CCS0621687164

978-1-5286-2670-5

UK Hydrogen Strategy

CP 475

HM Government

UK Hydrogen Strategy

August 2021

CP 475

UK Hydrogen Strategy

Presented to Parliament
by the Secretary of State for Business, Energy & Industrial Strategy
by Command of Her Majesty

August 2021

CP 475

We would like to acknowledge the following organisations for supplying images for this strategy:

On page 18, image credited to Colin Keldie, provided courtesy of Orkney Islands Council. The images on page 35 and 93 were provided courtesy of ITM Power. On page 36, image provided courtesy of Pale Plue Dot Energy. On page 61, image provided courtesy of Baxi Heating UK Ltd. The image on page 64 is provided courtesy of Wrightbus; the image on page 68 is provided courtesy of ZeroAvia.

This publication is available at www.gov.uk/official-documents

Any enquiries regarding this publication should be sent to us at ie.hydrogen@beis.gov.uk

ISBN 978-1-5286-2670-5

CCS0621687164 08/21

Printed on paper containing 75% recycled fibre content minimum

Printed in the UK by the APS Group on behalf of the Controller of Her Majesty's Stationery Office

Contents

Ministerial foreword

As the Prime Minister made clear when he launched his *Ten Point Plan for a Green Industrial Revolution* last year, developing a thriving low carbon hydrogen sector in the UK is a key plank of the government's plan to build back better with a cleaner, greener energy system. With the potential to overcome some of the trickiest decarbonisation challenges facing our economy – including our vital industrial sectors – and secure economic opportunities across the UK, low carbon hydrogen has a critical role to play in our transition to net zero.

Working with industry, our ambition is for 5GW of low carbon hydrogen production capacity by 2030 for use across the economy. This could produce hydrogen equivalent to the amount of gas consumed by over 3 million households in the UK each year. This new, low carbon hydrogen could help provide cleaner energy to power our economy and our everyday lives – from cookers to distilleries, film shoots to power plants, waste trucks to steel production, and 40 tonne diggers to the heat in our homes.

Meeting our ambition means rapid ramp up of production and use of hydrogen over the coming decade. In every country of the UK, there are ambitious, world-leading projects ready to deploy at scale, saving carbon and creating jobs. These trailblazers will help us fully understand the costs around hydrogen, its safety where hydrogen is being used in new ways, and just how far it can contribute to reducing our emissions.

The time for real world action is now. We have developed the first ever UK Hydrogen Strategy to set out clearly the key steps we need to take in the coming months and years to deliver against the promise that hydrogen presents – an exciting moment for technology providers, energy companies large and small, investors, innovators, and government at all levels.

Our ambition for hydrogen goes beyond decarbonisation. It also means a focus on supporting industry to develop sustainable, home-grown supply chains, create high quality jobs, and capitalise on British innovation and expertise. It means incentivising private investment and looking to increase export opportunities. It means strengthening our industrial heartlands, boosting our economy and driving national growth.

The Hydrogen Strategy builds on our national strengths. UK companies are already at the forefront of global hydrogen technology development. Our geology, infrastructure and technical know-how make us ideally positioned to be a global leader in hydrogen. We have a strong history of collaboration between government, industry and innovators to tackle climate change and grow our economy.

Alongside this Strategy we are also publishing a number of consultations – seeking views on our preferred Hydrogen Business Model, the design of our flagship £240m Net Zero Hydrogen Fund, and a UK Low Carbon Hydrogen Standard. These are policies that industry, including members of the Hydrogen Advisory Council which I co-Chair, have told us are key to drive early expansion of the UK hydrogen economy. This substantial suite of documents is supported by a detailed Analytical Annex and a report on Hydrogen Production Costs.

Taken together, the UK Hydrogen Strategy and supporting policy package lay the foundations for a thriving hydrogen economy, one that can support our trajectory to achieving our world-leading Sixth Carbon Budget and net zero commitments. I look forward to continuing to work closely with industry, innovators and investors to deliver real action on hydrogen, with real benefits for UK businesses and communities.

The Rt Hon Kwasi Kwarteng MP
Secretary of State for Business, Energy & Industrial Strategy

Executive summary

Hydrogen is one of a handful of new, low carbon solutions that will be critical for the UK's transition to net zero. As part of a deeply decarbonised, deeply renewable energy system, low carbon hydrogen could be a versatile replacement for high-carbon fuels used today – helping to bring down emissions in vital UK industrial sectors and providing flexible energy for power, heat and transport. The UK's vision, resources and know-how are ideally suited to rapidly developing a thriving hydrogen economy. Our world-class innovation and expertise offer opportunities for UK companies in growing domestic and global markets. The UK Hydrogen Strategy sets out how we will drive progress in the 2020s, to deliver our 5GW production ambition by 2030 and position hydrogen to help meet our Sixth Carbon Budget and net zero commitments.

The scale of the challenge is clear: with almost no low carbon production of hydrogen in the UK or globally today, meeting our 2030 ambition and delivering decarbonisation and economic benefits from hydrogen will require rapid and significant scale up over coming years. The work starts now.

The UK Hydrogen Strategy takes a holistic approach to developing a thriving UK hydrogen sector. It sets out what needs to happen to enable the production, distribution, storage and use of hydrogen and to secure economic opportunities for our industrial heartlands and across the UK. Guided by clear goals and principles, and a roadmap showing how we expect the hydrogen economy to evolve and scale up over the coming decade, the Strategy combines near term pace and action with clear, long term direction to unlock the innovation and investment critical to meeting our ambitions.

Chapter 1 of the Strategy sets out the case for low carbon hydrogen, briefly outlining how it is produced and used today before explaining its potential role in meeting net zero and in providing opportunities for UK firms and citizens to be at the forefront of the global transition to net zero. It explains how our 2030 ambition can deliver emissions savings to help meet our carbon budgets, as well as jobs and economic growth, helping to level up across the UK. It sets out our strategic framework, including our vision for 2030, the principles guiding our action, challenges to overcome and our key outcomes by 2030. Finally, it outlines the important role of the devolved nations in the UK's hydrogen story, and how government is working closely with the devolved administrations to help hydrogen contribute to emissions reductions and deliver local economic benefits across the UK.

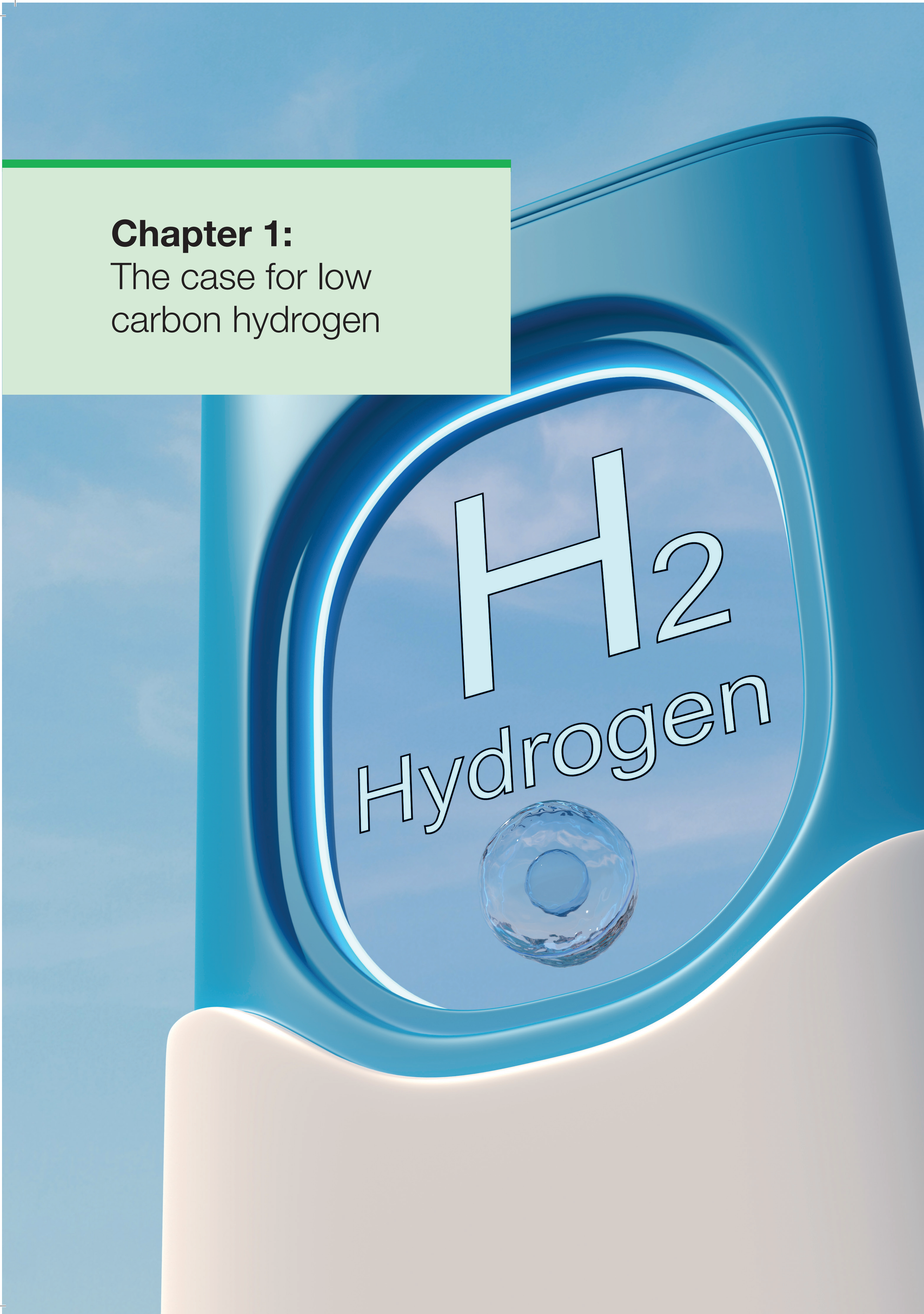
Chapter 2 forms the core of the Strategy, setting out our whole-systems approach to developing the UK hydrogen economy. It opens with our 2020s roadmap, which sets out a shared understanding, developed in partnership with industry, of how the hydrogen economy needs to evolve over the course of the decade and into the 2030s – and what needs to be in place to enable this. The chapter then considers each part of the hydrogen value chain in turn – from production, to networks and storage, to use across industry, power, buildings and transport – and outlines the actions we will take to deliver our 2030 ambition and position hydrogen for further scale up on a pathway to Carbon Budget Six and net zero. Finally, it considers how we will develop a thriving hydrogen market by 2030 – including the market and regulatory frameworks underpinning it and their interaction with the wider energy system, and the need to improve awareness and secure buy-in from potential users of hydrogen.

Chapter 3 explains how we will work to secure economic opportunities across the UK that can come from a thriving hydrogen economy – learning from the development of other low-carbon technologies and building this into our approach from the outset. It sets out how we will: build world class, sustainable supply chains across the full hydrogen value chain; create good quality jobs and upskill industry to drive regional growth and ensure that we have the right skills in the right place at the right time; maximise our research and innovation strengths to accelerate cost reduction and technology deployment, and to capitalise on the UK's world-leading expertise; and create an attractive environment to secure the right investment in UK projects while maximising the future export opportunities presented by a low-carbon hydrogen economy.

Chapter 4 builds on this to show how the UK is working with other leading hydrogen nations to drive global leadership on the development of low carbon hydrogen to support the world's transition to net zero. It sets out the UK's active role in many of the key institutions driving multilateral collaboration on hydrogen innovation and policy, and our ambition to actively seek opportunities for further collaboration with key partner countries to spur the development of thriving domestic, regional and ultimately international hydrogen markets.

Chapter 5 concludes the Strategy, setting out how we will track our progress to ensure we are developing a UK hydrogen economy in line with the principles and outcomes set out in Chapter 1 and our roadmap in Chapter 2. This chapter explains our approach – how we will be flexible, transparent, efficient and forward-looking in monitoring progress – and sets out the potential indicators and metrics we will use to track how we are delivering against our outcomes. This will help ensure that we can deliver our 2030 ambition and realise our vision for a low carbon hydrogen economy that drives us towards Carbon Budget Six and net zero, while making the most of the opportunities that hydrogen holds for the UK.

Chapter 1:
The case for low carbon hydrogen



Low carbon hydrogen will be critical for meeting the UK's legally binding commitment to achieve net zero by 2050, and Carbon Budget Six in the mid-2030s on the way to this. Hydrogen can support the deep decarbonisation of the UK economy, particularly in 'hard to electrify' UK industrial sectors, and can provide greener, flexible energy across power, heat and transport. Moreover, the UK's geography, geology, infrastructure and expertise make it particularly suited to rapidly developing a low carbon hydrogen economy, with the potential to become a global leader on hydrogen and secure economic opportunities across the UK.

Hydrogen is one of a handful of new low carbon solutions which can help the UK to achieve its world-leading emissions reductions target for Carbon Budget Six (CB6), and net zero by 2050. As set out in the Prime Minister's *Ten Point Plan for a Green Industrial Revolution*, working with industry, government is aiming for 5GW of low carbon hydrogen production capacity by 2030 for use across the economy. With virtually no low carbon hydrogen produced or used currently, particularly to supply energy, this will require rapid and significant scale up from where we are today.

The *Ten Point Plan* announced new funds and policies that will set us on the pathway to meet this ambition, including £240 million for government co-investment in production capacity through the Net Zero Hydrogen Fund (NZHF), a hydrogen business model to bring through private sector investment, and plans for a revenue mechanism to provide funding for the business model. Continued improvements in hydrogen technologies, enabled by pioneering UK research and innovation and international collaboration, will also be critical. The *Ten Point Plan* designated hydrogen as a key priority area in the Net Zero Innovation Portfolio, a £1 billion fund to accelerate commercialisation of low-carbon technologies and systems for net zero.

The 2020s will be critical for supporting energy users best suited to hydrogen as a low carbon solution to get ready to use it. We are accelerating work in this area. We are supporting fuel switching to hydrogen in industry through the £315 million Industrial Energy Transformation Fund and £20 million Industrial Fuel Switching Competition; establishing the evidence base for hydrogen use and storage in the power sector; rolling out demonstration competitions and trials (subject to funding) for the use of hydrogen in road freight, shipping and aviation; and pioneering trials of hydrogen heating – beginning with a hydrogen neighbourhood trial by 2023, followed by a large hydrogen village trial by 2025, and potentially a hydrogen town pilot before the end of the decade. We are working with the Health and Safety Executive (HSE) and industry to assess the potential for 20 per cent hydrogen blending into the gas network, and supporting the development of prototype 'hydrogen-ready' appliances such as boilers and cookers. The *Energy White Paper*, *Industrial Decarbonisation Strategy* and the recently published *Transport Decarbonisation Plan* set out further actions we are taking to bring forward hydrogen demand across industry, power, heat and transport.

This Strategy goes further, setting out a series of additional commitments and actions which show how government, in partnership with industry, the research and innovation community and wider civil society, will deliver our vision for a UK hydrogen economy.

By acting now we will be better positioned to stimulate domestic supply chains, enabling UK businesses to serve increasing international demand for hydrogen goods and services. Current evidence suggest that developing a UK hydrogen economy could also support over 9,000 jobs by 2030 – and up to 100,000 jobs by 2050 – across our industrial heartlands and across the UK.[1]

1.1 Hydrogen in the UK today

The UK has a longstanding history with hydrogen. Since the discovery of 'inflammable air' by Henry Cavendish in the mid-18th century, hydrogen has played a role in our everyday lives, from helping to fertilise our fields to providing part of the 'town gas' that lit our streets and heated our homes until the late 20th century.

There are almost no abundant natural sources of pure hydrogen, which means that it has to be manufactured. The most common production route is steam methane reformation, where natural gas is reacted with steam to form hydrogen. This is a carbon-intensive process, but one which can be made low carbon through the addition of carbon capture, usage and storage (CCUS) – to produce a gas often called 'blue hydrogen'. Hydrogen can also be 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. Today most hydrogen produced and used in the UK and globally is high carbon, coming from fossil fuels with no carbon capture; only a small fraction can be called low carbon.[2] For hydrogen to play a part in our journey to net zero, all current and future production will need to be low carbon.

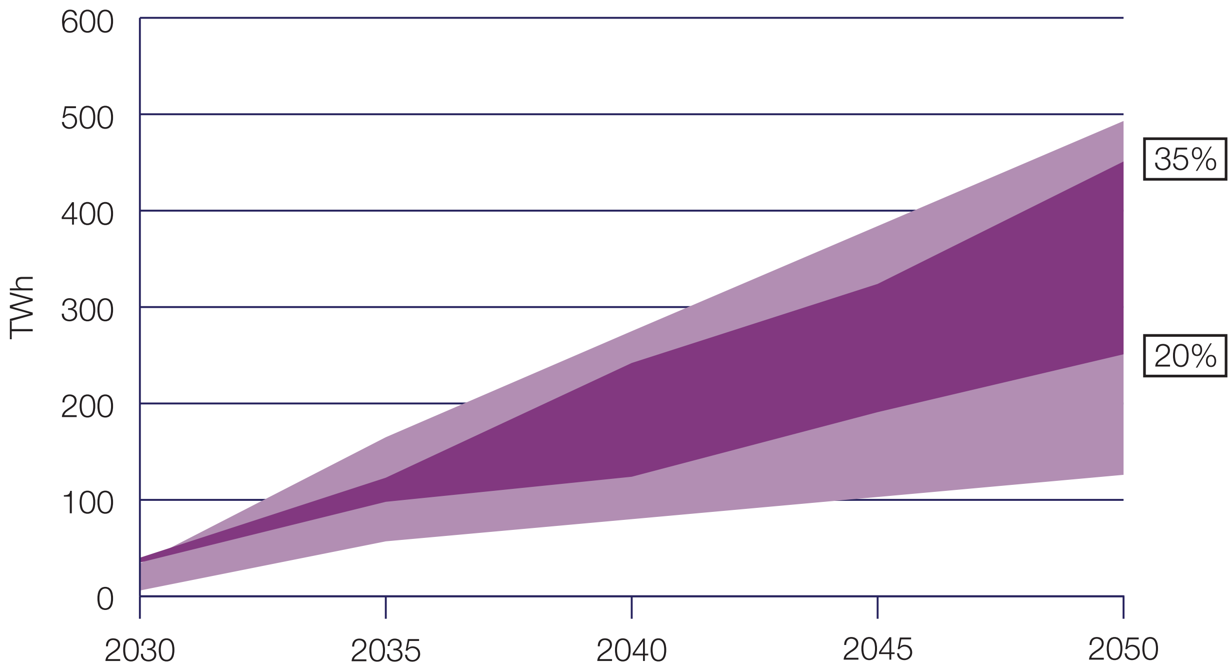
Current UK hydrogen production and use is heavily concentrated in chemicals and refineries.[3] This hydrogen, largely produced from natural gas (without carbon capture), is used as a feedstock, or input, into making other chemicals and plays a variety of roles in refineries to convert crude oil into different end products. In these two sectors, production and use of hydrogen usually happen on the same site, often integrated into a single industrial facility. Hydrogen is also used as a fuel, in far smaller volumes, across the UK. Hydrogen cars, trucks, buses and marine vessels are already operating and supported by a network of refuelling stations, with plans for hydrogen trains and aircraft underway. Hydrogen will soon be blended with natural gas and supplied safely to over 650 homes as part of a trial in Winlaton in the north-east of England.

British companies such as ITM Power, Johnson Matthey and Ceres Power are already producing the technology for low and zero carbon hydrogen, and they and many others are pushing new innovations all the time. The Orkney Islands in Scotland have generated global interest in a range of projects that show how challenges in a local energy system can sometimes be overcome with hydrogen; here producing hydrogen from excess renewable electricity that would otherwise has gone to waste, and using it to support decarbonisation of road transport, heat and ferry related activities. Across the UK, pioneering production and use projects have provided lessons, stimulated further research and innovation, and pointed the way to what is needed to deploy production capacity at pace and scale, and to unlock hydrogen as a low carbon fuel for new applications across the energy system.

1.2 The role of hydrogen in meeting net zero

Low carbon hydrogen will be essential for achieving net zero, and ahead of that, meeting our world-leading CB6 target to reduce emissions 78 per cent on 1990 levels by 2035. Analysis by BEIS for CB6 suggests 250-460TWh of hydrogen could be needed in 2050,[4] making up 20-35 per cent of UK final energy consumption (see Figure 1.2 below).[5] The size of the hydrogen economy in 2050 will depend on a number of factors – including the cost and availability of hydrogen and hydrogen-using technology relative to alternatives, such as electrification, biomass and use of CCUS. Nonetheless, there is consensus, from the Climate Change Committee (CCC) and others, that we will need significant amounts of low carbon hydrogen on the system by 2050.

Figure 1.2: Hydrogen demand and proportion of final energy consumption in 2050



% = hydrogen as proportion of total energy consumption in 2050

Source: Central range – illustrative net zero consistent scenarios in CB6 Impact Assessment. Full range – based on whole range from UK Hydrogen Strategy Analytical Annex. Final energy consumption from ECUK (2019).

As a gas, hydrogen has a distinct set of characteristics. It can be used in a fuel cell or combusted in a boiler, turbine or engine to generate heat or electricity. It can also be stored in various ways, including at very large scales, and can be transported to different end users, in much the same way as natural gas or liquid fuels today. Hydrogen is also an essential input to a range of chemical processes and in industrial production.

Low carbon hydrogen will play an important complementary and enabling role alongside clean electricity in decarbonising our energy system. It is suited to use in a number of sectors where electrification is not feasible or is too costly, and other decarbonisation options are limited. This may include generation of high temperature heat, as in industrial furnaces, and long-distance and heavy-duty transport. Similarly it is useful in areas where the flexibility and stability of a gas is valued, for example large scale or long duration energy storage and flexible power generation. However, hydrogen can only be considered as a decarbonisation option if it is readily available, at the right price, the right volume and with sufficient confidence it is low carbon. In addition, potential users must be able to purchase hydrogen-using equipment, with proper assurances about safety and reliability. This will be our focus for the 2020s, in order to deliver our 2030 ambition and set us on the pathway to CB6 and net zero.

1.3 The UK's hydrogen opportunity

As a result of its geography, geology, infrastructure and capabilities, the UK has an important opportunity to demonstrate global leadership in low carbon hydrogen and to secure competitive advantage. Building hydrogen production and enabling use across multiple sectors will be critical for developing domestic capacity and capabilities, and securing green jobs across the UK.

Developing a hydrogen economy requires tackling the 'chicken and egg' problem of growing supply and demand in tandem, and the UK offers favourable conditions for both to readily expand. When it comes to production, our 'twin track' approach capitalises on the UK's potential to produce large quantities of both electrolytic 'green' and CCUS-enabled 'blue' hydrogen. The UK reduced its power sector emissions by over 70 per cent between 1990 and 2019,[6] and generates more electricity from offshore wind than any other country.[7] The *Energy White Paper*, published in December 2020, sets out how we will expand renewable generation while decarbonising power sector emissions further, including through our ambition to quadruple offshore wind capacity to 40GW by 2030, and pursue new large-scale nuclear while investing in small-scale nuclear technologies. This low carbon electricity will be the primary route to decarbonisation for many parts the energy system, and will also support electrolytic production of hydrogen.

The *Energy White Paper* also sets out how the UK will deploy and support CCUS technology and infrastructure, with £1 billion of support allocated up to 2025 and a commitment to set out details of a revenue mechanism to bring through early-stage private investment in industrial carbon capture and hydrogen projects. The UK has the technology, know-how and storage potential to scale up CCUS across the country, unlocking new routes to CCUS-enabled hydrogen production.

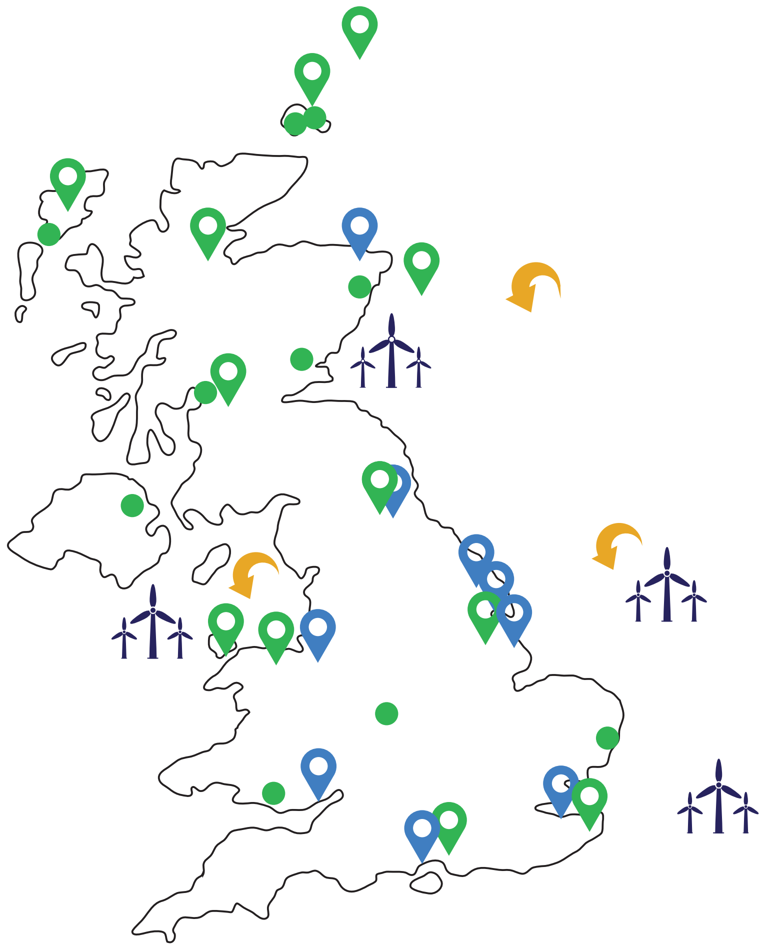
Early deployment of CCUS technology and infrastructure will likely be located in industrial clusters. Many of these are in coastal locations, with important links to CO_2 storage sites such as disused oil and gas fields. Government aims to establish CCUS in four industrial clusters by 2030 at the latest, supporting our ambition to capture 10Mt/CO_2 per annum.

In turn, industrial clusters and wider industry are significant potential demand centres for low carbon hydrogen. Today, numerous industrial sectors from chemicals to food and drink are exploring the role that hydrogen can play in their journey to net zero. UK Research and Innovation's (UKRI's) Industrial Decarbonisation Challenge provides up to £170 million – matched by £261 million from industry – to invest in developing industrial decarbonisation infrastructure including CCUS and low carbon hydrogen.

Figure 1.3: Proposed UK electrolytic and CCUS-enabled hydrogen production projects

Key

- Electrolytic production project (under 5MW)
- Electrolytic production project (over 5MW)
- CCUS enabled production project (100 MW+)
- CO_2 storage potential
- Offshore wind



Note: Includes plans and proposals for known projects that are in the public domain. Many more projects are under development in all parts of the UK. BEIS are continuing to gather intelligence on new projects as they emerge.

The UK also has decades of experience in production, distribution, storage, use and regulation of gas. Our widespread use of natural gas for power generation and for heat in industry and homes means that we have potential supply routes and numerous potential use cases for hydrogen gas. The UK also has favourable geology for large-scale storage of hydrogen, and is already storing hydrogen in salt caverns and exploring storage in disused oil and gas fields under the North Sea.

In addition, our well-developed North Sea oil and gas sectors and experience in renewables mean that the UK has developed supply chain strengths and innovative companies across the value chain poised to take advantage of the economic opportunities from developing low carbon hydrogen technologies. UK companies such as ITM Power, Johnson Matthey and Ceres Power are already recognised as being at the forefront of hydrogen technology development worldwide. Building on this strong base, we will draw on lessons from offshore wind and other low carbon technologies and aim to capitalise on our world-leading expertise in research and innovation and decarbonisation to put the UK at the forefront of emerging global hydrogen markets and opportunities.

The UK is well positioned to be a world leader in low carbon hydrogen production and use, delivering green jobs and growth to support levelling up across our industrial heartlands and across the UK. But we can only realise these economic opportunities if we act now to put in place the necessary environment and support to develop robust supply chains, upskill our people and secure high-quality jobs, and lay the groundwork to unlock investment and export opportunities. Our strategy seeks to maximise the economic benefits from a UK hydrogen economy and seize the potential of both domestic and international markets.

1.4 Our ambition for a thriving hydrogen economy by 2030

We recognise the importance of a clear goal alongside long term policy frameworks in bringing forward low carbon technologies. Our ambition for 5GW of low carbon hydrogen production capacity by 2030 is a signal of the government's firm commitment to work with industry to develop a strong and enduring UK hydrogen economy. This ambition is a means to an end, rather than an end in itself – positioning the UK hydrogen economy for the scale up needed to support CB6 in the mid-2030s and net zero by 2050, and to deliver clean growth opportunities across the UK. We use "our 2030 ambition" in places throughout this strategy as shorthand for this wider vision for the UK hydrogen economy by the end of the decade.

It is not possible today, in 2021, to predict with certainty the size of the future hydrogen market in a net zero energy system, nor the best pathway to reach that. We recognise that the UK has huge potential to produce and use low carbon hydrogen, and that many in industry think we could go further and faster. We welcome this drive and ambition and will continue to work with industry to deliver the strategic direction and supporting policy environment to achieve our 2030 ambition and position the UK hydrogen economy for the future growth and scale up needed for CB6 and net zero.

Delivering our 2030 ambition will yield significant emissions savings. Our modelling suggests that the use of low carbon hydrogen enabled by 5GW production capacity could deliver total emissions savings of around 41MtCO_2e between 2023 and 2032, equivalent to the carbon captured by 700 million trees over the same time period.[8] This covers the period of the UK's Fourth and Fifth Carbon Budgets (CB4 and 5), and will contribute to achieving our Nationally Determined Contribution (NDC) under the Paris Agreement of reducing emissions by 68 per cent compared to 1990 levels by 2030. Further scale up of low carbon hydrogen post-2030 would yield even larger emissions savings, and will play an important role in delivering CB6, to be set out in more detail in the government's forthcoming Net Zero Strategy.

Our 5GW ambition would also mean the creation of a thriving new hydrogen industry, which could support over 9,000 jobs and £900 million of GVA by 2030.[9] Government investment in hydrogen to de-risk early projects could unlock over £4 billion of private sector co-investment up to 2030.[10] Our ambition also sets us on a promising pathway post-2030. Our analysis shows that, under a high hydrogen scenario, up to 100,000 jobs and £13 billion of GVA could be generated from the UK hydrogen economy by 2050.[11]

Many countries around the world have signalled the importance of low carbon hydrogen in reducing emissions, and there is an expectation that a global market for trade in hydrogen will develop in the long term. However, it is unlikely that market will be mature by 2030, meaning that the UK cannot, and would not want to, rely solely on low carbon hydrogen imports. An over-reliance on imports could create risks around the security of supply for hydrogen and associated investment in the wider value chain. It would also reduce opportunities for UK companies to leverage domestic capabilities and strengths and translate these into clean growth opportunities. In contrast, moving quickly to develop a strong UK hydrogen economy by 2030 can help ensure security of supply and wider investment, create high-quality and sustainable jobs, and position UK companies to take advantage of opportunities in international markets.

We aspire to take a leading global role in developing low carbon hydrogen technologies and markets, working with our international partners including through existing initiatives for collaboration. This will be particularly important in the lead up to the UK hosting COP26 later this year, as we seek to turbo-charge the development and deployment of low carbon technologies that will help countries achieve their clean energy transitions – but will continue beyond COP26, as we pursue opportunities to work with other leading global hydrogen nations in helping to build a global hydrogen economy.

1.5 A strategic framework for the UK Hydrogen Strategy

In developing a UK hydrogen economy, it will be important that we set clear and consistent direction to give industry and investors confidence and certainty, whilst remaining flexible to ensure that we act on learning from early projects and can take decisions which offer the greatest decarbonisation and economic value in the long term. Our strategic framework informs the policy direction and commitments set out in this strategy, and will guide our actions over the course of the 2020s to provide a coherent long term approach.

Our vision

Our vision is that by 2030, the UK is a global leader on hydrogen, with 5GW of low carbon hydrogen production capacity driving decarbonisation across the economy and clear plans in place for future scale up towards Carbon Budget 6 and net zero, supporting new jobs and clean growth across the UK.

Our principles

Our principles will guide future policy decisions and government action, providing clarity on future policy direction for investors and users:

- **Long term value for money for taxpayers and consumers:** To deliver value for UK taxpayers and consumers we will seek to minimise the cost of action, and drive down costs over the long term, as we reach for our 5GW ambition and beyond to CB6 and net zero.
- **Growing the economy whilst cutting emissions**: We will harness opportunity to create new, high-quality jobs to support levelling up, including in transition from existing high carbon sectors. We will ensure that the actions we take are aligned to our net zero target, recognising that hydrogen production will need to become increasingly low carbon over time.
- **Securing strategic advantages for the UK:** We will nurture UK capabilities and technological expertise to grow new industries of the future, so that UK companies can position themselves at the forefront of the growing global hydrogen market. We will support private sector innovation, develop policy to mobilise private investment and promote UK export opportunities.
- **Minimising disruption and cost for consumers and households:** We will build on our successful hydrogen research and innovation to date to reduce costs, address risks and provide safety and technical assurance of technologies at commercial readiness, focusing on 'learning by doing' in the 2020s to minimise disruption and cost for consumers and households, and prime the UK market for expansion.
- **Keeping options open, adapting as the market develops:** There are uncertainties around the role of hydrogen in 2030 and out to 2050, including the likely split of production methods and scale of demand. We will seek to ensure optionality to deliver a number of credible pathways to 2050, bringing forward a range of technologies that could support our 2030 ambition and CB6 and net zero targets.
- **Taking a holistic approach:** We will focus on what needs to be done across the whole hydrogen system, supporting coordination across all those who need to play their part, and ensuring we stay in step with developments in the wider energy system as the UK drives to net zero.

We recognise that there may be trade-offs within and between some of these principles at any point in time. For example, the levelised cost of hydrogen using electrolytic production technology is higher today than for CCUS-enabled hydrogen, and it will take time for production to reach industrial scale. That said, with the right support today, this technology presents a genuine opportunity for export of UK expertise and technology, and there is also significant potential for longer-term cost reduction with continued innovation, scale up of manufacture and access to increased amounts of low-cost renewable electricity. This is a clear example of the need to seek balance across these principles in current and future policy decisions.

Challenges to overcome

There are a number of strategic challenges across the value chain that will need to be overcome in order 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.
- **Technological uncertainty:** While some technology is already in use, many applications need to be proven at scale before they can be widely deployed.
- **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.
- **Need for enabling infrastructure:** The use of hydrogen will require new networks and storage, as well as integration with CCUS, gas and electricity networks.
- **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.
- **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.

The chapters that follow discuss these challenges in further detail and outline how government will overcome them to develop a thriving UK hydrogen economy.

Outcomes by 2030

As we head towards 2030, we will measure our success across a range of strategic outcomes:

- **Progress towards 2030 ambition:** 5GW of low carbon hydrogen production capacity with potential for rapid expansion post-2030; hope to see 1GW production capacity by 2025.
- **Decarbonisation of existing UK hydrogen supply:** Existing hydrogen supply decarbonised through CCUS and/or supplemented by electrolytic hydrogen injection.
- **Lower cost of hydrogen production:** A decrease in the cost of low carbon hydrogen production driven by learning from early projects, more mature markets and technology innovation.
- **End-to-end hydrogen system with a diverse range of users:** End user demand in place across a range of sectors and locations across the UK, with significantly more end users able and willing to switch.
- **Increased public awareness:** Public and consumers are aware of and accept use of hydrogen across the energy system.
- **Promote UK economic growth and opportunities, including jobs:** Established UK capabilities and supply chain that translates into economic benefits, including through exports. UK is an international leader and attractive place for inward investment.
- **Emissions reduction under Carbon Budgets 4 and 5:** Hydrogen makes a material contribution to the UK's emissions reduction targets, including through setting us on a pathway to achieving CB6.
- **Preparation for ramp up beyond 2030 – on a pathway to net zero:** Requisite hydrogen infrastructure and technologies are in place with potential for expansion. Well established regulatory and market framework in place.
- **Evidence-based policy development:** Modelling of hydrogen in the energy system and input assumptions improved based on wider literature, qualitative and quantitative evidence and real-world learning. Delivery evidence from innovation and deployment projects collected and used to improve policy making.

We are developing clear indicators and metrics to monitor progress against these outcomes (set out in Chapter 5). This will be important to ensure that we remain on track to rapidly scale up activity across the hydrogen value chain over the course of the 2020s – so that we can realise our 2030 vision, and can position the UK hydrogen economy for scale up beyond this to CB6 and net zero, while making the most of the opportunities that hydrogen holds for UK businesses and citizens.

As our policy work progresses, we will provide regular updates to the work and actions outlined in this strategy – with the first of these updates expected in early 2022. We intend to publish these updates at half-yearly intervals to provide a clear signal of policy direction and provide industry and our other stakeholders with certainty as our thinking develops.

1.6 Hydrogen in Scotland, Wales and Northern Ireland

Developing a hydrogen economy is a whole-UK story, with potential to produce and use low carbon hydrogen right across the UK and provide local economic benefits, in support of UK and devolved administration net zero plans. The government is working with the devolved administrations to support research and innovation and deployment of low carbon hydrogen technologies, and there are already pioneering projects and companies producing and using low carbon hydrogen across Scotland, Wales and Northern Ireland.

Scotland has a key role to play in the development of a UK hydrogen economy, with the potential to produce industrial-scale quantities of hydrogen from offshore and onshore wind resources, wave and tidal power, as well as with CCUS – supported by a strong company base and valuable skills and assets in oil and gas, offshore wind, and energy systems. Economic analysis for the Scottish Government suggests that Scotland could deliver 21-126TWh of hydrogen per year by 2045, with up to 96TWh of hydrogen for export to Europe and the rest of the UK in the most ambitious scenario, delivering significant jobs and local economic benefits.[12] The Scottish Government published a Hydrogen Policy Statement in December 2020, which set out their vision for the development of a hydrogen economy in Scotland and ambitions for renewable and low carbon hydrogen generation. A Hydrogen Action Plan will be published later this year, supported by a £100m programme of investment from 2021 to 2026.[13]

Scotland is home to a number of world-leading hydrogen demonstration projects that are helping determine the role that hydrogen could play in Scotland and the UK's future energy system. The European Marine Energy Centre in the Orkney Islands has a £65 million portfolio of renewable hydrogen projects that is still growing – providing a smaller-scale example of elements of a hydrogen economy (see case study below). Aberdeen is host

to 25 hydrogen double decker buses which have helped establish the infrastructure to support an ecosystem of over 60 hydrogen fuelled vehicles of many shapes and sizes – a catalyst for the Aberdeen Hydrogen Hub initiative, which seeks to become one of the key model hydrogen regions in Europe. The H100 neighbourhood trial project in Fife is building a 100 per cent electrolytic hydrogen production and distribution network and installing 300 homes with new hydrogen boilers to demonstrate hydrogen for domestic heating in the UK (see case study at Chapter 2.4.3). In March 2021, the UK and Scottish Government also outlined plans to each invest £50m as part of Heads of Terms for the Islands Growth Deal, to support the future economic prosperity of Orkney, Shetland and the Outer Hebrides, including several projects providing support for hydrogen.[14]

Orkney Islands: BIG HIT project

BIG HIT (Building Innovative Green Hydrogen Systems in Isolated Territories) is a six-year, Orkney based demonstration project which aims to create an integrated low carbon and localised energy system establishing a replicable model of hydrogen production, storage, distribution and use for heat, power and transport. Funded by the Fuel Cells and Hydrogen Joint Undertaking, the project builds on Orkney's Surf'n'Turf project – an innovative community renewable energy project using wind and tidal energy to produce hydrogen. State-of-the-art Proton Exchange Membrane (PEM) electrolysers in Eday and Shapinsay Islands produce hydrogen from electrolysis, using locally generated wind and tidal energy. This hydrogen is stored and used for heat, power and transport in the surrounding area. BIG HIT positions Orkney as an operational and replicable small scale Hydrogen Territory: the learning from BIG HIT will support wider replication and deployment of renewable energy with fuel cell & hydrogen technologies in isolated or constrained territories.

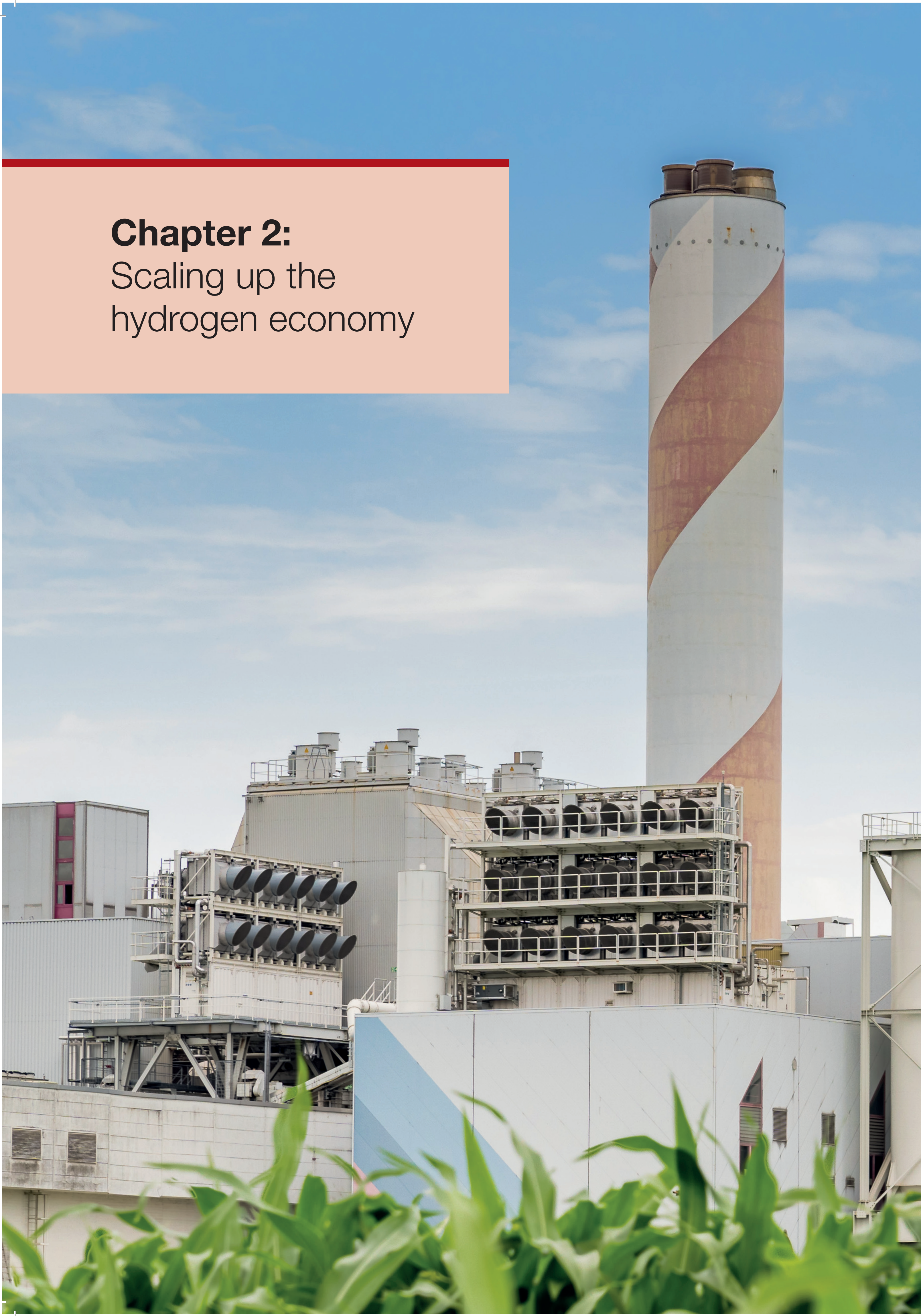
Wales has significant opportunities for low carbon hydrogen production and use. Its offshore wind and tidal and wave power potential, strong infrastructure networks and ports, research and development strengths, skills base and readily available internal markets provide a platform for deployment of hydrogen and fuel cell technologies under a favourable policy environment. The Welsh Government published a hydrogen pathway report in December 2020[15] and is now finalising its strategic position on hydrogen, which it will publish in early autumn 2021. A complementary Welsh Hydrogen Business Research and Innovation for Decarbonisation (H2BRID) initiative is also being developed for launch around the same time to support the challenges set by the Welsh hydrogen pathway and invest in innovative hydrogen projects across Wales.

Wales is home to several pioneering hydrogen companies, projects and research clusters. Welsh SME Riversimple is designing, building and testing innovative hydrogen fuel cell electric vehicles. The Dolphyn FLOW study is exploring the feasibility of a 100-300MW commercial hydrogen wind farm off South Wales, to be expanded in future, with hydrogen pipelines to strategic locations along the Milford Haven waterway for transport and heat applications, and potentially to Pembroke Dock for marine operations. The Hydrogen Centre, part of the Baglan Energy Park at Neath Port Talbot, is the focal point for a series of collaborative projects between the University of South Wales and other academic and industrial partners. The Centre focuses on experimental development of renewable hydrogen production and novel hydrogen energy storage, as well as further research and development of hydrogen vehicles, fuel cell applications and hydrogen energy systems. The UK Government also recently announced capital funding of up to £4.8m (subject to business case) for the Holyhead Hydrogen Hub, a demonstration hydrogen production plant and fuelling hub for HGVs to serve freight traffic at Holyhead and port-side vehicles, which could be operational by 2023.

Northern Ireland is likewise well-positioned to accelerate hydrogen innovation and deployment, with its significant wind resource, modern gas network, interconnection to Ireland and Great Britain, availability of salt cavern storage and strong reputation for engineering and manufacturing. Northern Ireland Water will be procuring a new electrolyser for one of its waste water treatment works – the first project of its kind in the UK. The public transport operator, Translink, is introducing new hydrogen buses built by local company Wrightbus in Ballymena and is procuring a new hydrogen fuelling station. The GenComm project led by Belfast Metropolitan College has received funding from both the EU and UK Government to trial hydrogen production via electrolysis for hydrogen buses. The Department for the Economy is currently consulting on policy options for a new Energy Strategy, including on hydrogen, which will set out Northern Ireland's energy focus and direction to 2050 and is expected to be published at the end of the year.

The UK Government is committed to working closely with the devolved administrations – including through the joint government-industry Hydrogen Advisory Council – to harness the UK's full potential to develop a world-leading hydrogen economy, and to make sure that low carbon hydrogen can contribute to emissions reduction and clean growth across the United Kingdom.

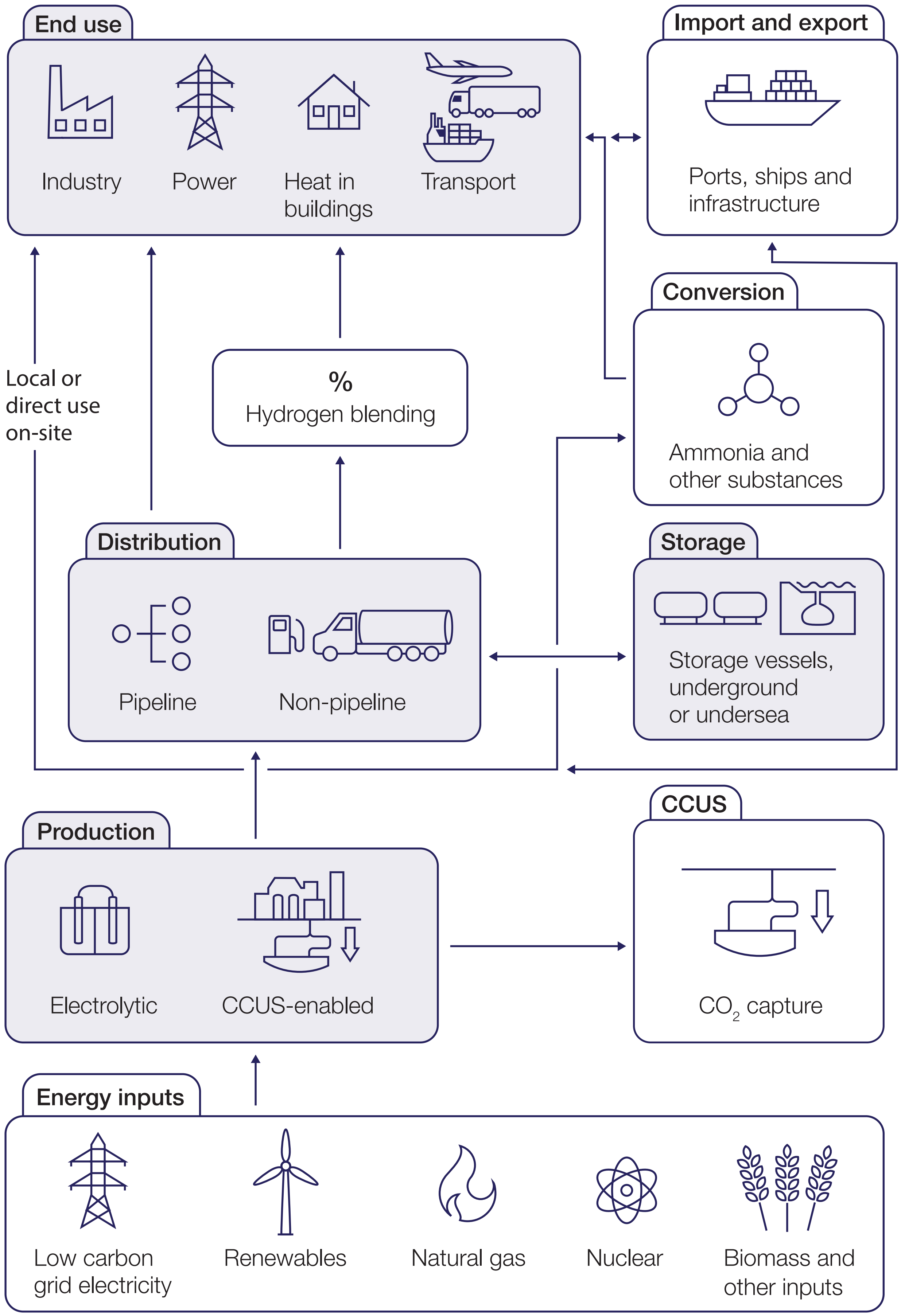
Chapter 2: Scaling up the hydrogen economy



Our ambition is clear, and the opportunities are great. Government cannot do it alone – we will need the collective efforts of industry, the research and innovation community and the UK public to be able to scale up the hydrogen economy over the coming decade to achieve our 2030 ambition. We know that action is needed across the entire hydrogen value chain in the 2020s to support commercial, technical and user readiness for new technologies and to create a thriving market for hydrogen and associated goods and services. The progress we make this decade will be crucial to pave the way for further scale up of production and use from 2030 so that hydrogen can contribute to achieving CB6 and net zero.

This chapter sets out government's whole-system approach to developing a UK hydrogen economy. It begins by outlining our 'roadmap' for the 2020s, our vision for how the hydrogen economy will develop and scale up over the course of the decade and into the 2030s, and how to enable this. The chapter then considers each part of the hydrogen value chain in detail and outlines the key steps that are needed to realise our 2030 ambition and position us for achieving our CB6 target. The chapter also sets out how we will create a thriving hydrogen market, supported by market and regulatory frameworks and with buy in and engagement from consumers and citizens. Further detail, including on demand by sector, factors influencing hydrogen supply mix, and analysis of the main barriers to hydrogen uptake across the value chain, is set out in our analytical annex.

Figure 2: The hydrogen value chain



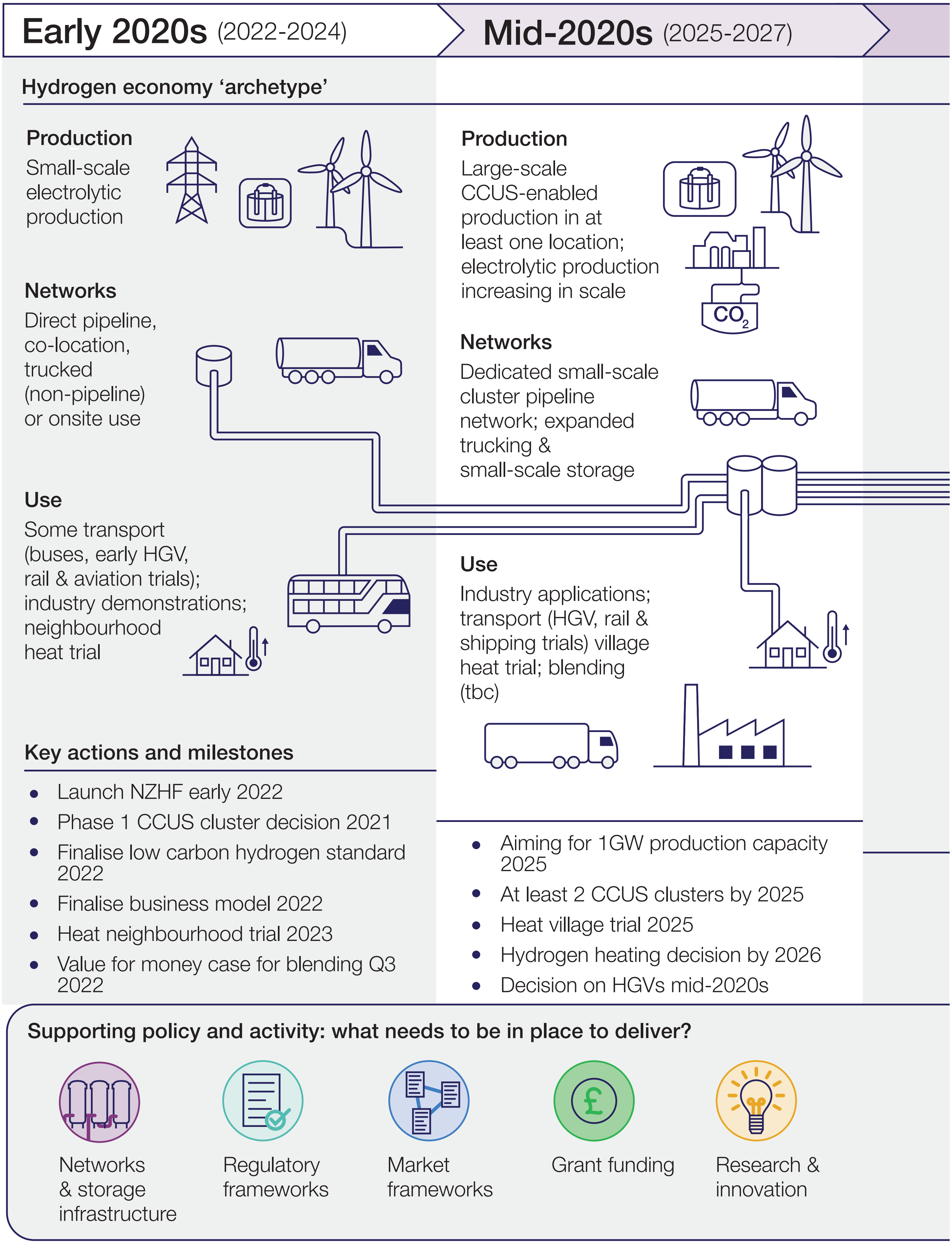
2.1 2020s Roadmap: a whole-system approach to developing a hydrogen economy

Our 2020s Roadmap (Figure 2.1 below) sets out our vision for how we expect the hydrogen economy will develop and scale up over the course of the decade, and what may be needed to enable this, framing the detail set out in the strategy. Developed in collaboration with industry through the Hydrogen Advisory Council, it is not a critical path, but is intended as a shared understanding and guide for what government and industry need to do during the 2020s to deliver our 2030 ambition and position the hydrogen economy for ramp up beyond this for CB6 and net zero.

The roadmap takes a 'whole-system approach' to developing the hydrogen economy, setting out how government and industry need to coordinate and deliver activity across the value chain and supporting policy, and how this will evolve over time. This will help bring forward early projects to build out the supply chain and enable learning by doing, while establishing the longer-term frameworks needed to develop a mature, competitive hydrogen economy and capture the resulting economic opportunities for the UK.

The roadmap is based around archetypes of a hydrogen economy we would expect to see in the early 2020s, mid-2020s and late 2020s, as well as by the mid-2030s for CB6. For each archetype, it sets out what supporting policies or activities need to be in place to deliver, with further detailed actions and commitments set out in the rest of the strategy. This roadmap and further detail offers a blueprint for implementation which will guide our work over the coming months and years.

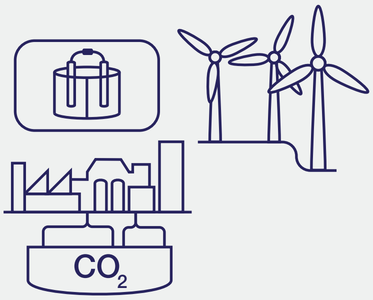
Figure 2.1: Hydrogen economy 2020s Roadmap



Late 2020s (2028-30)

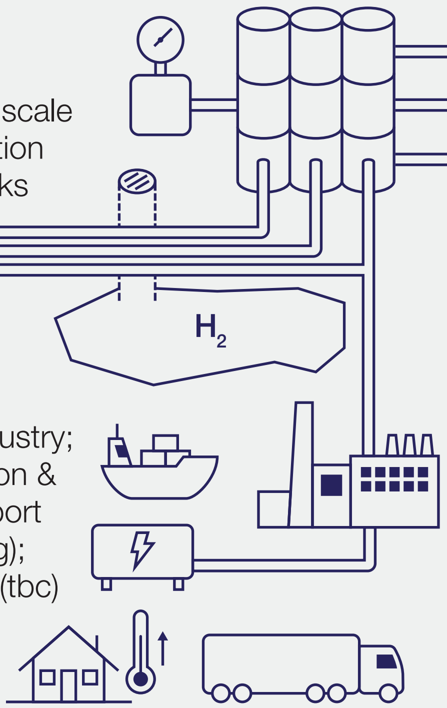
Production

Several large-scale CCUS-enabled projects & several large-scale electrolytic projects



Networks

Large cluster networks; large-scale storage; integration with gas networks



Use

Wide use in industry; power generation & flexibility; transport (HGVs, shipping); heat pilot town (tbc)

- Ambition for 5GW production capacity 2030
- 4 CCUS clusters by 2030
- Potential pilot hydrogen town by 2030
- Ambition for 40GW offshore wind by 2030

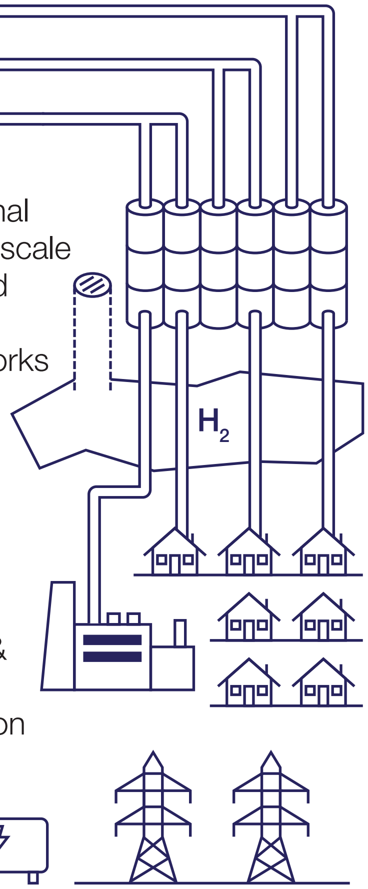
Mid-2030s onward

Production

Increasing scale & range of production – e.g. nuclear, biomass

Networks

Regional or national networks & large-scale storage integrated with CCUS, gas & electricity networks



Use

Full range of end users incl. steel; power system; greater shipping & aviation; potential gas grid conversion

- Sixth Carbon Budget

Sector development

International activity & markets

Public & consumer awareness

Private investment

Industry development & deployment

Supporting policy and activity: what needs to be in place to deliver?

	Early 2020s (2021-2024)	**Mid-2020s** (2025-2027)
Networks & storage infrastructure	Pipeline/ non pipeline/ co-location infrastructure in place Storage requirement and type(s) established for range of pathways (clusters, heat, power system) Decentralised storage in place	Dedicated networks in place/ repurposed, expanded trucking & necessary centralised storage in place Links in place with existing gas, & electricity & new CCUS networks Future of gas grid decision, informing future network/ storage infrastructure development
Regulatory frameworks	Networks delivered through existing regulatory and legal framework Regulatory signals (e.g. H_2 readiness) in place Wider standards (e,g. safety and purity) updated/in place Critical first-of-a-kind deployment barriers addressed Planning and permitting regimes in place	Initial network regulatory and legal framework in place including potentially blending Initial system operation in place Further deployment barriers addressed – purity, installation, equipment Gas billing methodology in place
Market frameworks	Hydrogen business model (BM) finalised and in place Wider market framework structures and implications for BM understood Low carbon hydrogen standard in place Revenue support (RTFO) in place for transport sector	Dedicated revenue support framework, financial arrangements & wider market frameworks in place and driving private investment Market framework aligned to wider energy system frameworks Hydrogen potentially blended into existing gas grid
Grant funding	Capital grant funding mechanisms in place driving investment across production, as well as end use e.g. industry, transport	Capital grant funding supporting investment & project delivery alongside revenue support
Research & innovation	Programmes in place coordinating effort, support & de-risking/ demos for production, industry, transport, storage, heating R&I ecosystems in place supporting supply chain development	Programmes in place & de-risking of less developed technologies for late 2020s/30s Questions addressed as technologies developed & deployed

Supporting policy and activity: what needs to be in place to deliver?

	Late 2020s (2028-2030)	**Mid-2030s onward**
Networks & storage infrastructure	Large dedicated networks & storage in place (new or repurposed)	Regional & potentially national distribution networks in place Multiple storage sites in place Import/export infrastructure in place
Regulatory frameworks	Long-term regulatory and legal framework and role for regulation in place to support network expansion Long term system operator(s) in place Necessary regulations, codes and standards addressed and in place	Framework in place enabling cross-border pipeline/ shipping trade Regulatory framework adapted as market matures
Market frameworks	Long-term market frameworks, financial arrangements & market design in place	Competitive open market in place including path to subsidy free production and use
Grant funding	Possible role for capital grant funding supporting investment & project delivery alongside revenue support	Competitive market drives bulk of private sector investment
Research & innovation	Programmes support and accelerate next generation technology development	Well-established R&I ecosystem continues to drive forward technological advances

Supporting policy and activity: what needs to be in place to deliver?

	Early 2020s (2021-2024)	**Mid-2020s** (2025-2027)
Sector development	Sector & government work to develop UK supply chains & skills base	Framework in place to support supply chain & skills development, maximising value to UK Plc.
International activity & markets	Key technology & regulatory barriers identified through coordinated effort/ info sharing Early progress made on technology innovation & cost reduction, standards & policy/ regulatory coordination	Coordinated innovation, policy & regulation delivering accelerated deployment across value chain in key markets
Public & consumer awareness	Critical end user consumer barriers understood e.g. heat, industry Civil society & regional stakeholders & community priorities understood	End user consumer barriers addressed for early projects Civil society, regional stakeholders fully engaged
Private investment	FEED and FID secured for early 2020s projects Strategic partnerships with key organisations in place Private investment secured for small scale projects Private capital for innovation in place Financial sector engaged on hydrogen	FEED & FID secured for large-scale CCUS enabled/ mid 2020s projects Private investment and financial arrangements secured unlocking deployment Private investment in demonstration/innovation Investment in workforce – training, resourcing
Industry development & deployment	Industry led technology development & testing across value chain (including with government support) Government engaged, including through formal consultation Consumers engaged including communities local to key hydrogen projects / participating in hydrogen trials Early 2020s projects constructed	Continued technology development & testing across value chain to enable wider range of applications & less developed technology Demand for projects secured & necessary enabling infrastructure Leading larger scale on/off cluster projects developed – industry, power, transport, potentially blending Mid 2020s projects constructed

Supporting policy and activity: what needs to be in place to deliver?

	Late 2020s (2028-2030)	**Mid-2030s onward**
Sector development	UK supply chains & skills base well positioned to support increased deployment & exports of technology, expertise & potentially hydrogen	UK supply chains & skills base capitalise on accelerated UK/ global deployment through exports of technology, expertise & hydrogen
International activity & markets	Significant cost reduction & commercialisation driving deployment across multiple markets Framework to facilitate cross border-trade finalised	Framework for international hydrogen trade and competitive open market in place
Public & consumer awareness	Consumer acceptance secured across end use sectors Widespread support secured for hydrogen	Hydrogen widely accepted as a decarbonised energy source
Private investment	FEED and FID secured for large-scale electrolytic/late 2020s projects Private sector investment in manufacturing facilities aligned to UK sector development opportunities New market entrants as market framework demonstrated	FEED and FID secured for 2030s projects Private investment drives hydrogen economy expansion New market entrants & business opportunities secured
Industry development & deployment	Project partnerships in place to secure benefits of shared infrastructure Second phase on-cluster projects & new small-/ medium-scale projects Late 2020s projects constructed	Post 2030 development & testing delivered New projects cluster/off cluster constructed and existing expanded

2.2 Hydrogen production

Key commitments

- 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.

There are a variety of different ways to produce hydrogen; whether this hydrogen is low carbon or not depends on the energy inputs and technologies used throughout this process. Current hydrogen production in the UK is almost all derived from fossil fuels, using steam methane reformation from natural gas without capturing and storing any of the resulting carbon emissions. At present an estimated 10-27TWh[16] of hydrogen is produced in the UK, mostly for use in the petrochemical sector. There is currently only a very small amount of electrolytic hydrogen production in the UK, mostly for use in localised transport projects or trials for different uses of hydrogen, such as blending into the gas grid.[17]

As we scale up low carbon production through the 2020s, we expect the main production methods to be steam methane reformation with carbon capture, and electrolytic hydrogen predominantly powered by renewables. But these are not the only methods that could play a role in our future energy mix.

The main hydrogen production methods expected to be deployed in the 2020s, and some methods currently under development that could play a role in the future, are included in Table 2.2 below. Further detail is included in the analytical annex and report on Low Carbon Hydrogen Standards published alongside this strategy.

Table 2.2: Overview of selected hydrogen production methods

Production method	Definition	Carbon Intensity estimates[18]	Levelised Costs[19]	Role to 2030 / 2050	Next steps
Steam methane reformation without carbon capture	Natural gas with methane reformation, mostly for use in petro-chemical sector	83.6 $gCO_2e/MJ\ H_2$ (LHV)	SMR (300MW) 2020: £64/MWh 2050: £130/MWh	Small amounts of existing supply have helped prove end use case in tests / trials.	Decarbonise existing use in industry
Steam methane reformation (SMR) or autothermal reformation (ATR) with carbon capture	Natural gas with methane reformation, but with CO2 emissions captured and stored or reused	ATR with CCS: 16.0 $gCO_2e/MJ\ H_2$ (LHV) SMR with CCS: 21.4 $gCO_2e/MJ\ H_2$ (LHV)	ATR (300MW): 2020: £62/MWh 2050: £65/MWh SMR (300MW): 2020: £59/MWh 2050: £67/MWh	Large scale projects expected from mid-2020s, bulk supply to kick start UK hydrogen economy	Carbon capture and storage infrastructure needs to be in place
Grid electrolysis	Using electricity from the grid to electrolyse water, splitting it into hydrogen and oxygen.	78.4 $gCO_2e/MJ\ H_2$ (note this is a blended figure using grid averages to calculate)	PEM (10MW): 2020: £197/MWh 2050: £155/MWh	To be determined based on further policy development	Further engagement and analysis required, e.g. via the consultation on the UK Low Carbon Hydrogen Standard
Renewable electrolysis	Using clean electricity to electrolyse water, splitting it into hydrogen and oxygen	0.1 $gCO_2e/MJ\ H_2$ (LHV)	PEM (10MW) (with dedicated offshore wind): 2025: £112/MWh 2050: £71/MWh	Small projects expected to be ready to build in early 2020s	Scale up technology, reduce costs over time

Production method	Definition	Carbon Intensity estimates[18]	Levelised Costs[19]	Role to 2030 / 2050	Next steps
Low temperature nuclear electrolysis	Low temperature electrolysis from existing nuclear facilities	Not modelled but expected low GHG emissions.	Not modelled by BEIS	Can apply existing technologies to current plants in the 2020s.	Further developments expected in 2020s.
High temperature nuclear electrolysis	High temperature nuclear power to electrolyse water	High temperature electrolysis: 4.8 $gCO_2e/MJ\ H_2$ (LHV)	Not modelled by BEIS	Could develop hydrogen from advanced nuclear for 2030s	Further innovation and developments expected in 2020s.
Bioenergy with carbon capture and storage (BECCS)	Biomass gasification with carbon capture and storage	-168.7 $gCO_2e/MJ\ H_2$ (LHV)	BECCS (473MW) 2030: £95/MWh (excl. carbon) £41/MWh (incl. carbon) 2050: £89/MWh (excl. carbon) -£28/MWh (incl. carbon)	Could begin production in 2030s	Further innovation and developments expected in 2020s. Developing position further in forthcoming Biomass Strategy
Thermochemical water splitting	Direct splitting of water using very high temperature heat from advanced modular nuclear facilities	Not modelled but expected low GHG emissions.	Not modelled by BEIS	Could develop hydrogen from advanced nuclear for mid-late 2030s	Further innovation work to develop to commercial technology
Methane Pyrolysis	Heat splits natural gas into hydrogen and solid carbon	Not modelled, but expected low GHG emissions	Not modelled by BEIS	Nascent technology still to be proven at scale	R&D / Innovation

Working with industry, the UK's ambition is for 5GW of low carbon hydrogen production capacity by 2030. This ambition is based on our understanding of the pipeline of projects that could come forward during the 2020s, and takes into account the challenges, constraints and costs involved in delivering this. As we work towards this ambition, we would hope to see the first gigawatt of low carbon hydrogen production capacity in place by 2025. This is a fast-evolving market, however, and we will need to ensure we continue to develop our understanding as trends develop and policy decisions influence investments. We believe that working towards 5GW of production capacity by 2030 is a stretching but deliverable ambition, building on the UK's strong track record of delivering significant cost reductions and large-scale deployment of offshore wind and solar power, and will put us on a credible trajectory aligning with a pathway to net zero.[20] Achieving this ambition is a key outcome for our strategy and is expected to bring forward over £4 billion of private investment in the period up to 2030.

To meet this ambition, the UK has committed to a 'twin track' approach to hydrogen production, supporting both electrolytic and CCUS-enabled hydrogen, ensuring we support a variety of different production methods to deliver the level of hydrogen needed to meet net zero. This approach sets the UK apart, giving us a competitive advantage and building on our strengths to ensure we can be confident in delivering our 2030 ambition and beyond. As outlined in Chapter 1, the UK's skills, capabilities, assets, and infrastructure mean that we have the potential to excel in both electrolytic and CCUS-enabled low carbon hydrogen production. Supporting these and other potential production routes will enable us to develop low carbon hydrogen rapidly at scale while future-proofing our net zero ambitions.[21]

This twin-track approach has already underpinned successful innovation through our Low Carbon Hydrogen Supply Competition, which set out to support development and cost reduction of a wide range of world-leading technologies. This has supported projects including methane reformers with higher carbon capture rates, scaling up of modules and support for the automated manufacture of electrolysers, and work to evidence the feasibility of electrolysis from low carbon nuclear.

As set out in the analytical annex published alongside this strategy, the proportion of hydrogen which will be supplied by particular technologies depends on a range of assumptions, which can only be tested through the market's reaction to the policies set out in this strategy and real, at-scale deployment of hydrogen across our complex energy system. Our Hydrogen Production Cost 2021 report suggests that, under central fuel price assumptions, CCUS-enabled methane reformation is currently the lowest cost low carbon hydrogen production technology. Given the potential production capacity of CCUS-enabled hydrogen plants, we would expect this route to be able to deliver a greater scale of hydrogen production as we look to establish a UK hydrogen economy during the 2020s. However, as referenced in Table 2.2 above, costs of electrolytic hydrogen are expected to decrease considerably over time, and in some cases could become cost-competitive with CCUS-enabled methane reformation as early as 2025. Given the range of uncertainties and variable assumptions in this area, and the rapid growth we need to meet our carbon budgets, we consider support for multiple production routes the most appropriate approach, rather than reliance on a single technology pathway.

How will we develop and scale up low carbon hydrogen production over the 2020s?

Our commitment to supporting multiple production routes will, we believe, bring forward the broad range of projects needed to ensure a rapid and cost-effective build out of the hydrogen economy. Greater competition will spur innovation, cost reductions and investment across the value chain. Deploying CCUS-enabled hydrogen capacity will achieve cost-effective near-term low carbon hydrogen production at scale, drive investment across the value chain (including transmission, distribution and storage), and pull a range of hydrogen technologies through to commercialisation. Alongside this, supporting the scale up of electrolytic hydrogen production can drive down costs to establish a cost-optimal and credible technology mix for our pathway to net zero. Our focus will be on promoting domestic production and supply chains, although we would expect to be an active participant in international markets as they develop, maximising export opportunities and utilising import opportunities as appropriate.

The first movers in the early 2020s are likely to be relatively small (up to 20MW) electrolytic hydrogen projects that can be deployed at pace, with production and end use closely linked, for example, at a transport depot or industrial site. By the mid-2020s we could start seeing larger (100MW) electrolytic hydrogen projects and the first CCUS-enabled hydrogen production facilities based in industrial clusters. At this stage producers could be catering for a growing range of customers across transport, industry and power generation as well as potential to supply hydrogen heat trials and blend low carbon hydrogen into the gas grid. By the end of the decade we could have multiple large CCUS-enabled (500MW+) production facilities across the UK, with extensive cluster networks and integration into the wider energy system. Achieving our 2030 ambition is expected to provide up to 42TWh of low carbon hydrogen for use across the economy.

Case study: ITM Power – electrolytic hydrogen production

Based in Sheffield, ITM Power are a world-leading manufacturer of PEM (proton exchange membrane) electrolysers, a technology for hydrogen production from water. The company's new Gigafactory is the world's largest electrolyser factory with a 1GW per annum capacity to produce renewable hydrogen for transport, heat and chemicals. In May 2020, ITM Power announced plans to establish a separate subsidiary – ITM Motive – to build, own and operate eight publicly accessible H_2 refuelling stations.

Several ITM projects are supported by government. The company's Gigastack project – led alongside Ørsted, Phillips 66 Limited and Element Energy – won funding from BEIS' Low Carbon Hydrogen Supply Competition. Gigastack is developing electrolyser technology to produce renewable hydrogen at industrial scale.

The exact production mix by 2030 will be influenced by a range of factors, such as carbon pricing and the policies being consulted on in parallel to this strategy. Alongside this, investor confidence and market forces will dictate the type of projects that will come forward during the 2020s. In the longer term, electrolytic hydrogen offers greater carbon reduction potential and cost reductions, making it cost-competitive with CCUS-enabled

hydrogen over time.[22] Using the 2020s to 'learn by doing', supported by research and innovation, will provide lead-in time needed to enable commercial production of electrolytic hydrogen at larger scale from the 2030s onwards, ensuring it can plug into a wider hydrogen value chain commercialised through large scale CCUS-enabled production.

Investors, developers and companies across the length and breadth of the UK are ready to build if the right policy environment is in place. We are aware of a potential pipeline of over 15GW of projects, from large scale CCUS-enabled production plants in our industrial heartlands, to wind or solar powered electrolysers in every corner of the UK. This includes plans for over 1GW of electrolytic hydrogen projects, ranging from concept stage to fully developed proposals, which are aiming to deploy in the early 2020s. Other production methods being proposed by industry include using biomethane or the electricity or heat from a nuclear reactor as energy inputs to hydrogen production.

Case study: Acorn Project – CCUS-enabled hydrogen production

Led by Pale Blue Dot Energy, the Acorn CCS and Hydrogen Project in St Fergus, Scotland (image left), aims to deliver an energy- and cost-effective process for low carbon hydrogen production for use in a range of applications including industrial fuel switching and decarbonising heating. The project, supported through BEIS' Low Carbon Hydrogen Supply Competition, conducted engineering studies to evaluate and develop the advanced reformation process, including assessment of Johnson Matthey's low carbon hydrogen technology and an alternative reformer technology.

From the 2030s onwards, we may see a wider range of production technologies coming to the market including more hydrogen from nuclear, using low carbon heat and power from small modular and advanced modular reactors, as well as bio-hydrogen with CCUS that can deliver negative emissions. A dynamic market will include multiple sources and end uses for hydrogen.

To meet our CB6 and net zero targets, there is likely to be a substantial ramp up in demand beyond 2030. Our analysis suggests that hydrogen demand could increase significantly in the early 2030s, suggesting 7-20GW of production capacity may be needed by 2035.[23] Demand could continue to increase rapidly over the 2030s and 2040s, requiring a corresponding increase in hydrogen production capacity to ensure there is sufficient supply to meet this.

In achieving our 2030 5GW ambition and delivering production levels needed for CB6 and net zero, we will have to work with industry and other stakeholders to better understand and overcome the barriers to growing a new energy vector for the UK. These barriers reflect the strategic challenges outlined in Chapter 1.5 and include:

- High production cost relative to high-carbon fuel alternatives.
- High technological and commercial risks for maintaining operation of first-of-a-kind projects and investment in next-of-a-kind deployment.
- Demand uncertainty due to current limited use of low carbon hydrogen in the UK.
- Lack of market structure, small number of end users potentially leading to the abuse of market power.
- Distribution and storage barriers, reflecting the current lack of sufficient carbon capture and storage and hydrogen transmission infrastructure.
- Policy and regulatory uncertainty, including the lack of established standards to define low carbon hydrogen (including non-emission standards), and related to the limited understanding of the regulatory impacts of hydrogen at a system-wide level.

Detailed description of these barriers can be found in the analytical annex (chapter 2).

What are we doing to deliver new low carbon production?

This strategy marks a turning point for low carbon hydrogen production in the UK. It is part of a comprehensive package of measures, set out by government alongside the strategy and beyond, that can help deliver our 2030 5GW production ambition and ensure that we are ready for the step-change needed in low carbon hydrogen production in the 2030s to help meet our CB6 commitments and put us on a pathway to net zero:

- **Research and innovation:** The UK is already at the forefront of research and innovation across the hydrogen value chain, reducing technological, environmental, social and economic barriers to production and end use. **We also recently launched our £60 million Low Carbon Hydrogen Supply 2 Competition, which will develop novel hydrogen supply solutions for a growing hydrogen economy.**

- **CCUS infrastructure:** In November 2020 we confirmed allocation of £1 billion for the Carbon Capture and Storage (CCS) Infrastructure Fund, to help overcome carbon capture, distribution and storage barriers and enable the establishment of a new CCUS sector. **In May this year, we set out the details of the Carbon Capture, Usage and Storage (CCUS) Cluster Sequencing Process, which will look to identify at least two CCUS clusters for deployment in the mid-2020s.** Projects within the clusters will have the opportunity to be considered to receive any necessary support including access to the CCS Infrastructure Fund, and business models for transport and storage, power, industrial carbon capture and low carbon hydrogen.

- **Hydrogen Business Model:** In the Prime Minister's *Ten Point Plan*, we confirmed our intention to develop business models to help bring through investment in new low carbon hydrogen projects and help build UK capability to meet net zero. Since then, we have worked to develop a Hydrogen Business Model intended to provide long-term revenue support to hydrogen producers to overcome the cost challenge of producing low carbon hydrogen compared to cheaper high-carbon alternatives. We consider our preferred business model would provide an investable commercial framework for producers while also meeting government's objectives for developing the low-carbon hydrogen market and ensuring value for money. **Further detail on our proposals is set out in the** Hydrogen Business Model Consultation **published alongside this strategy. We intend to provide a response to this consultation alongside indicative Heads of Terms in Q1 2022.**

- **Net Zero Hydrogen Fund (NZHF):** As set out in the Prime Minister's *Ten Point Plan*, **the NZHF will provide up to £240 million of government co-investment to support new low carbon hydrogen production out to 2025, kickstarting efforts to deliver our 2030 5GW ambition.** The aim of the Fund is to support commercial deployment of new low carbon hydrogen production projects during the 2020s, helping to address barriers related to commercial risk and high production costs of hydrogen compared to fossil fuel alternatives. We are consulting on the design and delivery of the NZHF alongside the publication of this strategy, and **we intend to launch the NZHF in early 2022.**

- **Low Carbon Hydrogen Standard:** If we are to achieve our CB6 and net zero commitments, we must ensure that the hydrogen production we are supporting is sufficiently low carbon, while not stifling innovation and growth. To help address barriers related to policy and regulatory uncertainty, we have identified and assessed a series of options for a UK low carbon emissions standard that could underpin the deployment of low carbon hydrogen. Alongside this Strategy we have published a report, prepared for government by E4Tech and Ludwig-Bölkow-Systemtechnik (LBST), which explores a range of factors including maximum acceptable levels of greenhouse gas (GHG) emissions associated with low carbon hydrogen production and the methodology for calculating these GHG emissions. **Alongside this strategy, we have also published our consultation on a 'UK Low Carbon Hydrogen Standard', which seeks views on the options for setting and implementing such a standard, and we intend to finalise design elements of a UK standard for low carbon hydrogen by early 2022.**

Chapter 2.5 sets out a wider range of policy and regulatory levers which we are exploring to support the development of the hydrogen economy, including production.

Our future production strategy

In most of the pathways modelled by BEIS for CB6, hydrogen demand doubles between 2030 and 2035, and continues to increase rapidly over the 2030s and 2040s. By 2050, between 250-460TWh of hydrogen could be needed across the economy, delivering up to a third of final energy consumption.[24] Current analysis suggests that in 2050, hydrogen will be supplied through a mix of steam methane reformation with CCUS, electrolysis from renewable electricity, and biomass gasification with carbon capture and storage (BECCS), a position supported by the CCC's CB6 advice.[25]

As the hydrogen economy expands and demand grows, researchers, innovators, investors and producers will respond with new technological advances that could deliver further production cost reductions or greater emissions savings. The role for other production methods, including existing and future nuclear technologies, methane pyrolysis, and thermochemical water splitting, will need to be assessed and integrated into our modelling as appropriate to give us an evolving picture of our future production mix. As we increase our understanding of the project pipeline, and the measures needed to overcome barriers to widespread deployment of a range of production technologies, we can form a better picture of our future production strategy. In doing so, we will continue to consider the wider environmental impacts of different methods of hydrogen production, such as resource requirements for land or water, or any potential changes in soil, water or air quality. The production of hydrogen is likely to need significant amounts of water and, together with industry, we will continue engaging with the Environment Agency, regional water resources groups and water companies to ensure appropriate plans are in place for sustainable water resources.

During 2021 we will gather further evidence through our consultations on a Hydrogen Business Model, the NZHF and the standard for low carbon hydrogen, and undertake additional work on our production pathway in line with CB6. This will give us a better understanding of the mix of production technologies, how we will meet a ramp-up in demand, and the role that new technologies could play in achieving the levels of production necessary to meet our future CB6 and net zero commitments. **We will develop further detail on our hydrogen production strategy and twin track approach, including less developed production methods, by early 2022.**

2.3 Hydrogen networks and storage

Key commitments

- 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.

The development of network infrastructure to allow low carbon hydrogen to be transported to storage points and end users is central to the expansion of the hydrogen economy. Networks for the purposes of distributing hydrogen (hereafter hydrogen networks) will include a range of pipeline and non-pipeline channels (e.g. road and rail vehicles, marine vessels) which are crucial to ensuring hydrogen can reach a full range of end users, and be a truly strategic low carbon energy source in a net zero system.

Existing hydrogen production and use in the UK is currently on a small scale, and hydrogen tends to be produced and used in the same location. There is limited distribution through hydrogen pipelines, used to supply industrial users located in industrial clusters, as well as some transport of hydrogen by road into these hubs in either compressed gaseous or liquefied form. Alongside this, there is limited use of above ground metal storage tanks in industrial facilities.

We will need to see significant development and scale up of hydrogen network and storage infrastructure for the development of a UK hydrogen economy and for low carbon hydrogen is to play its role in supporting UK decarbonisation over the 2020s, under CB6 and on a pathway to net zero.

2.3.1 Networks – hydrogen transmission and distribution

How will hydrogen networks develop and scale up over the 2020s and beyond?

Hydrogen networks will have to grow and diversify considerably over the 2020s to enable the UK to meet its 2030 ambition and prepare for ramp up to CB6 and beyond. We expect growth to be driven by production and demand. This will impact the shape and location of the network, and whether it evolves into a national system or a number of regionally-based networks. This decade will see key policy decisions taken that will influence how hydrogen networks develop and are operated. Such decisions will need to consider interplay with existing oil and gas infrastructure, CO_2 transport and storage infrastructure, and electricity infrastructure.

Strategic decisions on blending hydrogen into the gas grid and hydrogen for heating will have a significant impact on the development of hydrogen networks. Blending may result in investments in equipment and infrastructure needed to support rollout in localised portions of the existing gas networks (see Chapter 2.5.1 for further details), and the decision on the use of hydrogen for heating (see Chapter 2.4.3) will impact the nature and scale of hydrogen network scale up, including whether and the extent to which parts of the gas grid are repurposed or decommissioned in the longer-term.

By the late 2020s and 2030, with the expansion of hydrogen production to several large-scale CCUS-enabled projects and electrolytic projects at a range of sizes, the hydrogen pipeline network may span tens of kilometres in length, supplying end-users either within cluster regions or more broadly. By the mid-2030s, the hydrogen network could serve multiple end use applications extending to tens to hundreds of kilometres, potentially including hydrogen converted and distributed as ammonia for use as a shipping fuel.

Internationally, countries are considering the need for dedicated hydrogen networks, alongside conversion of existing gas infrastructure. The potential for pan-European dedicated hydrogen transport infrastructure[26] and the use of existing or new gas interconnectors between the UK and Belgium, Netherlands and Ireland may enable the UK to trade hydrogen or low carbon gas with our neighbours in the future.

As larger cluster networks expand and we have more end users and larger scale storage development, we would expect all parts of the hydrogen economy to reach technology and market maturity by 2050, with potentially national-level distribution.

How are we approaching the task?

There are several interrelated issues which we will need to consider in developing networks that can fulfil hydrogen's potential as a key enabler in decarbonising the UK energy system.

While we expect the initial growth in networks to be driven by the market and the needs of specific privately-operated projects, we believe *it will be important that initial investments and later evolution of the network are achieved in a coordinated manner*, which manages investment risks and delivers benefits to consumers while delivering our 2030 ambition and positioning the hydrogen economy for significant expected growth beyond this. We will need to consider whether and what policy mechanisms, such as incentives or regulation, are needed to ensure that network infrastructure is developed to allow later build out and interlinkages. We will also need to manage or mitigate the risk of stranded assets if pipelines developed for initial projects in the 2020s are not fit for purpose in the 2030s.

Issues around *whether and how to fund hydrogen networks* need to be considered, accounting for variables such as length of pipe, number of producers and end users, and capacity of pipe for future development. Funding considerations are likely to be different for different sizes and types of projects – for example, small scale early pipelines using new or connecting to existing small-scale infrastructure versus large scale pipelines which connect to larger network infrastructure, either new or repurposed from existing networks.

We will need to consider the *type of commercial frameworks and ownership structures* needed for end-to-end pipelines and for wider networks with many suppliers and end users. This will be particularly important when thinking about whether early commercial arrangements for the production and distribution of hydrogen will be sufficient to enable scale up of the hydrogen economy in the later 2020s, or whether changes are needed to support this. Issues related to regulating third-party access to infrastructure, monopolies and unbundling will need to be resolved to provide clarity to investors.

Decisions on where *CCUS infrastructure* will be installed will impact the development of networks for CCUS-enabled hydrogen production and vice-versa. These two policy areas will need to be co-developed to ensure optimum outcomes in both areas are achieved.

Decisions on heat and on the future of the existing gas network will have a significant impact on the size and design of hydrogen networks. While there may be efficiencies in repurposing parts of the gas network, this may not be appropriate for all parts of the country or for all end users.

We expect some *non-pipeline distribution* for areas without pipeline connections to emerge over the 2020s through trucks and other road transport, which could enable further use of hydrogen beyond production centres. We will need to understand the existing regulatory context for non-pipeline distribution and whether it is fit for purpose in an expanded hydrogen economy, as well as whether funding support would be needed.

What are we doing to deliver?

We recognise the need to put in place clear policies and supportive regulatory regimes and to build consumer acceptance to rapidly develop and deploy hydrogen networks.

There is already a range of work ongoing to explore the development of hydrogen networks. A variety of joint government and industry research, development and testing projects are underway, designed to help determine the safety, feasibility, costs and benefits of converting the existing gas grid to carry 100 per cent hydrogen (see Chapter 2.4.3). This includes identifying and characterising the possible options to transition the gas grid, including repurposing the existing grid, building new networks, or transitioning parts of the grid. This work will support strategic decisions in the mid-2020s on the role of hydrogen for heating and linkages with the existing gas grid. Other projects, such as those set out below, will also help inform the evidence base for developing hydrogen network infrastructure. **We will continue to support such research, development and testing projects to explore development of hydrogen network infrastructure.**

Exploring hydrogen network infrastructure

Project Union explores the development of a UK hydrogen network which would join industrial clusters around the country, potentially spanning 2000km. This National Grid project would repurpose around 25 per cent of the current gas transmission pipelines and could carry at least a quarter of the UK's current gas demand. The feasibility stage of the project is using net zero development funding to identify pipeline routes, assess the readiness of existing gas assets, and determine a transition plan for assets. The research will also explore how National Grid can start to convert pipelines in a phased approach from 2026.

H21 is a series of industry-led projects funded by Ofgem which test pure hydrogen in pipelines and connecting infrastructure to build the evidence base for hydrogen transport in dedicated pipelines. The findings from these programmes are being used to establish frameworks for pipeline safety which will be appraised by the HSE's Science Division, and help inform government's strategic decision on the longer-term role of hydrogen for heat by the mid-2020s (see Chapter 2.4.3).

FutureGrid aims to create a representative transmission network to trial hydrogen. The network will be built from a range of decommissioned transmission assets and will allow for real-time testing and analysis of the network in operation. Blends of hydrogen up to 100 per cent will be tested at transmission pressures to assess how the re-purposed assets perform, with construction to launch this year and testing in 2022. FutureGrid will connect to Northern Gas Network's existing H21 distribution network facility and the HyStreet homes to demonstrate that a complete 'beach-to-meter' network can be decarbonised. This £12.7million National Grid project is largely funded through Ofgem's Network Innovation Competition (£9.1 million) with the remaining amount from project partners. To allow testing to be undertaken in a controlled environment with no risk to the safety and reliability of the existing gas transmission network, the hydrogen research facility will remain separate from the main National Transmission System.

Future Billing Methodology is a Cadent Gas project to explore a range of different options for future gas billing to prepare for potential changes to gas blends. Future consumer gas billing methodologies will need to reflect the differences in calorific value between methane, biomethane and hydrogen to enable blending of these gases into the existing grid.

The Iron Mains Risk Reduction Programme decommissions gas distribution iron mains and replaces them with new plastic ones, which are potentially well-suited for transporting hydrogen within the existing gas grid over the long term. This project was introduced in 2002 and is regulated by the HSE.

We will also consider whether the costs of small-scale distribution infrastructure and connecting to existing networks operated by third parties could be factored into overall project costs of production under the proposed hydrogen business model. We expect that this model is unlikely to be appropriate for large scale projects or pipelines which form part of a larger network infrastructure, and we will need to explore whether funding for these larger projects is appropriate and what that might look like. **We will use the Hydrogen Business Model Consultation published alongside this strategy to seek views on a limited number of questions which will feed into the design of the business model and the hydrogen network review set out below.**

Beyond testing and evidence-building, we anticipate that work to explore investment signals and necessary amendments to legislation, regulatory frameworks and potential access to financing for hydrogen network projects in the early 2020s and the 2030s will be required. This will need to address issues such as:

- Uncertainties around the permitting procedures (and accompanying regulations) for new hydrogen pipeline infrastructure, which could be located in hydrogen supply hubs initially before wider network expansion.
- Potential need to further harmonise regulations between new hydrogen pipelines in clusters and existing hydrogen pipelines.
- How to provide sufficient flexibility for any future regulation of end use applications involving domestic consumers such as heating.

In the 2020s, we will seek to ensure that an appropriate legislative framework is in place to incentivise investment in resilient, efficient infrastructure, which integrates low carbon energy solutions over time. As part of this, **we will review the overarching market framework set out in the Gas Act 1986 to ensure appropriate powers and responsibilities are in place to facilitate a decarbonised gas future. We are also reviewing gas quality standards with a view to enabling the existing gas network to have access to a wider range of gases.** This will potentially include hydrogen, subject to hydrogen blending trials proving successful.

We will launch a Call for Evidence on the future of the gas system this year. Amongst other things, the Call for Evidence will look at the current gas types, including implications for a potential increased use of hydrogen in the system, and will seek to include questions on the potential role of hydrogen in the existing gas system. The outcome of the Call for Evidence should draw out expertise on gas across the energy sector, gather views from stakeholders and the public around the future role of gas in meeting our net zero target, highlight concerns that need to be addressed, including risks and barriers, and collect evidence on work currently being done by industry on the future role of the gas system that focuses on the net zero ambition.

We recognise the need for further detailed work to establish the policy approach for the development of hydrogen network infrastructure and the decisions to be taken over the course of the 2020s. In doing so, we will seek to identify where decisions and action can be taken quickly so as not to stifle progress driven by the market. We will work with key stakeholders including producers, network operators, regulators, local authorities and end users to consider the trade-offs between different models for the expansion and diversification of hydrogen networks, while taking into account a range of related policy decisions such as decisions on decarbonising heat and use of hydrogen in transport.

Building on work already underway, **we will undertake a review of systemic hydrogen network requirements in the 2020s and beyond**, including: whether funding or other incentives are needed; introduction of regulation specific to hydrogen networks; resilience and future-proofing ahead of potential regional and national networks; and interaction with wider networks including CCUS,[27] gas and electricity. We will develop policy in this area in several ways, including through discussion and consultation with the Hydrogen Advisory Council and its working groups, and the Hydrogen Business Model consultation published alongside this strategy. While we recognise that there is important learning to be drawn from existing regulatory models and the technical assessments that are being progressed by incumbent parties, we will not make assumptions about who owns and operates hydrogen pipelines, nor how these networks are governed, which will form part of the critical evidence appraisal. We will use the Hydrogen Business Model consultation to seek early views on some of these questions. **We will provide information on the status and outputs of this hydrogen network review in early 2022**.

2.3.2 Hydrogen storage

Hydrogen's ability to store energy for long periods of time and in large quantities is an important part of its strategic value to a fully decarbonised energy system, and we envisage hydrogen storage being a key part of future network infrastructure. Storage can support security of supply as production and use increase and become more spread over time and distance. Similarly, for a future energy system with a lot of intermittent renewable

power generation, hydrogen could be an important storage medium, converting excess renewable energy into a fuel for use across the economy, and supporting faster and greater integration of renewable capacity and the transition to a fully decarbonised power system (see Chapter 2.4.2).

There are a number of ways in which hydrogen can be stored:

- **Specialist tanks or storage vessels** can store MWh of energy, be stationary or mobile (such as tube trailers), and are purpose built using materials able to hold hydrogen at pressure.[28] These are already used in the chemicals industry and at hydrogen refuelling stations. Storage vessels have lower upfront costs than other methods, and are quicker to install or deploy; these may be attractive to projects seeking to balance their own supply and demand by storing lower volumes of hydrogen, or for use in areas without wider infrastructure, such as use of industrial non-road vehicles on construction sites.

- **Salt caverns (underground) storage** can store TWh of energy and are created by 'solution mining', where water is used to dissolve an underground space in a seam of rock salt, allowing hydrogen to be piped in and out. Hydrogen has been stored in caverns under Teesside since the 1970s,[29] and there is potential to repurpose caverns currently used for storing natural gas. The British Geological Survey suggests we have significant rock salt formations with potential for 1000s of terawatt hours of future storage.[30] Underground storage is able to provide large volume storage at lowest cost per unit of energy stored.[31] This is a significant strategic advantage for the UK compared to many other countries.

- **Depleted gas or oil fields (undersea) storage** while available in the UK, require further testing to be used for hydrogen. We will also need to consider competing storage demands, notably for CO_2, in these fields.

- **Hydrogen carriers (ammonia (NH_3), liquid organic hydrogen carriers (LOHCs, such as toluene), cryogenic liquid, substances such as metal hydrides)** provide a route to store energy from hydrogen at increased energy density. These storage methods may become more widely used as research and innovation reduces associated costs, complexity and efficiency losses.

Hydrogen storage in a net zero energy system

Storage can support the hydrogen economy in a range of ways that position it as a strategic asset not just for hydrogen, but as part of a fully decarbonised, net zero economy by 2050.

Most hydrogen today is produced and used directly in industrial processes, often with one operator overseeing both operations, largely removing the need for storage. However, as hydrogen takes on a wider role across the energy system and production methods evolve, storage may become more important to allow balancing within larger projects and to enable the hydrogen economy to develop in the most technically and economically efficient way, helping to manage swings in demand and supporting the transfer of energy across sectors and time.

Storage may be more important for hydrogen than it is today for natural gas because there are no natural reserves of hydrogen that can be relied upon at times of high demand. Hydrogen has to be manufactured, and there are optimal ways of doing so, including maintaining steady production across time. Storage can support this.

Storage could help the early development of the hydrogen economy where demand takes time to build or if there is change in the profile and nature of off-takers. Over time, should we see large scale use of hydrogen in heat, strategic underground storage would be highly valuable in meeting seasonal demand variations, and as discussed above, it may play an important role in smoothing the intermittency of renewable energy.

National Grid's 'Future Energy Scenarios 2021' suggest that between 12TWh and 51TWh of hydrogen storage will be required in 2050 across varying net zero compliant scenarios.[32] Similarly, Aurora Energy Research's 'Hydrogen for a Net Zero GB' report concludes that 19TWh of centralised salt cavern storage might be required by 2050.[33] The UK currently has seven salt caverns and depleted gas fields being used as active natural gas storage facilities, providing approximately 1.5 billion cubic meters, or 14.5TWh, of storage capacity.[34] Although some of this could be repurposed for hydrogen storage, providing the same level of energy storage as hydrogen would require greater capacity given that hydrogen has only a third the energy density of natural gas.

How will hydrogen storage scale up in the 2020s?

In the early 2020s, hydrogen storage vessels are likely to be the most common storage option, used for example at hydrogen refuelling stations coupled to electrolytic hydrogen production. In the mid-2020s, CCUS-enabled production for industrial fuel switching is likely to be designed to minimise supply-demand variations, as is the case on clusters today. Proposed cluster projects in development such as HyNet North West[35] and Zero Carbon Humber have identified local large scale underground storage options but these appear to be secondary phase needs.[36]

Case study: SSE Thermal and Equinor hydrogen storage facility

SSE Thermal and Equinor are developing plans for one of the world's largest hydrogen storage facilities at Aldbrough on the East Yorkshire coast. The project partners believe the facility could be storing low carbon hydrogen as early as 2028. With an expected capacity of at least 320GWh in the first phase, Aldbrough Hydrogen Storage would be significantly larger than any hydrogen storage facility in operation in the world today. The existing Aldbrough Gas Storage facility commissioned in 2011 holds 40 per cent of the UK's gas storage capacity in its nine underground salt caverns, each roughly the size of St. Paul's Cathedral. Upgrading the site to store hydrogen would involve creating new caverns and/or converting the existing caverns.

The Aldbrough site is ideally located to store the low carbon hydrogen set to be produced and used in the Humber region, where Equinor and SSE Thermal are developing large-scale hydrogen projects as part of the Zero Carbon Humber partnership.

Equinor has announced its intention to develop 1.8GW of blue hydrogen production in the region, while the two project partners have plans to develop the world's first major 100 per cent hydrogen-fired power station by the end of the decade in Keadby, North Lincolnshire. The Aldbrough facility will initially store the hydrogen produced for the Keadby power station, and hopes to support and enable growing hydrogen ambitions across the region, supplying an expanding diverse off-taker market including power, heat, industry and transport throughout the late 2020s and 2030s.

By the late 2020s, a town-scale pilot of hydrogen heating and the potential for hydrogen in power generation could increase the necessity of large scale storage such that underground facilities start to become important. We may also see some initial volumes of hydrogen converted and stored as ammonia for use in shipping by the end of the decade, with increased scale up in the 2030s.[37]

Where early storage needs are limited to above ground storage vessels connected to specific production and use, we anticipate that projects could receive sufficient support from our proposed Hydrogen Business Model or the Renewable Transport Fuel Obligation to meet associated storage costs. However, as larger scale storage becomes required and the market develops, storage-specific revenue support could be needed.

Developing large-scale hydrogen storage, particularly as a strategic asset, will require overcoming significant challenges, in particular:

- Understanding the optimal need for, pace of development and mix of hydrogen storage technologies. This is dependent upon multiple factors, some of which are uncertain, such as routes to fully decarbonise power and heat.

- Long lead times and complexity in strategic scale storage such as salt caverns and depleted oil and gas fields. Salt caverns can take up to ten years to develop with challenges such as the need for environmentally appropriate disposal of brine. Repurposing depleted oil and gas fields will require understanding of demand for storage at scale and planned decommissioning dates if investment is to be made to extend the life of assets.

- Need for significant levels of investment, with salt caverns costing potentially hundreds of millions of pounds to develop. Further work is needed to understand the need for and potentially develop suitable funding mechanisms to support this.

- Further research and innovation to increase the efficiency for hydrogen storage, develop the viability of more energy dense options at a variety of scales, and understand the safety and environmental impacts of different storage options.

What are we doing to deliver?

Government is committed to supporting research and innovation to enable hydrogen storage to fulfil its potential in the future energy system. We have supported hydrogen storage through the £33 million Hydrogen Supply Competition,[38] provided UKRI funding to support innovation from industry such as Project Centurion[39] (a hydrogen salt cavern storage demonstration project), and are discussing proposals from industry to store hydrogen in depleted gas fields and storage facilities.

Building on these early developments, **we recently launched an expression of interest for the £60 million Low Carbon Hydrogen Supply 2 competition.**[40] Similar to the first competition in 2018, this is an innovation competition open to support a range of demonstration projects including hydrogen storage technologies, alongside wider hydrogen supply solutions. **We have also launched our £68 million Longer Duration Energy Storage Demonstration competition,**[41] which aims to accelerate commercialisation of innovative longer duration energy storage projects at different technology readiness levels. Storing hydrogen produced from excess electricity as a means of providing key flexibility services to the UK power grid is included within the scope of the proposal, subject to eligibility criteria.

More broadly, understanding the views of industry and developing our understanding of possible storage needs in different hydrogen scenarios over time will be key to realising the potential of hydrogen storage. We recently published a *Call for Evidence on facilitating the deployment of large-scale and long-duration electricity storage*[42] seeking views from industry on the barriers that electricity storage technologies face, including hydrogen where this is used in the power system.

To build on this evidence including beyond the electricity system, **we will undertake a review of systemic hydrogen storage requirements in the 2020s and beyond, including its potential role as a critical enabler for some end use sectors.** The review will consider whether funding or other incentives are needed, whether further government regulation might be required to ensure that the necessary storage infrastructure is available when needed, and what form this might take. Working with technology developers, regulators, and other stakeholders via the Hydrogen Advisory Council and other forums, and informed by our consultation activities, this work will inform future government policy on storage. In the meantime, **the Hydrogen Business Model consultation that accompanies this strategy includes specific questions on the treatment of small-scale storage within the Hydrogen Business Model, as well as on the potential need for government intervention to facilitate investment in future larger scale storage.** Answers to these questions will help inform our storage review. **We will provide information on status and outputs of this review in early 2022, to facilitate further discussion with stakeholders.**

There is still much work to do to understand, develop and scale up the network and storage infrastructure required to support a thriving UK hydrogen economy and position hydrogen to support the wider decarbonisation of the energy system by the end of the decade. Getting it right will be help deliver our 2030 production ambition and contribute to emissions reduction across end use sectors, helping to achieve CB6 and put the UK on a pathway to net zero. Government will continue to work closely with industry, regulators, consumers and the research and innovation community over the coming months and years to make sure that we do.

2.4 Use of hydrogen

Key commitments

- 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.

As set out in Chapter 1, low carbon hydrogen will have an important complementary and enabling role alongside clean electricity in decarbonising our energy system, with potential to help decarbonise heavy industry and provide greener, flexible energy across power, heat and transport. The roadmap in Chapter 2.1 shows how we expect use of hydrogen across the economy to develop over the course of the 2020s and beyond, with early demonstration in industry, heat and power and limited use in transport applications in the earlier part of the decade developing into a wide range of uses across multiple sectors by the late 2020s and into the mid-2030s under CB6.

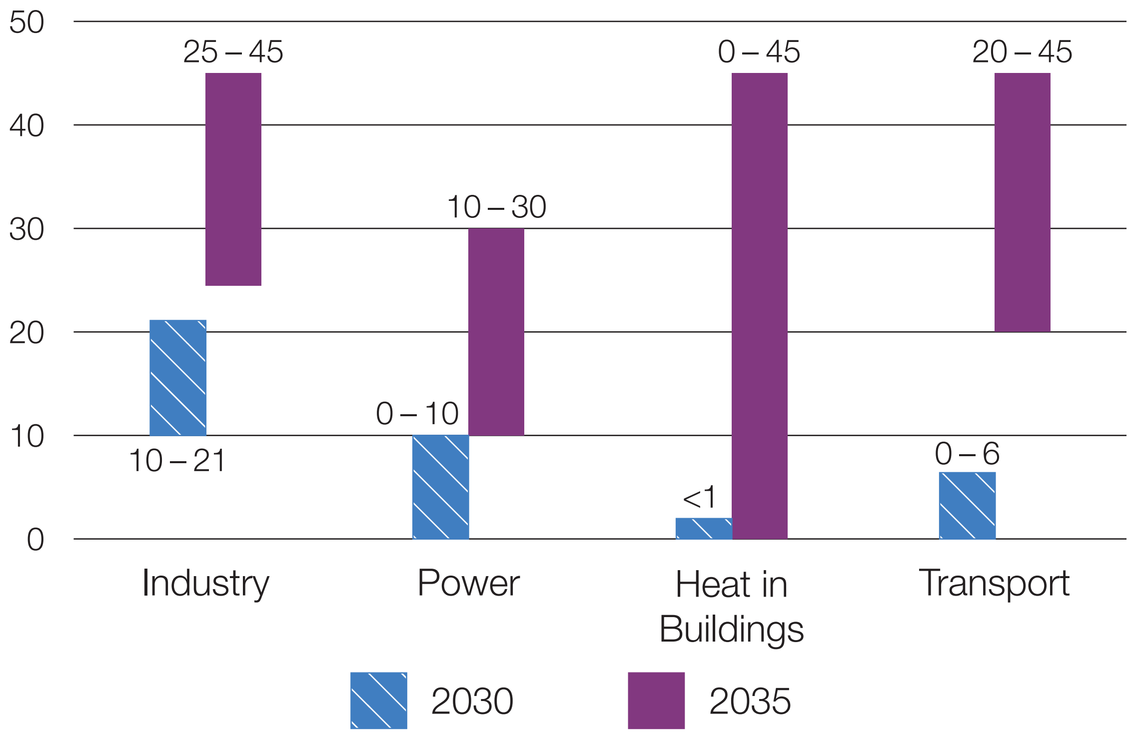
Unlocking the use of low carbon hydrogen can support efforts to deliver against many of the outcomes set out in Chapter 1.5, including decarbonising existing UK hydrogen production and use, establishing end-to-end systems with a diverse range of end users,

and supporting emissions reductions under CB4 and 5. The shift from fossil fuels to hydrogen can also be beneficial for the environment, including for air quality, although the extent of these benefits will depend on the mix of hydrogen technologies deployed. As such, deployment of hydrogen will need to consider these wider environmental costs and benefits.

In line with our strategic principles, we will support research, innovation and commercialisation of hydrogen technologies across a wide range of end uses, alongside testing and at-scale deployment, to help overcome the barriers facing low carbon hydrogen alternatives while allowing the market to determine the optimal technology mix. In doing so, we are aware that current early markets, for example road and depot-based transport, may differ from those where we expect hydrogen to play a more significant role in the longer term, such as in heavy industry. Our roadmap will help us design policy that encourages early use cases while bringing forward applications with the greatest strategic potential to support deep decarbonisation of the UK economy.

The state of current technology development, characteristics of hydrogen in relation to other low carbon energy sources and potential for cost reductions provide some indication of how the use of hydrogen in the UK is likely to develop in the near- to medium-term. Our analysis suggest potential hydrogen demand of up to 38TWh by 2030 split across sectors, not including use of hydrogen for blending into the gas grid. This could rise to 55-165TWh by 2035 under CB6 (see Figure 2.4 below).

Figure 2.4: Illustrative hydrogen demand in 2030 and 2035



Source: BEIS analysis (see analytical annex). Note: figures do not include blending into the gas grid.

We expect that industry will form a lead option for both early hydrogen use and in the longer term, with demand from hydrogen fuel switching picking up from the middle of this decade and hydrogen playing a key role in further decarbonisation of industry by the mid-2030s under CB6 and on the pathway to net zero.

Hydrogen is likely to play an important enabling role in a fully decarbonised power sector, through the system flexibility that electrolytic production and hydrogen storage can provide and the potential for flexible power generation using hydrogen as a fuel – helping to balance a more variable renewables-based electricity grid. We could see use of hydrogen in power in this way by the late 2020s with further scale up by the mid-2030s.

Hydrogen could also provide an important low carbon alternative – alongside electrification – to the UK's largely natural gas-based domestic heating sector, and government is supporting major studies and testing projects, including first-of-a-kind heating trials, to fill important evidence gaps on the costs, benefits and feasibility of using hydrogen for heating. This will be used to inform broader strategic decisions on heat decarbonisation in the middle of this decade. We are also exploring the option of blending hydrogen into the gas grid, with a decision to be taken in 2023 following testing of the safety, technical and economic case (see gas blending box in Chapter 2.5).

Finally, hydrogen is likely to be fundamental to achieving the full decarbonisation of transport, with particular potential in areas of heavy transport 'that batteries cannot reach'. Hydrogen buses are already in use in some UK towns and cities, and feasibility studies are underway for the use of hydrogen and other zero emission technologies in heavy goods vehicles (HGVs) with the aim of undertaking future years trials (subject to funding). We expect hydrogen to play a significant role in decarbonising international shipping and aviation, with demonstration and trials already underway, potential for early stage uses in shipping and aviation by the end of the decade, and an increasing role from the 2030s.

Given the wide range of applications and the strategic enabling role that hydrogen can play in an increasingly decarbonised economy, the 2020s will be critical to developing, testing and scaling up the use of low carbon hydrogen in the UK. The following sections set out how government and industry will work together to unlock the potential that hydrogen holds to decarbonise these important UK sectors.

2.4.1 Use of hydrogen in industry

It is clear that UK industrial sectors will play a vital role in developing a hydrogen economy over the next decade. Industry produced 16 per cent of UK emissions in 2018,[43] and hydrogen will be critical to decarbonise industrial processes that would be hard to abate with CCUS or electrification. The *Industrial Decarbonisation Strategy* published earlier this year sets out the policy and technology principles to decarbonise industry by 2050, including the installation of deep decarbonisation infrastructure such as hydrogen and CCUS networks in the 2020s.

Our industrial heartlands will likely lead the way for large scale low carbon hydrogen supply, and industrial users are expected to provide the most significant new demand for hydrogen by 2030 through industrial fuel switching. Today's hydrogen economy will need to scale up from its current base in the oil refining and chemical sectors, to enter other parts of industry and the wider energy system. We will develop policy to support and deliver this change, and to drive the decarbonisation of existing industrial hydrogen use.

Decarbonising current hydrogen production and use in industry

To meet our net zero ambition and develop the new low carbon hydrogen economy, we need to decarbonise existing industrial production of carbon intensive hydrogen. Today, hydrogen is mainly produced by steam methane reformation (without CCUS) for use as a feedstock, or as a by-product of other industrial processes. The most appropriate option to decarbonise existing production will vary for different types of industrial sites and will depend on factors such as the life cycle of current assets and the production method used. As the oil refining and chemical sectors are today often both producers and consumers of hydrogen, they could be important drivers of the transition to a low carbon hydrogen economy.

We will support hydrogen producers to decarbonise through, for example, the Industrial Carbon Capture and Hydrogen Business Models. Furthermore, we will finalise the design elements of a UK standard for low carbon hydrogen by early 2022.

We will also publish within a year a call for evidence to explore with industry the further interventions needed to phase out carbon intensive hydrogen and transition to low carbon production methods and sources, at the required pace to meet net zero.

Switching to low carbon hydrogen as an industrial fuel

Low carbon hydrogen can also provide an alternative to natural gas and other high carbon fuels currently used for industrial heating. This includes both indirect heating applications,

for example, using hydrogen to fuel steam boilers and combined heat and power (CHP) systems, and direct heating processes, such as melting glass in a furnace. Low carbon hydrogen is a good option for processes that are more expensive or harder to electrify, given its potential to replace natural gas.

The *Industrial Decarbonisation Strategy* set out that we expect, at a minimum, 20TWh per year of fossil fuel use to be replaced with low carbon alternatives, including hydrogen, electrification and biofuels, in 2030. Our latest analysis suggests that by 2030 demand from industry for low carbon hydrogen as a fuel could range from around 10TWh per year if supply is limited to clusters, up to around 20TWh per year if some dispersed sites are connected to pipelines.[44] Further demand could be realised from sites sourcing hydrogen from local electrolytic production. Fuel switching to low carbon hydrogen could yield carbon savings of around 3MtCO_2e per year by 2030, equivalent to taking 1.4 million cars off the road.

To meet CB6, we anticipate that industrial demand for low carbon hydrogen would need to continue to grow, reaching up to 45TWh by 2035. This increase would be driven by a growing number of sites with access to low carbon hydrogen, continued technology development to expand the range of processes capable of using hydrogen, and a shift in associated costs, such as the price of carbon, to make hydrogen an increasingly competitive fuel option. By 2050, in a scenario with widespread access to low carbon hydrogen across the UK, consumption in industry could be as high as 105TWh by 2050.

This strategy covers the full range of UK industrial sectors: metals and minerals, chemicals, food and drink, paper and pulp, ceramics, glass, oil refineries, and less energy-intensive manufacturing.[45] The greatest potential demand for low carbon hydrogen in 2030 arises from sectors such as chemicals and steel.

As set out in the *Industrial Decarbonisation Strategy*, decarbonising the steel sector will be essential to the decarbonisation of UK industry. The main options for doing so include using electric arc furnace technology coupled with hydrogen direct reduced iron, or CCUS. In collaboration with the Steel Council, we are considering the implications of the recommendation of the CCC to “set targets for ore-based steelmaking to reach near-zero emissions by 2035” and will provide an update in the forthcoming Net Zero Strategy.

Hydrogen could also be used to help abate the 6MtCO_2 emissions associated with the use of industrial non-road vehicles such as excavators and diggers used in a range of sectors. Machinery manufacturers are already developing equipment capable of using hydrogen, which alongside electrification may be an important way to decarbonise this sector. The adoption of hydrogen as a solution will depend on the development of wider hydrogen infrastructure.

We recognise that industry faces several barriers in fuel switching to low carbon hydrogen, even where it may offer the best decarbonisation option. These include the higher cost of low carbon hydrogen supply compared with fossil fuels; the capital cost of retrofitting or replacing equipment to be hydrogen-ready; the operational disruption of conversion and the subsequent costs associated with optimising new processes using hydrogen; and the operational risks associated with the security of supply of low carbon hydrogen, particularly in the short term while the market develops.

Demonstrating the technical performance of hydrogen, without compromising process efficiency or product quality, is also essential. As hydrogen has a distinct chemical composition and physical characteristics compared to current fuels, further research and testing will be needed in the 2020s. This will help industry to better understand how hydrogen transfers heat, how to limit any pollutants released during combustion (including NOx) and how this might impact materials and end products. In practice this will involve building on existing research with more lab-based studies, followed by at scale trials for distinct industrial processes.

What are we doing to deliver?

Given the scale of industrial emissions and the likely importance of hydrogen in replacing high-carbon fuels used in industry, it is critical that we demonstrate and scale up fuel switching to low carbon hydrogen on industrial sites during the 2020s. Government is already providing a range of funding opportunities that could support industry to switch to low carbon technologies including hydrogen, which complement the existing academic and private sector led initiatives in this area:

- The **£315 million Industrial Energy Transformation Fund** is supporting the uptake of technologies that improve efficiencies and reduce the carbon emissions associated with industrial processes. Hydrogen projects, subject to contract, were supported as part of Phase 1 of the competition.[46] The Fund aims to de-risk key technologies including hydrogen fuel switching by providing support for feasibility and engineering studies, and capital support for first movers to upgrade their industrial equipment. It will increase readiness for the hydrogen economy by building demand for hydrogen in industry and helping to develop the commercial case for low carbon hydrogen projects.

- The **£20 million Industrial Fuel Switching Competition** has allocated innovation funding to stimulate early investment in fuel switching processes and technologies. It has been highly successful in progressing the development of new fuel switching technologies across a range of sectors, including cement, refineries, glass and lime. The latest round of funding was awarded in winter 2019, with four projects moving from feasibility studies to demonstration, including the Mineral Products Association's world first demonstrations of firing hydrogen at commercial fuel supply scale for the manufacture of cement and lime.

- The **Green Distilleries Fund is providing £10 million of new innovation funding** to help distilleries go green. The programme is taking a portfolio approach and aims to fund a range of different solutions which could include electrification, hydrogen, biomass or waste. Nine of the 17 feasibility studies funded at Phase 1 are for projects using low carbon hydrogen.

Case study: Unilever demonstrates a hydrogen-fired industrial boiler

As part of the BEIS funded HyNet Industrial Fuel Switching competition, Unilever, working alongside Progressive Energy, is running a trial to switch an onsite natural gas fired boiler to hydrogen. The boiler, located at the Port Sunlight facility on the Wirral, raises steam needed for the manufacture of home and personal care products.

Switching to low carbon hydrogen allows the site to cut carbon emissions, with no change to manufacturing operations. This trial will provide Unilever with the evidence and confidence to convert existing boilers to run on low carbon hydrogen, once a supply is available. It seeks to demonstrate consistent steam production at the required temperature and pressure, reliable boiler operations, and adherence to NOx emissions limits.

Following successful trials on a representative boiler system at Dunphy Combustion's test site in 2021, a new 7MWth dual fuel (hydrogen and natural gas) burner will be installed in Unilever's boiler. The proportion of hydrogen fuel gas will be increased from 0 to 100 per cent over four days, with verification of steam quality and NOx emissions performance taking place, followed by several weeks of 100 per cent hydrogen firing for up to eight hours a day, providing steam for the Port Sunlight works.

Building on these successes, later this year we will launch a number of further funds to support industry to switch to hydrogen and other low carbon fuels:

- **We will provide further grant funding to support fuel switching technologies, including low carbon hydrogen, through Phase 2 of the £315m Industrial Energy Transformation Fund.**

- **We will launch a new £55m Industrial Fuel Switching 2 Competition to develop and demonstrate innovative solutions for industry to switch to low carbon fuels such as hydrogen.**

- **We will launch a new £40 million Red Diesel Replacement Competition to fund the development and demonstration of innovative technologies that enable Non-Road Mobile Machinery (NRMM) used for quarrying, mining, and construction to switch from red diesel to hydrogen or other low carbon fuels.**

Throughout the early 2020s, we will also be supporting the engineering and technical design elements of decarbonisation projects across the UK's industrial clusters through UKRI's **Industrial Decarbonisation Challenge**, to accelerate the deployment of technologies such as CCS and hydrogen fuel switching.

Building on this substantial existing industrial decarbonisation support, we will need additional dedicated support for fuel switching to hydrogen, including for further research and innovation, and demonstration and deployment of early use cases in the 2020s. To accelerate fuel switching to low carbon hydrogen, **we will seek to support research and innovation through the existing Net Zero Innovation Portfolio and initiatives led by the Industrial Decarbonisation Research & Innovation Centre (IDRIC). We will also**

engage with industry later this year on possible requirements for a research and innovation facility to support hydrogen use in industry and power.

Due to infrastructure requirements, demand will likely be concentrated in large industrial clusters during the 2020s, a significant proportion of which could arise from a small number of sites. These sites could act as 'pathfinders', proving the viability of hydrogen as a fuel at commercial scale, and helping to foster an initial market for low carbon hydrogen close to supply. **We will work with cluster projects to better understand the opportunities that pathfinder sites present, so to maximise the benefit to the sites themselves and the associated clusters.**

Initially, hydrogen will likely be used to fuel indirect heating technologies such as steam boilers and CHP units. Given the range of sectors that use steam as part of an industrial process, our analysis indicates that boilers and CHPs could make up around two thirds of demand for hydrogen fuel switching by 2030. We will therefore focus on policies to unlock the fuel switch potential for these technologies, taking into account replacement cycles of existing equipment. Work is ongoing to establish the role of hydrogen in decarbonising CHPs, and **by the end of this year we will launch a new call for evidence on 'hydrogen-ready' industrial equipment.**

Later in the decade, hydrogen could replace methane in different parts of the gas grid, either partially through blending or fully with 100 per cent hydrogen (see Chapter 2.5 for further detail on blending). Among the current users of the gas network, industry has the most variation in terms of types of equipment and uses of natural gas. Government is working with industry and with regulators to identify the changes that would be necessary to transition to full or blended hydrogen in the gas grid, and how this could impact industrial settings. **We will work with industrial end users to ensure their needs and the potential impacts of a full or partial transition to hydrogen via the gas grid are well understood.**

Collectively, this extensive set of measures will help UK industrial sectors better understand the challenges and opportunities of switching to low carbon hydrogen. Unlocking demand for low carbon hydrogen in industry will deliver significant carbon savings and help scale up the hydrogen economy. Demand from industry can act as an anchor to stimulate production, which will in turn help decarbonise other end use sectors in both industrial clusters and dispersed sites across the UK.

2.4.2 Use of hydrogen in power

As set out in the *Energy White Paper*, government is aiming for a fully decarbonised, reliable and low-cost power system by 2050, which will require the rapid growth in renewables which has been a key driver of emissions reductions to date. To meet CB6 on the way to this, we must aim for a largely decarbonised power sector by the mid-2030s. Deployment of renewables and other forms of low carbon generation is projected to further scale up, demand for electricity will increase as more sectors shift to electrification, and power generation will become more decentralised, variable and intermittent as we become increasingly dependent on wind and solar. To support this transition, we will need more flexible, low carbon generation and flexible technologies such as energy storage and demand-side response to manage demand peaks and to balance electricity supply and demand.

Low carbon hydrogen can play an important strategic role in meeting these future power system needs, and developing and scaling hydrogen in power during the 2020s can reduce the burden on other technologies such as renewables, CCUS and nuclear. While not a 'silver bullet', there are two key roles that hydrogen could play in the power system:

- **Flexible power generation** ('Gas to Power'): Low carbon hydrogen can play an important role in providing flexible power generation such as such as through rapid operating 'peaker' plants and larger scale but less flexible Combined Cycle Gas Turbines (CCGTs), helping to meet short- and longer-term peaks in demand. This hydrogen could be used either as a blend or at 100 per cent and would be supplied by pipeline or through access to storage. Our analysis[47] indicates that by 2030, we could see a small but important role for low carbon hydrogen to generate power, with demand for hydrogen in power ranging from 0-10TWh. We expect to see further ramp up beyond 2030: hydrogen demand could increase to 10-30TWh in 2035, and 25-40TWh by 2050. Using hydrogen in this way could also play a role in establishing secure offtake for hydrogen production projects in the near term.

- **System flexibility through electrolysis and storage** ('Power to Gas', 'Power to Gas to Power'): Electrolytic hydrogen production can also provide grid flexibility by drawing on 'excess' renewable or low carbon electricity that would otherwise be constrained or curtailed (where power cannot be transmitted) and where there is an economic case to do so. In this way electrolytic hydrogen can allow excess electricity to flow across different parts of the system, from power to gas, to transport or industry (often referred to as 'sector coupling'). This unlocks a wide range of system benefits and can provide an additional route to market for new and existing renewables capacity. Coupling this electrolytic production with storage, including long duration storage where hydrogen is a lead option (see Chapter 2.3.2), can help integrate hydrogen further into our power system by helping to balance the grid when generation from renewables is higher or lower than demand.

How will we develop and scale up hydrogen in power over the 2020s?

Use of hydrogen in power will need to rapidly scale up through learning by doing in the 2020s to support further decarbonisation by the 2030s and to realise this strategic role in a fully decarbonised power sector in the long term.

From the mid-2020s, as demand for flexible power generation increases, we expect hydrogen blends to be the primary use of hydrogen in the power sector, shifting to the first 100 per cent hydrogen turbines later in the decade. At smaller scales, we could see hydrogen fuel cells playing a role, replacing high carbon alternatives such as diesel generators to provide flexibility and backup generation for off grid locations and in cities, building on limited deployment to date. From 2030, we expect that low carbon hydrogen, and potentially ammonia (subject to meeting air quality and emissions standards), will play an increasing role in providing peaking capacity and ensuring security of supply.

As the need for flexibility and renewables deployment increases out to 2030, we expect to see increasing deployment of electrolyser capacity, both contributing to delivering our 5GW ambition and supporting decarbonisation of power and other sectors where there is an economic case to do so. The 2020s will be focused on deploying a future generation of electrolysers which will be larger and better adept at operating variably in line with renewables. Throughout the 2020s and out to 2030 we anticipate long duration hydrogen storage coming online and scaling up, integrating hydrogen into our power system and coupled with flexible generation where this is needed.

To achieve this integration of hydrogen in the power sector by 2030, we will need to tackle the key barriers to deployment in the early part of this decade:

- *Technology and user readiness:* We need to demonstrate a range of technologies across the hydrogen value chain, including next-generation electrolysers, large scale hydrogen storage, and 100 per cent hydrogen turbines, which are not yet commercially available in the UK. We also need to ensure hydrogen or ammonia firing is aligned to wider emissions standards. Secure availability of hydrogen will be critical to addressing this barrier.

- *Designing supporting policy and market frameworks:* We need to better understand the role of hydrogen across the power system, and drive investment in hydrogen power applications alongside hydrogen production, primarily through existing or planned policy frameworks to help unlock demand in the power sector.

- *Availability of networks and storage:* The location of hydrogen power generation and system flexibility in the 2020s and out to 2035 will in part be driven by the availability of hydrogen network and storage infrastructure, including non-pipeline distribution for smaller scale applications.

What are we doing to deliver?

There are currently few examples of low carbon hydrogen use in the power sector, despite hydrogen technologies being eligible to participate in electricity markets including the Capacity Market and balancing services, some fuel cells and turbines already being capable of accepting hydrogen, and testing underway to commercialise 100 per cent hydrogen turbines at larger scales. The Industrial Decarbonisation Challenge is also supporting the development of hydrogen power generation as part of wider cluster proposals.

In light of this, government has recently undertaken a series of actions to better understand the role of, and the support needed for, hydrogen in power, including:

- Publishing our **Modelling 2050 - Electricity System Analysis report**[48] alongside the Energy White Paper in December 2020 which focused on building our evidence base to better understand the implications of net zero on our power system, and included exploring the potential role of hydrogen in our changing energy system.

- Publishing a **Call for Evidence on enabling a high renewable, net zero electricity system** in December 2020,[49] which explored options to evolve the current Contracts for Difference (CfD) mechanism for future allocation rounds, including coupling of technologies that can deliver increased flexibility, such as electrolysis.

- Publishing a **Call for Evidence on 'Decarbonisation Readiness' for new power generation** in July 2021,[50] which sought views on removing the 300MW threshold and expanded the technology types covered to the majority of combustion equipment. The proposals include hydrogen conversion as an alternative decarbonisation route alongside CCUS. New build plants would need to be capable of accepting either hydrogen blends of 20 per cent or be 'CCUS ready' from initial operation. From 2030, plants would be expected to be capable of accepting 100 per cent hydrogen.

- Publishing a **Call for Evidence on facilitating the deployment of large-scale and long-duration electricity storage**, in July 2021,[51] which sought views on barriers that electricity storage technologies face, including information regarding hydrogen technologies that are used in the power system.

- Publishing **Capacity Market 2021: a Call for Evidence on early action to align with net zero** in July 2021,[52] particularly focusing on actions to bring forward more low carbon capacity in the future such as hydrogen-fired generation.

In addition to this evidence gathering activity, we recognise the need to take further concrete and coordinated action now to develop and scale up hydrogen use in the power sector. Building on recent announcements, **we will engage with industry to understand the economics and system impacts of introducing hydrogen into the power sector, including sector coupling and hydrogen energy storage.** Further updates will be published in due course, including the response to our recently published Decarbonisation Readiness Call for Evidence.

We will review the progress of our recent actions, and engage with relevant stakeholders and hydrogen projects early to ensure there is suitable support for hydrogen in the power sector to deliver against our vision for 2030.

We will also take steps to demonstrate the technologies needed for hydrogen use in power. As detailed in the Chapter 2.3, **subject to competition we are supporting innovation in energy storage through electrolysis via our £68 million Long Duration Storage Competition.** As set out in Chapter 2.4.1 above, **we will also engage with**

industry on possible requirements for a research and innovation facility to support hydrogen use in industry and power.

By building our evidence base, and taking early action to support research and innovation, demonstration and deployment of low carbon hydrogen technologies in power, we can support further decarbonisation of the power sector by 2030 and for CB6 and help to establish a reliable, long term source of low carbon hydrogen demand.

2.4.3 Use of hydrogen in heat in buildings

Heating comprises 74 per cent of buildings emissions in the UK and about 23 per cent of all UK emissions.[53] While the electricity that powers our lighting and appliances is decarbonising fast, the majority of buildings still rely on fossil fuels – largely natural gas – for space heating, hot water and cooking. Meeting our net zero target by 2050 will therefore require us to switch to low carbon alternatives to heat the 30 million residential, commercial, industrial and public sector buildings in the UK.[54]

Given the scale of this challenge, it is essential that we start the transition now to meet our emissions reductions targets cost-effectively, minimise disruption, and ensure that households continue to enjoy a reliable and comfortable heating system. Over the 2020s and early 2030s, our aim is to move to only installing low carbon heat systems that are compatible with our net zero target, and we will keep pace with the natural replacement cycles of heating systems throughout the rest of the 2030s and into the 2040s. Our forthcoming *Heat and Buildings Strategy* will set out how we plan to decarbonise heat in buildings in the UK.

How will we develop the potential use of hydrogen for heat over the 2020s?

While we are clear on the need to decarbonise heating to meet net zero, there is still a degree of uncertainty over the best route to decarbonising heat at scale in the UK. Low carbon hydrogen could be one of a few key options for decarbonising heat in buildings, alongside more established technologies such as electricity and heat networks. While there is more work to do to test the feasibility of using hydrogen, it could become a like-for-like alternative for buildings currently heated by natural gas from the grid.

We will need to be flexible in how we decarbonise heat in buildings given the diversity of heat demand across different building types and geographies in the UK. We are taking action to build heat pump and heat networks markets, especially in areas where we do not expect hydrogen to play a major role. Delaying action could prevent us from meeting near-term carbon budget and fuel poverty targets, making it harder to achieve our targets in later years.

Before hydrogen for heating can be considered as a potential option to decarbonise heat in buildings, we need to generate further evidence on the costs, benefits, safety, feasibility, air quality impacts and consumer experience of using low carbon hydrogen for heating relative to other more established heat decarbonisation technologies. The 2020s will be critical for understanding hydrogen's potential role, and government is working with industry, network operators and local partners on major studies and testing projects to help establish the evidence required.

Although we expect overall the demand for low carbon hydrogen for heating by 2030 to be relatively low (<1TWh), if the feasibility and positive case for hydrogen heating is established, heat in buildings could become a very significant source of future demand for hydrogen with implications for the design and timing of hydrogen production, storage and network infrastructure: our analysis suggests hydrogen demand for heat in buildings could be up to 45TWh by 2035.[55]

What are we doing to deliver?

A wide range of relevant work is already underway. For example, ongoing industry-led projects are exploring the distribution and transmission of hydrogen within gas networks, such as the HyNet project in the North West of England and H21 project on distribution across the North of England, and HyNTS and LTS Futures projects on transmission led by National Grid (see Chapter 2.3.1 for more detail). Additionally, the BEIS-funded £25m Hy4Heat programme, which is due to end this year, has supported the development and demonstration of '100 per cent hydrogen-ready' appliances and components. The Hy4Heat programme has also developed a framework for skills accreditation for heating engineers working with hydrogen.

As set out in the *Ten Point Plan*, **we are supporting industry to conduct first-of-a-kind hydrogen heating trials, including a neighbourhood trial by 2023 and a village scale trial by 2025.** The village trial will look to build on learning from the neighbourhood trial, involving a larger and more diverse range of consumers, and conversion of existing local area gas infrastructure to 100 per cent hydrogen.

The trials will provide evidence on the practical, logistical and technical issues involved in converting buildings and appliances. In particular, they will test and demonstrate how consumers experience the installation and use of hydrogen for heating in their homes and workplaces; the conversion, operation and performance of gas networks using hydrogen; and the skills and training required to deliver a conversion.

By 2025 we will also develop plans for a possible hydrogen heated town before the end of the decade. This planning work will also contribute important evidence on the feasibility and costs of converting from natural gas to hydrogen heating. We anticipate that if the case is made for wide scale conversion of the gas grid to full hydrogen, it would begin with converting a pilot town in the late 2020s and accelerate from the early 2030s, taking into account the practical implementation experience gained through the pilot.

The local trials and planning work, together with the results of our wider research and development and testing programme, will enable strategic decisions by 2026 on the role of hydrogen for heat and whether to proceed with the hydrogen town.

Case Study: hydrogen for heat in homes

H100 Fife Neighbourhood Trial: This Levenmouth, Fife-based project will deliver the world's first hydrogen-to-homes gas network in 2023. The trial will provide hydrogen to 300 homes for heating and cooking on an opt-in basis, switching from natural gas. The hydrogen used in these trials will be produced locally from offshore wind power. This ground-breaking project led by gas network SGN is collaboratively funded by SGN and its GDN partners Cadent, NGN and WWU, Ofgem and the Scottish Government. The H100 project will also provide evidence to assess consumers' experience of using hydrogen in the home and provide key learning on gas networks, such as constructing and operating a hydrogen network, that can be applied to future grid conversion projects.

We will continue to support research and innovation on hydrogen heating. Our new Net Zero Innovation Portfolio will allow further support to be directed towards innovation for end-users of hydrogen heating as needed, following on from Hy4Heat endpoints.

We are also accelerating work to consider how a market for hydrogen heating could operate, recognising the need to start adapting legislative and regulatory frameworks in advance of any strategic decisions being made on the role of hydrogen in heat. We are working with key regulators, including HSE and Ofgem, to ensure that we understand the regulatory changes, including timelines, that may be needed to roll out any future scenario for hydrogen heating.

Alongside wider market policy, we are actively considering the value of specific interventions to support the commercialisation of hydrogen heating products. **We aim to consult later this year on the case for enabling, or requiring, new natural gas boilers to be easily convertible to use hydrogen ('hydrogen-ready') by 2026.** We will also use this consultation to test proposals on the future of broader boiler and heating system efficiency and explore the best ways to reduce carbon emissions from our gas heating systems over the next decade.

Hydrogen has the potential to play a key role in decarbonising heat in buildings in the UK. We are rapidly delivering major studies and testing work to understand the feasibility of using hydrogen for heating, to inform broader strategic decisions in 2026 on heat decarbonisation.

2.4.4 Use of hydrogen in transport

Hydrogen is likely to be fundamental to achieving net zero in transport, potentially complementing electrification across modes of transport such as buses, trains and heavy goods vehicles (HGVs). It is also likely to provide solutions for sectors that will not be able to fully decarbonise otherwise, including aviation and shipping.

Low carbon hydrogen can provide an alternative to petrol, diesel and kerosene as it can be used directly in combustion engines, fuel cells and turbines or as feedstock for production of transport fuels, including ammonia and sustainable aviation fuels. We expect low carbon hydrogen to play a key role in decarbonising the sector, which is the largest single contributor to UK domestic GHG emissions and was responsible for 27 per cent of emissions in 2019.[56]

Transport is also a crucial early market for hydrogen, driving some of the earliest low carbon production in the UK. There are over 300 hydrogen vehicles on UK roads, mostly passenger cars and buses, and the government is supporting hydrogen use in transport with a **£23 million Hydrogen for Transport Programme**.[57]

Our latest analysis places transport as one of the biggest components of the hydrogen economy in future, with 2050 demand potentially reaching up to 140TWh.[58]

How will we develop and scale up hydrogen in transport over the 2020s?

We expect that the role of hydrogen in transport will evolve over the course of the 2020s and beyond. To date, road transport has been a leading early market for hydrogen in the UK. Going forward, we expect hydrogen vehicles, particularly depot-based transport including buses, to constitute the bulk of 2020s hydrogen demand from the mobility sector. Fuel cell hydrogen buses have a range similar to their diesel counterparts. Back-to-depot operating means hydrogen refuelling infrastructure can be more centralised and is likely to be compatible with distributed hydrogen production expected in this period. Concurrently, we will undertake a range of research and innovation activity which will focus on difficult to decarbonise transport modes, such as heavy road freight. As we demonstrate and understand these larger-scale applications we are likely to see more diversity in transport end uses in the late 2020s and early 2030s.

By 2030, we envisage hydrogen to be in use across a range of transport modes, including HGVs, buses and rail, along with early stage uses in commercial shipping and aviation. Our analysis shows there could be up to 6TWh demand for low carbon hydrogen from transport in 2030. Beyond this we expect to see an increased role for hydrogen in aviation and shipping decarbonisation which could become a large component of the overall hydrogen demand in the long term.[59] To meet CB6 in 2035 we estimate the demand from transport could be 20-45TWh.[60]

We recognise that the longer-term role for hydrogen in transport decarbonisation is not yet clear, but it is likely to be most effective in the areas where energy density requirements or duty cycles and refuelling times make it the most suitable low carbon energy source. Key challenges in this area include technology uncertainty, lack of existing hydrogen infrastructure, cost differentials and low numbers of hydrogen powered vehicles. Continued investment in research and innovation by government and industry will help to overcome these. As we learn more about ways in which hydrogen can be used in transport, we will need to put policy in place to support this technology rollout.

What are we doing to deliver?

Throughout the 2020s, government is taking forward a programme of development and demonstration of hydrogen technologies across different transport modes, to support commercial readiness and create real-world learning about the opportunities and barriers for any larger scale rollout.

Public transport

Approximately two per cent of England's local operator bus fleet is now zero emission – battery electric or hydrogen fuel cell.[61] **We will deliver the National Bus Strategy and its vision of a green bus revolution, including setting an end date for the sale of new diesel buses and the Zero Emission Bus Regional Areas (ZEBRA) scheme. ZEBRA will provide up to £120 million in 2021/22 to begin delivery of 4,000 new zero emission buses, either hydrogen or battery electric, and the infrastructure needed to support them.**

Rail is already one of the greenest ways of moving people and goods, and government is committed to making it even greener, in line with our net zero target by 2050. To decarbonise currently unelectrified parts of the network, electrification will likely be the best solution because electrified trains are faster, quicker to accelerate, more reliable and cheaper. There will also be a role for new traction technologies, like battery and hydrogen trains, on some lines where they make economic and operational sense.

Heavy Goods Vehicles

Large long-haul HGVs are the most challenging segment of the road sector for developing zero emission options due to their long journey distances and heavy payload requirements. Some vehicles are in constant use and therefore require fast refuelling to meet operational requirements. **We are investing up to £20 million this financial year in designing trials for electric road system and hydrogen fuel cell HGVs and to run a battery electric trial to establish the feasibility, deliverability, costs and benefits of these technologies in the UK.** To further support the shift away from fossil fuels, government is also consulting on the phase out date for the sale of new non-zero emission HGVs.

Shipping and aviation

Shipping and aviation are responsible for approximately five per cent of global emissions[62] and are some of the most difficult areas of transport to decarbonise.

Hydrogen in shipping

Low carbon hydrogen and hydrogen-derived fuels like ammonia and methanol are likely to play a crucial role in the decarbonisation of the maritime sector. Analysis commissioned by the Department for Transport (DfT) estimated that by 2050 there could be 75-95TWh of demand for hydrogen-based fuels (principally in the form of ammonia) from UK domestic and international shipping.[63] Coupled with decarbonisation of road and rail freight, hydrogen use in shipping could help create an end-to-end low carbon freight system from port to door.

The potential for adopting battery electric technology in the maritime sector is mostly constrained to domestic navigation: the size and weight required for battery powered ships means that their range is limited and they are not a compatible option with larger ship types.[64] Hydrogen could be used to decarbonise ships directly, through combustion or in fuel cells, or as feedstock for methanol or ammonia. Liquid ammonia is more energy dense than hydrogen meaning less storage volume is required on vessels, which may represent an effective option for larger ships on long-distance routes. Ammonia is also already internationally transported on ships so some infrastructure and supporting regulations are in place (although this ammonia is currently not low carbon).

Additionally, as set out in DfT's *Clean Maritime Plan*, research has estimated that the global market for the elements of alternative fuel production technologies in which the UK has a particular competitive advantage (for example, upfront design) could rise to around $11–15 billion per year (£8–£11 billion per year) by the middle of the century. If the UK were able to maintain its current export market share (estimated to be around 5 per cent of relevant global markets), this could result in economic benefits to the UK of around $490–690 (£360–£510) million per year by the middle of the century. This research also found that while there are significant opportunities for the UK across all abatement options considered, the UK has the strongest competitive advantage in hydrogen and ammonia production technologies, alongside onboard batteries and electric engines.[65] **Government launched the £20 million Clean Maritime Demonstration Competition in March this year, which aims to accelerate the design and development of zero emission vessels in the UK and will lay the foundations for a network of technology demonstrations, fast-tracking maritime decarbonisation.**[66]

Government is also exploring the establishment of a UK Shipping Office for Reducing Emissions (UK-SHORE). This is a dedicated unit within the Department for Transport focused on decarbonising the maritime sector. UKSHORE will build on the success of the Clean Maritime Demonstration Competition, delivering a suite of interventions inspired by our experience with decarbonising other transport modes, looking at programmes such as the Office for Zero Emission Vehicles and the Future Fuels for Flight and Freight Competition.

UK-SHORE aims to transform the UK into a global leader in the design and manufacturing of clean maritime technologies and fuels such as hydrogen and ammonia. Government will continue to engage with industry to consider how the establishment of this programme in cooperation with UKRI and Innovate UK could unlock the necessary industry investment in clean maritime technologies, tackling supply- and demand-side barriers as well as developing infrastructure and consumer confidence.

Case Study: hydrogen in shipping

HySeas III is the final development stage of a programme to deliver a procurement-ready design for what the team hopes will be the world's first sea-going vehicle and passenger ferry to employ carbon-free hydrogen as its energy source. The vessel is planned to operate in and around Orkney and will use hydrogen which is currently being produced on the islands from renewable energy. The HySeas project is supported by approximately £10.8 million in funding, of which £8 million is provided by the European Union Horizon 2020 programme.

Hydrogen in aviation

The proportion of UK GHG emissions from aviation is expected to increase in the future as other sectors decarbonise. We need to tackle these emissions and are keen to do so in a way that capitalises on UK strengths in the aerospace and aviation sectors. To realise this, government has established the Jet Zero Council, a partnership between industry and government, to focus efforts on accelerating decarbonisation, including with an aim to deliver zero emission transatlantic flight within a generation. More recently, in July 2021 we published our 'Jet Zero Consultation' which seeks view on our proposed approach to reaching net zero aviation.

While there are technological challenges to overcome before hydrogen is used in aviation, interest from the aviation industry is significant. Airbus have announced their ambition to develop and launch a zero-emission large commercial aircraft, powered by hydrogen propulsion, by 2035.[67] Alongside this, through the *Aerospace Technology Institute (ATI) programme*, government is supporting a number of projects in this area.

Case Study: Aerospace Technology Institute funded aviation innovation

HyFlyer I and II (£15m): This landmark project provided ZeroAvia with funding to retrofit a small (six seat) aircraft with a hydrogen fuel cell powertrain, which completed the first-ever hydrogen powered flight of commercial-grade aircraft in September 2020. The flight also showcased a full zero-carbon emission ecosystem, with onsite hydrogen production via electrolysis. The funding is also supporting the company to scale up their technology for use in a 19-seat aircraft. ZeroAvia plan to have a commercial product by 2024.

FlyZero (£15m): An in-depth study to help UK aerospace develop a zero-carbon emission aircraft by 2030. The ATI-led project will bring together expertise from across the UK supply chain and universities to explore the design challenges and market opportunity of potential zero-carbon emission aircraft concepts and will be key in answering questions on the role and importance of hydrogen in decarbonising aviation.

H2GEAR (£27m): This ongoing project aims to develop a liquid hydrogen propulsion system – where liquid hydrogen is converted within a fuel cell system - for a sub-regional aircraft that could be scaled up to larger aircrafts. The programme is led by GKN Aerospace, alongside a number of industry and academia partners, from their Global Technology Centre in Bristol. GKN Aerospace believes the entry into service of hydrogen powered aircraft could be as early as 2026.

Additionally, hydrogen can be used to refine and produce Sustainable Aviation Fuels (SAF).[68] SAF could play a key role in emissions reduction in the short and medium term and the development of a SAF industry in the UK could see thousands of new jobs across the country.[69] **In March this year, we launched the £15 million 'Green Fuels, Green Skies' competition to support the production of first-of-a-kind SAF plants in the UK.** Government has set out its proposed ambition for SAF uptake in its SAF blending mandate consultation, which was recently published.[70]

A multi-modal place-based approach

Areas with particularly strong hydrogen potential could help to improve our understanding of the role of hydrogen in transport, drive local industrial strategies and jump start green recovery. **The UK's first 'Hydrogen Transport Hub' in Tees Valley will bring together government, industry and academia to focus on future hydrogen research and development, real world testing and demonstrations.** The Hub, supported by £3 million of initial government development funding this year, will bring a number of hydrogen vehicles to public roads and waterways, alongside the associated refuelling infrastructure. **In March this year we also announced that we will provide £4.8 million (subject to business case) to support the development of a hydrogen hub in Holyhead, Wales.** This will pilot the creation of hydrogen from renewable energy and its use as a zero-emission fuel in HGVs.

Case Study: a 'living lab' for hydrogen powered transport

Tees Valley Hydrogen Transport Hub: The hub will act as a living lab to understand hydrogen's role in decarbonising the transport sector, through large scale trials across different transport modes and use cases. The first of its kind in the UK, this project will comprise of a set of facilities for the production, storage and distribution of green hydrogen to supply a network of refuelling stations and support operational trials of hydrogen powered vehicles including road, waterways and aviation. The hub brings together government, industry and academia, and is expected to be fully operational by 2025 (subject to funding). This year the Tees Valley area will see various pilot projects of hydrogen vehicle demonstrations across modes and use cases including, but not limited to, forklifts, cars, buses, HGVs and marine vessels.

Supporting policy: the Renewable Transport Fuel Obligation

The Renewable Transport Fuel Obligation (RTFO) aims to increase the use of renewable transport fuels. Hydrogen produced by electrolysis using renewable electricity, as well as biohydrogen, for example produced through methane reformation of biomethane, are supported through the scheme. In March 2021, government published a consultation on the amendments to the scheme which sought views on a number of issues related to hydrogen support, including expanding the scope of the RTFO to make renewable fuels from non-biological origin used in maritime, rail and non-road vehicles eligible for support. Government's response to the consultation was recently published, with changes intended to come into effect from January 2022.

Hydrogen is a key alternative to the use of fossil fuels in transport – as well as in industry, power and heat – and will be essential to meeting our CB6 and net zero targets. We will continue to build on our strengths in research and innovation and expertise along the hydrogen value chain to fully realise the potential of hydrogen to support decarbonisation across end use sectors over the coming decade and beyond.

2.5 Creating a market

Key commitments

- 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.

The development and scaling up of each part of the hydrogen value chain will rest on policy frameworks to support the early expansion of a low carbon hydrogen market over the 2020s, and its later evolution to a dynamic, competitive, integrated and liquid market from the 2030s onwards.

Energy markets have evolved significantly over time, from the move to privatisation in the 1980s, to the transformation brought about by the Electricity Market Reform (EMR) programme set out in the Energy Act 2013, which set the path for rapid UK power sector decarbonisation. We have also seen the market respond to the decline in domestic gas production from the North Sea by building new natural gas terminals and pipelines to improve diversity of supply.

EMR and the changes in supply of gas happened against the backdrop of an already functioning market, albeit one that faced significant challenges to enable the long term decarbonisation ambitions set out in the Climate Change Act 2008.[71] Now, with more stringent CB6 and net zero targets, we need to reach for a new set of technologies like CCUS and low carbon hydrogen, which must be supported by complex new infrastructure systems. These newcomers to the UK energy landscape, as enablers for a deeply decarbonised and deeply renewable system, require a whole-system approach to development, with new support models to stimulate nascent markets.

There is much we can learn from the evolution of the gas and electricity markets, particularly from EMR. However, the hydrogen market is both complex and in its infancy. Reform of energy markets takes time, as will the growth of the hydrogen market. It would be near impossible to design a fully functioning hydrogen market for 2050 today – not

least because there remains significant uncertainty about its precise role and scale on this timeframe.

As the CCC's and our own analysis makes clear, rapid progress and learning by doing in the 2020s is vital. The roadmap at Chapter 2.1 highlights a challenging trajectory to meet our 2030 ambition and CB6 beyond this. While government intervention across the hydrogen value chain will be essential, we remain committed to market-led approaches that build and maintain competitive tension. Given the nascent state of the hydrogen market, it will be important that we learn and evolve, just as we have in the renewables market. In this, we will work closely with private sector partners to develop policy and signal next steps to attract the investment required. While this strategy package sets out the initial steps, there is far more to do, and we will continue to develop policy over coming months and years.

As set out in Chapter 1.5, a key strategic principle for government will be to take a 'holistic approach' to delivering our 2030 ambition and creating a thriving market for low carbon hydrogen. This means that any decision or action taken across the hydrogen value chain will inform and be informed by broader objectives and plans for the UK energy system, environment, economy and society including those set out in the forthcoming Net Zero Strategy. We will consider the implications of decisions and changes in the wider energy system, including dependencies on the deployment of energy infrastructure such as CCUS or offshore wind, as well as the impact of low carbon hydrogen on the wider system, for example in the potential for hydrogen to support integration of renewables with added benefits for energy security and resilience. This systemic approach to policy development is critical for success, both for developing a thriving hydrogen economy and to deliver our broader net zero objectives.

Our approach will therefore not be limited to the commercialisation and application of new hydrogen technologies. Government action will be required to put in place a wider policy framework covering regulations and, where needed, market support mechanisms in production, demand and supporting network and storage infrastructure, taking account of evolution in the electricity and gas markets and linkages to wider economic activity and networks. It will also be essential to raise consumer awareness, seek buy-in and to work through key issues such as policy governance and fair distribution of the costs and benefits of low carbon hydrogen.

Features of the emerging hydrogen market

The hydrogen market is currently limited to specific industrial settings, with high carbon production and use typically co-located. At much lower volumes, small scale electrolytic hydrogen is also starting to be used in the transport sector. Low carbon hydrogen value chains will differ according to location and circumstances, and be driven by production method, network infrastructure availability and demand profile. Creating a hydrogen market fit to serve a deeply decarbonised energy system will require concerted action to bring forward the necessary private investment across the value chain and enable the balance of supply and demand in a nascent market.

As set out in the roadmap at Chapter 2.1, the hydrogen market can be expected to grow and change significantly over the 2020s and out to the mid-2030s. For this evolution to happen, we will need to overcome a number of barriers across the value chain, especially in the early phases of market development. Consistent with challenges set out in previous sections of this strategy and in detail in the analytical annex, these barriers include:

- *High production and user costs*, relative to high-carbon counterfactuals.
- *Demand uncertainty*, overall and arising from specific end-use sectors – with BEIS analysis for CB6 suggesting 250-460TWh of hydrogen could be needed in 2050.
- *Policy and regulatory uncertainty*, which in this nascent market may deter investments across the value chain, especially as the regulatory framework is complex, including regulations relating to the environment, safety, markets, competition, planning, and specific end uses.
- *First mover disadvantage*, with early adopters taking significant initial risks but 'sharing' benefits with later entrants.
- *Technology uncertainty*, with most hydrogen technologies yet to be commercially demonstrated at scale.
- *Investor uncertainty*, both on the production and demand side, as well as for supporting network and storage infrastructure.
- *Lack of hydrogen* distribution and storage (covered in more detail in Chapter 2.3).

To overcome these challenges, government intervention will be required, both specifically to bring forward investment in new hydrogen production capacity in line with our 2030 5GW ambition, and more widely across the value chain through targeted support and regulation. Such policies will seek to enable the low carbon hydrogen market to grow from fragmented initial stages to a highly integrated, competitive, transparent and liquid end state where hydrogen can compete against other technologies without support.

Different types of government intervention are likely to be required as the hydrogen market matures and expands, for instance to facilitate new end uses, noting that early uses may differ from those that will be most significant in the long term. The market failures and barriers faced by first-of-a-kind hydrogen projects operating in small, highly localised markets are unlikely to be the same as those faced by nth-of-a-kind projects operating in larger regional, national or even international markets. Greater price discovery and convergence, alongside cost reductions and learning by doing, will also affect the nature and structure of the market and policies that frame and support it. In time, the low carbon hydrogen market has the potential to become substantial, highly liquid and subsidy-free.

2.5.1 Developing the market framework for hydrogen

The market framework for low carbon hydrogen can be understood as the policies and interventions that directly or indirectly support or impede the supply and use of low carbon hydrogen, including the regulations that guide what markets it can be sold into, for instance in industry, power, heat or transport. This strategy and accompanying consultations, most notably on the Hydrogen Business Model, provide the first steps in developing the market framework for hydrogen. These are the steps we consider to be most important to kick-start the UK hydrogen economy, having worked closely with a wide range of stakeholders in recent years.

What are we doing to deliver?

In developing the market framework for low carbon hydrogen, we will need to balance policy certainty for investors with adapting and building flexibility to respond to future changes to the energy system. We will use the strategic principles outlined in Chapter 1.5 to inform the ongoing development of the market framework across the value chain.

Supporting innovation for first-of-a-kind projects

We are currently supporting hydrogen innovation through a number of mechanisms including the HySupply competitions, Industrial Fuel Switching competition and Hy4Heat programme. Supporting technical improvements and commercialisation of new hydrogen technologies will remain a key priority as government develops the £1 billion Net Zero Innovation Portfolio. Hydrogen project developers have to date also been able to access government co-investment through the £315m Industrial Energy Transformation Fund, £170m Industrial Decarbonisation Challenge and £10m Green Distilleries Fund which all support deployment of low carbon technologies including hydrogen.

Supporting hydrogen production

Our 2030 5GW ambition represents a step change in the scale of the UK hydrogen economy, and we are developing new policies to support the delivery of this ambition. In the near term, and as set out in Chapter 2.2 and the consultations published alongside this strategy, we are proposing two key interventions that will help to bring down the costs of producing hydrogen relative to high carbon alternatives:

- The **Net Zero Hydrogen Fund**, designed to provide initial co-investment for new low carbon hydrogen production, with the aim of de-risking private sector investment and reducing the lifetime costs of low carbon hydrogen projects;

- Our **Hydrogen Business Model**, to provide longer term revenue support to hydrogen producers to overcome the cost gap between low carbon hydrogen and higher carbon counterfactual fuels, with the aim of enabling producers to price hydrogen competitively and helping to bring through private sector investment in hydrogen projects. **We intend to provide a response to our consultation on a Hydrogen Business Model alongside indicative Heads of Terms in Q1 2022.**

Demand-side interventions: carbon pricing, standards and sector-specific policies

While capital and revenue support for production will help to support investor confidence, it is likely that barriers to the development of the market will remain, most notably on the demand side. These can be mitigated through a range of other decarbonisation policies across different parts of the energy system. For instance:

- **Carbon pricing**, such as through the UK Emissions Trading Scheme (ETS) and Carbon Price Support (CPS), which send clear long-term signals that carbon will become an increasing cost for industry, thus promoting investment in low carbon technologies including hydrogen as a route to reducing these costs. We have already committed to exploring expanding the ETS to the two thirds of UK emissions not currently covered by the scheme as an important means of strengthening this long-term price signal, and will set out our aspirations to continue to lead the world on carbon pricing in the run up to COP26.

- A **Low Carbon Hydrogen Standard**, which can help to support the demand for low carbon hydrogen by providing confidence to end users that the hydrogen purchased is a low carbon alternative to existing fuels. We are also considering whether in time, this could also be used to underpin international trade. We are publishing a consultation on a UK low carbon hydrogen standard alongside this strategy, as explained in Chapter 2.2.

- **Sector-specific policies**, such as the Renewable Transport Fuel Obligation (RTFO) in transport, the Capacity Market (CM) in the power sector, or the Industrial Energy Transformation Fund (IETF) in industry, which can also support the use of low carbon hydrogen for particular sectors.

We will continue to engage with industry stakeholders and monitor progress as the market grows and our understanding of the pathways to CB6 and net zero continues to develop. In doing so, we will consider if further government action is required for the hydrogen market overall to evolve in line with our roadmap, and as we continue to review the existing energy policy landscape for consistency with CB6 and net zero.

Specifically, **we will undertake further work to understand and develop appropriate market frameworks to drive investment and deployment, considering how**

these should evolve over time to bring forward first-of-a-kind and nth-of-a-kind projects across the value chain, and transition to longer term competitive market frameworks. We will aim to publish initial conclusions and proposals in our next strategy update in early 2022.

Taking a whole-system approach

As we do this it may be appropriate to kick start the hydrogen economy through stimulation of early demand from sectors for which hydrogen may not be a significant decarbonisation solution in the longer run. For instance, blending hydrogen into the existing gas network could potentially facilitate access to a significant source of early demand, ahead of longer term decisions of the decarbonisation of heat in buildings (see gas blending box below). Hydrogen storage facilities may also play a role in providing greater demand-side certainty, especially when coupled with flexible power generation, which we will consider further as we assess future commercial arrangements for storage (see Chapter 2.3).

The coordination of supply and demand, particularly the sequencing and geographical location of production and end-users, will also be critical, driven to a large extent by the evolution of the hydrogen networks and storage infrastructure, but also wider system considerations. For instance, hydrogen producers or users in particular locations might provide valuable electricity grid balancing services.

In designing policy, it will be important to not create market distortions that would overly incentivise hydrogen relative to other decarbonisation routes. As and when we design new support schemes, we will need to carefully consider how they interact with the existing policy landscape. **We will work across government to highlight the potential role of hydrogen in the future energy system and consider whether and how this should be reflected in the design of wider energy markets and policies (such as the capacity market or the green gas support scheme).**

Creating a market: Gas blending to facilitate an early use case for hydrogen

Government is considering whether to support blending of low carbon hydrogen into the current gas network, to help with the initial development of the hydrogen economy. The *Ten Point Plan* set commitments to complete necessary testing of blending up to 20 per cent hydrogen into the gas grid by 2023.[72] Similarly, the *Energy White Paper* notes ambitious intentions to enable up to 20 per cent hydrogen blending on the networks by 2023 (subject to trials and testing).[73]

Use of hydrogen in our gas network is not new. Until the late 1960s, most of UK gas was 'town gas', which contained around 50 per cent hydrogen (mixed with methane and carbon monoxide). Town gas was typically manufactured locally from coal or oil, and consequently had a high carbon footprint and significant variability from one town to another.

The discovery of significant reserves of natural gas in the North Sea led to the rollout of an extensive national gas transmission and distribution system, meaning that today our gas system is much larger, more interconnected and better regulated. Today, around 85 per cent of households use gas central heating,[74] and a variety of industrial users have specific gas requirements.

Under the Gas Safety (Management) Regulations 1996, current hydrogen content in the gas networks is limited to 0.1 per cent by volume.[75] A deliberate effort to safely blend new gases into the existing gas network therefore requires evidence gathering and Health and Safety Executive (HSE) approval, prior to any live deployment.

Government and industry must continue to work together to overcome several critical technical, regulatory and commercial hurdles that will confirm whether blending *should and could* be an early use case for low carbon hydrogen.

Safety demonstrations, such as HyDeploy[76] and FutureGrid,[77] are underway to explore the potential for blending at distribution and transmission network pressures, in addition to investigating impacts on end use. The current phases of both trials are due to conclude in 2023. A comprehensive value for money assessment is required to assess the costs and benefits of blending. This will include evaluating crucial timings envisaged for potential future use of 100 per cent hydrogen for heat. The current gas system is not yet designed to accommodate hydrogen. Consequently, government is working closely with key delivery partners to assess the regulatory, physical and system changes required across the gas market to facilitate blending.

While blending could yield potential strategic benefits, some of which may be contingent on wider developments in the hydrogen value chain and existing gas market, there are also limitations. The relative balance between these may change as we continue to understand the pathway to CB6 and net zero, and as the market for hydrogen matures.

Strategic role	Potential benefits	Limitations and contingencies
Supporting low carbon hydrogen production & early development of hydrogen economy	Blending could facilitate access to a significant source of demand for early low carbon hydrogen producers, potentially functioning as a useful sink for excess production (as an 'offtaker of last resort'). We recognise that blending could offer security for hydrogen production investment decisions, by providing a commercial option to sell hydrogen for gas consumer use.	As there are other 'demand offtakers' for hydrogen (such as in industry or power), depending on the blending value for money case, alternative offtakers might provide a preferable longer term use for hydrogen.
Transferable insights for future use of 100 per cent hydrogen for heat	Blending hydrogen into existing gas networks could accelerate some technical, regulatory and commercial changes that may facilitate a smoother transition to the potential use of pure hydrogen as a heating fuel. This might include reforming gas consumer billing methodologies or potentially altering governance of the Gas Safety (Management) Regulations 1996. Blending may also improve consumer awareness of the benefits and ease of using hydrogen as a heating fuel.	A use of 100 per cent hydrogen for heating scenario is still not certain and even if the UK proceeds with this option, further enabling changes would be required across all technical, regulatory and commercial areas.
GHG emissions reductions	Low carbon hydrogen is less carbon intensive than natural gas, and thus blending could help decarbonisation of the existing gas grid in the near term.	Hydrogen has a lower volumetric energy density compared to natural gas. This means that a significantly larger volume of hydrogen would need to be blended and deployed to make substantial carbon savings. Blending is not a sufficient route to long term gas decarbonisation required by net zero.

Government recognises that, should blending be rolled out, industry will need early sight of how it should be implemented. We are proposing five principles for delivery:

- Blending low carbon hydrogen across the existing gas network, or parts thereof, would remain within safe limits set by the HSE (likely up to 20 per cent by volume); and any proposed changes to gas quality and infrastructure would meet all safety requirements.
- Any proposed changes to gas quality and infrastructure should maintain existing system, pipeline, and consumer appliance operability.
- Blending should not prohibit a secure supply of gas for consumers.
- Any costs to consumers should be affordable (ensuring value for money).
- Blending could support initial development of the low carbon hydrogen economy, but blending is not a preferred long term offtaker.

Government, Ofgem, existing gas networks and wider industry must continue to share information and work closely on evidence gathering and aligning understanding on safety, physical roll out models and value for money. Forthcoming actions range from:

- Addressing safety, operability and technical concerns.
- Proposing an optimal, practical model for blending.
- Conducting a value for money assessment.
- Comparing the merit of blending versus other end uses for low carbon hydrogen.
- Creating a regulatory and commercial framework, for example – a new billing methodology.

This is essential work that we will prioritise in the coming years.

If there is a value for money and safety case for blending, government's intention is to enable blending of hydrogen into the existing gas grid at the earliest from 2023, as a measure to help bring forward early hydrogen production.

We will engage with industry and regulators to develop the safety case, technical and cost effectiveness assessments of blending up to 20 per cent hydrogen (by volume) into the existing gas network. Ahead of the completion of safety trials, we aim to provide an indicative assessment of the value for money case for blending by autumn 2022, with a final policy decision likely to take place in late 2023.

Ensuring appropriate funding mechanisms to support a developing hydrogen market

Low carbon hydrogen is currently more expensive than counterfactual fuels, and the additional costs cannot be directly passed onto customers if hydrogen is to be a competitive alternative. Funding must come from elsewhere to make hydrogen production and use commercially viable, and deciding how this is paid for and who bears the cost is a key question that must be addressed. The complex nature of the hydrogen market means that the impacts of a chosen funding mechanism must be considered across a range of different end use sectors and consumers, including their ability to absorb these costs, and the impact that additional costs would have on demand. **Further details of the revenue mechanism, which will provide funding for the Hydrogen Business Model, will be provided later this year.**

2.5.2 Ensuring a supportive regulatory framework

The regulatory framework as it relates to hydrogen is broad and complex, including rules and regulations relating to the environment, safety, markets, competition, planning and specific end uses. While early projects can be expected to operate within existing regulatory regimes, new rules and regulations may be required to facilitate the further expansion of the market and maintain competitive pressure over the course of the 2020s and beyond, especially should hydrogen networks connect to the existing gas network in the future, for instance, to enable blending or grid conversion.

What are we doing to deliver?

Government is working with regulators and industry to develop a common understanding of how current regulation supports or impedes the production and use of low carbon hydrogen – for instance, through the working group on standards and regulations under the Hydrogen Advisory Council. Projects such as HyLaw have analysed the legal and administrative processes applicable to hydrogen in several countries and identified the legal barriers to the deployment of hydrogen applications in the UK.[78]

Through such channels, we are considering both the immediate regulatory barriers to the initial development of the hydrogen economy, but also the broader regulatory framework for hydrogen, and how it will need to evolve as the hydrogen and wider energy markets develop over the course of the 2020s, to the mid-2030s and out to net zero in 2050. This work will allow government to plan and prioritise regulatory changes and provide clarity on the roles and responsibilities of different regulators. In doing so, we will consider and address four overarching and interdependent regulatory issues for the hydrogen economy.

Addressing regulatory barriers facing first-of-a-kind hydrogen projects

First-of-a-kind projects can act as critical innovators in the development of the technologies and policy interventions that will underpin the future hydrogen economy. However, they may encounter unexpected regulatory barriers, for instance relating to safety, planning, licensing or access to end use markets (for example, different regulations and regulators for households versus industry, transport versus heat). Such unforeseen barriers can significantly hinder early project development and related innovation.

Building on initiatives such as HyLaw and the experience of early industrial 'pathfinder' projects (see Chapter 2.4.1), **government will continue to work with industry and regulators in the early 2020s to identify and address regulatory barriers faced by first-of-a-kind hydrogen projects and consider changes needed to unlock hydrogen investment and deployment across the value chain. We will aim to publish initial conclusions and proposals in our next strategy update in early 2022.**

Using regulation to unlock access to new markets for hydrogen

Regulatory changes may also be required to unlock new markets for hydrogen (such as potentially mandating hydrogen-ready appliances in some areas), or to address regulatory barriers that limit the option of low carbon hydrogen (such as changing the Gas Safety Management Regulations (1996) to allow for hydrogen blending into the gas grid).

Government will continue to work with industry and regulators to consider what regulatory changes may be appropriate across the hydrogen value chain, in line with other commitments made in this strategy.

We will also work across government to highlight the potential role of hydrogen in the future energy system and consider whether and how this should be reflected in wider regulatory and policy changes (such as any future changes to the Gas Act 1986).

Identifying who should regulate an evolving future market for low carbon hydrogen, and how and when

As hydrogen networks expand out of initial clusters in the 2020s, and with critical decisions being made on blending hydrogen into the existing gas grid by 2023 (subject to trials and testing) and on the potential for use of 100 per cent hydrogen in heating in the mid-2020s, the nature and scale of hydrogen networks may alter significantly, potentially reaching right into people's homes. This would have important implications for the applicable regulatory and legal frameworks, with bespoke arrangements likely to be required, overseen and administered by new statutory bodies or existing ones with new powers.

The applicable regulations in the initial stages of market and network expansion may need to evolve as the market grows and matures. Identifying when changes are needed to enable the market to progress through phases of integration and expansion will be critical, and likely long lead-in times for regulatory changes will need to be taken into account. While we expect some regulatory changes will be required by the mid-2020s to support early network expansion, the long-term arrangements will likely not be in place until the late 2020s. Working through these issues will be an iterative process, and **we will formalise our engagement through the creation of a Hydrogen Regulators Forum, with representation across the relevant regulatory areas (including environmental, safety, markets, competition and planning).**

Ensuring that the potential role for hydrogen is considered in broader reviews of regulation

Any action to support and frame the hydrogen economy will need to be reflected in the broader energy system. This includes the rules, regulations and governance that guide how the energy system functions. As outlined in the *Energy White Paper*, there are numerous pieces of legislation and guidance that will need to be reviewed as the UK transitions to an affordable, secure and reliable energy system which delivers our net zero ambitions – for instance in relation to gas, electricity, CO_2 transport and storage and planning. **We will work across government and with regulators to ensure that the interlinkages between hydrogen and broader governance and regulatory changes are appropriately considered. We will consult this year on the institutional arrangements governing the energy system over the long term, including system operation and energy code governance.**

Developing a regulatory framework for the hydrogen economy that incentivises investment, provides long term certainty, maintains competitive pressure and supports integration with a wider net zero energy system will take time and work. Government will continue to work with regulators and industry to ensure that this regulatory framework can evolve over time in a way that supports our 2030 ambition and positions the hydrogen economy for scale up beyond this for CB6 and net zero.

2.5.3 Raising awareness and securing buy-in

Hydrogen has been used in the UK for many years, as described in Chapter 1, but its future role will be very different. Many potential users are not yet aware that hydrogen could be a low carbon solution for them. Even those who are aware would not find it easy to identify a reliable source of hydrogen, or its cost and carbon intensity. Similarly, many of the technologies users would need to switch to hydrogen, such as boilers and trucks, are not yet commercially available. This means that a critical part of our action in the early 2020s to create the market for hydrogen will be to ensure that energy consumers and businesses understand the potential of low-carbon hydrogen and how it operates, and to provide assurance that its development and rollout are underpinned by systems and frameworks appropriate for any energy carrier and related technologies.

What are we doing to deliver?

The transition to any new low carbon technology brings both opportunities and challenges for different stakeholders. We will draw on lessons learnt from raising awareness of other new and low carbon technologies, such as smart meters and electric vehicles, to ensure businesses and consumers can access and drive forward the low carbon hydrogen economy.

Additionally, we will work with industry to maximise the positive outcomes for the climate and environment that the growth of a low carbon hydrogen economy could bring, including for air quality, and will ensure that any potential trade-offs between the two are minimised. For example, we will support industry to work with the Environment Agency and other regulators to reduce the creation of nitrogen oxide (NOx) emissions that the combustion of hydrogen in an engine or boiler creates, helping to deliver on our air quality targets to deliver cleaner air for all.

We recognise the need for targeted engagement going forward to understand and work through key priorities for industry, businesses, civil society and households to secure buy-in and enable the use of low carbon hydrogen across different parts of the energy system. To help with this, we have established the Hydrogen Advisory Council which reflects a cross section of expertise on low carbon hydrogen across the value chain. We are also engaging with a wide range of stakeholders outside of this forum, recognising the importance of different perspectives in shaping this nascent policy agenda.

Broad and early stakeholder engagement allows for important public discourse on different aspects of our 2030 ambition and broader plans to deliver CB6 and reach net zero. We will continue to engage citizens and use the expertise of others to inform policy development by considering conclusions of citizen's assemblies which provide feedback from a representative sample of the UK (such as Climate Assembly UK's report, 'The Path to Net Zero).

This approach has already yielded important insights with technologies associated with low carbon hydrogen production. For example, in collaboration with UKRI and Sciencewise, last year we commissioned a public dialogue study to explore citizens' perceptions towards CCUS at both a local and non-local level. Public engagement will help us to understand different perspectives towards the substantial infrastructural and behavioural changes that are needed to decarbonise our energy system over the next 30 years, including in relation to the potential role of hydrogen.

While we recognise the crucial role that government can play in raising public awareness of the importance of decarbonising our energy system, including through low carbon hydrogen, we are mindful that this will be most effective carried out collaboratively with local communities to understand the priorities of and opportunities for different stakeholders. These groups are well placed to help us assess the fairness and affordability of different policy decisions to support the hydrogen economy as it grows.

Regulators and industry will also be engaging in activity to raise awareness for potential new uses case for hydrogen. Through the safety workstream of the Hy4heat programme, government is working with HSE on a project to assess the safe use of hydrogen gas in certain types of domestic properties and buildings (detached, semi-detached and terraced houses of standard construction), as part of preparation for the first community trials using hydrogen as a heating source.

The Hy4heat programme, in collaboration with NGN and Cadent, is also supporting the construction of two unoccupied homes in Gateshead that will feature Hy4Heat-funded prototype boilers, hobs, cookers, fires and meters to showcase the potential use of 100 per cent hydrogen for domestic heating. Members of the public will be able to see how these appliances compare with like-for-like ones that run on natural gas. Building on this learning, we are delivering a programme of work to assess the feasibility, costs and consumer experience of 100 per cent hydrogen heating (see Chapter 2.4.3). These include consumer trials which will be key to understanding how consumers could experience hydrogen heating.

The government sees this strategy as a significant step towards improving awareness, both of the potential role that hydrogen can play in decarbonising our energy system, and of the challenges involved in bringing this about. We will continue to explore opportunities for dialogue and information sharing on the challenges and opportunities for low carbon hydrogen, including in relation to other low carbon technologies. Public engagement is an important priority for government in the run up to COP26, and as we look to publish our forthcoming Net Zero Strategy.

Chapter 3:
Realising economic benefits for the UK

Key commitments

- 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**.

The UK's geography, geology, infrastructure and expertise make it particularly suited to rapidly developing a low carbon hydrogen economy. This offers a great opportunity for companies, communities and individuals. This chapter sets out our plans to maximise the economic benefits to the UK from this shift – supporting jobs and regional growth, making the best of our research and innovation strengths, and ensuring that businesses across the country are in a position to tap into the growing global hydrogen market.

The hydrogen economy is in the very early stages of development in the UK and globally. This presents an opportunity to put a focus on economic benefits at the heart of our approach from the outset as we look to deliver our 2030 ambition and contribute to achieving our CB6 and net zero targets.

We can draw on lessons from the development of other low carbon technologies to ensure that our companies, communities and individuals can be at the forefront of this opportunity – promoting world-class, sustainable supply chains and creating high value, skilled jobs. We will also make the UK an attractive place to invest in hydrogen and seek to maximise the export potential of our technologies and expertise. In doing so, we will support the government's *Plan for Growth*, driving local and regional opportunities, and helping to level up across our industrial heartlands and throughout the UK.

We will work in partnership with industry, the academic and research and innovation community, devolved administrations, local authorities, workers and civil society to harness the best of the UK's skills and capabilities. We will share these with – and learn from – expertise elsewhere, and capitalise on our world-leading academic and industrial research and innovation base.

Government will work to bring together the various existing and emerging businesses critical to enabling the hydrogen economy. Some of these will be well-established firms in the transport, industrial and oil and gas sectors; others will be emerging innovators designing and building fuel cells, electrolysers, and new components for the distribution and storage of hydrogen.

We want to see UK companies at the forefront of the growing global hydrogen market, and we are developing policy that will attract and secure investment in a pipeline of British projects, driving rapid progress to foster our exportable strengths and get ahead in the global market.

Analysis[79] suggests that in 2030 the UK hydrogen economy could be worth £900m and support over 9,000 jobs. Around a quarter of these jobs could be driven by British supply chain exports.

By 2050, under a high hydrogen scenario, the hydrogen economy could be worth up to £13 billion and support up to 100,000 jobs, with exports growing in relative importance.

3.1 Building a world class supply chain

Government will work to promote the growth of world-class, sustainable supply chains to underpin the deployment of early commercial scale UK hydrogen projects over the 2020s, and to be ready to support expansion of the sector from the 2030s.

The UK is well positioned to grow and develop supply chains across the full low carbon hydrogen value chain, from production, through to transportation, distribution and storage, and across various end uses in industry, power, heat and transport. These supply chains will be vital to underpinning our vision of growth in the hydrogen economy across the 2020s, and to position it for significant ramp up in the 2030s in line with CB6 and net zero.

To make sure that the UK can capitalise on these opportunities, we have carried out an initial assessment of current UK low carbon hydrogen supply chain capability and strengths, to identify opportunities and barriers to companies being able to thrive and support the full hydrogen value chain as it develops in line with our 2020s roadmap (see Figure 3.1 below).

Seizing the opportunity

We will work with industry, academia and other stakeholders to build on insights from other energy sectors to assess what actions government, industry and the research and innovation community could take to seize the supply chain opportunities presented by the early development of a low carbon hydrogen economy, and for UK businesses to position themselves at the forefront of the hydrogen economy. **We will set out more detail in a Hydrogen Sector Development Action Plan by early 2022.**

We will learn lessons from the development of the UK's world-leading oil and gas sector, driven in part through measures introduced in the 1970s. Similarly, we will draw on the expansion of other low carbon sectors, such as offshore wind, where early opportunities for UK investment, regional growth and job creation were not built in and capitalised on from the start, even while the UK has become a world leader in deployment.

Figure 3.1: UK supply chain development over the 2020s

Early 2020s	Mid 2020s	Late 2020s onward
• British supply chain companies lay the foundation to support our vision for the hydrogen economy in the near and long term. • The UK builds on its strengths in electrochemical technologies (fuel cells and electrolysers). British companies are exporting these technologies to markets in Europe and SE Asia. • Domestically, these are deployed in small-scale electrolytic production projects and in transport. • World-leading supply chains supporting other sectors, such as oil and gas, pivot towards supporting the hydrogen economy, offering opportunities to make use of UK skills, capabilities and technologies.	• The UK has the opportunity to deploy blue hydrogen projects, linked closely to the development of CCUS supply chains, as set out in the CCUS roadmap, taking advantage of UK CO_2 storage potential. • Supply chains across the value chain gear to support scaled-up deployment, and are positioned to support future growth of the domestic hydrogen economy. • UK continues to build on its world-class innovation. For instance, domestic hydrogen boilers which have the potential to serve the domestic market.	• Continued growth in low carbon hydrogen production, complemented by growing UK strengths in distribution and end-use markets such as in vehicles and industrial applications. • UK takes advantage of its natural assets, for instance in seizing opportunities for hydrogen storage. • UK supply chains and skills base are well positioned to support accelerated domestic deployment in support of net zero in the 2030s and beyond, and to seize opportunities to export technology, expertise, and hydrogen itself. • The hydrogen sector plays an important role in supporting other sectors, such as construction, automotive and steel, to anchor their supply chains in the UK by making it possible for them to decarbonise and develop a low-carbon proposition that will ultimately be exportable.

- Throughout, the breadth of the hydrogen value chain offers opportunity to seize on UK expertise in other sectors, such as high-end manufacturing, oil and gas, renewables, chemicals, safety, engineering, procurement and construction management (EPCm) and our functional strengths of planning, legal, professional and financial services.

In doing so, we will also focus on developing the next generation of technologies that will help fill the gaps in the supply chain, reduce costs and put the UK on a footing to grow at scale in the 2030s.

This work will include supply chains that currently support high carbon industries, which have the opportunity to pivot and build on their base capabilities and expertise to meet the needs of the UK hydrogen sector, as well as internationally. This will not be limited to CCUS-enabled hydrogen but will include strengths in process engineering, offshore engineering and re-purposing of offshore assets, and gas safety management. The new UK Energy Supply Chain Taskforce[80] will focus on ensuring UK supply chain companies can take advantage of clean growth opportunities in the UK and overseas.

The oil and gas sector's voluntary commitment through the *North Sea Transition Deal* to aim towards 50 per cent local content across the lifecycle of projects, including for hydrogen, will help safeguard long-established UK supply chains – and world-leading skills, capabilities, and innovation – that will be crucial to realising both the decarbonisation and economic benefits of the UK's transition to net zero.

Our expectation of industry

We will seek to introduce economic benefit assessments into the Net Zero Hydrogen Fund and Hydrogen Business Model. Consultations on the NZHF and the Hydrogen Business Model are taking place alongside the publication of this strategy. Our expectation is that hydrogen developers across the full value chain will work to ensure that competitive UK companies, including SMEs, are in a fair position to bid into hydrogen projects.

In establishing these assessment criteria, we will recognise that the hydrogen market is in its infancy and that intervening too firmly for first-of-a-kind projects could stifle cost-competitive growth. Over time, however, we anticipate that hydrogen will follow in the footsteps of established sectors like offshore wind and oil and gas to be able to put in place bold commitments to UK content.

Such measures might follow along the lines of the changes to the renewables supply chain plans being introduced through the Contract for Difference (CfD) allocation process. These will require a supply chain plan to be submitted to the Secretary of State before participation in CfD auctions, building on the offshore wind sector's voluntary commitment to 60 per cent local content through the *Offshore Wind Sector Deal*.

We will actively monitor the extent to which competitive UK businesses are benefitting as the hydrogen sector matures. If necessary, we will consider what options are open to ensure a fair playing field that includes UK businesses. **We will set out more detail on this in our Action Plan.**

Project visibility

To be successful, low-carbon hydrogen supply chains will also need to have good visibility of the opportunities ahead, across the full hydrogen value chain. **We will work with industry to improve visibility of the low carbon hydrogen project pipeline across the supply chain, learning from the success of initiatives in other low carbon sectors.**

3.2 Creating jobs and upskilling industry

Developing a hydrogen economy is a key component of the opportunity offered by our net zero target to transform the UK's industrial regions, attract investment, and create secure, good quality green jobs across the UK. Developing this nascent sector will require existing and important new skills to be available in the right place at the right time. We will work with partners to identify skills requirements and intervene if necessary, including to support workers from transitioning high carbon sectors.

Creating a successful hydrogen sector could support 9,000 direct jobs across the UK by 2030, with up to 100,000 supported directly by 2050.

These jobs, with additional indirect and induced[81] employment benefits, will help drive local economic growth and support the delivery of government's commitment to level up the UK.

Ensuring the right skills are available in the right place at the right time

Ensuring that the UK has the right skills and capabilities will be critical to achieving our hydrogen ambition.

As part of our work to develop the low carbon hydrogen sector, we will assess the opportunities for hydrogen employment across the UK. Over the next year, in collaboration with stakeholders, we will work to understand the profile of required skills over the 2020s and into the 2030s, in line with our roadmap set out in Chapter 2.1. **We will work with industry, trade unions, the devolved administrations, local authorities, and enterprise agencies to support sustained and quality jobs and ensure that there is effective and targeted investment in relevant skills.**

Creating good-quality[82] jobs in the hydrogen sector, particularly where these are in our industrial heartlands, will make a significant contribution to ensuring people do not have to relocate to succeed. As set out in the *Plan for Growth*, we will catalyse centres of excellence and help people connect to opportunity as a way to drive regional and local growth.

We believe that initiatives to invest in growing the skills base are best when led locally, to ensure skills are tailored to demand. The government's *Skills for Jobs: Lifelong Learning for Opportunity and Growth White Paper*[83] recognises that there are skills gaps at higher technical levels which might affect our ability to grow the green economy. Investing in these skills at both a local and a national level will be critical. **We will work with industry, education providers and local and regional authorities to explore opportunities for relevant skills programmes, including apprenticeships and re-skilling programmes.**

In doing so, we will work to ensure that the recent recommendations from the *Green Jobs Taskforce*[84] will inform the UK's forthcoming Net Zero Strategy, many of which are pertinent to the hydrogen sector. These recommendations aim to:

- Ensure the UK has the immediate skills needed to kick-start and deliver a green recovery.
- Develop a long-term plan to chart out skills requirements ahead of net zero.
- Ensure jobs in the green economy, such as the hydrogen sector, are high quality and inclusive.
- Support opportunities for workers in high carbon sectors, supporting them through the transition to zero carbon sectors.

To attract and retain talent, we will also work with the sector to ensure that equality of opportunity is considered from the outset. We are mindful of the *Offshore Wind* and *Nuclear Sector Deals'* diversity ambitions[85] and see no reason why the hydrogen sector cannot be at least as ambitious.

In support of this, **we will set up an Early Career Professionals Forum under the Hydrogen Advisory Council.** As an emerging sector, it will be important to ensure that early career professionals in the hydrogen economy are engaged and able to advise government.

Re-skilling workers from high carbon industries

Hydrogen provides an opportunity for those who have previously worked or are currently working in high carbon sectors to transition to support the green industrial revolution.

As an example, Oil & Gas UK has estimated that, between 2018 and 2030, the number of jobs directly and indirectly supported by the UK's offshore oil and gas industry could reduce from 147,000 to around 105,000.[86] Many skills in this industry will be transferable to clean growth industries, and hydrogen will provide significant opportunities – including project management, process engineering, repurposing of infrastructure and gas safety.

The recent *North Sea Transition Deal*[87] committed the government to continue to champion the role of the oil and gas sector and its workforce in the energy transition, supporting work on the sector's Integrated People and Skills Plan. In March 2021, the government announced £27m of funding for the Aberdeen Energy Transition Zone and £5m for a 'Global Underwater Hub', which will help support the industry's transition to renewable and low carbon energy technologies such as offshore wind, hydrogen and CCUS. We will work to support other initiatives in relevant sectors, and will support work to ensure portability and mutual recognition of professional qualifications to enable people to transition to new sectors such as hydrogen without re-certification.

We will work with industry and others to support workers in need of training so that they can access the new jobs that will become available. We will also work collaboratively with industry and education providers to explore what high-intensity up-skilling and re-training opportunities could be provided.

We will continue to support the work of the Energy Skills Alliance (ESA) established in 2019, which is working to produce a clear forecast of energy skills in the short term, deliver

an integrated energy apprenticeship scheme and develop a roadmap for aligning training and standards. The Hy4Heat programme has also developed a framework for skills accreditation for heating engineers working with hydrogen.

Our expectation of industry

We are aware of – and welcome – several initiatives being taken forward by developers and industry to support skills development. Many of these are tied to emerging hydrogen and CCUS clusters, providing opportunities for the UK skills base to thrive in industrial regions across the UK and maximising opportunities for jobs in the sector.

It is our expectation that the hydrogen sector, as it grows, will invest in growing its skills base and in supporting good-quality jobs, with equality of opportunity as a core focus from the outset.

To support this in the near term, we will seek to introduce measures through the Net Zero Hydrogen Fund, and in due course we would expect to do the same for the proposed Hydrogen Business Model. Our aim is to incentivise project developers to demonstrate how they intend to grow relevant skills and support good quality jobs and equality of opportunity throughout the supply chain.

We will continue to monitor this as the hydrogen sector matures and consult if necessary to identify barriers to sufficient private sector investment in growing the UK skills base and supporting good quality jobs and EDI.

3.3 Maximising our research and innovation strengths

Supporting research and innovation (R&I) will be key to cost-effective acceleration of the UK hydrogen economy and ensuring it can create and stimulate economic opportunities where the UK has expertise. We will take a whole-system approach to R&I throughout the 2020s to be able to deploy and integrate hydrogen technology and systems holistically in the context of wider social, environmental and economic developments.

The UK's existing hydrogen research base is strong. As the second most active country in hydrogen and fuel cell research in Europe, we are well placed to capture part of the global innovation potential in the hydrogen value chain and position the UK as a leading hydrogen technology developer.

Enhancing the ability of the UK R&I ecosystem to support commercialisation

We recognise that the technology journey – from idea to commercialisation – seldom moves from discovery research through to development (learning by research) and demonstration (learning by doing) in a linear way. It is an iterative process which must be further enabled to support the de-risking of current technology while next generation technology is developed.

UK government investment in internationally recognised hydrogen R&I projects has already enabled the development of many key hydrogen technologies, including those promoted by a handful of UK firms, such as Bramble Energy, Ceres Power and ITM Power, who have positioned themselves at the forefront of the global shift to hydrogen.[88]

We want to see others follow in the footsteps of these companies, for example by making the most of opportunities such as our **£1 billion Net Zero Innovation Portfolio (NZIP)**, which has made hydrogen one of ten key priority areas. NZIP itself represents a doubling of the UK's £505 million Energy Innovation Programme over the past five years. We aim for this new funding to be complemented by up to £3.5 billion of matched and follow-on funding from the private sector. **One of the first schemes to be launched under the NZIP is the £60 million Hydrogen Supply 2 Competition**, which will support the development of a wide range of innovative low carbon hydrogen supply solutions in the UK, and identify and scale up more efficient solutions for making clean hydrogen from water using electricity.

To provide crucial long-term certainty for researchers and innovators, we have also already committed to increasing our investment in research and development (R&D) to 2.4 per cent of GDP by 2027 and to increasing public funding for R&D to £22 billion per year by 2024. This will further boost the UK R&I ecosystem, including hydrogen-related activity.


ITM POWER
Energy Storage | Clean Fuel
HYDROGEN

Public sector funding is often key to leveraging private sector investment in innovation, and even more so in the context of unlocking commercialisation and creating a market for hydrogen. **We will work with the Hydrogen Advisory Council and other partners to better understand the scale, scope and type of private sector investment into hydrogen R&I in the UK, and how it can be further promoted.** Our new Innovation Strategy, which will be published later this year, will further outline how we intend to promote private sector investment in R&I more broadly in the UK.

With such a critical role to play in enabling the UK hydrogen economy, it is important that a joined up and strategic approach is taken to hydrogen R&I investment and prioritisation. Government has already established governance mechanisms through a Net Zero Innovation Board to ensure a coordinated, strategic approach to R&D and demonstration funding across public funding bodies, and to enhance the alignment of public and private sector innovation in support of net zero. Building on this, **we will work with experts, including through the newly established R&I working group under the Hydrogen Advisory Council, to develop a strategic and cross-cutting Hydrogen R&I Roadmap to inform public and private sector R&I investment and prioritisation.**

UK R&I in the global landscape

We recognise that the UK's world-leading R&I sits at the heart of a global network of excellence: UK expertise both benefits from and drives forward advances beyond our own borders. We believe that by engaging actively and openly to share research, progress in R&I can be accelerated and its benefits maximised.

We will use our role as one of the co-leads of Mission Innovation's new Clean Hydrogen Mission – and coordinator of its R&D pillar of activities – to champion this approach from the top down. Our commitment to the Mission affords us a unique opportunity to showcase UK R&I expertise and to leverage its outputs to spur further technological progress, and ensure innovation is commercialised in a way that can push forward hydrogen technology development. In Chapter 4 of this strategy, we set out how we will work to ensure this 'push' boost of R&I progress is joined-up with policy, regulatory and demand-focused actions that 'pull' its contributions through the value chain.

We will also continue to foster collaborative international research and information exchange on the production and deployment of hydrogen as a global energy carrier, through our active membership of the International Energy Agency (IEA) Hydrogen Technology Collaboration Programme (Hydrogen TCP).[89]

3.4 Attracting investment

The development of a UK hydrogen economy fit for net zero presents unique opportunities for investment in UK projects, associated infrastructure, supply chain companies, technologies and innovation. We will work to create an attractive environment to secure the right investment in UK projects, with benefits to UK business and communities.

We are confident that UK strengths and assets, including potential for rapid scale up across the domestic value chain, coupled with our strategic and policy approach, will create the right conditions to unlock the significant scale of private investment that will be needed to develop and grow the UK hydrogen economy. The development of other clean growth energy industries can give a sense of the scale of investment needed to develop and grow new low carbon sectors such as hydrogen: for example, according to Wind Europe[90] over the ten years to 2020 the UK leveraged €56 billion (around £47 billion) in our world-leading offshore wind industry, almost half of all European investment in the sector.

As a start, the *Ten Point Plan* outlined that over £4 billion of private investment could be unlocked over the 2020s, positioning the UK hydrogen sector to deploy at scale in the 2030s and supporting our ambitions in the context of the growing global market. Alongside this strategy, we are consulting on the primary means to stimulate deployment of – and investment in – hydrogen projects through the Net Zero Hydrogen Fund and the proposed Hydrogen Business Model.

The new UK Infrastructure Bank[91] launched in June this year will provide leadership to the market in the development of new technologies including hydrogen, particularly in scaling early-stage technologies that have moved through the R&D phase. The Bank will have an initial £12 billion of capital, and will invest in local authority and private sector infrastructure projects, as well as providing an advisory function to help with the development and delivery of projects. Through these investments the Bank will 'crowd-in' private investment to accelerate our progress to net zero whilst helping to level up across the UK.

The government has also established a new Office for Investment (OfI), which will support high value investment opportunities into the UK which align with key government priorities

– including the hydrogen sector and associated infrastructure – to drive economic recovery and growth across the UK, as well as advancing R&D. We will work closely with the OfI to support the aims and direction set out in this strategy.

We will also continue to champion the UK hydrogen sector, technologies and projects through our world-class UK trade networks, promoting opportunities for foreign investment.

Through these and our ongoing engagement and policy activity, we will continue to work with the investment community to support investment across the hydrogen value chain and its supply chains, with a view to ensuring that the UK hydrogen sector remains a world-class investment case.

3.5 Realising export opportunities

The green industrial revolution has created a once-in-a-generation opportunity for the UK, as well as globally. We will capitalise on our strengths, skills, capabilities, technologies, innovation and investment to position UK companies to springboard into the expanding global hydrogen economy.

Our vision is clear: maximise the investment, growth and export potential of the green industrial revolution. We want to see a lasting and sustainable clean energy sector that can exploit global clean growth opportunities such as those associated with low carbon hydrogen. This will, in turn, support the broader sustainability of the sector and drive down costs.

Analysis suggests that around a quarter of UK jobs in the hydrogen sector, and around 30 per cent of economic opportunity, could be driven by exports by 2030, with these growing in relative importance by 2050. The UK is already an exporter of fuel cell and electrolyser technologies, and our world class engineering, procurement and construction management (EPCm) services sector is well geared to support international opportunities

as the global hydrogen economy grows. Our regulatory framework and decades of experience in gas management and safety are strengths from which the rest of the world can learn and which we are well geared to support internationally.

While our focus in the near term will be on securing domestic deployment of both electrolytic and CCUS-enabled hydrogen projects, we expect that through this UK companies will be increasingly well-positioned to seize opportunities in other markets. We are already working through UK Export Finance, the UK's export credit agency, to support UK hydrogen companies to seize such opportunities – with £2 billion earmarked to finance clean growth projects overseas to create export opportunities for British businesses. UKEF is able to provide favourable financing terms for clean energy projects, as well as working capital and contract bond support for exporting SMEs in the clean growth sector.

New trading relationships will offer further avenues for our businesses to experience the benefits of exporting. We will seize the opportunities for the UK hydrogen sector presented by Global Britain as we advance new Free Trade Agreements.

To help make the most of these opportunities, we will look to work with countries that, like the UK, have an established oil and gas sector that can transition to a low carbon future through hydrogen, sharing learning and establishing common investment and export opportunities.

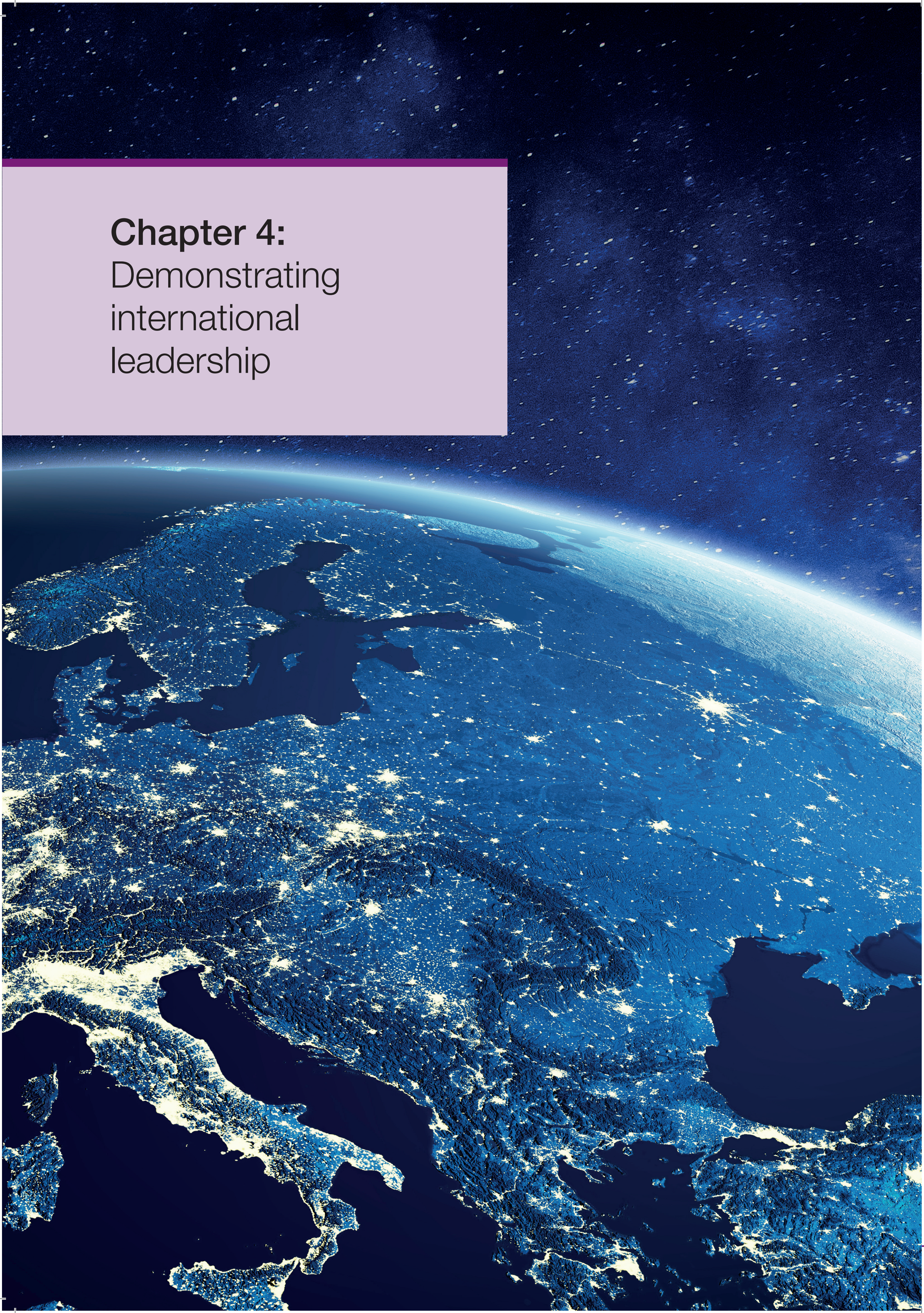
We will also look to position the UK so that it is able to seize opportunities to export hydrogen itself. A further export opportunity will lie in ammonia produced from low carbon hydrogen, building on trade links that exist for high carbon ammonia today. To put the UK in a position of strength to unlock and benefit from these opportunities for the longer term, we will work to identify any necessary requirements, such as certification, and any constraints, for instance around ports and infrastructure.

The Department for International Trade (DIT) is uniquely placed to promote UK businesses and associated supply chains to access global opportunities, working in 117 separate overseas markets.

DIT works to connect businesses to encourage exporting globally. Its staff use their local expertise, networks and government-to-government relationships to reduce market access barriers for UK businesses and connect businesses with overseas buyers. DIT can link UK-based engineering expertise to emerging global CCUS opportunities, providing intelligence on projects and advice on the supply chain value to the UK. It can also connect the UK industrial clusters to overseas projects.

We are clear that by working closely with industry, academia, and other stakeholders to foster a strong UK low carbon hydrogen sector; create jobs and develop relevant skills and capabilities; and exploit our world-leading innovation, investment and export opportunities, we will position the UK to take a clear global leadership role in hydrogen. The next chapter sets out how we will work with our international partners to help unlock the economic and decarbonisation benefits of hydrogen for the UK, while supporting the scale up of a global hydrogen economy.

Chapter 4: Demonstrating international leadership



Climate change is a global challenge, and requires a global response. The UK leads the world by example – we were the first major economy to legislate for net zero, and are achieving larger and faster emissions reductions than any comparable economy. The ambitions and commitments set out in this strategy demonstrate our similar determination to develop a low carbon hydrogen economy that will be a key part of our transition to net zero. We are equally determined to play a key role in international collaboration – learning from others and sharing our experience and expertise to help scale up further and faster – so that low carbon hydrogen can help with the wider global transition to net zero.

Coordinated international action on the deployment of low carbon hydrogen technologies will make the transition to net zero faster, easier and cheaper for all. Governments have a crucial role in supporting the coordination of the 'push' and 'pull' needed to develop and then move these technologies into the marketplace, ensure safe deployment and support early demand. By collaborating, we can accelerate progress towards these goals.

Today, low carbon hydrogen technologies remain at a relatively early stage of deployment. This makes international collaboration especially important, to help mitigate first-mover risks and create larger shared markets for the deployment of low carbon hydrogen. The UK is keen to work with other leading hydrogen proponents, both to share our own expertise, and to learn from the experience and knowledge of others. We will take an open and active approach to hydrogen collaboration and cooperation. We believe that:

- By sharing the outcomes of cutting-edge research, we can accelerate the supply 'push' of technological developments and cost reductions needed to allow production and deployment across sectors at scale.
- Through developing common technical and emissions codes and standards, we can support economies of scale – and facilitate a truly global market, with trade, energy security and climate benefits.
- By joining up policy and regulatory activity, we can expedite the creation of markets for low carbon hydrogen, 'pull' forward innovation and investment, and lay the groundwork for an integrated, competitive global hydrogen market.

While we recognise that the global market for low carbon hydrogen will take time to mature, the recent proliferation of national strategies and private sector commitments reflects substantial international ambition. The IEA estimates that in a scenario in line with the Paris Agreement, global low carbon hydrogen demand could reach 2,000TWh in 2030, and 10,500TWh in 2050.[92] In this scenario, hydrogen could meet seven per cent of final energy consumption and deliver 1.6 $GtCO_2$ per year of greenhouse gas abatement in 2050.[93] Other analysis suggests demand could be even higher: BNEF estimate that in a scenario with a strong policy framework supporting hydrogen, demand could reach 27,400TWh by 2050, meeting 24 per cent of final energy usage.[94] These projections underline hydrogen's potential to make a key contribution to global net zero. We must act together now to fully realise that potential.

The UK in international partnerships

The UK plays an active role in many of the key institutions driving multilateral collaboration on hydrogen innovation, policy and standards. These include Mission Innovation (MI), the Clean Energy Ministerial (CEM), the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), the Hydrogen Energy Ministerial, the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA).

The UK co-leads the MI Clean Hydrogen Mission, launched in June this year with a goal to foster innovation gains that enable clean hydrogen end-to-end costs of 2 USD/kg in the most competitive regions by 2030. This end cost is achievable, with production costs of USD 1.6-2.3/kg projected by 2030 for CCUS-enabled and electrolytic hydrogen in average regions respectively.[95] The Mission's focus on aligning and targeting innovation funding and research and demonstration programmes towards cost reduction across the supply chain

will help accelerate the development of a comprehensive, international value chain. We will continue to drive global collaboration through MI that facilitates these cost reductions, recognising that this will help accelerate global low carbon hydrogen deployment and the decarbonisation and economic benefits it brings. We are also a core member of the MI Zero Emission Shipping Mission, which aims to have at least 5 per cent of the global deep-sea fleet running on zero-emission fuels such as low carbon hydrogen, green ammonia, green methanol and advanced biofuels by 2030.

We will complement the work of the MI Clean Hydrogen Mission through participation in other forums. We are committed to driving implementation of the 'Tokyo Statement' and Global Action Agenda developed under the Hydrogen Energy Ministerial, whose activities are aimed at promoting hydrogen deployment and encouraging better coordination amongst member countries. We are a member of the CEM Hydrogen Initiative, and will champion its efforts to raise international policy ambition and advance low carbon hydrogen deployment at scale. We will continue to participate actively in IPHE discussions that bring together policymakers and stakeholders in pursuit of regulatory, standards, safety and education objectives, and where we are already contributing to exploring the requirements for future rules governing trade in hydrogen.

These partnerships are making strong progress, but we believe that together, we can go further. The UK will work with partners to strengthen the alignment of individual strands of international collaboration, seeking to develop a globally coordinated 'push-pull' strategy to drive development and deployment of low carbon hydrogen as swiftly and efficiently as possible. Governments are uniquely placed to support both innovation and deployment of technologies to increase supply ('push') and demonstrate and incentivise demand ('pull'), stimulating further private sector investment in research and innovation, production and end use. With strengths across the hydrogen value chain from research to commercial actors and a strong global network, the UK is well placed to work with other leading hydrogen proponents to galvanise this enhanced activity.

We will use our 2021 Presidency of the G7 and co-Presidency of COP26 to advance these international efforts. **Through the G7, we will reaffirm the importance of low carbon hydrogen in the clean energy transition, and seek commitments to increase its production and deployment.** This will support the establishment of a future international hydrogen market, based on recognition of the job-creation and sustainable growth potential of low carbon hydrogen.

Through our global climate leadership, including through our co-Presidency of COP26, we will seek to bring together public and private actors who recognise the crucial role that hydrogen can play in tackling emissions and unleashing clean growth, to facilitate greater coordination and progress across international hydrogen innovation, deployment and policy activity. This approach will include developing countries, and both public and private sector initiatives – sending a clear signal about hydrogen's place in the future global energy mix to give investors and innovators across the value chain confidence, certainty and clarity.

Opportunities for bilateral and regional collaboration

Alongside multilateral collaboration, we are keen to work with key partner countries to develop shared research and innovation activities, complementary policy frameworks and future trade opportunities. We recognise that, in cases of particularly well-matched hydrogen interests or shared challenges, more specific and in-depth collaboration can build on and complement the work of multilateral forums. We will embrace these opportunities.

Working with our North Sea and European neighbours will be key to developing common approaches that will support UK hydrogen investment and facilitate regional trade through interconnectors, pipelines and shared infrastructure. Opportunities include:

- Activities which build on, and complement, multilateral activities. For example, as co-leads of MI's Clean Hydrogen Mission, the UK and European Commission – and individual European partners – could expand on its work on regional value chains.
- Collaboration with North Sea partners to realise the region's potential significance for hydrogen production, storage and transportation, including facilitation of future North Sea trade.
- Activity under Horizon Europe. The UK played a strong role in the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), and will continue to make an active contribution to the Clean Hydrogen Partnership for Europe.

We will also continue to work with key global partners to develop our respective hydrogen economies and establish a global hydrogen market. Opportunities include:

- Joint research and innovation, especially where we share common interests – such as in decarbonising industrial sectors – or hold complementary expertise.

- Developing common regulatory approaches and other policies where appropriate – including by pooling insights on policy development and the feasibility of new use cases.
- Facilitating long-distance trade in hydrogen. As a leading maritime nation, the UK is well-positioned to build on existing trade in ammonia and to develop new trade routes in hydrogen derivatives to realise global trading opportunities.

Ensuring fair distribution of shared gains and supporting hydrogen through trade agreements

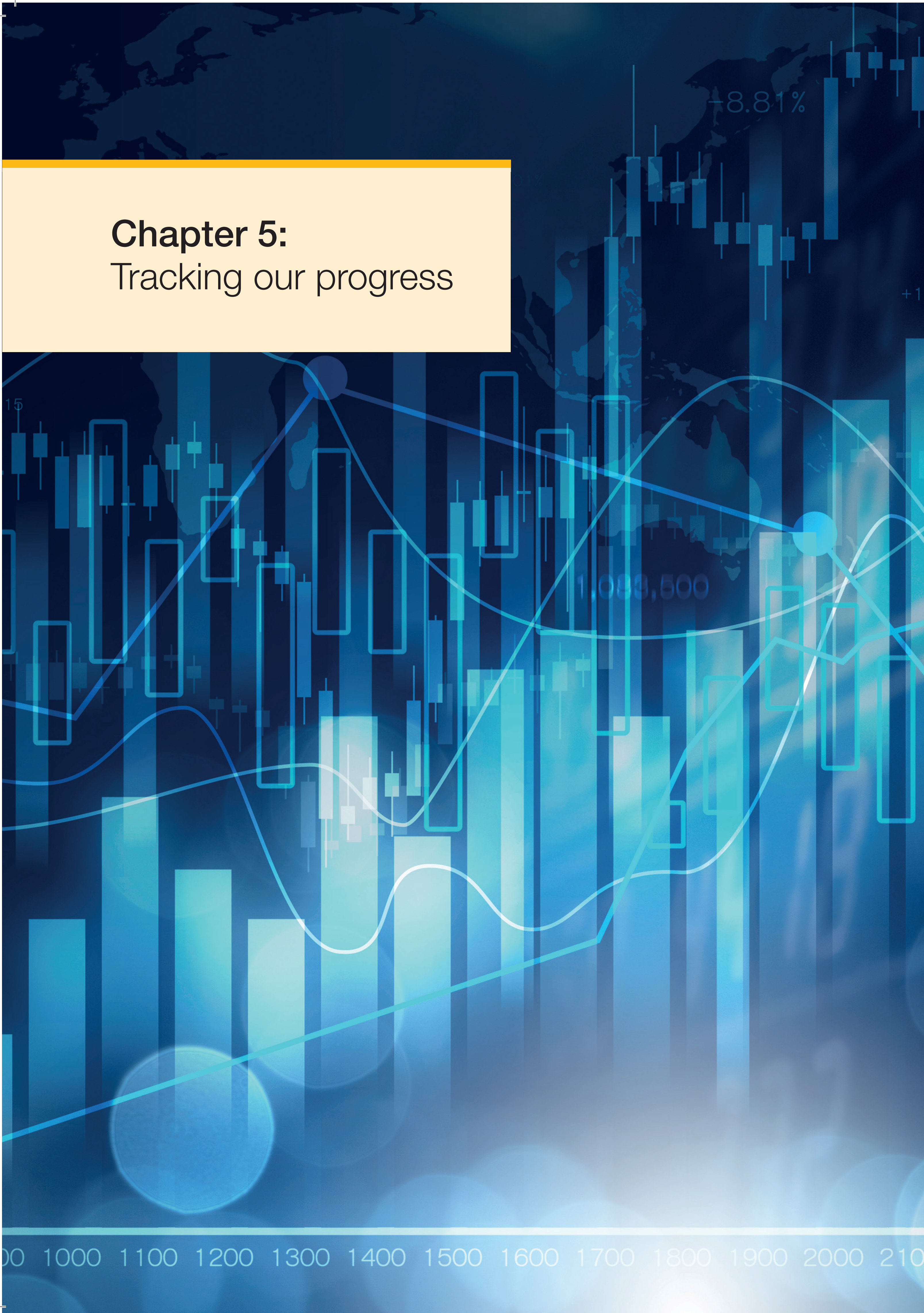
We will continue to support hydrogen-enabled low carbon transitions and share relevant UK expertise through Official Development Assistance, building on our work to date. This includes support to develop hydrogen roadmaps in Mexico and South Africa through the UK Partnering for Accelerated Climate Transitions programme, and UK Clean Energy Innovation Facility support for scoping green hydrogen production, priority uses and export opportunities in Morocco. Under our international CCUS programme, a global decarbonising natural gas study is analysing the use of CCUS across the natural gas value chain, including for hydrogen generation.

The UK will also use its position as a leading advocate for free trade to galvanise action on hydrogen. We will seize opportunities, including through Free Trade Agreements and our place in the World Trade Organization, to support the development of a global low carbon hydrogen market. This means ensuring an attractive trade regulation environment, reducing technical barriers to trade, and facilitating investment in hydrogen technologies and trading infrastructure. This approach is a natural extension of the support we will provide to the UK's own hydrogen sector, as set out in Chapter 3, and will allow our world-leading commercial sector to fulfil its potential to contribute to the global deployment of clean energy technologies.

Climate champion, proven partner: primed for hydrogen

The UK has a proven record of leadership in developing and deploying innovative clean energy solutions, supporting research, development and deployment activities that bring down costs, and creating the policy frameworks to enable scale-up. This has resulted in rapid decarbonisation while supporting clean growth. We have consistently shared our experience and lessons with the world, and sought to learn from and build on the achievement of others in turn. Our net zero ambition and collaborative approach will ensure that by 2030, the UK can stand with our partners at the heart of a new global low carbon hydrogen success story.

Chapter 5:
Tracking our progress



This strategy sets out the key steps needed in the 2020s to deliver our 5GW ambition by 2030 and create a thriving low carbon hydrogen economy in the UK to support our CB6 and net zero targets. We have detailed a number of commitments and actions that we will take to make this happen. The strategy is an ambitious, first of its kind document for hydrogen in the UK. It signals our long-term commitment to developing low carbon hydrogen as a credible, safe and affordable energy option in our journey to net zero.

The UK Hydrogen Strategy outlines a range of policies and initiatives already underway, and other commitments which we will take forward over the coming years (summarised at the end of the strategy), that will support the delivery of our 2030 ambition and the role of hydrogen in CB6 and net zero. We will design and implement these as well as any future policies following best practice guidance outlined in the HM Treasury Green Book.[96]

We will use the principles set out in Chapter 1.5 – long term value for money for taxpayers and consumers, growing the economy whilst cutting emissions, securing strategic advantages for the UK, minimising disruption and cost for consumers and households, keeping options open, adapting as the market develops and taking a holistic approach – to guide the actions we take over the coming decade. This includes the development of hydrogen-specific policies, for example the design of the Net Zero Hydrogen Fund and Hydrogen Business Model, as well as ensuring that the role of and opportunity for hydrogen is appropriately reflected in broader energy system developments, such as in delivering our goal of deploying CCUS in four industrial clusters and our aim for 40GW of offshore wind by 2030.

Our approach

Tracking our progress is essential to ensure that we are developing a UK hydrogen economy in line with the outcomes set out in Chapter 1.5 and our roadmap. As such, we will monitor progress against the outcomes while also supporting data collection on low carbon hydrogen more broadly, for example through incorporating data on its deployment into existing BEIS energy systems publications.[97] Our approach to monitoring aims to be flexible and transparent but also efficient – with a view to minimising reporting burdens on government and industry by, for example, making use of established data collection processes. This supports BEIS' vision, outlined in its monitoring and evaluation framework, to create the conditions for proportionate, good quality monitoring and evaluation across the department's policies.[98]

Flexible

As the market for low carbon hydrogen is still nascent, we will need to be flexible and adaptable in our approach to monitoring and evaluation. The success of UK offshore wind[99] shows how new low carbon technologies can defy expectations and analytical projections. The lesson is that we cannot know with certainty if the outcome measures and success indicators in this strategy will reflect the UK context in 2030. The exact mix of technologies, end use and locations which will make up the hydrogen economy is still unclear, as is how low carbon hydrogen will compare to and compete with other new low carbon technologies. We will remain alert to changes and market developments and be willing to amend our indicators and metrics if necessary.

Transparent

We want to make sure that our progress in developing a hydrogen economy is well understood, and we welcome public accountability. We are already following best practice guidance on sharing information for publicly funded hydrogen innovation projects. Sharing information and data in a transparent and open way can yield significant benefits. For example, sharing commercially appropriate insights from 'first-of-a-kind' projects will enable new project developers to better understand the conditions for success (which can make it easier to attract investment). Additionally, research conducted to date (primarily in the context of use of hydrogen for heat) has highlighted considerable public unfamiliarity with hydrogen as a technology and fuel source. The more we collect and share information, the more readily we can socialise this new decarbonisation option with the public. This strategy has signalled where there are gaps in our understanding and how we are initiating work to fill those gaps. As our understanding and delivery evolves, we will continue to keep the public informed on the progress of decarbonisation and the development of the hydrogen economy in the UK. The government will aim to publish a review of this strategy every five years, with regular updates to the market on policy development in the interim.

Efficient

This strategy details how developing a hydrogen economy cuts across a number of existing areas of economic, energy and climate policy. This means that data collected in relation to low carbon hydrogen will have multiple uses which can inform policy design and strategic prioritisation of government activity. To reflect the increasingly important role of hydrogen as a key energy vector we will incorporate data on its deployment into existing BEIS energy systems publications.[100] Similarly, we will mainstream hydrogen indicators into future monitoring frameworks, including implementation plans for the NZHF and the Hydrogen Business Model work.

Forward looking

The UK Hydrogen Strategy signals a step change in government's policy activity on hydrogen. Data collection and metrics will allow us to develop strong monitoring and evaluation processes for future policies. Evidence gathered through monitoring will develop our understanding of the hydrogen economy and will feed into the policy development cycle to ensure that future policies are evidence-based and effective.[101]

Outcomes

We will track progress against our outcomes through a set of key indicators and broader metrics where available (see Table 5 below). Given the early state of low carbon hydrogen deployment we will need to develop metrics and collect new information against many of the outcomes. Tracking a range of data will help us provide a comprehensive picture of the strategy's impact across the economy.

Table 5: Hydrogen strategy outcomes and indicative metrics

Strategy outcome	Potential indicators and metrics
Progress towards 2030 ambition	• Low carbon hydrogen capacity installed (GW) • Volume of hydrogen produced (TWh) • Breakdown by technology (such as electrolysis and methane reformation)
Decarbonisation of existing UK hydrogen economy	• Remaining volume of fossil fuel hydrogen produced (TWh)
Lower cost of hydrogen production	• Levelised cost (£/MWh)
End to end hydrogen system with diverse range of users	• Estimated volume of hydrogen used in the UK (TWh by sector)
Increased public awareness	• Percentage of people aware of/familiar with hydrogen

Promote UK economic growth and opportunities (including jobs)	• We are exploring using metrics such as:
	  • Number of low carbon hydrogen jobs available in different regions of UK and/or percentage of people trained or retrained into 'green' jobs within the sector
	  • R&D spend and patents
	  • Gross Value Added (GVA)

Emissions reduction under Carbon Budgets 4 and 5	• CO_2 emissions reduction from hydrogen
Evidence-based policy making	• Quantitative and qualitative data collected • Engagement with stakeholders and expert advice

We will develop clear metrics in line with Table 5 above to enable us to monitor progress against our outcomes and commitments in this strategy, including incorporating data on hydrogen production into the Digest of UK Energy Statistics (DUKES).

We recognise that industry, investors and other stakeholders will value and need further clarity on what government is doing to support the hydrogen economy as it develops and scales up over the course of the decade and beyond. As indicated in Chapter 1.5, we intend to provide regular updates to the market as our policy develops. The first of these is expected in early 2022, where we intend to provide a response to our Hydrogen Business Model consultation and indicative heads of terms, our hydrogen production strategy and finalised design elements of the low carbon hydrogen standard. This approach will support learning by doing and maintain ongoing dialogue and engagement, providing early certainty and clarity where possible while developing the sustainable, long term underpinnings of a dynamic, world-leading hydrogen economy and securing strategic advantages for the UK.

Delivering a thriving UK hydrogen economy

Low carbon hydrogen has a key role to play in the UK's net zero energy future. The 2020s will be critical for laying the groundwork to develop a thriving hydrogen economy by 2030, positioned for further ramp up to help meet CB6 and set us on a pathway to net zero by 2050. This strategy sets out our whole-system approach to meeting this ambition. This includes working closely with industry and the research and innovation community to scale up along the value chain and put in place the wider policy frameworks to support this, and to secure the economic opportunities that the hydrogen economy holds for the whole of the UK. In doing so, we will work with our international partners to ensure that low carbon hydrogen can contribute to the global transition to net zero, and we will track our progress to make sure that we deliver on our objectives. Building a thriving UK hydrogen economy is a once-in-a-lifetime opportunity to help create a new, clean energy industry of the future which can play a key role in the UK's transition to net zero and deliver real economic opportunities across the UK.

Full list of commitments

Chapter	Commitment
2.2 Production	We will work with industry to deliver our ambition for 5GW of low carbon hydrogen production capacity by 2030. In doing so, we would hope to see 1GW of production capacity by 2025.
	We will provide £240m for the Net Zero Hydrogen Fund out to 2024/25 for co-investment in early hydrogen production projects. We intend to launch this Fund in early 2022.
	We will provide up to £60 million under the Low Carbon Hydrogen Supply 2 competition, which will develop novel hydrogen supply solutions for a growing hydrogen economy.
	We intend to finalise the design elements of a UK standard for low carbon hydrogen by early 2022.
	We intend to provide a response to our consultation on a Hydrogen Business Model alongside indicative Heads of Terms in Q1 2022. We aim to finalise the business model in 2022, enabling the first contracts to be allocated from Q1 2023.
	We will develop further detail on our production strategy and twin track approach, including less developed production methods, by early 2022.
2.3 Networks & storage	We will continue to support research, development and testing projects to explore development of hydrogen network infrastructure.
	We will review the overarching market framework set out in the Gas Act 1986 to ensure appropriate powers and responsibilities are in place to facilitate a decarbonised gas future.
	We are reviewing gas quality standards with a view to enabling the existing gas network to have access to a wider range of gases in future, potentially including hydrogen.
	We will launch a Call for Evidence on the future of the gas system this year.
	We will undertake a review of systemic hydrogen network requirements in the 2020s and beyond, including need for economic regulation and funding. We will provide information on the status and outputs of this hydrogen network review in early 2022.
	We will provide up to £68 million for the Longer Duration Energy Storage Demonstration competition, with storing hydrogen produced from excess electricity in scope (subject to eligibility criteria).
	We will undertake a review of systemic hydrogen storage requirements in the 2020s and beyond, including need for economic regulation and funding. We will provide information on the status and outputs of this review in early 2022.
	We will use the Hydrogen Business Model consultation to seek views on a number of questions which will feed into our hydrogen network and storage reviews.
	We will provide up to £60 million under the Low Carbon Hydrogen Supply 2 competition, which will develop novel hydrogen supply solutions, including storage technologies.

Chapter	Commitment
2.4.1 End use: industry	Within a year, we will publish a Call for Evidence to explore with industry the further interventions needed to phase out carbon intensive hydrogen and transition to low carbon production methods and sources, at the required pace to meet net zero.
	We will provide grant funding to support fuel switching technologies, including low carbon hydrogen, through Phase 2 of the £315m Industrial Energy Transformation Fund.
	We will launch a new £55 million Industrial Fuel Switching 2 Competition later this year to develop and demonstrate innovative solutions for industry to switch to low carbon fuels such as hydrogen.
	We will launch a new £40 million Red Diesel Replacement Competition to fund the development and demonstration of innovative technologies that enable Non-Road Mobile Machinery (NRMM) used for quarrying, mining, and construction to switch from red diesel to hydrogen or other low carbon fuels.
	We will provide support for research and innovation to support use of hydrogen in industry through the Net Zero Innovation Portfolio and initiatives led by the Industrial Decarbonisation Research & Innovation Centre.
	We will work with cluster projects to better understand the opportunities that pathfinder sites present, so to maximise the benefit to the sites themselves and the associated clusters.
	By the end of this year we will launch a new Call for Evidence on 'hydrogen-ready' industrial equipment.
	We will work with industrial end users to ensure their needs and the potential impacts of a full or partial transition to hydrogen via the gas grid are well understood.
2.4.1&2 End use: industry & power	We will engage with industry later this year on possible requirements for a research and innovation facility to support hydrogen use in industry and power.
2.4.2 End use: power	We will engage with industry to understand the economics and system impacts of introducing hydrogen into the power sector, including the impacts of sector coupling and utilising hydrogen energy storage.
	We will review the progress of recent actions in the power sector, and engage with relevant stakeholders and hydrogen projects early to ensure there is suitable support for hydrogen in the power sector.
2.4.3 End use: heat in buildings	We will deliver hydrogen for heat trials (neighbourhood by 2023, village by 2025 and potential pilot town by 2030), with a view to inform our 2026 strategic decision point on the future of hydrogen for heat.
	We aim to consult later this year on the case for enabling, or requiring, new natural gas boilers to be easily convertible to use hydrogen ('hydrogen-ready') by 2026.

Chapter	Commitment
2.4.4 End use: transport	We will provide up to £120 million this year through the Zero Emission Bus Regional Areas (ZEBRA) scheme towards 4,000 new zero emission buses, either hydrogen or battery electric, and infrastructure needed to support them.
	We will provide up to £20 million this year to design trials for both electric road system and hydrogen long haul heavy road vehicles (HGVs) and to run a battery electric trial to establish the feasibility, deliverability, costs and benefits of each technology.
	We will provide up to £20 million this year for the Clean Maritime Demonstration Competition, to accelerate the design and development of zero emission marine vessels in the UK.
	We will provide up to £15 million this year for the 'Green Fuels, Green Skies' competition to support the production of first-of-a-kind sustainable aviation fuel plants in the UK.
	We will provide £3 million this year to support the development of a Hydrogen Transport Hub in Tees Valley, and £4.8 million (subject to business case) to support the development of a hydrogen hub in Holyhead, Wales.
2.5.1 Creating a market: market framework	We intend to provide a response to our consultation on a Hydrogen Business Model alongside indicative Heads of Terms in Q1 2022. We aim to finalise the business model in 2022, enabling the first contracts to be allocated from Q1 2023. We will provide further detail on the revenue mechanism which will provide funding for the Business Model later this year.
	We will undertake further work to understand and develop appropriate market frameworks to drive investment and deployment and transition to longer term competitive market frameworks. We will aim to publish initial conclusions and proposals in early 2022.
	We will work across government to highlight the potential role of hydrogen in the future energy system and consider how this should be reflected in the design of wider energy markets and policies (e.g. capacity market, green gas support scheme).
	We will continue to work with industry and regulators in the early 2020s to identify, prioritise and address regulatory barriers faced by hydrogen projects, and consider changes needed to unlock hydrogen investment and deployment across the value chain. We will aim to publish initial conclusions and proposals in early 2022.
Case study: gas blending	We will engage with industry and regulators to develop the safety case, technical and cost effectiveness assessments of blending up to 20 per cent hydrogen (by volume) into the existing gas network. Subject to completion of safety trials, we aim to provide an indicative assessment of the value for money case for blending by Q3 2022, with a final policy decision likely to take place in late 2023.

Chapter	Commitment
2.5.2 Creating a market: regulatory framework	We will continue to work with industry and regulators to consider what regulatory changes may be appropriate across the hydrogen value chain.
	We will work across government to highlight the potential role of hydrogen in the future energy system and consider whether and how this should be reflected in wider regulatory and policy changes.
	We will establish a Hydrogen Regulators Forum, with representation across the relevant regulatory areas (environmental, safety, markets, competition and planning).
	We will work across government and with regulators to ensure that interlinkages between hydrogen and broader governance and regulatory changes are appropriately considered. We will consult this year on the institutional arrangements governing the energy system over the long term, including system operation and energy code governance.
3.1 Economic benefits: supply chains	We will actively monitor the extent to which competitive UK businesses are benefitting as the hydrogen sector matures. If necessary, we will consider what options are open to ensure a fair playing field that includes UK businesses. We will set out more detail on this in our Hydrogen Sector Development Action Plan by early 2022.
	We will work with industry to improve visibility of the low-carbon hydrogen project pipeline across the supply chain, learning from the successes of initiatives in other low-carbon sectors.
3.2 Economic benefits: jobs and skills	As part of our work to develop the low carbon hydrogen sector, we will assess the opportunities for hydrogen employment across the UK.
	We will work with industry, trades unions, the devolved administrations, local authorities, and enterprise agencies to support sustained and quality jobs and ensure that there is effective and targeted investment in relevant skills.
	We will work with industry, education providers and local and regional authorities to explore opportunities for relevant skills programmes, including apprenticeships and re-skilling programmes.
	We will set up an Early Career Professionals Forum under the Hydrogen Advisory Council.
	We will continue to monitor skills as the hydrogen sector matures and consult if necessary to identify barriers to sufficient private sector investment into growing the UK skills base and supporting good quality jobs and equality of opportunity.

Chapter	Commitment
3.3 Economic benefits: maximising UK R&I strengths	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 and other partners to better understand the scale, scope and type of private sector investment into hydrogen R&I in the UK, and how it can be further incentivised.
	We will work with experts including the newly established R&I Working Group under the Hydrogen Advisory Council to develop a hydrogen technology R&I Roadmap to inform public and private sector R&I investment and prioritisation.
	We will use our role as one of the co-leads of Mission Innovation's new Clean Hydrogen Mission to champion open and active international engagement and research sharing to accelerate hydrogen R&I progress and maximise its benefits.
	We will continue to foster collaborative international research and information exchange through our active membership of the International Energy Agency (IEA) Hydrogen Technology Collaboration Programme (Hydrogen TCP).
4 International: demonstrating global leadership	Through the G7, including our Presidency this year, we will reaffirm the importance of low carbon hydrogen in the clean energy transition, and seek commitments to increase its production and deployment.
	Through our global climate leadership, including through our co-Presidency of COP26, we will seek to bring together public and private actors who recognise the crucial role that hydrogen can play in tackling emissions and unleashing clean growth to facilitate greater coordination and progress across international hydrogen innovation, deployment and policy activity.
5 Tracking our progress	We will develop metrics to enable us to monitor progress against our outcomes and the commitments in this strategy, including incorporating data on hydrogen production into the Digest of UK Energy Statistics.

Endnotes

1 Internal BEIS analysis based on the Energy Innovation Needs Assessment (EINA) methodology with updated domestic and global scenarios; figures consider the direct GVA and jobs linked to hydrogen production, stationary CHP fuel cells and domestic distribution only; EINA methodology provided by Vivid Economics (2019), 'Hydrogen and fuel cells (EINA sub-theme)' (viewed 1 June 2021)
2 Data from the Fuel Cells and Hydrogen Observatory suggests less than one per cent of hydrogen production capacity in the UK is from electrolysis, the carbon intensity of which depends on the electricity source; see Fuel Cells and Hydrogen Observatory (2021), 'Hydrogen Supply Capacity' (viewed 9 June 2021)
3 Fuel Cells and Hydrogen Observatory (2021), 'Hydrogen Demand' (viewed 9 June 2021)
4 Department for Business, Energy and Industrial Strategy (2021), 'Carbon Budget 6 Impact Assessment' (viewed 9 June 2021)
5 Hydrogen as a proportion of final energy consumption in 2050 in agriculture, industry, residential, services and transport sectors; excludes energy demand for resources, processing and electricity generation
6 Department for Business, Energy and Industrial Strategy (2021), 'Final UK greenhouse gas emissions national statistics' (viewed 9 June 2021)
7 HM Government (2020), 'The Ten Point Plan for a Green Industrial Revolution' (viewed 22 June 2021)
8 Based on estimates of carbon captured by trees over 10 year period; see Forestry Commission (2020), 'Responding to the Climate Emergency with New Trees and Woodlands' (viewed 16 June 2021); Forestry Commission (2019), 'Government Supported New Planting of Trees in England' (viewed 16 June 2021)
9 Internal BEIS analysis based on EINA methodology with updated domestic and global scenarios (see Figure 1)
10 HM Government (2020), 'The Ten Point Plan for a green industrial revolution' (viewed 1 June 2021)
11 Internal BEIS analysis based on EINA methodology with updated domestic and global scenarios (see Figure 1)
12 Scottish Government (2020), 'Scottish Hydrogen Assessment' (viewed on 21 June 2021)
13 Scottish Government (2020), 'Scottish Government Hydrogen Policy Statement' (viewed 21 June 2021)
14 UK Government (2021), 'Heads of Terms for the Islands Growth Deal' (viewed 21 June 2021)
15 Welsh Government & Element Energy (2020), 'Hydrogen in Wales: a pathway and next steps for developing the hydrogen energy sector in Wales' (viewed 22 June 2021)
16 DNV GL (2019), 'Hy4Heat, Hydrogen Purity – Final Report' (viewed 18 June 2021) and Energy Research Partnership (2016), 'Potential Role of Hydrogen in the UK Energy System' (viewed 18 June 2021)
17 For further detail, see: 'Current role of Hydrogen' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
18 2020s, central case scenario; for more detail on carbon intensity estimates, see: Department for Business, Energy and Industrial Strategy (2021), 'Consultation on UK Low Carbon Hydrogen'; E4tech (UK) Ltd and Ludwig-Bölkow-Systemtechnik GmbH (2021), 'Low Carbon Hydrogen Standard' (viewed 21 June 2021)
19 Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Production Costs 2021' (viewed 21 June 2021); estimates based on retail electricity and fuel prices; SMR without CCUS estimate based on capex specific for grey hydrogen production and 0% carbon capture; all other costs and technical specifications are in line with those for SMR + CCUS plants
20 For further detail, see: '2030 Ambition' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
21 BEIS analysis, as well as external analysis by the CCC and others, shows that a mix of production methods, including electrolytic and CCUS-enabled hydrogen production, will be compatible with reaching net zero in 2050
22 For further detail, see: 'Hydrogen Supply' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021); and Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Production Costs 2021' (viewed 21 June 2021)
23 For further detail, see: 'Supply beyond 2030' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
24 Department for Business, Energy & Industrial Strategy (2021), 'Carbon Budget 6 Impact Assessment' (viewed 9 June 2021)

25 For further detail, see: 'Supply beyond 2030' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
26 Gas for Climate (2021), 'The 'Extending The European Backbone: A European Hydrogen Infrastructure Vision Covering 21 Countries' (viewed 17 June 2021); page 4 sets out that by 2040, "a pan-European dedicated hydrogen transport infrastructure can be envisaged with a total length of around 39,700 kilometres, consisting of 69% repurposed existing infrastructure and 31% of new hydrogen pipelines"
27 The business model for CCUS transport and storage is currently under development with the latest commercial update, with implications for producers of CCUS-enabled hydrogen; see Department for Business, Energy & Industrial Strategy (2021), 'Carbon Capture, Usage and Storage An update on the business model for Industrial Carbon Capture' (viewed 17 June 2021)
28 Hydrogen has only one-third of the energy density by volume of natural gas and can cause embrittlement in certain materials, increasing risk of leakage; Arup (2016), 'Five minute guide to Hydrogen' (viewed 3 March 2021)
29 Inovyn and Storenergy (2019),'Project HySecure – Phase 1 Summary Sept 2019', page 4-5, Produced under the Department for Business, Energy and Industrial Strategy Low Carbon Hydrogen Supply Competition (viewed 21 June 2021)
30 Williams J and others, British Geological Survey (2020), 'Theoretical capacity for underground hydrogen storage in UK salt caverns' (viewed 21 June 2021)
31 Energy Networks Association (2021), 'Britain's Hydrogen Network Plan - Report' (viewed 21 June 2021)
32 National Grid ESO (2021), 'Future Energy Scenarios' (viewed 21 June 2021)
33 Gazias E and others, Aurora Energy Research (2020), 'Hydrogen for a Net Zero GB: an integrated energy market perspective' (viewed 25 June 2021)
34 Conversions undertaken by BEIS; see OfGEM (2021), 'GB Gas Storage Facilities' (viewed 21 June 2021)
35 HyNet North West (2020), 'HyNet North West – Unlocking Net Zero for the UK' (viewed 21 June 2021)
36 Equinor (2020), 'H2H Saltend - The First Step to a Zero Carbon Humber' (viewed 21 June 2021)
37 For further detail on the use of ammonia in shipping, see: 'Use of Hydrogen in Transport' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
38 Department for Business Energy and Industrial Strategy (2018), 'Low Carbon Hydrogen Supply Competition (closed)' (viewed 21 June 2021)
39 ITM Power, Inovyn, Storenergy, Cadent, Element Energy (2020), 'Project Centurion Feasibility Study', UK Research and Innovation (viewed 21 June 2021)
40 Department for Business, Energy & Industrial Strategy (2021), 'Low Carbon Hydrogen Supply 2 Competition' (viewed 21 June 2021)
41 Department for Business, Energy & Industrial Strategy (2021), 'Longer Duration Energy Storage Demonstration competition' (viewed 21 June 2021)
42 Department for Business, Energy & Industrial Strategy (2021) 'Facilitating the deployment of large-scale and long-duration electricity storage: call for evidence' (viewed 21 July 2021)
43 Or 72 $MtCO_2e$; see Department for Business, Energy and Industrial Strategy (2020), 'Final UK greenhouse gas emissions from national statistics: 1990 to 2018: Supplementary tables' (viewed 21 June 2021)
44 For further detail, see: 'Box 1' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
45 Less energy-intensive manufacturing includes the manufacturing of vehicles, wood products, pharmaceuticals and electronics, among other industries
46 Department for Business, Energy and Industrial Strategy (2021), 'IETF Phase 1: Summer competition winners' (viewed 22 June 2021)
47 For further detail, see: 'Box 2' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
48 Department for Business, Energy and Industrial Strategy (2020), 'Energy White Paper: Powering our Net Zero Future December 2020' (viewed June 2021)
49 Department for Business, Energy and Industrial Strategy (2020), 'Enabling a high renewable net zero electricity system Call for Evidence' (viewed June 2021)
50 Department for Business, Energy & Industrial Strategy and Welsh Government (2021), 'Decarbonisation Readiness: joint call for evidence on the expansion of the 2009 Carbon Capture Readiness requirements' (viewed 22 July 2021)

51 Department for Business, Energy & Industrial Strategy (2021), 'Facilitating the deployment of large-scale and long-duration electricity storage: call for evidence' (viewed 21 July)
52 Department for Business, Energy & Industrial Strategy (2021), 'Capacity Market 2021: A Call for Evidence on early action to align with net zero' (viewed 26 July 2021)
53 National Statistics (2020), 'Households projections for England', Table 401 and Department for Business, Energy and Industrial Strategy (2020), 'Non-domestic National Energy Efficiency Data-Framework' based on 2018 data (viewed April 2021)
54 National Statistics (2020), 'Households projections for England', Table 401 and Department for Business, Energy and Industrial Strategy (2020), 'Non-domestic National Energy Efficiency Data-Framework' based on 2018 data (viewed April 2021)
55 For further detail, see: 'Box 3' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
56 Department for Business Energy and Industrial Strategy (2021), 'UK Greenhouse Gas Emissions' (viewed June 2021)
57 Since 2017, the programme has been delivering new publicly accessible hydrogen refuelling stations, upgrading existing stations and increasing the uptake of fuel cell electric vehicles
58 For further detail, see: 'Box 4' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
59 By 2050, there could be 75-9TWh of demand for hydrogen-based fuels (including ammonia and methanol) in domestic and international shipping; for further detail, see: 'Box 4' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
60 For further detail, see: 'Box 4' in Department for Business, Energy and Industrial Strategy (2021), 'Hydrogen Analytical Annex' (viewed 21 June 2021)
61 Department for Transport (2020), 'Annual bus statistics: year ending March 2020' (viewed June 2021)
62 Lee and others (2013), 'Shipping and aviation emissions in the context of a 2°C emission pathway' (viewed June 2021)
63 UMAS, E4Tech, Frontier Economics, CE Delft (2019) 'Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution. Scenario Analysis: Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs. A Report for the Department for Transport' (viewed June 2021); based on the definition of UK international shipping that was adopted in the research commissioned by Department for Transport, the estimates for UK international shipping represent the potential hydrogen demand associated with the international shipping activity that transports UK imports; other definitions of UK international shipping would result in different estimates
64 UMAS, E4Tech, Frontier Economics, CE Delft (2019) 'Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution. Maritime Emission Reduction Options. A Summary Report for the Department for Transport' (viewed June 2021)
65 Department for Transport (2019), 'Clean Maritime Plan' (viewed June 2020)
66 H M Government (2021), '£20 million fund to propel green shipbuilding launched' (viewed June 2021)
67 Airbus (2021), 'ZEROe: towards the world's first zero-emission commercial aircraft' (viewed June 2021)
68 'SAF' describes low carbon alternatives to conventional, fossil-derived, aviation fuel which present chemical and physical characteristics similar to those of conventional jet fuel and can therefore be blended into current jet fuel without requiring any aircraft or engine modifications
69 Ricardo (2020), 'Targeted Aviation Advanced Biofuels Demonstration Competition – Feasibility Study' (viewed June 2021)
70 Department for Transport (2021) 'Mandating the use of sustainable aviation fuels in the UK' (viewed 23 July 2021)
71 The Climate Change Act 2008 set a legally binding target for reducing UK carbon dioxide emission by at least 80 per cent by 2050, compared to 1990 levels, which has since been superseded by our net zero target
72 H M Government (2020), 'The Ten Point Plan for a green industrial revolution' (viewed 14 June 2021)
73 Department for Business, Energy and Industrial Strategy (2020), 'Energy White Paper: Powering our net zero future' (viewed 14 June 2021)
74 National Grid (2021), 'Hydrogen: the future fuel to achieve net zero?' (viewed 14 June 2021)
75 Legislation.gov.uk (1996), 'Gas Safety (Management) Regulations 1996' (viewed 4 June 2021)
76 HyDeploy (2021), 'What is HyDeploy?' (viewed 14 June 2021)
77 National Grid (2021), 'FutureGrid' (viewed 14 June 2021)
78 HyLaw sought to identify legal barriers to the commercialisation of fuel cell and hydrogen technologies across 18 countries in Europe; see HyLaw (2021), 'About HyLAW' (viewed 14 June 2021)

79 Internal BEIS analysis based on the EINA methodology with updated domestic and global scenarios; figures consider the direct GVA and jobs linked to hydrogen production, stationary CHP fuel cells and domestic distribution only; EINA methodology provided by Vivid Economics (2019), 'Hydrogen and fuel cells (EINA sub-theme)' (viewed 1 June 2021)
80 Energy Industries Council (2021), 'press release', announcing joint BEIS-DIT-EIC Energy Supply Chain Taskforce (viewed 27 May 2021)
81 Defined as new jobs generated by increased local spending on goods and services
82 As defined in the Department for Business, Energy and Industrial Strategy (2018), 'Good Work Plan' (viewed June 2021)
83 Department for Education (2021), 'Skills for Jobs White Paper' (viewed June 2021)
84 Green Jobs Taskforce (2021), 'Green Jobs Taskforce report' (viewed on 14 July 2021)
85 For 40% women employed in those sectors by 2030; see Department for Business, Energy and Industrial Strategy (2019), 'Offshore Wind Sector Deal' and Department for Business, Energy and Industrial Strategy, (2018) 'Nuclear Sector Deal' (viewed June 2021)
86 Oil and Gas UK (2019), 'Workforce Report' (figure from 2018), (viewed 18 May 2021)
87 Department for Business, Energy and Industrial Strategy (2021), 'North Sea Transition Deal' (viewed June 2021)
88 Silverman D, Imperial College London (2020), 'Imperial pioneers innovation in clean energy sector' (viewed 18 June 2021); Durlacher Ltd (2004), 'Placing and Admission to the Alternative Investment Market' (viewed 18 June 2021)
89 Hydrogen TCP (2020), 'International Energy Agency' (viewed 21 June 2021)
90 Wind Europe (2021) 'Offshore Wind in Europe, Key Trends and Statistics 2020' (exchange rate based on monthly average between Jan 2011 and Dec 2020)
91 HM Treasury (2021), 'UK Infrastructure Bank Press Release' (viewed 17 June 2021)
92 Sustainable Development scenario from 'IEA Energy Technology Perspectives 2020' (viewed 17 May 2021)
93 GHG abatement estimated relative to IEA Stated Policy scenario, accounting for existing policy commitments
94 Strong policy scenario from 'Bloomberg New Energy Finance (BNEF) Hydrogen Economy Outlook 2020', (viewed 17 May 2021)
95 Hydrogen Council (2020), 'Path to hydrogen competitiveness – A cost perspective' (viewed 17 May 2021)
96 HM Treasury (2020), 'The Green Book' (viewed June 2021)
97 To include Digest of UK Energy Statistics (DUKES) and BEIS' Energy and emissions projections (EEP)
98 Department for Business, Energy and Industrial Strategy (2020), 'Monitoring and evaluation framework' (viewed June 2021)
99 Offshore wind prices in renewable Contracts for Difference auctions have fallen from £120/MWh in 2015 to around £40/MWh in 2019, and operational offshore wind capacity has increased from just over 1GW in 2010 to 10GW by 2019; see Department for Business, Energy and Industrial Strategy (2020), 'Energy White Paper: Powering our net zero future' (viewed June 2021)
100 To include Digest of UK Energy Statistics (DUKES) and BEIS' Energy and emissions projections (EEP)
101 For further detail on the policy development cycle, see: HM Treasury (2020), 'The Green Book' (viewed June 2021)