HydrogenOne
CAPITAL | FUTURE FUEL. NOW

The Bluffer's Guide to Hydrogen

January 2022

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

hydrogenonecapital.com

Table of Contents

Disclaimer

This document has been prepared for information and discussion purposes only. It contains information of a preliminary nature that is based on unverified and unaudited information. The information and opinions contained in this document are for background purposes only and do not purport to be full or complete. No reliance may be placed for any purpose on the information or opinions contained in this document or their accuracy or completeness. This document contains information from third party sources.

This document contains certain forward-looking statements. In some cases forward looking statements can be identified by the use of terms such as "believes", "estimates", "anticipates", "projects", "expects", "intends", "may", "will", "seeks" or "should" or variations thereof, or by discussions of strategy, plans, objectives, goals, future events or intentions. By their nature, forward-looking statements involve risk and uncertainty because they relate to future events and circumstances. Actual outcomes and results may differ materially from any outcomes or results expressed or implied by such forward-thinking statements.

HydrogenOne Capital LLP ("**HOC**") has taken all reasonable care to ensure that the facts stated in this document are true and accurate in all material respects and that there are no other material facts whose omission would make any statement of fact or opinion in this document misleading. All statements of opinion or belief contained in this document and any forward-looking statements represent HOC's own assessment and interpretation of information available to it as at the date of this document. No representation is made, or assurances are given that such statements or views are correct.

All information contained herein is subject to updating, revision and/or amendment (although there shall be no obligation to do so). No representation is made, assurance is given, or reliance may be placed, in any respect, that such information is correct and no responsibility is accepted by HOC or any of its officers, agents or advisers as to the accuracy, sufficiency or completeness of any of the information or opinions, or for any errors, omissions or misstatements, negligent or otherwise, contained in or excluded from this document or for any direct, indirect or consequential loss or damage suffered or incurred by any person in connection with the information contained herein (except to the extent that such liability arises out of fraud or fraudulent misrepresentation).

Nothing contained herein constitutes either an offer to sell, or the solicitation of an offer to acquire or subscribe for, shares or other securities or to enter into any agreement or arrangement in relation to matters discussed in this document. Nothing herein should be taken as a financial opinion or recommendation on the part of HOC, its officers, agents or advisers to enter into any transaction.

This document is not for release, publication or distribution, directly or indirectly, in whole or in part in any jurisdiction where such release, publication or distribution would be unlawful or would impose any unfulfilled registration, qualification, publication or approval requirements on HOC, its officers, agents or advisers. In particular, it should not be distributed or made available to persons with addresses in or who are resident in the United States of America ("United States"), Australia, Canada, the Republic of South Africa, New Zealand or Japan. Persons into whose possession this document comes must inform themselves about, and observe, any such restrictions as any failure to comply with such restrictions may constitute a violation of the securities law of any such jurisdiction.

Hydrogen – the elevator speech

- **The Paris Agreement and 'beyond diesel' mean that everyone is talking about clean hydrogen.**
- **This clean hydrogen can be used to clean up heavy industry and displace fossil fuels more generally.**
- **Paris Agreement means a Net Zero economy – clean hydrogen expected to be a $1tn market in that.**
- **'Beyond diesel' means installing hydrogen fuel in heavy vehicles like trucks, trains and ships**
- **You can use carbon capture and storage or renewable electricity to make clean hydrogen. This technology is proven and underway today.**
- **39 countries have hydrogen policies in place, with $70bn of funding. EU, China, Japan, California have the best investment climates for clean hydrogen**
- **In the UK, for example, there is already £3.5bn of low carbon government funding including hydrogen. Phase out of diesel from UK HGV starting 2035 underlines UK hydrogen potential.**
- **There are >500 clean hydrogen projects on the drawing board today, with spending that could reach >$700bn to 2030**
- **If you're into energy, this is all pretty hard to ignore. The sector has $1tn market potential in 2040. A 200x increase in clean hydrogen supply is anticipated 2019-2030, and…potentially 20% of the primary energy mix by 2050.**

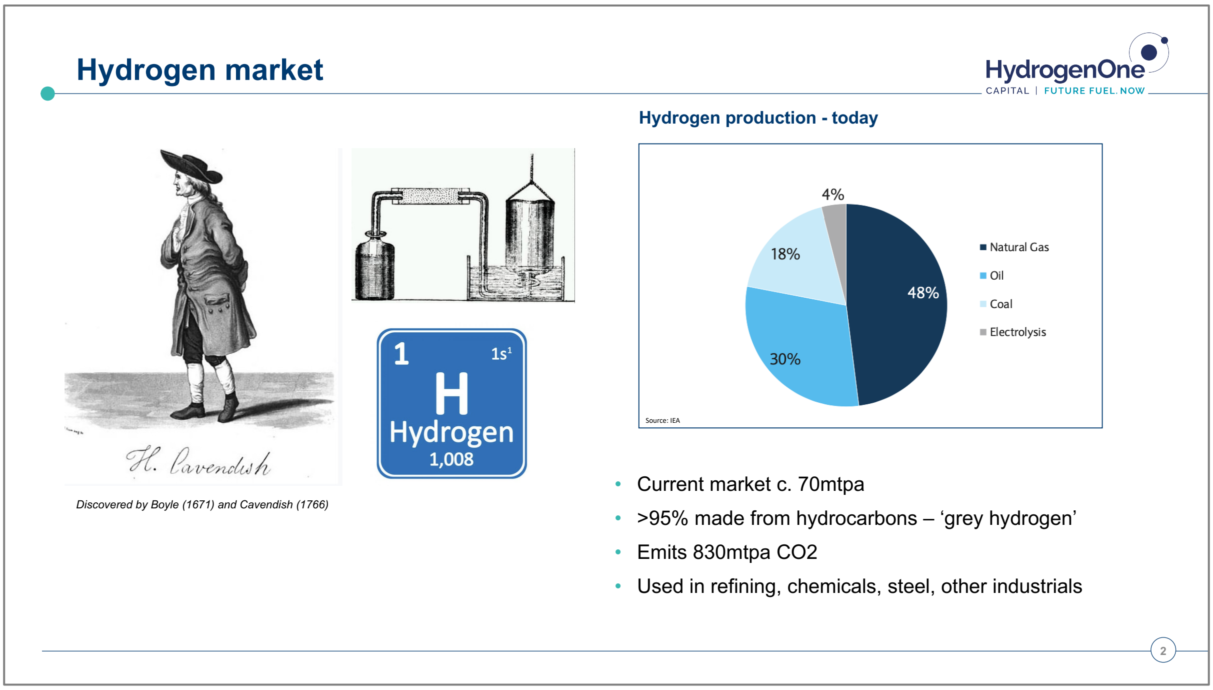
Key jargon

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

History lesson

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

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



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

The global CO_2 emissions from this are high, 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 GM made the first fuel cell vehicle.

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

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

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

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

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

HydrogenOne
CAPITAL | FUTURE FUEL. NOW

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

4

What drives demand for clean hydrogen?

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

The Paris Agreement has led 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.

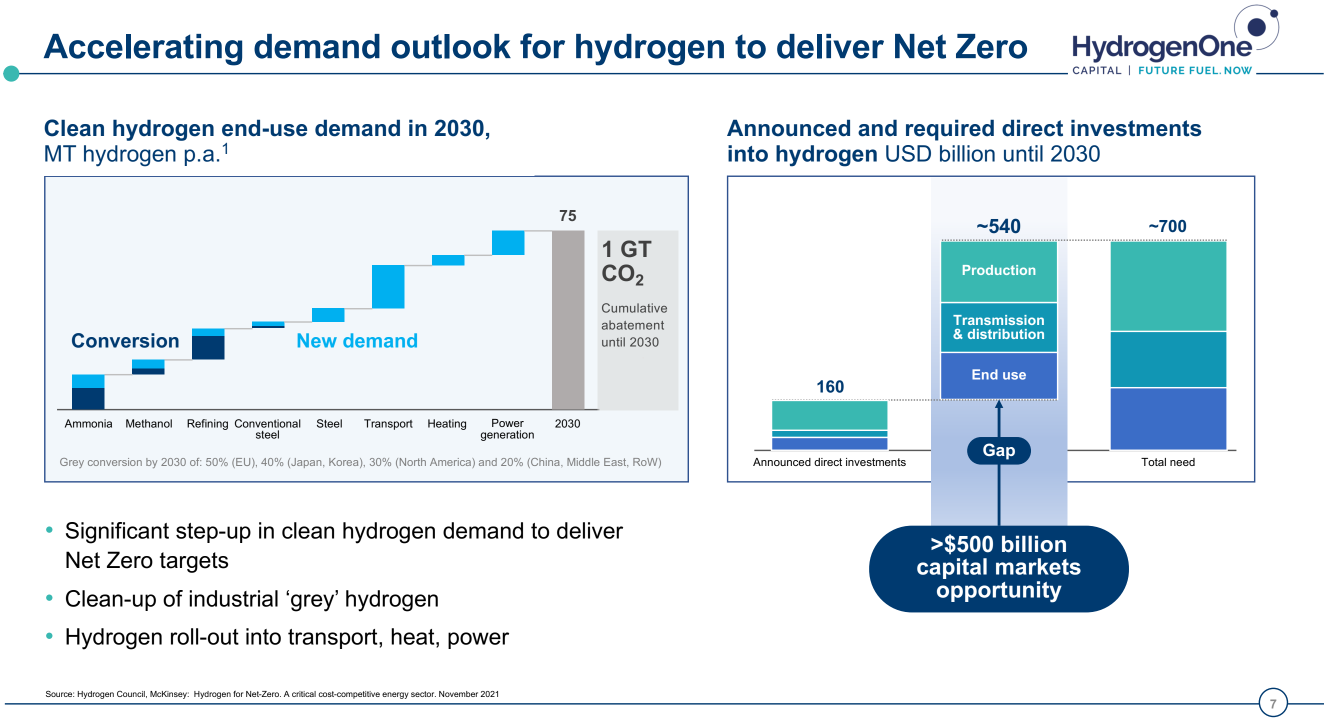
Burning fossil fuels for energy releases green-house gas and poisonous particulates. More than 20 countries have announced sales bans on internal combustion engine vehicles before 2035, and over 25 cities have pledged to buy only zero-emission buses from 2025 onwards. This is driven by Net Zero agendas,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

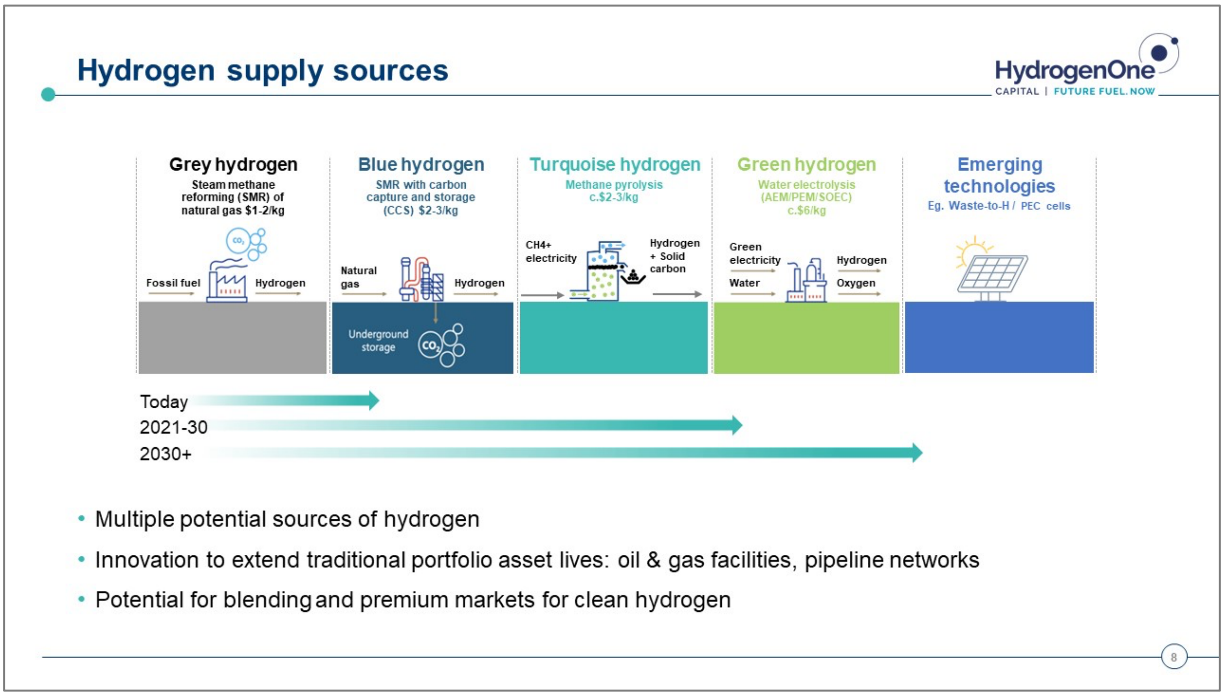
In the future, **clean hydrogen can displace fossil fuels in hard to decarbonize sectors**, either by burning it in power plants to replace natural gas, coal and oil, or by converting it to electricity through hydrogen fuel cells. Water vapour is the only by-product of using hydrogen as a fuel.

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



The hydrogen sector has $1tn market potential by 2040. A 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.

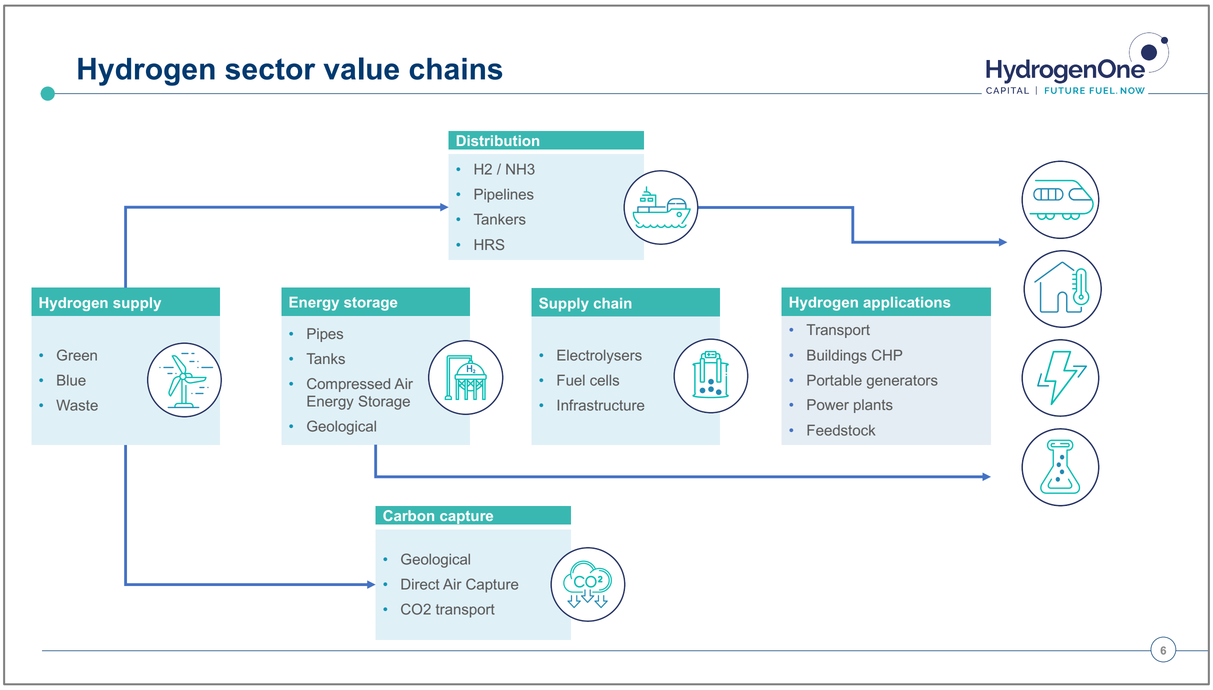
Blue hydrogen uses SMR, like grey, but captures the CO_2 and stores it.

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

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

By the end of 2021, there were at least 500 hydrogen projects announced world-wide, an increase of over 100% the year. Full value chain spending in clean hydrogen could reach $700bn to 2030.

What are the key components of the clean hydrogen industry?



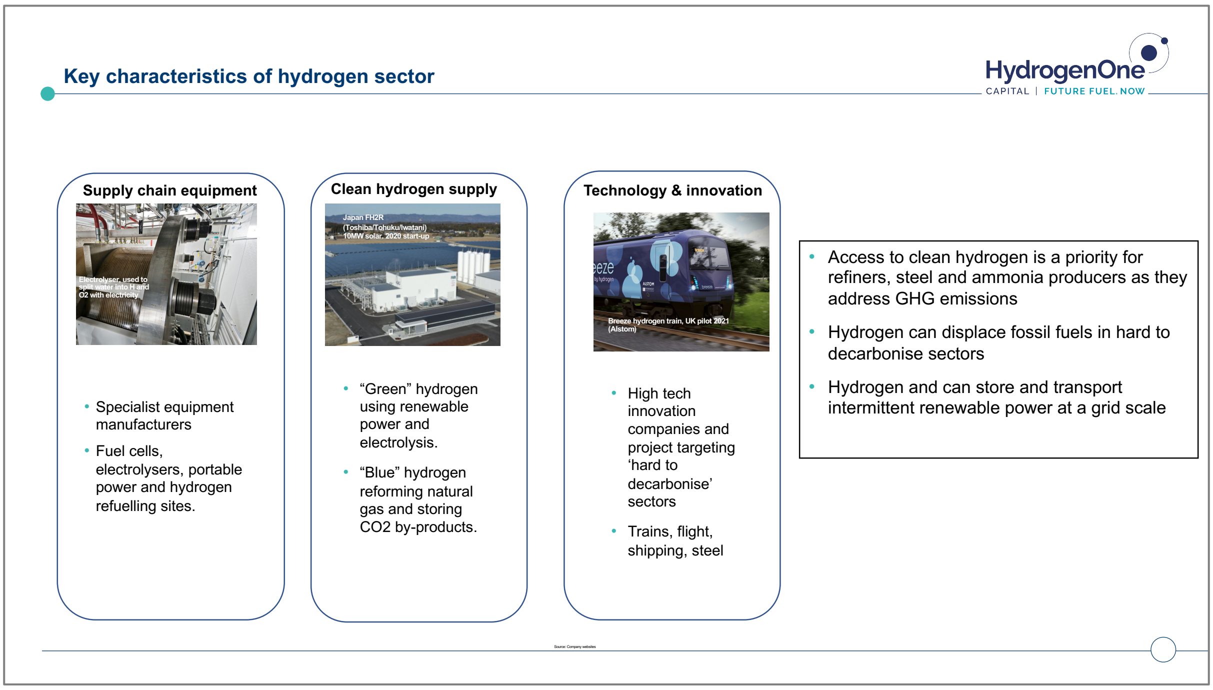
Clean hydrogen is made at industrial sites with access to low-cost green electricity ("green") or natural gas and geological CO_2 storage sites ("blue").

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

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

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

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



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

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

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

Myths in clean hydrogen

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

Blue versus Green

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

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

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

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

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

Battery electric cars versus hydrogen fuel cells

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

Reality: battery and fuel cell vehicles both have great niches

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

Hydrogen fuel cells flight versus synthetic aviation fuel

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

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

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

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

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

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

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

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

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

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

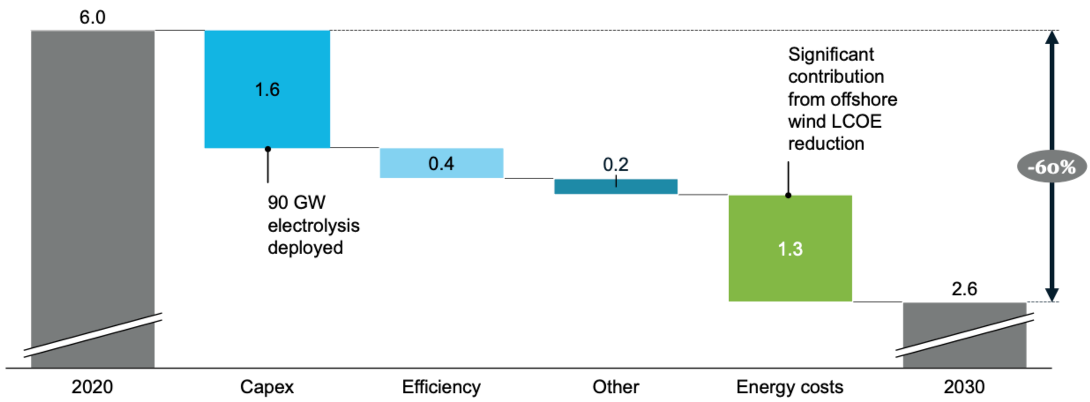
Fossil fuels market share will fall over time in the energy transition. They are expected to become more expensive due to carbon penalties and / or mitigation costs. But there will be 'low carbon fuels' with things like CCS applied.

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

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

Exhibit 13 | Renewable hydrogen from electrolysis cost trajectory

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



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

SOURCE: H21; McKinsey; Expert interview

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

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

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

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

Additionally, storage may become cheaper (not included).

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

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

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

Source: McKinsey 2020

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

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

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

Government policies

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

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

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

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

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

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

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

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

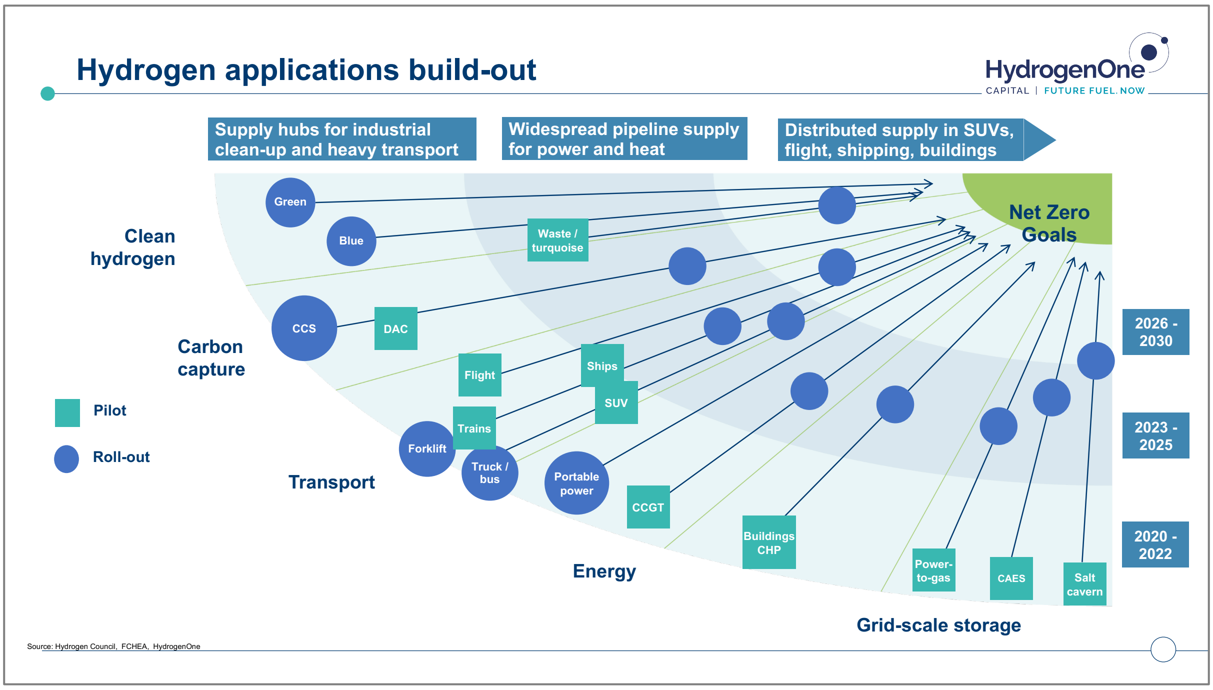
The **UK hydrogen policy** is at an earlier stage than other regions, but is gaining ground quickly. £3.5bn of government funding is in place for a strategy that emphasizes blue, as well as green hydrogen, using the UK's existing oil & gas industry and skills, and its abundant wind resources. The UK has committed to 5GW of low carbon hydrogen capacity by 2030, and has an intermediate target of 1GW by 2025. To date, the UK has an estimated 3.5MW of installed clean hydrogen production capacity.

See Appendix for an update on UK hydrogen policy.

How is clean hydrogen being rolled out?

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

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



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

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

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

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

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

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

Company perspectives

NanoSUN

Introduction

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

Key technologies

NanoSUN's flagship Pioneer Hydrogen Refuelling Station is a portable hydrogen refuelling station, delivering renewable hydrogen for use in a wide range of applications, including buses, vans, trucks, material handling, construction and backup solutions. By providing access to an efficient refuelling method, Pioneer encourages the development of hydrogen-powered fleets and industrial processes, displacing the use of fossil fuels and supporting decarbonisation in hard-to-abate industries.

Project spotlight – Double-decker Hydrogen Bus

Pioneer is a fully mobile, self-contained, automated refuelling 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.

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

Pioneer has already travelled across Germany and the Netherlands and is currently making its way across the UK. In October 2021, Pioneer delivered hydrogen refuelling 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 refuelling stops, facilitated by Pioneer.

Word from the top

"NanoSUN's mission is to accelerate the adoption of hydrogen fuel as 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 refuelling products and services."

- **Dean O'Connor, CEO**

Sunfire

sunfire®

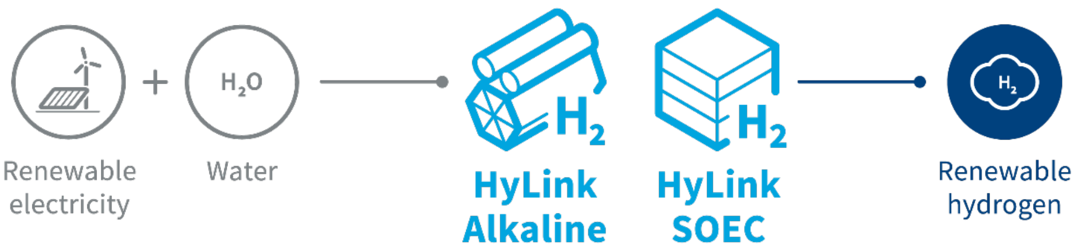
Introduction

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

Key Technologies

Sunfire-HyLink for Renewable Hydrogen Production

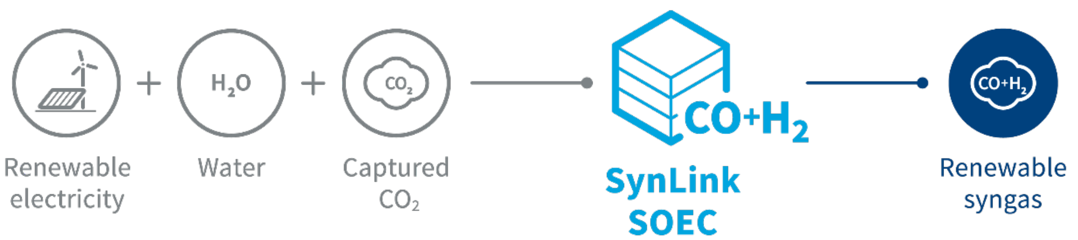
Sunfire's HyLink electrolysers utilise pressurized alkaline and solid oxide technologies to produce renewable hydrogen at scale. With applications as both an energy carrier and feedstock, this clean hydrogen is deployed to decarbonise industrial processes, such as refining, steelmaking and chemical production.



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 Spotlight - Salzgitter

In the European steel industry, hydrogen has the potential to reduce today's process-related CO_2 emissions by more than 95 %. Sunfire realizes a flagship hydrogen project with the steel producer Salzgitter. The project marks the implementation of the world's largest solid oxide electrolyser in an industrial environment to date. Until the end of 2022, the electrolyser will produce 100 tons of renewable, high-purity hydrogen that will be used for annealing processes in Salzgitter's integrated steelwork as a replacement for hydrogen produced from natural gas.

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 deliver on our purpose through developing, manufacturing and servicing high-quality electrolysis solutions. By providing renewable hydrogen and syngas as substitutes for fossil energy sources, we enable the transformation of carbon-intensive sectors towards net zero."

- ***Nils Andag, CEO***

HiiRoc

Introduction

HiiROC is focused on developing and commercialising its thermal plasma electrolysis technology, which significantly lowers the cost of zero-emission hydrogen, by “breaking down” other hydrocarbons like methane and biomethane.

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 results in zero CO_2 “turquoise 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 integrated into grid networks for clean electricity generation or used to decarbonise industrial activities, and the carbon black also has a range of applications including tires, 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 pilot units into a range of key customer segments, including:

- blending hydrogen in the natural gas grid, with Northern Gas Networks and its partners as part of its hydrogen programme
- decarbonising industry, including power generation and 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,
- production of low carbon synthetic fuels, including from biomethane, working with EPi in Chelmsford

By working in close partnership with its pilot unit customers, HiiROC aims to position the technology for future roll-out.

Word from the top

“HiiROC’s technology brings a truly differentiated proposition to the hydrogen story. We will produce low cost, zero emission 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 allow deployment of the initial pilot units in selected industry segments. The recent funding ensures we’re well positioned to move forward with both the technical and commercial development of the business.”

- ***Tim Davies, 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. Phase 1 is intended to be a GHG reduction project for the refinery, with follow on phases to supply clean hydrogen to local industry, producing up to 18TWh per year of low carbon hydrogen. Final investment decision (“FID”) for Phase 1 is scheduled for 2021.
- The Hydrogen to Humber Saltend project in the UK (H2H Saltend), led by Equinor, will produce hydrogen from natural gas with a 600MW auto thermal reformer, and CCS. The plant will use CCS facilities developed by the Zero Carbon Humber Alliance. The alliance is a consortium of Equinor, British power supplier Drax Group, and transmission network National Grid. They aim to develop a zero-carbon industrial cluster using CCS. FID is planned for 2023. The plant would then first operate in 2026.
- Saudi Aramco in partnership with SABIC and IEEJ shipped the world's first blue ammonia to Japan in September 2020. An initial 40 tons of blue ammonia were shipped from Saudi Arabia to Japan for zero-carbon power generation. The blue ammonia was created by converting natural gas into hydrogen which is then converted into ammonia for shipping and combustion at power plants.
- A consortium led by BP is maturing the H2Teeside blue hydrogen production facility in the UK, targeting 1GW of hydrogen production by 2030. The project would capture and send for storage up to two million tonnes of CO_2 per year

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

- Japan’s Fukushima Hydrogen Energy Research Field (FH2R) came on stream in March 2020 (10MW).
- Nikola Motor Company in the U.S. announced it had ordered 85 MW of alkaline electrolysers to support five hydrogen fueling stations.

- A consortium of Air Products, ACWA Power and NEOM announced plans to build a green ammonia plant in Saudi Arabia powered by 4GW of wind and solar power, to produce 237,000 tonnes a year of green hydrogen.
- NextEra Energy announced it was closing its last coal-fired power unit and investing in its first green hydrogen facility in Florida - a 20MW electrolyser to produce solar-powered green hydrogen.
- Iberdrola and Fertiberia of Spain announced a partnership to develop an integrated hydrogen plant with 100MW of solar PV, a 20MWh lithium-ion battery system and a 20MW electrolyser.
- The WESTKÜSTE100 consortium announced the construction a 30MW electrolyser at the Heide oil refinery in Hamburg. Includes a E30m grant from German government, with an expansion potential to 700MW.
- Mitsubishi announced standard packages (Hystore and Hydaptive) to integrate green hydrogen into power plants, with the technology selected at three projects: Danskammer Energy upgrade initiative in Newburgh, New York, with a capacity of 600 MW; for Balico in Virginia; and for EmberClear for its fully permitted 1,084 MW Harrison Power Project in Cadiz, Ohio.
- Iberdrola announced a UK plan to implement a network of green hydrogen production plants to supply fleets and heavy transport. The first of these will be located on the outskirts of Glasgow and will use solar and wind energy to operate a 10MW electrolysis unit.
- NorH2 in Netherlands – Shell and Gasunie - Europe’s largest proposed green hydrogen project starting 2027 to produce 800kt pa
- Asian renewable energy hub - 15GW renewable energy in W. Australia to enable green hydrogen production for domestic & export use from 2027.
- The HyGreen Provence project aims to develop a large-scale solar power and green hydrogen project in France’s Durance Luberon Verdon Agglomération (DLVA). Other partners include Engie and Air Liquide
- In January 2020, Port of Oostende, DEME Concessions and PMV announced a partnership to build a green hydrogen plant in the port area of Ostend, Belgium, by 2025. This project aims to tap curtailed power from Belgium’s existing wind capacity of 2.26GW
- The Arrowsmith Project in Australia, is expected to produce about 25 tonnes of green hydrogen a day using around 85MW of solar power, supplemented by 75MW of wind generation capacity.
- BP-led HyGreen is designed to produced 500MW of green hydrogen in 2030 and 60MW by 2023, in Teeside, UK
- Sinpoec have announced a 300MW plant in Xingjiag, on line in 2023, one of four such projects for the company in China.

Appendix 2:
UK hydrogen policy

The UK Government has put in place a series of policies in order to reduce the country's greenhouse gas emissions. As a result, UK greenhouse gas emissions have fallen by 43 per cent. since 1990, compared to a decline of 4 per cent. in the rest of the G7.

In November 2020, the UK Government set out a 10-point plan for delivery of its targets for a net zero emissions economy by 2050, spanning clean energy by sector, and green finance, including plans for CCS and clean hydrogen. The UK is committed to reducing CO2 emissions by at least two-thirds by 2035 and by at least 90 per cent. by 2050.

The UK Hydrogen Strategy was announced in August 2021, further defining the county's plans in this sector.

There is growing consensus, both within industry and UK Government, that the UK 2050 net zero target is only achievable through a significant ramp-up of low carbon hydrogen.

The UK has committed to 5GW of low carbon hydrogen capacity by 2030, and has an intermediate target of 1GW by 2025. To date, the UK has 3.5MW of installed clean hydrogen production capacity.

The UK government is offering incentives to investors in UK, building on the ten-point plan for a green industrial revolution that committed £12 billion of UK government investment, led by 40GW of offshore wind and low carbon hydrogen.

A series of subsequent, more detailed policy announcements are expected as a result of this, including the Hydrogen Business Model, likely including Contracts for Difference ("CFD") or grants, due to be published in Q1 2022, with the first contracts expected in Q1 2023. Additionally, the Government plans to launch the £240m Net Zero Hydrogen Fund in early 2022. UK Government commitment to hydrogen through various funds already announced that include clean hydrogen in their scope, totaling more than £3.5 billion. The UK Government will share the risk and costs of scaling up deployment of both Carbon Capture Utilization and Storage ("CCUS") and low carbon hydrogen. Policy reform includes initiatives to encourage consumers to switch to low carbon products, alongside initiatives to encourage fuel switching to hydrogen.

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

The Industrial Decarbonisation Strategy aims to encourage the 'cleaning-up' of the main industrial energy clusters in the UK, for example by capturing CO2 emissions, increasing the use of renewable energy, and installing significant blue hydrogen capacity for use in petrochemicals, refining and other heavy industries.

In November 2021, concurrent with the COP 26 meetings, the UK Government announced a series of fundamental changes to the heavy goods vehicles ('HGV') sector. The Investment Adviser believes that hydrogen with fuel cells, or hydrogen in internal combustion engines, both as a replacement for diesel, are the only viable solution today for decarbonization of HGV.

According to these new policies, all new heavy goods vehicles in the UK will be zero-emission by 2040. This, combined with the UK's 2030 phase out for petrol and diesel cars and vans, ending the sale of all polluting road vehicles within the next 2 decades.

The UK will become the first country in the world to commit to phasing out new, non-zero emission heavy goods vehicles weighing 26 tonnes and under by 2035, with all new HGVs sold in the UK to be zero emission by 2040

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

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

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

UK industrial cluster emissions (2018)