Department for
Business, Energy
& Industrial Strategy

Hydrogen Strategy update to the market: July 2022

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

Contents

Introduction

Low carbon hydrogen is our new home-grown super-fuel which will be vital for our energy security and to meet our legally binding commitment to achieve net zero by 2050. The UK Hydrogen Strategy, published in August 2021, outlined a comprehensive roadmap for the development of a thriving UK hydrogen economy over the coming decade. In the British Energy Security Strategy published in April this year, the government doubled the UK's hydrogen production ambition to up to 10GW, by 2030. This increased ambition cements our place firmly at the forefront of the global race to develop hydrogen as a secure, low carbon replacement for fossil fuels in the transition to greater energy security and net zero.

Since the publication of the UK Hydrogen Strategy, we have continued to deliver on our commitments, setting out new policy and funding for hydrogen across the value chain, and bringing together the international community around shared hydrogen objectives to rapidly develop a global hydrogen economy. Hydrogen was a key component of the Net Zero Strategy, COP26 and the British Energy Security Strategy. The Hydrogen Investment Package and opening of the £240 million Net Zero Hydrogen Fund in April marked a major step forward in delivering government support to drive further private investment into hydrogen production in the UK.

To keep industry informed on the government's ongoing work to develop the hydrogen economy, we committed in the UK Hydrogen Strategy to producing regular updates to the market as our policy develops. In addition to offering an accessible 'one stop shop' of government policy development and support schemes, these updates will provide industry and investors with further clarity on the direction of travel of hydrogen policy across the value chain, so that government and industry can work together most effectively and with the necessary pace to build a world-leading low carbon hydrogen sector in the UK.

Hydrogen production

The British Energy Security Strategy highlighted the critical role that low carbon hydrogen will play in our energy system, supporting both UK energy independence and our carbon reduction targets. We have now doubled the UK's ambition to **up to 10GW of low carbon hydrogen production capacity by 2030**, subject to affordability and value for money, **with at least half of this coming from electrolytic hydrogen**. Our aim is to have up to 1GW of electrolytic hydrogen and up to 1GW of carbon capture, usage and storage (CCUS)-enabled hydrogen operational or in construction by 2025.

To meet our stretching 2025 and 2030 ambitions for electrolytic and CCUS-enabled production, the Hydrogen Investment Package in April 2022 set out details of key government policy, including:

- The **£240 million Net Zero Hydrogen Fund (NZHF)** – with strands of support for development and capital expenditure across CCUS-enabled and non CCUS-enabled production projects. The first wave of funding opened on 25 April 2022.

- The **Hydrogen Business Model (HBM)**, including indicative **Heads of Terms** for the hydrogen business model contract – this will provide revenue support to facilitate investment in new low carbon hydrogen production. Funding for projects operational before March 2025 will be provided by up to £100 million of taxpayer funding committed by government through the Industrial Decarbonisation and Hydrogen Revenue Support (IDHRS) scheme announced in the Net Zero Strategy. **Beyond that, all revenue support for hydrogen production will be levy funded, subject to consultation and legislation being in place**.
- Our intention to hold a **joint HBM / NZHF allocation round for electrolytic projects, which has been launched alongside this strategy update**, with the aim to sign **contracts from 2023**. We are also aiming to run **annual HBM allocation rounds for electrolytic hydrogen**.
- The **Low Carbon Hydrogen Standard (LCHS)**, which defines what constitutes 'low carbon hydrogen' at the point of production, including the methodology for calculating emissions associated with hydrogen production and the steps producers are expected to take to prove compliance. The standard will help ensure new low carbon hydrogen production supported by government contributes to the UK's GHG emission reduction targets under the Climate Change Act.
- A commitment to build on the standard to **set up a hydrogen certification scheme by 2025**, demonstrating high quality British hydrogen for export and ensuring any imported hydrogen meets the same high standards that UK companies expect.

In the UK Hydrogen Strategy, we indicated that CCUS-enabled hydrogen production facilities based in industrial clusters were likely from the mid-2020s and committed to supporting research and innovation (R&I) to develop novel hydrogen supply solutions. To deliver this we have:

- Concluded Phase-1 of the CCUS Cluster Sequencing process: **HyNet and the East Coast Cluster have been announced as 'Track-1' clusters** to be prioritised for deployment in the mid-2020s, with the Scottish Cluster as a reserve. We are currently in the process of shortlisting CO_2 emitter projects – including CCUS-enabled hydrogen producers – to connect to these clusters, through Phase-2 of the Cluster Sequencing process.
- Awarded contracts for 23 feasibility studies and 5 demonstration projects under the £60 million Net Zero Innovation Portfolio (NZIP) **Low Carbon Hydrogen Supply 2 programme**, which funds innovative projects relating to the supply of hydrogen.
- Awarded contracts for the £5 million feasibility and design Phase 1 of the NZIP **Hydrogen BECCS Innovation Programme**. This funding is supporting both gasification related technologies (pre-processing and syngas upgrades), and other novel biohydrogen technologies that can be combined with carbon capture.

The UK Hydrogen Strategy also committed to go further in developing our **hydrogen production strategy**, considering the role of other technologies and supply routes, as well as increasing our understanding of the potential wider environmental impacts of hydrogen production. Since the publication of the Strategy, government has published a range of policy and guidance that builds up our strategic approach to hydrogen production. **Annex 1 sets out the key elements of our strategy for hydrogen production**, along with additional evidence, and points to further action being taken as part of our ongoing work on hydrogen production,

including the increased opportunity for the UK to benefit from becoming an exporter of low carbon hydrogen.

Hydrogen networks and storage

The importance of hydrogen transportation and storage (T&S) infrastructure to the growth of the hydrogen economy was underscored in the UK Hydrogen Strategy and by stakeholders in response to the HBM and NZHF consultations. We have continued to move rapidly, setting renewed ambitions and understanding the need for hydrogen T&S infrastructure:

Hydrogen T&S infrastructure business models

- In the British Energy Security Strategy government **committed to designing, by 2025, new business models to support the development of hydrogen T&S infrastructure**. It is our intention that these business models will provide investors and developers with the reassurance needed to bring forward the T&S infrastructure to meet our ambitions.
- We intend to adopt a pragmatic approach when considering support for small scale T&S costs for both CCUS-enabled and electrolytic hydrogen projects through the initial business model contracts awarded, taking into consideration necessity, affordability and value for money. Following review of stakeholder feedback to the NZHF consultation, **the scope of strand 2, which provides DEVEX support, now includes associated on-site T&S FEED costs**.

Hydrogen T&S Infrastructure requirements and innovation

- In our response to the HBM consultation, we provided an update on the review we committed to undertake on hydrogen T&S infrastructure requirements in the 2020s and beyond. **We intend to publish the consultancy study commissioned as part of this review to understand T&S requirements up to 2035 and beyond later this year.**
- **Later this year we also intend to publish a consultation to seek stakeholders' views on hydrogen T&S infrastructure** to support the design of the business models. We expect to include questions on high-level options for timings, funding and wider economic regulation for this infrastructure.
- We are in the process of setting up a **new Working Group on hydrogen T&S infrastructure under the Hydrogen Advisory Council**, with a focus on funding and economic regulation. It will be made up of a representative group of stakeholders across the hydrogen value chain.
- The Whitelee Green Hydrogen for Glasgow project, the UK's largest power-to hydrogen energy storage project and opened by Minister Hands in November 2021, has continued to progress. This is funded by the predecessor programme to the NZIP. Phase One of the project will generate enough hydrogen to fuel the equivalent of 225 buses travelling to and from Glasgow and Edinburgh each day.
- The Ocean-Fuel project, supported by £7 million in funding from UKRI, is exploring storage solutions including hydrogen and ammonia to help manage the issue of intermittent supply associated with wind energy.

Use of hydrogen

The 2020s roadmap set out in the UK Hydrogen Strategy showed how we anticipate that the use of hydrogen will increasingly decarbonise heavy industry and provide greener, flexible energy across power, transport, and potentially heat, through the 2020s and beyond. Government has moved at pace to meet this vision including engaging industry and wider stakeholders, and supporting innovation, demonstration projects and trials.

We continue to build evidence and develop policy to support use of hydrogen across the economy, accelerating work to stimulate early demand in the 2020s. This includes initially focusing on areas such as fuel switching in large 'anchor sites' in industrial clusters and exploring the potential for electrolytic hydrogen use in dispersed industrial sites, and exploring the need and case for market intervention to support hydrogen to power applications. Our engagement with industry has demonstrated that the power sector has the potential to deliver a pipeline of both new and refurbished power projects that could provide a significant source of hydrogen demand and aid the development of the hydrogen economy, with indication that 100% capable hydrogen firing generation equipment should be available on the open market by 2030. We continue to work across government to facilitate early rollout of hydrogen in transport applications such as buses, as well as accelerating research, trials and demonstration of hydrogen use in heavy goods vehicles (HGVs), maritime and aviation, and in an integrated manner across multiple transport modes through the Tees Valley Hydrogen Transport Hub. We are also continuing work to assess and develop the role of gas blending and hydrogen storage in balancing supply and demand in the early development of the market.

Use of hydrogen in industry

Since the publication of the UK Hydrogen Strategy, government has taken a number of actions to support industry's use of low carbon hydrogen, to aid industrial decarbonisation and support the growth of the hydrogen economy.

Policy development – we have:

- **Launched a call for evidence on 'hydrogen-ready' industrial equipment**, which focused on industrial boilers given the significant potential demand for hydrogen from this equipment category. We are analysing responses to this publication, which may form the basis for a further consultation. If evidence supports the use of environmental permitting to help decarbonise heat, then we anticipate that Decarbonisation Readiness requirements (see 'Use of hydrogen in power' below) could be expanded to cover combustion plants for heat.
- **Published and responded to a call for evidence on stakeholders' use of Combined Heat and Power (CHP) technology**, and potential routes and perceived barriers to decarbonisation. Responses indicated considerable interest in the potential of fuel switching from natural gas to hydrogen in future. Ongoing engagement with participants in the CHP Quality Assurance scheme includes assessing investment decision criteria

and preferred plans for decarbonisation, which will help inform future policy development.

- **Engaged closely with a small number of industrial sites in large clusters** to better understand the barriers they face to fuel switching, to identify any additional demand-side support needed. Given that demand for low carbon hydrogen will likely be concentrated in large industrial clusters during the 2020s, these sites could 'anchor' early demand and foster an initial market for hydrogen close to supply[1].
- **Considered the impact of major current and planned policies on existing hydrogen producers**, including the Industrial Carbon Capture Business Model (ICC BM) and the UK Emissions Trading Scheme (ETS). Our current thinking is that these policies are likely to be sufficient to incentivise and support decarbonisation, and that a call for evidence to explore further interventions to phase out carbon intensive hydrogen, as proposed in the Hydrogen Strategy, may not be needed at this time. We will continue to engage with existing industrial producers of hydrogen to test this thinking and will consider the most appropriate way of gathering further evidence to inform any future policy development as required[2].

Fuel switching and innovation – we have:

- **Launched Phase 2 of the £289 million Industrial Energy Transformation Fund** in England, Wales and Northern Ireland, to support a range of technologies, including fuel switches to low carbon hydrogen.
- **Launched the £26 million NZIP Industrial Hydrogen Accelerator** programme to support innovation projects exploring the potential to produce and use low carbon hydrogen for industrial processes.
- **Launched the NZIP Industries of Future innovation programme**, to support industry to develop decarbonisation roadmaps, initially through scoping studies.
- **Awarded c.£5.6 million in funding for 21 feasibility studies under Phase 1 of the £55 million NZIP Industrial Fuel Switching 2 competition** to support innovation to enable switching to low carbon fuels. 15 feasibility studies are related to or use hydrogen.
- **Awarded c.£6.7 million funding for 17 projects under Phase 1 of the £40 million NZIP Red Diesel Replacement scheme** to support innovation in component technologies to decarbonise Non-Road Mobile Machinery (NRMM) used for quarrying, mining and construction.
- **Awarded contracts for four demonstration projects under Phase 2 of the £12.33 million NZIP Green Distilleries programme** which funds innovative projects to decarbonise distilleries.

We have also engaged with industry on possible requirements for an R&I facility to support hydrogen use in industry and power. While BEIS is not currently developing this concept, in part due to mixed responses to the proposal, government continues to engage with stakeholders on how best to define and support industry's hydrogen R&I needs.

[1] These sites were referred to as "pathfinder sites" in the UK Hydrogen Strategy.
[2] See *Annex 1* for further detail

Use of hydrogen in power

Low carbon hydrogen can be a key component of our future energy system, providing flexible low carbon electricity generation and creating a pathway for the decarbonisation of unabated gas generation. This would support meeting **our commitment, announced in October 2021, to decarbonise the electricity system by 2035, subject to security of supply**. Government is actively pursuing the potential of hydrogen to power:

- **In summer 2022, we intend to publish a consultation on expanding existing Decarbonisation Readiness requirements** for new build and substantially refurbishing combustion power plants to demonstrate they have viable decarbonisation plans by converting to either hydrogen generation or CCUS technology.
- Taking forward our Net Zero Strategy commitment **to explore the need and case for further market intervention in hydrogen to power**. This includes assessing how markets and policies could best facilitate hydrogen power plants coming forward and identifying potential barriers to deployment.
- We are exploring ways to better align the **Capacity Market** with net zero, including by supporting investment in low carbon technologies such as hydrogen-fired generation and creating pathways for the decarbonisation of unabated gas generation. **We aim to consult on any design changes later in 2022.**

Use of hydrogen in heat

The Government is working with industry, regulators and others to deliver a range of research, development and testing projects to assess the feasibility, costs and benefits of using 100% hydrogen for heating, ahead of a strategic decision in 2026 on the role of hydrogen in decarbonising heat. Since publication of the UK Hydrogen Strategy, our continued activity in this area includes:

- **Supporting industry to deliver a neighbourhood trial of hydrogen for heating** (SGN's H100 Fife project in Levenmouth), with the trial due to commence in 2023 and involve around 300 homes.
- Announcing on 6 May 2022 that BEIS and Ofgem will be **taking forward Cadent's and NGN's proposals for potential hydrogen Village Trial locations**, covering areas within Whitby (Ellesmere Port) and Redcar (Teesside). Stage 2 (the detailed design stage of the Village Trial) will run until Spring 2023, after which we will make the final location selection.
- **Publishing in April 2022 the government response to a public consultation we ran in summer 2021 on facilitating a 'grid conversion' hydrogen heating trial**. The consultation response confirmed that we would proceed with legislation to: i) allow GDNs to effectively and safely carry out the activities needed to deliver the village trial, and ii) enable enhanced consumer protections to ensure that those living in the trial area continue to receive fair treatment.
- **Including the legislative changes proposed in the hydrogen heating trial consultation in the landmark Energy Security Bill**, which was introduced on 6 July 2022.

- Working towards the development of technical standards for domestic and non-domestic hydrogen gas installations, and on associated competence frameworks and training specifications for installers through the **Hydrogen Skills and Standards for Heat programme**. The programme has awarded contracts to undertake supporting technical research to close gaps in the existing hydrogen evidence base and enable the development of standards. A revised hydrogen reference standard (IGEM/H/1) was the first to be published in June 2022 under this work.
- **Producing final reports from the Hy4Heat programme** following certification of a number of domestic hydrogen appliances.
- As set out in the UK Hydrogen Strategy, government intends to **publish a consultation on domestic boiler and heating system standards**. This would consider measures designed to improve in-home boiler performance and increase energy efficiency; requiring new domestic gas boilers to be hydrogen-ready from 2026; and the role of gas boiler-heat pump hybrids in the transition to low-carbon heating.

Use of hydrogen in transport

As set out in the UK Hydrogen Strategy, hydrogen is likely to be fundamental to the full decarbonisation of UK transport, and heavy transport including shipping and aviation is likely to comprise one of the largest sources of demand for hydrogen in the longer term, rapidly scaling up, from the 2030s. Transport is also a key early market for low carbon hydrogen projects over the coming years, where we see other modes such as buses and HGVs playing a role in the early scale up of hydrogen demand. We anticipated that the role of government support for hydrogen in transport would change towards 2030 and beyond, with continued R&I investment necessary alongside policy to support the technologies' rollout. We have delivered significant progress since publication of the UK Hydrogen Strategy, including:

- Our **response to a consultation on the amendments to the Renewable Transport Fuel Obligation (RTFO)** was released on 14th July, with most changes coming into effect immediately. The consultation, published in March 2021, sought views on several issues related to hydrogen support. These included expanding the scope of the RTFO to make renewable fuels from non-biological origin to be used in maritime, which was implemented in January 2022, and options on the use of grid transmitted energy in hydrogen production coming in from 14th July 2022.
- During financial year 21/22 we **supported seven trial hydrogen transport projects in the Tees Valley Hydrogen Hub with £3 million funding.** The Hub will accelerate the development of hydrogen solutions for transport decarbonisation, and we intend to announce later this year what form future support for the Hub over the next three years will take. The Hub is already creating significant levels of industry interest, with BP and Protium Green Solutions recently announcing their intentions to build large scale green hydrogen production in the area.
- Our **£23 million Hydrogen for Transport Programme** recently came to a close, though some projects are continuing with delivery. The programme has increased the number of hydrogen refuelling stations (6 new stations and 5 upgrades), and deployed hundreds of hydrogen fuel cell vehicles on UK roads.

- In March 2022 the West Midlands Combined Authority received funding from the Zero Emission Bus Regional Areas (ZEBRA) scheme for **124 hydrogen fuel cell buses and accompanying refuelling infrastructure**, the largest hydrogen bus project in the country. .
- We invested **£20 million in 2021/22 as part of the zero emission road freight trials programme (ZERFT).** This programme was technology neutral and included three feasibility studies designing potential future trials for HGVs powered by hydrogen fuel cells, amongst other technologies. We recently announced an expansion of the programme to create the **£200 million Zero Emission Road Freight Demonstrator programme (ZERFD)**, which will demonstrate zero emission HGV technologies at scale on UK roads. The first two competitions will focus on battery electric and hydrogen fuel cell technologies and will be launched shortly. This is the largest currently announced comparative demonstration of zero emission HGV technologies anywhere in the world and could see hundreds more zero emission HGVs rolled out across the UK.
- In March 2022, **we announced £206 million for the UK Shipping Office for Reducing Emissions (or UK SHORE)**, a new unit within the Department for Transport (DfT) aimed at accelerating the decarbonisation of the maritime sector. This marks the biggest government investment ever in our commercial maritime sector, where hydrogen is likely to play a significant role.
- In May 2022, we announced the first of a series of interventions under UK SHORE, including the **second round of the Clean Maritime Demonstration Competition (CMDC)**. This competition will allocate up to £12 million for feasibility studies and pre-deployment trials in innovative clean maritime solutions and will run until August 2023. Later in 2022, we intend to launch a **third round of the CMDC which will support large technology demonstrations**.
- These build on the success of the first CMDC, which ran between March 2021 and March 2022 and allocated over £23 million funding to 55 projects across the UK to support design and development of zero emission shipping technologies and greener ports. **17 of these CMDC projects were related to hydrogen or hydrogen derived fuels such as ammonia.**
- At COP26 we also announced the **Clydebank Declaration for Green Shipping Corridors**: an initiative to kickstart the establishment of first mover maritime routes between two or more ports on which zero-emission shipping solutions are demonstrated and supported.

At the 2021 Spending Review we announced an extension of the Aerospace Technology Institute programme to 2031 and an increase in funding to £685 million over the Spending Review period, with investment in zero-carbon emission technologies such as hydrogen a priority. We also announced £180 million of funding to the UK Sustainable Aviation Fuel industry. The Aerospace Technology Institute have published reports from the Government funded **FlyZero project which highlights the opportunities of hydrogen in aviation**. We **published our Jet Zero Strategy on 19th July,** setting out our approach to the aviation sector reaching net zero by 2050.

Creating a market

We have made advances since the publication of the UK Hydrogen Strategy to establish wider policy frameworks that will support the development of a UK hydrogen economy.

Developing the market framework for hydrogen

- To progress our commitment to understand the potential role hydrogen can play in the future energy system and how it should be reflected in the design of wider energy markets and policies, **we are undertaking a policy mapping exercise and gap analysis across the hydrogen value chain.** This will identify policy interventions that impact hydrogen market development and their interactions to determine any potential policy gaps, constraints or market distortions to inform future policy development.

Ensuring a supportive regulatory framework

- As committed to in the UK Hydrogen Strategy, **we have established a Hydrogen Regulators Forum** to help determine current and future non-economic regulatory responsibilities across the hydrogen value chain. The Forum formalises our existing engagement with regulators and covers areas including environment, safety, technical standards and planning.
- Informed by the Regulators Forum, we will continue to work with industry and regulators in the early 2020s to identify, prioritise and implement any changes to the existing non-economic regulatory framework, including addressing any gaps, to support the growth of a hydrogen economy.

Gas blending

- We continue to target a **policy decision in 2023 on whether to allow up to 20% hydrogen blending** (by volume) in GB gas networks, subject to the outcomes from ongoing economic and safety assessments and wider strategic considerations.
- If the decision to proceed with blending is positive, we intend to start the legislative and regulatory process to enable blending, as well as the process to make any physical changes to distribution networks that are required. Given the timescales for this work, in the event that a decision is made in 2023 to allow blending up to 20% we do not anticipate blending at a commercial scale to commence before 2025 at the earliest.
- We recognise the potential value of blending to support the early development of the hydrogen economy through providing a flexible route to market for hydrogen producers whilst the number of end users grows and hydrogen transport and storage infrastructure develops.

- However as set out in the UK Hydrogen Strategy, use of hydrogen is most valuable where other routes to decarbonisation do not exist or are limited, particularly where direct electrification is not an option. Therefore, **we will be looking at the impact of blending on the supply of hydrogen to those end users who require it to decarbonise**. This is likely to be taken into account in the design of any potential financial support that is available for hydrogen producers for blended volumes.

Hydrogen sector development

Alongside this update we have published the **Hydrogen Sector Development Action Plan (SDAP)**, a key commitment made in the UK Hydrogen Strategy, as well as a short brochure setting out different sources of government funding for **hydrogen R&I**. The SDAP sets out what we have learned about key areas of sector development since publication of the Hydrogen Strategy and actions that government and industry are taking to maximise economic opportunities in UK hydrogen. The document covers investment, supply chains, jobs and skills, and trade and exports.

Investment

The doubling of our production ambition to 10GW has also increased the **scale of the UK investment potential to £9 billion by 2030**.To showcase the extent of the hydrogen opportunity and mobilise the private investment necessary to achieve this aim we have:

- **Published the Hydrogen Investor Roadmap** which sets out how we will deliver our ambition and the opportunities for potential investors across the hydrogen value chain. The Investor Roadmap is now being used to socialise the UK hydrogen ambition globally, with the Department for International Trade (DIT) engaging overseas investors and industry stakeholders interested in developing projects in the UK, and also to showcase UK progress towards developing long-term export opportunities. The Office for Investment, DIT and BEIS have also been in discussions with potential investors to facilitate their entry into the UK hydrogen market.
- **Actively engaged with investors to explain our policies and levers, and to understand their requirements.** As a first event, we co-hosted with the Global Infrastructure Investor Association the first Hydrogen investor roundtable, which will be followed by further engagement events. **We intend to develop tools to support greater visibility of investible projects across the value chain throughout the UK.**

Supply chains

- The future hydrogen economy, in the UK and globally, presents significant opportunities for UK business and citizens. The SDAP sets out in more detail the actions that government and industry will take to **build on existing UK strengths** to seize the economic benefits from the hydrogen economy as it grows.

- In addition, BEIS has commissioned research to better understand the scale of the opportunities based on **future supply chain needs**, existing supply chain capabilities and UK strengths. Findings from this research project are published alongside the SDAP.

Jobs and skills

- The **SDAP provides a deeper assessment of our understanding of the jobs and skills needs across the hydrogen value chain** to maximise the economic opportunity presented by the sector. It signals the early steps necessary to ensure the UK has access to the right skills in the right place at the right time.
- Through forums such as the **newly established Green Jobs Delivery Group**, we are continuing to engage with partners across industry, devolved administrations, local authorities and enterprise agencies to drive forward collaborative action and ensure there is effective and targeted investment in relevant skills.

Exports

The doubling of our production ambition also opens up an opportunity to position the UK as a future exporter of **low carbon hydrogen** (see Annex 1 for our thinking on exports and imports of hydrogen).

The Government is working with industry to assess strengths and capabilities in UK supply chains to help them benefit from the emerging global hydrogen economy and capitalise on export opportunities as they arise. For example, UK Export Finance recently enhanced its Export Development Guarantee to better support emerging clean growth technologies such as hydrogen.

Research and innovation

- Besides continuing to support hydrogen innovation through our **£1 billion Net Zero Innovation Portfolio**, we set out a roadmap and detail on key challenges and innovation needs to support scaling up low carbon hydrogen demand and supply in our **Net Zero Research and Innovation Framework** published alongside the Net Zero Strategy.
- We have also conducted further studies relating to important issues for the hydrogen economy, notably fugitive emissions and the atmospheric implications of hydrogen.
- We are collaborating closely with the research community on current challenges across the hydrogen value chain and find innovative solutions. UKRI have appointed **two hydrogen coordinators within UKRI** to network and build a multidisciplinary consortium, whilst **Innovate UK KTN's Hydrogen Economy Innovation Network** has continued to grow, now totalling approximately 3,000 members. The network has worked together with our UK Science and Innovation Network to deliver knowledge

sharing and collaboration events, and launch the very well received HydroGenerally podcast.
- Funded by InnovateUK and governed by Ofgem, we announced 40 projects to receive £4.57 million funding through the Discovery Phase of the Strategic Innovation Fund in March 2022. At least 15 of these projects are investigating the potential for hydrogen use and integration within energy networks.
- We have **announced £3.85 million funding through the Natural Environment Research Council to research the environmental response to hydrogen emissions**, running from October 2022, to address uncertainties and gaps in knowledge regarding hydrogen's environmental behaviour.

The **UK Public Sector Support for Hydrogen Research and Innovation brochure,** published alongside the SDAP and this strategy update, helps to demystify the UK hydrogen R&I landscape for innovators and investors. It provides an overview of relevant public R&I funding bodies in the UK, and clearly signposts how funding and support can be accessed.

Hydrogen Champion

In addition to government policy development, the UK Government has appointed a **Hydrogen Champion** to help galvanise industry and investors to deliver on the ambitions set out in the British Energy Security Strategy and UK Hydrogen Strategy. Jane Toogood has been appointed to this role, which will help drive industry investment and deployment at a critical stage in the early development of the UK hydrogen economy.

Demonstrating international leadership

Since launching the UK Hydrogen Strategy we have been actively engaging with international partners bilaterally and in key international forums to support the development of the UK and global hydrogen economy, demonstrating UK leadership and boosting investment in UK hydrogen.

COP 26

- **The UK's co-Presidency launched the Breakthrough Agenda, including the Hydrogen Breakthrough** which committed countries to work together with the goal to make affordable, low carbon hydrogen global available by 2030. 33 countries endorsed the Hydrogen Breakthrough, including all G7 members.
- Since the Breakthrough's launch we have worked collaboratively with leading initiatives and countries to develop a shared understanding of how international hydrogen cooperation can be strengthened and to identify priority actions to accelerate the pace of scale up of low carbon hydrogen.
- The Breakthrough Agenda's response to the State of Sector Transitions report currently being developed by the International Energy Agency (IEA), International Renewable

Energy Agency (IRENA) and UN High Level Action Champions will be published later this year.

G7

- Through the UK's 2021 G7 Presidency we achieved a clear statement of support for the role of low carbon hydrogen for the first time. The **G7 Hydrogen Action Pact,** being taken forward under Germany's 2022 G7 presidency, builds on this and will help drive further action.

Mission Innovation Clean Hydrogen Mission

- **The UK is one of five co-leads of Mission Innovation's Clean Hydrogen Mission**, with the goal of increasing the cost-competitiveness of clean hydrogen by reducing end-to-end costs to USD 2 per kilogram by 2030. The UK is actively shaping and co-leading the Mission's R&I activities, playing a key role to foster international collaboration and drive knowledge-sharing between stakeholders, innovators and policymakers.
- **At COP26 the Clean Hydrogen Mission launched a Discussion Paper** identifying some of the priorities and challenges that need to be addressed to drive technological breakthroughs and cost reduction for clean hydrogen. The Paper proposed key innovation priorities and areas of focus for the Mission's Action Plan, to be published in 2022.

We are also continuing to **build relationships and engage bilaterally with key international partners** to exchange knowledge and expertise, collaborate on cutting-edge innovation, and foster commercial relationships to spur the development of a dynamic hydrogen economy in the UK and globally.

Upcoming Opportunities

Ongoing engagement with industry continues to be at the heart of government's policy development on hydrogen. As set out in this update, there are numerous **upcoming opportunities for hydrogen innovators, industry and investors to feed into policy making and access government support for hydrogen technologies and projects:**

- A **joint HBM/ NZHF electrolytic allocation round**, which has been launched alongside this strategy update and is now open. We are also aiming to run annual HBM allocation rounds for electrolytic hydrogen;
- A **consultation that we intend to publish later this year on hydrogen T&S infrastructure** to support the design of T&S business models;
- A **consultation on expanding existing Decarbonisation Readiness requirements** for new build and substantially refurbishing combustion **power plants**, intended to be published in summer 2022;

- A **consultation on design changes to better align the Capacity Market** with net zero, which we aim to publish later in 2022;
- A **consultation on domestic boiler and heating system standards;**
- The **first two competitions of the Zero Emission Road Freight Demonstrator programme**, which we intend to launch shortly and will focus on battery electric and hydrogen fuel cell technologies;
- A **third round of the Clean Maritime Demonstration Competition** launching later in 2022, which will support large technology demonstrations;
- Engagement events for overseas investors and industry stakeholders interested in developing hydrogen projects in the UK with the **Department for International Trade**;
- Further engagement events, to be led by BEIS, with investors to explain our hydrogen policies and levers, and to understand their requirements. This includes the **Green Trade and Investment Expo** taking place this autumn, which will shine a spotlight on how the UK is delivering on net zero and the commercial opportunities through investment and exports.

Conclusion

Last year, the UK made clear its ambition to become a world leader in the development of a low carbon hydrogen economy to help achieve our net zero targets and secure economic benefits across the UK. Since then, we have raised our ambition even further and are now making extensive progress to realise it. With government and industry working together, the UK stands firmly at the forefront of global efforts to develop low carbon hydrogen as a clean, secure energy source of the future and to realise the opportunities it holds for UK businesses and citizens.

Annex 1: Hydrogen production strategy update

Developing policy, increasing ambition

In August 2021 the UK Hydrogen Strategy set out the Government's intention to develop multiple low carbon technologies to meet our stretching hydrogen production ambitions, including both water electrolysis ('green hydrogen', powered by low carbon electricity) and CCUS-enabled methane reformation ('blue hydrogen'). The Strategy also committed government to go further in developing our hydrogen production strategy, considering the role of other technologies and supply routes, as well as increasing our understanding of the potential wider environmental impacts of hydrogen production such as demand on water resources, air quality impacts, and use of rare earth minerals. Government has since published a range of documents relevant to our production thinking. The Net Zero Strategy and British Energy Security Strategy considered hydrogen production within the wider energy and climate context, while consultations and analysis to inform design of the Low Carbon Hydrogen Standard (LCHS), Net Zero Hydrogen Fund (NZHF) and Hydrogen Business Model (HBM) have also provided the buildings blocks for our production strategy.

The British Energy Security Strategy **doubled the UK's ambition to up to 10GW of low carbon hydrogen production capacity by 2030**, subject to affordability and value for money, **with at least half of this coming from electrolytic hydrogen**. The Strategy also set out our intention for up to 1GW of electrolytic hydrogen and up to 1GW of CCUS-enabled methane reformation operational or in construction by 2025. This increased ambition will better position us to meet the ramp up in hydrogen demand during the Sixth Carbon Budget (2033-37, as set out in the Net Zero Strategy) while also providing confidence to investors and hydrogen end users.

Our 'twin-track approach': supporting multiple production technologies

The HBM and NZHF, providing revenue and capital support respectively, will be key policies to help meet our production ambitions, with the LCHS ensuring supported projects are sufficiently low carbon. Throughout the development of these schemes, consultation and stakeholder engagement has informed our policy design and enabled us to deliver an approach that can support multiple production routes. The LCHS includes technology neutrality as a defining feature, informed by analysis undertaken by E4Tech showing that a range of production routes can deliver genuinely low carbon hydrogen to meet this standard.

The NZHF and HBM have also been designed to support multiple forms of hydrogen production across application strands, provided projects can meet the LCHS and wider eligibility requirements. Strands 1 and 2 of the NZHF are open to multiple technologies seeking development and capital support and launched in April 2022.

In some cases, it has been appropriate to target certain funding strands to individual technologies, which when combined provide a portfolio of technology opportunities:

- Strand 3, the first joint allocation window for the NZHF and HBM launching alongside this document, is aimed at providing funding to low carbon electrolytic hydrogen production facilities. This will allow for better comparison between projects with similar technologies and ensure the allocation round is able to meet its ambitious timelines. This does not preclude the inclusion of other technologies in future allocation rounds, where these can make a significant contribution to our hydrogen production ambitions and support broader energy policy.
- Phase-2 of the CCUS Cluster Sequencing Process, launched in November 2021, will select CCUS-enabled hydrogen projects to be supported through the HBM, that will connect to the chosen Track-1 clusters. We intend for projects that are shortlisted following the conclusion of the CCUS Cluster Sequencing Phase-2 Process to have the opportunity to apply for capital co-funding under Strand 4 of the NZHF. For this Strand, we plan to run an expression of interest stage in summer 2022, followed by an application stage in 2023.

Renewable hydrogen production for use in transport and non-road mobile machinery is also eligible for support under DfT's Renewable Transport Fuel Obligation (RTFO). Alongside proposed amendments to increase the scope and flexibility of the RTFO for hydrogen production and use, the Transport Decarbonisation Plan committed government to develop a long-term strategy for low carbon fuel use in the transport sector. Hydrogen can serve as a low carbon fuel itself as well as a feedstock for other low carbon fuels, such as synthetic hydrocarbons. BEIS and DfT will continue to work together on development of this strategy and associated research workstreams to understand implications for UK hydrogen production and specific technologies.

UK Production Pipeline

The UK's Hydrogen Investor Roadmap indicated that up to 20GW of potential hydrogen capacity has already been identified in the UK pipeline, and we are continually engaging with new projects as the market develops and investor confidence grows. While it is not guaranteed that all these projects will reach operation, the pipeline provides confidence that we are moving in the right direction to meet our ambitions. The Investor Roadmap also included a mapped sample of current production projects at various stages of development, showing the breadth of activity across the entirety of the UK. Electrolysis, predominantly powered by renewable energy, and CCUS-enabled methane reformation currently make up the bulk of this potential capacity; however, BEIS is aware of an increasing number of projects and companies developing other production routes, and this production diversity is likely to increase as more technologies reach commercial readiness. We will continue to build our understanding and view of the developing hydrogen production sector through market intelligence work and regular pipeline updates.

Electrolytic production within our future energy system

Hydrogen produced from electricity (as the primary energy input) is only as low carbon as the electricity used to produce it. It is therefore vital that electrolytic hydrogen production is powered by low carbon electricity generation, to deliver true emission reductions. Electricity used in hydrogen production can be supplied from a variety of sources with different associated greenhouse gas emissions; for example, dedicated off grid physical links to renewable or nuclear generators, or via sourcing from the wider electricity grid.

We must also consider the wider electricity system impacts involved in using electricity in hydrogen production, ensuring we maximise system benefits, whilst minimising any negative impacts on the electricity system. We recognise the right regulatory environment and incentives for electrolysers are needed to ensure we strike a balance between scaling up the hydrogen economy and achieving emissions reductions.

To ensure electricity used in hydrogen production does not divert electricity from other users, hydrogen production will need to be aligned to the scale up of renewables and new nuclear, as set out in the British Energy Security Strategy. Whilst we expect deployment of new low carbon power generation to increase significantly over the 2020s and beyond, in the near-term, levels of available dedicated low carbon generation and curtailed power sources for hydrogen production are expected to be limited and the grid will not be sufficiently decarbonised to be a primary source of low carbon input power until the 2030s. Over the longer term (2030s onwards), we expect there to be greater availability of dedicated low carbon generation and curtailed electricity, alongside a more decarbonised grid, allowing for greater opportunities for further scale up of electrolytic hydrogen production.

Electrolytic hydrogen production can be both a demand source for low carbon electricity, but also a unique method for utilising otherwise wasted ‘curtailed’ electricity, which is caused when we have more low carbon generation than we can use at that point in time. As we scale up deployment of renewables and nuclear, we expect that increasing levels of excess electricity generation can be used to produce hydrogen. This can be stored over time in large quantities and used to replace unabated natural gas, oil or diesel, providing clean energy for use in industry, power, transport and potentially heating. We also expect electrolytic hydrogen production to play an important role in integrating this new low carbon electricity generation into the broader electricity system, helping with system balancing and providing flexible capacity and storage, while reducing overall system costs.

The LCHS published in April 2022 sets out clear technical requirements for electricity inputs to ensure hydrogen produced is low carbon. This includes requirements to provide evidence electricity has been adequately accounted for in the system (and not double counted in emissions reporting by another user), and to provide links to a low carbon generation source through metering information to demonstrate the electrolyser operated at the same time as the electricity generator. The design of the LCHS incentivises grid-connected electrolytic hydrogen producers to use the grid flexibly, recognising that to meet the LCHS, an electrolyser is incentivised to source grid-connected electricity at times when the grid is lower carbon, such as when renewables are abundant.

We also recognise that certain types of electrolyser projects can provide demonstrable benefits to the wider electricity system, for example projects that contribute to new low carbon generation deployment ('additionality'). For example, there can be demonstratable benefits to linking hydrogen production to new build or life-extended low carbon generation, especially where this is unsubsidised by government support schemes (such as the Contracts for Difference), and that these types of projects should be incentivised and rewarded. We have therefore looked to incentivise and reward projects that meet additionality principles through allocation of HBM and NZHF support. Under current criteria, projects that meet these principles for additionality will improve their overall scoring when applying for funding through these schemes.

Furthermore, electrolytic hydrogen projects can bring significant system wide benefits by locating in an optimal position to help to manage network constraints, or to use excess electricity that would have otherwise been curtailed or constrained. Grid constraints occur when there is too much energy being generated for the electricity grid to handle, and curtailed electricity occurs when the network becomes overloaded with electricity, which can result in energy generators being asked to disconnect. These issues are particularly prevalent in specific areas of the UK and therefore hydrogen producers that can situate in optimal locations from a system perspective can help to manage these issues by ramping up or down demand to respond to system needs, using the hydrogen for specific purposes or storing it for later use.

Our approach in the LCHS and our broader policies announced in the Hydrogen Investment Package is reflective of our current and modelled understanding of the market including the commercial feasibility of different electrolyser operating models, technical requirements for electrolyser operation, the availability of low carbon generation (including curtailed electricity and new build generation), and our assessment of expected impacts on the electricity system of electrolytic hydrogen deployment. We will continue to assess these impacts and build evidence to ensure our position remains appropriate and facilitates economy-wide decarbonisation. The outcome of further analysis and policy work will feed into future allocation rounds and reviews of the LCHS and will be shared in future strategy updates.

Low carbon hydrogen from natural gas

The British Energy Security Strategy set out government's view on the role that natural gas can play in maintaining UK energy security, ensuring a strong and evolving North Sea industry alongside our transition to net zero. Production of hydrogen at scale is likely to be a key part of the role for natural gas in this transition. Analysis by both BEIS and the Climate Change Committee has previously indicated that low carbon hydrogen from natural gas will be important in scaling up production into the 2030s and can be consistent with our net zero commitments.

CCUS-enabled methane reformation involves splitting methane (CH_4), predominantly from natural gas, into hydrogen and carbon dioxide, which is then captured and permanently stored underground. These plants offer the largest individual production capacities of any projects in the current UK pipeline (up to 1GW), with the ability to produce hydrogen at consistent baseload close to large points of demand on industrial clusters from the mid-2020s onwards. BEIS is also aware of the potential of more novel technologies, including those that use highly

efficient plasma or microwave technologies to convert methane into hydrogen, leaving a solid carbon by-product. Government has supported the innovation of such technology under the Low Carbon Hydrogen Supply 2 Competition and is open to evidence on their potential to deliver low carbon hydrogen, including the lifecycle impact of carbon utilisation versus permanent sequestration.

We are aware of some reports presenting CCUS-enabled 'blue' hydrogen as being bad for the environment, inefficient, or too expensive. Most existing CCUS-enabled plants are in the US, which has a higher carbon intensity of gas supply compared to the UK and tend to be longstanding steam methane reformers (SMRs) that have been retrofitted with carbon capture technologies. Such operations are less efficient than modern autothermal reformation plants (ATRs) that have been designed specifically to work with carbon capture technology.

Analysis by E4Tech for the LCHS indicates such modern efficient methane reformation with carbon capture and storage can meet the UK's strict emissions criteria but highlighted the importance of ensuring high carbon dioxide capture rates and addressing fugitive emissions of methane related to natural gas extraction and transport. Hydrogen production projects eligible under Phase-2 of the Cluster Sequencing process are aiming for capture rates of 95% or more, enabling significant emissions reductions for end users relative to burning natural gas. As the British Energy Security Strategy made clear, the majority of the UK's natural gas comes from the UK continental shelf as well as via pipeline from Norway and the Netherlands. These represent some of the best managed sources of natural gas in the world. The North Sea Transition Deal sets out actions to continue to reduce the emission intensity of our domestic gas production, with the UK's offshore oil and gas sector committed to a 50% reduction in methane emissions and no routine methane flaring by 2030. Additionally, Norway and the Netherlands have the lowest natural gas supply emission intensities in the world according to the IEA's Global Methane Tracker .

Our supply of gas is also in no way dependent on Russia, with no gas pipelines directly linking the UK with Russia and Liquified Natural Gas (LNG) imports from Russia making up less than 4% of total UK gas supply in 2021. Building on this current position, the British Energy Security Strategy committed to phase out the use of Russian oil and coal by the end of 2022, and end imports of Russian LNG as soon as possible thereafter. All this provides confidence that low carbon hydrogen can be produced in the UK using natural gas from sources with some of the lowest downstream emissions and remain in line with our energy security needs.

BEIS' 2021 Hydrogen Production cost report previously indicated methane reformation with CCUS to have among the lowest levelized costs of all low carbon hydrogen production routes. Since then global wholesale gas prices have reached record highs, predominantly the result of global economic recovery after the Covid pandemic and Russia's unprovoked and illegal war on Ukraine. These recent increased gas prices are beyond those previously modelled by BEIS in our production cost report. However, methane reformation projects will not begin production until the mid-2020s, by which time it is not expected that the same drivers of high current prices will remain. Despite this, BEIS continues to keep input cost under review in considering the likely role of various technologies, including those using natural gas.

Existing hydrogen production

The UK Hydrogen Strategy referenced the need to decarbonise existing industrial production of carbon intensive hydrogen to meet our net zero ambition and develop the new low carbon hydrogen economy. Since publishing the Strategy, we have mapped the landscape of existing hydrogen production, and estimate that hydrogen is currently produced at around 30 sites in the UK, spanning various energy intensive industrial sectors and production methods.

The total estimated production capacity across these sites is approximately 2.5 GW. Around two thirds of this hydrogen is produced as a by-product of industrial processes, for example in oil refineries and steelworks, which is then used on site as a fuel or a feedstock. The remaining third of this hydrogen is produced by steam methane reformation without carbon capture for use as a feedstock, for example in ammonia production. A small number of large sites account for the majority of the UK's production capacity of hydrogen produced through this method.

A methodology for calculating emissions associated with by-product hydrogen has not been included in the current iteration of the LCHS. Further work has been undertaken and we will continue to gather evidence to inform a decision on the appropriate allocation method for by-product hydrogen. By-product hydrogen may be included as an eligible production pathway in future iterations of the standard when that work has been completed.

Hydrogen produced by steam methane reformation without carbon capture is not low carbon. For hydrogen to be certified as low carbon (for example under the future hydrogen certification scheme), these producers would need to change hydrogen production method to one that is low carbon, or else retrofit industrial carbon capture technology with support from the Industrial Carbon Capture Business Model (ICC BM). Existing producers of hydrogen by steam methane reformation for use as a feedstock may also choose to become offtakers of newly produced low carbon hydrogen, supported through the HBM, to displace or supplement the hydrogen they currently produce. Our current thinking is that the suite of major current and planned interventions, such as the UK ETS, the ICC BM and the HBM, will likely be sufficient to incentivise and support the decarbonisation or displacement of hydrogen currently produced by steam methane reformation without carbon capture. We will continue to engage with existing industrial producers of hydrogen to test this thinking and will consider the most appropriate way of gathering further evidence to inform any future policy development as required.

Hydrogen Imports and Exports

Since publication of the UK Hydrogen Strategy, there has been a rapid increase in global interest and investment concerning the development of an international market for low carbon hydrogen, often focused on the use of ammonia (NH_3) as a 'hydrogen carrier' when transporting hydrogen over significant distances.

The UK is keen to play a leading role in developing the global market for low carbon hydrogen and we are focused on working with others to ensure it is underpinned by effective common standards, for example through continued engagement with international forums such as the International Partnership for Fuel Cells in the Economy.

The increase in UK hydrogen production ambition with a greater focus on electrolytic hydrogen production, has now opened up potential opportunities to export hydrogen from the UK at scale, particularly to continental Europe where we see increasing hydrogen demand alongside established energy trading and interconnection with the UK. We are therefore actively monitoring and engaging with international developments and considering emerging evidence to ensure our approach realises the greatest opportunities for the UK, in terms of both carbon reduction and economic growth.

The British Energy Security Strategy set out our clear aim to make the UK more energy self-sufficient and therefore the Government is focussed on developing domestic production capacity to meet our need for low carbon hydrogen. We also expect that demand will not exceed domestic supply of hydrogen during the 2020s, particularly with electrolysers operating flexibility (not always to maximum capacity) to aid power system balancing. Realising the UK's 10GW hydrogen production ambition will ensure we can benefit from the opportunities of exporting low carbon hydrogen this decade, as well as producing sufficient hydrogen to meet domestic demand. Government policies, for example the HBM and NZHF[3], are therefore focused on developing a domestic economy in hydrogen production, rather than relying significantly on imports to meet domestic demand. This approach will support our goals to have reliable, secure energy that delivers against our emissions reduction targets and create opportunities for UK investment and growth.

In the longer term, we expect UK hydrogen demand to increase significantly during the 2030s, and that this could lead to a greater role for imports in building supply chain resilience and supporting energy security as part of a diverse supply mix.

When considering the role of imports in our hydrogen supply mix, we have looked at expected costs and carbon intensity, to better understand how different types of imports might compare against domestic UK production. In terms of cost-competitiveness, analysis by Bloomberg[4], IRENA and the IEA suggests that in the near term, most import channels are unlikely to be cheaper than UK domestic production with composition of costs varying considerably between costs associated with production, transport, storage and conversion. Potential exceptions are piped gaseous hydrogen from nearby countries, and possibly where ammonia is imported for direct use without the need for reconversion to hydrogen (such as in marine fuel or some power turbines). However, despite the UK's increased domestic production ambition and potential to become an exporter of low carbon hydrogen, we are aware of companies that view the UK as a competitive market for the import of hydrogen. Given the very early stage of market development, we welcome further evidence on potential costs in this area.

With regards to carbon intensity, analysis conducted by E4 Tech Limited and Ludwig-Bölkow-Systemtechnik GmbH on behalf of BEIS suggests that most electrolytic and a limited number of CCUS-enabled import channels could meet the Low Carbon Hydrogen Standard emissions threshold of 20gCO2e/MJ LHV. However, there are a considerable number of variables affecting this, including production technology, distance, transport method (shipping or

[3] In line with the position for other low carbon fuels, imported hydrogen for use in transport and NRMM can receive support under the RTFO where production meets sustainability requirements.
[4] Hydrogen: the Economics of Transport & Delivery, Bloomberg NEF, October 2019.

pipeline), the state in which the hydrogen is transported (gaseous or liquid hydrogen, ammonia) and whether this requires subsequent reconversion before end use.

The LCHS, which defines what the government considers to be 'low carbon' hydrogen, currently only applies to production supported by the NZHF and/or the HBM, not to the wider trade in hydrogen. However, we have committed to setting up a Certification Scheme by 2025 aimed at ensuring imported and exported hydrogen is appropriately low carbon and meets the high standards expected by UK producers and consumers of hydrogen.

We will continue to gather evidence and intelligence on the likely costs and carbon intensity of different import routes and will provide further updates on this as appropriate.

Other production routes

Nuclear related technologies

The UK Hydrogen Strategy pointed to the potential of nuclear technologies to produce low carbon hydrogen both now and in the future. Low carbon nuclear supplies 15% of UK electricity as a steady source of generation to complement intermittent renewables. This could power electrolysers today, while in the future small modular reactors and advanced modular reactors could facilitate greater deployment and use of nuclear-derived heat and power in high temperature electrolysers or via direct thermochemical water splitting.

Interest in the potential role of the nuclear sector in hydrogen has increased alongside a developing evidence base. In 2021 analysis by Urenco and Aurora Energy pointed to the potential of nuclear, alongside renewables, to reduce the cost of meeting UK hydrogen demand while the Nuclear Industry Association and Nuclear Sector Deal's Innovation Group both published strategic priorities to enable this production route. More recently, analysis by the UK's National Nuclear Laboratory has shown how a Regulated Asset Base funding model for nuclear power could enable low carbon hydrogen production at a competitive cost while reporting from the UK Hydrogen and Fuel Cell Association points to the value of flexible nuclear enabled hydrogen production in a future energy system while noting the related modelling challenges. BEIS also funded the Advanced Nuclear Skills and Innovation Campus (ANSIC) Pilot programme from August 2021-March 2022 which included an anchor project on nuclear generated hydrogen. This provided insights as to the potential role of high temperature gas reactors and other advanced modular reactors in hydrogen production and developed a shared understanding across nuclear and gas sectors. A second phase is proposed to further develop the evidence base for the deployment of nuclear enabled hydrogen.

Deployment of new nuclear generation is essential to realising this potential and government is taking forward key steps to address this. Earlier this year, the British Energy Security Strategy outlined our plan for up to 24GW of nuclear capacity by 2050 and the Nuclear Energy (Financing) Act 2022 became law, enabling use of the Regulated Asset Base funding model to support investment in new nuclear. The Government has also committed up to £385 million in the Advanced Nuclear Fund to support Small Modular and Advanced Modular Reactor development, including up to £210 million awarded as a grant to Rolls-Royce to develop their Small Modular Reactor design, which will be matched by industry. The Advanced Modular Reactor (AMR) Research, Development & Demonstration (RD&D) programme with the aim of

enabling an AMR demonstration by the early 2030s, at the latest, to understand the potential of the technology. The technology focus of the programme is high temperature gas reactors which have the potential to supply high temperature heat and power for hydrogen production.

In order to enable hydrogen production from nuclear technologies, the LCHS, NZHF and HBM have been designed to allow multiple production routes, including nuclear enabled hydrogen projects, to apply for support. With regards future technologies, BEIS recently announced new innovation support under the Low Carbon Hydrogen Supply 2 Competition to better understand and demonstrate the potential of hydrogen production using small and advanced modular reactors.

Hydrogen from Biomass

Biomass can be used as a feedstock to produce low carbon hydrogen or, if CCS is used, hydrogen with negative emissions (known as hydrogen bioenergy with carbon capture and storage or hydrogen BECCS). Gasification and pyrolysis technologies are often considered in relation to this production route, with both involving the use of heat to break down organic material in the presence of limited or no oxygen. Methods which enable the reforming of biomethane (such as that produced from anaerobic digestion of food and farm wastes) are also considered, alongside other less developed technologies.

While these production routes show promise, biomass is a limited resource with decarbonisation potential across several sectors, so it is important that its use is sustainable and prioritised accordingly. In November 2021 BEIS published the Biomass Policy Statement which set out a strategic view on the role of sustainable biomass in reaching net zero and included a priority use framework for considering the best use of biomass across the economy. In the context of this framework, as well as analysis by the CCC and BEIS, it is likely that the ability to use hydrogen BECCS to produce both hydrogen and negative emissions will constitute the most valuable use of biomass in hydrogen production, although innovation and the availability of CCS infrastructure will be important to enabling this.

BEIS is aware of nearer-term production projects looking to produce low carbon hydrogen from biomass, particularly involving the reforming of biomethane from anaerobic digestion. While these may have value in helping develop local hydrogen use, direct use of this biomethane in the gas grid is likely to deliver greater energy efficiency and carbon reduction benefits. Other policies across government already incentivise use of biomethane in the energy system, such as the Green Gas Support Scheme and the RTFO.

BEIS is taking forward actions to support development of biomass to hydrogen and welcomes further input from stakeholders on how best to enable this. The NZHF Strand 1 and 2 have the potential to support near-term hydrogen from biomass projects, with the LCHS setting sustainability criteria for biomass feedstocks in line with wider government policy, and the LCHS methodology ensuring that their supply chain and conversion to hydrogen are low carbon. While the first window for joint NZHF and hydrogen business model support is electrolytic only, this does not preclude the inclusion of other technologies like biomass in future allocation rounds. With regards hydrogen BECCS, BEIS launched the £5 million Hydrogen BECCS Innovation Programme earlier this year, as well as recently publishing a consultation on business models for Greenhouse Gas Removals to help develop our thinking

on support that may be required. Later this year BEIS intends to publish the UK Biomass Strategy, which will build on the Biomass Policy Statement.

Hydrogen from Fossil Waste

Alongside use in biomass projects, gasification and pyrolysis processes have also been developed to produce hydrogen from fossil or mixed waste streams, such as currently unrecyclable plastics or residual waste. Residual waste originates from a range of sectors, including households ("black bag waste"), commercial and industrial, and construction, demolition and excavation sources. It is usually sent for incineration at an energy recovery plant or to landfill and contains a mix of both fossil and biogenic material. Evidence published by BEIS suggests that these feedstocks, being fossil carbon-based or otherwise containing a significant fossil carbon element, would not deliver direct carbon savings in hydrogen production without being used alongside carbon capture and storage.

The government's approach is guided by the waste hierarchy, which ranks waste management solutions according to what is best for the environment. Hydrogen from fossil waste would be considered 'recovery' within the hierarchy. Therefore, in line with Waste Regulations (2011), it is important that this production route does not undermine prevention, reuse and recycling options where these may be viable. In line with the hierarchy, the Department for Environment, Food and Rural Affairs (Defra) has recently consulted on a legally binding, Environment Act 2021, target to reduce residual waste excluding major mineral wastes) by 50% by 2042 from 2019 levels, which would ultimately reduce the amount of residual waste available for use as a feedstock for hydrogen production.

However, use of materials that cannot be reused or recycled for hydrogen production could avoid emissions elsewhere, subject to appropriate lifecycle analysis and the energy source being replaced. Multiple respondents across Government's consultations on the NZHF and LCHS flagged the potential of these technologies, citing their ability to deliver hydrogen while avoiding waste entering landfill, incineration (including incineration with energy recovery) or being exported and BEIS is aware of UK projects considering this production route.

Appropriate carbon accounting is important in ensuring that hydrogen production from residual waste is sustainable. Different approaches can impact whether related hydrogen production is considered low carbon. A majority of respondents to the LCHS consultation advocated the use of a 'counterfactual approach'[5] to considering fossil waste feedstocks and for a consistent approach with other government policies, such as the RTFO. Given the carbon impacts of allowing fossil-based feedstocks, the lack of clear precedent to follow and the complexity of the issue, at this stage the LCHS does not currently account for fossil waste feedstocks with counterfactuals. Therefore, from the point of waste collection onwards, emissions from these feedstocks are treated in the same way as other fossil-based GHG emissions. Analysis in the development of the LCHS indicates that under this approach only projects with CCS are likely to be able to meet the standard and seek support under the NZHF and HBM.

[5] Adopting a "counterfactual approach" would mean comparing the greenhouse gas emissions from two scenarios: one where a unit of fossil waste is used for hydrogen production and one where the same unit of fossil waste is managed in a different way. The GHG intensity would then reflect the difference between the two scenarios.

BEIS will keep this position under review as the LCHS develops and continue to work across government on a consistent approach to waste counterfactuals. In particular, DfT have recently launched a technical consultation on supporting recycled carbon fuels under the RTFO. BEIS will work with DfT throughout this process and consider the consultation's findings and implications at future review points of the LCHS.

Environmental Impacts of hydrogen production

In the UK Hydrogen Strategy, we committed to continue to consider the wider environmental impacts of different methods of hydrogen production, such as resource requirements for water, atmospheric impacts and any potential changes in soil, water or air quality. We expect all planned hydrogen production projects to have robust integrated environmental assessments in place and to comply with the existing and future regulatory regime for environmental issues related to hydrogen production, such as environmental permitting, water permitting, and air and water quality regulations. We have set out further detail on how both Strands 2 and 3 of the NZHF will assess projects on their wider environmental impacts.

The production of hydrogen is likely to need significant amounts of water[6], and certain production methods have specific water quality requirements; for example, electrolysis requires high purity deionised water, and seawater used for electrolysis would need to be desalinated. Together with industry we are closely engaging with the Environment Agency, regional water resource groups and water companies to ensure appropriate plans are in place for sustainable water resources. We are conducting further analysis on water resource requirements for hydrogen production this year and will continue to work with key stakeholders to identify the main challenges around water resources, quality and regulations. Depending on the production method, there may be other environmental impacts that need to be taken into account, including on water quality, land availability and other key goals in the 25 Year Environment Plan.

On air quality, the scale up of the hydrogen economy is expected to have a significant net positive impact, as fossil fuels are replaced with lower emission hydrogen across a range of end use sectors, such as hydrogen fuel cells replacing combustion engines in buses. There are several areas of hydrogen production that may have potential air quality impacts if not properly managed, and we are collaborating with key stakeholders across government, industry and academia to monitor activities and build up our research and evidence base. For example, we are continuing to consider the air quality impacts around use of carbon dioxide-absorbent chemicals (organic stripping solvents such as organic amines) in CCUS-enabled hydrogen production, as well as ammonia emissions, such as from leakage and as digestate from anaerobic digestion. We are working with Defra and other relevant stakeholders to ensure these issues are considered in environmental permitting requirements, as well as monitoring and reporting on these likely impacts, for example through the National Air Pollution Control Programme.

[6] Estimates for electrolysis suggest it is likely to need between approx. 18-24 kg water per kg of hydrogen produced (IRENA, 2020). CCUS-enabled hydrogen production is estimated to need approx. 10kg of water per kg of hydrogen produced (for process and associated cooling) (Element, 2018).

In addition to potential air quality impacts, hydrogen is also considered to be an indirect greenhouse gas due to its interactions with other atmospheric gases. Effective use of hydrogen does not lead to its release into the atmosphere, but accidental emissions due to leakage or faulty equipment ('fugitive emissions') from hydrogen production plants could have a material impact on the atmosphere if left unaddressed. In April 2022 BEIS published a paper on 'Atmospheric implications of increased hydrogen use', following work with the University of Cambridge and the National Centre for Atmospheric Sciences with the University of Reading. This report suggested that hydrogen use in the economy will have significant climate benefits, but that some of these benefits will be partially offset if we emit hydrogen into the atmosphere, as it is an indirect greenhouse gas with a Global Warming Potential (GWP) of 11 due to its interaction with other atmospheric gases. Therefore we need to minimise leakage in production processes as well as in transport and end use, to ensure we maximise the climate benefit of hydrogen use in the economy. The LCHS includes clear guidance for hydrogen producers to monitor and reduce hydrogen emissions, and we will continue to consider whether a hydrogen GWP factor should be included in future iterations of the LCHS. We will continue to research atmospheric impacts of hydrogen use, including the role of soil as a sink, and methodologies and technologies to monitor and reduce fugitive emissions.

We are also working across Government, academia and industry on wider environmental issues related to hydrogen production, for example on risks associated with availability of rare earth metals and other critical materials essential to supply chains for hydrogen production. This includes the Critical Minerals Expert Committee, which aims to leverage the UK's extensive research expertise for the development of a Critical Minerals Strategy. The committee discusses actions the government can take to secure sustainable sources of these critical materials to help maintain national security and meet net zero ambitions.

We will continue to build our evidence base on the environmental impacts of hydrogen production, conducting further research and analysis where necessary and working with industry and across government to identify mitigations and resolutions to any challenges. We expect to provide further updates next year on the progress of this work, such as on water, air quality, atmospheric impacts and critical materials.