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The UK hydrogen economy: a review of global, national and regional policy

April 2022

Knowledge Applied

The UK hydrogen economy: a review of global, national and regional policy

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April 2022

DOI: 10.7190/cresr.2022.1169638300

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Summary

This report sets out current approaches to the development of hydrogen economies, looking at the policy driving this development and examples of activity, both in the UK and abroad. By addressing foundational questions about hydrogen as a fuel and outlining challenges and opportunities to implementing hydrogen, this report provides the basis for investigating the social and economic benefits.

Despite hydrogen (H) being the most plentiful element in the universe, the productive hydrogen gas (H_2) does not exist naturally in significant quantities and must be produced by human processes - primarily steam methane reforming (SMR) or electrolysis. Production of hydrogen[1] entails varying emissions and safety implications and the different methods are commonly codified by their 'colour':

- **Grey** hydrogen: currently the most common method of hydrogen production, utilising SMR.
- **Blue** hydrogen: SMR with carbon capture, utilisation and storage (CCUS) to reduce CO_2 emissions.
- **Green** hydrogen: electrolysis powered by renewable electricity and currently the lowest emission production method.

A difficulty in developing a hydrogen economy is that both production of, and demand for, hydrogen need to be stimulated simultaneously, often referred to as the 'chicken and egg' problem. Currently hydrogen use is largely limited to chemical production and oil refinery, but recent national and regional strategies are targeting a significant increase, supporting the use of hydrogen in new and emerging sectors including for industrial decarbonisation, transport, power generation, and to heat buildings. However, hydrogen has varying levels of impact across these different applications, and is competing with other, sometimes more mature and effective, alternatives.

On the ground, investment has been targeted at industrial clusters with 'hydrogen valleys' bringing together potential producers and users to kickstart integrated hydrogen economies. In the UK, this activity has been supported by the £171m Industrial Strategy Challenge Fund, which provided public funding to nine projects, such as Zero Carbon Humber and Acorn in Scotland. At a local level, opportunities in the wider supply chain has seen hydrogen included in nearly half (41 per cent) of Local Enterprise Partnership (LEP) Energy Strategies, with a focus on transport and residential heating.

This investment and activity comes despite significant challenges still needing to be addressed in both the production and deployment of hydrogen. This includes the high cost of 'green' production and questions over the effectiveness of CCUS at large scale for 'blue' production. There is also concern that a focus on 'blue' hydrogen locks the economy into continued fossil fuel use, and current strategies lack any commitment to transition to 'green' in the future.

[1] All references to hydrogen in this report refer to the productive form of hydrogen, H_2.

This report concludes by considering how this recent evolution in hydrogen production and deployment is being driven by partnerships comprised of oil and gas infrastructure owners, and is being framed in terms of providing a just transition of jobs from these industries. However, and despite the significant public funding allocated, it is not clear how decisions are being made or what benefits will accrue locally for those areas involved.

Introduction

1

The use of hydrogen as a green fuel has rapidly grown as a policy agenda in recent years. By the end of 2021 over thirty countries had produced hydrogen strategies and governments had committed more than $70 billion in public funding (Hydrogen Council, 2021).[2] The 2020s have been dubbed the 'decade of hydrogen' (Gill, 2020).

Because of its rapid reappearance in policy and investment strategies there has been little analysis to date of how hydrogen investment is being deployed regionally in the UK and beyond, and what this might mean for the variable social and economic benefits of hydrogen production and deployment in different places.

This report is the first output from a project funded by Sheffield Hallam University to investigate regional hydrogen investments, focusing on the implementation of hydrogen strategies in Northern Europe. The project aims to better understand how strategic decisions are being made about regional hydrogen plans, and what the likely implications are for a 'just transition' within and between regions.

In this report we set out to do three things:

1. Answer some foundational questions about hydrogen as a fuel, such as what hydrogen is, how it is produced and how it can be used as a fuel?
2. Map the global and European policy landscape for hydrogen production and deployment, including more detailed analysis of regional hydrogen plans in the UK.
3. Outline some of the key challenges for developing low or zero carbon hydrogen pathways.

Our analysis highlights the increasing attention paid to hydrogen within cities and regions, as a potential point of economic advantage, to shore-up industries vulnerable to decarbonisation pressures, and to potentially support wider decarbonisation goals. In the UK, large-scale projects have been private sector-led, heavily featuring offshore oil and gas companies, but backed up by national government funding. We map the range of different firms and stakeholders involved in these projects.

[2] The Energy Transitions Commission (2021:22) estimate that there could be $15 trillion of hydrogen investments between now and 2050, with this annual average on a par with the average $400-600 billion spent annually on upstream oil and gas over the last ten years (IEA, 2020a).

More broadly, regional strategies in the UK often focus on a wide range of potential uses for hydrogen and it is unlikely that all of these will be economically viable or the most efficient means of decarbonising individual sectors. Many plans within the UK also rely on the use of fossil-fuelled hydrogen production with carbon capture and storage (so-called 'blue' hydrogen). Many argue that this is the most feasible way of quickly increasing hydrogen production, and that blue hydrogen can act as a 'bridging' approach while the green hydrogen market matures. However, there is an on-going tension regarding production and use of so-called 'blue' hydrogen in plans for the next decade, with continuing debates around the feasibility and emissions 'escape' from carbon capture and storage facilities required, as well as the potential to lock economies into continued fossil fuel use in the medium-term future.

A second phase of this research will investigate the implementation of regional hydrogen strategies in more detail, through in-depth case studies of six regions in Northern Europe.

What is hydrogen and where does it come from?

2

Hydrogen (chemical symbol, H) is the 1st chemical element in the periodic table. It is an extremely small and lightweight atom, consisting of only a single positively charged proton orbited by a single negatively charged electron. Under standard conditions hydrogen exists as a gas and takes the form of a relatively stable and unreactive hydrogen molecule consisting of two hydrogen atoms (H_2). H_2 is lighter than air, colourless, odourless, non-toxic and highly combustible. However, most hydrogen found on Earth is combined with other atoms, such as in water, where it is bound to an oxygen atom (H_2O), or in hydrocarbons where it is combined with carbon (C) such as in methane (CH_4), ethane (C_2H_6) or propane (C_3H_8). Fossil fuels like natural gas and petrol are a mix of simpler hydrocarbons, for example natural gas is a mix of methane (85 per cent), ethane (5-15 per cent) and propane (<5 per cent). It is also a constituent of all organic matter (plants and animals) and many inorganic compounds (such as rocks and minerals).

2.1. Where does hydrogen gas come from?

Hydrogen gas (H_2) does not exist in nature in significant quantities. There are no exploitable reserves of hydrogen gas in nature: it must be produced through human-created processes, consuming energy and raw materials, resulting in emissions and environmental impacts. As such hydrogen is only as clean as its production methods (including raw materials, energy use, storage and transport). The source material for the creation of molecular hydrogen is most commonly hydrocarbons (for instance, natural gas) or water (H_2O), each requiring a different process (see Section 2.1.1). Hydrogen is currently manufactured globally and is used in a range of industrial or agricultural processes. 1700 TWh are produced per year globally and between 10 and 27 TWh is produced in the UK (BEIS, 2021a). There is currently a potential surplus of around 3.5 TWh of hydrogen from existing production (Energy Research Partnership, 2016). To put this in context UK demand for natural gas in 2020 was 690 TWh and the UK's consumption of electricity was 280 TWh.

2.1.1. Steam Methane Reforming (SMR)

Hydrogen has conventionally been produced using a process called Steam-Methane Reforming (SMR), resulting in 'grey' hydrogen. It uses methane (from natural gas), heat, pressure and water (as steam) to convert the methane to hydrogen gas (H_2) and carbon dioxide (CO_2). For SMR to be classed as 'clean' it must incorporate carbon capture, utilisation and storage (CCUS) technology to reduce CO_2 emissions from the manufacturing process, resulting in 'blue' hydrogen. CCUS technology remains largely experimental although is increasingly part of countries' plans for industrial decarbonisation. SMR currently takes place in large industrial facilities (similar to oil and gas refineries) to make the process efficient and safe.

2.1.2. Electrolysis

Two of the three atoms in water are hydrogen (H_2O). A process called electrolysis can be used to break bonds between atoms in the water molecule producing ‘green’ hydrogen (if using a renewable energy source) and oxygen gas. Around nine litres of water are required to produce 1 kg of H_2. Fresh water sources can be used, or seawater if desalination plants are used. The oxygen produced can also be utilised in healthcare or industrial sectors. The process requires electricity and special electrolyser materials (anode and cathodes) which determine the efficiency, capital costs and running costs. Electrolysis can take place at a small scale for local production or at a much larger scale suitable for infrastructure facilities.

2.2. Hydrogen and Emissions

Hydrogen production creates emissions and can have harmful environmental impacts. It is misleading to claim that hydrogen is a ‘clean’ fuel by focussing on the fact that the product of its combustion are only heat and water. As a reference point the emissions from the combustion of natural gas are 0.18kg of CO_2 per kWh of natural gas (do we need a source for this?). Where hydrogen is produced by SMR from natural gas the emissions have been estimated by one source at around 0.27 kg CO_2 per kWh of hydrogen (US Department of Energy, 2004). This can potentially be reduced by up to 85 per cent (to 0.04 kg CO_2 per kWh) using CCUS but this is not yet fully established as a scalable technology. Other studies (such as Tenhumburg and Büker, 2020) estimate that emissions from the electrolysis process using green electricity (including solar, wind or nuclear) are 0.015-0.033 kg CO_2 per kWh hydrogen depending upon the exact electrolyser technology and the source of electricity.

2.3. Hydrogen and Safety

Hydrogen is colourless, odourless and lighter than air. It can form explosive mixtures in air over a very wide range of concentrations. It can burn with an invisible flame only detectable with UV sensitive cameras or with a difficult to see blue flame. As a very light gas with a small molecular size it also has a propensity to leak from containers and piping that are not in perfect condition, known as fugitive emissions. Related to this Pearman and Prather (2020) note that the rapid expansion of the hydrogen economy risks hydrogen leaking into the atmosphere, the full impacts of which are currently poorly explored. However, research published by the UK’s Department for Business, Energy & Industrial Strategy (BEIS) earlier this year (Warwick et al, 2022) found that the Global Warming Potential (GWP) of fugitive hydrogen was around twice as high as previously estimated. This caution should be tempered by comparison to the multitude of negative climate impacts that arise from the existing fossil fuel industry (ibid.).

Hydrogen can, under certain conditions, affect the materials with which it is in contact, making materials more brittle and prone to failure. Combustion of hydrogen creates environments with very high water levels and potentially high levels of toxic gases (NOx), which might require special safety measures to prevent equipment damage or release of pollution. These issues are more challenging for hydrogen than for other gaseous fuels, such as natural gas. New safety measures for materials and equipment to handle hydrogen safely will be required in domestic and industrial settings. The high heat available from a hydrogen flame burning in air (which is around 70 per cent nitrogen, N_2) can generate large amounts of nitrogen oxides (NO_x) which are harmful to both humans and the environment. NOx emissions and levels in the environment are controlled by law and are a major constituent of urban air pollution.

Storage of large quantities of hydrogen will most likely require high pressures and very low temperatures which in themselves require stringent safety measures and place high demands on the materials and equipment used. While this is also the case for other gases (such as Liquefied Petroleum Gas (LPG) or liquid nitrogen storage) the unique properties of hydrogen will require new safety measures and the construction of many more storage sites.

2.4. Other Considerations for hydrogen

The adoption of hydrogen as a fuel in domestic or industrial settings is still at an early stage and many technical barriers remain. For example, in glass manufacture, using 100 per cent hydrogen profoundly affects the glass making process: it fundamentally alters furnace dynamics in terms of thermal, physical, and chemical environments. This would necessitate the redesign of furnaces to use hydrogen, including changes to construction materials, furnace shape and size, gas burner design, control of stack emissions, composition of the glass batch, and the layout and even location of the production site to account for the supply of hydrogen. Given that glass making furnaces are very large capital investments and are designed to last 20 to 50 years, a switch to hydrogen poses a significant challenge to the industry. Similar challenges are likely to be faced by other foundation industries, such as heavy clay products (bricks, roof tiles, pipes), cement production and steel making.

Sector summary

3

Hydrogen has been used in a wide variety of applications since the late eighteenth century. Initially used for buoyancy in balloon flights, the first mass produced hydrogen product was a cigar lighter, Döbereiner's Lamp, produced in 1823 (Zuttel et al., 2008: 10). Hydrogen became infamous during the fast rise and fall of the airship era in the early part of the twentieth century, with further infamy assured later that century as it became synonymous with the advancement of the atomic bomb. More positive applications began to develop during the second half of the twentieth century as it was used in rocket fuel technology, and then in the first commercial proton-exchange-membrane fuel cells (PEMFCs) in 1965, as part of NASA’s Project Gemini. In the United Kingdom post-World War 2 ’coal gas’, also referred to as ‘town gas’, was the primary gaseous fuel available for domestic and industrial use. Produced from coal it consisted of around 50 per cent hydrogen but was phased out as the UK’s natural gas supply (which does not contain hydrogen) came online in the late 1960s.

In recent decades hydrogen has been increasingly promoted as a viable alternative fuel that can help achieve net zero pathways globally and protect energy security domestically. As set out in Section 2, the extent to which hydrogen can contribute to net zero goals depends on the method used to produce it. These range from zero carbon ‘green’ hydrogen, produced using renewable energy, to ‘black’ or ‘brown hydrogen’, which require fossil fuel combustion. The spectrum of hydrogen production (see figure 3.1) includes different ‘colours’ with varying levels of carbon intensity and covers the current most common, and cheapest, form ‘grey’ hydrogen, created from natural gas reformation (O’Donnell et al., 2021), and an increasingly popular route in hydrogen investment plans, ‘blue’ hydrogen, which is fossil-fuel produced hydrogen with CCUS added to minimise CO_2 emissions.

Figure 3.1: The hydrogen colour spectrum

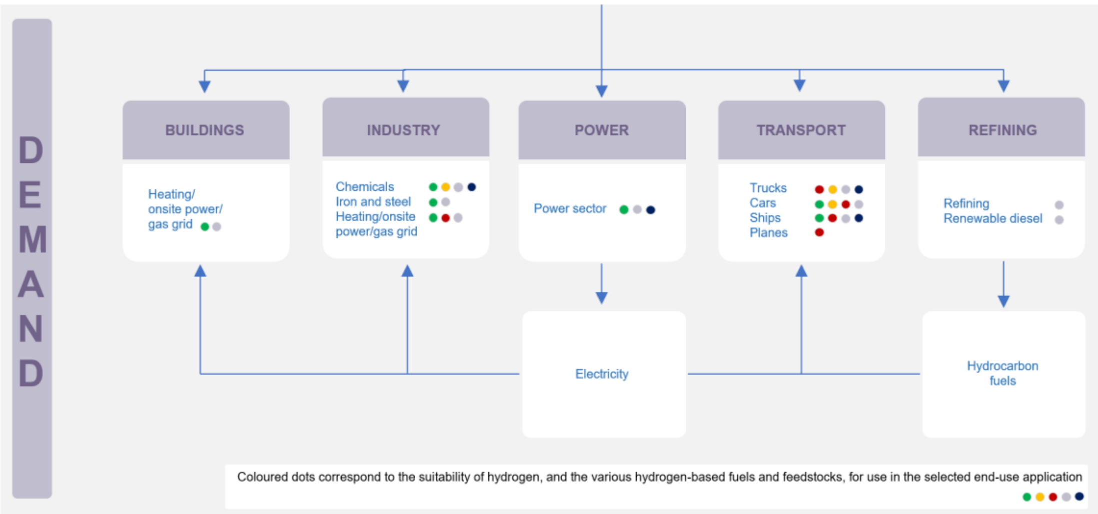
	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Source: GEI, 2021

The International Energy Agency, (IEA, 2019) outlines various potential uses for hydrogen in four domains: industry, transport, buildings, and power generation. Current hydrogen use is dominated by industry: specifically oil refining, ammonia production, methanol production and steel production, with hydrogen an option to decarbonise current fossil fuel production methods. Transport offers a variety of uses, the viability of which will depend heavily on efforts to reduce costs. These include personal and public transportation, freight, and shipping and aviation. Under 'Buildings' the focus is to decarbonise heat by blending hydrogen with the gas network, with the potential to deliver 100 per cent hydrogen heating in the future. And for 'Power Generation' the IEA suggests that the production of hydrogen could be a leading option to store intermittent renewable energy, or even used in gas turbines or coal-fired power plants to produce power with fewer emissions. These uses make up the demand side of the hydrogen value chain (see figure 3.2), whilst the different colours outlined above contribute to the supply side.

Figure 3.2: The demand side of the hydrogen value change



Source: IEA (2019: 29)

The variety of applications and supposed potential to decarbonise numerous sectors means that there is significant debate about the potential for hydrogen to become "all-encompassing" and/or have potential to provide niche uses in different sectors (Evans and Gabbatiss, 2020). The interest in and demand for hydrogen is rising as the range of potential applications continues to accelerate, and political appetite increases as decarbonisation pressures bite. The sector is at a potential tipping point with significant upscaling of production anticipated to meet growing demand across a range of applications, leading to the 2020s being dubbed the 'decade of hydrogen' (Gill, 2020).

4

International context

Hydrogen production is being pursued by an increasing number of countries. As of late 2021, over thirty countries had produced hydrogen strategies to drive development and reduce costs, with governments committing more than $70 billion in public funding (Hydrogen Council, 2021).[3] Some regions are well-suited to hydrogen production – particularly the minimal greenhouse gas emitting ‘green’ hydrogen – due to the abundance of, or potential for, renewable energy - and are aiming for large gains against their net zero targets. Others, such as Australia and China, aim to grow hydrogen production for export to countries which lack the natural resources to produce it. As such, many projects are located, or planned, around ports (Weichenhain et al., 2021) and are also connected to efforts to decarbonise the maritime industry and long-distance haulage.

Table 4.1: Examples of notable hydrogen projects and country-based approaches outside Europe

Country	Description
Saudi Arabia	The $5 billion ‘Helios Green Fuels’ plant is due to be operational by 2025 in Neom and will be powered by 4GW of solar and wind energy (Ratcliffe, 2021). This is driven by the need to reduce dependence on oil, particularly for exports.
Japan	Japan has ambitious plans for green hydrogen production, driven by a desire for improved energy security and self-sufficiency. This is laid out in their ‘basic hydrogen strategy’, which includes the aim to reduce electrolyser cost down from 200,000 to 50,000 yen by 2030 (METI, 2017). There is also the intention to underline the shift from nuclear to solar power that has taken place in Fukushima since the nuclear disaster in 2011 (FCHEA, 2020).
Australia	Driven by anticipation of increasing demand for hydrogen in places like Japan, Australia plans to capitalise on its renewable energy potential to produce green hydrogen for export (COAG Energy Council, 2019). Its aim is to be a major player in the hydrogen economy by 2030 and one of the top three exporters to Asian markets.
China	Is the world’s largest producer of hydrogen and is driving competition with European producers to reduce green hydrogen costs (Amelang, 2020). Currently, China’s production is heavily linked to fossil fuels, but commitment to net zero means a renewed push to reduce dependence on coal and a focus on green hydrogen. This could drive global development of green hydrogen in a similar way to how China pushed the development of solar power (Casey, 2021).

[3] The Energy Transitions Commission (2021: 22) estimate that there could be $15 trillion of hydrogen investments between now and 2050, with this annual average on a par with the average $400-600 billion spent annually on upstream oil and gas over the last ten years (IEA, 2020a).

4.1. European Union

The European Commission (2020) has set out ‘A hydrogen strategy for a climate-neutral Europe’, highlighting the value of hydrogen for use in hard to decarbonise industry and feedstock production. However, it notes that much of the current hydrogen in Europe still requires fossil fuel combustion and advocates a push for zero carbon hydrogen (not including embodied production of production equipment and transportation). Its strategy sets out plans to improve investment, regulation, and innovation to boost demand for hydrogen and scale up production. Funding has also been provided to build regionally integrated hydrogen ecosystems, or ‘hydrogen valleys’, of which there are now over 30 globally, 24 of which are in Europe (Weichenhain et al., 2021). These clusters bring together industry partners, often with oil and gas backgrounds, to build large-scale, geographically defined projects that incorporate broad supply chains across multiple sectors and uses of hydrogen (ibid.).

Table 4.2: Notable European Union hydrogen projects

Country	Description
Netherlands	Within the context of the EU strategy, the Netherlands is pursuing hydrogen in order to provide new jobs, clean air, and an energy transition (Janssen, 2020). They currently lead production capacity of low carbon hydrogen in the EU, with around 40,000 tonnes, nearly four times the nearest European country, France. Planned schemes set to increase that amount to two million tonnes by 2030 (IEA, 2020b), which would place them behind the UK (3.4m tonnes) if all schemes become operational (ibid.). They are also home to five of the EU’s hydrogen valleys.
Sweden	Sweden’s hydrogen strategy (SEA, 2021) sets an ambition for 5GW ‘green’ hydrogen production capacity by 2030. An important focus is emissions from its steelmaking industry. In 2020, Swedish steelmaker SSAB began testing operations on the HYBRIT pilot project, to deliver fossil free steel at its plant in Lulea in Northern Sweden. SSAB account for ten per cent of Sweden’s CO_2 emissions and the HYBRIT project aims to deliver commercially available fossil-free steel by 2026 (Reuters, 2020). This part of Sweden is being targeted for green hydrogen production due to its proximity to 15 hydro-electric power plants, which are soon to be joined by Europe’s largest onshore windfarm. Together this will provide 20 per cent of Sweden’s energy generation (Walter, 2021).

5

UK policy context

Hydrogen in the UK is shaped by several key factors. Commitment to net zero targets is the primary factor and efforts are underway to utilise hydrogen to decarbonise all energy consuming sectors: industry, transport, and heating, as well as in power generation itself. Policies linked to post-Covid economic growth and 'levelling up' agendas for post-industrial northern towns are also helping to further boost hydrogen opportunities.

The Energy White Paper, published in December 2020, highlights the ambitions and direction of the government for hydrogen to form part of the energy mix in the future, stating that, "we will switch to new, clean fuels such as hydrogen for heat, power and industrial processes" (BEIS, 2020: 3). This includes an aim to achieve production capacity of 5GW[4] and annual low-carbon hydrogen production to be 42TWh by 2030 (BEIS, 2020: 127)[5]. The White Paper also outlines a £240m 'net zero hydrogen fund' to catalyse R&D: the 2020 spending review then committed further £81m for hydrogen heating trials (HM Treasury, 2020). These figures are very modest compared to investment in some EU countries, with Germany aiming for the same target (5GW capacity by 2030) but pledging $9bn to fund development (Evans and Gabbatiss, 2020).

Nevertheless, efforts to drive the growth of hydrogen are strongly supported by the government's independent Committee on Climate Change (CCC), which incorporates hydrogen extensively across all sectors in its scenarios for achieving net zero: "hydrogen has the potential to replace fossil fuels in areas where electrification may reach limits of feasibility and cost-effectiveness, including a partial role for heat in buildings" (CCC, 2020: 83). Hydrogen is viewed as having potential to help ensure the UK's energy security, for example, the ability to capture renewable power and store it to help meet demand peaks. While incentives to use green hydrogen in transport and large-scale industrial processes are recommended, the low carbon, 'blue' hydrogen is also expected to enable a large production capacity that could then be exported (McDonald, 2021). However, 'blue' hydrogen production has yet to be successfully demonstrated at scale. Despite this, 'blue' hydrogen formed a major part of the recent UK hydrogen strategy (see section 5.1), which was first announced in the government's '10-point plan for a Green Industrial Revolution', and is part of efforts to recover from the Covid-19 pandemic and to meet net zero targets by 2050 (HM Government, 2020).

[4] This target was doubled to 10GW in the recent Energy Security Strategy (BEIS, 2022).
[5] For context, in 2017, the total energy generation capacity in the UK was 75.8GW, producing 323TWh over the course of the year.

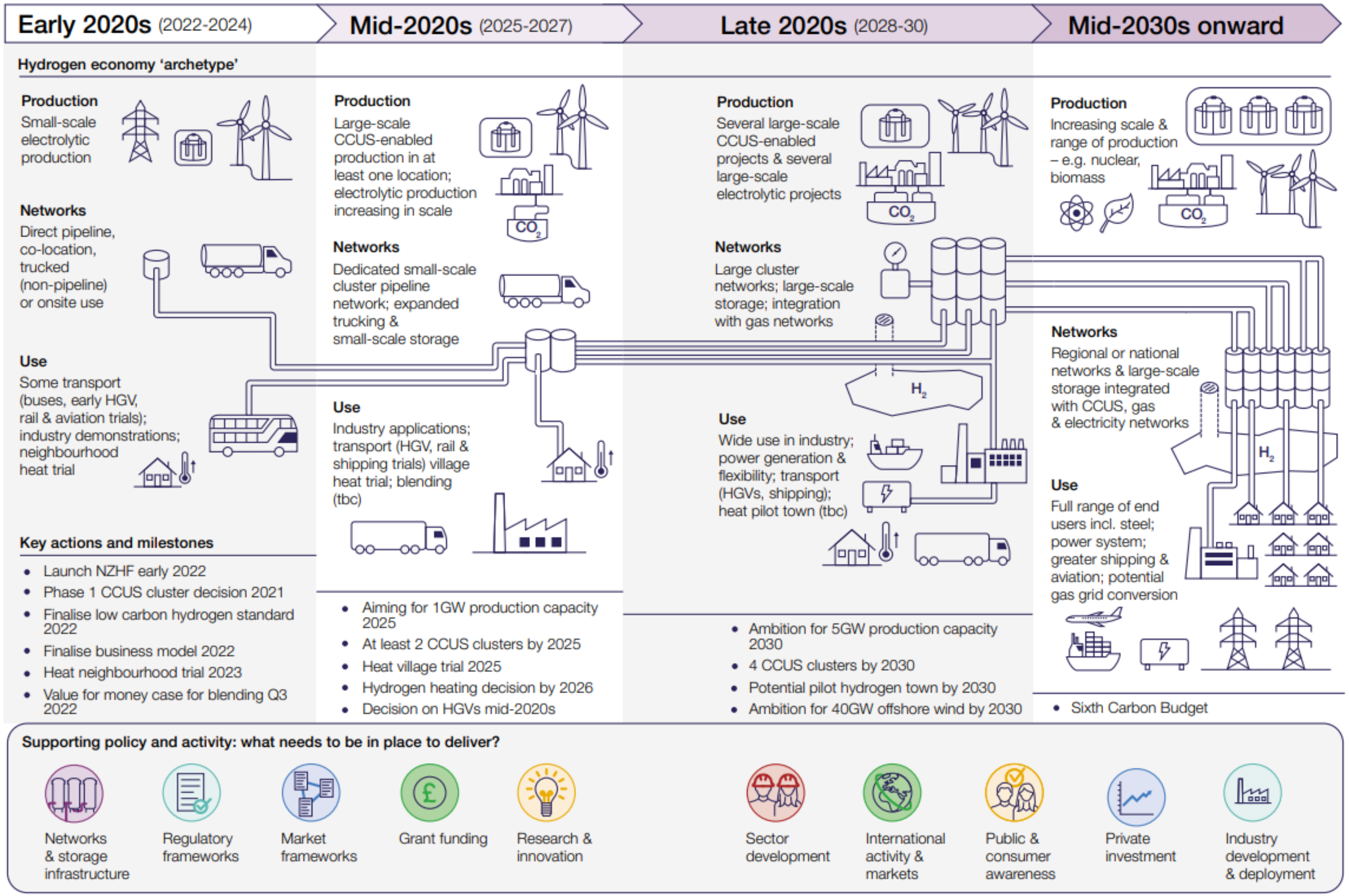
5.1. UK hydrogen strategy

Published in August 2021, the UK Hydrogen Strategy (BEIS, 2021b) strengthens interest in hydrogen production with support outlined for the very widest range of possible end uses. Acknowledging that a hydrogen economy in the UK requires parallel development of both the supply and demand sides – what is referred to as the 'chicken and egg' approach – the strategy sets out funding, along with policy and support activity, across the next decade and beyond. No use of hydrogen appears to have been left out with all aspects covered under the four headings of industry, power, heat in buildings, and transport (see table 5.1) and incorporated into a roadmap for the 2020s (see figure 5.1).

Table 5.1: End uses outlined in the UK hydrogen strategy

Category	Expected demand in 2030 (TWh)	Expected demand in 2035 (TWh)	Expected demand in 2050 (TWh)	End Uses
Industry	10-21	25-45	up to 105	• Industrial heating and fuel e.g. indirectly through steam boilers and combined heat and power (CHP) systems, and directly in heating processes, such as melting glass in a furnace. • Focus on chemicals and steel but also metals and minerals, food and drink, paper and pulp, ceramics, glass, oil refineries, and less energy-intensive manufacturing.
Power	0-10	10-30	25-40	• Flexible power generation (‘Gas to Power’): such as through rapid operating ‘peaker’ plants and larger scale but less flexible Combined Cycle Gas Turbines (CCGTs). • System flexibility through electrolysis and storage (‘Power to Gas’, ‘Power to Gas to Power’): provide grid flexibility by drawing on ‘excess’ renewable or low carbon electricity that would otherwise be constrained or curtailed (often referred to as ‘sector coupling’).
Heat in buildings	<1	0-45	Not stated	• Space heating, hot water and cooking in the 30 million residential, commercial, industrial and public sector buildings in the UK.
Transport	0-6	20-45	up to 140	• Used directly in combustion engines, fuel cells and turbines as an alternative to petrol, diesel and kerosene. • Production of transport fuels, including ammonia and sustainable aviation fuels. • Road transport: including cars but particularly depot-based transport, such as buses. HGVs pose a bigger challenge but options will also be pursued. • Trains, shipping, and aviation uses will also be trialled.

Figure 5.1: UK hydrogen economy roadmap



Source: BEIS (2021a: 24)

The motivation for pursuing this all-encompassing hydrogen economy is the need to deliver on the UK's net zero targets, and to achieve emission reductions outlined in carbon budget 6 (CCC, 2020). Further justification given is the need to generate early use cases. The opportunity to blend hydrogen into the gas network is seen as one such use case, with trials expected throughout the next decade and increasing in size from hydrogen neighbourhood, to village, to town.

Production of hydrogen in the UK is relatively low currently, and largely limited to private firms who produce high carbon hydrogen (usually ‘grey’ hydrogen) and utilise this on the same site: for instance, production for use in chemicals manufacture and oil refinery. There is an ambition to raise hydrogen production to a level that would enable exports and access to a global market of other decarbonising countries. However, this ambition is tempered by the reality of current production levels and barriers that need to be overcome: high production costs, demand uncertainty, policy and regulation uncertainty, technology and investor uncertainty, first mover disadvantage, and a current lack of hydrogen distribution and storage (BEIS, 2021b: 72). Further incentive comes through the potential for skills export. There is emphasis in the strategy on developing and exporting the skills and expertise that would be needed to establish hydrogen economies globally, building on the complementary skills that have already been established in the oil and gas industries. By 2030, the strategy expects that, "UK supply chains & skills base [will be] well positioned to support increased deployment & exports of technology, expertise & potentially hydrogen" (BEIS, 2021b: 29). To boost both production and use of hydrogen the strategy outlines 27 key commitments (see Appendix 1) under the headings of hydrogen production; hydrogen networks and storage; use of hydrogen; creating a market; and realising economic benefits for the UK.

6

UK local and regional approaches

Around the UK, a growing number of regional strategies for hydrogen economies are developing (see section 6.1). As highlighted above, hydrogen valleys, or clusters, have emerged across Europe with two located in the UK: Hynet in the North West of England and BIG HIT (Building Innovative Green Hydrogen Systems in Isolated Territories) on the Orkney Islands in Scotland. Hydrogen is also included in other low carbon clusters, such as Zero Carbon Humber in East Yorkshire and Acorn in North East Scotland. Many other regions are developing hydrogen strategies or have included hydrogen economy development in regional energy strategies, often based around local resources and perceived comparative advantages.

As part of the Department for Business, Energy and Industrial Strategy's (BEIS) 'Local Energy Programme', £4.8m was made available to establish five regional ‘local energy hubs’, comprised of agglomerations of all 38 of the Local Enterprise Partnerships (LEPs) in England.

Having identified that barriers to a low carbon economy exist at the local level and that there is limited capacity and capability amongst LEPs and local authorities to deliver local energy investment, £1.6m was allocated from this programme in 2017 to assist in the development of Local Energy strategies in each LEP area.[6] Together with the regional local energy hubs, low carbon energy projects would be developed and prioritised and a pipeline of local energy projects identified through the LEP energy strategies. 29 LEP energy strategies were produced, covering 34 of the 38 LEPs. This included 25 individual LEP strategies and four tri-LEP plans. Appendix 2 outlines the main energy technologies prioritised across the 29 strategies, the most prominent of which were district heating and smart grids.

Actions to develop hydrogen technologies were present in twelve of the strategies (41 per cent). Table 6.1 outlines these twelve strategies prioritising hydrogen and the type of hydrogen development that each focusses on. The most common utilisation of hydrogen in these strategies was for personal (67 per cent) and public (58 per cent) transport, with LEPs focussing on the development of fuel cells and refuelling infrastructure, along with trialling of bus and train technology. Application for HGVs, freight and delivery services was linked to this in six of these strategies (50 per cent), but after transport the most commonly pursued application was in the gas network, with 58 per cent of these strategies seeking to replace, or part replace, natural gas with hydrogen to provide decarbonised heating.

[6] Association for Public Service Excellence (APSE) - https://www.apse.org.uk/apse/index.cfm/local-authority-energy-collaboration/beis-local-energy-team/

Table 6.1: Hydrogen priorities from LEP energy strategies

LEP Name	Personal Transport	Public Transport	Residential Heat	HGV / Freight	Production	Industrial Heat	Infrastructure	Fuel Cells	Energy / Storage
D2N2	x		x						
Leicester & Leicestershire				x					
Leeds City Region	x	x	x	x				x	
Sheffield City Region	x	x	x	x	x	x			x
Humber			x	x	x	x	x		
Cheshire & Warrington		x	x		x	x	x	x	
South 2 East (tri-LEP)	x	x	x						
Local Energy East (tri-LEP)		x		x					
New Anglia	x				x				
Buckinghamshire	x								
Solent	x	x			x				
Swindon & Wiltshire	x	x	x	x		x			x
Totals	**8**	**7**	**7**	**6**	**5**	**3**	**3**	**2**	**1**
	67%	**58%**	**58%**	**50%**	**42%**	**25%**	**25%**	**17%**	**8%**

Only five strategies (42 per cent) had explicit actions to develop the production of hydrogen. These were: Sheffield City Region (SCR), the former Humber LEP (now covered by Hull & East Yorkshire), Cheshire and Warrington, New Anglia, and Solent.

Cheshire & Warrington emphasised links with Liverpool City Region LEP (for which no energy strategy was found) in developing the Hynet project (see section 6.1), and New Anglia highlighted the Hydrogen East cluster and the green hydrogen production potential around Bacton. SCR promoted local expertise in electrolyser production and ability to produce 'green' hydrogen, outlining a specific objective to:

> *"Locate areas in which hydrogen electrolysers could be deployed to offer storage and grid balancing, particularly where there are additional benefits (e.g. refilling station, injection into the gas network, industrial use, etc.)" (SCR, 2020: 53).*

Leeds City Region (LCR) also make extensive references to hydrogen based on the H21 City Gate project, which aims to convert its gas network to 100 per cent hydrogen by 2029:

> *"The total cost of hydrogen conversion for the city of Leeds is estimated at £2,054 million, with an additional £139 million ongoing OPEX costs per year. This investment would enable the provision of hydrogen to meet an average annual demand of 6 TWh/year" (LCR, 2018: 44).*

However, the LCR strategy notes that the production of hydrogen for this would take place in the nearby Tees Valley cluster.

The low level of focus on hydrogen across these strategies, and an interest primarily in transport and heating as opposed to production or industrial applications for those who do outline aims, may relate to the time when most strategies were produced: in 2018. Indicating how priorities have shifted since 2018 is the more recent publication of the New Anglia energy strategy, which was published early in 2021. Hydrogen production forms a significant part of this strategy, but New Anglia is also part of the Local Energy East Network strategy, published in 2018, which does not prioritise hydrogen production.

6.1. Hydrogen Valleys and regional decarbonisation clusters

In Europe there are currently 24 'hydrogen valleys.'[7] These focus on decarbonising existing industrial clusters, and aim to build a network of hydrogen infrastructure, often as part of a suite of developing decarbonising technologies, such as CCUS. There are two hydrogen valleys in the UK (see boxes 6.1 and 6.2), but these are also joined by an increasing number of existing industrial clusters, many of which are seeking not just to decarbonise but also to position themselves to take advantage of economic and export opportunities that may arise from the hydrogen economy. Many of these are led by private sector partnerships, with LEPs, local authorities and other public bodies providing a supporting role where they are involved.

Box 6.1: HyNet

Location	**North West England**
Partners	Progressive Energy (lead), Essar Oil, Johnson Matthey, SNC-Lavalin, CF Fertilisers UK Limited, Peel Environmental Limited, University of Chester, Cadent Gas Limited, Eni, Encirc, North West Hydrogen Alliance.
Description	A low-carbon hydrogen production plant for use in the region's industry, transport, homes, and businesses. Production of hydrogen will be from natural gas, with the project also including infrastructure to capture CO_2 emissions from energy-intensive industries in the area, and from the hydrogen plant, transporting and safely storing these emissions underground.
Goals	• Reduce carbon emissions by 10 million tonnes a year by 2030 – the equivalent of taking four million cars off the road (or two per cent of national emissions). • Provide nearly 50 per cent of the total hydrogen needed to meet the UK's net zero target. • Deliver 80 per cent of UK's clean power target for transport, industry and homes by 2030.
Link	https://hynet.co.uk

[7] These are large-scale regional hydrogen projects as identified through the EU funded 'Hydrogen Valleys' project. The full list of hydrogen valleys can be found on the Hydrogen Valleys Platform at https://www.h2v.eu/hydrogen-valleys

Box 6.2: Building Innovative Green Hydrogen Systems in Isolated Territories

Location	Orkney Islands, Scotland
Partners	Aragon Hydrogen Foundation (project coordination), ITM Power (technical leader), Scottish hydrogen and fuel cell association (lead partner), FHA, Orkney Council, Calvera, SDT, CES, EMEC, DTU, SymbioFC, Giacomini, Ministry of Transport and Infrastructure – Malta.
Description	A six-year demonstration project aiming to create an integrated low carbon and localised energy system establishing a replicable model of hydrogen production, storage, distribution and utilisation for low carbon heat, power and transport. Production of hydrogen on the islands of Eday and Shapinsay using wind and tidal energy and proton exchange membrane (PEM) electrolysers.
Goals	• 1.5MW production capacity (Shapinsay electrolyser is 1MW capacity and Eday electrolyser is 0.5MW capacity). • Demonstrate use of hydrogen as a flexible local energy store and vector, transporting hydrogen by tube trailer to the Orkney mainland. • Share learning to support wider replication and further deployments of renewable energy with fuel cell & hydrogen technologies in isolated or constrained territories.
Link	https://www.bighit.eu

In 2021, the Industrial Decarbonisation Challenge (UKRI, 2021a), mapped the UK's six largest industrial clusters, as part of the Industrial Clusters Mission (BEIS, 2021c). These clusters were Northern Scotland, Tees Valley, Humber, North West, South Wales, and the Black Country, recognising that:

> *"They secure 1.5 million jobs and annually export goods and services worth £320 billion. But they also release around 40 million tonnes of carbon dioxide per year, equating to one third of all business and industrial emissions" (UKRI, 2021a)*

In March, £171m was awarded by UKRI to nine decarbonisation projects in these clusters through the Industrial Strategy Challenge Fund (ISCF) (UKRI, 2021b). The awards and organisations involved are shown below in Appendix 3 with more detail on two of the projects – Zero Carbon Humber and Acorn in North East Scotland – highlighted in boxes 6.3 and 6.4 respectively.

Box 6.3: Zero Carbon Humber (ZCH)

Location	East Yorkshire, England
Partners	Associated British Ports (ABP), British Steel, Centrica, Drax, Equinor, Mitsubishi Power, National Grid, px, SSE Thermal, Triton Power, Uniper, University of Sheffield's Advanced Manufacturing Research Centre.
Description	Hydrogen to Humber (H2H) Saltend is ZCH's anchor project. It will establish the world's largest hydrogen production plant with carbon capture ('blue' hydrogen by reforming natural gas) and be the starting point for a CO_2 and hydrogen pipeline network. This will connect energy-intensive industrial sites throughout the region, offering businesses the options to directly capture their emissions or fuel-switch to hydrogen. Captured CO_2 will be compressed and stored under the southern North Sea using offshore infrastructure shared with the Teesside industrial cluster.
Goals	• Creation of the world's first net zero industrial cluster by 2040. • Expected to protect 55,000 existing jobs in the Humber and create 49,000 new ones. • Future plans to connect to the BioEnergy with Carbon Capture and Storage (BECCS) facility being developed at Drax Power Station, as well as to Uniper's hydrogen production in Immingham, making use of wind power to deliver 'green' hydrogen.
Link	https://www.zerocarbonhumber.co.uk

Box 6.4: Acorn

Location	North East Scotland
Partners	Pale Blue Dot (part of Storegga Group) (lead), Harbour Energy, Shell
Description	Acorn is comprised of Acorn CCS and Acorn Hydrogen and is targeting industrial CO_2 emissions and other 'hard to decarbonise' sectors. It will take North Sea natural gas and reform it into clean burning hydrogen with the CO_2 emissions removed and stored using the Acorn CCS infrastructure ('blue' hydrogen). The project makes use of oil and gas pipelines that are already in place, an offshore geology that is well suited for storing CO_2, and a region that is embracing hydrogen as a fuel of the future.
Goals	• Focus on blending hydrogen with the natural gas that is piped through the National Transmission System to transport the fuel into homes, offices and factories across the UK. • By 'blending at source' this means that replacing just two per cent of natural gas with hydrogen can cut around 400,000 tonnes a year of carbon emissions, with plans to grow to a 20 per cent blend.
Link	https://theacornproject.uk

Other recent examples of hydrogen projects being developed regionally include:

6.1.1. East Midlands Hydrogen Innovation Zone

The University of Nottingham recently published a proposal paper to, "demonstrate how inland areas can make the most efficient use of hydrogen" (UoN, 2021: 2).The proposal highlights a number of challenges in creating a national hydrogen capability, including ensuring grid connectivity, accurate assessment of growing usage across multiple sectors, securing investment over the whole system lifecycle, and undertaking the significant retraining and upskilling of the workforce that will be required. The proposal suggests that inland generation is needed to meet targets beyond current focus on coastal sites with lots of wind energy. However, decommissioned coal plants offer good sites for electrolysers due to grid connectivity, while linking to the new East

Midlands Airport and Gateway Industrial Cluster (EMAGIC), recently granted freeport status, offers opportunities to decarbonise international freight.

6.1.2. *Wales: Storage solutions for renewable energy*

The Wales Centre for Public Policy (Tilley et al., 2020) and the Institute for Welsh Affairs (Sen, 2020) have highlighted the potential for a hydrogen economy in Wales, and advocate for the Welsh Government to pursue production of 'green' hydrogen. Their reports recognise potential to link to and boost wind generation in the North Sea and to offer a surplus energy storage solution. It was suggested that having a viable storage option such as hydrogen could have prevented the cancellation of the Swansea Bay tidal lagoon project (Sen, 2020). There may also be supply chain opportunities with existing hydrogen clusters, such as Hynet (Tilley et al., 2020).

6.1.3. *Tees Valley: A multi-modal hydrogen transport hub*

Kickstarted with £3m in government funding from the Department for Transport, a masterplan has been produced for a multi-modal hydrogen transport hub in the Tees Valley (Mott MacDonald, 2021). The hub will include 'green' hydrogen production, storage, distribution, and refuelling stations from which existing and evolving transport networks and services can feed. It will bring together government, industry, and universities, to focus R&D, testing and trials to help understand the role of hydrogen as part of the energy transition in the transport sector. It is expected to accelerate development and commercialisation of hydrogen transport solutions to help meet current and future public and business needs and could be fully operational by 2025, potentially creating up to 10,000 new jobs.

7

Challenges for future hydrogen pathways

Advocates for hydrogen are keen to highlight the potential of the hydrogen economy as justification for strong commitments to investment, technology development, and positive regulation and incentives. But the Hydrogen Council note that of 200+ hydrogen projects across the hydrogen value chain globally, most (75 per cent) refer to announcements rather than committed funding. The Council emphasises the need for a clear pathway to lever in significant private sector funding to bring these projects to fruition. Similarly, The UK's Catapult Network[8] outline a potential UK 'green' hydrogen export market worth £48bn annually, with the possibility of £200bn of gross value added (GVA) and up to 120,000 jobs (Wyatt et al., 2021: 2). They too advocate for investment in innovation to prevent a "stall" that could "[negate] the huge appetite for private investment into these technologies in UK markets" (Wyatt et al., 2021: 6).

The Catapult Network's report on 'accelerating a UK hydrogen economy' involved members from three centres – renewable energy, energy systems, and high value manufacturing. This combination of expertise helps underline the complexities of delivering a clear pathway for hydrogen, and advocates broadly have highlighted targeting investment, technology development, and regulation in three core areas of the hydrogen value chain: production, distribution, and consumption:

Production: Requires that the "critical trifecta of offshore wind, low carbon hydrogen production and carbon sequestration [is] solved at scale" (Wyatt et al., 2021: 6) with investment to drive down costs and deliver the government's target of 5GW of hydrogen capacity by 2030. This requires the right regulatory framework to drive clean hydrogen, and in addition to continued reductions in the cost of renewable energy there are arguments for supporting "hydrogen giga-scale projects" (Hydrogen Council, 2021: v). These could enable multi-renewable source production sites e.g. combined wind and solar power. According to the Hydrogen Council, development at this scale could put 'green' and 'grey' hydrogen at cost parity as early as 2028 in some high performing global regions. However, this would also need further action to scale up value chains for electrolysers and carbon management.

8 A not-for-profit organisation incorporating nine leading technology and innovation centres, aiming to transform the UK's capability for innovation in sectors of strength - https://catapult.org.uk/

Distribution: The wide variety of potential end uses of hydrogen leaves some doubt regarding priority areas for hydrogen distribution, which creates risks for development of next generation hydrogen systems (Wyatt et al., 2021). Existing gas pipelines can be used but will require modifications, including upgrading from iron to 'hydrogen ready' plastic pipes, a process that is already underway in the UK (Evans and Gabbatiss, 2020). The UK is also looking to plug in to the European Hydrogen Backbone. This project, established by several European gas infrastructure providers under the banner 'Gas for Climate', aims to boost the existing network to 6,800km by 2030 and 23,000km by 2040, to be able to distribute hydrogen across Europe (Wang et al., 2020). However, the IEA (2019) suggests that transportation of hydrogen over 1,500km is likely to be more cost effective via shipping, in the form of liquid hydrogen, such as ammonia. Others argue that locating potential high users such as train and freight refuelling close to production sites should be prioritised to minimise costs, along with investment and regulation for carriers (Hydrogen Council, 2021).

Consumption**:** The focus here is on accelerated technology development, with fuel cell technology, hydrogen combustion, storage and balance of plant needed to make hydrogen a viable alternative to electrification (Wyatt et al., 2021). As this is an emerging market there is need to build demand for hydrogen from end users (Arup, 2019), and the Hydrogen Council (2021) argues that "hydrogen can be the most competitive low-carbon solution for 22 end applications, including long haul trucking, shipping and steel". Consistent policy and regulation is needed to develop this market, but it is also vital to establish the right business model and de-risk the sector. In their report to BEIS, Thornhill and Deasley (2020) outline six criteria (see figure 7.1) that should be followed in order to deliver a business model that will offer "an incentive to invest in low carbon hydrogen production, while limiting costs to consumers and taxpayers" (Thornhill and Deasley, 2020: 6). With hydrogen not yet commercially competitive, and future growth likely to require significant private sector investment, there is still some concern around how governments intend to de-risk investment and ensure there will be no sudden policy changes that wipe out significant investments.

Figure 7.1: Criteria for low carbon hydrogen business models

	Criteria	Considerations
1	**Incentivise producers to provide value to the economy**	▪ Drive decarbonisation ▪ Direct low carbon hydrogen where it provides the highest decarbonisation value ▪ Provide valuable service to low carbon hydrogen consumers ▪ Incentivise efficient management of production costs (capex and opex) ▪ Incentivise efficient production levels
2	**Instil confidence among investors**	▪ Allocate **risks** in way that attracts investment and finance at the appropriate cost of capital
3	**Limit costs to tax payers and bill payers**	▪ Allocate **risks** in a way that limits costs to consumers and billpayers ▪ Avoid over-paying, or paying for production that is not required ▪ Compatibility with fair and practical cost distribution
4	**Be practical and simple**	▪ Administrative ease for government ▪ Practicality and simplicity for investors ▪ Limited complementary policy requirements ▪ Potential for timely implementation
5	**Be compatible with the wider value chain**	▪ Compatibility with lead options for CCUS and H2 T&S ▪ Interaction with existing and planned policy support in other parts of the value chain ▪ Interaction with the carbon price
6	**Be compatible with a path to a subsidy free world**	▪ Ease of reducing payments for future investments ▪ Potential for technology neutrality ▪ Ease of moving to a subsidy free world over time

Source: Thornhill and Deasley, 2020: 7

7.1. From 'blue' to 'green' hydrogen

The language used to support much of the planning for hydrogen, particularly in the UK, is around a need for 'low carbon hydrogen'. This targets using fossil fuels and CCUS to deliver 'blue' hydrogen, justified in strategies by current high costs of 'green' hydrogen and a need to rapidly reduce CO_2 in hard to decarbonise sectors. The argument is that hydrogen can play a vital role in reducing emissions and deliver on net zero targets, and the development of CCUS technology, accelerated by a focus on 'blue' hydrogen, can supposedly reduce costs so that improved CCUS can be deployed in the hardest to decarbonise industries. The challenge is that limited commercial examples of CCUS exist, meaning that it has yet to be effectively deployed at scale (Hansard, 2021) and question marks remain over its ability to deliver the CO_2 reductions claimed (Howarth and Jacobson, 2021). As both costs and capacity of renewable energy improves the purported aim is to transition to a greater proportion of 'green' hydrogen, as well as to higher levels of electrification across all sectors: incentives need to be provided to ensure that this transition occurs.

8

Conclusion

This report outlined hydrogen policy agendas globally, across Europe and in the UK. It focused in particular on regional strategies and implementation, including detailed analysis of city-regional strategies in England. The analysis points to the rapid growth in hydrogen as a subnational, as well as national and international, policy focus with new regional strategies and investments being announced on a regular basis.

Hydrogen – in some form - is increasingly viewed as a vital part of any low carbon transition. However, the variety of production methods and potential applications means it is necessary to clearly identify how best to develop and deploy hydrogen in each country and region. In particular, countries need to look at where hydrogen can have the highest impact in decarbonising a sector and identify which sectors might be hardest to decarbonise through direct use of renewable energy.

We want to highlight five key points from our analysis:

- The wide variety of potential applications might increase demand and support a more diverse business model to spur development of hydrogen, but these too have varying levels of viability that risk spreading development resources too thinly. Public investment and national strategy needs to be consistent and targeted in order to satisfactorily de-risk the hydrogen economy and encourage the necessary development from the private sector.
- Local and regional plans are at a relatively nascent stage, and this reflects wider uncertainties about the long-term production and deployment potential of hydrogen as a route to decarbonisation in different sectors. However, over the last 2-3 years we have seen the focus of strategies evolve, with newer local and regional strategies suggesting some shift in emphasis away from transport and heat to hydrogen production and industrial decarbonisation as more emphasis is placed on net zero targets.
- ‘Blue’ hydrogen is being planned as a source of low carbon fuel in some of the most ambitious regional hydrogen investment plans. Yet there remain debates about its feasibility to deliver cost-effective low carbon hydrogen at scale. ‘Blue’ hydrogen also locks regions into fossil-fuel extraction and use. This can be seen as supporting employment in potentially vulnerable industries but it also delays economy-wide fossil-fuel phaseout and potentially diverts investment from renewable energy solutions. It is also worth noting that there appears to be less focus on decarbonising existing hydrogen generation for sectors like ammonia production: strategies have mostly focused on new and emerging uses for hydrogen.

- Many of the partnerships, clusters, and global lobbying groups pushing for more investment in hydrogen are heavily comprised of existing, or former, oil and gas infrastructure owners and executives. Expertise in repurposing this infrastructure to support the development of hydrogen, particularly the distribution networks, is increasingly considered part of a 'just transition', enabling jobs to be maintained or created in many industrial areas. This is reflected in the prevalence of 'just transition' sections on many major companies' websites outlining their commitment to a low carbon transition that maintains jobs and opportunities (Shell, undated: BP, undated: SSE, 2020).
- At the same time, it is not clear how hydrogen investment decisions are being made locally: who is involved in decision-making and how? This also has implications for a just transition and our empirical research will explore further the extent to which (for example) local citizens participate in the design and implementation of hydrogen futures, and what the perceived benefits are for those citizens.

Drawing from these points, this report raises a series of questions for investigation through our regional case studies, including:

- How are investment decisions made about location of local/regional projects?
- What are the local/regional benefits of developing hydrogen economies, in terms of (for example) jobs, skills or energy costs?
- To what extent are different publics taking part in decision-making for local/regional hydrogen deployment?
- How does hydrogen investment affect other plans for energy transition in regions where investment is deployed?

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Appendix 1: Key commitments in UK hydrogen strategy

Hydrogen production	• Ambition for 5GW of low carbon hydrogen production capacity by 2030. • We will launch the £240m Net Zero Hydrogen Fund in early 2022 for co-investment in early hydrogen production projects. • We will deliver the £60 million Low Carbon Hydrogen Supply 2 competition. • We will finalise design of UK standard for low carbon hydrogen by early 2022. • We will finalise Hydrogen Business Model in 2022, enabling first contracts to be allocated from Q1 2023. • We will provide further detail on our production strategy and twin track approach by early 2022.
Hydrogen networks and storage	• We will launch a call for evidence on the future of the gas system in 2021. • We will review systemic hydrogen network and storage requirements in the 2020s and beyond, including need for economic regulation and funding, and provide an update in early 2022. • We will deliver the £68 million Longer Duration Energy Storage Demonstration competition. • We will deliver the £60 million Low Carbon Hydrogen Supply 2 competition.
Use of hydrogen	• We will launch a call for evidence on 'hydrogen-ready' industrial equipment by the end of 2021. • We will launch a call for evidence on phase out of carbon intensive hydrogen production in industry within a year. • We will deliver Phase 2 of the £315m Industrial Energy Transformation Fund. • We will launch a £55 million Industrial Fuel Switching 2 competition in 2021. • We will prepare for hydrogen for heat trials – a hydrogen neighbourhood by 2023, hydrogen village by 2025 and potential pilot hydrogen town by 2030. • We aim to consult in 2021 on 'hydrogen-ready' boilers by 2026. • We will continue our multi-million pound support for transport decarbonisation, including for deployment, trials and demonstration of hydrogen buses, HGVs, shipping, aviation and multi-modal transport hubs.

Creating a market	• We will set out further detail on the revenue mechanism which will provide funding for the Business Model in 2021. • We will establish a Hydrogen Regulators Forum in 2021. • We will assess market frameworks to drive investment and deployment of hydrogen, and provide an update in early 2022. • We will assess regulatory barriers facing hydrogen projects, and provide an update in early 2022. • • We will complete an indicative assessment of the value for money case for blending up to 20 per cent hydrogen into the existing gas network by late 2022, and aim to make a final policy decision in late 2023.
Realising economic benefits for the UK	• We will prepare a Hydrogen Sector Development Action Plan, including for UK supply chains, by early 2022. • We will establish an Early Career Professionals Forum under the Hydrogen Advisory Council. • We will support hydrogen innovation as one of the ten key priority areas in the £1bn Net Zero Innovation Portfolio. • We will work with the Hydrogen Advisory Council Research & Innovation Working Group to develop a UK hydrogen technology R&I roadmap. • We will deliver as one of the co-leads of Mission Innovation's new Clean Hydrogen Mission.

Source: (BEIS, 2021b)

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Appendix 2: Technology priorities in LEP energy strategies

BEIS Local Energy Hub	LEP Name	District Heating	Smart Grids	Solar	Fuel Poverty	Hydrogen	Comm unity Energy	Energy Storage	Wind	Biomass	Gas	Mine Water / Geo thermal	Nuclear
Midlands Energy Hub	*West Midlands (tri-LEP)*				x								
	Black Country	x		x				x	x	x	x	x	X
	Coventry & Warwickshire												
	Greater Birmingham & Solihull	x	x				x						
	D2N2		x	x	x	X	x	x				x	
	Greater Lincolnshire												
	Leicester & Leicestershire					X							
	Stoke-on-Trent & Staffordshire	x	x	x	x		x						
	The Marches		x		x								
	Worcestershire		x		x								

BEIS Local Energy Hub	LEP Name	District Heating	Smart Grids	Solar	Fuel Poverty	Hydrogen	Comm unity Energy	Energy Storage	Wind	Biomass	Gas	Mine Water / Geo thermal	Nuclear
North East and Yorkshire Energy Hub	Hull & East Yorkshire*	x		x		x			x	x			
	Leeds City Region	x	x	x	x	x	x	x		x		x	
	North East	x		x	x		x		x		x	x	
	Sheffield City Region	x	x	x		x	x	x	x			x	
	Tees Valley												
	York & North Yorkshire	x		x			x	x		x			
Local Energy North West Hub	Cheshire & Warrington	x	x			x		x				x	x
	Cumbria	x			x		x	x		x			x
	Greater Manchester												
	Lancashire	x							x		x		
	Liverpool City Region												
Greater South East Energy Hub	*South 2 East (tri-LEP)*	x	x	x		x			x	x	x		
	Coast to Capital												
	Enterprise M3												
	South East												
	Local Energy East Network (tri-LEP)	x	x	x	x	x	x	x	x		x		x
	Cambridgeshire & Peterborough												
	Hertfordshire												
	New Anglia					x			x	x	x		x
	Buckinghamshire	x	x			x	x						
	London												
	OxLEP		x	x			x	x		x			
	South East Midlands	x											

BEIS Local Energy Hub	LEP Name	District Heating	Smart Grids	Solar	Fuel Poverty	Hydrogen	Comm unity Energy	Energy Storage	Wind	Biomass	Gas	Mine Water / Geo thermal	Nuclear
	Thames Valley Berkshire												
South West Energy Hub	*South West (tri-LEP)*	x	x	x	x				x			x	
	Cornwall & Isles of Scilly												
	Dorset												
	Heart of the South West												
	gfirst				x					x	x		
	Solent	x	x	x		x			x				
	Swindon & Wiltshire		x			x		x					
	West of England		x	x	x								
Totals (from 29 strategies)**		17	16	14	12	12	11	10	10	9	7	7	5
		59%	55%	48%	41%	41%	38%	34%	34%	31%	24%	24%	17%

*Hull and East Yorkshire LEP was established in April 2021 and does not yet have an energy strategy. Data is instead included from the former Humber LEP energy strategy.

**There are 29 energy strategies, comprised of 25 individual LEP strategies and four tri-LEP plans – some LEPs covered under tri-LEP plans also have their own individual strategy e.g. Black Country. Blue boxes connect the areas covered by the four tri-LEP strategies, red names refer to where no energy strategy could be found

Appendix 3: Mapping UK hydrogen clusters

A3

Fund	Cluster / Project	Other Clusters Involved	Organisations	Region	Money Received
UKRI: Industrial Strategy Challenge Fund - Industrial Decarbonisation Programme	Hynet (offshore)		Progressive Energy Ltd (lead) ENI UK Ltd	NW	£13,324,521
	Hynet (onshore)		Progressive Energy Ltd (lead) Cadent Gas Ltd University of Chester CF Fertilisers UK Ltd ENI UK Ltd Essar Oil (UK) Ltd Castle Cement Ltd Inovyn Enterprises Ltd.	NW	£19,451,381
	Scotland's net zero infrastructure (offshore)		Pale Blue Dot Energy Ltd (lead) Petrofac Facilities Management Ltd.	Scotland	£11,347,956
	Scotland's net zero infrastructure (onshore)		Pale Blue Dot Energy Ltd (lead) University of Strathclyde Neccus SSE Generation Ltd National Grid Plc GBTron Power Ltd.	Scotland	£19,956,777

Fund	Cluster / Project	Other Clusters Involved	Organisations	Region	Money Received
UKRI: Industrial Strategy Challenge Fund - Industrial Decarbonisation Programme	Net zero Teesside (onshore)		BP Exploration Operating Company Ltd (lead) The North East of England Process Industry Cluster Ltd Sembcorp Utilities (UK) Ltd Boc Ltd Shell UK Ltd CF Fertilisers UK Ltd Tees Valley Combined Authority Eni UK Ltd Equinor New Energy Ltd National Grid Carbon Ltd Total Gas & Power Chartering Ltd.	NE	£28,052,338
	Northern endurance partnership	Net Zero Teeside Zero Carbon Humber	BP Exploration Operating Company Ltd (lead) Shell UK Ltd Eni UK Ltd Equinor New Energy Ltd National Grid Carbon Ltd Total Gas & Power Chartering Ltd.	NE and Yorks	£24,002,130
	Zero Carbon Humber (ZCH) partnership		Equinor New Energy Ltd (lead) University of Sheffield British Steel Ltd National Grid Carbon Ltd Centrica Storage Ltd Saltend Cogeneration Company Ltd Associated British Ports Drax Corporate Ltd Uniper UK Ltd PX Ltd SSE Generation Ltd Mitsubishi Hitachi Power Systems Europe Ltd.	Yorks	£21,496,246
	Humber Zero		VPI Immingham LLP (lead) Phillips 66 Ltd.	Yorks	£12,692,948
	South Wales Industrial Cluster (SWIC)		Costain Oil, Gas & Process Ltd (lead) Tarmac Trading Ltd Tata Steel UK Ltd	Wales	£19,999,997

Fund	Cluster / Project	Other Clusters Involved	Organisations	Region	Money Received
			University of South Wales Progressive Energy Ltd Wales & West Utilities Ltd Milford Haven Port Authority RWE Generation UK Plc CR Plus Ltd Valero Energy UK Ltd Capital Law Ltd Associated British Ports Sector Development Wales Partnership Ltd Simec Uskmouth Power Ltd Lanzatech UK Ltd Lightsource BP Renewable Energy Investments Ltd Shell UK.		
BEIS: Energy Innovation Programme	Hy4Heat		Arup (lead) Kiwa Gastec Progressive Energy Embers Yo Energy	UK	£20,000,000
BEIS: Hydrogen Supply Competition 1	Dolphyn		Environmental Resources Management Limited (lead)	Scotland	£3,120,000
	Hynet		Progressive Energy (lead) Essar Johnson Matthey SNC-Lavalin	NW	£7,480,000
	Gigastack		ITM Power Trading Ltd (lead)	Yorks	£7,500,000
	Acorn Hydrogen Project		Pale Blue Dot Energy (lead)	Scotland	£2,700,000
	Bulk Hydrogen Production by Sorbent Enhanced Steam Reforming (HyPER)		Cranfield University (lead)	SE	£7,440,000