Green Hydrogen State of the Nation Report

The United Kingdom

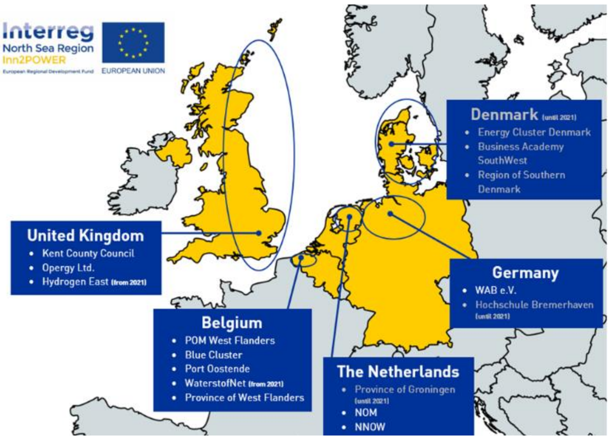
A report highlighting the Status and Development of the Green Hydrogen Sector in the clusters of Belgium, the UK, Germany, and the Netherlands.

Contents

1. Introduction

About Inn2POWER

This Inn2POWER project brings together the forces of nine partners in four countries in the North Sea region (NSR): the UK, Belgium, the Netherlands, and Germany. The aim is to expand the capacity for innovation and improve access to the offshore wind industry and green hydrogen for SMEs through connecting offshore wind and green hydrogen businesses in the NSR.



The overriding vision of Inn2POWER is to strengthen the North Sea Regions through supporting SMEs to collaborate and enter new markets through Inn2POWER's company directly, focusing on offshore wind and green hydrogen; grant easy access to test and demonstration facilities; and to improve knowledge, skills and availability of qualified staff.

About the Report

This report provides a snapshot of the current green hydrogen landscape in the UK and has been produced by Opergy, Hydrogen East and Kent County Council. It runs through the hydrogen policy landscape in the UK, which has favoured a twin-track approach – meaning both blue and green hydrogen will be pursued – and how it has developed, culminating in April's Energy Security Strategy, which saw a new 10GW target for low carbon hydrogen production set for 2030.

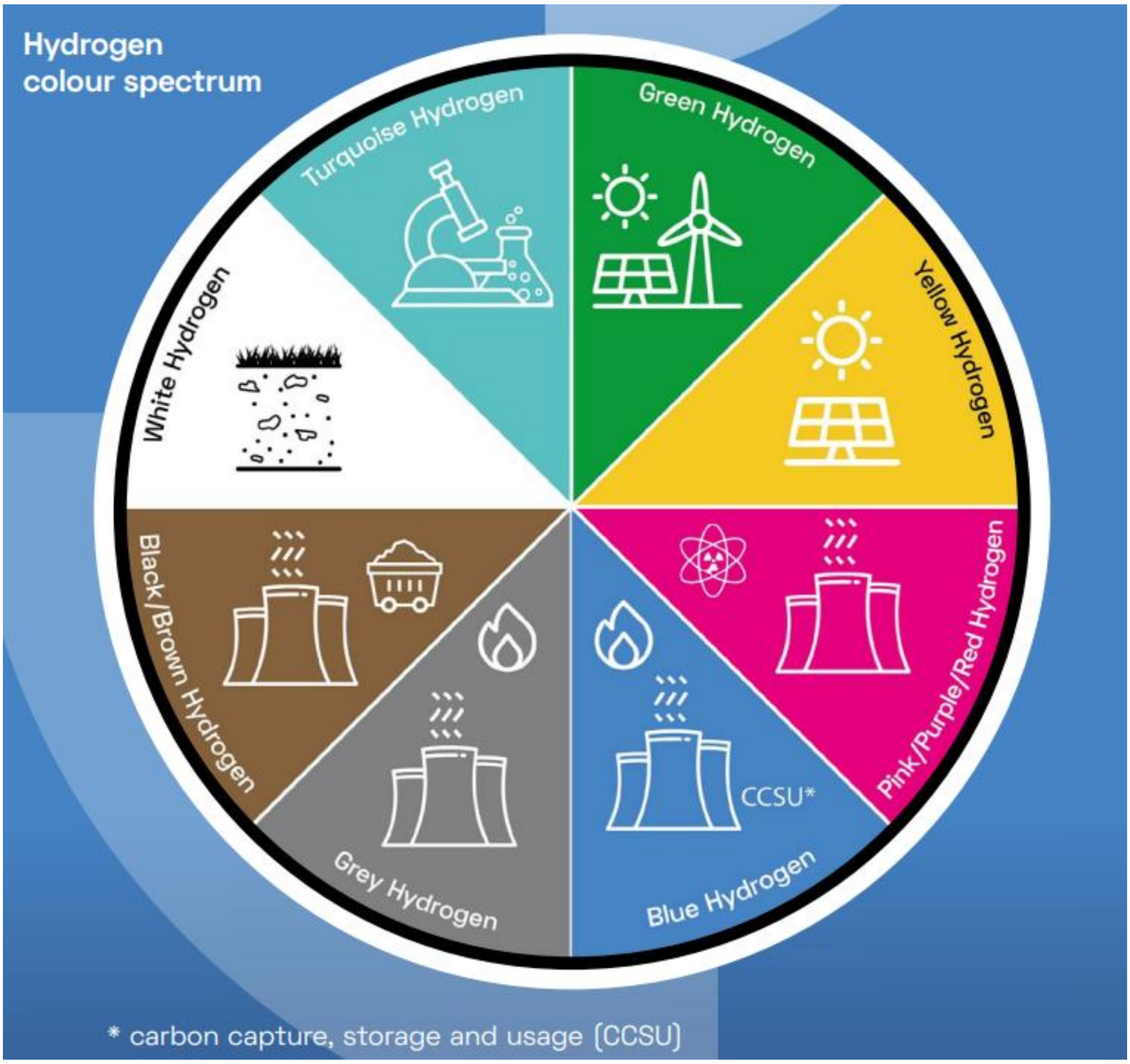
The report also explores the state of play when it comes to hydrogen's role in industrial clusters, some of the key hydrogen projects and trials that are either in development or ongoing and delves into the challenges facing the development of a green hydrogen sector, as well as the opportunities that one would provide. For the reports on Germany, Belgium and the Netherlands, as well as a summary of all four State of the Nation reports, visit the Inn2POWER website.

2. Defining Green Hydrogen

Green hydrogen is not an independent energy vector; it is always paired with or dependant on another technology to produce the power for hydrogen production. For this report, and the Inn2POWER project, we will focus on the developing 'Green Hydrogen' Sector across the North Sea Region (NSR). This chapter outlines what is meant by this definition.

The Rainbow of Hydrogen Production

The source of power used to drive the process of Hydrogen Production is commonly referred to using a colour-code1[1]. The term 'Green Hydrogen' has become commonly used to describe hydrogen production powered by low-carbon and renewable sources of power.



[1] *Hydrogen colour spectrum* – Western Gateway Partnership "Western Gateway Hydrogen Ecosystem 2022"

The following table[2] summarises the general definitions of Green Hydrogen as compared to other types of Hydrogen Production in greater depth.

Colour	Process	Impact
Green Hydrogen	Electrolysis, using renewable energy to split water into its component parts (H2 + O2) emitting zero-CO2.	No harmful greenhouse has emissions, ability to "store" surplus electricity from renewable sources.
Pink, Purple or Red Hydrogen	As green hydrogen, using nuclear power instead of renewable energy.	No carbon emissions, ability to "store" surplus electricity.
Yellow Hydrogen	Yellow hydrogen is a relatively new phrase for hydrogen made through electrolysis using solar power.	Cleanest (alongside wind) man made gas via electrolysers. Long term sustainability, a favourite in the quest for a circular economy.
Black and Brown Hydrogen	Gasification, using black coal or lignite (brown coal) to heat water and break it down. Also known as "town gas".	Along with the component parts of water, other harmful elements are produced: carbon dioxide (CO2), carbon monoxide (CO), methane (CH4), and ethylene (C2H4).
Grey Hydrogen	Steam Methane Reforming (SMR), using methane to heat water and break it down and emitting CO2 as by-product.	As above, produces other harmful elements: CH4 and CO2.
Blue Hydrogen	Steam Methane Reforming (SMR) and passing CO2 through carbon capture, use and storage (CCUS).	Grey hydrogen but with carbon capture so it is seen as a lower carbon option.
Turquoise Hydrogen	Using Methane Pyrolysis, natural gas is passed through a molten metal that releases hydrogen and solid carbon using renewable energy.	Solid carbon can be used for industrial applications, so it is seen as a lower carbon option.
White hydrogen	Naturally-occurring geological hydrogen found in underground deposits and created through fracking.	-

The UK government strategy documents do not place emphasis on the colour of hydrogen, and instead have looked to establish a low-carbon hydrogen standard which provides a threshold for carbon emissions per kilogram of hydrogen produced. This is not

[2] *The hydrogen colour spectrum* – National Grid

to say that green hydrogen is underserved in policy, as the government hopes that at least half of the 2030 hydrogen production capacity should come from 'electrolytic hydrogen.'

Defining Green Hydrogen Across the NSR

More specifically, Green Hydrogen has been defined at the European level in the EU's *Hydrogen Strategy; A case for urgent action towards implementation* published in July 2020. This defines green hydrogen as follows:

"*hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. The full life-cycle greenhouse gas emissions of the production of renewable hydrogen are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements".*

Across the other countries in Europe, definitions are outlined across strategy and policy documents published by each nation.

UK - UK Hydrogen Strategy (publishing.service.gov.uk)
DEFINITION: Hydrogen which is produced through electrolysis, where electricity is used to split water into hydrogen and oxygen – gas from this process is often referred to as 'green hydrogen' or zero carbon hydrogen when the electricity comes from renewable sources.

For the purposes of the UK definition, hydrogen production via nuclear powered electrolysis is considered within the scope of Green Hydrogen.

Germany - Nationales Reformprogramm 2020 (bmwi.de)
DEFINITION: The Federal Government considers only hydrogen that has been produced using renewable energy (green hydrogen) to be sustainable in the long term. The Federal Government therefore seeks to use green hydrogen, promote its rapid market rollout and establish the necessary value chains.

The Netherlands & Belgium seemingly use the EU definitions with hydrogen papers published by Netherlands government (Government Strategy on Hydrogen | Publication | Government.nl) about the existing state of the nation and market for hydrogen (transport, electricity, agriculture, buildings).

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3. The Green Hydrogen Policy Landscape

National Policy Landscape

Back in 2019, the UK passed laws to end its contribution to global warming by 2050 and reach net zero[3]. This followed advice from the Climate Change Committee (CCC)[4], which set out how the UK had the foundations in place to pursue such a target, with policies to deliver key pillars of a net zero economy either active or in development. This included the development of low-carbon hydrogen – a "necessity not an option".

After legislating for net zero, the government's first real "landmark moment" came with the publication of the Prime Minister's *10-Point Plan for a Green Industrial Revolution* in November 2020[5]. This set out how government will look to support green jobs and accelerate the UK's path to net zero, including "driving the growth of low carbon hydrogen". Within this, it set a target for 5GW of low carbon hydrogen production capacity by 2030, supporting up to 8,000 jobs in the process. It cited world-leading electrolyser companies in the UK and unparalleled carbon capture and storage sites it can maximise en route.

The plan set out a series of target milestones government will work towards, which have been reiterated in further publications since:

- 2021 – Publish a Hydrogen Strategy and begin consultation on the government's preferred business models for hydrogen.
- 2022 – Finalise the hydrogen business models.
- 2023 – Work with industry to complete testing necessary to allow up to 20% blending of hydrogen into the gas distribution grid for all homes on the gas grid.
- 2023 – Support industry to begin hydrogen heating trials in a local neighbourhood.
- 2025 – 1GW of hydrogen production capacity.
- 2025 – Support industry in beginning a large village heating trial, as well as setting out plans for a possible pilot hydrogen town before the end of the decade.

Following on from the *10-Point Plan*, the government brought forward its *Energy White Paper*[6] in December 2020, where it signalled its commitment to switch to new, clean fuels such as hydrogen for heat, power and industrial processes. It highlighted how a variety of production technologies will be needed to satisfy the level of anticipated clean hydrogen demand in 2050, citing methane reformation with carbon capture, utilisation and storage (CCUS), biomass gasification with CCUS, and electrolytic hydrogen using renewable or nuclear generated electricity as options. It also cited the government's ambition to invest

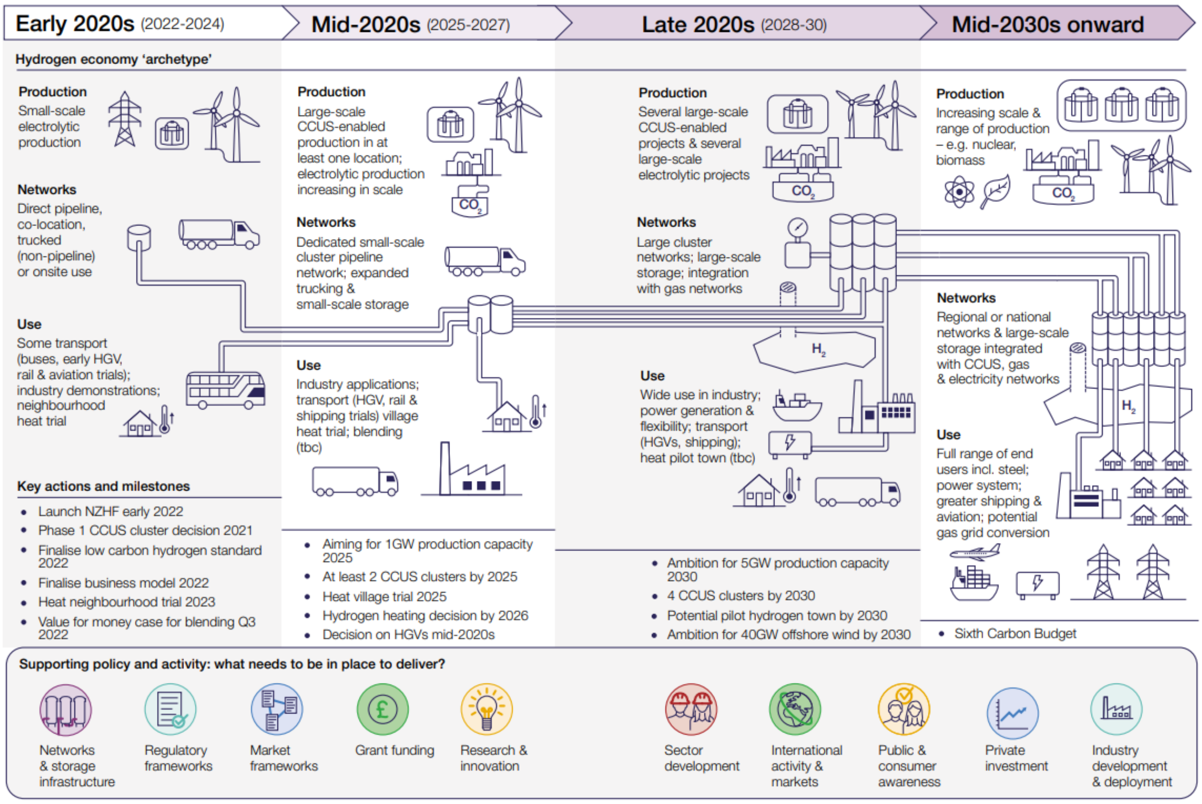
[3] UK becomes first major economy to pass net zero emissions law - BEIS
[4] Net Zero – The UK's contribution to stopping global warming – CCC
[5] The ten point plan for a green industrial revolution – BEIS
[6] Energy white paper: Powering our net zero future – BEIS

£1bn in a UK energy innovation programme to develop technologies of the future, with clean hydrogen referenced here.

March 2021 saw the publication of the *North Sea Transition Deal*[7], agreed between the offshore oil and gas industry and the government, setting out an ambitious programme for how the sector and government can collaborate to deliver the skills, innovation and new infrastructure needed to meet greenhouse gas emissions reduction targets.

Once more, this set out hydrogen ambitions, with the deal committing the sector to work with government to deliver the ambition for 5GW of low carbon hydrogen production capacity by 2030; invest in RD&D for hydrogen technologies that support the production, transportation, storage and consumption of hydrogen at lower cost; and support the development and deployment of offshore green hydrogen production using offshore wind to enable the hydrogen technology to reach full maturity.

A specific *UK Hydrogen Strategy*[8] finally arrived in August 2021, where the government sought to outline how the UK will rapidly and significantly scale up production and lay the foundations for a 2030 low carbon hydrogen economy, as illustrated in the figure below, with around 250-460TWh of hydrogen estimated to be required by 2050.



[7] North Sea Transition Deal - BEIS
[8] UK hydrogen strategy – BEIS

Within this, it pledged to take both a whole-systems and twin-track approach to developing a hydrogen economy. This twin-track approach means it will support both electrolytic green hydrogen and carbon-capture-enabled blue hydrogen production, as well as other potential routes.

In the strategy, it also pledged to provide further detail on its production strategy in 2022, with consultations launched on a £240mn Net Zero Hydrogen Fund[9], a UK standard for low carbon hydrogen[10], and hydrogen business models[11].

This was followed later in the year by the *Net Zero Strategy*[12], where the government identified cleaner fuels, including hydrogen, as being key to successfully delivering the 2050 net zero target. It cited increased electrification and low carbon hydrogen generation as key green technologies and energy carriers, to be deployed alongside CCUS and biomass. Through respective scenarios it modelled, it found potential for low carbon hydrogen production of 240TWh, 500TWh and 330TWh respectively. It tipped 10GW of low carbon hydrogen production capacity to be needed in 2035, if heat is electrified, though if hydrogen is widely used for heat, this figure would rise to 17GW.

It did acknowledge the potential role for hydrogen in heat and buildings, confirming it is committed to establishing large-scale trials of hydrogen for heating, ahead of taking decisions in 2026, as well as confirming it will consult on the case for enabling, or requiring, hydrogen-ready boilers. The *Heat and Buildings Strategy*[13] was also published the same day as the *Net Zero Strategy*, reiterating the 2026 deadline and also pledging an indicative assessment of the value for money case for blending hydrogen in the gas grid for autumn 2022, before taking a final policy decision in 2023.

In December 2021, the government launched a consultation to inform the development of possible options to enable or require hydrogen-ready industrial boiler equipment. This closed in March 2022, with the feedback currently being analysed. In February 2022, it published details on an Industrial Hydrogen Accelerator Programme, which opened for applications in April. This competition is seeking to fund demonstrations and feasibility and FEED studies in industrial settings, and forms part of the government's £1bn Net Zero Innovation Portfolio, which is aiming to accelerate the commercialisation of innovative clean energy technologies and processes through the 2020s and 2030s.

More recently, April 2022 saw the release of an *Energy Security Strategy*[14], following rising global energy prices and Russia's invasion of Ukraine. Within this, the government raised

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[9] Designing the Net Zero Hydrogen Fund - BEIS
[10] Designing a UK low carbon hydrogen standard - BEIS
[11] Design of a business model for low carbon hydrogen - BEIS
[12] Net Zero Strategy: Build Back Greener - BEIS
[13] Heat and buildings strategy - BEIS
[14] British energy security strategy - BEIS

the ambition for low carbon hydrogen from 5GW to 10GW by 2030 with "at least" half coming from green hydrogen – the figure below provides an overview of the measures proposed within the *Energy Security Strategy*.

Hydrogen
Boost our commitment to green H_2, accelerating our H_2 economy

Key measures	End 2022 ambition	2023 ambition	2024 ambition	2025 ambition	2030 ambition	2050 ambition
• Double our ambition to up to 10GW hydrogen production capacity, at least 50% from electrolytic projects • Aim to run annual allocation rounds for the hydrogen business model, moving to price-competitive allocation by 2025 as soon as legislation and market conditions allow • Aim that up to 1GW of electrolytic hydrogen is in operation or construction by 2025, alongside our existing commitment up to 1GW of CCUS-enabled hydrogen • Design Transport & Storage business models by 2025	• Complete **final hydrogen business model** • **Net Zero Hydrogen Fund** open and funding allocated • Launch **UK Low Carbon Hydrogen Standard**	• **Decision on blending up to 20% hydrogen into natural gas grid** • Award **first business model contracts** to electrolytic and CCUS-enabled hydrogen projects • Hydrogen heating **neighbourhood trial** begins	• Allocate second round of **business model contracts** to electrolytic hydrogen projects	• **Up to 1GW** electrolytic 'green' hydrogen and up to 1GW of CCUS-enabled 'blue' operational or in construction by 2025 • Hydrogen **Transport & Storage business models** designed • Hydrogen heating **village trial** begins and plan for **town pilot** • **Hydrogen certification scheme set up**	• Up to **10GW** low carbon hydrogen production capacity, double previous 5GW ambition • Hydrogen **Transport & Storage business models** in place	• There could be 240-500TWh low carbon hydrogen supply by 2050

It laid out plans to run annual allocation rounds for electrolytic hydrogen, ahead of moving to price competitive allocations from 2025, once legislation and market conditions allow. This is designed to bring forward up to 1GW of electrolytic hydrogen (either in construction or operation) by 2025. It has also pledged to design new business models for hydrogen transport and storage infrastructure by 2025, something that will be essential in growing the hydrogen economy, as well as setting up a low-carbon hydrogen certification scheme in 2025.

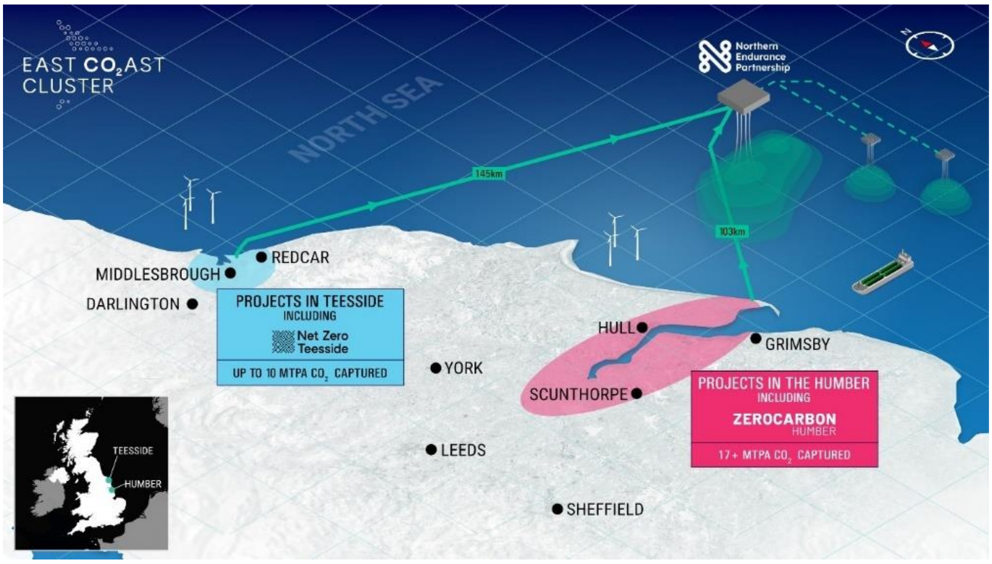
A draft *Low Carbon Hydrogen Standard*[15] was also published in April, with the government setting out guidance for hydrogen producers on greenhouse gas emissions reporting and sustainability criteria. To be classified as low carbon, hydrogen producers will have to meet a greenhouse gas emissions intensity of 20g carbon dioxide equivalent (CO2e)/mega joules (MJ) lower heating value (LHV) of produced hydrogen or less, with strong evidence to validate emissions estimates.

The *Net Zero Hydrogen Fund*[16], first mentioned in the *10-Point Plan* has also since opened for applications, with strands 1 and 2 of the competition to provide capital expenditure and development expenditure to support the commercial deployment of new low carbon hydrogen production projects in the 2020s. Strand 1 will provide development expenditure support for front end engineering design and post-FEED studies, while strand

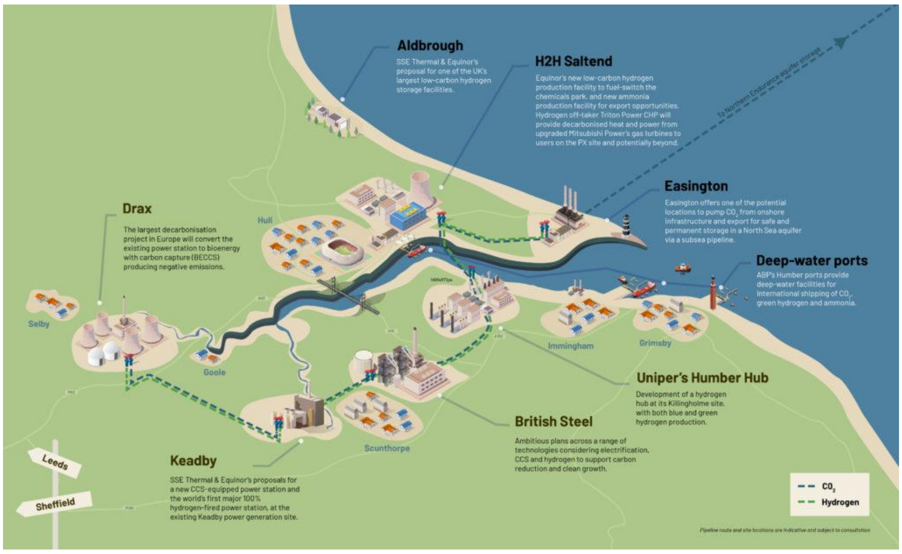
15 UK Low Carbon Hydrogen Standard: emissions reporting and sustainability criteria - BEIS
16 Net Zero Hydrogen Fund strand 1 and strand 2 - BEIS

2 will see CAPEX provided for projects that do not require a hydrogen specific business model to be viable in the longer term.

Regional / Cluster Policy Landscape



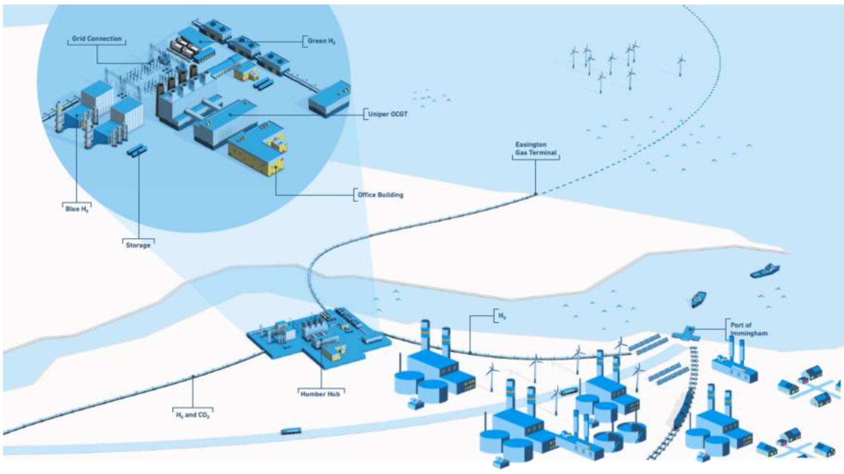
The East Coast Cluster (pictured right[17]) is one of two to be selected through the government's track 1 carbon capture, usage and storage (CCUS) cluster sequencing process. It will remove 50% of the UK's industrial cluster CO2 emissions, protect thousands of jobs – supporting an average of 25,000 a year between 2023 and 2050 – and establish the region as a globally-competitive, climate-friendly hub for industry and innovation.



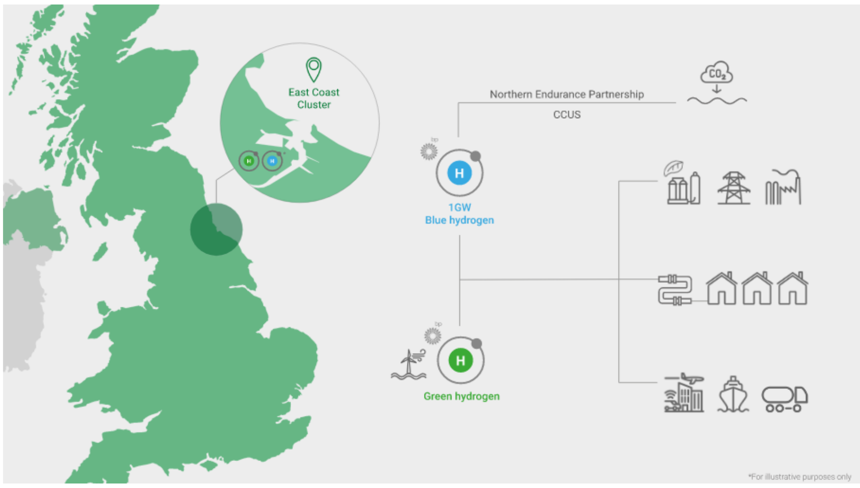
In January 2022, individual projects submitted bids to connect onto the East Coast Cluster as part of the Phase-2 cluster sequencing process[18], before 25 were then shortlisted in March 2022 having met the government's eligibility criteria. The figure[19] to the left shows some of the those involved. The hydrogen projects are: H2NorthEast, Uniper's Humber Hub Blue Project, bp's H2Teesside and Hydrogen to Humber (H2H) Saltend.

[17] East Coast Cluster – Zero Carbon Humber
[18] Cluster sequencing Phase-2: eligible projects (power CCUS, hydrogen and ICC) - BEIS
[19] East Coast Cluster Isometric – Zero Carbon Humber

H2NorthEast is a low carbon blue hydrogen project being developed by Kellas Midstream – it will be a 1GW production facility, based around Kellas' existing Central Area Transmission System facility. Uniper's Humber Hub (pictured below[20]) project will be a large-scale, low carbon hydrogen production facility at its Killingholme site, with the development including blue hydrogen production capability with a capacity of up to 720MW using gas reformation technology with carbon capture and storage. This will then be fed into the East Coast Cluster. It is also exploring the potential development of up to 100MW of green hydrogen production at Killingholme.



bp's H2Teesside (picture below[21]) is its "world-scale hydrogen project" that would produce 1GW of CCUS-enabled blue hydrogen and start-up in 2027, capturing and sending for storage up to 2mn tonnes of carbon dioxide per year via the Northern Endurance Partnership.



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[20] *Humber Hub* – Uniper Energy

[21] *Hydrogen projects in Teesside* - bp

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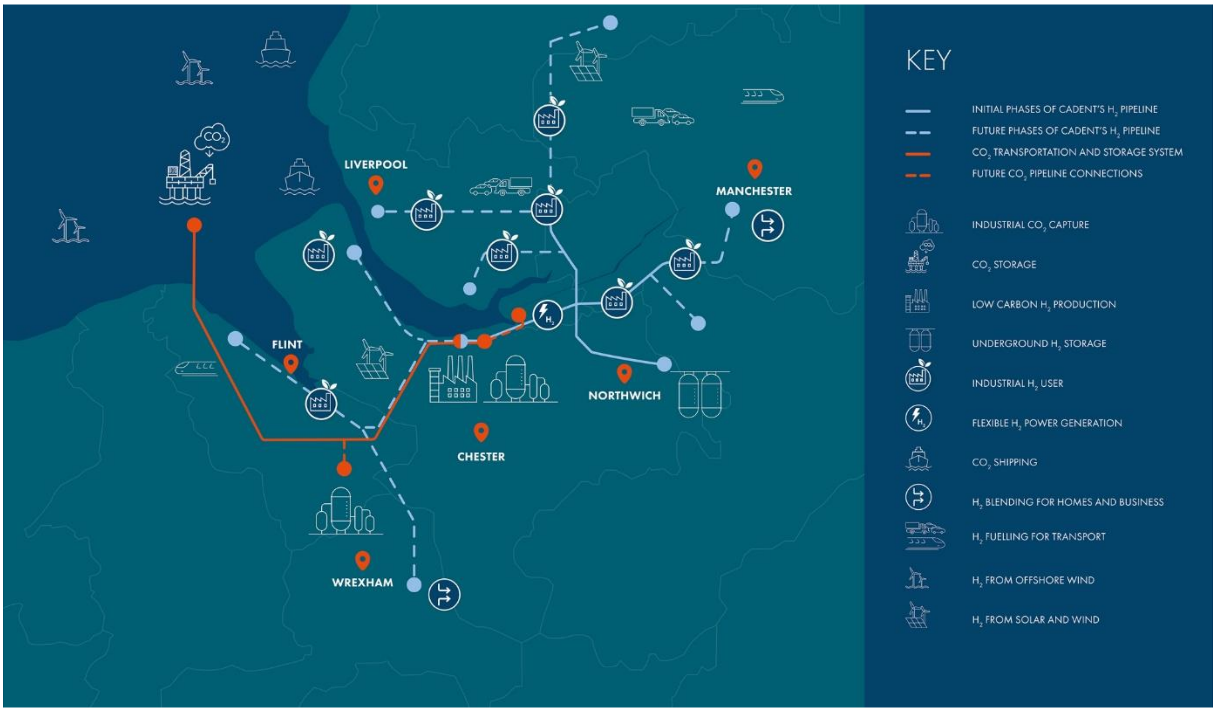
Finally, the **Hydrogen to Humber (H2H) Saltend** project[22] will be located at Saltend Chemicals Park, consisting of a 600MW auto thermal reformer with carbon capture in the initial phase, which converts natural gas to hydrogen.

This will enable industrial customers in the park to fully switch to hydrogen, with the power plant in the park able to move to a 30% hydrogen to natural gas blend. It should reduce emissions from Saltend Chemicals Park by nearly 900,000 tonnes of CO2. In later phases, it will be able to expand to serve other industrial users in the park and across the Humber, contributing to the cluster reaching net zero by 2040, enabling a large-scale hydrogen network, open to both blue hydrogen and green hydrogen, as well as a network of transporting and storing captured CO2 emissions.

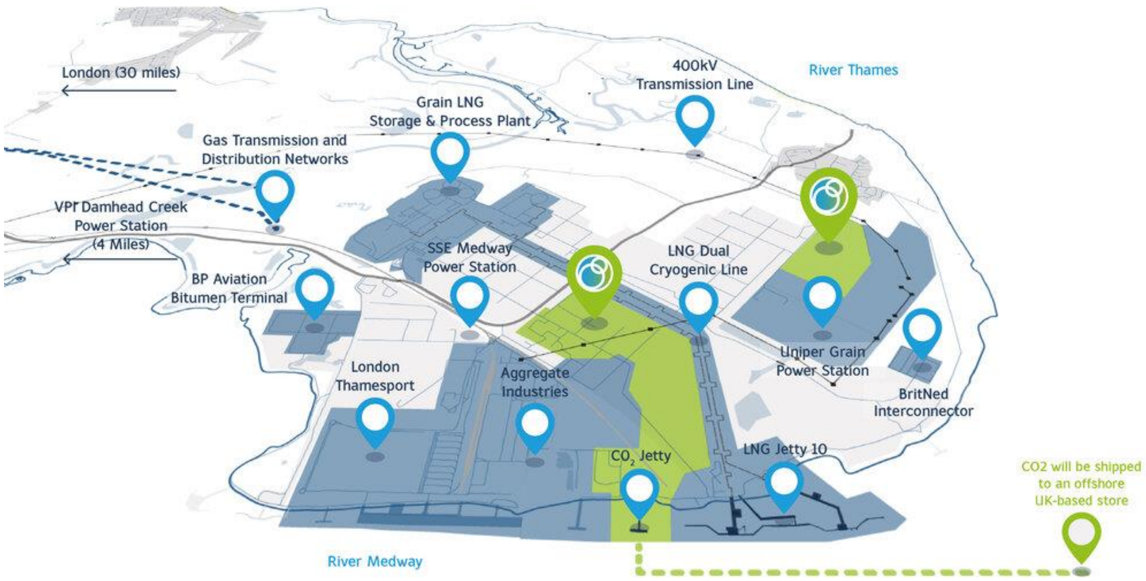
HyNet North West (pictured below[23]) was the second cluster selected, with this set to start decarbonising the North West and Wales from 2025. It is set to reduce carbon emissions by 10mn tonnes a year by 2030 and is currently focused on developing carbon capture and storage infrastructure, hydrogen transport infrastructure and developing a hydrogen production plant.



Two hydrogen projects met the eligibility criteria as part of the Phase-2 cluster sequencing process. **Project Cavendish** (pictured overleaf[24]) is dedicated to kickstarting a hydrogen economy in the South East of England. It could contribute 700MW of blue hydrogen by

[22] H2H Saltend - Equinor
[23] *What is HyNet?* – HyNet North West
[24] Project Cavendish

2026, rising to 1.75GW by 2030, abating 1.2mn tonnes of CO2 a year then 3mn a year by the same milestones.

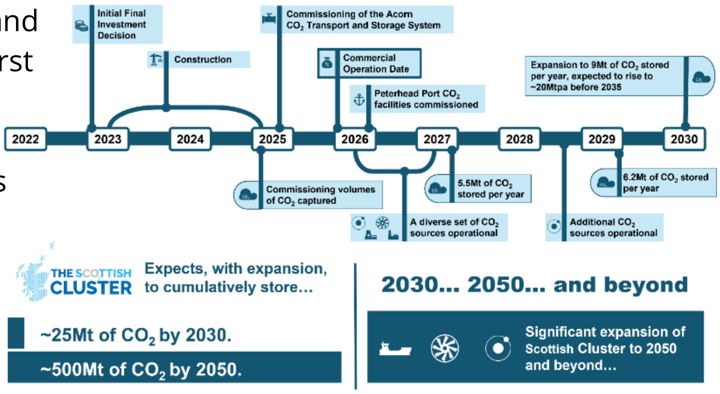


Then there is also the HyNet Hydrogen Production Project (HPP)[25], which consists of two phases, both including hydrogen production process areas that are capable of producing the energy equivalent of enough fuel to fill approximately 1,800 medium sized average UK cars every hour, combined. It also includes associated utilities, site pipelines, storage

[25] HPP – HyNet North West

infrastructure and tie-ins to the underground pipelines that will export hydrogen and carbon dioxide.

The phases will be delivered in sequence, with the first consisting of the first hydrogen production process area and all the associated infrastructure that will be needed so that hydrogen production can begin, followed by a second phase that will add further infrastructure in order to increase the amount of hydrogen being produced.



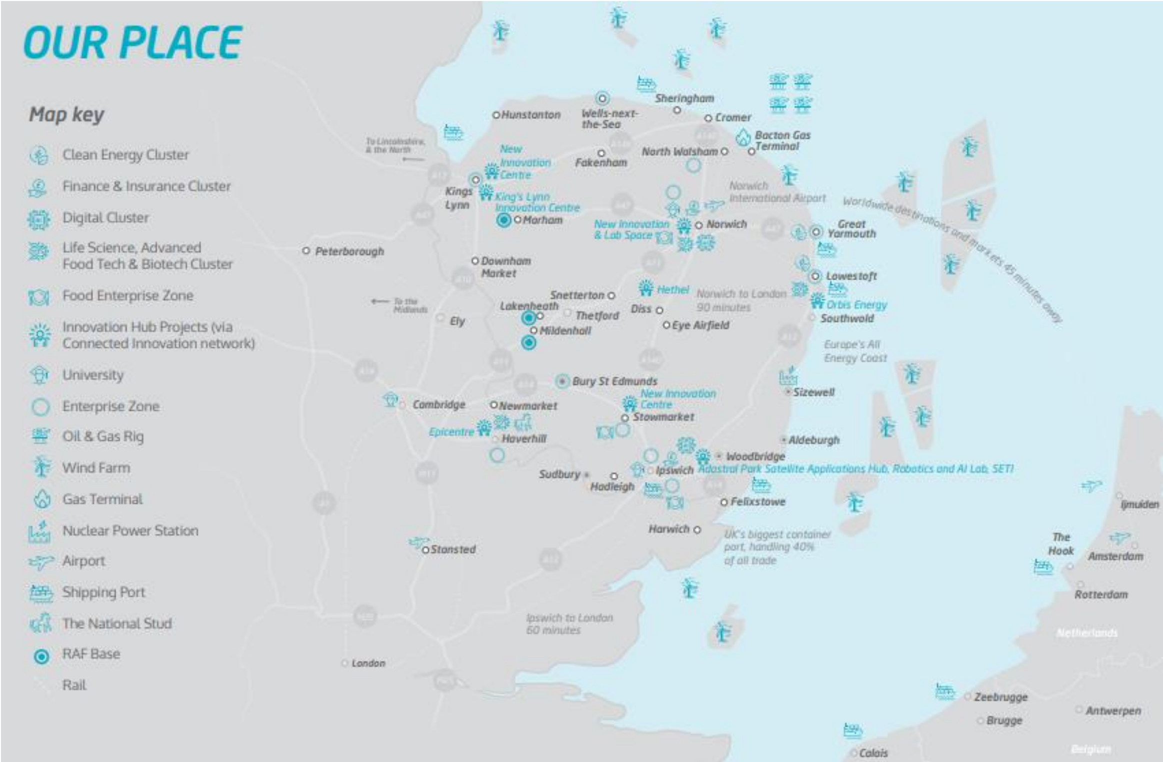
When selecting the East Coast Cluster and HyNet North West clusters as the UK's first CCUS clusters for the mid-2020s, the government named The Scottish Cluster[26] as a reserve project – the figure[27] below shows a timeline for the cluster, as well as impacts. Through deploying CCS, hydrogen and Direct Air Capture technologies, the Scottish Cluster could support an average of 15,100 jobs between 2022-2050, enable carbon capture deployment across a diverse set of emitters and a robust and resilient multi-option CO2 transport and storage system. It is expected to include nine different UK CO2 sources between 2025 and 2030, as well as hydrogen generation plant and the deployment of DAC technology.

The hydrogen projects involved under the Scottish Cluster include Acorn Hydrogen. Acorn Hydrogen (pictured left[28]) will take North Sea natural gas and reform it to clean burning hydrogen with CO2 emissions created from generation the hydrogen then safely removed and stored using Acorn CCS infrastructure.

The first Acorn Hydrogen plant is expected to be online in 2025, with Acorn Hydrogen's initial focus on blending hydrogen with natural gas piped through the National Transmission System to transport it into homes, offices and factories UK-wide.

26 The Scottish Cluster
27 SCOTTISH CLUSTER EXPECTED TO DELIVER 20,600 JOBS IN THE NEXT DECADE - Storegga
28 What is Acorn Hydrogen? – The Acorn Project

In the **East of England**, there are ambitions for Norfolk and Suffolk to become the UK hub for renewable energy, due to its existing landscape of onshore and offshore renewable energy generation[29], alongside gas and nuclear, and the more recent development of the hydrogen sector.



The energy sector across the East already delivers a considerable proportion of the UK's renewable energy production. The region has significant offshore wind capacity which can be used to transition into the production of green hydrogen, alongside solar power and a potential new nuclear reactor development at Sizewell.

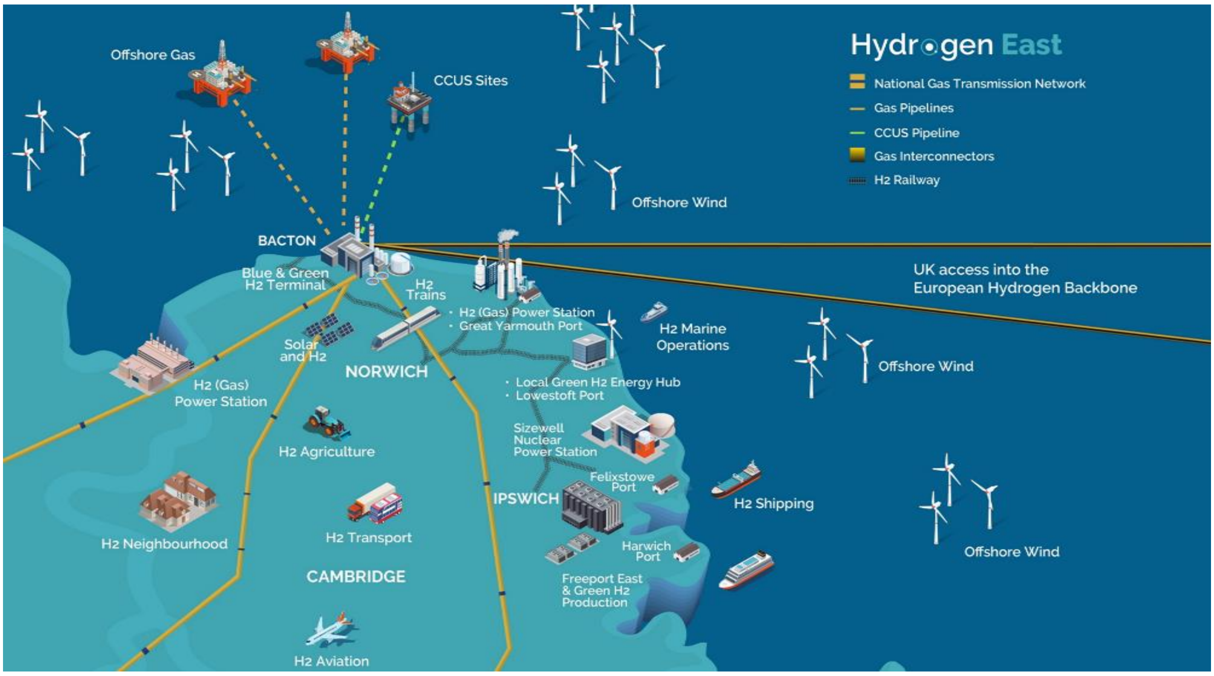
New Anglia Local Enterprise Partnership launched an economic strategy for Norfolk and Suffolk, setting out how the respective counties can become a centre for the UK's clean energy sector. It focuses on actions required over the next three to five years to accelerate Norfolk and Suffolk's transition to a zero-carbon economy and does draw on opportunities for hydrogen.

It cited the potential of **Bacton** to become a significant hydrogen production site for London and the South East, while pledging to work with Hydrogen East to deliver a viable route map for Norfolk and Suffolk to become a leading hydrogen region; it will deliver new, and adapt existing infrastructure, ensuring it is flexible, resilience and sustainable, supporting people, businesses and places, with this involving building on the area's strengths and expertise in clean energy, AI and emerging opportunities in hydrogen; while

[29] Norfolk and Suffolk Economic Strategy – New Anglia LEP

an Alternative Fuel Strategy and action plan is in development with Cambridgeshire and Peterborough Combined Authority. It also noted clear investable hydrogen proposals being developed and securing investment is a measure for success.

Hydrogen East, for its part, has unveiled a vision for a first-of-its-kind hydrogen cluster in the East of England[30]. The proposal outlines six core electrolyser sites across Norfolk and Suffolk as an initial step, which can then pave the way for development and improved infrastructure to be implemented, before further scaled as the demand for clean hydrogen then grows.



Elsewhere, there is substantial potential for the development of a **hydrogen ecosystem in East Kent**, with its plentiful supply of renewable energy, emerging and long-term sustainable hydrogen demand, a thriving research and innovation community and a strong skills and training partnership all identified as key characteristics in its favour. There is potential for a hydrogen corridor running through Kent with over 10,000 heavy goods vehicles passing through the county every day and additional opportunity for airfreight and maritime demand.

The three districts of Dover, Canterbury and Thanet have over 700MW of onshore generation, while the Nemolink interconnector provides local access to a further 1,000MW. There are three offshore wind farms with a collective capacity of 1,070MW, with the region also home to Ryze Energy, a developing a hydrogen production facility at Herne Bay.

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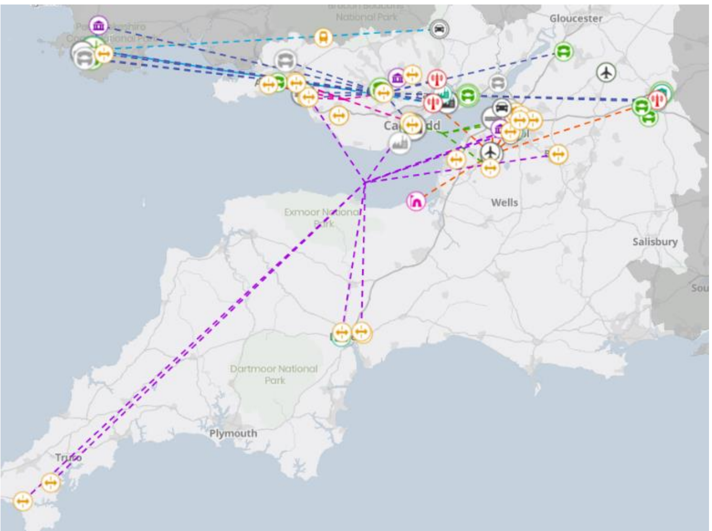
[30] Vision unveiled for first of its kind hydrogen cluster in the East of England – Hydrogen East

Short-term demand is already emerging for testing and demonstrator projects Kent. It has companies that are actively and directly engaged in the hydrogen agenda operating in East Kent including Hypoint at Discovery Park, which is focused on new lightweight fuel cell development for aviation; Cummins, focused on fuel cell technology for static energy solutions; Ryze Energy, focused on hydrogen production at Herne Bay; and CMB.TECH, which is exploring hydrogen fuelled support vessels in Ramsgate Harbour.

The universities of Kent, Canterbury Christ Church and Greenwich are involved in energy and hydrogen related research and innovation, with the equipment to test materials and products, complemented by facilities at Discovery Park. They were also joint hosts to a hydrogen summit in November 2021. Through further education for mechanical and electrical engineering, as well as robotics and wider environmental training at East Kent College, the region can support future hydrogen technical skills and ensure a sustainable pipeline of talent across multiple career pathways. Energy and logistics skills hubs in Ramsgate and Dover are under development.

This development could be focused on a hub of the ecosystem at Discovery Park which has the culture, facilities and space to grow and develop as a hydrogen hub. It has chemical, biological, pharmaceutical and analytical research, high-specification labs, pure water generation plant, HVAC system, access to warehousing, excellent logistics facilities, is seeing a manufacturing village under development and will launch a 30,000^{2}ft incubator facility later this year. It has strong transport links and is also close to maritime, air transport, logistics, industry and renewable energy sites, most being within six miles.



Moving across the country, the Western Gateway Partnership and GW4 Alliance have also unveiled a vision for South West England and South Wales to become the **UK's first Hydrogen Ecosystem**[31], with hydrogen sat at the core of a world-leading "Green Energy Super Cluster". It noted that it has a range of organisations across the area already working on hydrogen initiatives that encompass all the use cases a future hydrogen economy would need to serve - rail, maritime, aviation, domestic heating and industrial processes – with these highlighted through an interactive map (pictured above[32]).

[31] Western Gateway Hydrogen Ecosystem 2022 – Western Gateway Partnership

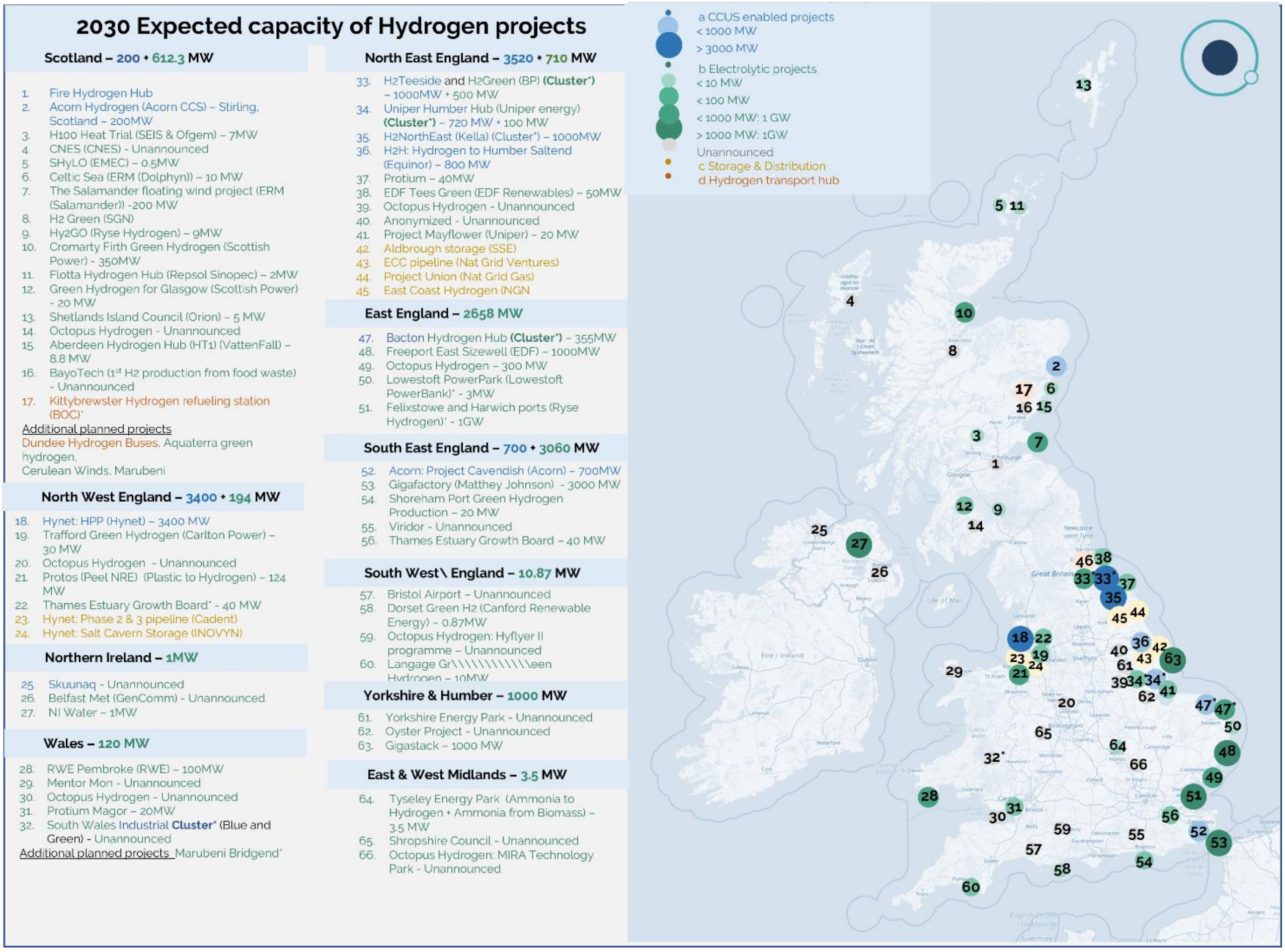
[32] Interactive Map – Western Gateway Partnership

4. The Green Hydrogen Development Pipeline

The UK has pursued both blue and green hydrogen projects, though are signs of the latter gaining momentum in 2022, with the Energy Security Strategy perhaps notable in particular with its commitment to having "at least" half (5GW) of its 10GW low carbon hydrogen production target coming from green hydrogen.

National Development Pipeline

The below figure offers a breakdown of projects across the UK, broken down by region and expected capacity in 2030. The rest of this section will offer greater detail on some of the larger projects in development.



In **Scotland**, ScottishPower's **Green Hydrogen for Glasgow** project[33] is looking to build a 20MW electrolyser near Whitelee windfarm – the UK's largest onshore windfarm – as part of a green hydrogen facility producing up to 8 tonnes of green hydrogen per day. The **Gigastack**

[33] Green Hydrogen for Glasgow - ScottishPower

project[34] in Humberside is eyeing the commercial operation of a 100MW scale electrolyser system powered by offshore wind by 2025. Then there's bp, which has unveiled plans for HyGreen Teesside[35], a large-scale green hydrogen production facility in the North East of England, capable of delivering up to 500Mwe of hydrogen production by 2030.

Sticking with Teesside, EDF Renewables and Hynamics have set out plans for Tees Green Hydrogen[36] which will use electricity from the nearby Teesside offshore windfarm, along with a new 49.9MW solar farm, to power an electrolyser 30-50MW in size initially, with the potential to scale to over 500MW to correlate with emerging demand. Octopus Hydrogen and BayWa r.e. have also joined forces[37] to collaborate on innovative green hydrogen production facilities at renewable project sites across the UK, with a project pipeline identified with the potential to produce up to 6,500kg per day of green hydrogen as an initial step.

The government has revealed successful projects under its £60mn Low Carbon Hydrogen Supply 2 funding competition, with a total of 28 selected[38]. These include ITM Power's Gigatest - part of the aforementioned Gigastack project - which was awarded £9.3mn as ITM looks to accelerate the commercial development of its 4th generation Proton Exchange Membrane electrolyser stack and new Gigafactory manufacturing site in Sheffield. It will build its first 4th generation 5MW stack as part of Gigatest.

Another successful project was a Gemserv-led consortium's Tyseley Ammonia to Green Hydrogen project[39], awarded £6.7mn to design, build, commission and then operate the world's largest and most efficient ammonia to hydrogen integrated membrane reactor.

It is also worth noting a number of trials taking place, including that of HyDeploy[40], which has been seeking to show how a blend of hydrogen gas can be used as a safe, low carbon energy source for heat in industry and homes. A successful first phase saw live testing of blended gas with a hydrogen content of up to 20% supplied to 100 homes and 30 university buildings at Keele University over 18 months, before being followed by a second which has seen a larger trial – 668 homes, a school and a number of small businesses near Gateshead with a 20% blend. This is due to conclude in summer 2022.

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[34] Vision – Gigastack Project
[35] Bp plans major green hydrogen project in Teesside - bp
[36] New green hydrogen project by EDF Renewables UK and Hynamics comes to Teesside - EDF
[37] Octopus Hydrogen and BayWa r.e. announce green hydrogen partnership – Octopus Hydrogen
[38] Low Carbon Hydrogen Supply 2 competition: successful projects - BEIS
[39] Tyseley Energy Park to host world-leading ammonia to hydrogen project with new Government backing – Tyseley Energy Park
[40] Project Phases - HyDeploy

Green hydrogen injection into the NTS[41] is under investigation by National Grid, Cadent, CNG Services and Element Energy, with a focus on the commercial and technical challenges of injection and blending small volumes of green hydrogen into the National Transmission System (NTS). Ofgem is also funding two detailed design studies from Cadent and Northern Gas Networks for Hydrogen Villages[42].

Water security is a major issue in the UK. As the population grows, demand for water also rises, yet supply does not keep pace.

The water stress classification has classified areas in the East of England, South East, East Midlands, most of the West midlands and some parts of the South West as "serious", with the number of companies under serious water stress increasing from nine out of 24 in 2013[43] to 17 out of 23 in 2021 across England and Wales.

The Environment Agency published a significant assessment[44] on the health of England's water resources, revealing more than 3bn litres of water – or 20% of supply – is being lost through leaks every day in England. According to the report, most locations will not be able to meet water demand by the 2050s[45], especially in the South East, with climate change having a considerable impact by then on how much rain there is. This, combined with the growing population, will see the gaps between water demand and supply in the UK clear 600mn litres per day in 2050[46].

This issue has led to concerns over production of hydrogen in water stressed regions, with desalination of seawater considered a valuable alternative to address both water scarcity and hydrogen production feedstock. ERM Dolphyn and Source Energie have announced plans to develop gigawatt scale green hydrogen floating wind sites[47] in the Celtic Sea. The modular design combines electrolysis, desalination and hydrogen production on a floating wind platform, with a 300MW "Dylan" site the first under development in the Celtic Sea, 60km west of Milford Haven, and set to be operational by the end of 2028. The government awarded the project £8.6mn through its Low Carbon Hydrogen Supply 2 competition.
There is also a pilot project at Vattenfall's 97MW Aberdeen offshore windfarm – the Hydrogen Turbine 1 (HT1) project[48] - which also received funding (£9.3mn) through the government's Low Carbon Hydrogen Supply 2 fund. This is being talked of as a world-first

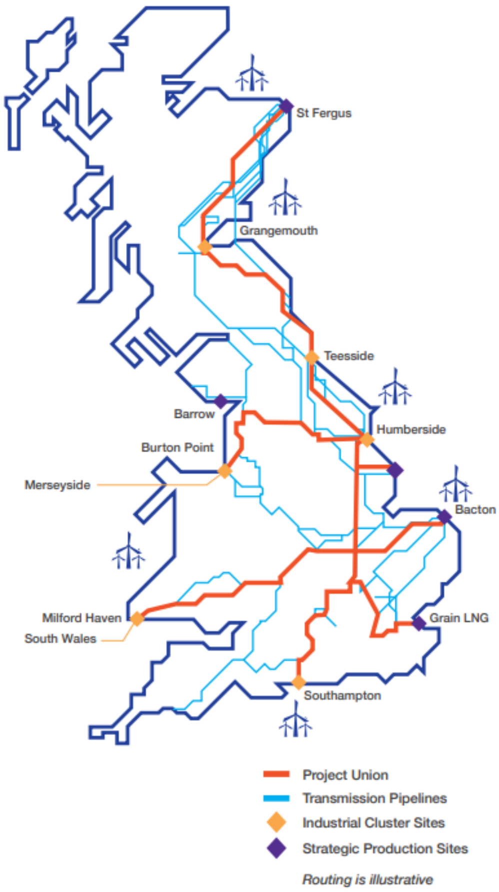
[41] National Grid granted £1.5m Ofgem funding for innovation projects to accelerate progress towards net zero – National Grid
[42] Hydrogen Village Trial Detailed Design Studies Decision - Ofgem
[43] Water stressed areas – final classification – Environment Agency and Natural Resources Wales
[44] State of the environment – Environment Agency
[45] Preserving our water resources in a changing climate – industry and government tackle threat to future water supplies – Environment Agency
[46] WRE Strategic Advisory Group Webinar 29/07/22 – Water Resources East
[47] ERM Dolphyn and Source Energie announce plans to develop Gigawatt scale "green hydrogen" floating wind sites in the Celtic Sea - ERM
[48] Hydrogen Turbine 1 - Vattenfall

full scale demonstration combining offshore wind and green hydrogen production, with an electrolyser integrated into the turbine itself. It consists of hydrogen production equipment, including desalination, electrolysis and associated balance-of-plant closely integrated with the turbine power electronics, physically coupled with the turbine, on an extended platform at the base of the turbine. It is expected to operate from 2025 without requiring energy supply from the national grid, with the hydrogen transported to shore through a pipeline for processing and delivery to end users.

Regional / Cluster Development Pipeline

As previously stated, there are hydrogen projects in development under the **East Coast Cluster**, **HyNet North West** and **Scottish Cluster**, while elsewhere National Grid is exploring plans for a UK hydrogen backbone – **Project Union**[49].

Project Union will link industrial clusters around Britain as it looks to reach net zero by 2050, creating a 2,000km hydrogen network by 2030, repurposing around 25% of current gas transmission pipelines. It will connect the Grangemouth, Teesside and Humberside industrial clusters, while establishing links with Southampton, the North West and South Wales. It will also explore how to connect to the interconnectors coming in from the Bacton gas terminal in Norfolk, as well as St. Fergus, allowing the UK hydrogen backbone to link up with the EU hydrogen backbone.

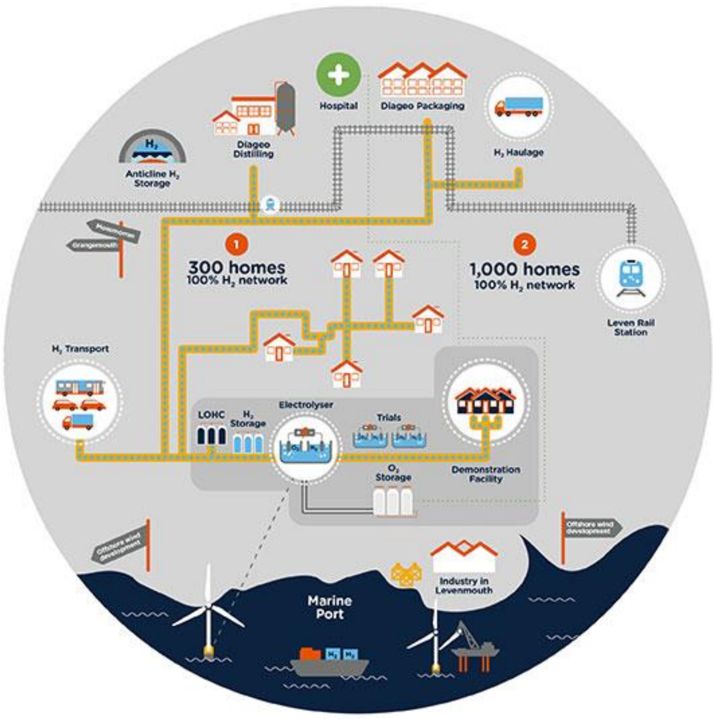


The connectivity, flexibility and resilience provided by the backbone will benefit hydrogen producers, users and stakeholders, while also enabling effective market growth and efficient expansion. The transmission system will provide accessibility of hydrogen infrastructure, allowing for the decarbonisation of different sectors and maintaining capital growth. Project Union is forecast to support £300mn annual GVA and a peak of 3,100 jobs during construction. Down in Southampton, ExxonMobil, SGN and the Green Investment Group are exploring plans for a **Southampton hydrogen hub**[50]. An initial feasibility study found annual hydrogen

[49] Project Union – National Grid
[50] ExxonMobil, SGN, and Green Investment Group sign MoU to explore potential for Southampton hydrogen hub - GIG

demand from the cluster – identified as one of six major industrial clusters by the government - could hit 37TWh by 2050, with it also estimating carbon capture facilities could initially capture around 3mn tonnes of CO2 per year, including from initial hydrogen production of around 4.3TWh per year.

The <u>**Gas Goes Green**</u> programme[51] is a collaboration of all five of Britain's gas network companies: Cadent, National Grid, Northern Gas Networks, SGN and Wales & West Utilities (WWU). It is focused on the changes needed to convert gas to hydrogen and biomethane infrastructure, with an aim to create the world's first net zero carbon gas grid by speeding up a switch from natural gas to hydrogen for 85% of UK households connected to the gas grid. It is to research, implement and coordinate innovative projects to ensure safe and secure hydrogen delivery, such as <u>**H100 Fife**</u>[52] (pictured below) in Scotland that will bring green hydrogen into homes in 2023. H100 Fife will be a world-first green hydrogen-to-homes heating network on the Fife coast, initially heating around 300 local homes using hydrogen produced by an electrolysis plant, powered by a nearby offshore wind turbine during its first stage.



<u>**East Coast Hydrogen**</u>[53] from Cadent, Northern Gas Networks and National Grid is set to repurpose and build new hydrogen pipelines across the North East of England, connecting

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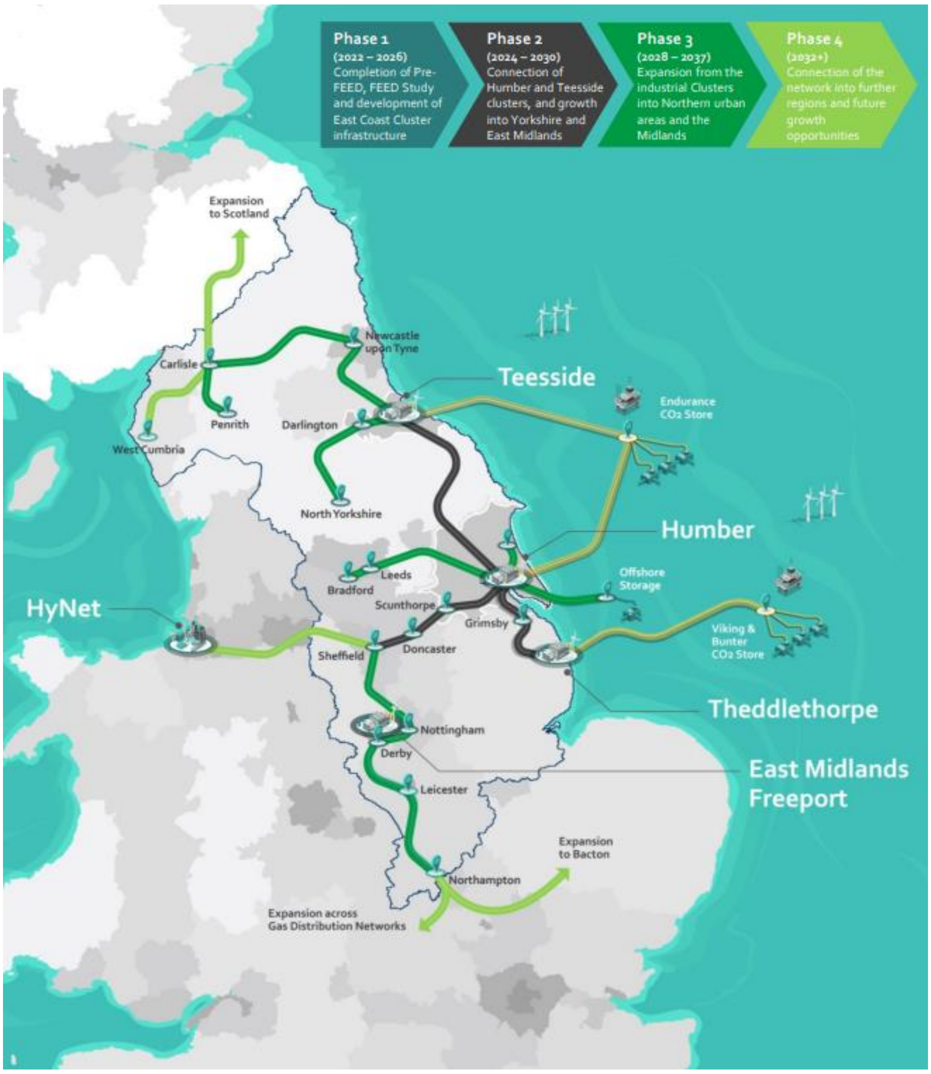
51 Gas Goes Green - ENA
52 H100 Fife - SGN
53 East Coast Hydrogen report marks first major step to convert UK's gas networks to hydrogen – National Grid

the Humberside and Teesside industrial clusters initially, before then spreading wider. It is set to have four stages (as the figure below illustrates) with the first (2022-2026) involving involving pre-FEED, FEED study and the development of East Coast Cluster infrastructure; the second (2024-2030) including the connection of the Humberside and Teesside clusters, as well as growth into Yorkshire and the East Midlands; the third (2028-2037) will see expansion from the industrial clusters and into Northern urban areas; before stage four (2032 onwards) will involve connection of the network into further regions and future growth opportunities. This will include expansion into Bacton in the East of England. East Coast Hydrogen will use low carbon hydrogen from multiple production methods, with these supplied to major industry, local businesses, transport hubs, power stations and domestic end users.



H21[54] is a suite of gas industry projects, led by Northern Gas Networks, to prove the gas network can safely transport hydrogen in the future, while National Grid's FutureGrid

54 H21

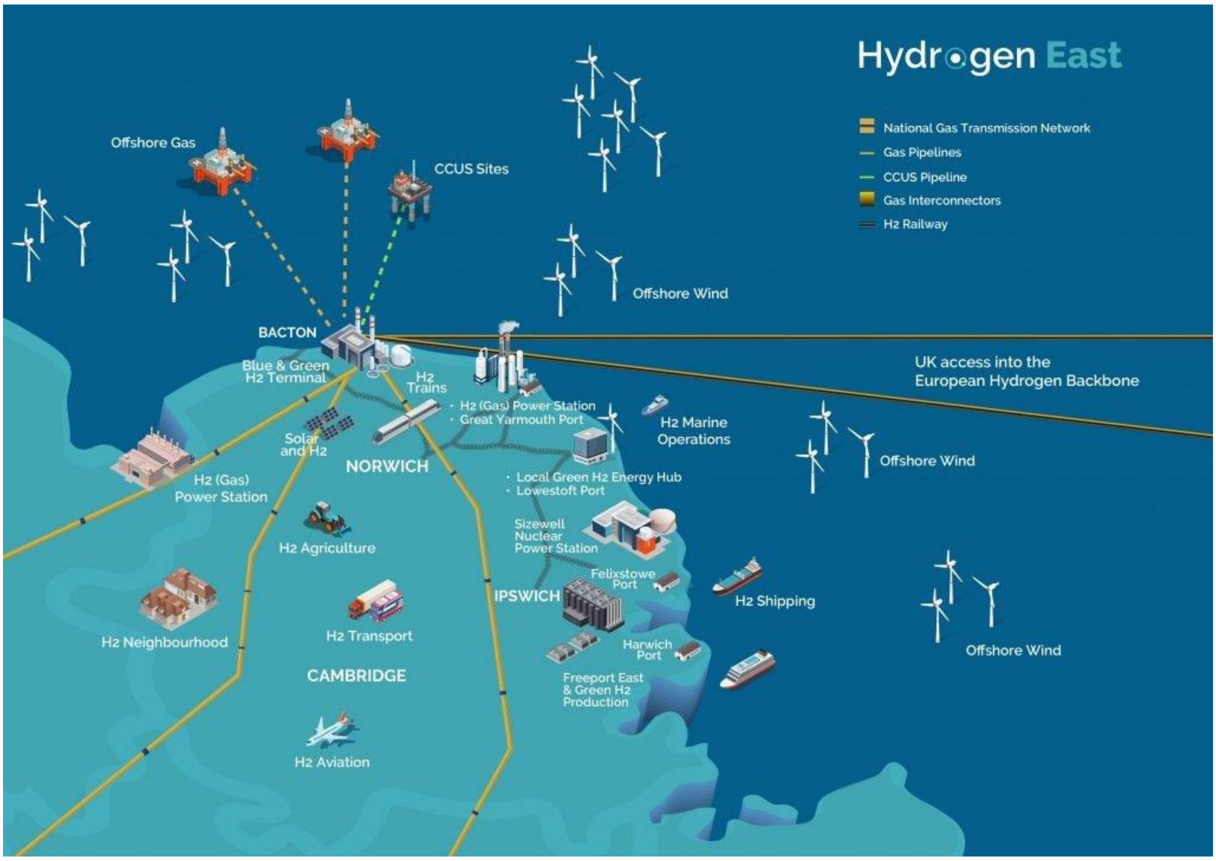
project[55] is “the first of many steps” towards a full-scale conversion of the existing National Transmission System to transport hydrogen. It will see a test facility constructed from decommissioned assets that will be used to carry out a wide range of hydrogen tests in an offline environment, demonstrating its impact on those assets and the operation of the network. The testing plan can be seen in the figure below.

Other projects worth noting include Cadent, SGN and National Grid Transmission’s Capital Hydrogen Project[56] which will set out the potential benefits and opportunities hydrogen offers the capital and Britain. The companies will work together on a feasibility study for the transition of London’s gas networks to hydrogen as the first stage of the programme, which is set to consist of a series of projects lasting for 15-20 years. The feasibility study will identify how much hydrogen is needed by the capital over the next 30 years, where it will be produced and stored, and how it will be transported to where it is needed. This research is expected to conclude in October 2022, with the companies noting the identification of hydrogen demand in the capital also has to potential to stimulate production in nascent energy hubs, such as those in Southampton and Bacton in Norfolk.

[55] FutureGrid – National Grid

[56] London study to kick-start hydrogen vision for capital in support of net zero carbon target - SGN

Bacton itself has been the focus for a potential hub for hydrogen development[57][58]. This Bacton Energy Hub would be focused on blue hydrogen, though this could expand over time into a wider sub-regional hub that combines both blue and green hydrogen and integrates with solar and other renewable technologies locally – not least offshore wind and potentially nuclear sectors, with Sizewell C under development. It is not expected to deliver hydrogen to the mainland system until around 2030 at the earliest.



At Sizewell C, EDF has been exploring ways it could produce and use hydrogen[59], given how it could help lower emissions during construction of the power system and, once Sizewell C is operational, the heat it generates alongside electricity could then be used to make hydrogen more efficiently. Sizewell C has been seeking partners to develop a small demonstrator project[60] using an electrolyser that has the potential to produce up to 800kg of hydrogen per day. This would be powered by electricity from the neighbouring Sizewell B, with the potential to scale it up to meet demand. It is also looking at options to source hydrogen regionally. An initial aim is to introduce hydrogen buses for the workforce, which would be able to pull through investment in production capability.

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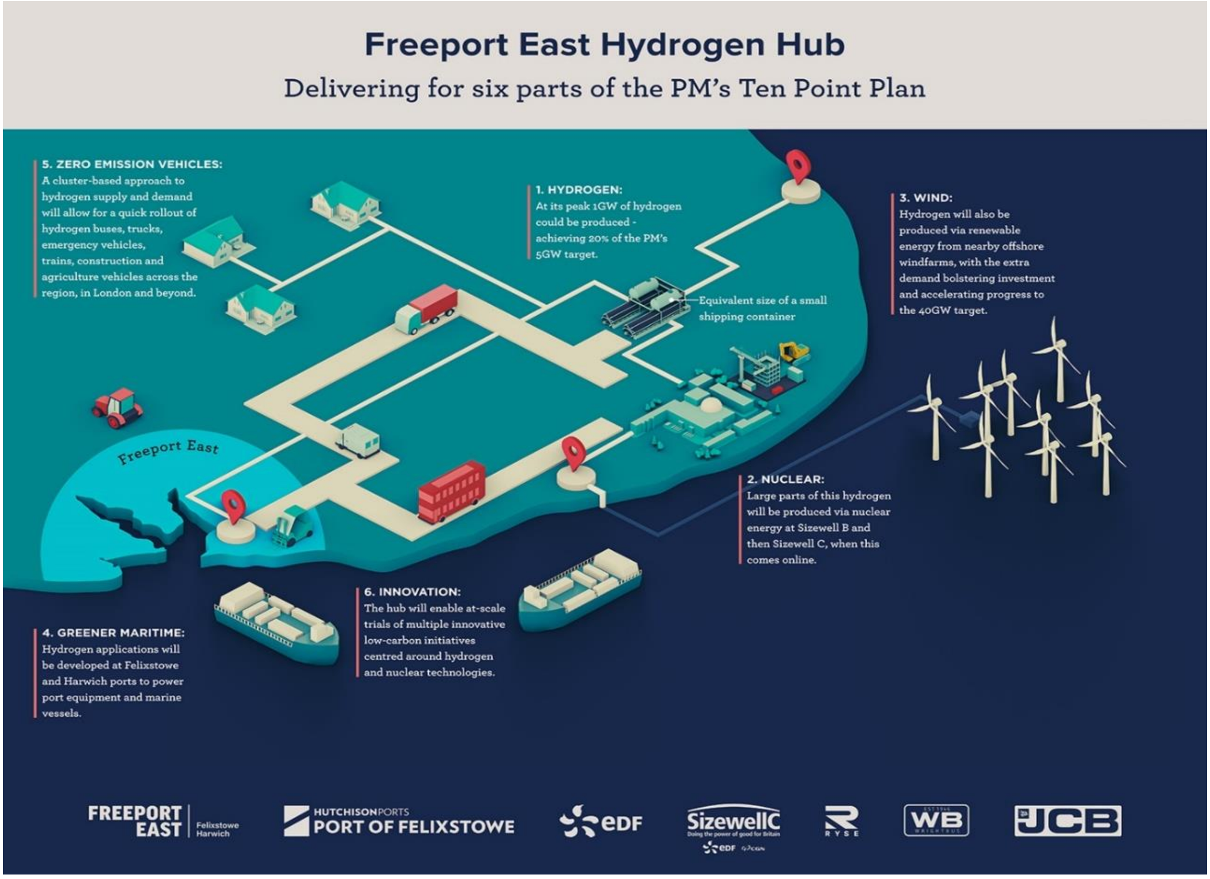
57 Bacton Energy Hub – North Sea Transition Authority
58 Bacton Energy Hub – Hydrogen East
59 Sizewell C and hydrogen – EDF Energy
60 Sizewell C seeks partners to develop Hydrogen and Direct Air Capture – EDF Energy

Sticking with the East of England, Freeport East[61] is focused on Felixstowe and Harwich and could see early adoption of hydrogen production and support supply to port side operations and other local use cases.



ScottishPower, with Hutchison Ports, have also recently unveiled plans for a Green Hydrogen Fuels Hub[62] at the Port of Felixstowe. Reportedly worth £150mn, this 100MW facility could deliver up to 40 tonnes of green hydrogen per day, helping to decarbonize industry and transportation in the region. Plans are being developed to use green hydrogen for onshore purposes, including road, rail and industrial use, as well as having the potential to create liquid forms such as green ammonia which could then be used to provide clean fuels for shipping and aviation. This would pave the way for opportunities for cost-effective export to international markets.

The Lowestoft PowerPark project[63] has explored how a smart local energy system could be established on land between the Port of Lowestoft and Ness Point, investigating how existing, refurbished and potential energy assets in the area can be integrated into one energy hub. An initial study explored how a hydrogen electrolyser could be deployed in conjunction with local renewable electricity generation, providing decarbonised fuel for

[61] Our vision for Freeport East – Freeport East

[62] SCOTTISHPOWER VISION FOR GREEN HYDROGEN FUELS HUB AT PORT OF FELIXSTOWE - ScottishPower

[63] Green light for Lowestoft PowerPark hydrogen project – Hydrogen East

local transport fleets. Planning consent was received in February 2022 for a 3MW project consisting of three hydrogen electrolysers and associated storage, with the potential to produce up to 470 tonnes of hydrogen per year. Construction has also commenced on a 7MW flexible generation site to bring grid stability to the wider Lowestoft area at times of high demand and grid system stress.

Johnson Matthey (JM) has revealed plans to produce of 3GW hydrogen fuel cell components in the UK at its Royston factory supported by UK government through the Automotive Transformation Fund (ATF). The gigafactory[64], which is projected to be operational by the first half of 2024, would cost £80 million ($95.08 million). This has the potential to be a key area of focus for the area in the creation of a hydrogen innovation ecosystem and supply chain, with significant export potential for the UK. Modern manufacturing techniques will be used at the Royston site to ramp up the production of fuel cell components to fulfil customer demand. By utilising the decommissioned Clean Air production plant to manufacture both fuel cell and green hydrogen components, the site's capacity might eventually be almost tripled in the future.

Further south, the Thames Estuary[65] has the potential for wide-scale hydrogen infrastructure, supporting decarbonisation across London and the wider UK. Existing windfarms across the estuary provide an opportunity for wind to be used in combination with hydrogen, with its Hydrogen Route Map[66] setting out plans to deliver jobs and stimulate the economy through a “Green Blue” vision.

Hydrogen Sussex[67] has been formed to support and facilitate the hydrogen economy across Sussex, with key projects including a renewable energy hub at the Port of Shoreham involving the development of all port-based hydrogen, ammonia and new onshore wind and solar power generation. Green hydrogen and renewable electricity will be provided to the port’s 39 heavy forklift trucks and 12 HGVs initially.

5. Developing a Hydrogen Network

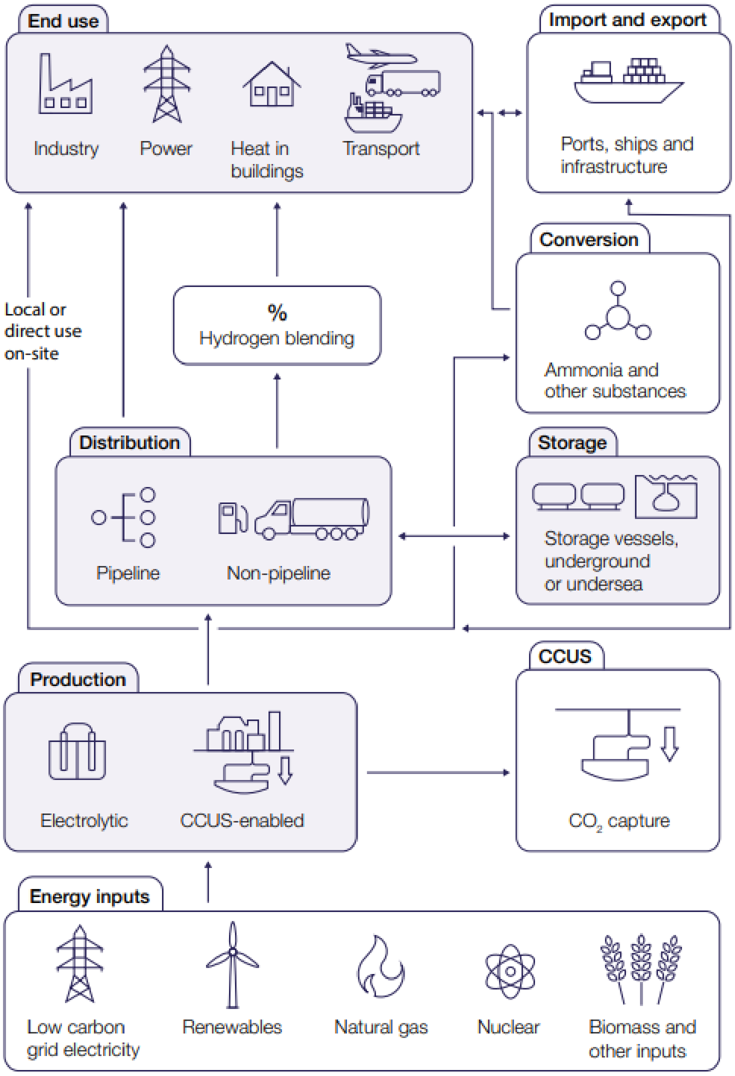
The gas network companies have already been carrying out a significant number of projects to ensure that the gas networks are prepared for the hydrogen pathway and to verify that it can be accomplished effectively and efficiently. The government will receive the data needed for this initial stage to enable policy decisions regarding network conversion.

64 https://matthey.com/products-and-markets/energy/hydrogen
65 Hydrogen in the Thames Estuary – Thames Estuary
66 Hydrogen Route Map – Thames Estuary
67 Hydrogen Sussex

GAS NETWORK HYDROGEN PATHWAY PROJECTS		
	EXISTING PROJECTS	PLANNED PROJECTS TO 2025
AREA DOMESTIC CONVERSION	• H21 Phase 1 and Phase 2 • HyDeploy and HyDeploy 2 • H100 • Hy4Heat programme (led by BEIS) • Cadent blending framework report	• H100 • H21 Phase 3 • HyNet Homes
HEAVY TRANSPORT	• H2GV • Cadent Gas Transport Pathways	
INDUSTRIAL CLUSTERS	Network collaboration in cluster projects, including: • HyNet • Grangemouth • Southampton Water • NECCUS • SWIC • Zero Carbon Humber • Net Zero Teesside	Network collaboration in cluster projects, including: • HyNet • Grangemouth • Southampton Water • NECCUS • SWIC • Zero Carbon Humber • Net Zero Teesside
EXISTING NETWORK PREPARATION	Current projects are focused on ensuring the gas networks are ready for a green gas transformation: • HyHy • GMaP – hydrogen workstream • GGG WS4.1 – entry connection standardisation • GGG WS2.1 Strengthening the case for GS(M)R amendment • LTS Futures • Feasibility of hydrogen in the NTS • Aberdeen Vision • Hydrogen deblending • GDNs have already replaced 60,000 km of iron pipelines with polyethylene, 62.5% completion of the mains replacement programme. • Future Billing methodology • Real Time Networks • Optinet • SGN Biomethane • Freedom Project • NGN Hydrogen Conversion Strategy	Planned projects are focused on ensuring the gas networks are equipped to deliver a green gas transformation: • Future LTS • H21 Safety case for trials • IMRP • HyNTS FutureGrid • Common future end states and transition pathways • Assessment methodology • Behavioural change and disruption • System Transformation data project • New modelling tools and capability • Investigation of impacts of purging during conversion • Transmission modelling • Distribution modelling • System Operator transition to hydrogen • System Transformation outputs • Network Safety & Impacts projects
NEW HYDROGEN NETWORKS	• Aberdeen Vision (note elements of this project cover hydrogen blending in the NTS and other elements a new hydrogen pipeline) • Project Cavendish • HyNet Homes	• Aberdeen Vision (ongoing project) • Project Cavendish (ongoing project) • HyNet Homes (ongoing project)

[68]

[68] Gas Network Hydrogen Pathway Projects – ENA



[69]

[69] The hydrogen value chain – BEIS “Hydrogen Strategy”

Stakeholders in value chains

Value chains	Types	Stakeholders
Energy inputs	Low carbon grid electricity	SP Energy Networks, Northern Ireland electricity Networks, Manx Utilities, ESB Networks, Western Power distribution, Scottish & Southern Electricity Networks, Northern Powergrid, Electricity Northwest, UK Power Networks, National Grid, EirGid, Eclipse Power Networks, Energy Assets Networks, UK Power Distribution, Energy Networks Association, EEEGR
	Renewables	Octopus Energy, Siemens Gamesa Renewable Energy, Catapult, Orsted, SSE Renewables, EDF Renewables, Canford Renewable Energy
	Natural gas	SGN, Northern Gas Networks, Cadent, Wales&West Utilities, Manx Utilities, Gas Networks Ireland,
	Nuclear	EDF (Sizewell)
Production	Electrolytic	Johnson Matthey, ITM Power, BOC, North West (Progressive Energy), South Wales (CR Plus, Milford Haven Port Authority, Costain, University of South Wales), Humber (Equinor, Centrica), Scotland (Pale Blue Dot, SHFCA), Teesside (BP), Octopus Hydrogen, Scottish Power, CPH2, EMEC, Ofgem, ERM Dolphyn, Ryze Hydrogen, Anglia Water, Ricardo, Scottish Power, Focal Sun, Cranfield University, University of Cambridge
Distribution	Pipeline	National Grid, Ofgem, BEIS
	Non-pipeline	NanoSun, Element 2, Exelby Services, UKH2Mobility
Hydrogen blending		Gas Goes Green Advisory Group, BEIS Blending Group, Future of Gas Steering Group, Cadent, NREL
End use	Industry	Chemical Industries Association, Unilever, Ceramic, Duomo, Limpsfield Burners, SpaceRay, Bosch, Mantec Technical Ceramics Limited, Eastham Refinery Limited, Kelloggs, Jaguar Land Rover, PepsiCo, Encric, Novelis, Kraft Heinz, Essity, Pilkington Glass, Toyota Tsusho
	Power	SSE, National Grid ESO
	Heat in buildings	Worcester Bosch, Citizens Advice, Ideal Heating
	Transport	Shell, Airbus, easyJet, Toyota, Hyundai
Storage	Storage vessels	Storenergy, Equinor, ITM Power, H2Go Power
Conversion	Ammonia and other substances	Shoreham port, H2Green, Local Fuel, Ricardo, Airports and ports in the UK
Import and export	Ports, ships and infrastructure	Cadent, Orkney

6. Challenges & Opportunities for green hydrogen sector

A green hydrogen sector has already been identified as a significant economic opportunity, with the Offshore Wind Industry Council (OWIC) Offshore Renewable Energy (ORE) Catapult claiming back in 2020[70] that the production and overseas export of electrolysers could produce up to £320bn of GVA and create 120,000 jobs by 2050.

Other opportunity areas include transport, with the UK government's *Hydrogen Strategy*[71] predicting that hydrogen will be in use across a range of transport modes, including HGVs, uses and rail, as well as potentially in commercial shipping. It can also help to tackle the UK's hard-to-electrify sectors on a pathway to delivering net zero, solve the challenge of integrating renewables and boost the UK's energy security[72].

Green hydrogen also presents an opportunity to retrain across industries. The government's *Net Zero Strategy*[73] lists hydrogen as among the sectors where the oil and gas workforce could have transferable skills, while the *Hydrogen Strategy* cites opportunities in project management, process engineering, repurposing of infrastructure and gas safety. Tracking back to the OWIC and ORE Catapult's report, it suggested that the combination of additional offshore wind deployment and electrolyser manufacturing in the UK could create over 120,000 new jobs, replacing those lost in conventional oil and gas and other high carbon industries.

In terms of the challenges, it is worth looking to the government's *Hydrogen Strategy* which lists a number across the value chain that need to be overcome to produce and use hydrogen at scale in the UK:

- Cost of hydrogen relative to existing high carbon fuels: Although costs are likely to reduce significantly and rapidly as innovation and deployment accelerate, hydrogen is currently much more costly to produce and use than existing fossil fuels.
- Policy and regulatory uncertainty: Hydrogen is a nascent area of energy policy; industry is looking to government to provide capital and revenue support, regulatory levers and incentives, assurance on quality and safety, direction on supply chains and skills, and broader strategic decisions.
- The need for supply and demand coordination: Developing a hydrogen economy will require overcoming the "chicken and egg" problem of needing to develop new production and use cases in tandem and balancing supply and demand, including potentially through storage over time.

[70] Offshore Wind and Hydrogen – Solving the Integration Challenge – OWIC & ORE Catapult
[71] UK Hydrogen Strategy - BEIS
[72] New report sets out key steps to unlocking at least 5 gigawatts of green hydrogen - RenewableUK
[73] Net Zero Strategy - BEIS

- Need for “first-of-a-kind” and “next-of-a-kind” investment and deployment: Scaling up a low carbon hydrogen economy will require addressing first mover disadvantage and other barriers to bring forward early projects while establishing a sustainable environment for increasing investment and deployment in the longer term.

7. Barriers & Opportunities for Innovation

The repositioning of major oil companies across the North Sea oil and gas networks offers an opportunity to take innovative approaches to developing green hydrogen production, while there are projects across the industrial clusters for chemicals, iron, steel, glass, ceramics and paper manufacturing where hydrogen and biomethane can be used to decarbonise them.

As per the Offshore Wind Industry Council and Offshore Renewable Energy Catapult's 2020 report[74] into solving the integration challenge of offshore wind and hydrogen, the UK also has a strong industrial base and world-leading academic research community which means it is well placed to develop a sustainable, low-cost green hydrogen industry.

The Energy Networks Association, as part of its *Hydrogen Network Plan*[75], held workshops with participants including producers, transporters, industrial users and consumer and policy experts, with a view shared on the potential for green hydrogen. They felt periods of low electricity prices will enable electrolysers and integrated offshore wind and hydrogen farms to be developed in the 2030s and 2040s. Molecules were noted as being the best way to fully harness offshore wind resources, with it highlighted in Europe that there are already enquiries for 10-100MW electrolysers. These could then be co-located where offshore wind comes to shore.

The UK is also well placed to export hydrogen technology and know-how. ITM Power, for example, manufacturers electrolyser equipment that it exports around the world and is currently looking to grow its after-care operations and maintenance offering to support installed electrolysers globally. As previously stated, the OWIC and ORE Catapult believe production and overseas export of electrolysers could produce up to £320bn of GVA by 2050, while the Scottish government forecast[76] that becoming an exporter of green hydrogen to Europe could create up to £25bn of GVA and more than 300,000 jobs in Scotland by 2045.

Another opportunity is for the UK to become a "centre of excellence" for fuel cell production, as per the Advanced Propulsion Centre (APC)[77]. The APC is forecasting rapid growth in fuel cell platforms for light duty vehicles from 2030, something that will happen as hydrogen refuelling networks expand and hydrogen as a fuel at the pump falls to $4-5/kg. The APC is expecting 14GW of on-board fuel stack power and 400,000 hydrogen carbon fibre tanks will be needed to meet the demands of FCEV production in the UK by 2035. It is calling for the supply chain to be localised and vehicle production anchored in the UK, noting most manufactured vehicles in the UK are types where the power, utility, range and off-road capability are important and could benefit from a hydrogen powertrain.

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[74] Offshore Wind and Hydrogen – Solving the Integration Challenge – OWIC & ORE Catapult
[75] Britain's Hydrogen Network Plan - ENA
[76] Scottish Government Hydrogen Policy Statement – Scottish Government
[77] UK could be centre of excellence for fuel cell production – Hydrogen East

This idea of localising supply chains is echoed by RenewableUK which set out[78] the opportunity the UK has to develop supply chains for green hydrogen and maximise the local content opportunity. The UK did not seize the opportunity for onshore wind, with RenewableUK warning that supply chain bottlenecks can delay green hydrogen projects from becoming operational and prevent the establishment of a pipeline of projects needed to boost production.

Moving to rail, the HydroFLEX demonstrator project[79] is developing the UK's first hydrogen train by converting an electric train over, while the Holistic Hydrogen Approach to Heavy Duty Transport (H2H) project[80] is looking to be a catalyst to remove all diesel trains from the UK network by 2040 and will see green hydrogen used to test prototype hydrogen-electric trains. In this area, the UK has the manufacturing infrastructure to support future hydrogen rolling stock production with Bombardier, Siemens and Hitachi all having a manufacturing facility in the country. There is also plenty of activity in aviation with government-backed plans[81] for a liquid hydrogen plane – the FlyZero project – just one such example.

The industrial and transportation sectors have been cited above and another opportunity a shift to green hydrogen could offer them is that of power-to-x. This concept could expand the viability of hydrogen conversion, with power-to-x enabling the conversion of renewable power into a new valuable product. From the point of view of hydrogen application, green hydrogen combined with carbon recovered from industrial sources, such as fossil fuels, blue hydrogen and CCUS facilities, along with high concentrated renewable resources could be used to produce a range of other e-products and e-fuels for the transportation sector, such as e-methanol or e-methane for marine vessels, e-hydrocarbons for aviation and heavy-duty road transportation, and dimethyl ether for long-distance road transportation. It will also provide various opportunities for industrial power supply from generated power to their production too.

Looking more at some of the barriers, RenewableUK's report stressed the need to learn from offshore wind when it comes to business models. Green hydrogen projects are to need financial support to reach financial investment decisions and begin construction, thus allowing a scaling up to the levels required to drive down the costs of the entire industry. It noted this has been seen successfully through the Contracts for Difference (CfD) scheme which has driven significant price reductions in the offshore wind sector.

Sticking with the RenewableUK report, it identified planning and permitting barriers as a challenge, stressing the need for a simpler and faster national permitting procedure across the UK. Clear guidance is needed on how individual electrolytic projects are consented through the planning system. It explained that most hydrogen projects will likely involve technologies requiring interaction with several planning bodies and different

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[78] New report sets out key steps to unlocking at least 5 gigawatts of green hydrogen - RenewableUK

[79] UK embraces hydrogen-fuelled future as transport hub and train announced – Department for Transport

[80] Ricardo partners on innovative hydrogen-electric train trial - Ricardo

[81] Government-backed liquid hydrogen plane paves way for zero emission flight – Department for Transport

support regimes – something these bodies will not be able to do in a timely fashion for electrolytic projects to enable 5GW of green hydrogen by 2030.

It also noted the UK's existing gas storage capacity is relatively low at 16TWh. Large-scale hydrogen storage and interconnection with the European hydrogen backbone could help the UK to wean itself off natural gas, diversify its energy supply and have reserves at the ready, though any such strategy for hydrogen storage is undeveloped. Highlighting the opportunity, it explained that dedicated hydrogen infrastructure can integrate large volumes of renewables, create cross-border markets for hydrogen and decarbonise large clusters of industry.

The UK government's own *Hydrogen Strategy* lists technological uncertainty as a challenge to producing and using hydrogen at scale in the UK, explaining that while some technology is already in use, many applications need to be proven at scale before they can be widely deployed. Then, once more looking back at the ENA's *Hydrogen Network Plan*, a general view uncovered among producers and industrial clusters was that green hydrogen at scale will not happen before the 2030s. Concerns were expressed over the UK's ability to manufacture and install enough electrolyser capacity to provide baseload hydrogen, as well as the planning, water and infrastructure requirements, even if green hydrogen does prove cost competitive on paper.

8. Conclusion

Momentum for hydrogen is growing in the UK, with the government's ambition doubling in the space of 17 months from 5GW (Ten Point Plan) to 10GW (Energy Security Strategy), with at least half of this coming from green hydrogen. There also appears a real appetite across the country to embrace hydrogen, with it featuring in both industrial clusters selected (East Coast Cluster and HyNet North West) as track 1 clusters through the government's carbon capture, usage and storage cluster sequencing process, and ambitions from the likes of the East of England and South West England and South Wales to establish hydrogen hubs and ecosystems of their own.

There are also a growing number of hydrogen trials ongoing and projects in development, notably East Coast Hydrogen, which is striving to repurpose and build new hydrogen pipelines across the North East of England, before expanding further.

There is also Project Union, which will seek to link industrial clusters around Britain and create a 2,000km hydrogen network by 2030, repurposing around 25% of current gas transmission pipelines in the process and allow for a UK hydrogen backbone to link up with the EU hydrogen backbone, mostly likely through Bacton in the East of England.

The UK also has a number of opportunities to exploit when it comes to building a green hydrogen sector, not least its substantial offshore wind capacity – which is aiming to reach 50GW by 2030, but the repositioning of major oil and gas companies across the North Sea offers a chance to take innovative approaches to developing green hydrogen production, while there is potential to export hydrogen technology and know-how as well – something which could bring in major economic benefits. A strong industrial base, as well as a world-leading academic research community have also been cited as elements putting the UK in a good place to develop a green hydrogen industry.

There remain challenges, however, not least a lack of existing gas storage capacity with a strategy for hydrogen storage underdeveloped. Large-scale hydrogen storage and interconnection with the European Hydrogen Backbone are likely to prove crucial in helping the UK shift away from natural gas, therefore there is a need to focus on creating dedicated hydrogen infrastructure that can integrate large volumes of renewables, create cross-border markets for hydrogen and decarbonise large clusters of industry.

While support schemes are starting to develop and business models are being finalised, inspiration can perhaps be taken from the offshore wind sector and how the Contracts for Difference (CfD) scheme has driven its scale-up. Policy and regulation must continue evolving to match ambitions and give the industry the certainty it needs to develop at the pace required. The ambition is there and resources are there to exploit, the focus now must be on the details.