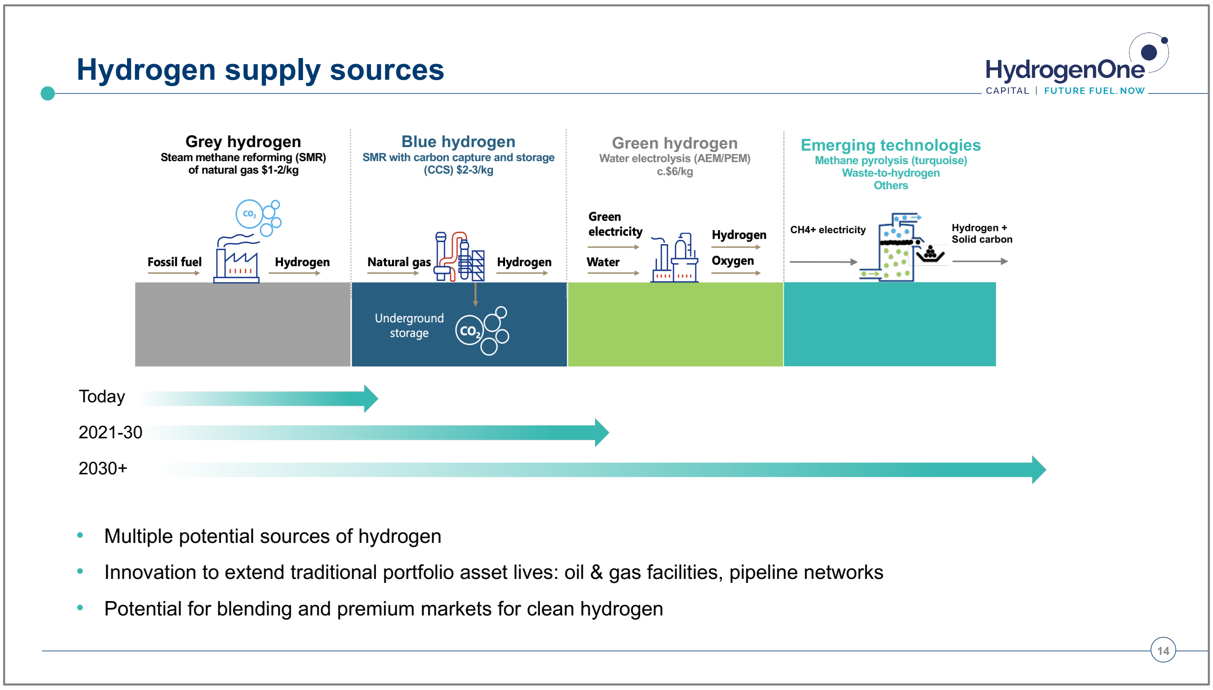
Access to clean hydrogen is a priority for refiners and steel and ammonia producers as they address GHG emissions. Heavy industry such as steel and oil refining are under tremendous pressure to reduce or eliminate grey hydrogen from processes, to reduce the GHG emissions that result from this. Much of today's demand for clean hydrogen is basically a clean-up of grey hydrogen.

In the future, **clean hydrogen can displace fossil fuels in hard to decarbonize sectors**, either by burning it in power plants to replace natural gas, coal and oil, or by converting it to electricity through hydrogen fuel cells. Water vapour is the only by-product of using hydrogen as a fuel.

Hydrogen can store and transport intermittent renewable power at a grid scale. As wind and solar become a large percentage of electricity supply over time, the electric grid will need large scale electricity storage to offset periods of low wind and low light. By converting electricity to hydrogen, the energy can be stored over long periods of time either in pipelines and tanks, or in underground salt caverns.

The hydrogen sector has $1tn market potential by 2040. A 20x increase in clean hydrogen supply is anticipated to 2030, and 500x to 2050, as the scale-up of renewable power alongside the phase-out of fossil fuels, improves the economics of established hydrogen technologies.

Where does clean hydrogen come from?



You hear a lot of jargon on where hydrogen comes from – colour codes. We think of four basic types, and there are one or two others out there.

Grey hydrogen is how we make it today. By heating methane gas with steam, a process called steam methane reforming – (SMR). This is efficient but releases CO_2. This is a large industry today and has been around for decades.

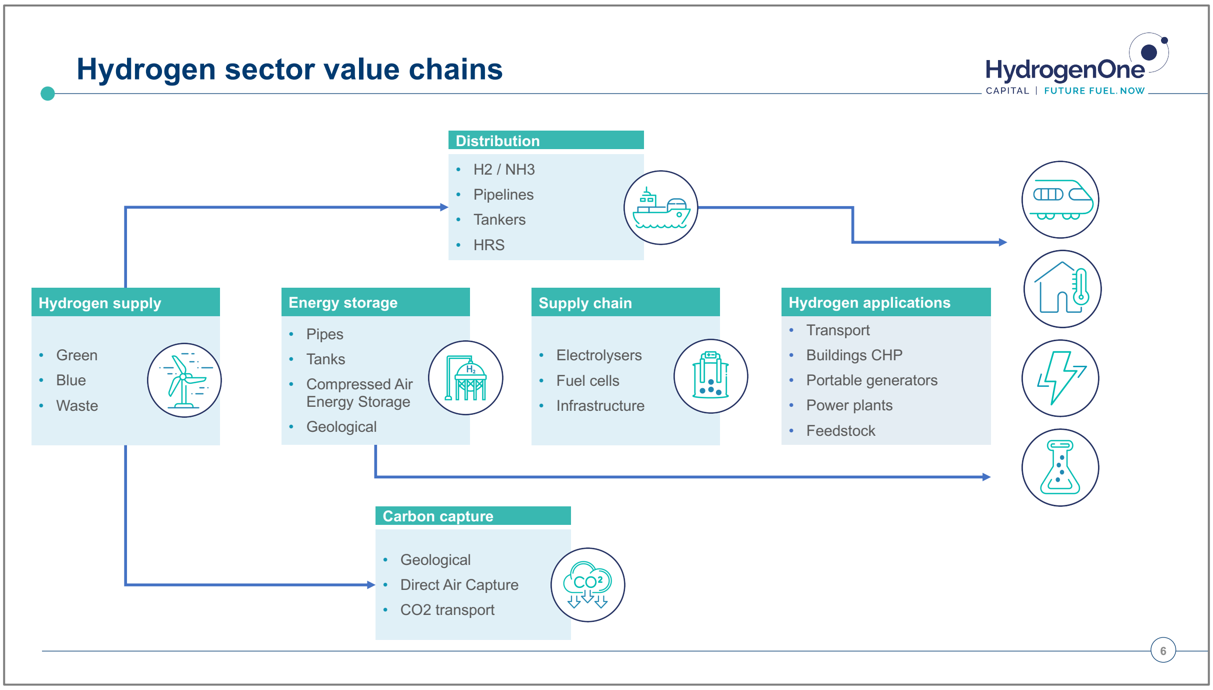
Blue hydrogen uses SMR, like grey, but captures the CO_2 and stores it.

Green does not involve hydrocarbons, and uses renewable electricity – eg wind and solar – to run electrolysers, which make hydrogen and O_2.

Turquoise is a pyrolysis treatment (chemical decomposition at high temperatures) of conventional natural gas, which produces hydrogen and solid carbon as a by-product. This is really at the R&D stage.

At the start of 2021, there are at least 228 hydrogen projects announced world-wide, representing a total capital cost of over $300 billion, of which $80 billion are in production, construction or in detailed design. Over half of this potential (55%) sits in Europe. (see Appendix 1).

What are the key components of the clean hydrogen industry?



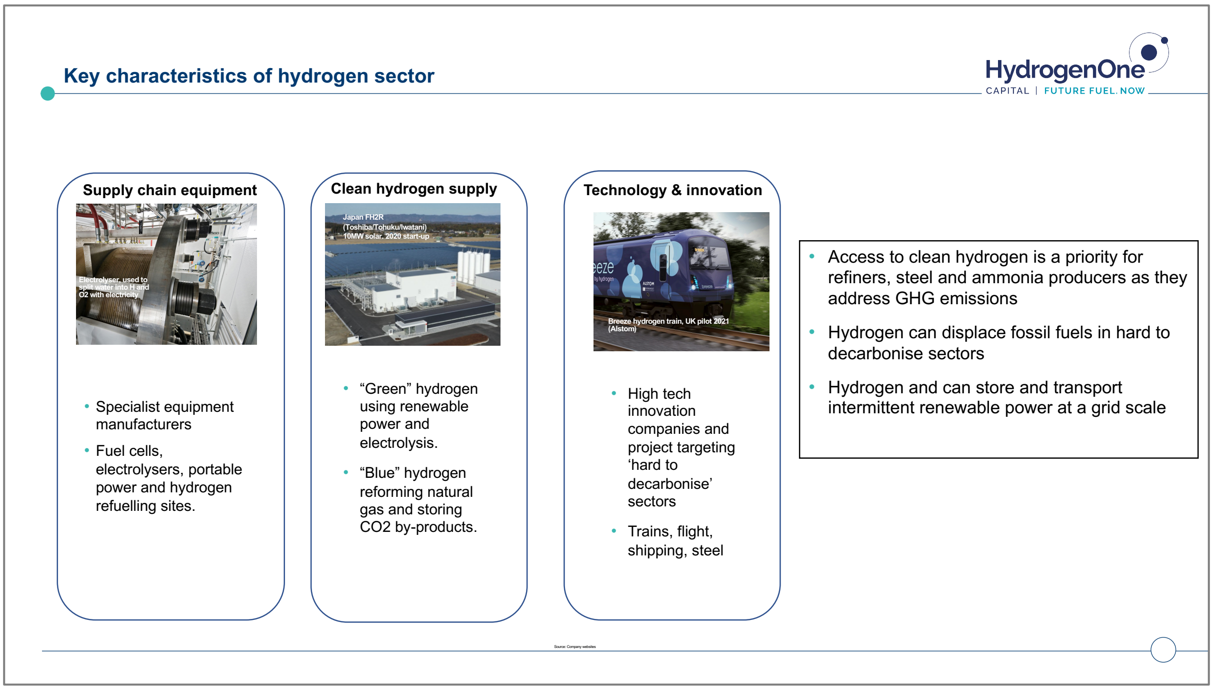
Clean hydrogen is made at industrial sites with access to low-cost green electricity ("green") or natural gas and geological CO_2 storage sites ("blue").

The hydrogen is **shipped or stored** in pipelines and tanks to customers. For industries such as oil refining, hydrogen is used in the desulphurization of crude oil, amongst other processes. Alternatively, fuel cells are used to convert the hydrogen to electricity or heat – this can take place in trucks, trains and buses via hydrogen tanks, or in large buildings such as hotels and offices, using combined heat and power (CHP) units.

Hydrogen has a similar *energy mass* (energy per kilogramme) as conventional liquid fuels such as gasoline. However, hydrogen has a lower *volumetric energy density*, and the gas compressed and stored in pressurised tanks for storage and shipment. Some participants are planning to ship large volumes of liquid hydrogen from supply sources to customers, or to transport hydrogen by first converting it to liquid ammonia. Liquid hydrogen storage needs cryogenic tanks maintained at -253°C. Ammonia has a high hydrogen content (17.65 wt per cent.), it has an established distribution network, and ability to be liquefied at 10 bar or -33°C.

Electrolysers are the key component of green hydrogen supply. These car-sized units use electricity to split water into O_2 and hydrogen. Companies such as ITM Power in the UK, and Siemens Energy in Germany are major electroyser suppliers.

Fuel cells, which are brick-sized to cooker-sized units, convert hydrogen to electricity with water as a by-product. Ballard Power in Canada, and Powercell in Sweden are major fuel cell suppliers.



Once produced hydrogen has to be transported and stored. There is an established manufacturing industry that is adapting to the new specifications required for hydrogen gas. These business supply compression, pipelines and storage cylinders and tanks.

Over time Hydrogen Refueling Stations (HRS) are expected to move from specialized truck, bus and train depots to mainstream petrol station forecourts. Other applications include the decarbonization of portable power from diesel and petrol powered generators to hydrogen powered units.

One of the most attractive things about hydrogen gas is the relatively easy modifications that can be made to existing infrastructure to introduce a zero carbon fuel.

Myths in clean hydrogen

Hydrogen sector has plenty of ill-informed commentary, and plenty of lobbying between competing industry groups. Here are the main arguments, and a rational middle:

Blue versus Green

Blue hydrogen uses a natural gas feedstock, hence supports continued fossil fuels drilling and production. Protagonists of green hydrogen, particularly companies involved in making renewable power and electrolysers, lobby against blue, and characterize it as an oil company in disguise.

Reality: Blue hydrogen is a viable option for clean hydrogen NOW

- A ultra-low GHG emissions fuel, which is the whole point.
- Cost-competitive with grey hydrogen, whereas green hydrogen is more expensive
- Enables the continued use of natural gas wells and pipeline infrastructure that would otherwise have to be scrapped. This accounts for multi-trillions of dollars of sunk capital

Reality: Green hydrogen is a good short to medium-term option

- Complementary with blue and will scale up as renewable power grows
- Relatively high cost today, and a little behind blue in terms of cost curve

Battery electric cars versus hydrogen fuel cells

Proponents of battery electric cars argue that hydrogen fuel cells don't compete.

Reality: battery and fuel cell vehicles both have great niches

Battery electric is the best option for cars over short to medium distances. However, batteries can't store enough energy at a reasonable size to move heavy vehicles over long distances. Hydrogen fuel cells are the best option for trucks, trains (on tracks that are not electrified), fork lift and SUV.

Hydrogen fuel cells flight versus synthetic aviation fuel

This is a complex area, that is really in the innovation / R&D stage. It's too soon to call this, however companies like British Airways and Airbus are investing in the technologies.

Reality: hydrogen fuel for flight has great potential but is not proven commercially

Hydrogen tanks that feed fuel cells to power turbo prop planes is a real option, and there are test flights underway today (eg ZeroAvia). This could work for short haul commercial flight eg 50 seaters. Airbus are developing commercial jet engines to potentially burn hydrogen by storing fuel in the fuselage.

Hydrogen has been used in jet engines in the Russian aviation sector. However, bulky and strong liquid hydrogen tanks are needed to fuel long distance flight, or innovation in hydrogen storage, due to hydrogen's low energy density compared to traditional jet fuel.

A viable alternative is to combine clean hydrogen with CO_2 to make synthetic aviation fuel. This is World War 2 technology ("Fischer Tropsch") which was developed to make transport fuels from coal and gas. It is, however, relatively high cost.

Clean hydrogen is high cost and won't compete with fossil fuels.

These arguments centre on the cost and time required to build up hydrogen infrastructure versus producing lower carbon, oil and gas via CCS.

Reality: these are old arguments that are rapidly falling away. As an example, all of the big oil companies, including fossil fuel enthusiasts ExxonMobil now have hydrogen and carbon capture strategies – ExxonMobil see hydrogen as a $1tn market medium term; BP see hydrogen as up to 15% of the energy mix long term. The debate has really shifted to the timescales.

There are headline hydrogen prices on a $/kg basis:

- Grey $1-2/kg: established market price. This source of hydrogen will be phased out
- Blue $2-3/kg: includes CCS cost
- Green $3-6/kg: higher price, which reflects early-stage projects

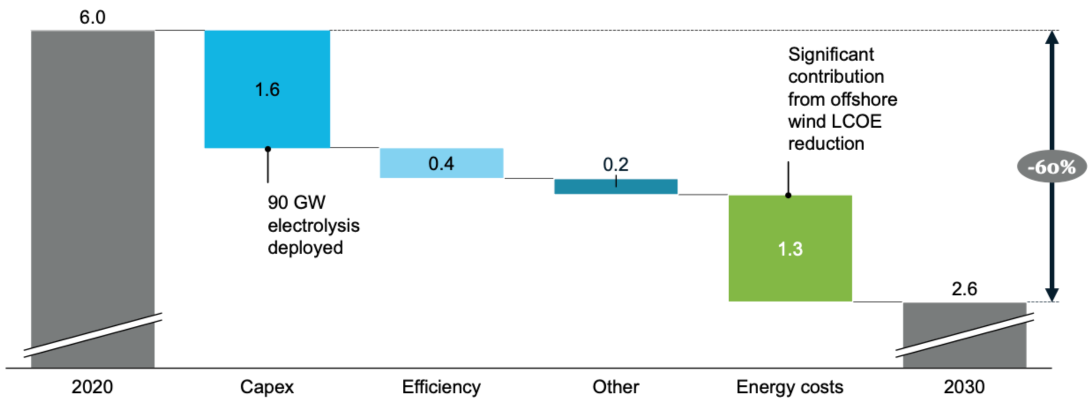
Fossil fuels market share will fall over time in the energy transition. They are expected to become more expensive due to carbon penalties and / or mitigation costs. But there will be 'low carbon fuels' with things like CCS applied.

Hydrogen is cost competitive with other low carbon fuels including such fossil fuels at a hydrogen cost of $1-4/kg (building heating $4, trucks $3, cars $2, industrial heat and power <$2). These costs are in the range of grey and blue hydrogen today. Green hydrogen costs are around $6/kg, which are 60% lower than 2010 and are expected to be $2-$3/kg in 2030 due to electrolyser scale up (-$2/kg) and lower green electricity costs (-$1.3/kg).

Most categories eg transport and heat/power reach cost equivalence with other low carbon energy in 2030.

Exhibit 13 | Renewable hydrogen from electrolysis cost trajectory

Cost reduction lever for hydrogen for electrolysis[1] connected to dedicated offshore wind in Europe (average case)
USD/kg hydrogen



1. Assume 4,000 Nm3/h (~20 MW) PEM electrolysers connected to offshore wind, excludes compression and storage
2. Germany assumed

SOURCE: H21; McKinsey; Expert interview

Capex decreases ~60% for the full system driven by scale in production, learning rate, and technological improvements.

Increasing system size from ~2 MW to ~90MW.

Efficiency improves from ~65% to ~70% in 2030.

Other O&M costs go down following reduction in parts cost and learning to operate systems.

Additionally, storage may become cheaper (not included).

Energy costs[2] offshore wind LCOE decreases from 57 to 33 USD/MWh, and is assumed to be dedicated to hydrogen production.

Grid fees decrease from ~15 to 10 USD/MWh.

Load factor of 50%, i.e. ~4,400 full load hours equivalent.

Source: McKinsey 2020

You can't put hydrogen into natural gas networks, can you?

Various theories that hydrogen will corrode pipes, it will leak, and that it can't be burnt in power plants and domestic boilers.

Reality: this is an out-of-date concept. In the early stage, there will be blending of hydrogen and natural gas in existing networks. For example, HyDeploy (UK) has trailed a 20% hydrogen blend with natural gas into domestic boilers (2021). Pure hydrogen boilers are on the market today. Gas turbines that use hydrogen in power plants are being deployed in the Netherlands, Japan and the USA.

Government policies

The hydrogen economy is a truly global proposition. Different countries and regions have different strengths and challenges across the demand-side and the supply-side requirements of the hydrogen supply chain.

Wind and solar-rich regions are investing in domestic supplies and long-range export potential.

For example, Japan and Germany, who are ‘short’ renewables and natural gas, are engaged politically with Saudi Arabia, Morocco, Australia and others to secure supply.

Fossil fuels producing regions are evolving their technology bases to renewables generally, and support the use of blue hydrogen to extend the useful life of natural gas infrastructure.

Many countries have policies, targets and funding in place to put hydrogen into the transport sector for Net Zero and air quality. Globally $70 billion of public funding is in place for this.

California, for example, has laws requiring all new passenger vehicles to zero emissions by 2035, and has targets and grants in place to increase hydrogen penetration.

The EU, Japan, South Korea and California have the most advanced policy formation.

In the EU for example, 2020 saw EU targets for hydrogen to meet 14% of Europe’s energy needs by 2050. To help reach this goal, from 2020 to 2024, it will support the installation of at least 6GW of renewable hydrogen electrolysers in the EU, and the production of up to one million tonnes of renewable hydrogen. From 2025 to 2030, hydrogen needs to become an intrinsic part of the integrated energy system, with at least 40GW of renewable hydrogen electrolysers and the production of up to ten million tonnes of renewable hydrogen in the EU.

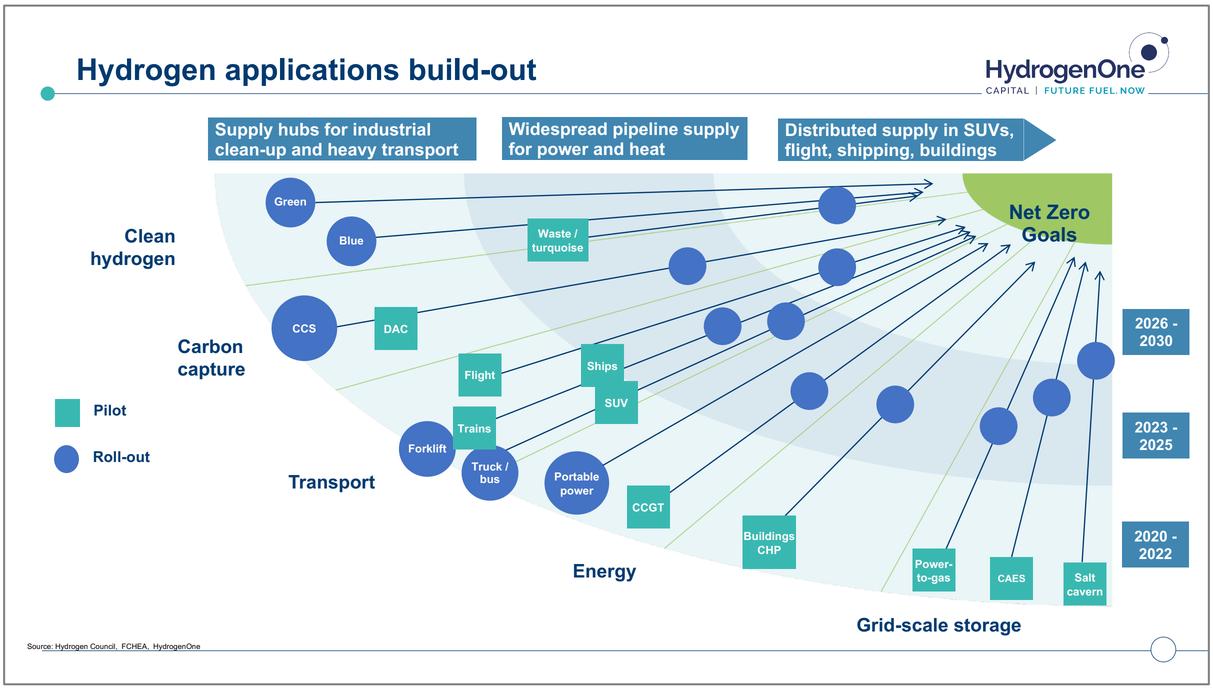
The **UK hydrogen policy** is at an earlier stage than other regions, but is gaining ground quickly. £3.5bn of government funding is in place for a strategy that emphasizes blue, as well as green hydrogen, using the UK’s existing oil & gas industry and skills, and its abundant wind resources. Further policy announcements are expected, ahead of the COP 26 meeting in November 2021.

See Appendix for an update on UK hydrogen policy.

How is clean hydrogen being rolled out?

HydrogenOne believes that the clean hydrogen industry is investable now and is gathering momentum.

2021-2025. In the next four years we anticipate the go-ahead of material scale blue and green hydrogen production projects. This includes blue hydrogen schemes integrated with refineries, chemicals and steel plants, to reduce the GHG footprint of these facilities through cleaner hydrogen feedstock supplies.



We expect material green hydrogen manufacturing to commence, particularly in around the high-quality wind resources in the North Sea (UK, Netherlands, Denmark), the wind and solar resources of Southern Europe, Middle East and Australia. We expect many of these activities to be clustered around industrial zones and ports, with off-takers in incumbent hydrogen-consuming sectors and centralised bus and truck fleets.

Hydrogen fuel cells have been deployed at commercial scale in selective transport applications, such as fork lift, city buses, and portable power generators. We expect to see rapid build out of these applications to continue, particularly in the multiple countries and cities that have committed to early phase out of ICE transport. Much of this hydrogen will be derived from dedicated hydrogen hubs, which will have offtake agreements and supply logistics configured to specific transport fleets, industrial sites and other customers.

2025-2030. In this timeframe, we expect to see the emergence of larger clean hydrogen manufacturing sites, with a more rapid pace in growth in green hydrogen ahead of other sources, at 500MW or larger scale. As intermittent and seasonal renewable energy grows in the overall mix, the requirement for energy storage for system buffering will be met by geological storage of hydrogen and Compresses Air Energy Storage (CAES). Blending technologies and mandates to distribute hydrogen via modified natural gas infrastructure will become widespread.

Hydrogen should be more widely available to short term contracted and spot market customers at this time.

We expect to see the deployment at scale of hydrogen used for building-scale heat and power ("CHP"), and hydrogen burned in modified turbines at large scale power plants, which are in the pilot stage today. A wider uptake of hydrogen in trucks, trains and shipping will come alongside the buildout of HRS. We expect to see hydrogen introduced more widely by blending with natural gas in modified natural gas grids.

2030 and beyond. In the longer term, once single hydrogen production projects have been scaled up to 1GW and beyond, and distributed projects have been successfully built-in industrial centers and ports, we expect that hydrogen use will move into the public consumer areas. At this point fuel cells could be economic for passenger vehicles, particularly heavy applications such as SUVs. Hydrogen will likely have been rigorously tested in the aerospace industry and hydrogen powered aircraft could be in mainstream use, either in fuel cells for turboprop, or via synthetic fuels in jets.

Appendix 1:
Blue and green hydrogen project examples

A number of full-scale **blue hydrogen** projects are in production or in design, including:

- Shell-operated Quest, in Alberta, has been producing 900 tonnes per day of blue hydrogen since 2015, for use in crude oil refining, with geological CCS of the associated GHGs.

- A Valero/Air Products joint venture in Texas has been producing 500 tonnes per day of blue hydrogen since 2013, with the associated CO_2 injected into oil reservoirs to improve oil recovery. These small-scale commercial projects have established the technologies and reliability of blue hydrogen, which is set for rapid expansion in the coming five years.

- Hynet, in the north west of England. This project would add SMR capacity at the Essar Stanlow refinery, with offshore CCS in depleted gas reservoirs in Liverpool Bay. Phase 1 is intended to be a GHG reduction project for the refinery, with follow on phases to supply clean hydrogen to local industry, producing up to 18TWh per year of low carbon hydrogen. Final investment decision ("FID") for Phase 1 is scheduled for 2021.

- The Hydrogen to Humber Saltend project in the UK (H2H Saltend), led by Equinor, will produce hydrogen from natural gas with a 600MW auto thermal reformer, and CCS. The plant will use CCS facilities developed by the Zero Carbon Humber Alliance. The alliance is a consortium of Equinor, British power supplier Drax Group, and transmission network National Grid. They aim to develop a zero-carbon industrial cluster using CCS. FID is planned for 2023. The plant would then first operate in 2026.

- Saudi Aramco in partnership with SABIC and IEEJ shipped the world's first blue ammonia to Japan in September 2020. An initial 40 tons of blue ammonia were shipped from Saudi Arabia to Japan for zero-carbon power generation. The blue ammonia was created by converting natural gas into hydrogen which is then converted into ammonia for shipping and combustion at power plants.

- A consortium led by BP is maturing the H2Teeside blue hydrogen production facility in the UK, targeting 1GW of hydrogen production by 2030. The project would capture and send for storage up to two million tonnes of CO_2 per year

A number of **full-scale green** hydrogen projects are in production or in design, including:

- Japan's Fukushima Hydrogen Energy Research Field (FH2R) came on stream in March 2020 (10MW).
- Nikola Motor Company in the U.S. announced it had ordered 85 MW of alkaline electrolysers to support five hydrogen fueling stations.
- A consortium of Air Products, ACWA Power and NEOM announced plans to build a green ammonia plant in Saudi Arabia powered by 4GW of wind and solar power, to produce 237,000 tonnes a year of green hydrogen.
- NextEra Energy announced it was closing its last coal-fired power unit and investing in its first green hydrogen facility in Florida - a 20MW electrolyser to produce solar-powered green hydrogen.
- Iberdrola and Fertiberia of Spain announced a partnership to develop an integrated hydrogen plant with 100MW of solar PV, a 20MWh lithium-ion battery system and a 20MW electrolyser.
- The WESTKÜSTE100 consortium announced the construction a 30MW electrolyser at the Heide oil refinery in Hamburg. Includes a E30m grant from German government, with an expansion potential to 700MW.
- Mitsubishi announced standard packages (Hystore and Hydaptive) to integrate green hydrogen into power plants, with the technology selected at three projects: Danskammer Energy upgrade initiative in Newburgh, New York, with a capacity of 600 MW; for Balico in Virginia; and for EmberClear for its fully permitted 1,084 MW Harrison Power Project in Cadiz, Ohio.
- Iberdrola announced a UK plan to implement a network of green hydrogen production plants to supply fleets and heavy transport. The first of these will be located on the outskirts of Glasgow and will use solar and wind energy to operate a 10MW electrolysis unit.
- NorH2 in Netherlands – Shell and Gasunie - Europe's largest proposed green hydrogen project starting 2027 to produce 800kt pa
- Asian renewable energy hub - 15GW renewable energy in W. Australia to enable green hydrogen production for domestic & export use from 2027.
- The HyGreen Provence project aims to develop a large-scale solar power and green hydrogen project in France's Durance Luberon Verdon Agglomération (DLVA). Other partners include Engie and Air Liquide
- In January 2020, Port of Oostende, DEME Concessions and PMV announced a partnership to build a green hydrogen plant in the port area of Ostend, Belgium, by 2025. This project aims to tap curtailed power from Belgium's existing wind capacity of 2.26GW
- The Arrowsmith Project in Australia, is expected to produce about 25 tonnes of green hydrogen a day using around 85MW of solar power, supplemented by 75MW of wind generation capacity.

Appendix 2:
UK hydrogen policy

The UK Government has put in place a series of policies in order to reduce the country's greenhouse gas emissions. As a result, UK greenhouse gas emissions have fallen by 43% since 1990, compared to a decline of 2% in the rest of the G7.

That said, the UK's hydrogen strategy is less well advanced than other regions, but is catching up rapidly.

In November 2020, the UK Government set out a 10 point plan and £12 billion of funding, for delivery of its targets for a net zero emissions economy by 2050, spanning clean energy by sector, and green finance, including plans for CCS and clean hydrogen.

The UK has committed to 5GW of low carbon hydrogen capacity by 2030, and has an intermediate target of 1GW by 2025. To date, the UK has just 3.5MW of installed production capacity, so there is significant scope to develop low carbon to achieve this target.

A series of subsequent, more detailed policy announcements are expected as a result of this, including contract-for-difference (CFD), or grants. UK Government will share the risk and costs of scaling up deployment of both CCUS and low carbon hydrogen. Policy reform includes initiatives to encourage consumers to switch to low carbon products, alongside initiatives to encourage fuel switching to hydrogen.

What is emerging is a policy that sees material blue hydrogen based around North Sea oil and gas infrastructure and CCUS, and growth in green hydrogen over time. This will be centred on a series of industrial clusters, as part of the UK Government's Industrial Decarbonisation Strategy, launched in March 2021.

The picture is certainly made more complicated by the juxtaposition of regional strategies, national and international advocacy, and funding (Wales, Scotland), and UK policy.

UK Government commitment through various clean energy funds that include hydrogen already announced totals more than £3.5 billion. Further funding or financial support is expected to become available as current policy reviews and consultation are concluded.

Two noteworthy business models being **consulted on in the Summer 2021** are the low carbon hydrogen support models and CCUS support models. Both are expected to provide significant support (>£1.2bn in total) and should offer long term incentives to private sector project investors.

There are multiple hydrogen-related funds and initiative in place in the UK:

UK Government Fund	Description	Indicative Funding
Industrial Energy Transformation Fund	To help polluting industries to reduce carbon emissions, e.g. by replacing natural gas with hydrogen	£315 million
Emerging Energy Technologies Fund (Scotland)	To support the development of Scottish hydrogen and Carbon Capture and Storage (CCS) industries, and support the development of Negative Emissions Technologies (NETs)	£100-180 million for LCH specifically
Scottish Island Green Hydrogen Fund	To boost green jobs and innovation in sustainable energy	£50 million
Industrial Decarbonisation Challenge (IDC)	Decarbonisation of industrial clusters	£170 million from 2019 – 2024.
Net Zero Innovation Portfolio (2021- 2025)	Decarbonisation, including: hydrogen, CCUS, bioenergy and artificial intelligence	£200 million per year. Total of £1 billion from 2021-2026.
CCUS Infrastructure Fund	The fund will facilitate the delivery of CCUS at four clusters, two by the mid-2020s and a further two by 2030	£100 million per year. Total of £1 billion from 2021 - 2030.
Clean Steel Fund	Steel industry	£250 million total funds (in development as of January 2021)
Net Zero Hydrogen Fund	Deployment of low carbon hydrogen production and encourages private sector investment	Government spending: £60 million per year. Total of £240 million from 2021 - 2025.
Automotive Transformation Fund (ATF)	Electrification of UK vehicles and their supply chains Securing battery cell manufacturing (‘gigafactories’)	£500 million

Source: UK Government, Industrial Decarbonisation Strategy, March 2021 and BEIS, 2020

Recently, the Industrial Decarbonisation Challenge was run as a competition by UK Research and Innovation (UKRI), with consequent funding announced on the 17th March 2021[1] as follows:

1. HyNet (offshore) – hydrogen and CCUS – £13.3million
2. HyNet (onshore) – hydrogen and CCUS – £19.5 million
3. Scotland's net zero infrastructure (offshore) – £11.3 million
4. Scotland's net zero infrastructure (onshore) – £20 million
5. Net zero Teesside (onshore) – £28 million
6. Northern endurance partnership – £24 million
7. Zero Carbon Humber (ZCH) partnership – £21.5 million
8. Humber Zero – £12.7 million
9. South Wales Industrial Cluster (SWIC) – £20 million

UK industrial cluster emissions (2018)

[1] https://www.ukri.org/news/ukri-awards-171m-in-uk-decarbonisation-to-nine-projects/