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# The Bluffer's Guide to Hydrogen

2023

HydrogenOne Capital LLP was founded by Dr JJ Traynor and Richard Hulf, as a specialist investment manager in clean hydrogen.

Our "Bluffer's Guide" is a starter pack for this quite complex and rapidly-growing sector.

When we launched in 2020, we were tracking 20 listed hydrogen companies, 50 or so privates, and about 200MW of green hydrogen on line.

The world has changed… some 40 listed names today, >200 private companies, 800MW of green hydrogen on line, and 13GW in development. The market has invested $13 billion of fresh capital since 2020 in the theme, with a capital opportunity on the table of at least $300bn to 2030.

**hydrogenonecapital.com**

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# Hydrogen – the elevator speech

- Climate change, air quality and energy security. The three big drivers of the clean hydrogen theme
- Today's 'grey' hydrogen sector is a 90mtpa, $175bn/year market that emits 830mtpa of $CO_2$. The incumbents? Fertilizers, chemicals, oil refiners, steel makers. Sorting this out is the major demand pull for clean hydrogen today
- Hydrogen can be used more broadly in today's fossil fuel system, especially to move heavy objects like ships, trains, trucks, HGV, and by blending into natural gas networks
- As countries accelerate into renewables to address climate change and energy security, clean hydrogen is a solution for large scale storage of surplus electricity and shipping energy over long distances
- Electrolysis is the key technology to make 'green' hydrogen. Fuel cells can turn it back into electricity. The emissions? Water or $O_2$
- Methane reforming and carbon capture are used to make 'blue' hydrogen, from fossil fuels. Enthusiasts, basically oil companies, call this 'low carbon'. ESG gurus, not so much
- 39 countries have hydrogen policies in place, with $70bn of funding. Europe and the USA have significant incentive packages and policy support to make this happen. The US Inflation Reduction Act is a tectonic change for the hydrogen industry
- There are >1,000 clean hydrogen projects on the drawing board today, with spending that could reach >$300bn to 2030
- If you're into energy, this is all pretty hard to ignore. The sector has $1 trillion market potential in 2040. A 200x increase in clean hydrogen supply is anticipated 2019-2030, and… potentially 20% of the energy mix by 2050

# HydrogenOne Capital LLP

The world's first listed hydrogen fund, we invest in clean hydrogen and related technologies for a climate-positive impact. Our "Bluffer's Guide" serves as an entry level to this quite complex and rapidly-growing sector. When we launched our fund, in 2020, we were tracking 20 listed hydrogen companies, 50 or so privates, and about 200MW of green hydrogen on line.

The world has changed… some 40 listed names today, >200 private companies, 800MW of green hydrogen on line, and 13GW in development. The market overall has invested $13 billion of fresh capital since 2020 in the theme, with a capital opportunity of at least $300bn to 2030.

*https://hydrogenonecapitalgrowthplc.com*

# Key jargon

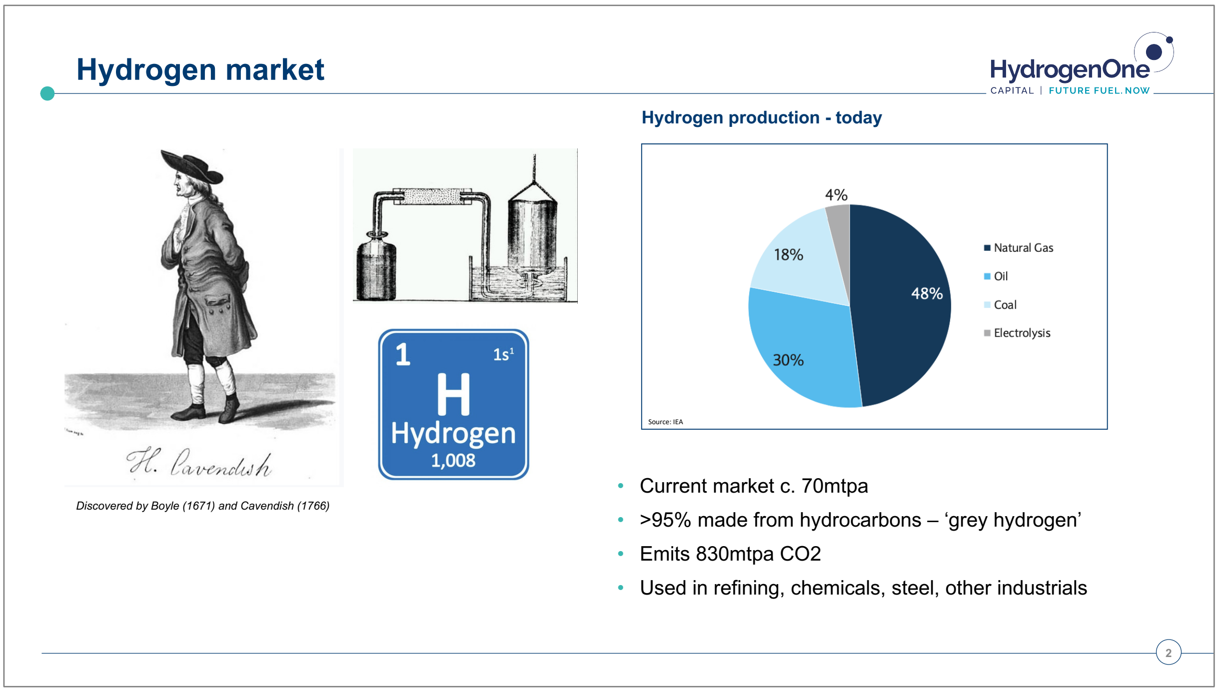
| Jargon | Explained | Key players examples |
|---|---|---|
| **Electrolysers** | Decades-old technology going through a renaissance. Car to shipping container-sized units. Electricity enters/leaves via an anode/cathode, and passes through an electrolyte to release heat, hydrogen and oxygen. There are various types of electrolysers, reflecting innovation and the specific purpose of the installation | |
| **…Alkaline electrolysers ("AEL")** | The original. The workhorse today. Uses potassium and sodium hydroxide electrolyte, and nickel plates. 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, Sunfire, HydrogenPro, Thyssenkrupp Nucera, John Cockerill |
| **…Proton exchange membrane electrolysers ("PEM")** | 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. Contain things like platinum, iridium and PFAS ("forever chemicals"), hence require recycling and permit work-arounds | Cummins, ITM, NEL, Ohmium, Siemens Energy |
| **…Solid oxide electrolysers ("SOEC")** | 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) and is high efficiency | Elcogen, Haldor Topseo, Sunfire |
| **…Anion exchange membrane electrolysers ("AEM")** | Newer tech, which uses a low concentration alkaline than AEL. Safer to handle, and can use lower purity water than AEL. Really at the innovation stage | Enapter Sunfire |
| **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, Bramble Energy |
| **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, INEOS, 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 | Air Liquide, Air Products, Linde |

| Jargon | Explained | Key players examples |
|---|---|---|
| | greenhouse gas ("GHG") emissions (2X UK annually). Steam methane reforming ("SMR") is the main process used as well as Autothermal Reforming ("ATR") | |
| **Blue Hydrogen** | Takes grey hydrogen, but captures and stores the GHG in geological reservoirs ("CCS"). Matches the skill-sets of integrated oil companies. Sometimes called 'low carbon' | 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, ERM, multiple smaller players |
| **Other colours of hydrogen** | ***Yellow*** – takes excess nuclear electricity into electrolysis. aka Pink<br>***Turquoise*** – splits natural gas into hydrogen and solid carbon<br>***White*** – naturally-occurring hydrogen trapped in geological reservoirs.<br>No-one really knows how this works<br>***Gold*** – microbes eat up oil in depleted reservoirs and let off hydrogen, or in-situ burning of oil reservoirs, which apparently does this as well | HiiRoc, Monolith<br>Cemvita<br>Mali |
| **Power-to-X** | Conversion of excess electricity supply to storable fuel eg hydrogen and ammonia | Everyone in electrolysis is interested in this |
| **Can I drink hydrogen?** | Not wise, since this is -259.2 degrees C. This is a lot colder than liquefied natural gas (LNG), -162 degrees C and more expensive to handle. Better to make green ammonia with clean hydrogen, which boils at -33 degrees C. Hence the interest in green ammonia as a clean hydrogen carrier. If you want to drink liquid hydrogen, stick to sparkling water, which costs $500/barrel versus Brent Crude at $80, which says quite a lot about societal priorities and would be a whole different Bluffer's Guide. | Maersk<br>Air Liquide<br>Fortescue Future Fuels |
| **Solid state storage & liquid carriers** | Innovation around combining hydrogen with metal micro-mesh into "metal hydrides" or "solid hydrogen". Takes up more space than compressed gas, but works for stationary power. Liquid carriers combine hydrogen with organic compounds such as benzyl toluene, resulting in a liquid at ambient temperature and pressure – a liquid organic hydrogen carrier ("LOHC"). Needs a chemical process at each end of the chain – hydrogenation and dehydrogenation. | GKN Hydrogen<br>Hydrogenious |

# 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 today is pretty big, at some 90 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, almost 2X UK total $CO_2$ 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 General Motors 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**

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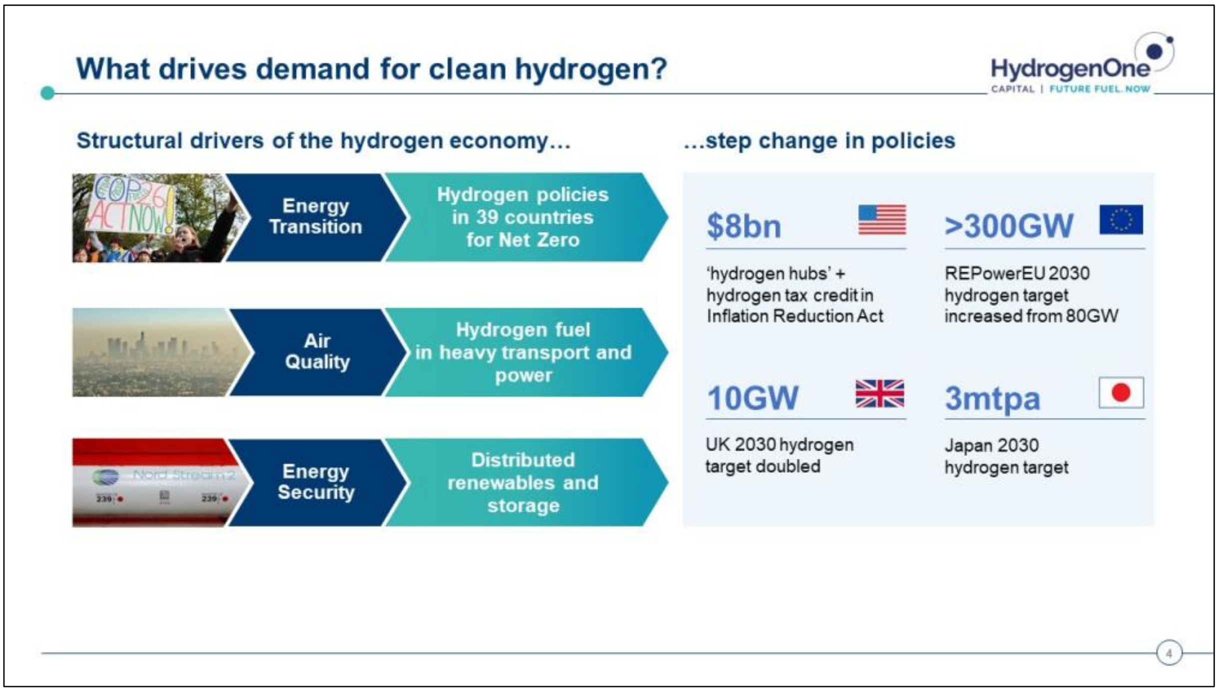
# What drives demand for clean hydrogen?

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 39 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.

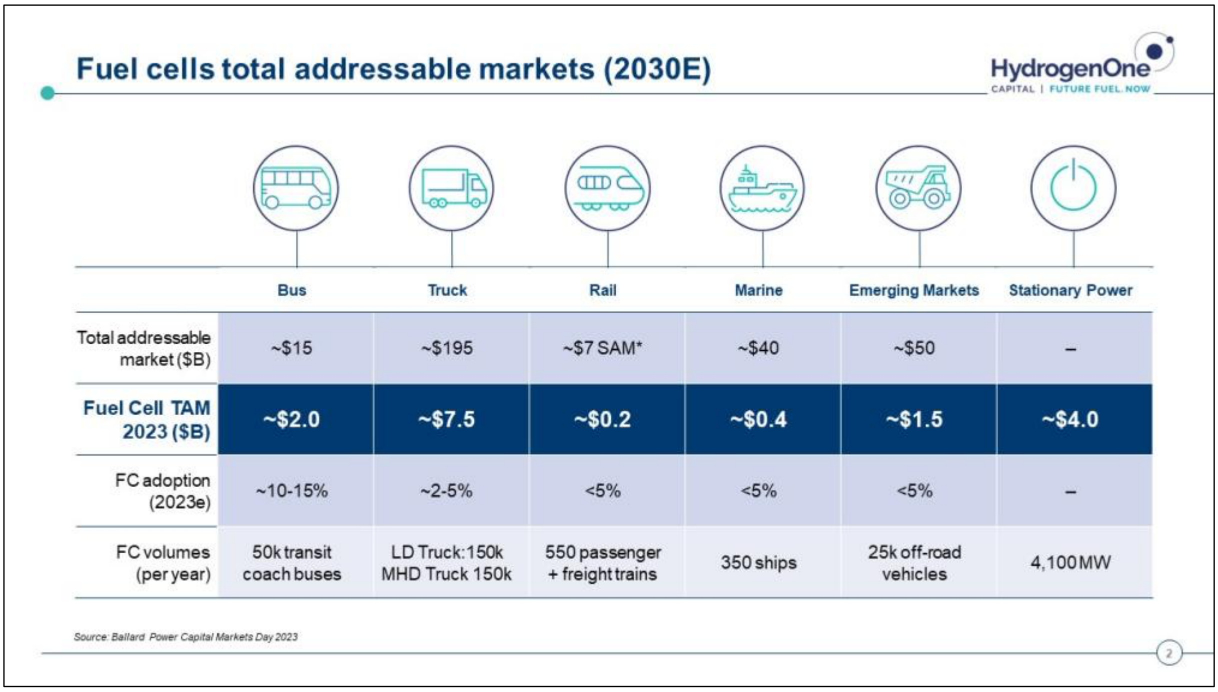
Burning fossil fuels for energy releases green-house gas and poisonous particulates. More than 20 countries have announced sales bans on internal combustion engine vehicles before 2035, and over 25 cities have pledged to buy only zero-emission buses from 2025 onwards. This is driven by Net Zero agendas,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




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. Many governments are assessing and setting targets for the phase out of grey hydrogen from industry, for example in the EU, under the "RED" rules (Renewables Directive), in industry, 42% of all hydrogen used is targeted to come from renewable sources by 2030, rising to 60% by 2035, which for Germany alone case would require up to 83TWh of renewable 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 fuel cells alone could be a $15 billion total addressable market by 2030.


**Fuel cells total addressable markets (2030E)**

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| | Bus | Truck | Rail | Marine | Emerging Markets | Stationary Power |
|---|---|---|---|---|---|---|
| Total addressable market ($B) | ~$15 | ~$195 | ~$7 SAM* | ~$40 | ~$50 | – |
| **Fuel Cell TAM 2023 ($B)** | **~$2.0** | **~$7.5** | **~$0.2** | **~$0.4** | **~$1.5** | **~$4.0** |
| FC adoption (2023e) | ~10-15% | ~2-5% | <5% | <5% | <5% | – |
| FC volumes (per year) | 50k transit coach buses | LD Truck: 150k MHD Truck 150k | 550 passenger + freight trains | 350 ships | 25k off-road vehicles | 4,100 MW |

*Source: Ballard Power Capital Markets Day 2023*

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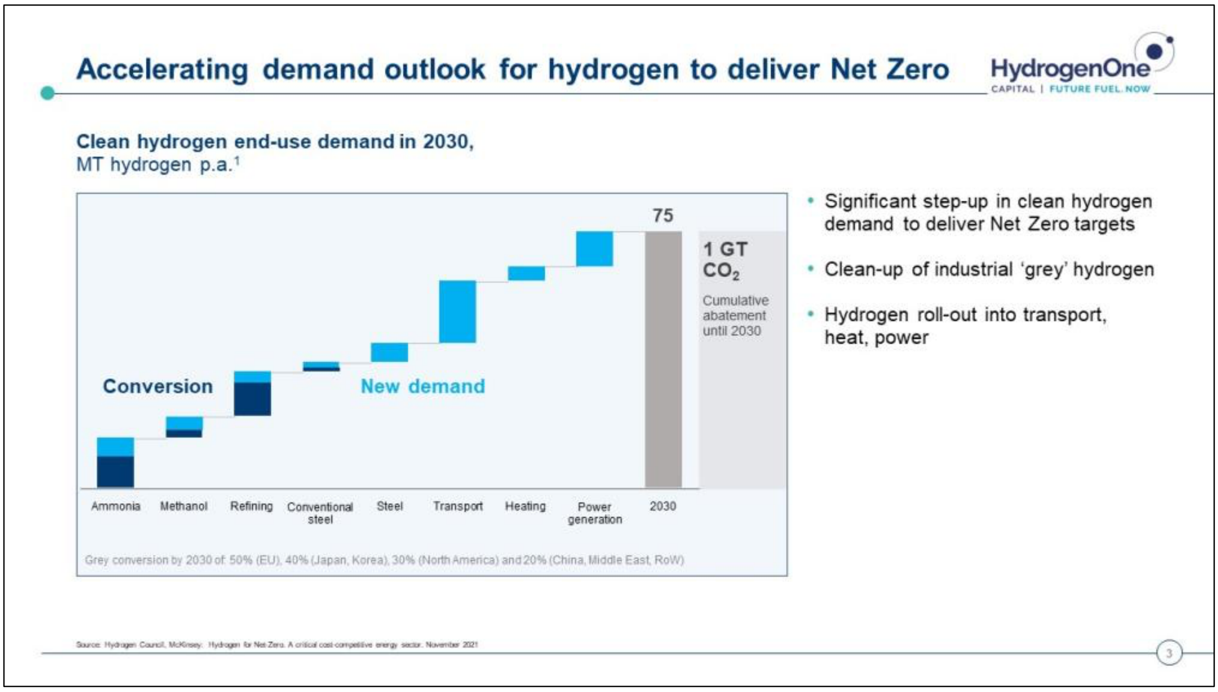
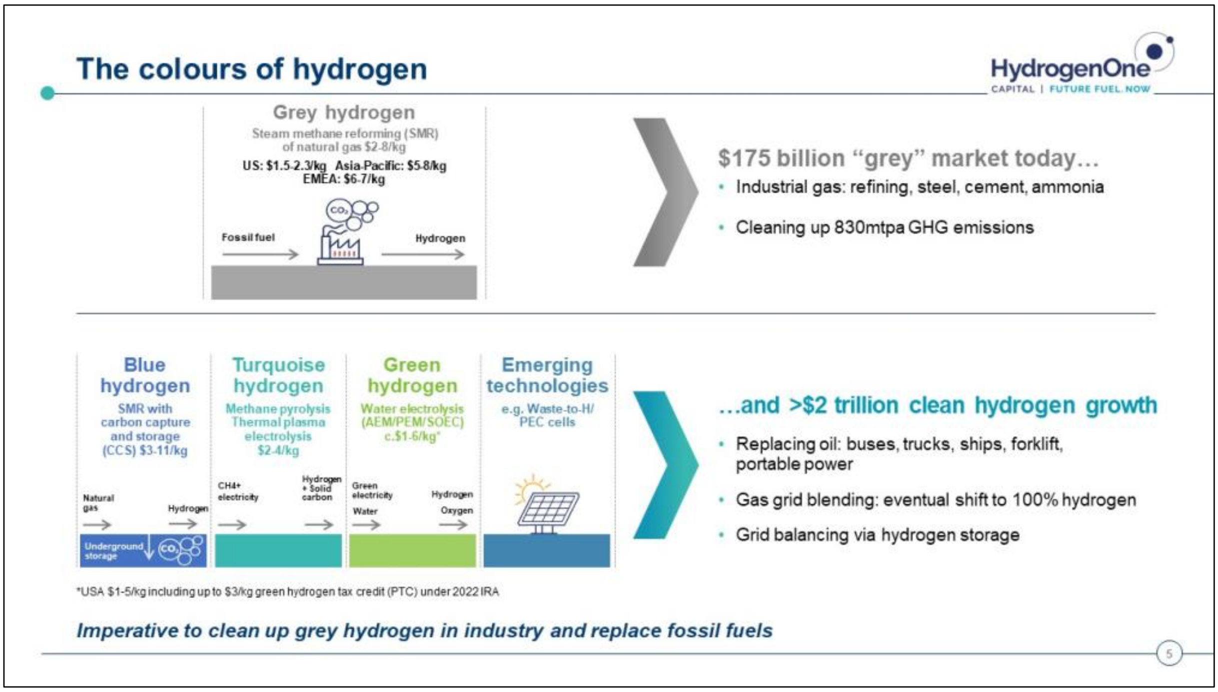
In the aftermath of Russia's invasion of Ukraine, policy makers have stepped up efforts to wean economies off Russia oil and gas, and at the same time accelerate the energy transition to net zero. As renewable energy grows in the mix, the intermittency of the energy mix will also increase ("because of the weather"). Converting surplus electricity to green hydrogen through electrolysis is set to become an important storage and transmission medium for renewable power, at large scale.

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 sun. 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. Many countries are introducing legislation to allow for hydrogen blending in natural gas grids, typically up to 20%, which is the level that is burnable in modern domestic natural gas boilers.




The hydrogen sector has $1tn market potential by 2040. A 200x increase in clean hydrogen supply is anticipated from 2019 to 2030 in order to achieve Net Zero, as the scale-up of renewable power alongside the phase-out of fossil fuels, improves the economics of established hydrogen technologies. Clean hydrogen could be 20% of the energy mix by 2050.

# 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.

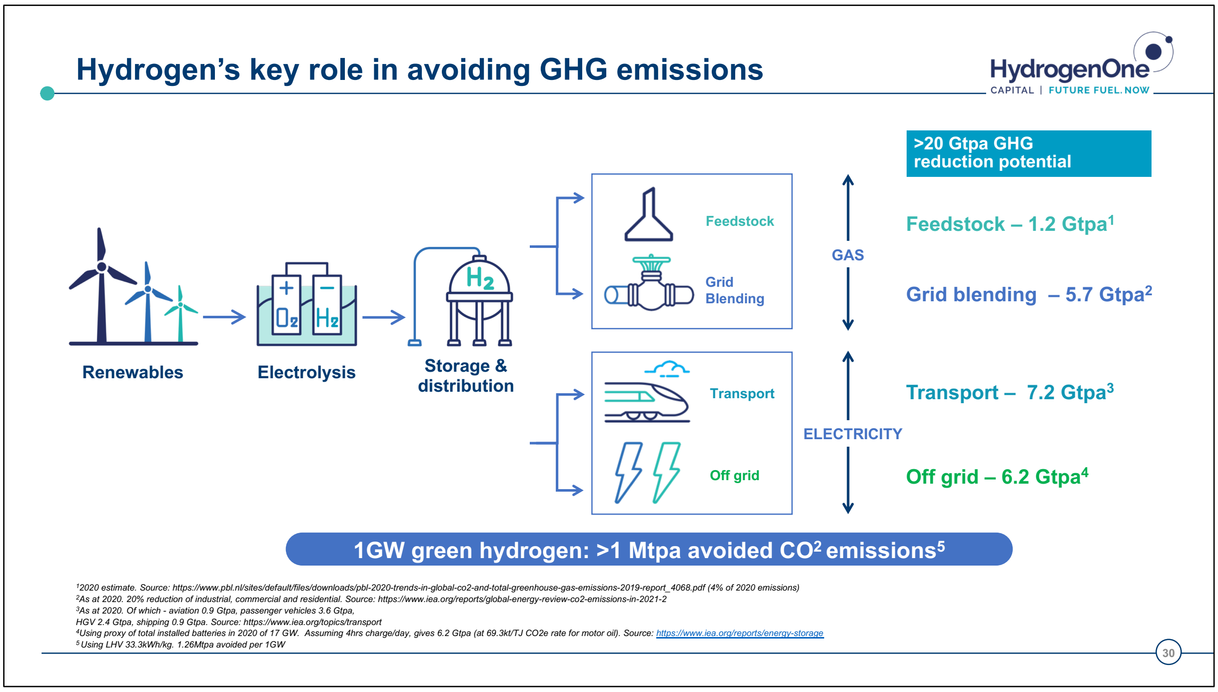
**Grey hydrogen** is how we make it today. By heating methane gas with steam, a process called steam methane reforming – ("SMR"). This is efficient but releases $CO_2$. This is a large industry today and has been around for decades.

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

**Green** does not involve hydrocarbons, and uses renewable electricity – e.g. 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.

## 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").

If you know the renewable power and natural gas industries, then green hydrogen is familiar ground. Dedicated wind, hydro or solar power, or a renewable PPA, provide electricity that powers electrolysers, which make hydrogen. This is compressed and sold to off-takers, typical in industry and transport. The off-taker provides a Hydrogen Sales Agreement ("HSA"), which underpins the financing for the infrastructure.

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.

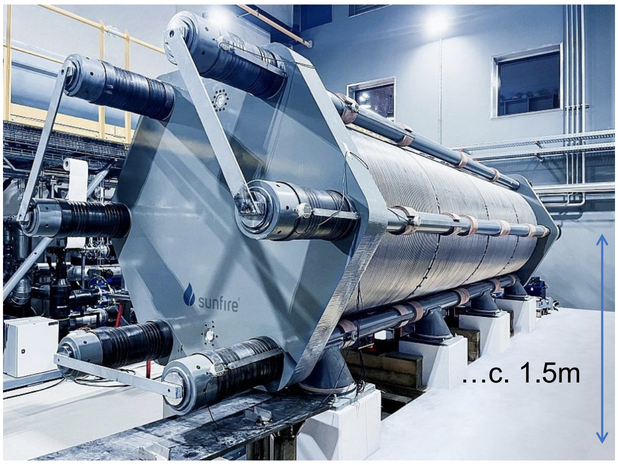
Hydrogen has a similar *energy mass* (energy per kilogramme) as conventional liquid fuels such as gasoline. However, hydrogen has a lower *volumetric energy density*, and the gas is compressed and stored in pressurised tanks for storage and shipment. Some participants are planning to ship large volumes 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 the 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. INEOS is currently Europe's largest electrolyser technology operator, with 400,000 tonnes per annum of hydrogen production.

## Alkaline electrolysers

Galvanizing plant that makes
1.5m tall metal 'plates'

…the plates are formed into 'stacks'…photo is 10MW
Alkaline electrolyser stack (AEL)




*Source: Sunfire*

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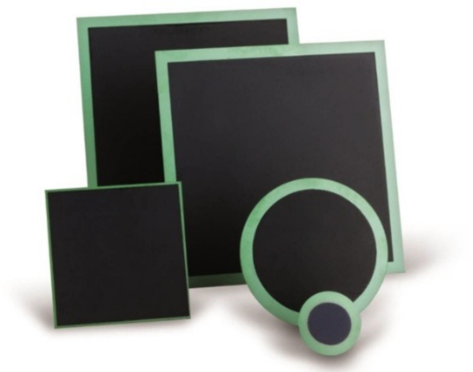
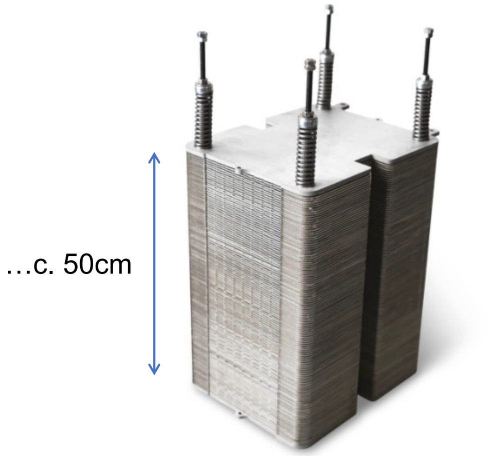
## Hydrogen fuel cells and stacks

*Individual fuel cells….*



*…assembled into fuel cell stacks….*




*Source: Elcogen*

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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 businesses supply compression, pipelines, 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.

**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.

According to the Hydrogen Council, there are some $170bn of hydrogen investments in advanced planning, FEED or under construction today.

## Hydrogen development gathering pace

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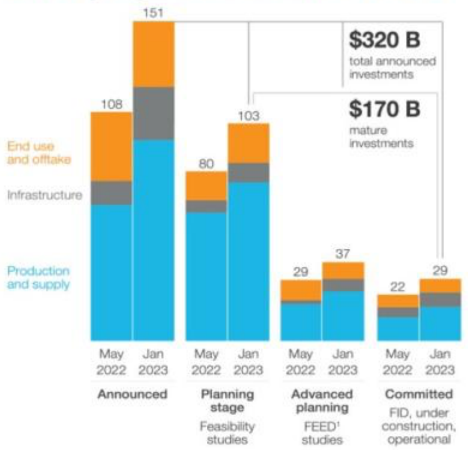
### Direct hydrogen investments until 2030, $B




### Outlook for key hydrogen markets

| Total addressable market, $b | 2030 | 2050 |
|---|---|---|
| Hydrogen Production | 600 | 1,650 |
| Storage & Distribution | 20 | 75 |
| Supply Chain | 40 | 525 |
| Hydrogen Applications | 30 | 350 |
| Total | 690 | 2,600 |

*Source: https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf*

# Hydrogen in transport

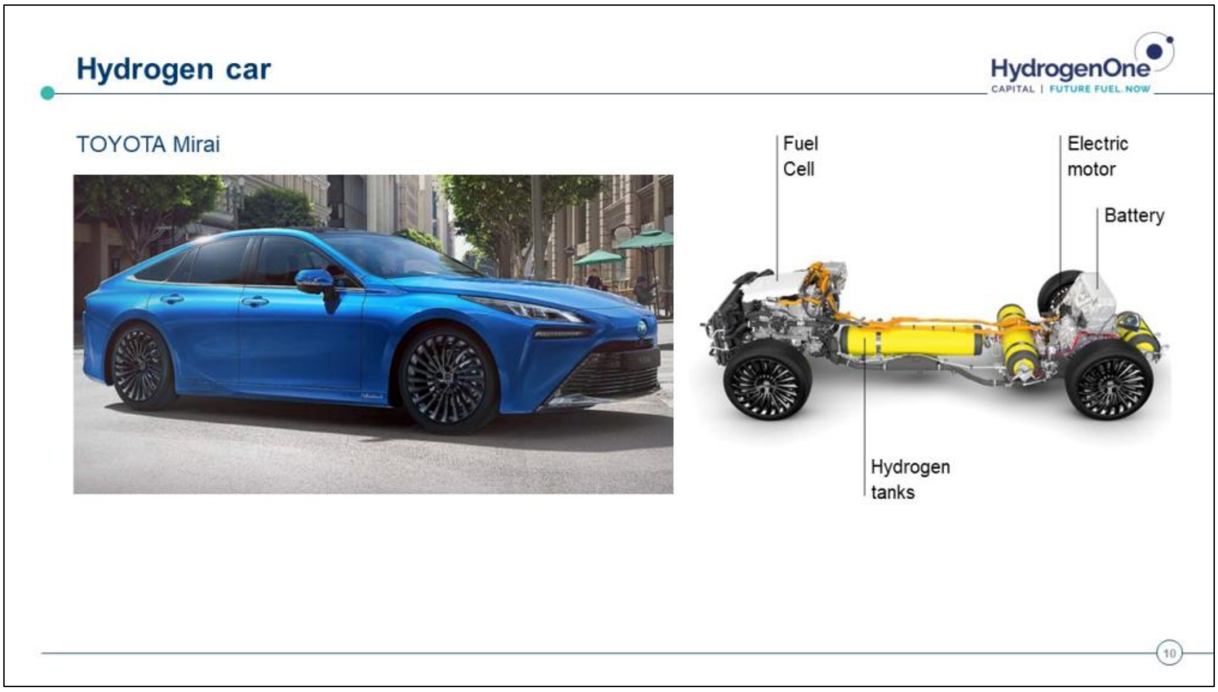
With some 80,000 fuel cell electric vehicles ("FCEV") in use worldwide today, hydrogen has arrived as a viable transport fuel for medium to heavy trucks, trains, and forklifts. The shipping market and aviation are fast emerging as the next wave of hydrogen for transport applications.

China dominates the transport sector outlook, with 2030 targets for 1 million FCEVs and 1,000 hydrogen refuelling sites. We would also point to Germany as being particularly advanced in this area.

## Fuel cell cars

It remains to be seen if fuel cell cars will be established as competitors for battery electric, but there is no shortage of auto companies working on this.

The hydrogen passenger car market is dominated by Japanese and Korean players, with the Honda Clarity, Toyota Mirai and Hyundai Nexo (previously ix35) representing c. 98% of FCEV sales to date. European OEMs are catching up, with BMW, Mercedes, Renault and Stellantis selling on a limited basis. Chevrolet, Ford and Nissan have experimented with hydrogen vehicles in the past, but there are no recent or current models.



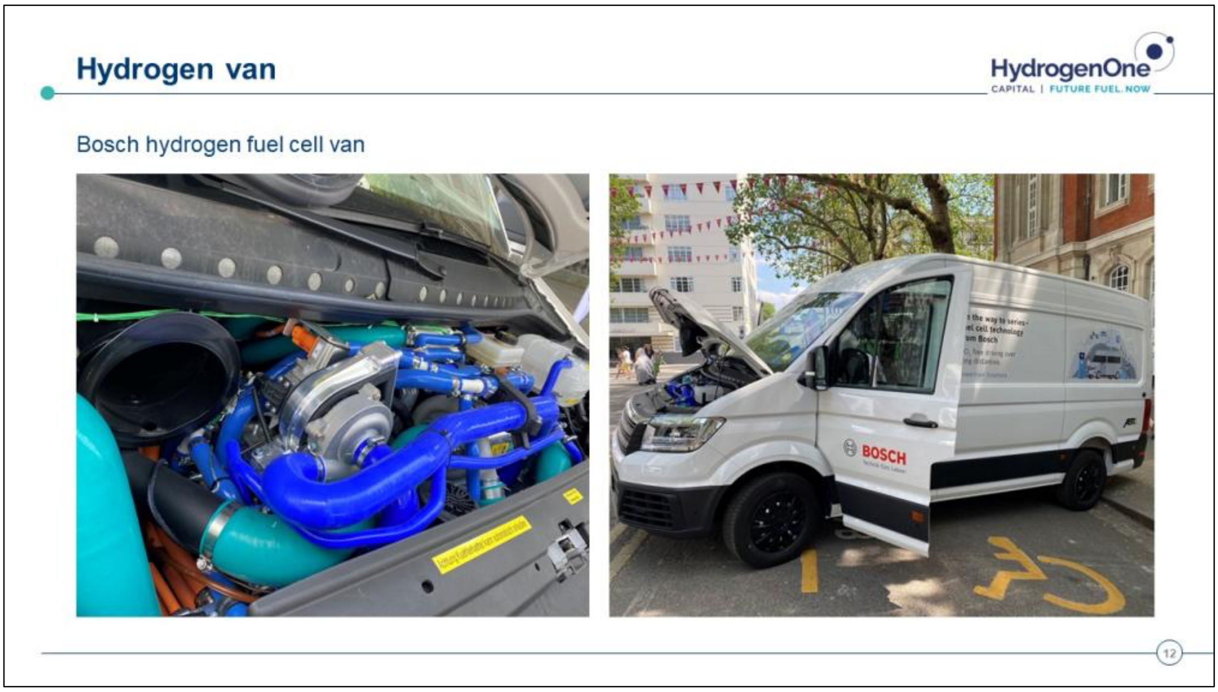

## Fuel cell trucks

Diesel phase out from heavy transport makes for a significant hydrogen opportunity. Batteries seem to us to be highly unlikely to ever be small enough or powerful enough to work in these larger and heavier vehicles. A combination battery (for start-up) and fuel cell seems a likely winner.

The global fuel cell truck market has developed more recently than fuel cell cars, with Hyundai introducing the first FCEV truck to the market in 2020. We see a great deal more models coming to the market in the next few years, eventually reaching potentially 3% penetration by 2040. This market is characterised by joint ventures:

- Toyota selling fuel cells to Paccar, VDL and Hino
- Toyota Motor Europe ("TME") has joined with Dutch VDL Groep ("VDL") using Toyota's fuel cell technology
- Paccar will use FCEV in the Kenworth T680, Peterbilt 579 (2024). The DAF owned subsidiary appears to be going for hydrogen combustion in the XF. More below
- DAF's parent company PACCAR has started extensive trials with hydrogen-powered trucks with fuel cell technology working with Toyota and Shell
- Daimler-Volvo joint venture called Cellcentric
- Scania are working with Cummins fuel cells in the HyTrucks project, a jointly created initiative project in the Netherlands run by Air Liquide and the Port of Rotterdam Authority. Scania is owned by VW
- The EU-funded H2Haul project will demonstrate 16 new heavy-duty hydrogen fuel cell trucks in collaboration with IVECO and VDL

- H2Accelerate aims to accelerate the use of hydrogen as a fuel for heavy duty road transport in Europe. The group is comprised of hydrogen suppliers Shell, Linde, and TotalEnergies, and vehicle OEMs Daimler, Iveco Group, and the Volvo Group
- Nikola and IVECO had a hydrogen joint venture set up in 2019. In 2023, IVECO purchased the 100% ownership of the JV
- Symbio is a joint venture between Symbio, Michelin and Faurecia, as well as GTI and other industry partners
- Gaussin have produced a demonstrator hydrogen truck, that completed the Dakar Rally in 2033…20 minutes refuelling and 800km range
- Smaller truck makers using larger manufacturers units. One example would be Gersthofen from Germany. They have developed a fuel cell vehicle called Energon, based on Iveco Strator.
- The larger Chinese manufacturers such as Beiqi Foton Motor, Dayun, Donfeng Motor, FAW Group and Great Wall Motor should also be on the market-watcher’s radar, but there is limited visibility today.



## Hydrogen truck

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Daimler hydrogen fuel cell truck


Gaussin hydrogen truck in the Dakar Rally

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## Hydrogen combustion trucks

Unlike FCEV trucks some manufacturers are finding ways to use hydrogen as a combustible fuel in their engines. Cummins has unveiled a medium-duty truck powered by a hydrogen internal combustion engine installed in a Mercedes-Benz Atego 4x2 truck.

## Hydrogen Buses

Fuel Cell electric buses have been successfully trialled in major cities all over the world in the last decade with most buses having been sold more recently in China, the US State of California and British Colombia in Canada. In Europe fleets are now in operation in England, Scotland, Japan, China, USA, South Korea, France, Germany and Spain.

Toyota are a major global supplier to the hydrogen bus industry, with a series of joint ventures - Hino Toyota (Japan), Toyota Caetano (Portugal), VDL (Netherlands).

Daimler AG became Mercedes Benz on 1 February 2022. Daimler truck still maintains the EvoBus subsidiary that sells electric buses. The new eCitaro hydrogen bus is sold under the Mercedes brand.

In terms of cost, a standard diesel bus costs roughly $330,000 compared to hydrogen buses of around $500,000, hybrid of $480,000. Hydrogen bus costs should reduce when they are manufactured in larger quantities.

# Hydrogen blending in natural gas grids

Hydrogen can be safely blended with natural gas, in existing or modified natural gas networks. This has the advantages of a built in market for hydrogen and getting it to customers, without rebuilding the energy system along the way. Globally, the race is on to deliver this, with the UK, Germany, Italy, New Zealand, and others all working to inject a higher percentage of hydrogen into gas networks, while ensuring the integrity of existing infrastructure and appliances is not compromised.

The UK's gas network spans 284,000 km, with 85% of UK homes connected to the gas grid. Historically, the grid was fuelled by "town gas" – a heavy-polluting gas created from coal and consisting mainly of hydrogen, methane, and carbon monoxide – until it was displaced by cleaner and more affordable North Sea natural gas in the 1970s, marking somewhat of an energy transition.

Though heating is a notoriously hard-to-abate sector, blending – the process of mixing natural gas with up to 20% clean hydrogen – offers one viable solution. A 20% hydrogen blend in the UK could save up to 6 million tonnes of $CO_2e$ every year – the equivalent of taking 2.5 million cars off the road – or a total of around 41 million tonnes of $CO_2e$ between 2023 and 2032.

The UK Government has championed the development of hydrogen blending, making it a key pillar of its decarbonisation ambitions. The UK has proven that a 20% blend in its own gas network is indeed feasible following the success of Northern Gas Network's "HyDeploy" pilot project late last year, delivered in partnership with Keele University. The HyDeploy project delivered more than 42,000 $m^3$ of hydrogen to 100 homes and 30 university buildings at Keele University in Staffordshire saving more than 27 tonnes of carbon emissions. With minimal modifications to the current gas grid infrastructure, no changes to customers' appliances and no pipeline disintegration, HyDeploy confirmed hydrogen's potential to transform the UK's gas network.

# Myths in clean hydrogen

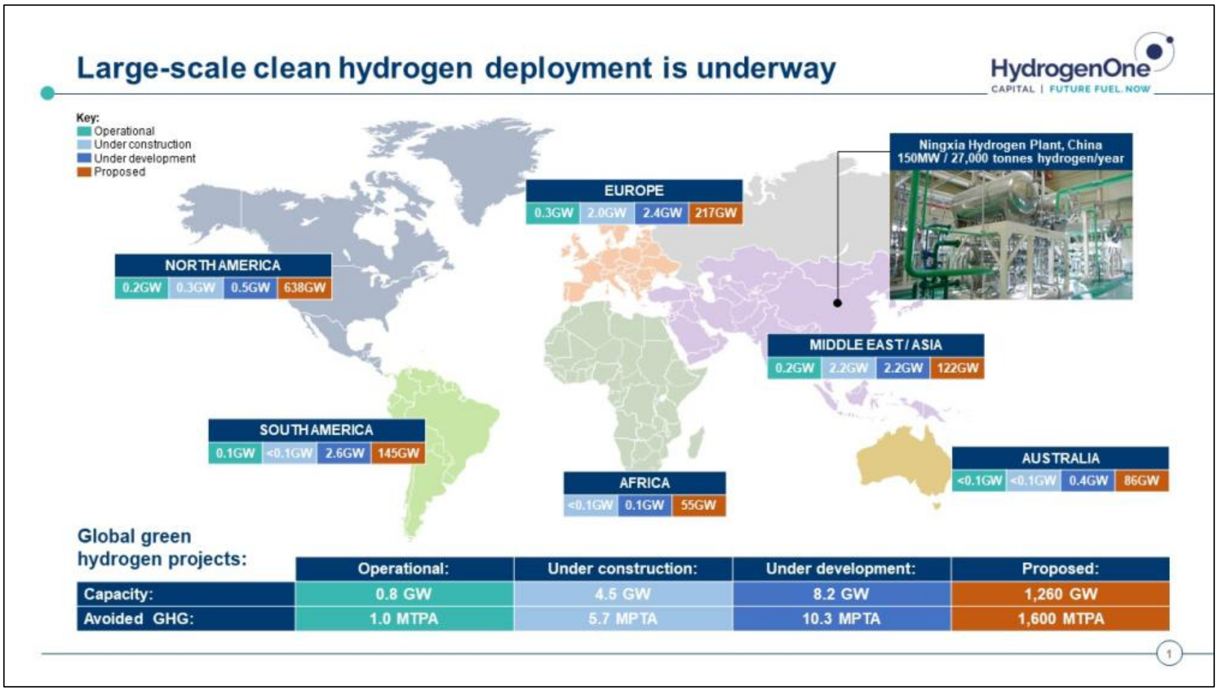
Hydrogen sector has plenty of ill-informed commentary, and plenty of lobbying between competing industry groups. Here are the main arguments, and a rational middle:

### Clean hydrogen projects are just conceptual

For sure there is a cottage industry of "projects by press release", as companies position for hydrogen growth.

Today, we see more than 170 green hydrogen projects on stream world-wide, totalling 800MW of capacity.

There are vast databases on this put together by consultants. The most widely-read is the annual Hydrogen Council "Insights" report (https://hydrogencouncil.com/en/hydrogen-insights-2023). This study cites 1,040 announced hydrogen projects, requiring $320bn spending to 2030.




We are tracking over 170 projects on line, totaling 800MW, then 13GW in over 140 projects that are under construction or advanced development, meaning money is being spent on land, electrolysers, FEED studies. Some 4.5GW of this is under construction today, and a further 1,200GW in over 480 projects that have serious intent to build.

## 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

## Reality: this is really about GHG emissions, not one technology vs another

- Sensible governments such as USA and UK require maximum GHG emissions intensity, properly-defined renewable power sources and fugitive gas strategies as part of the definition of “clean hydrogen”, and are not hung on green/blue/biogas etc as the source of the H2

## Hydrogen is a greenhouse gas

Building out a hydrogen system will result in leaks, as is the case in the natural gas industry. Hydrogen will therefore contribute to global warming.

## Reality: this is over-played. Hydrogen is a GHG, but is substantially less so than fossil

- Hydrogen could impact the distribution of ozone and methane in the atmosphere. However it oxidises quickly to water, or is absorbed by soils
- The climate impact would be about 0.6% of the fossil fuel economy, if hydrogen was to totally replace fossil (which it won't)
- Fugitive methane is 30X more harmful to the climate than $CO_2$. This overwhelmingly comes from old oil & gas wells. There a million of these in production in the USA alone, and over three million abandoned wells there. These are very hard to seal. The hydrogen industry will need to engineer to limit fugitive hydrogen, but this is on the ground, not under it, and is eminently doable. There's a lot of oil & gas industry spinning going on here

## Green hydrogen uses too much water

Electrolysers use a lot of water, and will take away drinking water and farm water, etc

## Reality: This is basically oil lobby propaganda

- Electrolysers split water into hydrogen and oxygen. The hydrogen is consumed by fuel cells that make electricity, and, er, water. The produced water doesn't go back to the original source, but it's not being destroyed.
- You need 9-10kg of water to make 1kg of hydrogen in an electrolyser. Scale that up. If green hydrogen abates 10 billion tonnes/year of GHG, which is the assumption in the IPCC worst case climate change model (RCP 8.5), that would need 2.3 billion tonnes per year of hydrogen, made from 20.5 billion m3, per year of freshwater. That water accounts for only 1.5 ppm of Earth's available freshwater (0.0000015%).
- Irrigated agriculture uses 2,800 billion m3/year of water. You can do your part there, by eating fewer avocado pears. Fossil fuels extraction and power generation uses 250 billion m3/year of water. Which all needs to be turned off. This compares to 21 billion m3 / year for the future hydrogen economy.
- A 20MW electrolyser module operated at average 50% capacity will consume approx. 17,000 tons of water per year. You may not want to put it in some place where farmers draw water from wells. The permits for that will get emotional. However, you could install desalination for your hydrogen water, which adds about $0.01/kg to hydrogen production cost. Electrolysers use demineralised water, which animals and plants don't drink anyway.

## 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

## I don't see hydrogen service stations… is this for real?

A common narrative in countries that aren't leaders in hydrogen eg the UK.

## Reality: strong growth in hydrogen services stations (aka "HRS") in South Korea, Japan, Germany and California. Who's buying? Trucks.

- At the end of 2022, 814 hydrogen refuelling stations were in operation worldwide. Concrete plans are already in place for 315 additional refuelling station locations. Europe had 254 hydrogen stations at year end, 105 of which are in Germany. France is still second in Europe with 44 operating stations, followed by the UK and the Netherlands with 17 each
- Germany is definitely one to watch… Westfalen, H2Mobility, Jet H2 Energy all have big plans to add significant capacity… and higher volume stations. H2Mobility alone are planning to grow from 90 stations to 300 by 2030
- Many countries are planning for the phase out of fossil fuels from transport. This is a significant opportunity for hydrogen in heavy vehicles (trucks, buses), where batteries are too large to be economic. 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
- Lots of headroom here… the USA alone has over 100,000 gasoline stations and globally there could be 400,000 of these climate change accelerators. The incumbents, mostly oil companies, are looking for ways to green up these otherwise-stranded assets

## Hydrogen refueling stations

| | 2013 | 2018 | 2022 |
|---|---|---|---|
| **Asia Pacific** | 50 | 140 | 450 |
| **Europe** | 70 | 150 | 250 |
| **North America** | 65 | 75 | 100 |
| **RoW** | 1 | 4 | 13 |
| **Global** | 186 | 369 | 814 |
| ***Includes…*** | | | |
| **Germany** | 12 | 32 | 105 |
| **UK** | 12 | 14 | 17 |

*Source: https://www.h2stations.org/statistics/*

## 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 (e.g. ZeroAvia, Universal Hydrogen). This could work for short haul commercial flight e.g. 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.

Economic recovery from COVID and Russia's invasion of Ukraine have resulted in more 'normal' fossil fuel prices c.$80-$120 Brent. This is a markedly-different position than the 2015-2020 "$40" world, and reflects the real replacement cost of fossil fuels. As an example, all of the big oil companies, 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.

These are headline hydrogen costs on a $/kg basis:

- Grey $1-8/kg: established market price. The large range is related to the natural gas cost. This source of hydrogen will be phased out
- Blue $3-11/kg: includes CCS cost
- Green $1-6/kg: in the range of grey and blue. The low-end is in the US, including IRA tax credits

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 clean hydrogen today. Green hydrogen costs at the top end are around $6/kg, which are 60% lower than 2010 and are expected to further reduce as electrolysers scale up and become more efficient.

## Can you drill for native hydrogen, like you do for oil & gas?

Hydrogen can be produced from geological reservoirs, and you don't need Green hydrogen at all. This is White hydrogen.

### Reality: This is something certainly worth following, but there are quite some challenges

Native hydrogen has been found in volcanic rocks, salt mines and sedimentary rocks, most notably in water wells drilled in Mali in the 1980s, and put on line by Petroma Inc, in 2012. Geologists are not too clear on how it got there – is this gas that comes from igneous (hot) rocks, or is it gas emitted by microbes (biogenic gas), and how it is trapped? Predicting the presence of this gas is very difficult – oil & gas exploration wells have a 1 in 10 chance of success, or worse, after 150 years of geologic studies to improve the odds, and the cost of onshore wells can be $15 million each. Expect to see geologists working over records of old wells, and fund raising to re-drill them for hydrogen. The gas may or may not be near markets, and hence the transport cost could be prohibitive versus manufactured hydrogen. Fuel cells need extremely clean hydrogen. Native hydrogen will likely need clean up facilities, as does natural gas, which can cost $100s of millions. Native hydrogen could have a role at a local level, but it doesn't seem likely to fundamentally change the outlook for Green.

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

Various conspiracy 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.

We are seeing hydrogen blending gathering pace, although 100% hydrogen networks are some way out. Town gas (from coal) in the UK was 20% hydrogen ie before North Sea gas. Germany has authorized 10% hydrogen blending. In the UK, expect to see government policy on blending, probably 20%, by the end of 2023. HyDeploy (UK) has trailed a 20% hydrogen blend with natural gas into current domestic boilers (2021). Pure hydrogen boilers are on the market today, although they are pricey. Gas turbines that use hydrogen in power plants are being deployed in the Netherlands, Japan and the USA.

# Government policies

Some 40 countries and territories have policies in place to support growth in the clean hydrogen industry. Increasingly, there is competition between countries to attract investment in the theme, particularly in the aftermath of the 2022 Inflation Reduction Act, in the USA, which is really a game-changer for this industry.

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

## Hydrogen policies and support mechanisms

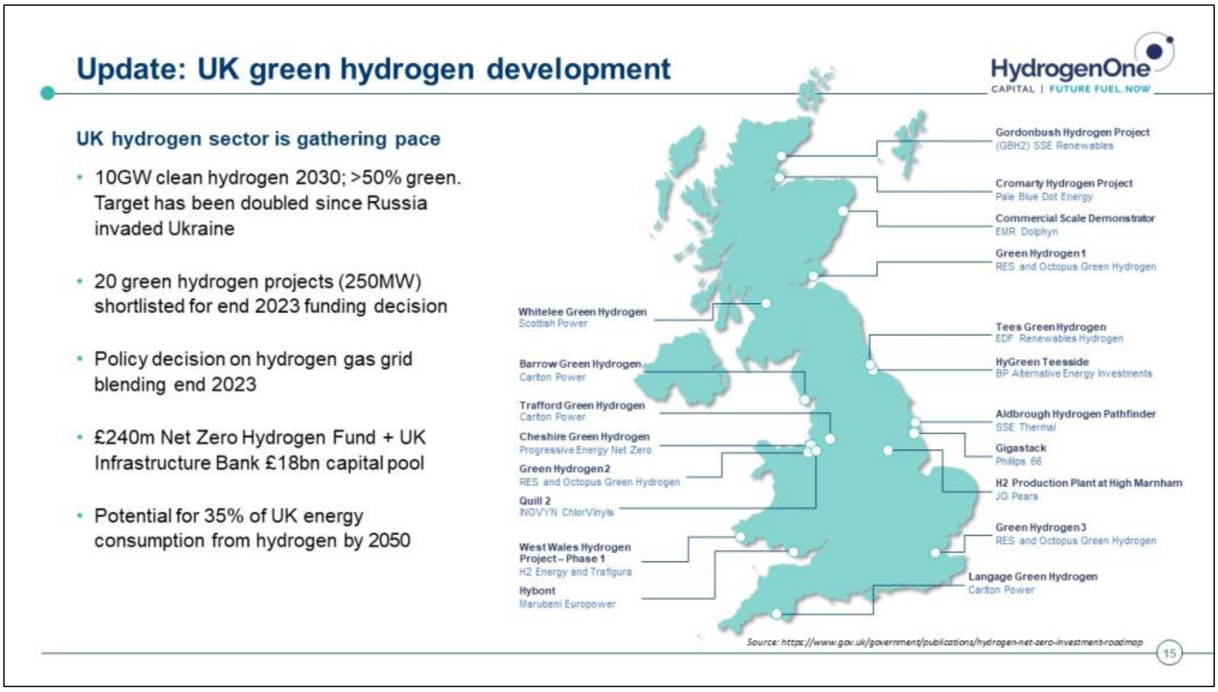
| | USA | EU | UK | RoW |
|---|---|---|---|---|
| **Legislation** | Inflation Reduction Act (2022) | • REpowerEU<br>• (2022)<br>• RED II (2009+)<br>• Fit for 55 (2023) | • Hydrogen Strategy (2021)<br>• UK Low Carbon Hydrogen Standard | At least 39 countries and territories have clean hydrogen strategies |
| **Scope** | Green & blue | Overwhelmingly green. Blue lobby continues | Green & blue | Green dominates |
| **Enablers** | • 'Hydrogen Hubs' $8bn<br>• IRA tax credits | • IPCEI (>E5bn so far)<br>• Country level grants<br>• EU Hydrogen Bank | • Net Zero Hydrogen Fund<br>• UKIB (share of £18bn) | Typically top down GW targets for 2030-50 |
| **Credits / subsidy** | • Up to $3/kg H2<br>• Must emit <0.45tCO2/tH2 (green)<br>• Must sequester 4t CO2 per t H2 | EU Hydrogen Bank<br>• Auction (2023) for E800m / max E4/kg<br>• E3bn budget<br>• Country-level CO2 credits, eg Germany E30/t CO2 | Hydrogen Business Model<br>CFD for revenue or capex<br>• £240m 1st tranche<br>• Must be <20gCO2e/MJ H2 and 99.9% pure | >$70bn announced support |
| **Targets** | Est. 22GW/year electrolysis 2028 (1GW 2022) | Est. 300GW 2030 (<1GW 2022) | 10GW 2030 | $320bn capex required for announced projects to 2030 |

2020 saw **EU targets** for hydrogen to meet 14% of Europe's energy needs by 2050. In 2022, the EU reshaped its energy policy to the REPowerEU 2030 plan, which calls for over 300GW of clean hydrogen by 2030, compared to 80GW in previous plans. Some EUR 5.4 billion in hydrogen subsidies have recently been approved under Important Projects of Common European Interest ("IPCEI"), which are expected to unlock a further EUR 8.8bn of private investment. The Hy2Tech scheme, also announced in 2022, links 41 projects and 35 companies building out the hydrogen sector, and has qualified for IPCEI funding. The EU's Hydrogen Bank will auction E800m of opex subsidy to green hydrogen in 2023. There are additional sources of grant funding at a country level in multiple EU countries.

In the **United States**, the Department of Energy has announced a US$8bn programme to develop clean regional hydrogen hubs across the country, as part of net zero ambitions by 2050. The 2022 Inflation Reduction Act set aside US$369bn for climate and energy proposals. Within this Act, there is a tax credit for clean hydrogen of US$0.6/kg to US$3/kg, depending on life cycle emissions. This is expected to make green hydrogen cost competitive with grey hydrogen, and make US clean hydrogen amongst the lowest cost in the world.

In **India**, in early 2023, the Government announced the Strategic Interventions for Green Hydrogen Transition Programme ("SIGHT"). This programme envisages c.$100bn of investment to 2030, 60-100GW of electrolyser capacity, resulting in 5 million tonnes per annum of green hydrogen production. This is initially planned to address GHG emissions from the fertiliser, refining and iron and steel sectors, by replacing grey hydrogen there.

In **the UK**, 2030 clean hydrogen targets have been doubled this year to 10GW. The UK Government has recently announced a national clean hydrogen subsidy scheme called Hydrogen Business Model ("HBM"), which will use a contracts-for-difference style set-up to help fund an initial 1GW of clean hydrogen projects in 2023, as part of the target to reach 10GW of low-carbon hydrogen by 2030, in a potentially £9 billion sector. This is in addition to the Net Zero Hydrogen Fund ("NZHF") with up to £240 million of grant funding to support the upfront costs of developing and building low carbon hydrogen production projects.




In **Denmark**, a Hydrogen and Power-to-X strategy was announced in March 2022, calling for 4GW to 6GW of installed hydrogen electrolysis by 2030, using wind and solar power, putting DKK 1.25 billion of subsidy funding in place, and the policy and regulatory frameworks that are required for this.

As a further example, in 2019 the **Netherlands** set targets for 3GW to 4GW of electrolysis by 2030 with multi-billion- euro funding support announced by the Netherlands government. The government is providing EUR 750 million of funding support for a “hydrogen backbone”, retrofitting existing natural gas pipelines to transport hydrogen between five industrial clusters in the Netherlands, and at cross-border connection points.

# Company perspectives

BRAMBLE
ENERGY

## Bramble Energy

### Introduction

Bramble is a technology company on a mission to drive transformational change in the energy sector worldwide. With their PCB-X™ platform, the company is accelerating global decarbonisation and creating viable clean energy.

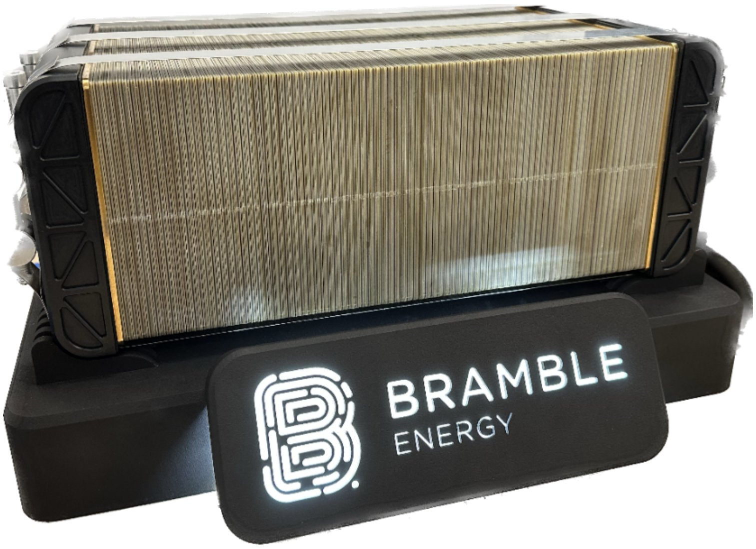
The scalable technology delivers carbon-neutral energy at low cost for unlimited applications, such as portable energy and mobility.

## Key Technologies

Utilising their revolutionary PCB-X™ platform, the PCBFC™ innovation applies existing and cost-effective production methods and materials from the well-established PCB industry, reducing cost and complexity in manufacturing hydrogen fuel cells.

The availability of hydrogen as a fuel, with the environmental advantage of a zero-emission system gives fuel cells the potential to be an outstanding renewable energy solution. Bramble's fuel cells can be scaled to demand and have widespread applications – from providing clean power for heavy and long-distance transport, to delivering portable, zero carbon, off-grid power. Bramble's technology solutions play a critical role in the clean hydrogen sector.

## Project Spotlight




Bramble Energy PCBFC™ Banded Stack

Bramble's PCBFC™ stack technology has been integrated into a Renault Kangoo ZE. This demonstrator vehicle was developed to showcase the reduced cost, form factor flexibility and high-performance capability of the Bramble high power density liquid cooled fuel cells. The phase 1 results of the collaboration were based around a Renault Kangoo ZE delivery vehicle that saw a Bramble fuel cell integrated into the vehicle powertrain as a range extender. Range extenders in light commercial vehicles offer various benefits including reduced charging time, longer range and a more user-friendly experience.

The PCBFC™ strips back traditional fuel cell complexity and reduces weight, negating the need for separate sealing materials and lowering the number of components without negatively impacting build quality or performance. Our latest development with integration partner, MAHLE Powertrain has created a derivative with a higher power output and increased overall efficiency.

### Word from the top

"At Bramble Energy we aim to enable the transition from diesel to hydrogen by providing high-performance, affordable technology solutions. PCBFC™ is the first of our platform technologies to reach the market and we continue to develop core offerings in sensing and electrolysis."

**Dr Tom Mason, CEO**

## Cranfield Aerospace Solutions

### Introduction

We are a UK-based aviation pioneer which, via Project Fresson, is developing a world-leading hydrogen propulsion system for the Britten-Norman Islander 9-seat aircraft, with the aim to deliver the world's first, zero-emissions passenger aircraft solution by 2026. Our ultimate goal is to design and manufacture low and zero carbon sub-regional and regional aircraft and to play a critical role in the decarbonisation of the aviation industry.

We are a regulatory-approved aerospace design, manufacture and maintenance organisation who have been at the cutting edge of aircraft development for over 30 years, having been trusted by global aerospace OEMs, including Rolls Royce, Airbus, Boeing as well as NASA to undertake complex R&D projects which have included aircraft design, modification and assembly.

In April 2023 we announced that we intend to merge with Britten-Norman to create the market's only fully integrated, hydrogen aviation technology and airframe manufacturing company.

### Key Technologies

Development of, and integration into an aircraft of a gaseous hydrogen fuel cell propulsion system including certification for passenger flight.

The merger with Britten Norman will enable the delivery of a series production, type-certified, zero-emissions aircraft product based on a proven and certified airframe.

## Project Spotlight

Project Fresson is the core focus of the company to deliver a zero-emissions aircraft product, certified by passenger flight by 2026.


## Word from the top

"As other sectors decarbonise quickly, it is imperative that the aviation industry accelerates its own transition to new, clean aircraft. Looking to the future we will use the combined experience of Cranfield Aerospace and Britten-Norman to produce an entirely new aircraft design, optimised around hydrogen fuel cell technology.

Phase 1 of our zero-emissions aircraft roadmap is to deliver the world's first fully certified, truly green, passenger-carrying aircraft using hydrogen fuel cell technology. The end solution will deliver emissions-free commercial air travel and is planned to be certified for passenger flight in 2026"

**Paul Hutton, CEO**

elcogen
Affordable green hydrogen

# Elcogen

## Introduction

Elcogen is a leading supplier of Solid Oxide Fuel Cell (“SOFC”) and Electrolyser Cell (“SOEC”) components and technology. Based in Estonia and Finland, Elcogen supplies solid oxide cells, stacks and modules to the global market and Elcogen’s technology is a key enabler in making the energy transition affordable for everyone.

## Key Technologies

***elcoCell***

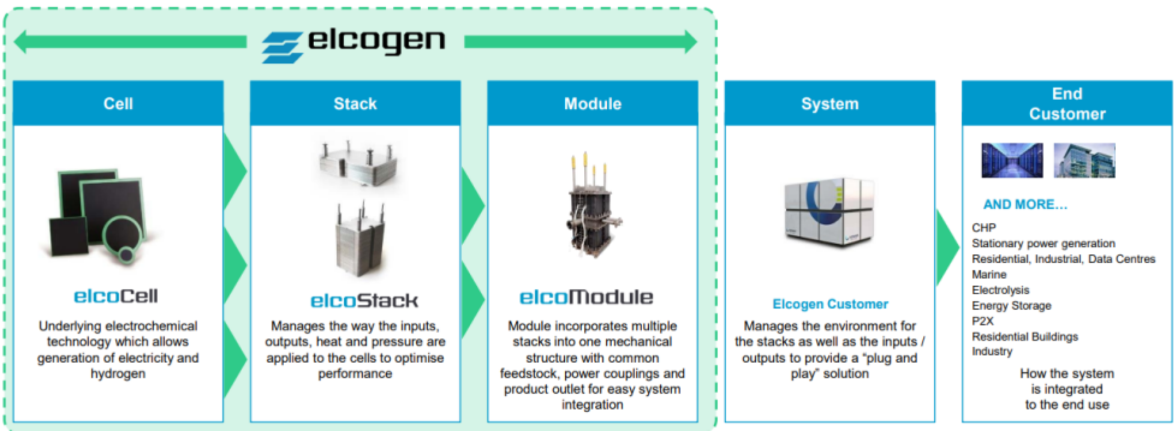
Elcogen supplies planar, Solid Oxide electrode-supported Cells (“SOC”) operating at 600-800°C. Elcogen’s elcoCell is the market’s most efficient solid oxide cell technology, suitable for electrolysis (“SOEC”), co-electrolysis (“co-SOEC”) and reversible (“rSOC”) operation modes.

***elcoStack***

Elcogen’s cells can be incorporated into third party stacks, but Elcogen also offers its own stack family, elcoStack, with E350 and E1000 stacks for R&D and validation purposes and the E3000 commercial stack for integration into fuel cell systems for stationary power generation and maritime applications and electrolyser systems for production of green hydrogen.

***elcoModule***

Elcogen also offers a range of stack modules, elcoModule, for ease of integration. The stack modules consist of a compression system, gas manifolds and an air distribution structure which enables the elcoStack E3000 to reach optimum performance.



## Project Spotlight

***Production capacity scale-up***


To respond to growing customer demand for fuel cell and especially electrolysis applications, Elcogen is scaling its production capacity with plans for a new 60 MW SOFC / 240 MW SOEC factory in Tallinn. Ramp-up of manufacturing capacity in the new facility is currently scheduled for 2025.

## Word from the top

"We believe the fuel of the future is green hydrogen and our technology is a key enabler in making this transition affordable for everyone. We develop and manufacture the world's most efficient solid oxide technology, allowing our customers and partners to deliver emission-free electricity, green hydrogen and energy storage solutions. We are developing cutting-edge technology, growing our customer base and revenues, and scaling production to drive net-zero ambitions forward."

**Enn Õunpuu, CEO**

Gen₂ Energy

## Gen2 Energy

### Introduction
Gen2 Energy is a Norwegian company dedicated to develop, build, own and operate a full value chain for green hydrogen. The company's purpose is to produce green hydrogen on a large scale based on cheap renewable energy in Norway, distribute it through bespoke solutions for land and seaborne transport, and make it easy to adapt for the customer.

### Key Technologies
Gen2 Energy are planning to build low opex and capex development hydrogen production plants. Power price is roughly 90% of opex when producing green hydrogen, and Norway, in particular North Norway, has some of the cheapest power prices in Europe due to surplus production. For example in 2022, the power price in North Norway was EUR24/MWh, while it was EUR240/MWh in the UK. For low capex, we utilize a mix of wind and hydro power, allowing for use of cheap production equipment and high utilisation, bringing down the levelised cost of hydrogen.

### Project Spotlight – 100MW facility in Mosjøen, Norway
The first project under development is located in Mosjøen, Norway. The area was acquired in September 2021, is regulated for industry, and in March 2023 it received a major milestone with the detailed zoning plan being unanimously approved in the municipality. The facility will produce compressed hydrogen, to be filled into containers, and transported by purpose built vessels, trains and trucks. Our target market is the UK and Northern Europe.


## Word from the top

"We aim to develop, build, own and operate large scale facilities for production of zero emission green hydrogen and develop an integrated hydrogen value chain. Norway, our home market, has a strong advantage for hydrogen production with both cheap and base load renewable energy available, and our large-scale facilities allows for economies of scale while transporting the volumes to Europe."

**Jonas Meyer, CEO**

HH2E

## HH2E

### Introduction

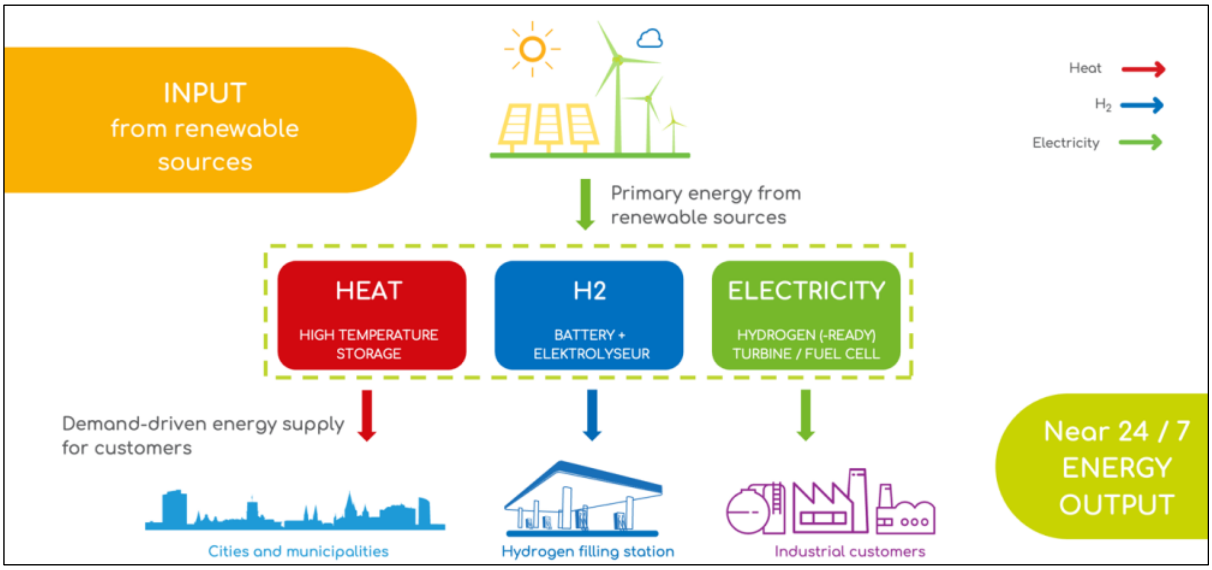
HH2E is a German green hydrogen project developer with a focus on industrial customers.

Green hydrogen produced in Germany plays a vital role in achieving the country's decarbonisation, security of supply, and energy sovereignty goals. The HH2E plants transform the fluctuating feed-in of solar and wind energy into green hydrogen production.

HH2E targets locations of decommissioned nuclear and coal-fired power stations to develop the "power stations of the future". The existing grid connection, infrastructure, local demand and community support make these sites attractive locations.

### Key Technologies

HH2E stands for the flexible mix of complementary technologies. This makes the use of renewable energies feasible on a large scale.



## Company Spotlight

HH2E's projects start with a capacity of 100MW and an investment volume of multi billion euros in the first wave of projects, with the goal of creating at least 400MW of green hydrogen capacity by 2025/26 and 4GW by 2030.

Two projects have already been made public and are in advanced planning phase: Lubmin in Mecklenburg-Vorpommern, and Thierbach in Saxony. The company has also reserved further sites and works closely to secure multi-site capacity with suppliers and multi-site offtake with customers.

## Word from the top

"HH2E is a new green energy company in Germany established to change the game of energy. With our very concrete plans to build green H2 plants, we are bringing entrepreneurial spirit to demonstrate that the energy transition is real and happening now."

**Alexander Voigt, Co-Founder & Board Member of HH2E AG**

## HH2E Thierbach

### Introduction

The HH2E Thierbach project is located in the eastern German state of Saxony and designed for an initial input capacity of 100MW, targeted to go live by end 2025, with an annual production capacity of at least 6,000 tonnes of green hydrogen. A further expansion to 1GW is envisaged by 2030.

The region of Borna played an important role in the industrialization of Germany during the 19th century, with several lignite mines located there. Today, many of those open-cast mines have been closed and some flooded to become the large lakes that are so present in the region's landscape. In addition, large solar power generation parks have been and continue to be built, from where much renewable power needed to produce green hydrogen will come. There is strong political support for investment into green energy.

### Key Technologies

The technology mix developed by HH2E harnesses the volatility of renewable energy production by combining an alkaline electrolyser with a high-capacity battery, which enables near-constant production of cost-competitive green hydrogen that will be fully compliant with the EU's RED II regulation.

### Project Spotlight


The project is being developed by HH2E and is currently in the advanced stages of technical planning and planning approvals, as well as securing offtake agreements. Customers are expected to include the transportation sector (heavy goods vehicles) and industrial/municipal users, with delivery via road trailer and pipeline.

The Thierbach project development consortium is comprised of HH2E AG, Foresight Group and HydrogenOne Capital Growth plc. The Final Investment Decision ("FID") is targeted for later this year, with initial building work possible in Q4.

## Word from the top

"Domestic green hydrogen production is essential to secure cost-competitive energy supply and deliver energy sovereignty and decarbonisation. Building a plant in Thierbach (Saxony), on the site of a former coal power station, is a tangible step towards sustainable green energy in Germany."

**Mark Page, Managing Director HH2E Thierbach**

## HiiROC

### Introduction

HiiROC's transformational thermal plasma electrolysis technology significantly lowers the cost of zero-emission hydrogen, releasing the hydrogen from hydrocarbons, like methane, flare gas and biomethane.

HiiROC's technology is applicable across all hydrogen sectors and scales, covering emissions abatement, production of clean hydrogen, and the removal of atmospheric carbon dioxide (using biomethane).

With the commissioning of client site pilots in 2023, HiiROC's development has progressed considerably since the last capital raise, positioning it for rollout and commercialisation with these and other clients in 2024.

### Key Technologies

HiiROC's proprietary technology converts biomethane, flare gas or natural gas into clean hydrogen and carbon black, through an innovative electrolysis process using thermal plasma.

This process results in zero-emission, i.e. no $CO_2$, "emerald hydrogen" at a comparable cost to steam methane reforming but without the emissions and using only one-fifth of the energy required by water electrolysis.

The zero-carbon hydrogen can be sold to existing or new users of hydrogen, integrated into grid networks for clean electricity generation or used to decarbonise industrial activities. The carbon black produced has a range of applications including tyres, building materials and as a soil enhancer.

HiiROC's modular technology can be placed at the point of demand, enabling the use of existing infrastructure and avoiding hydrogen transportation and storage costs.

## Project Spotlights

HiiROC is pursuing deployment of units into a range of key customer segments, including:

- blending hydrogen in the natural gas grid;
- power management and storage of excess renewables including working with Centrica on decarbonising peaker plants;
- decarbonising industry, including the manufacture of steel and cement, alongside developing specific use cases for carbon black;
- mitigating gas flaring, working with Boeing, with a pilot to be deployed onto an existing onshore flare;
- mobility, working with Hyundai, supplying to fuel cells for vehicle, rail freight and passenger transport; and
- production of low carbon synthetic fuels, including from biomethane, working with Epi.

By working in close partnership with its pilot unit customers, HiiROC is well positioned for global roll-out.

## Word from the Top

"HiiROC's technology brings a truly differentiated proposition to the hydrogen story. We produce low cost, zero emission emerald hydrogen, delivered to customers on a modular, scalable basis at the point of demand, avoiding transportation and storage costs. We're building the infrastructure and working with our strategic partners to deploy pilot units across the hydrogen sectors demonstrating the versatility of our technology."

**Tim Davies, CEO**

NanoSUN

## NanoSUN

### Introduction

NanoSUN develops and manufactures mobile hydrogen refueling stations, providing the infrastructure needed to accelerate the adoption of hydrogen-powered vehicles and facilitate hydrogen mobility.

### Key Technologies

NanoSUN's flagship Pioneer Hydrogen Refueling Station is a truly mobile hydrogen refueling station, delivering renewable hydrogen for use in a wide range of applications, including buses, vans, trucks, material handling, construction and backup solutions for fixed filling stations.


Pioneer relies on innovative cascade refueling technology to ensure more vehicle tanks are refueled at higher fill pressures, providing faster refuel times and better hydrogen gas utilisation.

Offering cascade dispensing also avoids the use of compressors, improving reliability and making Pioneer quick, easy and cost effective to deploy, encouraging the development of hydrogen-powered fleets supporting decarbonisation in hard-to-abate industries.

### Project Spotlights


Pioneer is a fully mobile, self-contained, automated refueling solution that offers an affordable way of delivering transportation-grade hydrogen directly to the point of use, where it is dispensed into hydrogen powered vehicles efficiently and safely.

In October 2021, Pioneer delivered hydrogen refueling to the world's first hydrogen double-deck bus developed by Wrightbus. As it made its UK Hydrogen Roadshow journey from London to Glasgow for COP26, the bus undertook two hydrogen refueling stops, facilitated by Pioneer.

In January 2023, Pioneer was deployed with customer Octopus Hydrogen, to purge and fill Alexander Dennis Enviro400FCEV buses for testing in Larbert, Scotland.

Following successful approvals from TÜV Rheinland, Pioneer is now in regular service with Stadtwerke Brühl and its transport service provider Regionalverkehr Köln GmbH ("RVK"), refueling buses in Bruhl, Germany, through our partners Westfalen AG.


## Word from the Top

"NanoSUN's mission is to accelerate the adoption of hydrogen fuel as a key element of the transition to clean energy. Our strategy is to bridge the gap between low-cost, green sources of hydrogen and hydrogen vehicles by providing operators with safe, low-cost and convenient refueling products and services."

**Neil Tierney, CEO**

Strohm

## Strohm

### Introduction

Strohm offers a superior thermoplastic composite pipeline solution ("TCP") for offshore Renewable Energy and Conventional Oil & Gas applications. Strohm has the world's largest track-record after being the first to bring the technology to the oil and gas industry in 2007. TCP reduces total installed and life cycle cost for subsea flowlines, jumpers and risers, and has proven to reduce the $CO_2$ footprint of pipeline infrastructures by more than 50%.

The company is committed to driving sustainability with its range of TCP solutions which enable clients towards their net-zero carbon emissions targets and supports the renewables sector.

TCP is a strong, non-corrosive, spoolable, lightweight technology which is delivered in long lengths, resulting in a significant reduction of transportation and installation costs. TCP is installed using small vessels or subsea pallets, significantly reducing $CO_2$ emissions. It is also 100% recyclable.

### Key Technologies

Strohm developed and introduced composite pipe based on a variety of fibres and thermoplastic compounds, thereby being the world's first. Key technologies include continuous production technologies, automated melt-fusing technologies for thermoplastic composites, design methodologies including digital prototyping, material development and qualification technologies.

The firm's know-how also includes qualification, installation and in-place analysis to ensure full lifetime support for its clients.

### Project Spotlights

One of the concepts developed and marketed by Strohm is that of the TCP on Demand, which enables clients to terminate TCP on site and install TCP offshore without the need for diving, thereby reducing cost and footprint. The concept lends itself to that of offshore hydrogen pipe installation for wind parks, where multiple wind turbine generators can be connected fast and efficient. The picture shows one of the latest projects where multiple TCP products are terminated on location for a client in Asia, ready to be installed.


## Word from the Top

"In Strohm, we are excited about the future in energy. Where we developed and introduced our technology in the Oil & Gas sector, we have created the world's largest track record with zero failures of pipe installed. On this basis, we have built up and increased our production capacity, where we produce TCP in large volumes with high quality and efficiency. Now this technology is ready to be deployed on offshore hydrogen applications and we see the first projects coming in this space. Our sustainable future requires technologies to be made available at pace, technologies that have been proven and de-risked already, which can be scaled up now. This is what TCP and Strohm brings to the market."

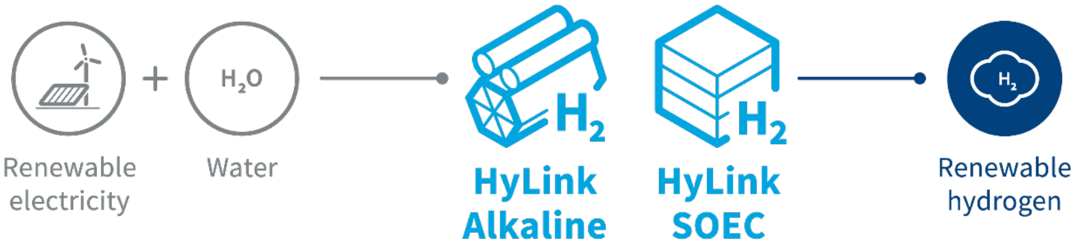
**Martin van Onna, CEO**

sunfire®

## Sunfire

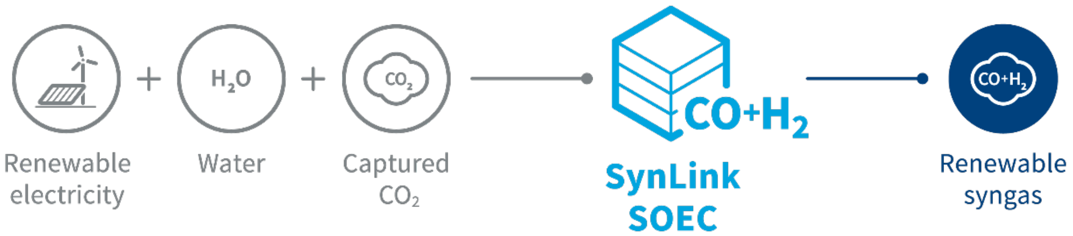
### Introduction
Sunfire is a global leader in the development and production of industrial electrolysers, the technology that transforms renewable electricity into renewable hydrogen or syngas for industrial applications.

### Key Technologies
***Sunfire-HyLink for Renewable Hydrogen Production***
Sunfire's HyLink electrolysers utilise pressurized alkaline and solid oxide technologies to produce renewable hydrogen at scale. With applications as both an energy carrier and feedstock, this clean hydrogen is deployed to decarbonise industrial processes, such as refining, steelmaking and chemical production.




***Sunfire-SynLink for Syngas Production***
Sunfire's SynLink solid oxide electrolyser processes water steam and captured $CO_2$ to produce syngas – a mixture of hydrogen and carbon monoxide. As a renewable feed gas, syngas displaces fossil fuels and decarbonises industrial supply chains – particularly within the fuels and chemical industry.

Syngas can be further processed into synthetic crude, a sustainable substitute for crude oil. This renewable fuel can then be refined into different blends of e-fuels – used as an alternative fuel in aviation, maritime and road transport – supporting net-zero mobility.



## Project Spotlights

***Salzgitter***

In the European steel industry, hydrogen has the potential to reduce today's process-related $CO_2$ emissions by more than 95%. Together with Salzgitter AG, Sunfire is a pioneer in green steel production. Since 2019, the project partners have been operating a high-temperature electrolyser to produce high-purity hydrogen for annealing processes in Salzgitter's integrated steelworks. With a record production of almost 100 tonnes of green hydrogen for the climate-neutral production of green steel, the project was successfully completed in autumn 2022. This is not the only success story within the project: Sunfire's electrolyser achieved a record electrical efficiency of 84% el LHV.

## Word from the Top

“We aim for replacing fossil fuels with renewables in all areas of life – creating a sustainable future for generations to come. We provide our customers with efficient and reliable electrolysis system solutions from one trustworthy source to decarbonize their processes, while safeguarding revenues. With green hydrogen about to become as critical as water or power supply for the industry, we stand ready to help industries secure their future through the supply of proven electrolyzers for fossil-free energy production.”

**Nils Aldag, CEO**

# 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. The plan includes Phase 1 producing 350MW of blue hydrogen from 2026, capturing some 600 thousand tonnes of $CO_2$ using HyNet's carbon-capture infrastructure. FEED of Phase 2 will be completed in 2023 which includes a second blue hydrogen plant of 700MW
- 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. The plant is currently under construction and would then first operate in 2027
- Saudi Aramco in partnership with SABIC and IEEJ shipped the world's first blue ammonia to Japan in September 2020. An initial 40 tonnes 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 2 million tonnes of $CO_2$ per year
- Air Products is currently building a world's first net-zero hydrogen energy complex in Edmonton, Alberta. The new facility will capture >95% of $CO_2$ produced by generating hydrogen from natural gas and envisioned to reach 1,500 tonnes per day of blue hydrogen. The plant is expected to be operational in 2026
- Air Liquide has been producing blue hydrogen via SMR since 2015, for the neighbouring refinery, Esso Raffinage SAF, in Port Jerome, France. It uses a carbon capture technology via a cryogenic process which improves efficiency of hydrogen production
- Doosan is currently building Korea's first blue hydrogen plant, expected to be operation in 2023. It will produce 5 tonnes of blue hydrogen per day, which will be used to supply hydrogen refuelling stations

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)
- 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. This project reached $8.4bn financial close in May 2023
- A project developed by Iberdrola for Fertiberia is operational with a 20MW electrolyser, producing 3000 tonnes of green hydrogen per year. The project also includes a 100MW solar PV plant to power the electrolyser, along with a 20MWh lithium-ion battery system
- The Da'an project in Western Jilin, China, is currently under construction, which includes 46000 Nm3/h hydrogen production from 50 sets of PEM systems and 39 sets of alkaline systems, along with 800MW of wind and solar and 80MWh of battery storage
- Djewels 1 in Groningen, Netherlands, has received final construction permit to build a green hydrogen plant. Developed by HyCC and Gasunie, it will produce 3000 tonnes per year of green hydrogen and first operate in 2024
- Asian renewable energy hub – 14GW renewable energy in Western Australia to enable green hydrogen production for domestic & export use from 2027
- Green Hydrogen International has announced 2 giga-scale green hydrogen developments in Quebec and Nova Scotia, each of which involves 300GW installed capacity of electrolysis, powered by offshore wind power, and producing over 43 million tonnes of green hydrogen per year
- H2 Green Steel is currently building an 800MW green hydrogen plant near Boden, Sweden. Powered by hydropower, it aims to produce Europe's first commercial green steel by 2025
- The Energy Bureau of China's Inner Mongolia Autonomous Region has approved a project, developed by Sinopec, to produce green hydrogen from a network of wind and solar plants to transform one of China's major coal-mining regions. Construction has started in Feb 2023 in Ordos City, Inner Mongolia
- Shell is constructing a 200MW green hydrogen plant (Holland Hydrogen I) in Netherlands, drawing electricity from an offshore wind farm. Targeting first operations in 2025, it will produce 60 tonnes of green hydrogen per day for its own production of gasoline, diesel and jet fuel in a nearby refinery in Rotterdam
- The Ningxia Solar Hydrogen Project, developed by Baofeng Energy, in China, has been producing up to 27,000 tonnes of green hydrogen per year to reduce the large consumption of coal in the area
- Unigel has installed the first industrial scale green hydrogen plant in Brazil. The first phase has a total capacity of 60MW, producing 10,000 tonnes of green hydrogen per year, which will feed one of the world's largest green ammonia plants
- TotalEnergies's Normandy platform at the La Mède biorefinery, in France, has begun production in 2023. Its 40MW electrolyser will produce 5 tonnes of green hydrogen per day to feed the needs of the biofuel production at the biorefinery, avoiding 15,000 tonnes of $CO_2$ emissions per year

- Air Liquide has opened its largest liquid hydrogen facility in Nevada, USA. It will produce 30 tonnes of liquid green hydrogen per day for numerous consumers in the clean mobility market, enough to power 40,000 fuel cell vehicles ("FCVs") in California
- The largest hydrogen pilot factory and first of its kind built inside a building has begun operations in Heroya, Norway. Developed by Yara, the 24MW system will produce 10,368kg of green hydrogen per day
- Steel manufacturer Ovako has built a hydrogen facility near Stockholm, Sweden. NEL has delivered 20MW of alkaline electrolysers, producing 8 tonnes of green hydrogen per day, which will be used at one of Ovako's steel mills, reducing $CO_2$ emissions by up to 20,000 tonnes per year
- Air Liquide's 20MW PEM electrolyser in Becancour, Canada, has been producing 8.2 tonnes of green hydrogen per year since 2021 for industrial markets in Canada and USA
- The first phase of Everfuel's HySynergy project at the Federicia facility has been completed in 2022. The 20MW electrolyser will produce 8 tonnes of green hydrogen per day from renewable wind power, along with 10 tonnes of storage capacity. Phase 2 FEED is underway to produce a further 40 tonnes of green hydrogen per day, aiming to receive approvals and funding in 2023, and commissioning by 2025
- The Arrowsmith Project in Australia is expected to produce up to 300 tonnes of green hydrogen per day, from 700MW electrolysers, 750MW of solar PV, 550MW of wind capacity and 240MW of batteries. Further expansion of the grid will allow up to 7GW of wind and solar to be sourced, to feed up to 2,100MW of electrolysers. The green hydrogen will mostly be exported to meet demand in Asia, in particular Japan and South Korea
- BP-led HyGreen is designed to produced 500MW of green hydrogen in 2030 and 60MW by 2023, in Teeside, UK
- Sinopec have announced a 300MW plant in Xingjiang, currently under construction and expected to be operational in 2023, one of four such projects for the company in China

## Largest green hydrogen projects in advanced development or operational

| Project | Stage of development | Country | Installed capacity, MW | Hydrogen production, tonnes/yr | Operator | Offtaker (where known) |
|---|---|---|---|---|---|---|
| **Marítimo Dragão - Qair** | Development (FEED) | BRA | 2,240 | 296,000 | Qair Brasil | |
| **Helios Green Fuels (Neom)** | Development (FEED) | SAU | 2,000 | 237,250 | Helios. Air Products (construction), Thyssenkrupp (electrolysers) | Air Products (exclusive) |
| **LONGi Hydrogen Project (Da'an Project)** | Under Construction (post-FID) | CHN | 1,500 | 180,000 | LONGi Hydrogen Energy | |
| **H2 Green Steel (H2GS)** | Under Construction (post-FID) | SWE | 800 | 125,000 | H2 Green Steel | Various green steel industries |
| **SALCOS - first expansion** | Development (FEED) | DEU | 785 | | | |
| **HYBRIT demo** | Under Construction (post-FID) | SWE | 500 | 60,000 | SSAB, LKAB, Vattenfall | Steel production in Gallivare, Sweden |
| **Desert Bloom, phase 1** | Development (FEED) | AUS | 400 | 20,000 | Desert Bloom | NT's power utility |
| **LADWP – NREL Intermountain Power Project (Scattergood)** | Development (FEED) | USA | 346 | | | |
| **ECB Omega Green biofuel project** | Development (FEED) | PRY | 310 | | BSBIOS | Renewable diesel and jet fuel |
| **HySynergy, phase 2 (Fredericia)** | Development (FEED) | DNK | 300 | 14,600 | HySynergy | |
| **Cromarty Hydrogen Project (Storegga) (Phase 1: 50MW)** | Development (FEED) | GBR | 300 | 7,300 | ScottishPower, Storegga | |
| **AccionaPlug JV (Various projects)** | Development (FEED) | ESP | 291 | 36,500 | Acciona Energia | Industrial and mobility business segments |
| **Sinopec – Kuqa (Xinjiang Solar Hydrogen Project)** | Under Construction (post-FID) | CHN | 260 | 20,000 | Sinopec | 3 HPAs all for industrial purposes (undisclosed) |
| **Inner Mongolia green hydrogen (Ordos)** | Under Construction (post-FID) | CHN | 239 | 30,000 | Sinopec | Nearby chemical plant. 3 HPAs all for industrial purposes (undisclosed) |
| **Holland Hydrogen - phase 1** | Under Construction (post-FID) | NLD | 200 | 21,900 | Shell | Shell Energy and Chemicals Park Rotterdam (via HyTransPort pipeline) |
| **Get H2 Lingen, phases 1&2** | Under Construction (post-FID) | DEU | 200 | 35,040 | RWE (with BP, Evonik, Nowega, OGE) | Marl Chemical Park (Evonik), Ruhr Oel Refinery Gelsenkirchen (BP) (via pipeline) |

| Project | Stage of development | Country | Installed capacity, MW | Hydrogen production, tonnes/yr | Operator | Offtaker (where known) |
|---|---|---|---|---|---|---|
| **Trafford Low Carbon Energy Park** | Development (FEED) | GBR | 200 | | | |
| **Huadian Baotou City Damaoqi Hydrogen Production Electrolysis Project** | Under Construction (post-FID) | CHN | 200 | | Huadian Heavy | |
| **Ningxia Solar Hydrogen Project** | Operational | CHN | 150 | 11,224 | Baofeng Energy | 3 HPAs all for industrial purposes (undisclosed) |
| **Jintongling Biomass Gasification** | Development (FEED) | CHN | 127 | | | |
| **Plug Power – New York Science, Technology and Advanced Manufacturing Park (STAMP) (Project Gateway)** | Under Construction (post-FID) | USA | 120 | 16,425 | New York Power Authority, Plug | Plug transportation fuel for customers (freight-transportation and logistics), Phillips 66 MOU |
| **Fertiglobe (EBIC, Ain Sokhna, Egypt)** | Development (FEED) | EGY | 100 | 15,000 | Fertiglobe | |
| **GreenLab (GreenHyScale project), Phase 1: 24MW** | Under Construction (post-FID) | DNK | 100 | | GreenLab | |
| **Air Liquide liquid hydrogen production plant** | Operational | USA | 87 | 10,950 | Air Liquide | Fuel cell vehicles in California via their 14 liquid H2 trailers. Heavy duty applications at Port of Long Beach |
| **Barataria - pHYnix, Phase 2** | Under Construction (post-FID) | ESP | 70 | 12,000 | pHYnix | Local industry or (non-)commercial transportation in Madrid |
| **Camacari Industrial Complex** | Operational | BRA | 60 | 10,000 | Unigel | Steel industry, oil refining and e-fuels. Green ammonia for fertilizer and acrylics production |
| **ArcelorMittal Hamburg** | Development (FEED) | DEU | 50 | | | |
| **Datong City solar plant (Phase 1: 10MW)** | Development (FEED) | CHN | 50 | | | |
| **Delfzijl – VoltH2 - Phase I** | Development (FEED) | NLD | 50 | | VoltH2 | |
| **Terneuzen – VoltH2 (Phase 1: 25MW)** | Development (FEED) | BEL | 50 | 2,000 | VoltH2 | |
| **Masshylia project - Total's La Mède biorefinery** | Operational | FRA | 40 | 1,825 | TotalEnergies | SAF |

| Project | Stage of development | Country | Installed capacity, MW | Hydrogen production, tonnes/yr | Operator | Offtaker (where known) |
|---|---|---|---|---|---|---|
| **Shell China – Zhangjiakou, Phase 2** | Under Construction (post-FID) | CHN | 40 | | Shell, Zhangjiakou City Transport Construction Investment Holding Group Co. Ltd | Fuel cell vehicles in city |
| **Plug Power - Kingsland, Camden County, Georgia (Peachtree)** | Under Construction (post-FID) | USA | 37 | 5,475 | ABB | Fuel transportation – material handling, FCV |
| **Solena Group Plasma enhanced gasification (SGH2)** | Under Construction (post-FID) | USA | 36 | 4,500 | SGH2 Energy Global Corporation | HRS |
| **OMNI CT – California** | Development (FEED) | USA | 36 | | | |
| **Yosemite Clean Energy – Oroville** | Development (FEED) | USA | 32 | 8,760 | Yosemite Clean Energy | |
| **Siemens-Air Liquide Oberhausen (Phase 1: 20MW)** | Under Construction (post-FID) | DEU | 30 | 2,900 | Air Liquide, Siemens | Steel production in Duisburg |
| **Westkuste 100 (Phase 1) – HyScale 100, Heide** | Development (FEED) | DEU | 30 | | Hynamics | |
| **LSB Industries (Pryor)** | Operational | USA | 30 | 5,310 | LSB, Bloom | |
| **Energy Park Bad Lauchstädt project, Reallabor** | Under Construction (post-FID) | DEU | 30 | 2,427 | Uniper | |
| **Science Parks of Tainan and Hsinchu** | Operational | TWN | 25 | 3,937 | Air Liquide | Semiconductor industry and emerging hydrogen energy applications in Taiwan |
| **Vlissingen – VoltH2 - Phase I** | Development (FEED) | NLD | 25 | 2,000 | VoltH2 | |
| **Cavendish NextGen Hydrogen Hub** | Under Construction (post-FID) | USA | 25 | | Florida Power and Light Company ("FPL") | Blend into natural gas pipeline |
| **Industrial Cachimayo** | Operational | PER | 25 | | Enaex Group (Industrias Cachimayo) | Ammonium nitrate production |
| **Linde Leuna Chemical Complex** | Development (FEED) | DEU | 24 | | | |
| **Linde Porsgrunn site** | Operational | NOR | 24 | 3,784 | Yara | Green ammonia plant (Yara) |
| **Air Products Arizona** | Under Construction (post-FID) | USA | 22 | 3,650 | Air Products | |
| **WIVA P&G Hydrogen Region (HyWest)** | Development (FEED) | AUT | 21 | | | |
| **NEL – Ovako (Hofors Rolling Project)** | Operational | SWE | 20 | 2,920 | Ovako | Steel production (internal) |

| Project | Stage of development | Country | Installed capacity, MW | Hydrogen production, tonnes/yr | Operator | Offtaker (where known) |
|---|---|---|---|---|---|---|
| **HySynergy, Phase 1 (Fredericia)** | Operational | DNK | 20 | 2,920 | Everfuel AS | Industry and vehicle OEMs in own HRS. Crossbridge Energy refinery |
| **Air Liquide Becancour** | Operational | CAN | 20 | 2,993 | Air Liquide | Industrial customers in Canada/USA |
| **Shell China – Zhangjiakou, Phase 1** | Operational | CHN | 20 | | Shell, Zhangjiakou City Transport Construction Investment Holding Group Co. Ltd | Fuel cell vehicles in city |
| **Element One (Element Eins), Phase 1** | Development (FEED) | DEU | 20 | | Thyssengas, Gasunie, TenneT | |
| **Gela refinery** | Development (FEED) | ITA | 20 | | Eni | |
| **Evolugen/Gazifère H2 injection project** | Development (FEED) | CAN | 20 | | | |
| **Green Hydrogen for Scotland** | Development (FEED) | GBR | 20 | 2,920 | ScottishPower | FCVs |
| **CF Industries - Donaldsonville Nitrogen Complex** | Under Construction (post-FID) | USA | 20 | 3,540 | CF Industries | JERA (green ammonia) |
| **Fertiberia/Iberdrola - Puertollano I** | Operational | ESP | 20 | 3,000 | Grupo Fertiberia, Triton | Ammonia production (own plant) |
| **Djewels Chemiepark – Delfzijl, Phase 1** | Development (FEED) | NLD | 20 | 3,000 | Djewels | |
| **Rafnes chemical plants** | Development (FEED) | NOR | 20 | | | |
| **P2X Harjavalta project** | Under Construction (post-FID) | FIN | 20 | 3,800 | P2X Solutions | |
| **Petrobrazi refinery OMV** | Development (FEED) | ROU | 20 | 2,600 | OMV | Refinery (internal) |

# Appendix 2:
# Transport sector key players

## Hydrogen cars

| Manufacturer | Model | Sales start/end | Price | Technology |
|---|---|---|---|---|
| **Toyota** | Mirai | 2015 | $50k | 134kW motor, 5kg tank, >500km range |
| | Crown | 2023 | | 128kW cell |
| **Hyundai** | Nexo | 2018 | $80k | 100kW cell, 120kW motor, 6.33kg tank |
| | Ix35 | 2013/2018 | $65k | 100kW motor, 5.64kg tank, 600km range |
| | Staria | 2023 | | 100kW cell |
| | SUV | 2025 | | |
| **Honda** | FCX Clarity | 2008/2016 | | 100kW motor, 4.1kg tank, 380km range |
| | Clarity | 2016/2022 | $35k | 100kW motor, 4.1kg tank, 380km range |
| | CRV-Hydrogen | 2024 | | |
| **Stellantis** | Citroen e-Jumpy | 2021 | | 45kW fuel cell, 4.4kg tank, 10.5kW battery |
| | Peugeot e-Expert | 2021 | | |
| | Open Vivaro-e | 2021 | | |
| **Mercedes-Benz** | GLC F-Cell | 2019/2023 | $35k | 4.4kg tank, 147kW motor, 437km range |
| **BMW** | I Hydrogen NEXT | 2023 | | 125kW cell, 6kg tank, 500km range |
| **Renault** | Master Van H2 | 2022 | | 6.4kg tank, 400km range, 33kWh battery |
| | Master ZE | 2020 | | 57kW motor, 33kWh battery, 320km |
| | Kangaroo ZE | 2019 | $48k | 44kW motor, 33kWh battery, 350km |

## Hydrogen trucks

| Manufacturer | Model | Country | Technology |
|---|---|---|---|
| **Toyota** | Multiple models | Japan | 44 tonne tractor unit |
| **Hyzon** | HYHD-200 | USA | 350 mile range, 374hp continuous |
| | HYMAX SERIES | | 400-680 kilometer range |
| | HYHD-110 | | 350 mile range, 374hp continuous |
| **Hyundai** | Xcient | S Korea | 6.5 tonne and HGV units commercial |
| **Paccar (Kenworth)** | T680, 579 | USA | 450 mile range, 415hp continuous |
| **Cellcentric** | HGV 44t | Germ/Swe | 150kW, can be doubled up |
| **HVS** | Demonstrator | UK | 40 tonne FCEV, 600km range |
| **Nikola** | TRE FCEV | USA | 500 mile range, 536hp continuous |

| | | | |
|---|---|---|---|
| **Tevva** | 7.5t electric | UK | 7.5 tonne battery/Loop fuel cell |
| **IVECO** | HGV 44t | Italy | NA |
| **Symbio** | Cascadia | USA | Symbio H2 Central Valley Express |
| **Scania** | HyTrucks | Sweden | 20 trucks delivered by 2024 |

## **Hydrogen** combustion **engines**

| Manufacturer | Model | Country | Technology |
|---|---|---|---|
| **JCB** | Mercedes | | Installed in 7.5 tonne Mercedes |
| **Paccar (DAF)** | DAF XF | Netherlands | Hydrogen combustion |

## Hydrogen bus

| Manufacturer | Model | Country | Technology |
|---|---|---|---|
| **Arthur Bus** | H2 Bus 12/18 | Germany | Installed in 7.5 tonne Mercedes |
| **Wright Bus** | Hydroliner | N Ireland | 48kW, 280 mile range |
| **Alexander Dennis** | Enviro400FCEV | UK | 250kW, 300 mile range |
| **Caetano Bus** | H2 City Gold | Portugal | 180kW, 400km range |
| **Hino** | Toyota Sora | Japan | 228kW |
| **Mercedes Benz** | eCitaro FC | Germany | 250kW, 400km range |
| **Toyota** | FC Sora | Japan | 228kW |
| **Rampini** | Hydron | Italy | 200km range |
| **Safra** | Hycity | France | 250kW, 350km range |
| **Solaris** | Urbino 18 | Poland | 250kW |
| **VanHool** | A12/13/18 | Belgium | 100kW |
| **Hyundai** | Elec City | S Korea | 180kW, 474km range |
| **New Flyer** | Charge H2 | Canada | 100kW, 370 mile range |
| **Nanjing Golden Dragon Bus** | Skywall NJ6106 FCEV | China | NA |
| **Foton** | AUV | China | NA |
| **Yutong** | F12 | China | NA |
| **Geely** | Yuan Cheng F12 | China | NA |
| **Zhongteng Bus** | LCK6126 | China | NA |
| **ENC** | AXESS-FC 40 | USA | NA |
| **Hyzon** | High floor Coach | USA | 195kW, 261hp, 250 mile range |
| **VDL** | Hydrogen bus | Netherlands | 230km range, trailer unit |