Hy-Impact Series
Hydrogen in the UK, from technical to economic

A summary of four studies assessing the role of hydrogen in the UK net-zero transition

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A report for

equinor

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Element Energy is a strategic energy consultancy, specialising in the intelligent analysis of low carbon energy. Element Energy provides consultancy services across a wide range of sectors, including carbon capture and storage and industrial decarbonisation, smart electricity and gas networks, energy storage, renewable energy systems and low carbon vehicles. Our team of over 50 specialists provides consultancy on both technical and strategic issues, believing that the technical and engineering understanding of real world challenges supports the strategy development.

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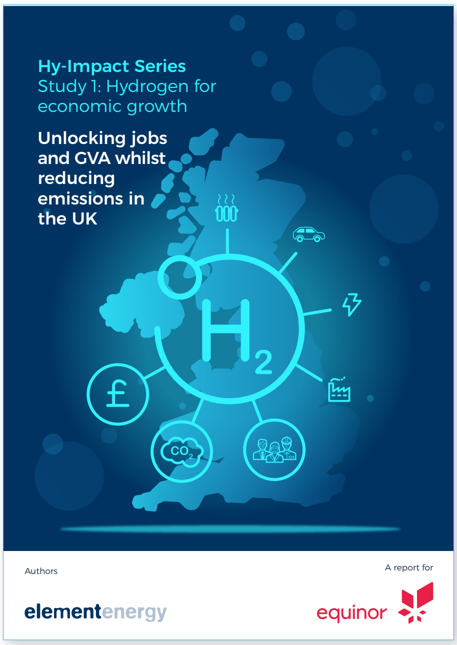
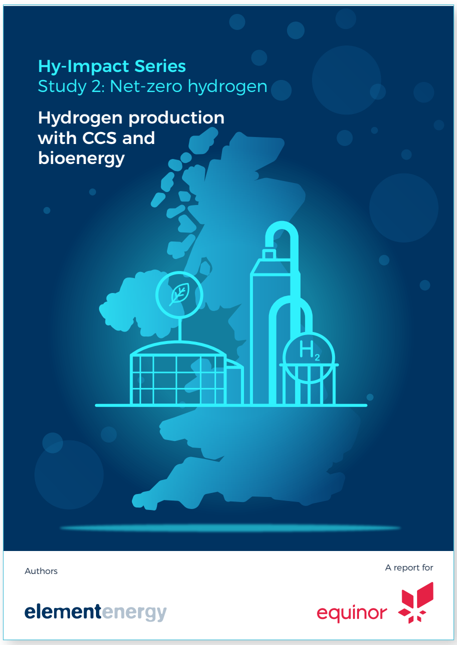
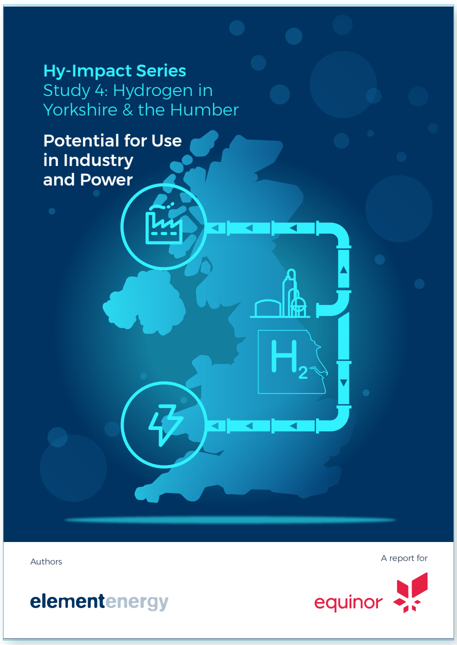
“Developing carbon capture and storage technology and low-carbon hydrogen is a necessity, not an option”

Committee on Climate Change Net-Zero Report Press Release May 2019







Hy-Impact is a series of four studies exploring the introduction of hydrogen and carbon capture and storage to the UK economy

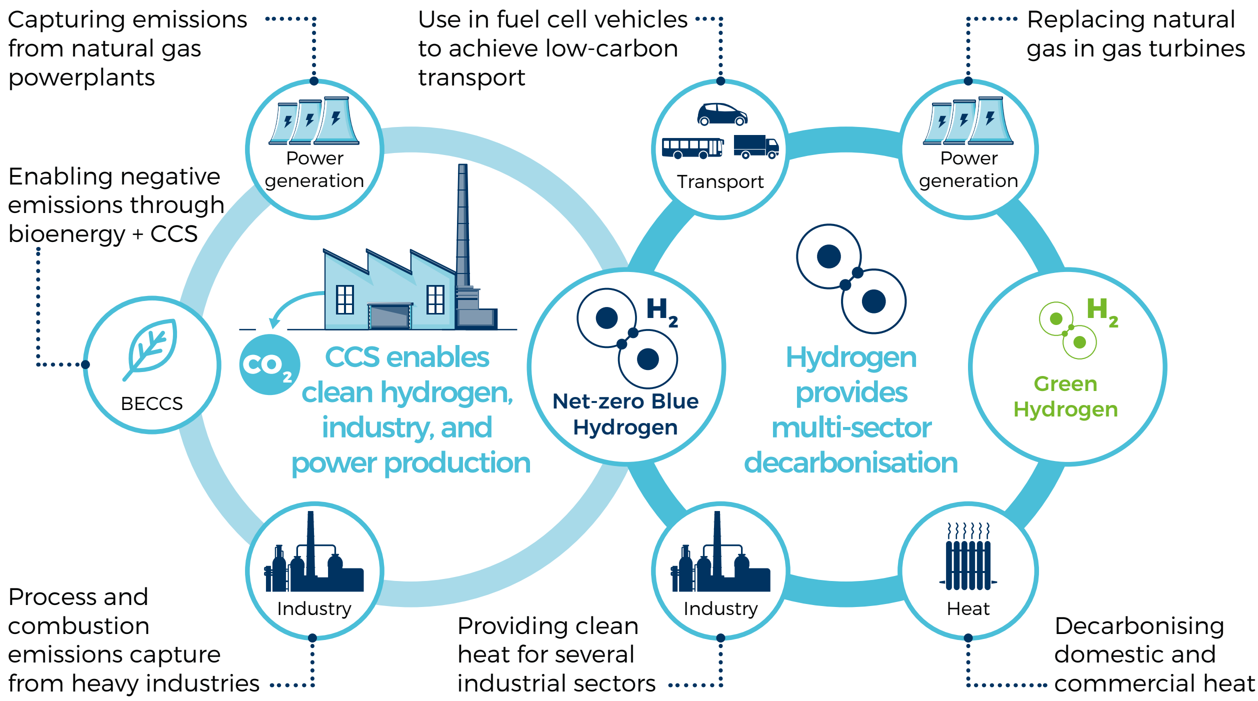
Hydrogen and CCS in the UK: role in the UK net-zero transition

The UK has committed to net-zero greenhouse gas emissions by 2050

The UK was the first major nation to commit to net-zero greenhouse gas emissions by 2050, following recommendations by the Committee on Climate Change (CCC) in their recently published "Net-Zero" report. The report concluded that "net-zero is necessary, feasible and cost-effective… the science demands it; the evidence is before you; we must start at once". The report also laid out the wide range of technologies, mature and new, that are required across the economy.

Hydrogen and CCS are key technologies to achieve this goal

The CCC recommended investment into two complementary technologies, hydrogen and carbon capture and storage (CCS), due to their pivotal roles in enabling long-term decarbonisation. Hydrogen is used as an energy carrier similar to natural gas, and is capable of decarbonising multiple sectors, including industry, heat, power generation and transport. CCS has a crucial role to play in capturing process and combustion emissions from sectors such as industry and power, including negative emissions technologies such as bioenergy with CCS (BECCS).



Hydrogen, produced in conjunction with CCS and bioenergy, can be net-zero

Ultra-low carbon hydrogen can be produced through either reformation of natural gas with CCS or electrolysis with renewables, referred to as blue and green hydrogen respectively. Blue hydrogen can be delivered at scale with net-zero or net-negative emissions dependent upon the amount of biogas feedstock in the natural gas mix.

There are a number of questions remaining around the future of hydrogen and CCS in the UK. This series of studies aims to provide key evidence around the following themes:

1. Hydrogen for Economic Growth

£18 billion in value and over 200,000 jobs could be generated by deployment of hydrogen and CCS in the UK economy

This series of studies starts by examining how a future UK economy could benefit from the development of hydrogen and CCS technologies. Three scenarios for hydrogen and CCS deployment, with varying levels of ambition, were developed to understand the level of investment required and the potential economic, strategic, environmental and employment benefits.

2. Net-zero Hydrogen

There is sufficient bioenergy to enable net-negative hydrogen production in even the most ambitious scenario

Net-zero or net-negative hydrogen can be produced by blending biogas into the natural gas feedstock. The second study examines the bioenergy resource required to meet future hydrogen demand, as well as the financial and emissions implications of different decarbonisation scenarios.

3. Hydrogen for Power Generation

Hydrogen and CCS power technologies can cost-effectively replace a significant number of planned power generation assets

Hydrogen and CCS can be used for low-carbon power generation to diversify the power portfolio, reduce electricity imports and provide resilience to high levels of renewable energy generation. This work assessed the financial and emissions implications of these generation methods when compared with natural gas and nuclear options, under a rising carbon price.

4. Hydrogen in Yorkshire & The Humber

The Humber region could represent an opportunity for early hydrogen deployment, with potential demand of 13 TWh/year hydrogen in industry and up to 165 TWh/year in power plants

The Yorkshire and Humber industrial cluster is the UK's largest by both greenhouse gas emissions and energy usage. The work identified large industrial and power sites in the region and assessed their potential for use of hydrogen by 2030.

Study 1 - Hydrogen for Economic Growth: Unlocking jobs and value whilst reducing emissions in the UK

Although hydrogen and carbon capture and storage (CCS) are recognised as key technologies enabling the UK to reach its ambitious net-zero targets by 2050, there is still uncertainty regarding the scale and timeframe of their deployment. This study examines three "*what if*" scenarios, varying in scale, scope, and complexity, providing grounds for the rapid deployment of hydrogen and CCS technologies. The scenarios range from deploying these technologies in UK industry to achieving national cross-sectoral deployment and international export capabilities. This analysis not only examines the technical aspects of decarbonising different sectors of the UK economy, but also provides an understanding of the level of investment required and the expected benefits, beyond achieving decarbonisation targets.

Industry decarbonisation alone could create 43,000 new job opportunities

Decarbonising UK industry would require capturing process and post-combustion emissions from five energy intensive industrial sectors: cement, ammonia, ethylene, refineries, and iron and steel plants. CCS could be supplemented by fuel switching to hydrogen in these and other industrial sectors, including non-ferrous metallurgy, chemicals, paper, and mineral processing. In this scenario, 115 TWh/year hydrogen would be used in 2050 and ~23 $MtCO_2$/year would be captured whilst providing 43,000 jobs.

Decarbonising heat, industry, transport and power could quadruple these benefits

Economy-wide UK decarbonisation would involve the use of hydrogen for domestic, commercial, and industrial heating and power generation, as well as the adoption of hydrogen mobility across five transport subsectors. In addition to its deployment in industry, CCS would also help decarbonise conventional natural gas power stations. Coupled with the emissions captured from hydrogen production, 197 $MtCO_2$/year would be captured by 2050. Such an ambitious roll-out would result in 195,000 jobs, including direct employment in infrastructure deployment and operational roles, as well as indirect supply-chain opportunities.

Over 25,000 more jobs could be created by becoming a world decarbonisation leader

Building a world-leading decarbonised economy which is also able to export low-carbon energy carriers such as hydrogen and electricity generated from hydrogen, would require a total capex of £176 billion by 2050 and an annual operational spending of £16 billion in 2050. We estimate that a total of 221,000 people would be working in related activities whilst 260 $MtCO_2$/year would be captured by 2050.

Additional benefits unlocked by investment in hydrogen and CCS are significant

- Potential for inward investment and regeneration of areas with above average unemployment.
- UK export potential from leading expertise in hydrogen and CCS technologies and associated skills.
- Unlocking potential for the trade of low-carbon products such as blue ammonia and clean steel.
- Revenues from CO_2 shipped and stored by other countries within UK storage sites.

UK 2050: The benefits unlocked by hydrogen and CCS under three ambition scenarios

Industry decarbonisation

Introducing blue hydrogen and CCS to UK's industry could rejuvenate industrial areas

115 TWh/year hydrogen

48 $MtCO_2$/year captured

£4 billion annual GVA*

*GVA = Gross Value Added

43,000 jobs created

Decarbonised UK economy

Adopting hydrogen and CCS in industry, power, heating and mobility at a national level could quadruple economic benefits

735 TWh/year hydrogen

197 $MtCO_2$/year captured

£16 billion annual GVA*

195,000 jobs created

World leading decarbonisation

Decarbonising the UK economy and consolidating production of hydrogen for exports could help other economies decarbonise with additional UK benefits

1,040 TWh/year hydrogen

260 $MtCO_2$/year captured

£18 billion annual GVA*

221,000 jobs created

Study 2 - Net-zero Hydrogen:
Hydrogen production with CCS and bioenergy

Blue hydrogen can be net-zero or net-negative emissions when biogas is used as a feedstock in production

Blue hydrogen is a form of low-carbon hydrogen produced cost-effectively at large scale from natural gas via reforming, with the CO_2 emissions captured through CCS. The small amount of remaining emissions of this production pathway can be offset through blending of sustainable biomethane into the natural gas feedstock, thus harnessing waste that would otherwise decompose and emit carbon dioxide.

There is sufficient bioenergy available to produce net-negative hydrogen for even the most ambitious UK hydrogen deployment level

- Bioenergy with CCS will be key to offsetting emissions from hard-to-decarbonise sectors such as industry, aviation, and off-gas grid homes, with the remaining bioenergy resources allocated to hydrogen and electricity production.
- In terms of bioenergy supply, we estimate a total availability between 132 and 345 TWh/year in 2050, depending on availability of domestic biomass, biomass imports, and biogenic wastes.
- We envisage hydrogen reaching a demand of up to 1,040 TWh/year in the most ambitious case, corresponding to a “World leading decarbonised economy”, as examined in study 1.
- In the central bioenergy availability estimate, there will be sufficient bioenergy to produce net-negative emissions hydrogen even in the most ambitious hydrogen deployment scenario, whilst allowing adequate bioenergy resources for sectors, such as aviation, industry, synthetic fuel production, and off-grid houses.

The maximum cost of abatement using hydrogen is estimated at £137/tCO_2, 21% lower than alternatives in some applications

A hydrogen cost between £41 and £48 per MWh_{H2}, increasing with higher biogas usage, is expected, with the produced hydrogen providing zero or net-negative emissions (-10 $kgCO_2/MWh_{H2}$ using a 9.3% biogas mix). The cost of carbon abatement via net-negative hydrogen of £137/tCO_2 would be competitive with other negative emissions technologies, such as bioenergy with CCS (BECCS) in the power sector, which was estimated by the CCC to cost £158/tCO_2.

The UK’s gas import dependence in 2050 is likely to be comparable with or reduced relative to today, protecting security of UK energy supply

The natural gas demand is expected to reduce by at least 150 TWh/year in two of the three hydrogen scenarios presented in the report. The reduction is mainly due to energy efficiency measures and electrification of some heat applications. Overall, this results in a similar level of natural gas imports to today, despite falling domestic gas production. Although natural gas demand increases relative to today’s usage in the highest hydrogen deployment scenario (1,040 TWh/year), this is driven by the UK’s export of hydrogen and electricity produced from hydrogen, delivering additional benefits.

Biogas blending has a significant impact on hydrogen production costs and emissions

	Natural gas	Blue H_2	Net-Zero H_2	Net-Negative H_2
Emissions	+185 $kgCO_2/MWh_{NG}$	+9 $kgCO_2/MWh_{H2}$	0 $kgCO_2/MWh_{H2}$	-10 $kgCO_2/MWh_{H2}$
Emissions savings[1] ($MtCO_2$/year)		89	93	98
Hydrogen fuel costs		£40/MWh	£44/MWh	£48/MWh
Abatement cost[1]		£109/tCO_2	£123/tCO_2	£137/tCO_2

[1]Relative to natural gas; all outputs are for 2050

Net-negative hydrogen

Estimated bioenergy supply could satisfy even the most ambitious net-negative hydrogen deployment scenarios

UK hydrogen demand ambition 2050 (TWh/year)[2]	272	505	1,040
Maximum bioenergy demand for hydrogen[3] 2050 (TWh/year)	50 (226 TWh/year)	77 (226 TWh/year)	105 (226 TWh/year)

[2]First two scenarios are different from Study 1 – see full report for details

[3]Total bioenergy availability in the Central Case (226 TWh/year) exceeds demand required to achieve net-negative hydrogen production

Natural gas prices based on BEIS central forecast (£21/MWh 2030 onwards)

Assuming 9.3% biogas mix for hydrogen production

Study 3 - Hydrogen for Power Generation: Opportunities for hydrogen and CCS in the UK power mix

Hydrogen fuelled gas turbines and post combustion CCS with natural gas plants are flexible low-carbon power generation options for the UK's future

The power mix comprises of both baseload generation, with high load factors, and flexible generation, with low load factors, which react to changes in supply and demand of power. Renewables, whilst clean and often cost-effective, require complementary low-carbon technologies. Hydrogen and CCS could play an important role in the future UK generation mix, with hydrogen gas turbines fuelled by negative emission hydrogen, and natural gas turbines coupled with CCS.

- This analysis focuses on lifecycle electricity generation costs of different technologies under future carbon pricing (BEIS projection, £79/tCO_2 in 2035, rising to £206/tCO_2 in 2050) and shows an opportunity for hydrogen and CCS technologies to diversify the 2035 UK power mix by replacing the new build capacity projected by BEIS.

> "The majority of nuclear and unabated gas power plants projected to be built by 2035 can be cost effectively replaced by hydrogen and CCS technologies under this carbon price projection"

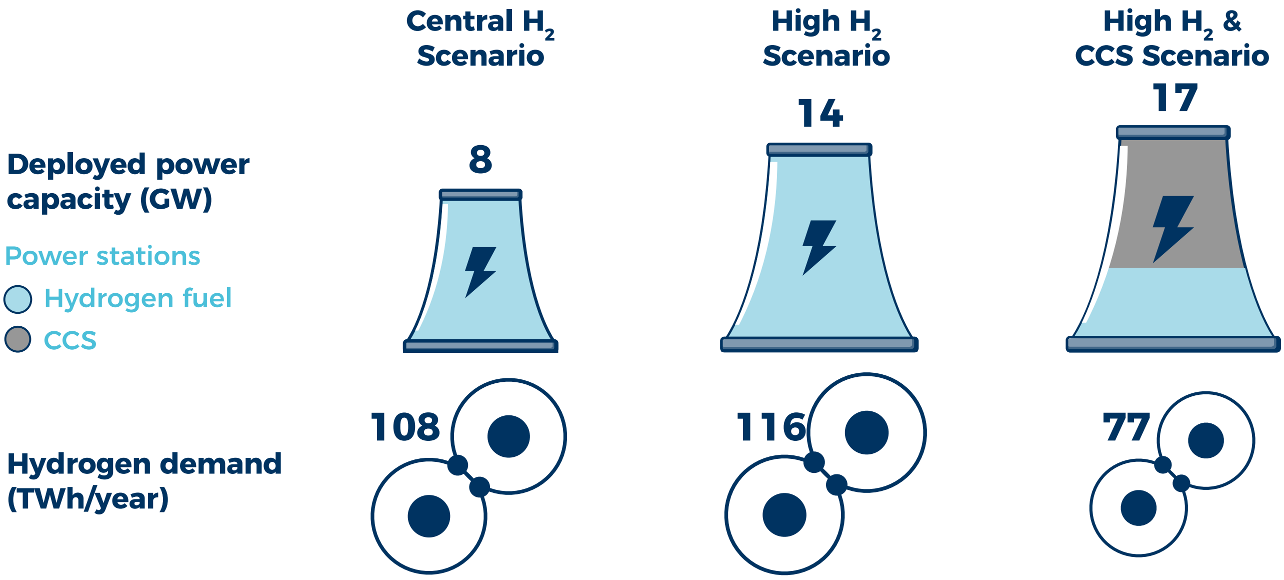
- Evidence suggest that all projected 12.3 GW of new nuclear plants operating as baseload generators, may be cost effectively replaced by hydrogen or CCS power technologies, under the BEIS carbon price projections. The best fit for each technology would depend on the purpose and utilisation of future power plants.
- Post combustion CCS plants are a better replacement for high-load factor generation assets than hydrogen, due to their lower fuel costs. Conversely, new gas turbines providing flexible generation (low load factor) could be more economically replaced by hydrogen turbines, given their much lower capital costs compared to the alternative CCS technologies.
- Retrofit of existing unabated natural gas plants with either 100% hydrogen turbines or with CCS, without life extension through turbine replacement, is not found to be cost-effective under current assumptions, although ongoing research and development may lead to significant cost reductions in the future.
- Additionally it was found that hydrogen could be cost-effectively blended with natural gas in existing turbines from the early 2030s without major retrofit.

Hydrogen and CCS power technologies could save up to 24% of power sector emissions by 2035 in the most ambitious scenario, whilst reducing costs

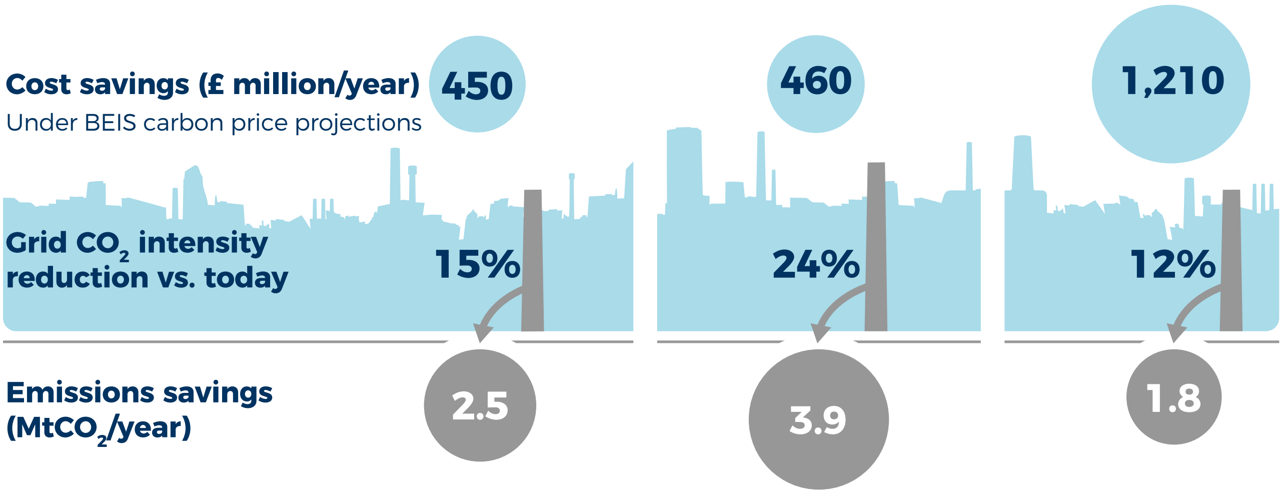
The three scenarios examine the replacement of 6 - 9 GW of new nuclear power generation and 1.4 - 3.1 GW of new gas plants with hydrogen or CCS power technologies. In addition, blending hydrogen as fuel for up to 5.5 GW of unabated gas plants is considered. Such a deployment would lead to an abatement of 1.8 to 3.9 MtCO_2/year by 2035, 11-24% of power sector emissions. Annual cost savings of £450 - £1,210 million could be achieved compared to the current BEIS projection, with the largest saving coming from power CCS replacing nuclear plants. Hydrogen and CCS power technologies could also diversify the generation portfolio, reduce electricity imports and provide system resilience to high levels of renewable energy generation.

UK power in 2035 under three low-carbon generation scenarios...

... would require a diversification of technologies with opportunities for hydrogen and CCS



Hydrogen and CCS technologies could reduce electricity carbon intensity by 24% and achieve significant cost savings



Natural gas prices based on BEIS central forecast (£21/MWh 2030 onwards)

Study 4 - Hydrogen in Yorkshire & the Humber: Potential for use in industry and power

The Yorkshire and Humber cluster is the largest of the six major UK industrial clusters by both greenhouse gas emissions and energy usage

The wider Yorkshire and Humber cluster incorporates a large region from the Humber estuary across much of Yorkshire and North Lincolnshire. The study area stretches to and beyond Leeds, Sheffield, and York, the areas surrounding the Drax site where plans for hydrogen production are underway. Whilst this region presents a strong opportunity for decarbonisation of UK industry and power, the cluster must develop a clear decarbonisation strategy in order to enable a successful transition, supporting clean economic growth.

The delivery of hydrogen to energy intensive end users represents a credible early pathway for large scale hydrogen deployment

Large energy users present an opportunity to kick-start the hydrogen transition, testing and proving hydrogen production, transmission and end-use technologies. Delivering hydrogen to large users through new pipework, allowing simultaneous availability of natural gas and hydrogen, enables time for onsite tests of 100% hydrogen equipment and reduces risks to industry. The Humber region is diverse, with a range of industrial sites and existing and planned power stations, providing compelling opportunities for technical advancements and the development of a local hydrogen economy specialised in low-carbon commodities such as steel.

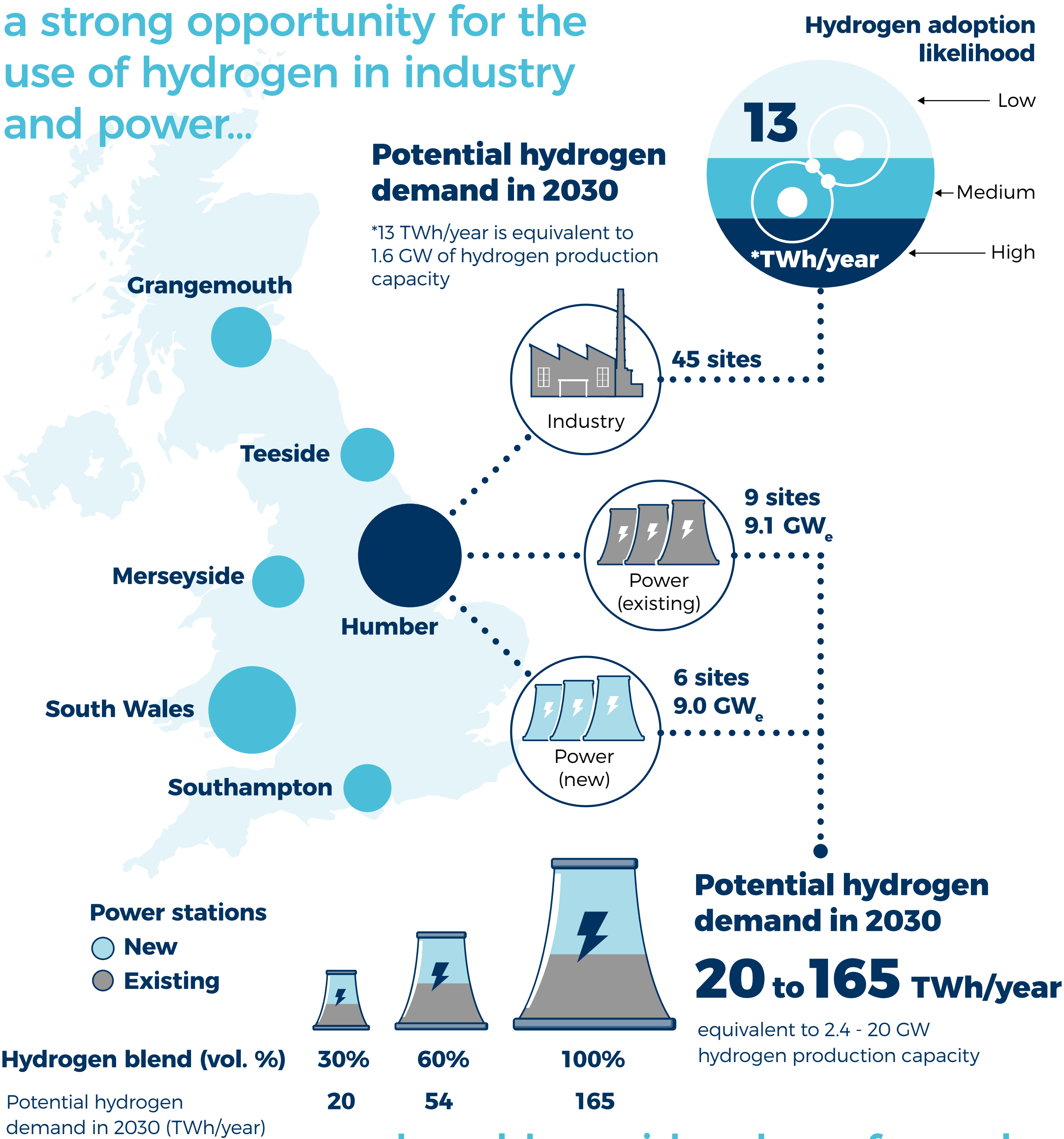
45 large industrial sites, 9 existing power stations and 6 prospective new power stations were identified for their potential to use hydrogen as a fuel

45 large industrial sites were identified, many of which could use hydrogen in place of natural gas in heating applications, such as in steel, chemicals, lime and glass manufacturing in the region. The assessment of the potential of industrial sites to be early movers in hydrogen use considered: the likely hydrogen demand in 2030; the distance from the Drax hydrogen production facility; a range of factors influencing the likelihood of conversion, such as technical barriers, cost of conversion, organisation strategy and outlook. For the power stations, hydrogen was considered as an option for blending with natural gas (30% or 90% hydrogen by volume) or as a full 100% conversion.

The potential hydrogen consumption in 2030 was found to be up to 13 TWh/year for industry and 20-165 TWh/year for power generation, avoiding up to 33 $MtCO_2$/year

For industry, converting to hydrogen for heat applications would lead to a demand up to ~13 TWh/year of hydrogen (1.6 GW hydrogen production capacity) in 2030, with a resulting emissions savings of 3.5 $MtCO_2$/year. Hydrogen demand from current and prospective power stations could reach 20 - 165 TWh/year depending on the blending ratio of hydrogen with natural gas, and could result in avoiding up to 30 $MtCO_2$/year in emissions. To facilitate this opportunity, investment support is needed to incentivise industry, and the cluster must develop a coherent vision to reach net-zero emissions.

The Humber region presents a strong opportunity for the use of hydrogen in industry and power...

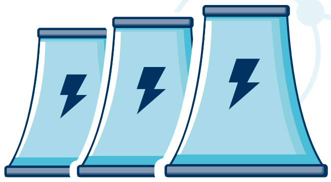


... and could provide a base for early hydrogen economy development

Hydrogen for Growth: A roadmap to Net-Zero 2050

2020

Funding required to support hydrogen and CCS projects through to Final Investment Decision

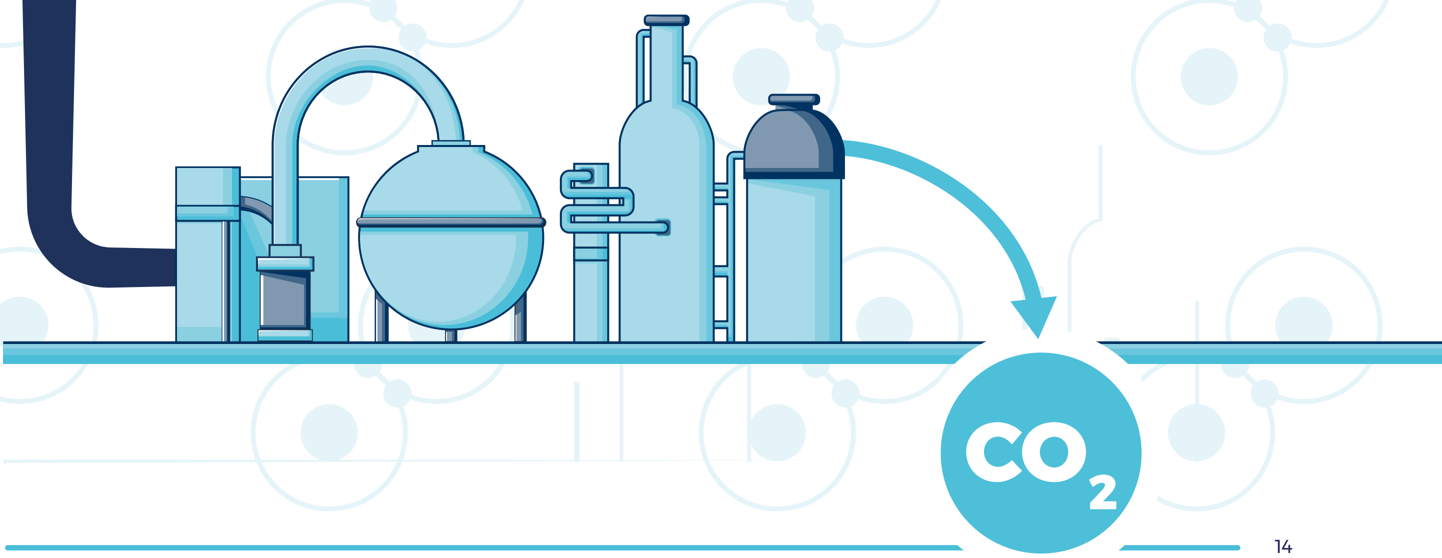


2035

Up to 17 GW of installed power generation capacity could use hydrogen and CCS technologies

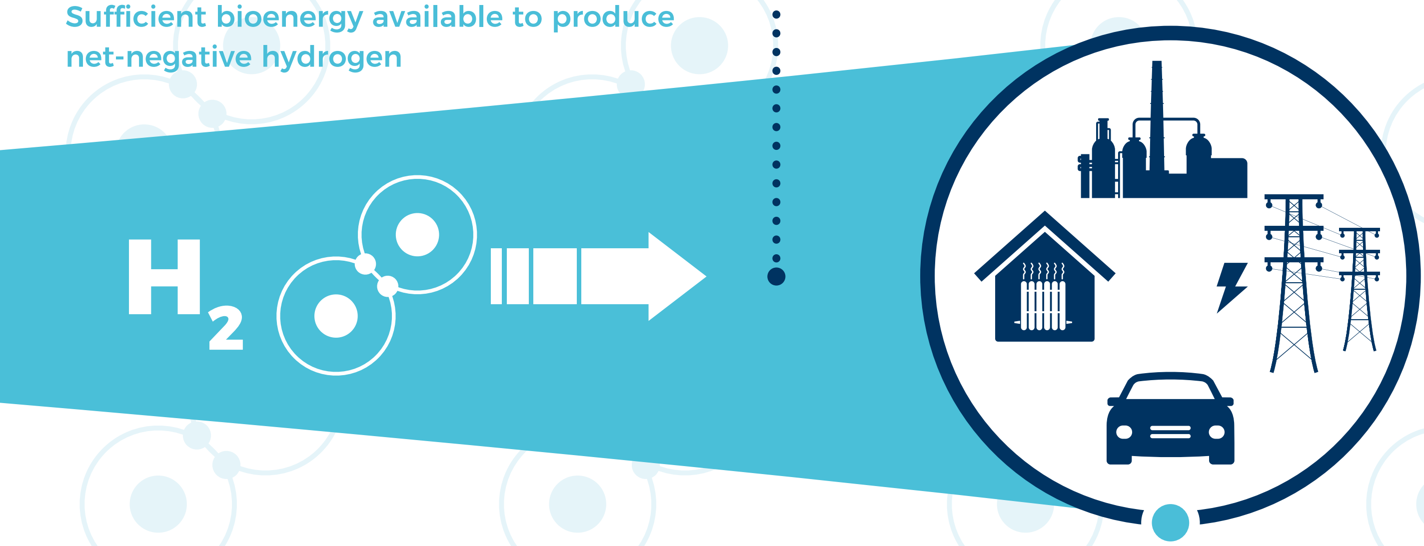
2030

Up to 13 TWh/year of hydrogen could be used by industry in the Yorkshire and Humber cluster



2050
UK NET-ZERO TARGET

Sufficient bioenergy available to produce net-negative hydrogen



Decarbonised UK economy

195,000 jobs, £16 billion in GVA, and 197 $MtCO_2$/year captured by 2050

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Element Energy is a dynamic and growing strategic energy consultancy, specialising in the intelligent analysis of low carbon energy.

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