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Science and Technology Committee

The role of hydrogen in achieving Net Zero

Fourth Report of Session 2022–23

Report, together with formal minutes relating to the report

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Summary

Hydrogen is a gas of high calorific value and when burned does not produce carbon dioxide, which is a harmful greenhouse gas. So, in principle hydrogen could play a role in decarbonising our economy and help reach Net Zero emissions by 2050, the UK's legal target.

Pure hydrogen deposits on the planet are rare and limited, so the extent to which hydrogen can be produced without creating greenhouse gas emissions determines whether it can make a useful contribution to decarbonisation. Currently in the UK hydrogen is overwhelmingly produced from fossil-fuel intensive processes—so called "grey hydrogen"—grey hydrogen globally accounts for 2% of carbon emissions.

Hydrogen used in a Net Zero system will be either produced by processes which generate carbon dioxide but which is permanently extracted and stored ("blue hydrogen"), or through the use of renewable power to allow the electrolysis of water ("green hydrogen").

Carbon capture, utilisation and storage (CCUS) is a technology that is currently not deployed at the large scale required to make a material contribution to our emissions reductions, nor are the economic and commercial conditions established for its mass use. This means that blue hydrogen cannot be relied on as a high-volume contribution to decarbonisation in the short- to medium-term.

The rapid expansion of renewable energy provides important possibilities for the mass production of green hydrogen in the future. But currently, we heard there is unmet need for renewable-sourced electricity to contribute directly to our power supplies as demand for electricity rises in both domestic and industrial settings.

The use of green electricity in producing, through electrolysing water, hydrogen for use as a fuel inevitably involves the loss of energy through the inefficiency of all such industrial processes. That said, we heard that if there was a large proportion of the electricity grid based on renewables, green hydrogen production might become very cheap during periods of low electricity consumption.

To make a large contribution to reducing greenhouse gas emissions in the UK, the production of hydrogen requires significant advances in the economic deployment of CCUS and/or the development of a renewable-to-hydrogen capacity. The timing of these is uncertain, and it would be unwise to assume that hydrogen can make a very large contribution to reducing UK greenhouse gas emissions in the short- to medium-term.

To maximise the future possibilities of using hydrogen to decarbonise the economy, clear commitments will be needed by the Government in the short- and medium-term to the development and deployment of carbon capture, usage and storage and renewable energy.

Using hydrogen to replace fossil fuels within our energy system would entail significant investment in the networks and infrastructure needed to distribute it around the country. For example, were hydrogen to replace petrol and diesel in passenger cars and heavy goods vehicles, an extensive and new network of hydrogen refuelling stations would be needed across the UK.

If hydrogen were to completely or substantially replace gas in domestic heating systems, a massive and costly programme of replacing boilers, meters and network infrastructure would likely be required.[1]

It seems likely that any future use of hydrogen will be limited rather than universal. It is likely to be best suited to applications or places which are:

- Hard to electrify—such as some parts of the rail network;
- Uses that do not require the creation of an extensive refuelling network—such as local bus services operating out of a fixed number of depots; and
- Users who are adjacent to, or accessible to, places where hydrogen is produced, such as industrial clusters.

In addition, hydrogen has important potential uses as:

- a means of energy storage; and
- a source power for energy intensive industries like steel, glass and mineral production.

This limited—rather than universal—use of hydrogen should inform Government decisions. For example, we disagree with the Climate Change Committee's recommendation that the Government should mandate new domestic boilers to be hydrogen-ready from 2025.

In our view multiple changes will be needed to the way we obtain, use and store energy if we are to reach Net Zero emissions by 2050. Hydrogen will have its place in this portfolio. But we do not believe that it will be the panacea to our problems that might sometimes be inferred from the hopes placed on it.

Essential questions remain to be answered as to how in future large quantities of hydrogen can be produced, distributed, and used in ways that are compatible with Net Zero and cost efficiency.

In the words of one of the witnesses to our inquiry, hydrogen is likely to be a "big niche" where it will play a major role in certain sectors of the economy, and be a "huge growth story" over the next 30 years, but "it will not be everything".

To help it achieve that potential requires the Government to have a clear view of its practical deployment and to now turn the high-level Hydrogen Strategy into a set of operational decisions.

1 It may, nevertheless, be feasible and desirable to blend some hydrogen with natural gas using existing infrastructure and equipment.

1 Introduction

1. Hydrogen has gained increasing prominence worldwide as an 'energy vector', which can be used to contribute towards the transition to a Net Zero economy.[2] As of September 2022, 40 countries had hydrogen strategies in place, detailing the planned investment in production and proposals for hydrogen use.[3] Goldman Sachs estimated in 2020 that low-carbon hydrogen would have a global market share of at least €10 trillion in 2050.[4]

2. In the central projection of the then Committee on Climate Change's pathways towards Net Zero in December 2020,[5] there was an anticipated low-carbon hydrogen demand of 225 TWh[6] in 2050.[7] This is comparable to the current annual electricity demand in the UK of approximately 330 TWh, and significantly larger than the current hydrogen demand of approximately 30 TWh, of which only around 1 TWh is low-carbon.[8]

3. The UK Government's Hydrogen Strategy was published on 17 August 2021 and the Government's Heat and Buildings and Net Zero Strategies were published on 19 October 2021.[9] The Hydrogen Strategy included targets for hydrogen production, consultations on the role of hydrogen in several sectors and plans for trials in heating and development of low-carbon hydrogen use in industrial clusters. The British Energy Security Strategy (April 2022) and updates to the market on the Hydrogen Strategy (July and December 2022) contained further commitments.[10] In this Report we refer to some of the announcements and decisions in these publications, which were published after we had concluded gathering oral and written evidence.

4. We heard in our inquiry, and the Hydrogen Strategy made clear, that hydrogen has a range of potential applications within the industry, transport, energy storage and heating sectors.[11] However, alongside several of the possible applications of hydrogen there are alternative technologies. Electrification and heat networks for heating could provide competing low-carbon solutions, for example.[12] This creates uncertainty in several sectors, such as domestic heating, energy storage and road transport, about the extent to which certain technologies should be widely scaled.[13]

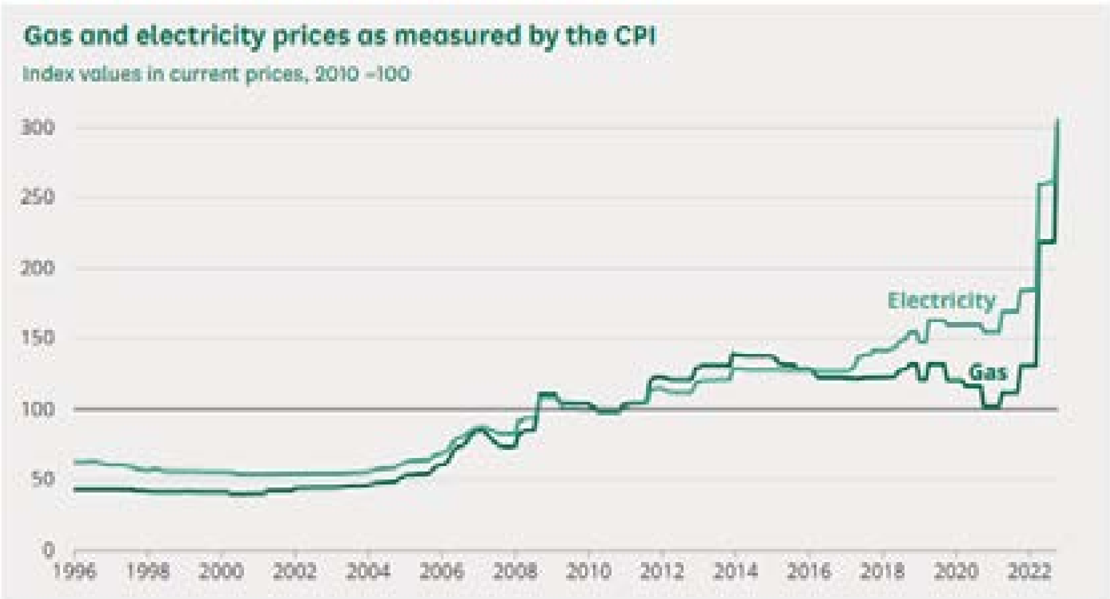
2 The Royal Society (HNZ0079)
3 Hydrogen Council and McKinsey & Company, Hydrogen Insights 2022, 20 September 2022, p. 2
4 Goldman Sachs Research, Green Hydrogen: The Next Transformational Driver of the Utilities Industry, 22 September 2020, p. 1
5 In December 2020, the Committee on Climate Change was renamed the Climate Change Committee. When referring to evidence or publications from the Committee before the change we refer to the 'former' Committee on Climate Change.
6 Terawatt-hours is a unit of energy. For example, the UK's annual UK electricity demand was 334.2 TWh in 2021.
7 Q56
8 The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net Zero (9 December 2020); and Department for Business, Energy and Industrial Strategy, Chapter 5: Electricity, July 2021
9 Department for Business, Energy and Industrial Strategy, UK Hydrogen Strategy, CP 475, 17 August 2021; Department for Business, Energy and Industrial Strategy, Heat and Buildings Strategy, CP 388, 19 October 2021; and Department for Business, Energy and Industrial Strategy, Net Zero strategy: building back greener, 19 October 2021.
10 Department for Business, Energy and Industrial Strategy, British Energy Security Strategy, 7 April 2022; Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market, 20 July 2022 and Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market, 13 December 2022
11 For example, see: University of Kent (HNZ0001); The Royal Society (HNZ0079); Department for Business, Energy and Industrial Strategy (HNZ0090), UK Research and Innovation (UKRI) (HNZ0091) and Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
12 Q241
13 Centre for Sustainable Road Freight, University of Cambridge (HNZ0020) and University of Birmingham (HNZ0030)

Our inquiry

5. We launched our inquiry with a call for evidence on the suitability of the Government's announced plans for encouraging the growth of low-carbon hydrogen and their current progress, how the Government could best address the engineering and commercial challenges of hydrogen use, and how the Government should decide between competing low-carbon options, for example for heating between electrification and heat networks.[14] We have published 100 written submissions and taken oral evidence from 38 witnesses, including experts and practitioners, the Government Chief Scientific Adviser, Sir Patrick Vallance, and the then Secretary of State for Business Energy and Industrial Strategy, Rt Hon Kwasi Kwarteng MP. To assist us with our work, we appointed Professor John Loughhead, former Chair of the Mission Innovation Steering Committee and former Chief Scientific Adviser to the Department for Business, Energy and Industrial Strategy, as a Specialist Adviser for our inquiry.[15] We are grateful to everyone who contributed to our inquiry.

6. Since our oral evidence sessions as part of this inquiry there have been developments which have affected the energy market in the UK, including the price of gas and electricity:

- The Russia-Ukraine conflict has caused governments around the world, including in the UK, to reconsider their energy sources; and
- Energy prices for consumers have risen sharply, as illustrated by the House of Commons Library in a December 2022 paper:[16]



Individuals and households have been put under considerable pressure by rising bills and discussions about sources of energy and the resilience of our energy system have been brought to the fore. There have also been valuable new technical and policy-focused contributions from industry, sectoral bodies, and other Governments—these are referred to where appropriate throughout our Report.

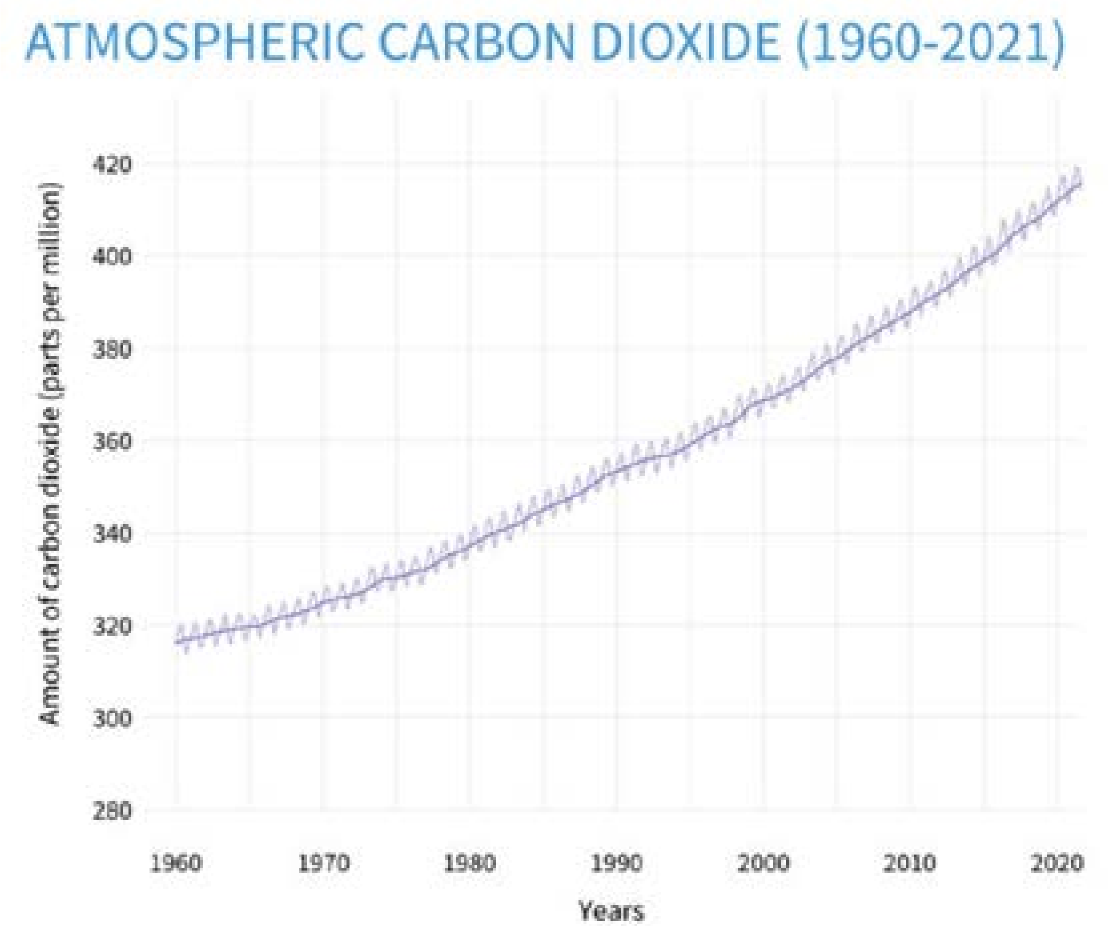
14 House of Commons Science and Technology Committee, 'How can hydrogen contribute to Net Zero? MPs launch inquiry', published 7 December 2020

15 For declaration of interests, see the formal minutes.

16 House of Commons Library, Domestic energy prices, 2 December 2022, p. 22

7. In meeting its commitment to meet Net Zero emissions by 2050, the Government must carefully assess the impact of any changes, including by using hydrogen in the UK's energy's system, on individuals and households, as well as the wider economic benefits. When considering the recommendations in our Report, we ask the Government to provide, where necessary and where they are accepting our recommendation, an assessment of the change in cost of implementing the recommendation. We note that few governments have estimated the cost of reaching Net Zero by 2050. In one scenario, a report commissioned by the New Zealand Government put the cost of New Zealand reaching Net Zero at NZ$85 billion annually (equivalent to 16.8% of New Zealand's projected annual GDP).[17] The international context is also important as all countries need to contribute to reaching Net Zero, and according to data from the US National Oceanic and Atmospheric Administration, the global growth rate of atmospheric carbon dioxide has continued to increase since 1960:[18]

Amount of carbon dioxide in the atmosphere, 1960–2021



17 New Zealand Institute of Economic Research, Economic impact analysis of 2050 emissions targets: a dynamic Computable General Equilibrium analysis: final report to Ministry for the Environment, 18 June 2018, p. 15

18 National Oceanic and Atmospheric Administration, Climate Change: Atmospheric Carbon Dioxide, accessed 14 December 2022

Aims of this Report

8. In this Report we assess the Government's Hydrogen Strategy[19] and make recommendations for how the UK should develop and deploy hydrogen to contribute to the UK reaching Net Zero based on the technologies currently available:

- in Chapter 2 we discuss the role that hydrogen could play in the overall decarbonisation strategy and the UK's energy system;
- in Chapter 3 we review the processes of low-carbon hydrogen production and assess the extent to which the Government's Hydrogen Strategy is feasible and appropriate;
- in Chapter 4 we analyse the applications of hydrogen across several sectors and identify recommendations for Government policy in sectors where a decision should be made;
- in Chapter 5 the issue of domestic metering of hydrogen use is explored, with some further recommendations around the role of the energy regulator Ofgem;
- in Chapter 6 we evaluate the Government's Hydrogen Strategy and recommend that it makes further progress on determining the role of hydrogen in the UK; and
- In Chapter 7 we offer an overall conclusion.

9. Our recommendations focus on, but are not limited to:

- **The need to make decisions on what technological solutions should be prioritised**: we have heard that the challenges surrounding reaching Net Zero emissions by 2050 are so significant that rapid action will be required on all fronts, and there are important decisions to be made about which technologies to prioritise. Several witnesses called on the Government to make firm decisions on the role of hydrogen in the economy.
- **The need to learn from international counterparts**: regulatory frameworks, scales of investment and rapid development of hydrogen infrastructure in other countries offer strong signals for the UK to play a full part in developing the international policy and regulations to ensure the development of low-carbon hydrogen in the UK can proceed.
- **The need for adaptable equipment and flexible systems wherever possible in domestic metering and clarity over the role of the regulator**: we heard evidence, for example, that the current generation of smart meters is not compatible with hydrogen use, and therefore the current roll-out of smart meters will not be so effective under several future domestic heating scenarios. There is a need for clarity on different metering technologies and an assessment of the overall costs of smart metering compatible with hydrogen in the gas grid. The issue of metering domestic hydrogen use has not been adequately addressed by the energy regulator, and there are questions over the role of Ofgem in protecting the interests of the consumer.

19 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021

2 Hydrogen's potential contribution to Net Zero

10. Reaching Net Zero greenhouse gas emissions by 2050 is a very significant challenge that requires urgent action across many sectors of the economy,[20] and the International Energy Agency has said an "unprecedented clean technology push to 2030" is required.[21] Much of the evidence that we received explained that hydrogen had some role to play in decarbonising the UK's energy system.[22] In contrast to fossil fuels, when hydrogen is used as a fuel, it does not produce any carbon dioxide. Instead, water is produced as a by-product (see equation below).

$$\text{Hydrogen} + \text{Oxygen} \longrightarrow \text{Water} \quad (+\text{energy})$$
$$2H_2 + O_2 \longrightarrow 2H_2O$$

We heard evidence that the role of hydrogen should be viewed from a systems rather than an individual application perspective, in which the scale and processes of hydrogen production are considered with its end uses and its distinctive features as an energy vector.[23] In this Chapter we discuss the potential unique contribution that hydrogen can provide to a decarbonised energy grid, and how hydrogen use should intersect with other decarbonisation priorities.

Hydrogen as part of the decarbonisation strategy

11. The August 2021 Intergovernmental Panel on Climate Change (IPCC) report described how global warming of 1.5°C would be reached by 2040 in all future scenarios, and that if emissions were not significantly decreased in the next few years, this would happen earlier: "Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades".[24]

12. Decarbonising the UK energy system is a significant challenge and we heard that urgent action was required on multiple fronts. Dr Jenifer Baxter, Chief Engineer at the Institution of Mechanical Engineers, told us that since only 16% of the UK's energy comes from electricity, and about half of that is renewable energy, "over 90% of the energy system needs to be changed" in order to decarbonise.[25] Professor David Cebon, Professor of Mechanical Engineering at the University of Cambridge, also emphasised that "if we are going to hit anything like the 1.5°C global warming target, we need to massively decarbonise immediately",[26] and Sir Patrick Vallance, Government Chief Scientific

20 For example, see: The Royal Society (HNZ0079), University of Birmingham (HNZ0030), Energy Systems Catapult (HNZ0066) and Qq22, 425, 428, 503
21 International Energy Agency, Net Zero by 2050: A roadmap for the Global Energy Sector, 11 May 2021, p. 14
22 For example, see: UK Research and Innovation (UKRI) (HNZ0091), Department for Business, Energy and Industrial Strategy (HNZ0090), Thames Estuary Growth Board (HNZ0015), Centrica plc (HNZ0073) and Qq32–33, 75, 91
23 For example, see: Energy Systems Catapult (HNZ0066); Business Modelling Associates UK LTD (HNZ0017) and Qq1, 34, 425, 441, 450, 453, 506
24 Intergovernmental Panel on Climate Change (IPCC), Climate Change 2021: The Physical Science Basis, 9 August 2021, B.1
25 Q34, see also Q425
26 Q22

Adviser, told us "we have a very significant problem to get to Net Zero, and we should go as fast as we can go".[27] In March 2022, Sir Patrick said it was important to make the right decisions and to work back from 2050 to identify decision points if the deployment of hydrogen was to contribute to reaching Net Zero. He described R&D investment as being able "to optimise the chance of being able to make a good decision":

> If we can optimise our R&D spend in that space, that will allow us to make the right decisions at the time you need to come off the fence and say, "We are going to implement this because we have got an implementation plan that needs to roll out".[28]

13. Guy Newey, now Chief Executive of the Energy Systems Catapult, told us that if no action was taken over the next five years, we "will not meet our Net Zero target":

> The Net Zero targets are incredibly ambitious and difficult, and that is across the board of the economy. The easy bit is electrification, which we have made loads of progress on. It is still a huge challenge to make your whole system work all the time on low-carbon [...] We have no time to waste. We need to up the pace, for sure.[29]

14. Our evidence supported the 2018 report from the then Committee on Climate Change, *Hydrogen in a low-carbon economy*, which argued that the role of hydrogen should to be considered alongside other decarbonisation priorities such as increasing the roll-out of renewables, widespread electrification and efficiency and domestic insulation improvements.[30] Professor Marcus Newborough, Development Director at ITM Power, told us that "energy efficiency should come first, electrification second, and green hydrogen third" (for an explanation of the different types of hydrogen, see box one in Chapter 3).[31]

15. The Government's *Ten Point Plan for a Green Industrial Revolution*, published in November 2020, outlined £12 billion of funding and several commitments and milestones across ten policy areas to accelerate the transition to a Net Zero economy.[32] Several detailed strategies have been published following the Ten Point Plan, including the Energy White Paper, the Industrial Decarbonisation Strategy, the Transport Decarbonisation Plan, the Hydrogen Strategy, the Heat and Buildings Strategy and the Net Zero Strategy.[33]

16. Baroness Brown of Cambridge, Chair of the Carbon Trust and former Vice Chair of the then Committee on Climate Change, told us that the Government needed a "completely integrated approach right across different Government Departments", where the hydrogen

27 Q22, Q503

28 Oral evidence taken before the Science and Technology Committee on 30 March 2022, HC (2021–22) 1205, Q85.

29 Q428

30 The Committee on Climate Change, Hydrogen in a low-carbon economy (November 2018). See also The Royal Society (HNZ0079) and Professor Jon Gluyas (Executive Director at Durham Energy Institute); Dr Jonathan Radcliffe (Reader in Energy Systems and Policy at University of Birmingham); Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry at University of Cambridge) (HNZ0101)

31 Q91; see also Qq62, 253

32 HM Government, The Ten Point Plan for a Green Industrial Revolution, 18 November 2020

33 Department for Business, Energy and Industrial Strategy, The Energy White Paper: Powering our Net Zero Future', CP 337, 14 December 2020; Department for Business, Energy and Industrial Strategy, Industrial Decarbonisation Strategy, CP 399, 17 March 2021; Department for Transport, Transport decarbonisation plan, 14 July 2021; Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021; Department for Business, Energy and Industrial Strategy, heat and buildings strategy, CP 388, 19 October 2021; and Department for Business, Energy and Industrial Strategy, Net Zero Strategy: building back greener, 19 October 2021.

strategy was linked to the electrification strategy in areas such as low-carbon buses, but that this integration was something we "have not seen enough of".[34] Sir Patrick Vallance also told us that "this is a systems problem that needs a full systems integration" between different Government departments.[35]

17. Further, the Net Zero goal is an international effort, and the decisions that the UK Government makes on the role of hydrogen in reaching Net Zero are part of the global energy transition.[36] Professor Paul Monks, Chief Scientific Adviser to the Department for Business, Energy and Industrial Strategy and Sir Patrick both highlighted the role that the UK plays in the Mission Innovation project, a global initiative launched at the COP21 Paris Climate Conference, to support innovation and investment to make "clean energy affordable, attractive and accessible to all" this decade.[37] Representatives from the aviation and shipping industries emphasised the need for international collaboration in their industries, and highlighted the importance of decisions made by the UK being in line with those of other countries.[38] Experts from Germany also called for international collaboration in regulating low-carbon hydrogen use.[39] Several submissions to our inquiry said the UK should learn from the hydrogen strategies of many other countries, to ensure that it was playing a significant role in the global market and maintaining a position of leadership.[40]

18. **To meet the 2050 Net Zero target, decisions need to be urgently taken by the Government, which will help define hydrogen's place in the UK's overall decarbonisation strategy. These decisions should be integrated across Government, in policy areas such as those identified in the Ten Point Plan for a Green Industrial Revolution. Decisions on hydrogen should be made in an international context and take into consideration the approaches of other countries both in terms of lessons to be learned and collaborations to be pursued.** ***The Government should, in the next two months, outline a series of decision points between now and 2050 that will determine the role of hydrogen in the UK, in each policy area identified in the Ten Point Plan for a Green Industrial Revolution. This should be accompanied by an outline of the scientific and technological progress that needs to be made to allow hydrogen to play its part in our energy system.***

The unique contribution of hydrogen in the energy system

19. Several witnesses and submissions to our inquiry argued that hydrogen had an important role to play not generally but rather in certain sectors for decarbonisation, such as in industrial applications.[41] To decarbonise other sectors such as energy storage and domestic heat we heard conflicting evidence on the role of hydrogen.[42] This choice between

34 Q63
35 Qq492–493; Prime Minister's Office, 10 Downing Street, Prime Minister sets out plans to realise and maximise the opportunities of scientific and technological breakthroughs, 21 June 2021
36 Q233
37 Qq494, 503 and Mission Innovation, 'Mission Innovation 2.0 Vision', 2 June 2021
38 Qq205, 208, 212, 229 and 236
39 Qq379–380
40 UK Hydrogen and Fuel Cell Association (HNZ0011); Thames Estuary Growth Board (HNZ0015); Alstom UK (HNZ0018); Hydrogen Strategy Now campaign (HNZ0024); ITM Power (HNZ0027); University of Birmingham (HNZ0030); HyDeploy (HNZ0040) and Imperial College London (HNZ0047)
41 See for example: Progressive Energy; HyNet North West (HNZ0022); Mineral Products Association (HNZ0025); ITM Power (HNZ0027); E3G (HNZ0043); The Royal Society (HNZ0079) and Qq23, 25, 32, 40
42 Qq271, 459 and 489

different technology options is partly better illustrated by the comparative efficiency of alternative technologies and the eventual costs to the consumer.[43] Professor Cebon told us that energy efficiency considerations were fundamental, as they underpinned economic efficiency:

> The Achilles heel of hydrogen processes is inefficiency. With inefficiency comes cost. If processes are inefficient, you use a lot more energy. The consumer pays for energy, not for carbon, so if you use a lot more energy, it costs a lot of money. Ultimately, that ends up in the national bottom line, so an inefficient energy system is inefficient for the economy. For example, if the cost of heating buildings is very high, consumers have to provide that money or the Government have to provide some sort of subsidy, and there is no headroom for collecting tax.[44]

20. An alternative framing considers the role of hydrogen in the UK energy system.[45] Mark Neller, director and Energy Business Leader at engineering consultancy Arup, described how the use of hydrogen should be viewed from four perspectives:

- **Engineering and technical**: "what are the technical challenges? How do we overcome those? Do we have a solution that works technically?";
- **Delivery**: "how are we going to go from where we are today to our low-carbon future?";
- **Economic**: "what does it mean for UK plc in jobs, the economy and the cost to consumers?"; and
- **Consumer**: "what does this mean to homeowners? What does this mean to people who are using the energy system, and how do we make this transition acceptable to them?"[46]

21. Wider consideration of the energy system is also needed to appreciate the contribution that hydrogen can make to decarbonisation. In this inquiry, we heard of several niche but essential roles for hydrogen in making a unique contribution to the energy system. We detail these in the paragraphs that follow.

22. **Hydrogen as a clean-burning gaseous fuel**—we heard evidence that hydrogen has an essential role to play in certain applications because the UK will always have a need for a gaseous fuel in its energy system. Professor Newborough told us that a large quantity of hydrogen production can be expected "because, simply, we need a lot of molecules; we use a lot of energy in the form of molecular energy, or fuel, as opposed to electricity".[47] Franz Lehner, Head of International Cooperation at NOW GmbH (The German National Organization for Hydrogen and Fuel Cell Technology) commented:

43 The International Council on Clean Transportation (HNZ0002); Mr Steve Green CEng (HNZ0009); Centre for Sustainable Road Freight, University of Cambridge; Centre for Sustainable Road Freight, University of Cambridge (HNZ0020); University of Birmingham (HNZ0030) and Qq22, 33, 385

44 Q4

45 For example, see: Business Modelling Associates UK LTD (HNZ0017); Wales & West Utilities (HNZ0028) para 14; Energy Systems Catapult (HNZ0066); Anglo American (HNZ0087) and Qq1, 34, 425, 441, 450, 453, 506

46 Q425

47 Q75

> We can electrify a lot of sectors, but there will always be a need for a molecule-based energy carrier in the same way as we use fossil fuels today [...] if we cannot agree that green molecules will be abundant by 2050, we cannot reach Net Zero.[48]

Similarly, National Grid explained in its written evidence that hydrogen had a potentially important role in meeting demand as it could help "to manage peak [demand] for decarbonised heating":

> Currently, gas networks transport three times the energy that electricity networks do. Transporting hydrogen in pipelines could create similar flexible benefits that 'linepack' currently provides in the gas networks to respond to demand.[49]

23. **Hydrogen and electrification have different infrastructure requirements**—we received evidence that there were distinct infrastructure requirements for the direct deployment of hydrogen and for electrification of parts of the energy system,[50] and that different infrastructure requirements could cause different levels of disruption to the consumer.[51] For example, the supply of hydrogen for domestic heating could use existing gas infrastructure with a hydrogen boiler installed, whereas a heat pump required a retrofit to a home.[52] We also heard that different infrastructure requirements had different upfront costs: installing a heat pump (i.e. without other improvements such as new insulation) was estimated by HyDeploy to cost between £9–11,000 in comparison with a purchase price for a new hydrogen or hydrogen-ready boiler at approximately £2,000.[53]

24. **Hydrogen for domestic heating could be easier for consumers to adapt to**—Carl Arntzen, CEO of Worcester Bosch, told us that the operation of a heat pump to heat a home was very different to that of a boiler since a heat pump uses a "shallow temperature gradient" to heat a home,[54] whilst HyDeploy, the energy demonstration project aiming to establish the viability of hydrogen blending in the gas grid told us that "hydrogen boilers can generate significantly higher temperatures than heat pumps, which makes them better suited to heating poorly insulated buildings".[55] Carl Arntzen suggested that the challenge of persuading consumers to change "from one technology to another should not be underestimated".[56] Conversely, we also heard evidence that the use of hydrogen in domestic heating required consumer acceptance and trust that hydrogen was a safe means for heating a home.[57]

25. **Hydrogen could provide resilience to the UK's energy system**—we heard evidence that hydrogen could be an effective means of providing energy resilience across several sectors of the UK economy.[58] Professor Katsuhiko Hirose, CEO and Chief Consultant,

48 Qq371, 389
49 National Grid (HNZ0038). Linepack is the total of volume of gas that can be stored in a gas pipeline.
50 Imperial College London (HNZ0047); Shell UK (HNZ0059); EDF (HNZ0065); Riversimple Movement Ltd (HNZ0076)
51 Energy Networks Association (HNZ0032); Energy and Utilities Alliance (HNZ0070) and Q6
52 Q259
53 The Committee on Climate Change, 'Hydrogen in a low-carbon economy', 22 November 2018 and HyDeploy (HNZ0040)
54 Q259
55 HyDeploy (HNZ0040)
56 Q254
57 OGTC (HNZ0016); Institution of Chemical Engineers (HNZ0031); HyDeploy (HNZ0040) and UK Research and Innovation (UKRI) (HNZ0091)
58 Qq33, 154, 163, 293, 333, 339, 352; HyDeploy (HNZ0040); Professor Jon Gluyas (Executive Director at Durham Energy Institute); Dr Jonathan Radcliffe (Reader in Energy Systems and Policy at University of Birmingham); Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry at University of Cambridge) (HNZ0101)

HyWealth Co., and Visiting Professor at Kyushu University in Japan, spoke about the importance of considering the wider economics of hydrogen use rather than just considerations of energy efficiency:

> efficiency is very important in deciding the future, but economics is more important. I always said that this is something like milk and cheese. You have a lot of production of milk in summer. If you convert it to cheese, you can eat it in winter and you can trade. The efficiency is less but the economics can be better.[59]

He added that "carbon neutrality is not a goal. A sustainable society and life is the goal" and that a "wider diversity profile" of energy sources was needed for a sustainable and resilient energy system, both for Japan and the UK.[60] The National Engineering Policy Centre (an organisation led by the Royal Academy of Engineering to connect policymakers to engineering expertise) also told us that whilst hydrogen uses were inefficient:

> this efficiency measure does not necessarily account for the realities of a complex hydrogen system involving multiple forms of common production, storage, transport and end-use. For example, hydrogen is also one of several fuels which could be used to power heat networks. Interoperability, stability, resilience and security of supply are currently and should remain key factors in decision-making.[61]

26. In addition, Dave Rowlands, Wincanton Fleet Engineering Director, commented on the need for resilience in a decarbonised transport sector:

> I have a concern that the whole infrastructure for transport could be reliant on electricity supply. It would be prudent to have a hydrogen supply as a back-up, or indeed, to ensure that we have resilience. We need to look at the whole strategy of our fuelling in this country so that we pick more than one means of having car, van or truck move on the road, to supply the goods to the country.[62]

27. Anthony Green, Hydrogen Project Director at National Grid, told us that hydrogen could provide resilience in the domestic heating system, where a "whole-systems approach" involving a balance between electricity and gas would "get the benefits of resilience against the benefits of cost".[63]

28. **Hydrogen may improve national energy security**—Professor Jon Gluyas, Executive Director of the Durham Energy Institute, commented on the need for the UK to reduce its dependence on gas to improve energy security.[64] In 2020, indigenous production met 42% of demand for natural gas, with the remainder met by imports from Norway, Belgium and the Netherlands.[65] Professor Gluyas told us that on a cold winter's day the gas supply was "only 1% above our demand level", and added that "if we could reduce our dependency on

59 Q352
60 Q352
61 National Engineering Policy Centre (NEPC) (HNZ0078) para 11
62 Q154
63 Q293
64 Q313
65 Department for Business, Energy and Industrial Strategy, Digest of UK Energy Statistics (DUKES): natural gas, 28 July 2022

gas, […] we would improve our security".[66] Rolls Royce Ltd also commented:

> It is important to recognise that energy has dominated global geo-politics since the beginning of the industrial revolution, and it seems unlikely that this will change substantively in the future. Having a strong national capability in Hydrogen energy may be of significance beyond the core focus of Net Zero.[67]

29. Countries such as Japan and Germany are also using hydrogen as a means of improving their energy security.[68] Professor Newborough said a potential benefit of hydrogen could be to reduce the UK's dependency on importing gas, although this depended on the means of production of hydrogen. He told us that hydrogen produced with renewable energy [green hydrogen] could reduce dependence on imports, since it was produced with "British energy"—"it is wind and sun that is striking our territory". However, if hydrogen was produced using fossil fuels and the carbon emissions were stored [blue hydrogen], "you have to import the natural gas from Norway or Russia".[69] Professor Cebon estimated that production of hydrogen from fossil fuels could increase natural gas imports by 30%, which would "double the UK's imported natural gas, taking it to about 65%", which "has a very serious implication for energy security".[70]

The UK Hydrogen Strategy

30. The UK Government's Hydrogen Strategy recognised the energy system benefits of hydrogen use. The strategy discussed the "potential for hydrogen to support integration of renewables with added benefits for energy security and resilience" as part of a "holistic approach" to the hydrogen economy and a "systemic approach to policy development":

> 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.[71]

31. **Hydrogen has several distinctive features as a low-carbon gaseous fuel and could contribute to the UK's energy system, including through improving resilience and energy security. Whilst in some applications hydrogen is less efficient compared to alternative low-carbon technologies, the wider energy system benefits of deploying hydrogen must be acknowledged, and we welcome the Government's whole systems approach in its Hydrogen Strategy. *Consideration should be given to broader benefits, such as system resilience and national security, as well as price competitiveness as a fuel, in implementing the Hydrogen Strategy.***

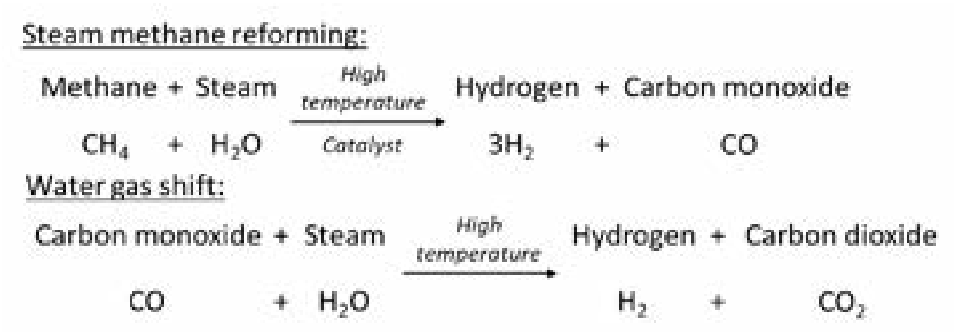
66 Q313
67 Rolls-Royce plc (HNZ0029)
68 Qq339, 355, 358, 360 and 362
69 Q106
70 Q8
71 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021

3 Hydrogen production

32. This Chapter discusses the need for low-carbon hydrogen production and the forms that this can take (see box one). It further discusses the feasibility of the different forms of hydrogen production, and then provides recommendations for its development.

Box 1: Types of Hydrogen production

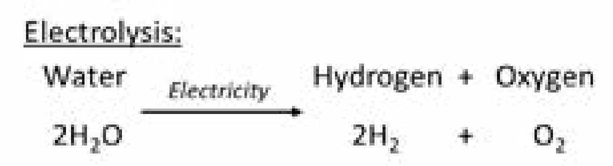
In 2021 the International Energy Agency found that globally 62% of hydrogen was produced using natural gas without carbon capture, use and storage (CCUS), 19% using coal and 18% as a by-product of naphtha reforming at refineries.[72] This is called **'grey hydrogen'**. The production of hydrogen from natural gas occurs through a chemical process called steam methane reformation, where steam is reacted with natural gas at a high temperature over a catalyst to produce syngas (a mixture of hydrogen and carbon monoxide).[73] The carbon monoxide is then converted into carbon dioxide and hydrogen in the 'water-gas shift reaction' (see equation below). Further processing is then carried out to separate the hydrogen.



Grey hydrogen production accounts for approximately 2% of total global carbon emissions, according to a 2019 report by the International Energy Agency.[74]

If the carbon dioxide arising from production is not allowed into the atmosphere through carbon capture and storage, this is called '**blue hydrogen**', and can be categorised as a low-carbon form of hydrogen production.

Hydrogen can also be produced through electrolysis of water. Electrolysis is a chemical process where an electric current is passed through water in an electrolyser, causing the water to dissociate into its component hydrogen and oxygen (see equation below). If the electricity used in this process is renewable the resultant hydrogen is called **'green hydrogen'**.[75]



Both green and blue hydrogen are proven technologies with trials and smaller production plants in operation. According to a report from the International Renewable Energy Agency (IRENA), green hydrogen costs have the potential to rapidly decrease and become cost-competitive with blue hydrogen and even grey hydrogen in some locations, if strategies are adopted to reduce the cost of electrolysers and there is a supply of green electricity.[76]

Another technology with potential is hydrogen produced from nuclear energy through two processes: electrolysis (similar to green hydrogen) and high temperature thermochemical hydrogen generation from waste heat in the plant (not yet available).[77] Hydrogen produced from nuclear energy is called '**pink hydrogen**'. This is referred to in the Government's Hydrogen Strategy as a means of production of hydrogen from the mid-2030s onwards with anticipated costs comparable to blue hydrogen.[78] The evidence we received from respondents and witnesses mainly focussed on green and blue hydrogen.

72 International Energy Agency, Global Hydrogen Review 2022, 22 September 2022, p. 71
73 The Royal Society, Options for producing low-carbon hydrogen at scale, February 2018, p. 10
74 International Energy Agency, The Future of Hydrogen, 14 June 2019, p. 37
75 Less than 0.1% of global hydrogen production is 'green' according to the IEA (The Future of Hydrogen, June 2019)
76 IRENA, Making the breakthrough: Green hydrogen policies and technology costs, 2 April 2021
77 Dalton Nuclear Institute, The University of Manchester (HNZ0071)
78 UK Government, The Ten Point Plan for a Green Industrial Revolution (2020); Nuclear Industry Association (HNZ0036); Sizewell C (HNZ0062)

The Government's hydrogen production strategy

33. There are several means of producing hydrogen, each with different technology requirements and carbon emissions. These are specified in a colour scheme which labels the origin of hydrogen and are described in Box 1.

34. The Government set out its aim to achieve "5GW of low-carbon hydrogen production capacity by 2030 for use across the economy" in the UK Hydrogen Strategy and said in its Net Zero Strategy that it expected this to rise to 10 or 17GW by 2035, depending on the role of hydrogen for heat.[79] This target was subsequently doubled to 10GW in the April 2022 British Energy Security Strategy.[80] Scotland has also set a target of 5GW of green and low-carbon hydrogen production by 2030, with 25GW of such production capacity by 2045.[81]

35. The advantages and disadvantages of green and blue hydrogen were extensively discussed during our inquiry, and many witnesses highlighted the importance of both increasing the scale of low-carbon hydrogen adoption quickly.[82] On this point, the then Secretary of State for Business, Energy and Industrial Strategy, Kwasi Kwarteng MP, told us that the UK would follow "a twin-track approach: we are investing in the production of blue hydrogen as well as green hydrogen".[83] This contrasts with the approach of other countries, including Germany, whose strategies strongly emphasise green hydrogen production.[84]

36. The 2020 Energy White Paper allocated £1 billion of funding to establish carbon capture, use and storage (CCUS) in four industrial clusters, for which one of the stated applications was "low-carbon hydrogen production".[85] The then Secretary of State for Business, Energy and Industrial Strategy told us that:

> Once you have carbon capture, the production of blue hydrogen, as we have discussed, fits very neatly with that. The representatives of the industrial clusters that I have spoken to, notably in the Humber estuary and on Teesside—have repeatedly said that the carbon capture that they want to see will be allied to the production of blue hydrogen. I think that, as a low-regrets minimum, we will be committed to CCUS and to the production of blue hydrogen.[86]

The then Secretary of State also highlighted the production of green hydrogen from companies such as ITM Power as allowing for the "production of both forms of hydrogen" to take place.[87] ITM Power had a market capitalisation of approximately £3.5 billion in early 2021, but since our inquiry finished taking evidence this has fallen after production delays.[88]

79 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021 and HM Government, Net Zero Strategy: Build Back Greener, 19 October 2021
80 Department for Business, Energy and Industrial Strategy, British Energy Security Strategy, 7 April 2022
81 The Scottish Government, Scottish Government Hydrogen Policy Statement, 21 December 2020
82 For example, see: National Engineering Policy Centre (NEPC) (HNZ0078); OGUK (HNZ0084); Institution of Mechanical Engineers (HNZ0086); Department for Business, Energy and Industrial Strategy (HNZ0090); UK Research and Innovation (UKRI) (HNZ0091) and Qq363, 429, 441–443, and 466–467.
83 Q497
84 The German Federal Government, The National Hydrogen Strategy, 3 June 2020; Qq361, 364, 368
85 UK Government, The Ten Point Plan for a Green Industrial Revolution, 18 November 2020
86 Q515
87 Q515
88 Financial Times, UK green hydrogen set back after ITM suffers further production hit, 27 October 2022

37. Several witnesses expressed a strong desire for low-carbon hydrogen to be prioritised by the Government.[89] Professor Cebon warned that there was a risk that the development of hydrogen infrastructure would simply lead to the adoption of grey hydrogen, and the replacement of fossil fuels with grey hydrogen would increase carbon emissions, therefore low-carbon hydrogen needed to be incentivised:

> If you promote a hydrogen economy and you do not get green hydrogen in place, and you do not get the carbon taxes in place, grey hydrogen will fill the gap. It is much cheaper than blue or green. The problem with grey hydrogen is that, if you replace natural gas with grey hydrogen, or diesel vehicles with grey hydrogen, for heating or for vehicles, the carbon emissions are significantly higher […] Do not set up a system where grey hydrogen steps in.[90]

He added that emissions were 40% higher for grey hydrogen compared to fossil fuels in vehicles, and twice as high if grey hydrogen was used instead of a natural gas boiler to heat a home.[91]

Green and blue hydrogen production

38. Several witnesses highlighted the importance of both green and blue hydrogen.[92] Most were positive about both, putting an emphasis on blue hydrogen in the short term since it was currently cheaper and more directly available than green hydrogen, but also beginning early investment in green hydrogen since decreases in cost were anticipated with further development.[93] Angus McIntosh, Director of Energy Futures at SGN, told us that the UK had "enough hydrogen production capacity", and low-carbon hydrogen production could be started "relatively quickly" through blue, and replaced over time with green.[94] Similarly, Dr Richard Leese, Director for Industrial Policy, Energy and Climate Change at the Mineral Products Association, told us that he saw "blue hydrogen predominantly as a stepping-stone, and probably the first move", and Tim Dumenil, Acorn Hydrogen Project Manager at Pale Blue Dot Energy, when asked where the focus should be, said "yes for blue hydrogen in the short term, but yes for green hydrogen in the long term".[95]

Blue hydrogen as a transition towards green hydrogen

39. Several witnesses argued that that the inclusion of blue hydrogen in the Government's strategy was sensible and that it offered a transition towards green hydrogen.[96] This argument was based on scalability and cost:

- **Scalability—**The trade association, Oil and Gas UK (OGUK), said blue hydrogen

89 Qq23, 42
90 Q23
91 Q23
92 Institution of Chemical Engineers (HNZ0031) para 7; The Hydrogen Taskforce (HNZ0045); National Engineering Policy Centre (NEPC) (HNZ0078) para 7; Qq36–37, 67–68, 110, 265,
93 Wales & West Utilities (HNZ0028); Energy Networks Association (HNZ0032) and Nuclear Industry Association (HNZ0036)
94 Q265
95 Qq110, 114
96 Qq35—36; OGTC (HNZ0016); E3G (HNZ0043); Shell UK (HNZ0059); Centre for Energy Transition, University of Aberdeen (HNZ0082); OGUK (HNZ0084); UK Research and Innovation (UKRI) (HNZ0091); Q37,

was the "main way that hydrogen can be deployed at scale by 2030" and UK Research and Innovation (UKRI) similarly argued that a joint approach "enables production to be brought forward at scale this decade, while at the same time scaling up green hydrogen which is likely to dominate the global market in the long term".[97]

- **Cost—**Costs are subject to fluctuation, but several analysts estimated that the cost of green hydrogen would decrease to be cost-competitive with blue hydrogen some time from 2030 to the mid-2040s.[98] This cost reduction would be due to what Michael Liebreich called the "experience curve", as electrolyser production is scaled up and renewable energy costs decreased.[99] The UK Hydrogen Strategy stated that "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",[100] and this was expected through a widespread deployment. In this way, the adoption of blue hydrogen in the short-term could be a more cost-effective way of developing early demand in low-carbon hydrogen production before green hydrogen becomes cost-competitive and while natural gas reserves are adequate. Tim Dumenil, Acorn Hydrogen Project, argued that green and blue hydrogen "need to accelerate together and eventually enable this transition from blue through to green as the UK natural gas resources decline".[101] The Government acknowledged in the Net Zero Strategy that it had a role to play in making low-carbon hydrogen competitive: "Lessons learnt from the success of UK offshore wind deployment suggests government intervention to address this cost difference is a key requirement to bring forward hydrogen supply at scale".[102]

40. However, we also heard a desire for the UK to focus on a commitment to green hydrogen.[103] Dr Martin Hanton, Technical Director at the TÜV SÜD National Engineering Laboratory, argued in his submission to our inquiry that the "focus of the UK's target should be tightened to 5GW of green hydrogen specifically", since for green hydrogen there was "only a small, indirect CO_2 by-product to be dealt with vs a large and direct CO_2 by-product for blue hydrogen" and the UK was in a "privileged position of abundant renewable energy potential".[104] The climate change think tank Third Generation Environmentalism (E3G) also encouraged the UK to be "ambitious in its plans to scale up green hydrogen production".[105] ITM Power argued that a "failure to prioritise green hydrogen will prevent significant progress in developing the UK hydrogen economy over the next 5 years".[106]

97 OGUK (HNZ0084); UK Research and Innovation (UKRI) (HNZ0091)
98 Dr Andy Palmer CMG (CEO at Palmer Automotive) (HNZ0008); ITM Power (HNZ0027); Energy Networks Association (HNZ0032); UK H2Mobility, Element Energy (HNZ0033); BloombergNEF, ''Green' Hydrogen to Outcompete 'Blue' Everywhere by 2030', May 5, 2021. Accessed 12 Aug 2021; International Renewable Energy Agency, Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5 C Climate Goal, 1 December 2020; Q443
99 Qq42–43
100 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
101 Q108
102 HM Government, Net Zero Strategy: Build Back Greener, 19 October 2021
103 See, for example: TÜV SÜD National Engineering Laboratory (part of National Measurement System) (HNZ0003); ITM Power (HNZ0027); European Marine Energy Centre Ltd (HNZ0039); E3G (HNZ0043); Ryse Hydrogen and Wrightbus (HNZ0057) and Greenpeace UK (HNZ0063)
104 TÜV SÜD National Engineering Laboratory (part of National Measurement System) (HNZ0003)
105 E3G (HNZ0043)
106 ITM Power (HNZ0027)

41. Tim Dumenil was among those who told us that the scale of green hydrogen projects was much smaller than the current scale of blue hydrogen, and that whilst the largest proven blue hydrogen production was 1800 MW, the:

> largest proven demonstra tor of green hydrogen is 20 MW in Bécancour, Canada. That comprises a series of 2.5 MW stacks. The largest installed electrolyser today, a single-stack electrolyser, is a 10 -megawatt unit in Fukushima, Japan. The scale difference is stark.[107]

However, some witnesses such as Professor Newborough argued that “green hydrogen can be deployed quickly”, since electrolysers are purchased and installed on timescales of a year or less, whereas blue hydrogen needs “extensive feasibility studies prior to major investment” for CCUS deployment.[108] Eric Heymann, Senior Economist, Deutsche Bank Research, pointed out, however, that to meet demand from using energy sources such as green hydrogen, significantly more renewable electricity would be needed.[109]

42. There is therefore an expectation for green hydrogen to be produced at ever-increasing scale along with blue hydrogen over the coming decades. Baroness Brown told us that the Climate Change Committee[110] expected that “there will be more electrolytic hydrogen by 2050” than blue hydrogen, and the mix of low-carbon hydrogen by 2050 would include “40% green hydrogen, 35% blue hydrogen, and some of the rest coming from bioenergy to hydrogen processes”.[111] She added that there was uncertainty around how quickly CCUS could be developed, and how quickly offshore wind power could be developed for green hydrogen production.[112]

43. Several witnesses, including Baroness Brown, also argued that if there was a large proportion of the electricity grid based on renewables, green hydrogen production might become very cheap during periods of low electricity consumption.[113] However, others such as Rolls Royce told us that “it is likely that curtailed renewable electricity may only be able to account for 10–15% of total energy demand for Hydrogen” and the Institution of Chemical Engineers told us that since electricity demand is increasing, “times of surplus are likely to be less frequent and smaller in magnitude”, so low-cost green hydrogen may only play a niche role in hydrogen deployment.[114]

44. **The Government has chosen at this stage to support the development of both green and blue hydrogen. We heard that the initial adoption of blue hydrogen will be cheaper than green hydrogen, and ready to use in certain niche industrial settings sooner. However, several analysts have argued that green hydrogen will become cheaper than blue hydrogen over time.**

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107 Q108

108 ITM Power (HNZ0027); Ryse Hydrogen and Wrightbus (HNZ0057) and Q82

109 Q388

110 In December 2020, the Committee on Climate Change was renamed the Climate Change Committee. When referring to evidence or publications from the Committee before the change we refer to the then Committee on Climate Change.

111 Q67

112 Qq67–68

113 Qq67–68; Professor Gordon Andrews (Professor of Combustion Engineering at The University of Leeds) (HNZ0010); SGN (HNZ0061); Sizewell C (HNZ0062) and Riversimple Movement Ltd (HNZ0076)

114 Rolls-Royce plc (HNZ0029) and Institution of Chemical Engineers (HNZ0031)

Concerns with blue hydrogen

45. Several submissions to our inquiry argued that blue hydrogen alone should not be used in the long-term.[115] The extent to which green and blue hydrogen should be used in the mid-term, however, was contested in our evidence.

46. **Dependence on carbon capture, utilisation and storage (CCUS)**—blue hydrogen is dependent on CCUS.[116] ITM Power told the Committee that the "first carbon capture and storage projects in the UK will not come online until 2025 at the earliest" whereas "electrolysers and green hydrogen can be produced at scale today", although it might require more renewable electricity to be available.[117] Some evidence advised against the use of blue hydrogen not only due to it not being zero carbon but also because CCUS had not been sufficiently demonstrated at scale.[118] Climate change think tank Third Generation Environmentalism (E3G) argued that:

> Blue hydrogen is not an "easy" technology, and significant progress would be needed on CCS within the next decade if it is to play any meaningful role in the transition period—with care taken to avoid a 'lock in' of dependence on fossil hydrogen technology and infrastructure.[119]

However, Michael Liebreich noted that even green hydrogen had a carbon footprint:

> every kilo of renewable hydrogen that we produce has a footprint or casts a shadow in terms of the land use, the offshore resource use, or the area use, that we need to add to the system. It is not like the renewable is totally clean and wonderful and the blue hydrogen is somehow tainted and evil.[120]

47. Several witnesses highlighted the uncertainty surrounding the future development of carbon capture, utilisation and storage (CCUS) and the infrastructure needed for blue hydrogen production. Professor Cebon told us that there was a need for the "whole infrastructure":

> which does not exist in the UK, and it is a whole infrastructure for building salt caverns and salt caverns offshore so you can store hydrogen. There is huge uncertainty in all of that. There is low technology readiness.[121]

Baroness Brown of Cambridge highlighted significant uncertainty in the development and scaling up of CCUS over the coming decades, which made it hard to predict what role blue hydrogen would have in the UK Net Zero economy by 2050.[122] In addition, the Institution of Chemical Engineers noted that there were "long-term liabilities connected with underground CO2 storage".[123] The Royal Academy of Engineering and National Engineering Policy Centre also highlighted the need to secure domestic capacity "to meet

115 Manchester Fuel Cell Innovation Centre - Manchester Metropolitan University (HNZ0023); ITM Power (HNZ0027); Nuclear Industry Association (HNZ0036); E3G (HNZ0043); UK Research and Innovation (UKRI) (HNZ0091); Q110
116 The Royal Society (HNZ0079)
117 ITM Power (HNZ0027) and Q388
118 Manchester Fuel Cell Innovation Centre - Manchester Metropolitan University (HNZ0023); ITM Power (HNZ0027); E3G (HNZ0043) and Greenpeace UK (HNZ0063)
119 E3G (HNZ0043)
120 Q37
121 Q16
122 Q67
123 Institution of Chemical Engineers (HNZ0031) para 15

the CO2 capture requirements for blue hydrogen production and other sectors by enabling the necessary infrastructure deployment and putting in place a robust monitoring regime".[124]

48. Several witnesses, including Guy Newey from the Energy Systems Catapult, highlighted the importance of further innovation in the capture rate for CCUS.[125] Whilst Guy Newey agreed that there was a "very important role for blue hydrogen going forward", he pointed out a significant technical challenge with blue hydrogen arising from the CO_2 capture rate of CCUS:

> If you capture 90% of the carbon emissions through the blue hydrogen process, that makes it very difficult to see a world where blue can be a significant part of Net Zero when you are getting to 2050 levels of target. It should very much be part of the next 10 years. If you could get that capture rate up to 98% or 99%—that is a fantastic innovation engineering challenge and is not straightforward—it suddenly becomes much more valuable to do it.[126]

49. Modelling studies by Imperial College London—consistent with similar analyses from other international academic groups—found that increasing the capture rate from 90% to 95% could be achieved without significant additional cost and that capture rates of up to 99% were economically achievable using existing technologies, so further performance improvements might be possible.[127] Baroness Brown of Cambridge acknowledged the potential in the UK for blue hydrogen production but also said high capture rates of CCUS were essential:

> It will be critical that the carbon capture and storage is initially giving us blue hydrogen where at least 95% of the CO_2 has been captured. As we get towards 2050, we would want that to be moving towards 99%. If you have blue hydrogen with 99% CO_2 capture, then that is a pretty good, low-carbon fuel. […] because of our geology, we also have a huge resource for storing captured CO_2. We are also a good place for producing blue hydrogen, and, if we can get right up to those 99% capture rates, it is probably a good way of making hydrogen relatively cheaply.[128]

50. The UK Hydrogen Fuel Cell Association position paper, *The Case for Blue Hydrogen*, explained that, whilst there was no currently accepted definition of the capture rate associated with blue hydrogen production, UK blue hydrogen projects aimed for a rate of at least 95%.[129]

51. **Fugitive methane emissions**—evidence from EDF Energy highlighted the risk of fugitive methane emissions arising from leaking and venting natural gas through the processes of extraction, transport and production.[130] However, Michael Liebreich told us

124 The Royal Academy of Engineering and National Engineering Policy Centre, The role of hydrogen in a net zero energy system, 8 September 2022, p. 33
125 Qq441, 499—500
126 Q441
127 Danaci et al. (2021) 'En Route to Zero Emissions for Power and Industry with Amine-Based Post-combustion Capture', Environ. Sci. Technol., 55, 15, 10619–10632
128 Qq70, 72
129 UK Hydrogen and Fuel Cell Association, The case for Blue Hydrogen, 6 July 2021
130 EDF (HNZ0065)

that both the issues of fugitive methane emissions "escaping in the supply chain" and increased capture rates "are problems that will yield to research investment"—"there are approaches to get nearly 100% carbon dioxide capture while making blue hydrogen", and that some operators were able to capture fugitive emissions effectively.[131] At COP26 in Glasgow in November 2021 several countries, including the UK, signed up to the Global Methane Pledge to cut methane emission levels by 30% by 2030.[132]

52. **Demand for electricity and natural gas**—Professor David Cebon, Professor of Mechanical Engineering at the University of Cambridge, told us that "huge amounts of sustainable electricity" would be needed for widespread use of green hydrogen due to inefficiencies in producing and using it.[133] The then Committee on Climate Change has stated that "producing hydrogen in bulk from electrolysis […] would entail extremely challenging build rates for zero-carbon electricity generation capacity".[134] Blue hydrogen—produced from fossil fuels—would enable hydrogen usage without the major increases in electricity demand required by green hydrogen. However, the University of Birmingham argued that "turning natural gas into [blue] hydrogen […] will increase natural gas demand by about 30%", leading to a greater reliance on imports.[135]

53. **Continued dependence on fossil fuels**—Dr Jenifer Baxter, Chief Engineer at the Institution of Mechanical Engineers, commented:

> There is a reality check on whether we want to be bound to a fossil fuel system in the future […] I suggest that it is much better to look at the possibilities for the generation of green hydrogen or using, potentially, biomethane for some form of autothermal reforming as well, with carbon capture and storage or use of that carbon dioxide in another way.[136]

54. **Purity**—Blue hydrogen is produced by chemically reforming hydrocarbons and the impurities in the hydrocarbon come through the process. Several witnesses explained that these impurities made blue hydrogen unsuitable for fuel cells unless they were removed.[137] For example, the Institution of Chemical Engineers noted that transport applications of hydrogen "require a high purity" of hydrogen and Professor Paul Monks, Chief Scientific Adviser to the Department for Business, Energy and Industrial Strategy, told us that, for example, carbon monoxide in the hydrogen fuel mix "poisons the metal in the fuel cells".[138] However, these impurities can be removed through established chemical engineering processes such as pressure swing adsorption.[139]

55. **There is uncertainty about the extent to which blue hydrogen can play a role in a Net Zero economy in the mid to long term, even if it may be cheaper and ready to deploy in certain industrial settings sooner than green hydrogen, as some industrial**

131 Q37
132 See, for example: Sky News, COP26: World leaders pledge to cut methane emission levels by 30% by 2030 in 'game-changing commitment', 2 November 2021
133 Q6
134 The Committee on Climate Change, Hydrogen in a low-carbon economy, 22 November 2018
135 University of Birmingham (HNZ0030); see also Q8
136 Q35
137 Manchester Fuel Cell Innovation Centre - Manchester Metropolitan University (HNZ0023); Institution of Chemical Engineers (HNZ0031) para 13; Q499
138 Institution of Chemical Engineers (HNZ0031) para 13; Q499
139 S. Sircar & T. C. Golden (2000) 'Purification of Hydrogen by Pressure Swing Adsorption', Separation Science and Technology, 35:5, 667–687, DOI: 10.1081/SS-100100183

users already possess the necessary infrastructure. *The Government should not be dependent on either blue or green hydrogen alone in the short-term. The Government's decision to continue using blue hydrogen should be dependent on the standard CO_2 capture rate reaching 95% by 2030 and in excess of 99% well in advance of 2050. In its response to this Report the Government should set out its expectations of how much CO_2 could be captured in hydrogen production and which industrial settings it sees as being ready to utilise blue hydrogen prior to 2050.*

56. ***Carbon capture, utilisation and storage (CCUS) technology should be an area of priority research interest for the Department for Business, Energy and Industrial Strategy, and a strategic priority for UK Research and Innovation.***

International comparisons

57. Several countries are making significant plans to produce and prioritise green hydrogen. According to a 2021 report from energy analyst Aurora Energy Research, "200GW is planned for installation globally by 2030, in advance of a proven market".[140] The European Union's (EU's) *Hydrogen strategy for a climate-neutral Europe* set out its aim to decarbonise hydrogen production and expand its use to replace fossil fuel use across the bloc by 2050.[141] The EU strategy included a "2×40GW" green hydrogen initiative—40GW of EU electrolyser capacity by 2030 plus an additional 40GW across North Africa and Ukraine.[142] Germany has prioritised green hydrogen exclusively in its hydrogen strategy, with a target of 5GW of green hydrogen production by 2030.[143] Franz Lehner from NOW GmbH told us that the likely reason for this was that Germany lacked fossil fuel reserves and that green hydrogen presented an opportunity for German manufacturing.[144] In addition, Germany has allocated €2 billion of funding to foster international partnerships to import green hydrogen internationally.[145]

58. Professor Takeo Kikkawa, a Distinguished Fellow at the Graduate School of International Management, International University of Japan, told us that hydrogen would be "crucial" to decarbonisation in Japan, "especially in the iron and steel and petrochemical industry" which are among the highest CO_2 emitting sectors within Japan's economy.[146] Japan also increasingly uses hydrogen to decarbonise its power sector, and Professor Kikkawa estimated that in 2050 30–40% of Japan's electricity would come from hydrogen.[147] However, since Japan has limited availability of renewable energy and no fossil fuel resources, Japanese domestic production of hydrogen would be limited.[148] Japan is expected instead to rely on an international hydrogen supply chain, importing low-carbon hydrogen from countries such as Australia or Chile.[149] Professor Kikkawa told us "up to 2030 blue hydrogen is more important than green hydrogen. After that we will shift from blue to green, step by step, until 2050".[150]

140 Aurora Energy Research, Hydrogen Market Attractiveness Report (HyMAR) 11 May 2021
141 European Commission, A hydrogen strategy for a climate neutral Europe, 8 July 2020
142 European Commission, A hydrogen strategy for a climate-neutral Europe, 8 July 2020
143 The German Federal Government, The National Hydrogen Strategy, 3 June 2020
144 Q366
145 The German Federal Government, The National Hydrogen Strategy, 3 June 2020
146 Qq334–336
147 Q341
148 Qq333 and 350
149 Q339 and
150 Q347

59. Considering the emphasis that countries such as Germany are putting on green hydrogen development, we were told that to be competitive the UK should increase its commitment to green hydrogen production.[151] Professor Marcus Newborough, Development Director at ITM Power, told the Committee that "about a dozen countries have come out prioritising green" and:

> As a manufacturer we feel that other countries have pushed out there, ranging from Germany and France, all the way across to Chile and Australia, with very forthright green hydrogen ambition […]We think there is a danger of a conflicted message potentially in a strategy that tries to advocate both blue and green. We are hoping for greater clarity and prioritisation of green.[152]

However, Tim Dumenil of Pale Blue Dot Energy argued that blue and green hydrogen were "complementary" and it was not helpful to separate the two, and instead the strategy should focus on "clean hydrogen".[153]

60. When asked how the UK's approach should differ to Japan's, Professor Katsuhiko Hirose, CEO and Chief Consultant, HyWealth Co., also emphasised green hydrogen development. He told us that the UK had "a huge potential for wind power already" and "should use that the most and hydrogen to enhance its use".[154] Scottish Carbon Capture and Storage commented that Dolphyn, a large-scale offshore wind green hydrogen pilot project, had demonstrated the potential for the North Sea region to "become an international scale hydrogen generation complex".[155]

61. Some contributors said the Government should set a specific target for green hydrogen production capacity.[156] The University of Nottingham commented that since grey, blue and green hydrogen produce different levels of CO_2 emissions, "all sources of hydrogen should have their specific targets". There is therefore a need for "targets of delivered output for grey, blue and green hydrogen".[157]

62. The Department for Business, Energy and Industrial Strategy told us that "levels of green and blue hydrogen production…will depend on market developments in the 2020s".[158] The UK Government's Hydrogen Strategy stated:

> 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.

Several policy consultations for hydrogen production were launched alongside the strategy itself. These included:

- the hydrogen business model to support low-carbon hydrogen adoption and

151 ITM Power (HNZ0027)
152 Q99
153 Q99
154 Q352
155 Department for Business, Energy and Industrial Strategy, Dolphyn Hydrogen Phase 1 - Final Report, 9 October 2019 and Scottish Carbon Capture and Storage (HNZ0034)
156 TÜV SÜD National Engineering Laboratory (part of National Measurement System) (HNZ0003); University of Nottingham (HNZ0021) and Ryse Hydrogen and Wrightbus (HNZ0057)
157 University of Nottingham (HNZ0021) para 1.1
158 Department for Business, Energy and Industrial Strategy (HNZ0090)

development;[159]

- the design of the Net Zero Hydrogen Fund, a £240 million "government co-investment to support new low-carbon hydrogen production out to 2025";[160] and
- the design of the Low-Carbon Hydrogen Standard which will specify the maximum carbon footprint associated with low-carbon hydrogen.[161]

63. In the April 2022 British Energy Security Strategy the Government doubled its 5GW production capacity target to 10GW, with "at least half of this coming from electrolytic hydrogen".[162] The Government also published updates to the Hydrogen Strategy in July and December 2022, which re-affirmed this commitment and set out the Government's aim "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".[163] In December 2022 the Government announced £25 million in funding "to accelerate the deployment of hydrogen from bioenergy with carbon capture and storage (BECCS), a unique 'negative emission' technology that can permanently remove CO2 from the atmosphere. Biomass absorbs CO2 during growth which is then captured and permanently stored during the hydrogen generation process".[164]

64. Baroness Brown told us that the development of green hydrogen production was "closely connected to the rate at which renewables on the grid will be increasing", but that since there was a 40GW target for the development of offshore wind by 2030, a target for green hydrogen production could be set because "it is quite logical for the electrolytic hydrogen to be growing as the renewables on the grid grow".[165]

65. **Several countries are prioritising green hydrogen in their hydrogen strategies, and it seems likely that international interest in demonstrably low-carbon hydrogen, including green hydrogen, will continue to grow. This offers an opportunity for the UK to become a leader in green hydrogen production and development.** ***The Government needs to provide more clarity in its updates to market on the hydrogen strategy, with a view to guaranteeing significant green hydrogen development over the next decade. In its response to this Report, the Government should set out how it intends to support the development in the UK of green hydrogen projects at scale during this decade, to ensure that green hydrogen can be produced in the UK and so it can become cost-competitive with blue hydrogen. This should include additional efforts to reduce the cost of electrolysers.***

66. ***The Government should set a 2030 target for green hydrogen production to ensure that full-scale development of green hydrogen is incentivised to take place in the short-term and to make it more likely that the UK develops a green hydrogen production***

159 Department for Business, Energy and Industrial Strategy, Design of a business model for low carbon hydrogen, published 17 August 2021
160 Department for Business, Energy and Industrial Strategy, Designing the Net Zero Hydrogen Fund – Consultation, published 17 August 2021
161 Department for Business, Energy and Industrial Strategy, Options for a UK low carbon hydrogen standard: report, published 17 August 2021
162 Department for Business, Energy and Industrial Strategy, British Energy Security Strategy, 7 April 2022
163 Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market: July 2022, 20 July 2022 and Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market: December 2022, 13 December 2022
164 GOV.UK, £102 million government backing for nuclear and hydrogen innovation in the UK, 13 December 2022
165 Qq68–69

capacity. The Government should be clear whether any targets it sets are for capacity to produce, or are an expectation of how much hydrogen the UK expects to produce and use. The Government should also indicate when grey hydrogen production will be phased out.

4 Hydrogen applications

67. This Chapter: discusses applications in the UK energy system where hydrogen could potentially play a role; explores within each sector where hydrogen can be used most effectively; and considers how we should assess the overall role of hydrogen within the UK economy.

Energy storage

68. Hydrogen has a potential application as an inter-seasonal energy storage technology. By producing sufficient quantities of low-carbon hydrogen and safely storing it, it would be possible to develop a grid-scale store of energy to meet particular energy demands at certain times of year, such as for electricity or heating.[166] Such energy stores would increase the long-term resilience and security of the UK energy system, as discussed in Chapter 2.

69. Referring to the UK's seasonal energy demands, SGN told us that the "electricity grid's ability to satisfy heat demand during a winter cold spell is significantly restricted by the challenge of storing electricity at scale at an affordable cost".[167] The then Committee on Climate Change projected that reaching Net Zero would require a "significant expansion of low-carbon generation […] in conjunction with more flexible demand and use of storage" because of the seasonal variation of renewable energy sources.[168]

70. Written evidence submitted by Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry, University of Cambridge), Professor John Gluyas (Executive Director of Durham Energy Institute) and Dr Jonathan Radcliffe (Reader in Energy Systems and Policy, University of Birmingham) noted that because of the UK's dependence on electricity from variable renewable sources "we will need many forms of storage" and "there is a case for accelerating innovation in energy storage in particular, with research and opening-up market mechanisms to incentivise deployment".[169] Dr Radcliffe further told us:

> We will need a much larger amount of energy storage as we transition through to low carbon, especially as we get towards Net Zero, and the opportunity for having more flexibility in the electricity system from fossil fuel power stations is reduced significantly. Energy storage will allow us to balance the supply and demand from variable renewables much more effectively and allow greater integration over time.[170]

71. The British Geological Survey noted that whilst there were a variety of options for commercial scale hydrogen storage, "the environmental impacts of a major upscaling

166 University of Kent (HNZ0001); British Geological Survey (HNZ0026); Scottish Carbon Capture and Storage (HNZ0034); Imperial College London (HNZ0047); SGN (HNZ0061); EDF (HNZ0065) and Professor Jon Gluyas (Executive Director at Durham Energy Institute); Dr Jonathan Radcliffe (Reader in Energy Systems and Policy at University of Birmingham); Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry at University of Cambridge) (HNZ0101)

167 SGN (HNZ0061)

168 The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net Zero, 9 December 2020

169 Professor Jon Gluyas (Executive Director at Durham Energy Institute); Dr Jonathan Radcliffe (Reader in Energy Systems and Policy at University of Birmingham); Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry at University of Cambridge) (HNZ0101)

170 Q294

of hydrogen storage are poorly understood" and would require a "UK national baseline environmental study" to identify means of limiting the environmental impact of such innovation.[171]

72. There are technologies other than hydrogen which offer possible means of providing grid-scale energy storage. These include compressed air, cryogenic (liquid air) and pumped hydropower.[172] Professor Cebon argued that these other options were more cost-effective, since in any application using hydrogen, produced with electric power, to generate electricity again represented a 'round-trip' efficiency of only 30%, compared to "70% or more" for alternative technologies, which also have a lower levelised cost of the necessary storage and infrastructure.[173] Professor Grey, Dr Radcliffe and Professor Gluyas told us that:

> There is a general need to be scaling-up all these technologies with technological innovation and supportive policy, to the level at which they can contribute to managing the energy system, integrated across heat, power and transport.[174]

The Government's policy on developing low-carbon energy storage

73. The UK Government's Hydrogen Strategy also acknowledged the role of hydrogen for "large scale or long duration energy storage and flexible power generation" and anticipated the UK taking advantage of its "natural assets" in hydrogen storage during the 2020s:

> 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.[175]

74. The Strategy said that the Government would "provide up to £68 million for the Longer Duration Energy Storage Demonstration competition, with storing hydrogen produced from excess electricity in scope" and the £330 million Industrial Energy Transformation Fund and Industrial Fuel Switching Competition to establish the "evidence base for hydrogen use and storage in the power sector".[176] In November 2021 the Government announced £9.4 million of funding to support a hydrogen storage project near Glasgow being developed by ITM Power and BOC, in conjunction with Scottish Power's Hydrogen division.[177] In the British Energy Security Strategy, the Government committed to designing a new business model for hydrogen storage infrastructure by 2025,[178] and the

171 British Geological Survey (HNZ0026)

172 Centre for Sustainable Road Freight, University of Cambridge; Centre for Sustainable Road Freight, University of Cambridge (HNZ0020)

173 Qq5, 31

174 Professor Jon Gluyas (Executive Director at Durham Energy Institute); Dr Jonathan Radcliffe (Reader in Energy Systems and Policy at University of Birmingham); Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry at University of Cambridge) (HNZ0101)

175 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021, chapters 1.2, 2.4 and 3.1

176 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021, chapters 1.0 and 2.4

177 GOV.UK, Glasgow to be home to first-of-a-kind hydrogen storage project, 22 November 2021

178 Department for Business, Energy and Industrial Strategy, British Energy Security Strategy, 7 April 2022

Hydrogen Strategy update to market in July 2022 said it intended "to adopt a pragmatic approach when considering support for small scale T&S [transport and storage] costs for both CCUS-enabled and electrolytic hydrogen projects through the initial business model contracts awarded".[179] In December 2022 the Government published an external assessment of hydrogen transportation and storage infrastructure requirements up to 2035. The report, prepared by consultancies Frazer Nash and Cornwall Insight, found "significant uncertainty in cost predictions" due to variability in demand, difficulty in predicting required transport and storage requirements, and variability in unit costs of transport and storage.[180]

75. **Energy storage for electricity generation is widely recognised as an important component of the Net Zero economy, and there are several potential technologies available for energy storage. Hydrogen has unique features as a means of energy storage, since as a clean-burning gas it can be transported through existing infrastructure and stored safely for long periods of time, if necessary. We welcome the Government's recognition of the potential role of hydrogen as an important means of energy storage.** ***The Government should continue to provide the necessary policy support and infrastructure for grid-scale energy storage technologies. Findings from hydrogen energy storage trials should be recorded and shared between trials to ensure that as much is learned as possible.***

Power for industry

76. UK industry had a total energy consumption of 265 TWh in 2021 and, according to the Government's Industrial Decarbonisation Strategy, published in April 2021, metals and minerals, chemicals, food and drink, paper and pulp, ceramics, glass, oil refineries and less energy-intensive manufacturing accounted for one-sixth of UK carbon emissions. There are three broad potential uses for low-carbon hydrogen in industry:

- to replace carbon-intensive hydrogen;
- to enable new low-carbon processes to replace existing processes; and
- as a fuel for providing the high temperatures required by high-temperature industrial processes.[181]

77. Carbon-intensive hydrogen is already produced at scale for industrial applications, primarily for use in oil refining and chemical industries such as ammonia production and fertilisers. Paul Booth, Chair of Tees Valley Local Enterprise Partnership, highlighted the potential for using green hydrogen to produce ammonia, to make "green fertiliser", and explained that hydrogen could also be used to "chemically recycle polymer".[182]

78. Other industrial applications include the glass and steel industries. British Glass and Glass Futures told us that hydrogen could replace natural gas to provide the high

179 Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market: July 2022, 20 July 2022

180 Frazer Nash and Cornwall Insight, Hydrogen Transportation and Storage Infrastructure: Assessment of requirements up to 2035, 13 December 2022, p. 5

181 Department for Business, Energy and Industrial Strategy, Digest of UK Energy Statistics (DUKES): energy, 28 July 2022 and Department for Business, Energy and Industrial Strategy, Industrial Decarbonisation Strategy, CP 399, 17 March 2021

182 Q112

temperatures required, and the Mineral Products Association discussed the possibility of using hydrogen to decarbonise cement and lime production.[183] British Glass and Glass Futures said "significant investment will be required to switch a glass manufacturing site from natural gas to hydrogen", and said that there needed to be sufficient financial support and incentives for a site to switch to hydrogen, with any extra costs covered.[184]

79. Several witnesses, including Baroness Brown of Cambridge, argued that replacing hydrogen with low-carbon hydrogen in these sectors was a no-regrets policy for the Government.[185] In particular, the use of blue hydrogen with CCUS in industrial clusters would introduce low-carbon hydrogen into the economy. Professor Wu, Head of Engineering at Cardiff University, told us that it was "more economical" if hydrogen use in heat and transport was used in a "local energy system", since an "economy of scale" could be developed within the region to decrease costs.[186]

80. The then Secretary of State for Business, Energy and Industrial Strategy, Kwasi Kwarteng MP, told us that he anticipated the production and use of blue hydrogen would begin in geographically confined industrial clusters, since "heavy industry in the industrial clusters was very interested in looking at hydrogen to decarbonise". He also agreed that the use of hydrogen in heavy industry "would be a no-regrets first step in the use of hydrogen".[187]

81. However, Paul Booth told us that "there are factories around the UK that are not in clusters that emit CO_2" which would also need to be decarbonised, and he suggested that infrastructure could be developed that enabled a "distributed system" to support these areas.[188] He also highlighted the importance of a regulatory framework to incentivise the uptake of low-carbon hydrogen:

> it is not necessarily asking the Government for money. It is asking for certainty in policy, and within those frameworks an understanding of the huge capital investments that companies have to make to ensure a certain payback. The risk, of course, is that the investments are not made because that certainty does not exist.[189]

82. Hydrogen also has a potential role in decarbonising steel, with electrification as an alternative.[190] Tata Steel Europe told us "the question is not whether hydrogen will play a role, but when and under what conditions", and forecast the availability of large-scale hydrogen use from approximately 2040.[191] It also argued that as "almost every aspect of the UK Government's decarbonisation plan is steel intensive" the Government should support the development of domestic low-carbon steel production,[192] and that as "operational costs are anticipated to be much higher for a decarbonised steel process than traditional forms of steel production", there was a need for "large-scale public funding" to enable infrastructure development.[193] It described the potential role of a "contracts for difference"

183 British Glass, Glass Futures Ltd (HNZ0035) and Mineral Products Association (HNZ0025)
184 British Glass, Glass Futures Ltd (HNZ0035)
185 Qq2–4, 61; Shell UK (HNZ0059)
186 Q252
187 Q516
188 Q134
189 Q123
190 Q435
191 Tata Steel Europe (HNZ0096)
192 Tata Steel Europe (HNZ0096)
193 Tata Steel Europe (HNZ0096)

approach, to "support steelmakers with the additional cost of carbon reduction".[194] Celsa Steel also commented on the need for the UK to "align its electricity prices to near competitor countries" to enable private investment.[195] Similar recommendations were made by Liberty Steel, British Steel and Michael Liebreich.[196] Dr Pei, Executive Vice-President and Chief Technical Officer at steel manufacturer SSAB, also told us that such policy support would be necessary to keep low-carbon steel internationally competitive.[197]

83. Beyond steel, the Mineral Products Association said it was important to prioritise the use of low-carbon hydrogen in industry, since other possible applications, such as domestic heating or transport "would likely be as easily served with electric solutions, which is not currently an option for cement and lime which could use hydrogen".[198]

Government commitments to decarbonise industry

84. The Government's Hydrogen Strategy explained there would be two industrial clusters with CCUS to produce low-carbon hydrogen running by 2025 and two more by 2030.[199] The then Secretary of State for Business, Energy and Industrial Strategy told us that these areas were a key initial application for hydrogen use, and that "as a low-regrets minimum, we will be committed to CCUS and to the production of blue hydrogen".[200] The Government's Net Zero Strategy also explained that hydrogen was a technically feasible option for most industrial processes and "modelling indicates it is the least-cost option to decarbonise harder to electrify sites, processes, and sectors".[201]

85. In its Industrial Decarbonisation Strategy, published in March 2021, the Government also anticipated that emissions from the industrial sector "will need to reduce by at least two-thirds by 2035 and by at least 90% by 2050". The timeline specified included "testing hydrogen as a fuel for heating in industrial process" from 2020 to 2030, and "widespread fuel switching" to low-carbon technologies from 2025 to 2035. Hydrogen was an option to decarbonise "Iron & Steel" industrial clusters and dispersed "energy intensive" sectors.[202] The strategy said it was critical to demonstrate:

> fuel switching to hydrogen in industrial sites in parallel to ramping up low carbon hydrogen production. In the short term, early, low-regret opportunities for conversion to hydrogen include steam boilers and combined heat and power processes on chemicals, refineries and paper. In the longer term, hydrogen is currently the most promising low carbon option for high temperature direct firing. These high temperature hydrogen technologies are not yet commercially ready and require innovation and testing to bring them to maturity.[203]

194 Tata Steel Europe (HNZ0096)
195 Celsa Steel UK (HNZ0100)
196 Liberty Steel (HNZ0097); British Steel (HNZ0098) and Q50
197 Q127
198 Mineral Products Association (HNZ0025) para 30
199 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
200 Qq467–468, 488, 515–516
201 HM Government, Net Zero Strategy: Build Back Greener, 19 October 2021
202 Department for Business, Energy and Industrial Strategy, Industrial Decarbonisation Strategy, CP 399, 17 March 2021
203 Department for Business, Energy and Industrial Strategy, Industrial Decarbonisation Strategy, CP 399, 17 March 2021

86. The strategy also acknowledged that the "Government should play a key role in delivery of large infrastructure projects for key technologies (for example CCUS and hydrogen networks) where there is a shared benefit and the risk or cost is too great for the private sector". It went on to say that the Government "will work with industry to develop a UK standard that defines low-carbon hydrogen".[204] Similarly, the UK Government's Hydrogen Strategy said:

> 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 [the Sixth Carbon Budget] and on the pathway to Net Zero.[205]

The Hydrogen Strategy specified that £335 million of funding would be provided for fuel switching to hydrogen in industry and the Hydrogen Business Model would provide a system of revenue support to help make low-carbon hydrogen a price competitive decarbonisation option to encourage users to switch to it (a vital addition to less specific mechanisms such as carbon pricing and support for carbon capture, renewable transport fuels and individual hydrogen projects).[206] The Government announced in November 2021 over £11 million of funding to support four projects which were seeking to decarbonise distilling processes.[207] A role is expected for hydrogen and biogas in these projects.

87. **Hydrogen can undoubtedly help key UK industrial sectors decarbonise. There is a widespread recognition of the importance of regulatory reform and an effective business model in incentivising a switch to low-carbon hydrogen use. We welcome the Government's use of industrial clusters to trial the use of hydrogen.** ***The Government must design and establish effective mechanisms to capture and learn the lessons from these trials and demonstrably apply the lessons from the industrial clusters to be set up by 2025 to those which will be in operation by 2030.***

Hydrogen in transport

The Government's commitments to decarbonising transport

88. Transport had an energy consumption of 507 TWh in 2021,[208] and is the largest emitting sector of greenhouse gas emissions of the UK economy, producing 24% of the UK's total emissions in 2020.[209]

89. The Institution of Engineering and Technology has identified three key factors that will determine the future role of hydrogen in transport: consumer choice, production of zero carbon hydrogen at scale, and development of storage and distribution.[210] Our

204 Department for Business, Energy and Industrial Strategy, Industrial Decarbonisation Strategy, CP 399, 17 March 2021
205 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
206 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021; and Department for Business, Energy and Industrial Strategy, Low-carbon Hydrogen Business Model: consultation on a business model for low-carbon hydrogen, 17 August 2021
207 Gov.UK, Funding helps UK distilleries fuel a greener future, 24 November 2021
208 Department for Business, Energy and Industrial Strategy, Digest of UK Energy Statistics (DUKES): energy, 28 July 2022
209 Department for Transport, Transport and environment statistics 2022, 20 October 2022
210 The Institution of Engineering and Technology, Hydrogen's potential as a fuel for road transport, 1 November 2022, p. 21

inquiry also heard evidence that the use of hydrogen in transport varied significantly by mode of transport and was unlikely to have an equal split across each sector.[211] The Government's Hydrogen Strategy outlined several potential transport applications:

> 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.[212]

90. The 2020 Department for Transport report, *Decarbonising Transport: Setting the Challenge*, discussed a primary role for electrification in passenger cars and a potential, but uncertain role for hydrogen in other transport applications:

> Electric batteries are a viable technology for smaller vehicles today, but the fuel for delivering a solution for larger road, marine and rail vehicles is not yet clear. Hydrogen is a potential solution, and the UK has a number of world leading centres that could readily test the viability of the hydrogen economy for transport.[213]

The UK Hydrogen Strategy, published in August 2021, suggested a greater role for hydrogen in transport than the 2020 strategy:

> 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.[214]

Passenger cars

91. Some submissions argued that hydrogen fuel cell cars held some advantages over battery electric cars such as longer ranges and faster refuelling, smaller changes to customer behaviour, less peak demand on the electricity grid, and reduced demand for rare materials for battery manufacture.[215]

211 For example, see: University of Kent (HNZ0001); National grid (HNZ0038); The Hydrogen Taskforce (HNZ0045); Shell UK (HNZ0059) and Energy Systems Catapult (HNZ0066)
212 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
213 Department for Transport, Decarbonising Transport Setting the Challenge, 4 March 2020
214 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021, p. 64
215 UK H2Mobility, Element Energy (HNZ0033); TUV SUD National Engineering Laboratory (part of National Measurement System) (HNZ0003) and Riversimple Movement Ltd (HNZ0076)

92. Others argued that electric cars were already well developed, being increasingly deployed and would likely continue to be so.[216] Professor Monks, Chief Scientific Adviser to the Department for Business, Energy and Industrial Strategy, told us "it is clear that hydrogen has a role to play in transportation, and it is clear that its greatest benefit seems to be in heavy transportation, rather than for light-duty passenger vehicles".[217] In its 2020 Energy White Paper, the Government stated that battery electric vehicles were "well-placed to deliver the bulk of decarbonisation for cars and vans",[218] and in September 2022 the UK marked its millionth battery electric vehicle registration.[219] A 2018 report by the European Environment Agency highlighted 2013 findings that for a typical electric vehicle "life cycle [greenhouse gas] emissions from [electric vehicles] charged using the average European electricity mix [were] 17–21 % and 26–30 % lower than similar diesel and petrol vehicles".[220]

93. The Department for Transport's July 2021 Transport Decarbonisation Strategy described how the "transition to EVs is central to government's Net Zero commitment".[221] Our predecessor Committee in 2019 recommended that environmental impact assessments be required for electric vehicles:

> Any move to electric vehicles must have an associated environmental impact assessment, including the potential for recycling lead, lithium, cobalt, nickel and graphite. Hydrogen technology may prove to be cheaper and less environmentally damaging than battery-powered electric vehicles. The Government should not rely on a single technology.[222]

In response to our predecessor's recommendation, the Government explained that it had "conducted an independently verified assessment of the environmental performance of the fuels and technologies available to consumers", and said that with the current UK energy mix, "battery electric vehicles produce the lowest greenhouse gas emissions of all the energy sources and fuels assessed, irrespective of vehicle type and operation".[223] The Transport Decarbonisation Strategy also made commitments in relation to hydrogen and said that £3 million would be invested in 2021 "to establish the UK's first multi-modal hydrogen transport hub in Tees Valley".[224] This funding, the Government said, would support "collaborative R&D pilot projects and pop-up trials that demonstrate hydrogen technology solutions across transport modes and forge new industry and academic partnerships".[225] The Government announced in October 2022 that the Tees Valley

216 University of Kent (HNZ0001); Dr Andy Palmer CMG (CEO at Palmer Automotive) (HNZ0008); Tom Baxter (Consultant Chemical Engineer at PDB) (HNZ0012); Mr Gordon Taylor (Consultant at G T Systems) (HNZ0054) and Shell UK (HNZ0059)

217 Q488

218 Department for Business, Energy and Industrial Strategy, The Energy White Paper: Powering our Net Zero Future', CP 337, 14 December 2020

219 Society of Motor Manufacturers and Traders, New car market up as plate change September marks one million EV milestone, 5 October 2022

220 European Environment Agency, Electric vehicles from life cycle and circular economy perspective, 22 November 2018, p. 57

221 Department for Transport, Transport decarbonisation plan, 14 July 2021

222 Science and Technology Committee, Twentieth Report of Session 2017–19, Clean Growth: Technologies for meeting the UK's emissions reduction targets, HC 1454, para 132

223 Science and Technology Committee, First Special Report of Session 2019, Clean Growth: Technologies for meeting the UK's emissions reduction targets: Government and Ofgem Responses to the Committee's Twentieth Report of Session 2017–19, HC 287, page 19

224 Department for Transport, Transport decarbonisation plan, 14 July 2021

225 Department for Transport, Transport decarbonisation plan, 14 July 2021

hub would "host a new £20 million competition, where successful bidders will push the boundaries of hydrogen to see how it can be used to create a cleaner and more efficient transport sector".[226]

94. **Passenger battery electric vehicles for road transport have established a seemingly unassailable lead over other green alternatives, meaning that it looks likely that hydrogen will play in the near future, at most, a small part in decarbonising passenger cars.**

Heavy Goods Vehicles (HGVs)

95. Gloria Esposito, Head of Sustainability at Zemo Partnership, a transport decarbonisation public-private partnership of over 200 organisations, told us they saw "a potential role for hydrogen vehicles where battery electric vehicles and battery technology might find it more challenging—for example, where there are longer routes", and the market for hydrogen-fuelled heavy goods vehicles (HGVs) is expected to grow "in the latter part of this decade".[227] The Hydrogen Strategy noted that:

> 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.[228]

Hydrogen fuel cell manufacturer Arcola Energy commented on the benefits of faster refuelling and longer range for hydrogen powered heavy-duty transport, but noted that:

> Even in heavy-duty transport BEVs [Battery Electric Vehicles] will have an important role, particularly where operators can match or evolve business operations to suit the more limited capabilities of the vehicles.[229]

96. Dave Rowlands, Fleet Engineering Director at Wincanton, explained that for hydrogen to be adopted by HGVs, there was a need for a "similar network for hydrogen" refuelling compared to what already exists for diesel vehicles in the UK.[230] He further said that there "needs to be a national network for every town and city, or even village, to have the certainty of refuelling" whether electric or hydrogen is adopted.[231] However, the then Secretary of State for Business, Energy and Industrial Strategy, Kwasi Kwarteng MP, told us that the hydrogen economy would develop regionally and then subsequently spread across the country. He said that hydrogen would "in the first instance, probably be centred around the CCUS clusters" and "over time, that technology can be dispersed and investment can be made across the UK".[232]

97. To understand the role of hydrogen in decarbonising HGVs, there is a need for trials. Gloria Esposito told us:

226 Department for Transport, Tees Valley Hydrogen Hub boosted by £20 million competition, 6 October 2022
227 Q137
228 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
229 Arcola Energy (HNZ0049)
230 Q148
231 Q160
232 Q488

> we really need demonstration trials to understand how they will operate in reallife circumstances, and how the infrastructure associated with that will work. We need to understand the efficiency and durability of these vehicles. We need to understand the cost and the energy efficiency of the system.[233]

Dave Rowlands told us that for hydrogen HGVs to be adopted, the "early adopters need some funds to be able to make them viable, because they are simply not going to pay back in their lifetime".[234] He further added that the infrastructure would need to be in place for HGVs to be adopted and "there has to be a 10 to 15-year plan" for hydrogen to be adopted in the HGV sector.[235] We note, however, that hydrogen HGVs have been used in trials in Europe in 2020 and 2021,[236] in the Port of Los Angeles starting in 2021,[237] and that as part of the Tees Valley hydrogen trial Sainsbury's would be trialling a hydrogen HGV developed by Element Energy.[238]

98. We also heard that there was a role for international collaboration where HGVs might travel across borders.[239] In July 2021 the European Commission pledged to offer hydrogen refuelling stations at 150km intervals on major highways, as a commitment to HGV infrastructure.[240] In contrast, whilst the then Secretary of State acknowledged that hydrogen HGVs would be one of "three main sources of demand for hydrogen" alongside domestic heating and industry, the UK Government's Hydrogen Strategy contained no infrastructure commitments for hydrogen refuelling stations, since the strategy was focused on hydrogen production and incentivising investment in hydrogen production.[241]

99. In March 2021 the UK Government committed £4.8 million to the Holyhead Hydrogen Hub, "a demonstration hydrogen production plant and fuelling hub for HGVs to serve freight traffic at Holyhead and port-side vehicles".[242] The plans received approval in October 2022 and the Hub is expected to be operational by 2025.[243]

100. The Hydrogen Strategy aimed for a decision on the role of hydrogen in HGVs in the "mid-2020s", and "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".[244] In November 2021, the Government made a commitment that "all new heavy goods vehicles in the UK will be zero-emission by 2040", although the announcement made no reference to the role of hydrogen in reaching this ambition.[245] In August 2022 Innovate UK opened the Zero Emission Road Freight demonstration programme, which made up to £140 million available to demonstration projects focused on HGVs across three strands: zero emission road freight battery electric trucks,[246] zero

233 Q141
234 Q144
235 Q145
236 The Sunday Times Driving, Hyundai delivers 10 hydrogen-powered lorries to Europe, 6 July 2020; and Reuters, Hyundai raises hydrogen game as new trucks roll into Europe, 24 May 2021
237 Port of Los Angeles, LA Port's 'HHGV' initiative, 7 June 2021
238 GOV.UK, Competition winners to deliver UK's first hydrogen transport trials in Tees Valley, 17 August 2021
239 Q494
240 European Commission, European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions, 14 July 2021
241 Qq495–496
242 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
243 Wales247.co.uk, Plans for Holyhead Hydrogen Hub receive green light, 26 October 2022
244 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
245 GOV.UK, UK confirms pledge for zero-emission HGVs by 2040 and unveils new chargepoint design, 10 November 2021
246 GOV.UK Innovation Funding Service, Zero emission road freight battery electric truck demonstration, 15 August 2022

emission road freight hydrogen fuel cell trucks,[247] and zero emission road freight battery and hydrogen.[248] Successful projects are expected to begin in early 2023 and will be funded until March 2025.[249]

101. **Whilst there is lower round-trip efficiency compared to electrification, hydrogen vehicles have the advantage of shorter refuelling times and longer ranges. This therefore makes hydrogen a potentially viable alternative to electrification for HGVs, but widespread adoption of hydrogen in HGVs can only be achieved with an assurance that hydrogen will be widely available across the country. Whilst other countries have given commitments to hydrogen refuelling stations, the UK has been more reticent to date.** ***More trials for heavy goods vehicles, beyond those already announced and forthcoming as part of the Zero Emission Road Freight demonstration programme, need to take place in the next five years to ensure that a firm decision can be made on the role of hydrogen in HGVs in time to develop the infrastructure needed to deliver carbon emission reductions. Trials could be localised to minimise the initial infrastructure requirements. Any early adoption of hydrogen HGVs is likely to require subsidy by the Government to overcome the higher cost for the operators.***

Buses

102. Hydrogen was seen as having the potential to play a role in fuelling buses. The advantage for buses is that—unlike HGVs—they operate in a local area rather than roaming the country, meaning that a source of supply of hydrogen at the depot is sufficient, without the need for a comprehensive national network of hydrogen refuelling stations needing to be established. Professor Nilay Shah, Head of the Department of Chemical Engineering at Imperial College London, explained that hydrogen "would already be cost-competitive for buses, for example, as a replacement for diesel".[250] Professor Newborough similarly saw a role for hydrogen in buses: "green hydrogen is very good for making early steps—for example, for refuelling buses in bus depots" and Mark Neller advocated deploying hydrogen across services, including buses, which were within local government control.[251] Nonetheless, Baroness Brown of Cambridge emphasised the need for joined-up thinking:

> I would like to see a more balanced focus on the trials and a stronger focus on linking things like the low-carbon buses the Department for Transport talks about to the hydrogen strategy as well as to an electrification strategy, so that we make sure we are taking a completely integrated approach right across different Government Departments.[252]

Although evidence to our inquiry was not unanimous in agreeing that hydrogen should be prioritised as the low-carbon fuel for buses,[253] we note that in the UK several trials of hydrogen buses are taking or have taken place, including in Aberdeen, Belfast,

247 GOV.UK Innovation Funding Service, Zero emission road freight hydrogen fuel cell truck demonstration, 15 August 2022

248 GOV.UK Innovation Funding Service, Zero emission road freight battery and hydrogen demonstration, 15 August 2022

249 GOV.UK Innovation Funding Service, Zero emission road freight battery and hydrogen demonstration, 15 August 2022

250 Q3

251 Q75 and Q449

252 Q63

253 See, for example: Dr Andy Palmer CMG (CEO at Palmer Automotive) (HNZ0008) on hydrogen's use in urban buses, and Tom Baxter (Consultant Chemical Engineer at PDB) (HNZ0012).

Birmingham, Dundee and London.[254] In its Net Zero Strategy the Government said that it would:

> support delivery of 4,000 new zero emission buses, either battery electric or hydrogen, and the infrastructure needed to support them. This will be the single largest investment ever made in zero emission buses, representing the replacement of nearly 12% of England's local operator bus fleet.[255]

103. **We welcome the trials of hydrogen buses which are taking place in the UK.** ***The Government should continue to support such trials and come to a rapid view of the contribution that hydrogen-fuelled buses can make. Trials should consider the implications for other applications such as HGVs, and the decisions the trials will help to inform.***

Trains

104. Mike Muldoon, head of business development, UK and Ireland at rolling stock manufacturer Alstom, told us that the company saw hydrogen as "part of the mix necessary to decarbonise the network".[256] He said that hydrogen was developing internationally in the form of "regional passenger trains—trains that are not running on high-speed, high-intensity routes", and that hydrogen could be used as a form of energy storage on trains between electrified sections of track since hydrogen had a higher energy density per unit mass than batteries.[257] However, he also saw a greater role for electrification as a "well-known and well-demonstrated technology" in the rail sector.[258]

105. Dr Helen McAllister, strategy and planning director at Network Rail, agreed with these remarks, and told us that hydrogen was best suited to "around 4% or 5%" of the rail network in "geographically specific" areas, with the rest of the network electrified.[259] Dr McAllister also suggested that the use of hydrogen was "as an interim technology in areas that would not be electrified until later on, more towards 2050, so you could realise carbon savings earlier by using hydrogen technology in the interim", and further anticipated the use of hybrid trains as part of rail decarbonisation.[260]

106. The Government's hydrogen strategy expressed a preference for electrification, but also recognised the role of hydrogen in certain parts of the rail network:

> 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.[261]

107. Trials and demonstration projects for trains are being run across the country. In September 2020 the HydroFLEX prototype hydrogen train ran on Network Rail's network,

254 UK H2Mobility, Element Energy (HNZ0033) and Ryse Hydrogen and Wrightbus (HNZ0057)
255 HM Government, Net Zero Strategy: Build Back Greener, 19 October 2021
256 Q166
257 Q167
258 Q166
259 Qq168, 184
260 Qq168, 185
261 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021

developed by rolling stock company Porterbrook and the University of Birmingham, with a £750,000 grant from the Department for Transport.[262] Trips on the demonstrator vehicle were also available to delegates at COP26 in Glasgow.[263] Successful trials for trains have also taken place overseas, including a 20-month trial by Alstom in Germany and a passenger service in Austria.[264] In September 2022 the Alstom Coradia iLint successfully travelled 1,175 kilometres without stopping to refuel.[265]

108. Industry has expressed a desire to work with the Government to further develop the role of hydrogen in trains. Alstom UK told us that the "supply chain and delivery infrastructure" was lacking alternative fuels, and "Government investment is urgently needed to stimulate demand" for hydrogen trains.[266]

109. **Hydrogen has a modest but potentially critical role to play in decarbonising the rail network, where electrification is not suitable or cannot be delivered in time to contribute towards meeting Net Zero. Whilst trials and demonstration projects are underway in hydrogen trains, there is no clear plan to develop the role of hydrogen in this sector. Some countries, such as Austria and Germany, are already using hydrogen trains.** ***In response to this Report, the Government should set out the lessons it has learned from the use of hydrogen trains overseas and how it will use this information in trials of hydrogen trains in the UK.***

110. ***The Government must identify, with industry, the train lines where it is unlikely that electrification will be viable before 2050 and start trials of hydrogen trains on these lines in the next five years.***

Shipping and aviation

Shipping

111. Several witnesses said that whilst coastal shipping could be operated with electrical power from batteries, electrification was not an option for long-haul freight shipping and hydrogen derived fuels were an important option.[267] Professor Cebon, Professor of Mechanical Engineering at the University of Cambridge, told us that "coastal shipping can and should be electrified or hybridised. Aircraft and long-haul shipping are much more difficult. In those applications, there is a strong case for biofuels and e-fuels".[268] E-fuels are "made using captured carbon dioxide in a reaction with hydrogen, generated by the electrolysis of water".[269] He added that since e-fuels were derived from hydrogen there would be an increased cost of production compared to conventional aviation fuels.[270, 271]

262 Porterbrook (HNZ0007) and University of Birmingham (HNZ0030)
263 International Railway Journal, Porterbrook shows HydroFlex demonstrator at COP26, 12 November 2021
264 Alstom UK (HNZ0018)
265 Alstom, Alstom's Coradia iLint successfully travels 1,175 km without refueling its hydrogen tank, 16 September 2022
266 Alstom UK (HNZ0018)
267 Qq1, 4, 57, 325, 422, 428, 449, 455, 502 and European Marine Energy Centre Ltd (HNZ0039); University of Southampton (HNZ0050); Institution of Mechanical Engineers (HNZ0086)
268 Q4
269 The Royal Society, Sustainable synthetic carbon based fuels for transport, 16 September 2019
270 University of Kent (HNZ0001) and The Royal Society, Sustainable synthetic carbon based fuels for transport, 16 September 2019
271 Q4

Michael Liebreich also told us that using hydrogen or a derived fuel in shipping or aviation would have a significant "cost gap" that would need to be addressed on the demand side, since they were currently using cheaper fuels.[272]

112. Dr Morton Bo Christiansen, Head of Decarbonisation at container shipping company Maersk, told us that hydrogen was not a practical option for use as a fuel in shipping, since "it takes up too much space".[273] However, hydrogen could be used to make either ammonia fuel using nitrogen, or a form of methanol using biogenic CO_2. He said both fuels had potential with methanol fuel as the more mature technology, and ammonia as a "very promising future fuel".[274] Dr Christiansen added that:

> the real challenge for us as an industry is not about the engines or the vessels; it is about producing the fuels at a cost that our customers can accept. It will be more expensive. The challenge we are looking at is scaling these things at a price point that is acceptable to customers.[275]

113. Richard Clegg, Chief Executive of the Lloyd's Register Foundation,[276] told us that the challenge was that "nobody knows which fuel type" to invest in, and nobody wanted to risk having "stranded assets" if global choices for shipping fuel turn out not to be what they invested in.[277] He added that, whilst there was a desire to decarbonise shipping, the economic and practical drivers were not there and these needed to come "from government through policy and regulation".[278] Maritime UK, an umbrella organisation for the UK maritime sector, told us that the "numerous options for low-carbon fuel in the maritime sector […] makes it challenging to develop infrastructure and for ports to bunker", and that "consolidation is therefore required".[279]

Aviation

114. Several witnesses told us that aviation was a "hard-to-abate" sector alongside shipping where electrification was not an option.[280] The December 2020 report from the then Committee on Climate Change found that aviation was "one of the sectors in which we expect there to be significant remaining positive emissions by 2050, given the limited set of options for decarbonisation", and any remaining emissions would need to be offset for aviation to be Net Zero by 2050.[281] Hybrid Air Vehicles told us that "two of the challenges for hydrogen adoption in aviation are the propulsion technology and delivery infrastructure required".[282]

115. There are two possible forms of sustainable aviation fuel—synthetic biofuels which are chemically derived from biomass and are likely to be limited in supply, and e-fuels, which use "hydrogen as a main ingredient", although other inputs, such as carbon

272 Q42
273 Q200
274 Q200
275 Q201
276 The Lloyd's Register Foundation is a research and education charity which owns Lloyd's Register, a technical and business services organisation and maritime classification society.
277 Q209
278 Q214
279 Maritime UK (HNZ0080)
280 Qq1, 33, 42, 271, 325, 325, 387—388, 449, University of Nottingham (HNZ0021) and Institution of Mechanical Engineers (HNZ0086)
281 The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net Zero, 9 December 2020
282 Hybrid Air Vehicles (HNZ0052)

dioxide, are needed.[283] Glen Llewellyn, Vice-President, Zero Emission Aircraft, Airbus, told us that the company saw "synthetic fuel as being extremely scalable". This hydrogen-based technology had more potential for significant reductions in production costs than biofuels. He also said the use of sustainable aviation fuel needed to scale up "in the 2020 to 2030 timeframe".[284] Dr Brian Yutko, chief engineer for sustainability and future mobility, Boeing, further added that "sustainable aviation fuels offer the most immediate and, far and away, the largest potential to reduce carbon emissions over the next 20 to 30 years in all aviation segments".[285] Beyond 2050 projections, Airbus told us that direct hydrogen combustion was "emerging as one of the most promising options to decarbonise the aviation sector".[286] The Royal Air Force, Defence Equipment & Support and industry partners Airbus, AirTanker and Rolls-Royce have explored other sustainable options, and in November 2022 an RAF Voyager successfully undertook a 90-minute flight from Brize Norton with all engines fuelled by 100% sustainable aviation fuel.[287]

116. We also heard that the UK Government could play an important role in incentivising aviation decarbonisation. When asked about the role of the UK in decarbonising aviation, Mr Llewellyn said there "needs to be a massive increase in the amount of renewable energy available and the amount of sustainable aviation fuel available", and whatever can be done to increase the scaling of these resources is beneficial.[288] He also commented on the potential co-benefits of technology development, since the aviation industry was using technologies from the energy and automotive sectors and increasing their commercial viability.[289] These technologies would then be used across several sectors after development, meaning that technology investment in one sector had commercial benefits across several sectors.[290] He added that "the countries that see the circular effect of the technologies will be the countries that position themselves best for the future world, which is decarbonised", and recommended doubling the research and technology budget of the Aerospace Technology Institute (ATI) (sponsored by the Department for Business, Energy and Industrial Strategy).[291] We note that in December 2021, the Government announced that its funding of the ATI had supported the unveiling of a concept midsized hydrogen powered aircraft.[292] Aircraft developer ZeroAvia has also signed an agreement with AGS Airports, which operates Aberdeen, Glasgow and Southampton airports, which will see the two "work towards a demonstration flight from ABZ using ZeroAvia's ZA600 hydrogen-electric powertrain, which is intended to be certified in 2024 in commercial operation as early as 2025".[293]

117. Dr Yutko told us that the UK Government had been supportive of the development of sustainable aviation fuels.[294] He further added that Boeing had committed to "removing the technical barriers to wide-scale use on current and future aircraft" and they supported the Government enabling positive incentives and "working with producers and users to

283 Q218, University of Kent (HNZ0001) and The Royal Society, Sustainable synthetic carbon based fuels for transport, 16 September 2019
284 Q218
285 Q220
286 Airbus (HNZ0051) and Q218
287 GOV.UK, Royal Air Force completes world-first sustainable fuel military transporter flight, 18 November 2022
288 Q231
289 Q231
290 Q231
291 Q231
292 GOV.UK, Government-backed liquid hydrogen plane paves way for zero emission flight, 6 December 2021
293 Simple Flying, ZeroAvia Wants To Bring Zero-Emission Flights To Scotland, 2 November 2022
294 Q230

catalyse sustainable aviation fuel use”.[295]

International collaboration in HGVs, shipping and aviation

118. We heard evidence that HGVs, aviation and shipping industries would require international collaboration for decarbonisation, and that the UK was well placed to play a leading role in these efforts.[296] In its 2020 Energy White Paper the Government similarly stated that “aviation and maritime are international by nature and require international solutions”, and further suggested that it would aim to “harness the UK as a global centre of expertise, driving low-carbon innovation and global leadership”.[297] Richard Clegg from Lloyd’s Register Foundation told us that “shipping is a globally distributed industry” and required “national and international distributor infrastructure”.[298] He also said that policy needs to “create demonstrators for uptake and early adoption, particularly involving international partners. This is not the UK going solo on any of this”.[299] Dr Yukto from Boeing also told the Committee that aviation “is an international game”, and that Boeing advocated that “places of big influence” including the UK “use their global influence to get global measures in place”.[300]

119. **Hydrogen has an important role to play in decarbonising shipping and aviation, but parts of the transport industry want more clarity from Government about the intended role of hydrogen since there are significant infrastructure requirements and substantial costs that need to be met. There are also significant infrastructure requirements associated with hydrogen deployment in aviation and shipping but the likely ‘winner’ from amongst the potential low-carbon technologies in these sectors has yet to emerge and the choice will be internationally, rather than domestically, determined.** ***In its response to this Report, the Government should set out its strategy for participation in international fora to shape a global outcome on the role of hydrogen in shipping and aviation.***

120. ***The Government should use its influence internationally, following its leadership of COP26 and involvement in Mission Innovation, to set standards and timelines for decisions on the role of alternative fuels and hydrogen within aviation and shipping. In these areas the Government should seek to lead the development of standards that can be adopted internationally.***

Domestic heating

121. Decarbonising the heating sector in the UK is a significant challenge. Gas boilers heat 85% of UK homes, and UK domestic heating accounts for 15% of the UK’s carbon footprint.[301] Mark Neller, Director and Energy Business Leader from engineering consultancy Arup, told us that on a cold winter’s day, half of the UK’s total energy use comes through the gas grid.[302] To decarbonise the heating sector, several witnesses highlighted the importance

295 Q230
296 Qq494–495 and The Hydrogen Taskforce (HNZ0045)
297 Department for Business, Energy and Industrial Strategy, The Energy White Paper: Powering our Net Zero Future, CP 337, 14 December 2020
298 Q203
299 Q205
300 Q229
301 Qq48 and 242
302 Q425

of improving the energy efficiency of residential buildings in addition to adopting low-carbon technologies.[303] The Government has also announced a new Energy Efficiency Taskforce, which will be charged with delivering improvements across the UK economy:

> to bring down bills for households, businesses and the public sector with an ambition to reduce the UK's final energy consumption from buildings and industry by 15% by 2030 against 2021 levels.[304]

122. The then Committee on Climate Change's (CCC) Sixth Carbon Budget set out three technologies which could play a role in decarbonising heat:

- Installing heat pumps (which use electricity to transfer heat from outside a building to inside it, operating similarly to a refrigerator in reverse);
- connecting buildings to heat networks (local pipe networks that distribute hot water from a central source); and
- converting heating systems to run off hydrogen.

The CCC advised that to meet the 2050 Net Zero target there should be a hydrogen-ready boiler mandate from 2025, and a ban on sales of natural gas boilers from 2033. They further advised that there should be "more than 5 million heat pumps by 2030".[305]

123. Our evidence contained conflicting views on the role of hydrogen in domestic heating. Some evidence to our inquiry argued for the prioritisation of heat pumps, since they were significantly more efficient and cost-effective than hydrogen boilers.[306] Professor Cebon told us that "it takes six times more electricity to heat a home using green hydrogen than it does to heat a home with a heat pump" and Michael Liebreich commented that "the inherent inefficiency [of hydrogen] is devastating compared to heat pumps".[307] Analysis from the International Council on Clean Transportation found that "in 2050 heat pumps will be more cost-effective than any heating pathway relying on low-carbon hydrogen", and analysis from Imperial College London estimated that heating with hydrogen would cost three times as much as heating with natural gas.[308] Anthony Green, Hydrogen Project Director at National Grid, told us that he was concerned that if a mixture of electricity and hydrogen were adopted, in which hydrogen would be more expensive long-term, this could mean "people were left in fuel poverty, and the very people in the worst situation were left having to pay more".[309]

124. However, some witnesses argued against heat pumps as a solution for low-carbon domestic heating, citing the expensive cost of installation, changes to consumer habits and practical limits to their installation. We heard a range for the cost of a heat pump (air source) from £9,000 to over £15,000, in comparison to approximately £2,000 for a new hydrogen boiler.[310] The cost of a ground source heat pump has been estimated to be

303 Qq2, 16, 251, 253, 274, 277, 314, 424 and Institution of Mechanical Engineers (HNZ0086)
304 HM Treasury, Autumn Statement 2022, 17 November 2022, p. 48
305 The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net Zero, 9 December 2020
306 Mr Steve Green (HNZ0009); Centre for Sustainable Road Freight, University of Cambridge; Centre for Sustainable Road Freight, University of Cambridge (HNZ0020); E3G (HNZ0043)
307 Qq8, 33
308 The International Council on Clean Transportation (HNZ0002); Hydrogen for heating? Decarbonization options for households in the United Kingdom in 2050 by Baldino et al. (2020); Q12, Sunny N., MacDowell N. and Shah, N. 'What is needed to deliver carbon-neutral heat using hydrogen and CCS?' Energy Environ. Sci., 2020, 13, 4204–4224 DOI: 10.1039/D0EE02016H (Paper) Energy Environ. Sci., 2020, 13, 4204–4224
309 Q293
310 The Committee on Climate Change, Hydrogen in a low-carbon economy, 22 November 2018; Qq19, 48 and HyDeploy (HNZ0040)

between approximately £24,000–£49,000.[311] In addition, Dr Jenifer Baxter, Chief Engineer at the Institution of Mechanical Engineers, told us that several types of properties in the UK were not able to fit either a ground, or air, source heat pump.[312] By comparison, fitting a home to use hydrogen would be significantly cheaper and less disruptive, costing £2–3,000, and could utilise much of the existing gas network.[313] Carl Arntzen, CEO of boiler manufacturer Worcester Bosch, told us it would be challenging to retrofit heat pumps in Victorian and Georgian houses,[314] and noted that the operation of a heat pump would be different to what consumers were used to. Heat pumps use lower delivery temperatures and have a smaller peak power output compared to gas boilers and, when operated in their most efficient way they heat a home on a longer timescale than boilers. He concluded that barriers to "consumer behavioural change, from one technology to another, should not be underestimated".[315] He also predicted that the costs of hydrogen products would decrease over time.[316]

125. We also heard that using hydrogen in heating would help meet the high winter heating demand, which in an electrified scenario would put great strain on the national grid. National Grid noted that currently the "gas networks transport three times the energy that electricity networks do".[317] Notably, hydrogen has the ability to function as a store of energy on inter-seasonal timescales—as discussed earlier in this Chapter. However, Consultant Chemical Engineer and Visiting Professor at the University of Strathclyde, Tom Baxter, noted that if energy efficiency and electrification were prioritised, the energy efficiency improvements could halve total energy demand, reducing seasonal variations by up to two-thirds.[318]

126. Several witnesses advocated a mixed strategy that involved hydrogen, electrification and heat networks.[319] The Energy Networks Association, for example, predicted that the "future of heat will be much more diverse than it is now, with heat networks, hydrogen, and heat pumps as well as hybrid solutions working alongside one-another".[320] The hydrogen energy project HyDeploy told us that "[hydrogen, electrification and heat networks] will play a role, although there is currently no clear consensus on the optimum mix".[321] EDF told us that since "national peak heat demand is high", complete electrification of heating would be "challenging in terms of the scale of network and generating capacity which would be required"; they therefore recommended a "mixed strategy with a major role for electrification alongside lower carbon hydrogen", with hydrogen used as a source of heat in certain regions.[322]

127. The 2020 Energy Systems Catapult Report also argued for a diverse range of technologies to be used in future, with a major role for electrification. The report, *Innovating to Net Zero,* explained that predicted energy pathways "suggest declining usage of the gas

311 Energy Saving Trust, Ground source heat pumps, accessed 14 December 2022
312 Q48
313 Shell UK (HNZ0059);
314 Q242
315 Qq259, 254. See also SGN (HNZ0061) and Cadent (HNZ0042)
316 Q260
317 National grid (HNZ0038)
318 Tom Baxter (Consultant Chemical Engineer at PDB) (HNZ0012)
319 Energy Networks Association (HNZ0032); Vaillant Group UK Ltd (HNZ0037); National grid (HNZ0038); Cadent (HNZ0042); The Hydrogen Taskforce (HNZ0045); Shell UK (HNZ0059)
320 Energy Networks Association (HNZ0032)
321 HyDeploy (HNZ0040)
322 EDF (HNZ0065) para 6

networks, as the deployment of heat pumps and heat networks gathers pace, weakening their economic case".[323] However, the report also said that in some scenarios, gas networks would be maintained in certain regions where the switch to full electrification proved too costly, and that hybrid heating systems would be supported in these homes.[324] The then Committee on Climate Change also produced a Net Zero change trajectory in 2020 which forecast a hybrid heating scenario, with 11% of UK homes heated using hydrogen.[325]

128. Professor Jianzhong Wu, Head of Engineering at Cardiff University, told us that "strong intervention" and "clear policy" was required from the Government to ensure the uptake and rollout of low-carbon technologies to decarbonise heat.[326] Heating systems manufacturer Vaillant Group UK Ltd told us that hydrogen for heat would be "led by Government policy" and "an industry change of such huge magnitude ultimately needs clarity on the roll out, including clearly defined timescales and expectations".[327] The company further stated the need for an "allocation of hydrogen for home heating" in the Government strategy, and cautioned that without clear government policy and regulations "there is limited drive for manufacturers to invest in the development of expensive future technologies".[328] In contrast, a clear policy "will allow manufacturers to understand the allocation of hydrogen supply for heating (as opposed to other market sectors)".[329]

129. The Climate Change Committee's (CCC) 2021 Joint Recommendations report highlighted that the "deployment of energy efficiency measures and heat pumps" and "roll-out of low-carbon heat networks and hydrogen trials" are "four priority areas over the next decade".[330] The CCC further stated that:

> We should not delay on heat pumps or low-carbon heat networks as viable solutions for most of the country—hydrogen can be part of the mix but has not yet been proven at scale and should not be a cause to delay other options.[331]

The Government's commitments to decarbonising heating

130. The UK Government's Hydrogen Strategy said that there would be a "2026 strategic decision point on the future of hydrogen for heat", informed by a series of hydrogen for heat trials:

> 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

323 Energy Systems Catapult Innovating to Net Zero, 10 March 2020
324 Energy Systems Catapult Innovating to Net Zero, 10 March 2020
325 Q63; The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net Zero, 9 December 2020
326 Q250
327 Vaillant Group UK Ltd (HNZ0037)
328 Vaillant Group UK Ltd (HNZ0037)
329 Vaillant Group UK Ltd (HNZ0037)
330 The Climate Change Committee, Joint Recommendations 2021 Report to Parliament, 1 June 2021
331 The Committee on Climate Change, Joint Recommendations 2021 Report to Parliament, 1 June 2021

testing of the safety, technical and economic case.[332]

131. The Heat and Buildings Strategy, published by the Government in October 2021, indicated—as witnesses had explained to us—that the future of heating would be more diverse and suggested that there was uncertainty on whether hydrogen would play a role:

> The future is likely to see a mix of low-carbon technologies used for heating: electrification of heat for buildings using hydronic (air-to-water or ground-to-water) heat pumps, heat networks and potentially switching the natural gas in the grid to low-carbon hydrogen.[333]

132. However, the Government indicated that the timing of a decision on hydrogen was important: "Leaving the decision to invest in hydrogen for heat later than the mid-2020s would bring considerable risk of limiting its potential role".[334] To therefore enable decisions to be made, the Heat and Buildings Strategy set out specific steps the Government would take to assess the feasibility of hydrogen for heating, including:

- Developing hydrogen for heating buildings by thoroughly assessing the feasibility, safety, consumer experience and other costs and benefits, by the middle of the decade;
- Establishing large-scale trials of hydrogen for heating;
- Enabling blending of hydrogen in the gas grid;
- Consulting on hydrogen-ready boilers; and
- Developing the evidence base necessary to take strategic decisions on the role of hydrogen for heating buildings in 2026.[335]

133. **Hydrogen could play a role in domestic heating, but the extent of its potential is still uncertain and looks likely to be limited rather than widespread. We are unconvinced its deployment will prove to be economically viable by the time the Government has said it will determine the role of hydrogen boilers, in 2026.**

Overall role of hydrogen in the UK economy

134. Overall, several witnesses told us that low-carbon hydrogen will likely play a residual role in the Net Zero economy.[336] For example, Guy Newey from the Energy Systems Catapult told us that hydrogen would be a "big niche", where it will play a major role in certain sectors of the economy and be a "huge growth story" over the next 30 years (from 30 TWh per year of grey hydrogen to 200–300 TWh of low-carbon hydrogen per year), "but it will not be everything".[337] Michael Liebreich described the role of hydrogen as decarbonising "the parts that direct electrification does not reach".[338] In a similar vein, the UK Hydrogen Strategy highlighted the applications for hydrogen in transport as being

332 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
333 HM Government, Heat and Buildings Strategy, CP 388, 19 October 2021
334 HM Government, Heat and Buildings Strategy, CP 388, 19 October 2021
335 HM Government, Heat and Buildings Strategy, CP 388, 19 October 2021
336 Qq62, 91, 253, 423
337 Q423
338 Q33

those "that batteries cannot reach".[339] In its subsequent Net Zero Strategy, published in October 2021, the Government made similar comments on the uses of energy sources other than electricity:

> While electricity will be the primary source of energy, we cannot rely on it alone. Many sectors require low carbon energy, including those where electrification is not a viable option, making the supply of cleaner fuels essential to achieving net zero.[340]

More specifically on the role of hydrogen, the Net Zero Strategy said: "Hydrogen can complement the electricity system, especially in harder to electrify areas like parts of industry and heating, and in heavier transport such as aviation and shipping".[341] The then Committee on Climate Change's Sixth Carbon Budget included a range of illustrative scenarios that were consistent with Net Zero in 2050, with the proportion of hydrogen energy consumption in the range 20–35%.[342]

135. Whilst it is likely that hydrogen will play a niche role in a Net Zero energy system, to do so would still require decisions to be taken soon to ensure the UK could reach Net Zero by 2050. For example, the Government Chief Scientific Adviser, Sir Patrick Vallance, explained that information required to make decisions was needed in "a few years, not decades",[343] and explained that:

> The issue as I see it is that, if we work back from 2050 and ask what the timescale is to get things deployed at total scale, we quickly get to somewhere in the 2020s to have to make our answer. Therefore, the immediate R&D question is: what are the unknowns that stop us being able to make the decision today, and how quickly can we answer them? That, I believe, is where most of the R&D effort needs to be at the moment, to try to answer how we make the decision.[344]

Guy Newey explained that if decisions on how to decarbonise the UK were not made in the next five years, the consequences would be serious and the UK "will not meet our net-zero target".[345]

The role of innovation

136. Hydrogen's role in several applications depends to a large extent on the shape and pace of development of a range of yet-to-mature technologies. These include more effective and cost-effective ways of producing low-carbon hydrogen;[346] and, alternatively, innovation—as yet unscaled, in development, still theoretical, or even unforeseen—such as large-scale greenhouse gas removal technology, may make Net Zero easier to attain.[347]

137. **Overall, whilst there are a variety of possible applications of hydrogen technology across every sector of the UK economy, we agree with the Government that on the basis**

339 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
340 HM Government, Net Zero Strategy: Build Back Greener, 19 October 2021
341 HM Government, Net Zero Strategy: Build Back Greener, 19 October 2021
342 The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net Zero, 9 December 2020
343 Q490
344 Q489
345 Q428
346 Qq43, 441
347 National Infrastructure Commission, Engineered greenhouse gas removals, 29 July 2021

of present knowledge and the technology available it seems that the role of hydrogen will be to decarbonise specific, limited areas where electrification is either not possible or clearly not optimal, such as the industrial clusters currently developing hydrogen capabilities. The clusters may also offer a future production option for some of the hydrogen required in other applications. ***The Government should prioritise the use of hydrogen in those sectors where there is a genuine prospect of technical, feasible and economically viable deployment. The Government should work closely with businesses and international partners to set, in the 2020s, a realistic strategy for the adoption and use of hydrogen in these sectors.***

5 Hydrogen metering and the role of Ofgem

138. This Chapter discusses the role of metering hydrogen use, in particular the question of domestic demand and the role of the energy regulator, Ofgem, in determining levels of hydrogen consumption.

The role of metering

139. Metering is an essential component of hydrogen use and will occur at every point along the hydrogen value chain. The Flow Measurement Special Interest Group (SIG), operating within the professional members institution, the Institute of Measurement and Control, told us:

> every financial and fiscal transaction with hydrogen will be based upon the reading from a flow meter, whether this be hydrogen gas supplied to the home, refuelling of a vehicle or large-scale industrial supply and usage. In essence, flow meters will be the cash registers, much as they are for the fossil fuel-based energy system today.[348]

140. Since hydrogen has different physical properties to other gases, changes may need to be made in domestic appliances to meter the consumption of hydrogen.[349] Flow Measurement SIG told us that since hydrogen was "exceptionally light, with less energy by volume, but far more by mass" than conventional fossil fuels, taking measurements could be challenging for the meters in common usage today, and "many are not fully tested or calibrated to accurately measure hydrogen".[350]

141. Dr Martin Hanton, Technical Director of TÜV SÜD National Engineering Laboratory, told us that there was "fundamentally no major reason" to think that metering hydrogen use in the UK was an insurmountable challenge, but work needed to be done to study the suitability of existing metering, and establish whether corrections needed to be made or new technologies introduced.[351] In particular, he highlighted the complication of a scenario of hydrogen blending, where a mixture of hydrogen and natural gas would be used within the gas grid, which would introduce the need for additional metering.[352]

142. We also heard concerns that the current generation of smart gas meters may not be compatible with hydrogen use in the grid. When asked if the generation of smart meters that were currently being rolled out across the UK would work with hydrogen, Angus McIntosh, Director of Energy Futures at SGN (a gas distribution company), told us:

> The answer is no. There are quite a number of lessons to learn from the smart metering roll-out, but current installations will not be hydrogen compatible in their current form. We would need to replace them with hydrogen-ready versions, which have exactly the same functionality but are just forward compatible.[353]

348 Flow Measurement SIG, Institute of Measurement and Control (HNZ0013)
349 Q510
350 Flow Measurement SIG, Institute of Measurement and Control (HNZ0013)
351 Q390
352 Qq390, 395
353 Q290

He added that operators were "already seeing some of the issues with smart meters not being compatible when customers change supplier and they lose their smart meter functionality".[354] This was an issue a predecessor Committee of ours highlighted in a September 2016 Report on smart meters.[355] Dr Hanton told us that this was an area where more evidence was needed, but "we certainly do not have evidence that says they will be compatible".[356] Mark Neller, Director and Energy Business Leader at engineering consultancy Arup also told us that it was "highly likely" that the current generation of smart meters would not be compatible with hydrogen use, and work should be done to explore whether it was possible to replace a smart meter with a hydrogen-ready meter and "recalibrate the instrumentation" so that they could monitor hydrogen instead of natural gas.[357]

143. Further, we heard that there had been some work done on hydrogen-ready smart meters. Dr Hanton told us that the HyDeploy project (a hydrogen energy project to demonstrate the safety of 20% hydrogen blending) was gathering evidence to investigate the metering of blended hydrogen use, but not 100% hydrogen in the gas grid.[358] Mark Neller told us that through the Hy4Heat programme, a programme which explored the potential use of hydrogen gas for heating UK homes and businesses, "prototype smart hydrogen meters" were being developed by two manufacturers funded by the Department for Business, Energy and Industrial Strategy. Since our inquiry finished taking evidence the Hy4Heat programme has concluded, with its final report documenting a series of outputs including 13 domestic appliance types; and further patent applications submitted by Bosch.[359] It is expected that lessons from the programme will be applied to future community trials, with Mark Taylor, Deputy Director for Energy Innovation at the Department for Business, Energy and Industrial Strategy, saying that "consumers in the H100 Fife neighbourhood should be using hydrogen for heating and cooking from as early as 2023".[360]

144. Dr Hanton told us it was "quite pressing that we start to answer the metrology issues around meters", to prevent metering issues from being "the weak link in the chain" in the UK's use of hydrogen in the domestic grid.[361] Whilst metering was a necessary component of the use and storage of hydrogen, he said that "metering is something that is quite often overlooked or taken for granted".[362] Dr Hanton said that "there has been a lot of innovation work already undertaken" which had "quite rightly" been focused on the "safety aspects", but there had been very little attention given to metering.[363] He further commented in written evidence:

> there needs to be a real drive to understand the accuracy of, and establish standards for, the metering of the hydrogen blends and pure hydrogen. This would need to be an international endeavour because many of the meter manufacturers are based overseas, and the network is physically connected

354 Q292
355 House of Commons Science and Technology Committee, Evidence Check: Smart metering of electricity and gas, HC (2016–17) 161
356 Q391
357 Q438
358 Qq391, 395; HyDeploy (HNZ0040)
359 Hy4Heat, Final Progess Report, 26 April 2022
360 Hy4Heat, Final Progess Report, 26 April 2022
361 Q421
362 Q414
363 Q421

to other networks overseas.[364]

In addition, the National Physical Laboratory stated that hydrogen metrology infrastructure would need to be developed at an "unprecedented rate", and called on the Government to "identify, prioritise and address measurement needs [...] to enable a hydrogen economy".[365]

145. **Metering is an essential component of any use case for hydrogen in domestic settings. We have heard that the current generation of gas smart meters are designed to measure volume flows of natural gas which are much lower than hydrogen volume flows for the same energy delivery, so are unlikely to be compatible. Larger volume capacity meters, or alternatives which measure mass flow, may be required.**

The role of Ofgem and its work on hydrogen

146. As the national energy regulator, Ofgem's overall role is to "protect energy consumers, especially vulnerable people, by ensuring they are treated fairly and benefit from a cleaner, greener environment".[366] Dr Jane Dennett-Thorpe, Ofgem's Deputy Director of Decarbonisation and Energy Transition, told us that Ofgem operated within the overall policy framework of the energy sector set out by the Government and the Department for Business, Energy and Industrial Strategy, and "often work with Government to inform their policy decisions to ensure that they are deliverable and delivering for consumers".[367]

147. Ofgem outlined its work to support the Government's hydrogen strategy through innovation in heating, gas grid blending and the development of industrial clusters. Ofgem awarded funding through the annual Gas Network Innovation Competition, which was an opportunity for gas networks to "develop and demonstrate new technologies, operating and commercial arrangements for the industry".[368] This included £6.7 million for the HyDeploy programme and £9 million for the H21 programme, which sought to demonstrate the safe use of 20% blended hydrogen and 100% hydrogen in the gas grid respectively.[369] This programme was replaced with the Strategic Innovation Fund in April 2021, with a new set of price controls.[370]

148. In its Innovation Vision published in May 2021, Ofgem highlighted an interest in targeting innovation across a wide range of applications to ensure the "feasibility and safety" of hydrogen. This concern applied across the hydrogen supply chain and range of applications with the aim of establishing effective commercial and regulatory models to protect industrial and commercial users, particularly those in vulnerable situations.[371]

149. Dr Dennett-Thorpe also told us that Ofgem was considering the regulations required for use of low-carbon hydrogen in several applications, with a particular focus on industrial clusters since that was where low-carbon hydrogen use would start.[372] Since our inquiry finished taking evidence, Ofgem and the Government have confirmed they will take forward proposals by Cadent and NGN "to deliver a 100% hydrogen heating

364 TÜV SÜD National Engineering Laboratory (part of National Measurement System) (HNZ0003)
365 National Physical Laboratory (HNZ0088)
366 Ofgem, Our role and responsibilities, accessed 22 November 2022
367 Q392
368 Ofgem, Gas Network Innovation Competition (RIIO-1), accessed 23 August 2021
369 HyDeploy (HNZ0040), Qq399, 415, 417
370 Ofgem, RIIO-2 Strategic Innovation Fund, 23 March 2021
371 Ofgem, Innovation Narrative 2021–2025, accessed 23 August 2021
372 Q392

neighbourhood trial by 2023 and a village trial by 2025",[373] and awarded £8 million in funding via its Strategic Innovation Fund to 18 projects focused on "clean forms of heat, zero emission transport, data and digitalisation, and whole system integration",[374] including the future use of hydrogen in the UK's energy system.

Ofgem's role in domestic hydrogen metering

150. On being questioned about the role of Ofgem in addressing the challenges in domestic metering, Dr Dennett-Thorpe told us that Ofgem was not currently studying domestic metering for hydrogen.[375] She said, "there needs to be a policy framework and Government are the lead on domestic metering" and that Ofgem would "work within that framework".[376] She added that the role of metering is one of the areas that would be addressed "by the mid-2020s" through the funded innovation projects.[377] Dr Dennett-Thorpe also said that Ofgem was "enabling the necessary research and development to take place to enable" questions around smart gas meter compatibility with hydrogen to be answered.[378] In subsequent correspondence the Chair of Ofgem, Professor Martin Cave, explained that:

> a decision on the future of hydrogen and its role in home heating needs to be determined by government before any further decision on whether hydrogen compatible smart meters should be rolled out.
>
> We would expect any government decision on metering to take account of the full range of costs and benefits to consumers. If, following this, BEIS made changes to the regulatory framework, then we would ensure that energy suppliers complied with amended obligations.[379]

However, Dr Hanton told us previously that since there was currently only a small amount of work funded to investigate domestic gas metering, there "certainly is a need to commission" a more "wide-ranging study to examine this particular point".[380]

151. Further, whilst Dr Dennett-Thorpe acknowledged that there was a possibility that large-scale replacement of existing smart metering would be needed, Ofgem was unable to provide cost estimates for this, since there was uncertainty about the detail and scope of what exactly would need to be replaced, and when, and how this might be managed alongside the "natural replacement rates" of the meters for which gas meters had an anticipated lifetime of 10 to 15 years.[381]

152. Professor Cave also said responsibility for the technical aspects of metrology sat within the Department for Business, Energy and Industrial Strategy (BEIS) and had done so since 2009:

373 Ofgem, Hydrogen Village Trial Detailed Design Studies Decision, 6 May 2022
374 Ofgem, Ofgem's Strategic Innovation Fund pushes further ahead with innovation projects to help in the drive to bring down consumer costs, decarbonise the energy system and reduce dependence on costly fossil fuel imports, 26 July 2022
375 Q392
376 Q392
377 Qq392, 407
378 Q410
379 Correspondence from Professor Martin Cave, Chair, Ofgem, relating to smart meters and the role of hydrogen in achieving Net Zero, 9 August 2021
380 Q401
381 Q404

> In terms of the technical aspects of metrology, including the testing, certification and assurance of metering accuracy, responsibility for this area was transferred from Ofgem to the National Measurement and Regulation Office in 2009, and now sits within the Office of Product Safety Standards which is a part of the Department for Business, Energy and Industrial Strategy.[382]

153. **The energy regulator Ofgem has not worked on understanding hydrogen domestic metering and has not been able to say whether the current roll-out of smart meters will prove ineffective if hydrogen is used in domestic metering. Ofgem was also unable to provide cost estimates for how expensive a hydrogen-ready smart meter roll-out would be under different scenarios, or what the cost implications would be for the consumer. This has arisen, it was suggested to us, because the responsibility for domestic metering is no longer within the remit of Ofgem. Domestic metering is an issue that has been overlooked, and we are concerned that Ofgem is not fulfilling its specified remit of protecting the consumer.**

154. ***An urgent project on metering domestic hydrogen use needs to be undertaken. This should include an assessment of:***

- ***whether and when the current generation of gas smart meters need to be (a) adapted, or (b) replaced;***
- ***what technology could and should be used in new meters to accommodate different fuels and to reflect the timing and pace of different transition scenarios; and***
- ***the likely costs of domestic metering under the various scenarios.***

This work should be completed by the beginning of 2024 to ensure that a resilient approach to metering has been developed to underpin the Government's decisions on the role of hydrogen in domestic heating and to lay the foundations for an appropriate pace of change should the decision be to adopt hydrogen for domestic heating.

382 Correspondence from Professor Martin Cave, Chair, Ofgem, relating to smart meters and the role of hydrogen in achieving Net Zero, 9 August 2021

6 The Government's hydrogen strategy

155. This Chapter assesses the UK hydrogen strategy and provides recommendations across key areas where policies can be implemented through comparison with the strategies of other countries.[383] We were unable to discuss the details of the published strategy with our witnesses as key documents were published after the conclusion of our evidence-taking. However, our evidence included much discussion of, and several recommendations for, what needed to be included in such a strategy.

International comparisons

156. We heard oral evidence from witnesses discussing the Japanese and German hydrogen strategies.[384] In addition, comparisons of the UK's approach to the hydrogen strategies of other countries were also provided throughout our written evidence,[385] and since our inquiry finished taking evidence other countries, such as Singapore,[386] have published detailed low-carbon transition plans with hydrogen playing a key role in different paths to Net Zero. Whilst each national context is of course different, our evidence suggested that the strategies of Japan and Germany presented lessons from which the UK Government could learn.

Japan

157. As discussed in Chapter 3, Professor Takeo Kikkawa, Distinguished Fellow at the Graduate School of International Management, International University of Japan, emphasised the importance of hydrogen to decarbonising Japan's economy, despite limited short- to medium-term production potential. He also said that the country had put a significant emphasis on hydrogen fuel cell vehicles, with infrastructure developments and government subsidies to encourage adoption of hydrogen throughout the road transport sector.[387] The Japanese Government has allocated $20 billion for stimulating the Net Zero economy, $3 billion of which is for developing international trade and $700 million is dedicated to stimulating green hydrogen production. Japan intends to import 1GW of low-carbon hydrogen (300,000 tonnes, estimated by the University of Southampton at between £5.5–11 billion worth annually)[388] in 2030 and 15–30GW (5–10 million tonnes) by 2050.[389] Mark Neller, Energy Business Leader from engineering consultancy Arup, when commenting on the export of hydrogen from Australia and Japan told us that "an

383 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
384 Qq333–389
385 See TÜV SÜD National Engineering Laboratory (part of National Measurement System) (HNZ0003); UK Hydrogen and Fuel Cell Association (HNZ0011); Thames Estuary Growth Board (HNZ0015); Alstom UK (HNZ0018); Hydrogen Strategy Now campaign (HNZ0024); ITM Power (HNZ0027); University of Birmingham (HNZ0030); Energy Networks Association (HNZ0032); Scottish Carbon Capture and Storage (HNZ0034); Vaillant Group UK Ltd (HNZ0037); National grid (HNZ0038); HyDeploy (HNZ0040); Cadent (HNZ0042); E3G (HNZ0043); The Hydrogen Taskforce (HNZ0045); Imperial College London (HNZ0047); Arcola Energy (HNZ0049); University of Southampton (HNZ0050); Shetland Islands Council (HNZ0053); Johnson Matthey (HNZ0056); Ryse Hydrogen and Wrightbus (HNZ0057); Shell UK (HNZ0059); SGN (HNZ0061); Unitrove (HNZ0072); Microcab Industries Ltd (HNZ0075); PA Consulting Group; Reaction Engines (HNZ0077); Green Alliance (HNZ0095) and Liberty Steel (HNZ0097)
386 Energy Market Authority, Energy 2050 Committee: Charting the energy transition to 2050, 22 March 2022
387 Q349
388 Hydrogen energy is 120MJ/kg so 300,000 tonnes (= 300 million kg) is 36,000 million MJ or 36 million GJ. A GWh is 1GW (1GJ/s) for 3600 seconds, i.e. 3,600GJ. 36 million GJ is thus 10,000 GWh—8,760 hours in the year so it's equivalent to 1.14GW of power continuously.
389 University of Southampton (HNZ0050)

international trade in low-carbon hydrogen" will likely develop in the coming years.[390]

158. When asked what the UK can learn from the Japanese hydrogen strategy, Professor Kikkawa commented on the prominence of hydrogen fuel cells in the Japanese strategy and suggested that the UK should consider using fuel cells for commercial trucking and buses.[391] Professor Hirose told us that the UK should use hydrogen as a means of providing resilience for the energy system. He also suggested the Government should exploit the North Sea offshore wind resource to produce green hydrogen.[392]

Germany

159. In April 2021, energy market analyst, Aurora Energy Research, reported that Germany had the leading market for low-carbon hydrogen development in Europe.[393] The German hydrogen strategy, published in June 2020, put a clear focus on green hydrogen, since the German Government considered only green hydrogen "to be sustainable in the long term".[394] The German National Hydrogen Strategy included 38 measures to be taken between 2020 and 2024, to develop a domestic hydrogen economy.[395] These covered the production and use of hydrogen across a range of sectors including supply, industry, heating, traffic, infrastructure, innovation and developing foreign trade partnerships.[396] Franz Lehner, Head of International Cooperation at NOW GmbH (The National Organization for Hydrogen and Fuel Cell Technology) told us that a unique feature of the German strategy was that it was "equipped with large funds available". The strategy was supported with €9 billion from a Federal Government stimulus package, €2 billion of which was dedicated to developing international trade in green hydrogen.[397]

160. To facilitate the development of a green hydrogen industry and market, the German Government had also enacted legislation to support the production of green hydrogen. In January 2021, a Renewable Energies Sources Act was passed, which aimed to support the production and industrial use of green hydrogen by partially exempting producers from having to pay an existing electricity levy for power consumed in the production of green hydrogen.[398] Germany has also already enacted legislation to enable blending of hydrogen in the German gas network.[399] Mark Neller, Energy Business Leader from engineering consultancy Arup told us:

> The German hydrogen strategy has provided a really good foundation for the German economy—the amount of investment, the way that is signalled to the market and the level of commitment. [...] It is the pace at which they are moving that is particularly impressive—the fact that it was published over a year ago and they have already started enacting legislation to support it. That provides an interesting comparison.[400]

390 Q442
391 Q351
392 Qq350 and 352
393 Aurora Energy Research, Hydrogen Market Attractiveness Report (HyMAR), published April 2021
394 Q361
395 The German Federal Government, The National Hydrogen Strategy, 3 June 2020
396 The German Federal Government, The National Hydrogen Strategy, 3 June 2020
397 Q375 and The German Federal Government, The National Hydrogen Strategy, 3 June 2020
398 German Federal Ministry of Justice and Consumer Protection, Renewable Energy Sources Act, amended July 16, 2021
399 Q431
400 Q442

161. When asked how the UK should be learning from the German hydrogen strategy, Eric Heymann, senior analyst at Deutschebank Research, told us that the UK should seek to address "the whole value chain" of hydrogen use and learn from the successes and mistakes of several countries including Germany.[401] Several witnesses however recommended that the UK Government develop its commitments to funding the hydrogen economy in line with other nations such as Germany.[402] For example, Imperial College London commented that for the hydrogen fuel cell market "near-term markets are currently seen as most likely to grow outside the UK" since:

> UK policy support for the development of domestic [hydrogen fuel cell] markets is considered poorer than in the European Union, North America and East Asia. Other countries have provided grants to bridge the cost difference or have used public procurement to grow a market, with the aim of building domestic industries as future export industries. [...] The weak UK market relative to other countries is a barrier to UK companies scaling-up production and reducing costs through innovation.[403]

162. However, Franz Lehner told us that adopting a "market-based approach" where you "tackle the regulatory environment to set a stimulus for change" was a more effective approach than "putting a lot of funding into buying equipment".[404] Arcola Energy told us that whilst "the proposed hydrogen fund is smaller than comparator strategies announced by other countries", as the scale of deployment increases over time "the commercial case will strengthen with time and scale, reducing the need for public support".[405]

163. The then Secretary of State for Business, Energy and Industrial Strategy told us that the "key to the hydrogen strategy" was to develop "an investible proposition that can incentivise private operators and private investment in the production of hydrogen".[406] However, the University of Birmingham told us:

> Compared to the EU and countries like Germany, the UK lacks structures that deliver reliability, accountability, and long-term stability that is required for private investment. [...] If major industry investment is to be involved, a stable and reliable framework is required for the UK [...] Other European countries such as Germany have similar institutions (NOW GmbH) which are organised as Public Private Partnerships. The UK lacks such structures that deliver reliability, accountability, and long-term stability that is required for private investment.[407]

It further noted that the rapid developments in hydrogen infrastructure across the EU and in countries like Japan and South Korea proved that a "well-structured and reliable political and regulatory framework" could lead to positive "technical and commercial developments".[408]

401 Q383
402 UK Hydrogen and Fuel Cell Association (HNZ0011); Thames Estuary Growth Board (HNZ0015); Hydrogen Strategy Now campaign (HNZ0024); National grid (HNZ0038); E3G (HNZ0043); University of Southampton (HNZ0050); Shetland Islands Council (HNZ0053); Unitrove (HNZ0072) and PA Consulting Group; Reaction Engines (HNZ0077)
403 Imperial College London (HNZ0047)
404 Q384
405 Arcola Energy (HNZ0049)
406 Q497
407 University of Birmingham (HNZ0030)
408 University of Birmingham (HNZ0030)

164. We heard that there was a need for international collaboration on standards and certification. Professor Hirose, Franz Lehner and Eric Heymann, for example, all highlighted how the definitions of green and blue hydrogen and in particular green hydrogen certification would be important areas for international collaboration.[409] Since our inquiry finished taking evidence the Hydrogen Council has argued in a 2022 report that an International Organisation for Standardisation (ISO) is necessary:

> To enable trade of hydrogen and its derivatives, international coordination, credible common standards and robust certification systems for hydrogen are required. A common global ISO standard methodology for assessing the carbon footprint of different hydrogen production pathways is essential to allow the hydrogen with the lowest carbon footprint to reveal its climate benefits.[410]

The UK Government in December announced a new energy partnership with the US Administration, which includes a commitment to further promote the use of clean hydrogen internationally, via the Hydrogen Breakthrough Agenda and other international fora.[411]

165. **Several countries including Germany, Japan and Singapore have well developed hydrogen strategies with significant public funding to support the development of infrastructure, production and use of low-carbon hydrogen. Through public-private partnerships, Germany and Japan have structures intended to enable the development of a regulatory framework and provide confidence to consumers for private investment. The UK's main international competitors in this field also tend to have specific bodies responsible for the delivery of their government's targets.** ***Given the evidence received on the importance of whole systems performance, the Government should designate or create a single department or agency with responsibility and accountability for delivering cross-departmental Net Zero commitments, including those relating to delivering the hydrogen strategy.***

The need for and timing of Government decision-making

166. Industry representatives from a variety of sectors told us that hydrogen technology was a viable means of decarbonisation within their respective industries.[412] Evidence from several academics and research institutions also supported the potential for hydrogen as a viable technology in many applications:[413]

- The UK Research and Innovation (UKRI) submission stated that hydrogen "can be used as fuel for heat, transport, a vector for energy storage, a feedstock into industrial processes and as an alternative fuel, which will increase the resilience of our energy system";[414]

409 Qq350, 381–382
410 Hydrogen Council and McKinsey & Company, Hydrogen Insights 2022, 20 September 2022, pp. 15–16
411 GOV.UK, UK and US announce new energy partnership, 7 December 2022
412 See for example: Alstom UK (HNZ0018); ZeroAvia (HNZ0019); British Glass, Glass Futures Ltd (HNZ0035); National grid (HNZ0038); Arcola Energy (HNZ0049); EDF (HNZ0065); Centrica plc (HNZ0073); JCB (HNZ0083) and Tata Steel Europe (HNZ0096)
413 See, for example: University of Kent (HNZ0001); The Royal Society (HNZ0079)
414 UK Research and Innovation (UKRI) (HNZ0091)

- The Institution of Chemical Engineers reported that "the technology to deploy a low-carbon hydrogen sector is already available"; and
- The University of Birmingham said that "hydrogen and hydrogen use technologies are all available in the global markets".[415]

However, some thought that work would be needed to make it viable, or viable on the required scale. For example, the Health and Safety Executive highlighted potential safety concerns with the rapid expansion of hydrogen use, as well as "engineering and regulatory challenges", but said that with sufficient engineering the safe large-scale use of hydrogen could be maintained across several applications.[416] Further, witnesses such as Guy Newey of Energy Systems Catapult, discussed the importance of further research and innovation, but this was mainly to improve processes such as the capture rate of carbon capture, utilisation and storage (CCUS), or to provide more technological options such as the development of hydrogen production in high temperature nuclear reactors.[417]

167. Several witnesses highlighted that the primary challenge with developing the low-carbon hydrogen economy was large-scale implementation.[418] One of the key barriers to large-scale implementation was the fact that there needed to be a market, necessary infrastructure and regulation for low-carbon hydrogen developed alongside hydrogen production. Professor Nilay Shah, Head of the Department of Chemical Engineering at Imperial College London, told us that "you need to get all aspects of the system up and running in one go. There is no point subsidising someone to produce hydrogen if there is nobody to transport, store or use it".[419]

168. Sir Patrick Vallance, Government Chief Scientific Adviser, told us that an issue with the scalability of technologies across sectors is that we did not yet know where hydrogen was the best economic option:

> We already know that we can get hydrogen in trains, and we can get hydrogen in heavy goods vehicles. We know that we can power boats. The question is not, "Can you do it?", but, as we scale, "Do you want to do it?" […] For those technologies, it is no longer, "Can you do it?" It is about the scaling challenge and the price challenge that comes with that, which we need to try to articulate to get answers that allow firm decisions to be made.[420]

There have been several conflicting views surrounding the role of hydrogen in certain sectors, as we outlined in Chapter 4.[421] Sir Patrick commented on the "strong opposing views" that we heard over the course of the inquiry as indications that it was not known what the best technological solutions were in several cases.[422]

169. As there is uncertainty about the best technological options, we heard that the Government appeared to be holding back on key decisions in terms of technology choice

415 Institution of Chemical Engineers (HNZ0031) and University of Birmingham (HNZ0030)
416 The Health and Safety Executive (HNZ0046)
417 Qq422, 433, 441 and 489
418 Qq23, 44 and Rolls-Royce plc (HNZ0029)
419 Q23
420 Q490
421 For example, see: Centre for Sustainable Road Freight, University of Cambridge; Centre for Sustainable Road Freight, University of Cambridge (HNZ0020); E3G (HNZ0043); The Hydrogen Taskforce (HNZ0045); Greenpeace UK (HNZ0063); Qq8–12 and 48
422 Q489

in certain sectors. Sir Patrick told us that the key question was "what are the unknowns that stop us being able to make the decision today, and how quickly can we answer them?".[423] He gave examples of consumer acceptance and the feasibility of delivery of hydrogen in the gas grid as questions "we need to try to get answers to relatively quickly to be able to make long-term strategic decisions".[424] He also stressed the importance of making decisions "in the 2020s" on which technologies to back, but also said that "there will definitely be situations" where there is a need to provide policy support for several technologies.[425] Baroness Brown of Cambridge, Chair of the Carbon Trust and former Vice Chair of the then Committee on Climate Change, also told us that the UK would need to be making decisions "through the 2020s".[426] The then Secretary of State for Business, Energy and Industrial Strategy, Kwasi Kwarteng MP, told us that:

> it would be a foolhardy Minister who told you exactly what the energy mix would be in 2050. From my point of view, we have to keep an open mind about different technologies to get to Net Zero. That does not mean that we are not investing and supporting certain technologies, but we have to have an open mind […] in 2021 it is very difficult to know what the capacity of these different technologies will be.[427]

However, he also added that "at the same time, you have to make choices", and explained that he believed that "the right balance has been struck" since the Government had made a clear position on supporting "CCUS and the production of hydrogen" whilst "not privileging that over other forms of decarbonisation—for example, electrification".[428]

170. The Government's Hydrogen Strategy emphasised "keeping options open, adapting as the market develops" as a means of addressing uncertainty in decision-making.[429] It included several decisions that were to be made in the 2020s on the role of hydrogen in the UK economy, such as deciding the role of hydrogen in heavy goods vehicles "in the mid-2020s", and a decision on hydrogen in heating "by 2026".[430]

171. Several witnesses stressed the importance of trials in reducing uncertainty around decision-making. Baroness Brown highlighted this in relation to a range of applications such as heavy transportation (where the efficiency of transporting hydrogen and local generation by electrolysis was being assessed against the electricity demands of fast-charging electric lorries).[431] She said that "we have the next five to seven years to really get a move on with those trials".[432] The then Secretary of State also highlighted the importance of trials to provide information to the Government on the role of hydrogen in domestic heating.[433] However, Dr Jane Dennett-Thorpe, Deputy Director of Decarbonisation and Energy Transition at Ofgem, told us that the question of the role of hydrogen in domestic heating would not be answered solely by the current suite of trials. These programmes were focused on assessing the safety, feasibility, and regulatory barriers associated with

423 Q489
424 Q489
425 Qq489–491
426 Q59
427 Qq460, 465
428 Q485
429 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
430 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
431 Q60
432 Qq58–59
433 Qq481, 517–518

hydrogen use in the grid. Dr Dennett-Thorpe said other evidence would therefore be required to inform Government decision-making.[434]

172. Several witnesses and submissions argued that the Government should make firm decisions now on the role of hydrogen in the economy, rather than wait.[435] For example, the University of Nottingham told us that "the hydrogen economy suffers from uncertainty. It is vital that government shows a strong steer and commitment to support industry to make the investment into these new technologies".[436] Professor Cebon and Dr Ainalis from the Centre for Sustainable Road Freight told us that "without Government decisions on which technologies to support and the legislative and financial environments to support them, there is little chance of achieving the 2030 target".[437]

173. Michael Liebreich told us that the UK "will have to choose some winners" because of the practical investment required in developing infrastructure in certain sectors such as heavy goods vehicles:

> If we want to have electric trucking in the UK, there are infrastructure and planning questions. There are major investments by other major companies that will have to be made. At some point, we have to stop the mantra of all technology might improve, when the fact is that some of them have just got thermodynamic and microeconomic challenges. […] We have to be realistic here, and there are decisions. […] In some areas, where we can say, "Look, we have had 30 years of trying this or that, and it has not worked", and the thermodynamics, microeconomics and the economics are not in its favour, we surely have got to move on.[438]

He also added that "there are areas where you can be technology neutral" such as steel manufacture, where research is promising and should not be curtailed.[439]

174. Professor Cebon also told us that "the economics will dictate what happens", and the most economic option comes from energy efficiency, since efficiency enables technologies to be cheaply available:

> The economics of this will work out by itself. The problem is that there is a lot of delay and confusion going on […] when we could be decarbonising. There is a great danger of confusion and delay pushing decisions out five or 10 years […] If we are going to hit anything like the 1.5 °C global warming target, we need to massively decarbonise immediately. We cannot wait for hydrogen to get us numbers in a straight line, because it never will. The fundamental inefficiencies mean that it is far more expensive than electrification.[440]

434 Qq415, 417–420
435 Centre for Sustainable Road Freight, University of Cambridge (HNZ0020); University of Nottingham (HNZ0021); National grid (HNZ0038); Qq46, 22
436 University of Nottingham (HNZ0021)
437 Centre for Sustainable Road Freight, University of Cambridge; Centre for Sustainable Road Freight, University of Cambridge (HNZ0020)
438 Q46
439 Q46
440 Q22

Further, Guy Newey of the Energy Systems Catapult told us that there was a need, from an innovation perspective, to choose some technologies to support, and that there was an inevitability to making mistakes:

> From an innovation point of view, you have to choose some technologies to support. You should be really thinking about what the global scale potential of this particular technology is and whether the UK has definite comparative advantage in that space. Then, to a certain extent, you have to roll the dice. You want to be constantly iterating and saying, "I am not sure this is actually turning out" […]
>
> If you are not getting anything wrong, it is not working and it is not innovation policy. There will be mistakes made, and politicians have to be honest about that. The rigorous analysis of "you are going to pick winners but it will be based on clear criteria" is absolutely essential.[441]

175. The climate change think tank Third Generation Environmentalism (E3G) produced an analysis of the UK Government's Hydrogen Strategy, and similarly found that there was a lack of clarity from the Government on the options that should be pursued and when decisions would be made.[442] E3G commented that "currently the Strategy allows industry to lead the way in certain instances, with the Government following from behind". E3G recommended that:

> The Government must rapidly develop a new engagement mechanism to better reflect scientists, communities, workers, civil society and consumer interest organisations in decision-making procedures. Clarity over the parameters used for critical decisions, such as on blending and heating, should be provided.[443]

176. Professor Rob Gross, Director of the UK Energy Research Centre and Professor of Energy Policy and Technology at Imperial College London, also recognised the potential role of hydrogen across several sectors, although given the "miniscule amount of hydrogen we use for energy today the challenge is huge", and there is a need for clear decisions on the role of hydrogen:

> As well as figuring out how to make lots of clean hydrogen much more cheaply we will also need to decide where to use it first, and importantly, where we can manage without it. The strategy makes a start on all of that but there is a long, long way to go.[444]

177. **The Government's hydrogen strategy and subsequent updates to the market provide a framework with an intention for further consultations rather than early or firm decisions. The Government's understandable desire to keep its options open pending market and technological developments may not provide the clarity that investors require to proceed. The Government needs to trade the risk of failing to meet Net Zero if decisions on how to reach it are not taken soon enough against the risk of pursuing unproven technologies or solutions that are not cost-effective which would**

441 Q459
442 E3G, Lifting the lid on the UK Hydrogen Strategy, 19 August 2021
443 E3G, Lifting the lid on the UK Hydrogen Strategy, 19 August 2021
444 Science Media Centre, Expert reaction to the Government's hydrogen strategy, 17 August 2021

then set the UK back at a later stage. ***Alongside the series of decision points between now and 2050 required to determine the role of hydrogen in the UK, the Government should, in its response to this Report, set out clear criteria to identify the potential role of hydrogen in each sector.***

178. There are several possible ways through which Government action on hydrogen deployment and scaling-up could be used to achieve a number of strategic objectives. In the paragraphs which follow we set out possible strategic objectives highlighted to us in evidence.

179. **Delivery of Net Zero**—Guy Newey told us that if we did not act for the next five years, we would not meet our Net Zero target and we have "no time to waste".[445] Sir Patrick Vallance also told us "we should go as fast as we can" in our efforts to get to Net Zero.[446]

180. **Developing a resilient low-carbon energy system based on multiple energy sources**—hydrogen has the potential to provide energy resilience to the UK's economy and to reduce its future dependence on electricity, although Government action is needed to support this. Michael Liebreich emphasised the need to have "deep resilience" in the electricity grid to account for unusual weather patterns or cyber terrorist attacks, which could involve storing hydrogen for several years:

> If we put hydrogen into salt caverns and keep it there, and it might not be used for five years, which company is going to do that? The markets will not supply the price signal without support from the Government.[447]

181. **Securing international competitive advantage**—several other countries have developed ambitious hydrogen strategies backed by national investment strategies, including €9 billion in Germany, over $9.5 billion in the US and $4.1 billion in South Korea.[448] Several submissions told us that the UK's level of ambition did not match that of other countries and as the UK Hydrogen and Fuel Cell Association submission summarised "without rapid and ambitious progress, the UK was at substantial risk of falling behind".[449] Guy Newey told us that the UK was "in a race across all the fronts of Net Zero" and should be working hard to identify where in the hydrogen value chain it had a comparative advantage.[450] Mark Neller, Business Leader from engineering consultancy Arup, told us that if the Government stalled on action in hydrogen over the next five years, the UK would also have "missed a fantastic opportunity to be a leading economy in the hydrogen sector":

> We have a brilliant opportunity in the UK—with boilers, buses, our car manufacturing, our fuel cell technology in the midlands, aviation, shipping, clean steel manufacturing—but there is a narrowing and rapidly

445 Q428

446 Q503

447 Q47

448 Imperial College London (HNZ0047) para 7 and National law Review, Infrastructure Investment and Jobs Act: Accelerating the Deployment of Hydrogen, 18 November 2021

449 UK Hydrogen and Fuel Cell Association (HNZ0011); Thames Estuary Growth Board (HNZ0015); Alstom UK (HNZ0018); Hydrogen Strategy Now campaign (HNZ0024); University of Birmingham (HNZ0030); Energy Networks Association (HNZ0032); E3G (HNZ0043); Shetland Islands Council (HNZ0053); Ryse Hydrogen and Wrightbus (HNZ0057); SGN (HNZ0061); Unitrove (HNZ0072) and Green Alliance (HNZ0095)

450 Q442

> closing window for us to seize that opportunity and to grow the economy and generate jobs in those places that need it most.[451]

In addition, whilst the UK should be learning from the successes and failures of other countries, Mr Neller added that the UK could benefit from a "first-mover advantage" in several manufacturing sectors, such as electrolyser manufacturing and hydrogen-ready boilers.[452] Sir Patrick Vallance told us in March 2022 that the UK needed to lead in some areas, and follow in others:

> I am not naive enough to think that all of the discoveries come from the UK—it is a global issue, and we need to be well connected globally— but I do think there is a genuine economic and societal benefit from getting the great research that is going on in the UK translated into solutions for net zero, and there will be export opportunities as well. That doesn't mean that we should not also be followers in some aspects, because there will be bits that we are not good at and we don't know about, but there is a business opportunity.[453]

182. The UK has also demonstrated thought leadership on the issue of hydrogen through the H21 project, where the role of gas in domestic heating was identified in July 2016.[454] UK Research and Innovation (UKRI) told us that the UK had "many world-class projects being supported with funding from the UK Government".[455]

183. Since the publication of the Hydrogen Strategy the Government has also published a Hydrogen Sector Development Action Plan, which identified several likely early adopters of hydrogen fuel:

> Industry is expected to form a lead option for early hydrogen use, with demand from hydrogen fuel switching picking up from the middle of the decade and hydrogen playing a key role in industrial decarbonisation by the mid-2030s under Carbon Budget 6. Low-regret opportunities for conversion to hydrogen include steam boilers and combined heat and power processes for 19 chemicals, refineries and paper. In the longer term, hydrogen is also a promising option for high temperature direct firing.[456]

The action plan was accompanied by a sample of publicly confirmed potential hydrogen projects across the UK,[457] but the Government has also said that the plan should not be viewed as exhaustive.[458]

184. **There appear to be opportunities and advantages in the UK accelerating its decarbonisation of the economy by focusing on hydrogen and becoming a leader in low- carbon hydrogen production, distribution, and deployment for multiple purposes.**

451 Q428
452 Qq383–384, 427
453 Oral evidence taken before the Science and Technology Committee on 30 March 2022, HC (2021–22) 1205, Q84.
454 H21, H21 Leeds City Gate Executive Summary, 8 July 2016
455 UK Research and Innovation (UKRI) (HNZ0091)
456 Department for Business, Energy and Industrial Strategy, Hydrogen Sector Development Action Plan, 20 July 2022
457 Department for Business, Energy and Industrial Strategy, Sample of potential hydrogen projects across the UK, 20 July 2022
458 Department for Business, Energy and Industrial Strategy, Hydrogen Sector Development Action Plan, 20 July 2022

But, as discussed in this Report there are still uncertainties which entail the risk that technologies do not prove reliable in time, or require excessive costs for consumers and taxpayers. We welcome the Hydrogen Sector Development Action Plan as a step towards making these choices.

185. ***The Government should identify its priorities for hydrogen in the economy and recognise the opportunity of hydrogen development in delivering Net Zero and developing a resilient energy system. In its response to this Report, the Government should set out what further work has been done and what more is planned to identify the sectors where the UK has a competitive advantage that it can deploy, and prioritise funding and large-scale deployment in those areas initially.***

The role of innovation and research and development

186. There are several areas of the hydrogen economy where technological developments that come through large-scale deployment can provide a significant boost to the cost of operating hydrogen technologies. This includes improving the CCUS capture rate and improving electrolyser manufacturing to reduce the cost of green hydrogen.[459]

187. UKRI told us that "continued investment in research and innovation that tackles existing challenges remains critical for a successful hydrogen economy in the short and long term":

> However, without support for business innovation, demonstrators and transformation, and participation in international initiatives, UK supply chains risk becoming uncompetitive. This could lead to missed opportunities to create high-value jobs in the sector, and increased reliance on imports of key components. Appropriate policy choices underpinned by public funding are critical in catalysing the private sector investment needed to stimulate a reliable and competitively priced hydrogen market in the UK that will help boost the productivity of UK industry and attract inward investment.[460]

188. UKRI has funded projects such as the Green Ammonia Demonstrator and provided funding into hydrogen innovation through the Industrial Decarbonisation Challenge Fund and the Future Flight Challenge programme.[461] Continuing to fund such innovation projects in specific areas alongside clear policy direction and large-scale rollout of hydrogen technology can provide a clear signal to the market.[462]

189. The importance of innovation in technology and a continued commitment to innovation was recognised in the UK Government Hydrogen Strategy: "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".[463] The £1 billion Net Zero Innovation Portfolio identified hydrogen as a priority area for funding.[464]

459 Qq43, 441
460 UK Research and Innovation (UKRI) (HNZ0091)
461 ESPRC Green Ammonia Demonstrator accessed 25 August 2021; UKRI, Industrial Decarbonisation Challenge Fund, accessed 25 August 2021; UKRI, Future Flight Challenge accessed 25 August 2021
462 UK Research and Innovation (UKRI) (HNZ0091)
463 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
464 Department for Business, Energy and Industrial Strategy Net Zero Innovation Portfolio, published 3 March 2021

190. In addition to addressing technical aspects to improve the efficacy of established processes, research has highlighted a role for innovation to support the development of new technologies with lower current technological readiness. This includes the production of hydrogen from algae or directly from sunlight, amongst others.[465] In the view of the National Infrastructure Commission, policy support may be needed for their rollout.[466]

191. **Whilst much of the technology needed for hydrogen exists and can be scaled up with sufficient policy incentives, innovation in low-carbon hydrogen technology remains important. This includes both the further development of techniques and technologies that are already proven, and the further development, and bringing-to-market, of projects that are less well-known.** ***Funding bodies, like UKRI, having identified the need for such research, should reflect this in their funding programmes. In many cases, such research is more efficiently funded through our grants system than indirectly through subsidised deployment.***

Funding for low-carbon technology

192. Adoption of low-carbon hydrogen technology within a sector is, initially at least, likely to be associated with significant additional costs for several reasons, including:

- **The additional production cost of low-carbon hydrogen over grey hydrogen**—although there was uncertainty and regional variation around these figures,[467] and Michael Liebreich, CEO of Liebreich Associates told us that costs were estimated to decrease, "[low-carbon] hydrogen is not now economic".[468]

- **The infrastructure requirements in a variety of sectors to adopt hydrogen use**—sectors where the end use currently does not involve hydrogen is likely to require the development or adaptation of infrastructure for distribution, supply or refuelling. We have discussed the potential for natural gas networks to carry hydrogen for domestic use but, for example, Tata Steel Europe told us that "hydrogen-based steelmaking cannot be retrofitted onto existing production routes". Similarly, British Glass and Glass Futures Ltd told us that to use hydrogen in glass manufacturing is "likely to require a full furnace rebuild".[469] Apart from infrastructure at end use, there are costs associated with transportation and storage of hydrogen, particularly if the end use would require hydrogen to be widely available for vehicle refuelling across the country, as would be the case in the heavy goods transportation sector.[470]

- **The additional processing of fuel costs**—we heard that to decarbonise the aviation and shipping sectors, low-carbon hydrogen may not always directly replace conventional shipping and aviation fuels, but it would be a feedstock for deriving fuels such as ammonia and sustainable aviation fuels.[471] This further increases the cost of switching to low-carbon fuels from conventional aviation

465 Archita Sharma, Shailendra Kumar Arya, Hydrogen from algal biomass: A review of production process, Biotechnology Reports, Volume 15, 2017, Pages 63–69,ISSN 2215–017X, https://doi.org/10.1016/j.btre.2017.06.001 and National Infrastructure Commission, Engineered greenhouse gas removals, 29 July 2021
466 National Infrastructure Commission, Engineered greenhouse gas removals, 29 July 2021
467 See Box One.
468 Q42
469 British Glass, Glass Futures Ltd (HNZ0035) and Tata Steel Europe (HNZ0096)
470 Qq147–148
471 Qq200–201, 218

> and shipping fuel and further reduces the fundamental economic efficiency as hydrogen as an energy source by adding a further transformation required before use. Michael Liebreich told us there would need to be some Government policy to close the "economic gap" associated with the extra cost of green and blue hydrogen.[472] Professor Cebon, Professor of Mechanical Engineering at the University of Cambridge, warned that since grey hydrogen was "much cheaper than blue or green" there was a danger that grey hydrogen would be used after the hydrogen infrastructure had been adopted, "which would dramatically increase carbon emissions" even if the end use replaced the use of natural gas.[473]

193. A 'contracts for difference' (CfD) approach[474] was advocated by several industries and industry bodies as a means of providing more certainty to producers and investors.[475] For example, the Energy Networks Association told us that "CfDs are a proven success in the power sector and they may function well for supporting industry CCUS as well as parts of the hydrogen system".[476] The British Standards Institution told us:

> A CfD market structure is seen as the most appropriate regime, given its familiarity with the financing sector and proven track record of stimulating markets. A CfD structure would also create competition from investors which would allow a reduction in support over time in line with market maturity and technology scale, as has been shown through the development of the wind power market.[477]

194. The International Energy Agency has also argued that CfDs "could help to reduce the current cost gap of low-carbon hydrogen production compared to existing unabated production from fossil fuels".[478] However, Dr Baxter commented that there was an issue that CfDs were not necessarily ideal for the hydrogen economy, and other options should be considered:

> For hydrogen, there is a slight difficulty with CfD, which people mentioned in the previous session, in that, because hydrogen can be used for multiple purposes, it is difficult to run a clean CfD auction. Direct subsidy may be more appropriate in certain areas.[479]

Professor Shah of Imperial College London also told us that the Government should "find a balance of capital grant and CfD to supply hydrogen on a basis that allows people to

472 Q42

473 Q23

474 The Contracts for Difference (CfD) Scheme is the Government's main mechanism for supporting investment in low-carbon electricity generation by protecting providers and consumers. Government-backed contracts provide relevant producers with a flat (indexed) rate for the electricity they produce over a 15-year period; the difference between the 'strike price' (a price for electricity reflecting the cost of investing in a particular low-carbon technology) and the 'reference price' (a measure of the average market price for electricity in the GB market).

475 UK Hydrogen and Fuel Cell Association (HNZ0011); Thames Estuary Growth Board (HNZ0015); OGTC (HNZ0016); Progressive Energy; HyNet North West (HNZ0022); Hydrogen Strategy Now campaign (HNZ0024); Energy Networks Association (HNZ0032); European Marine Energy Centre Ltd (HNZ0039); HyDeploy (HNZ0040); British Standards Institution (BSI) (HNZ0048); Johnson Matthey (HNZ0056); Shell UK (HNZ0059); EDF (HNZ0065); Tata Steel Europe (HNZ0096) and Liberty Steel (HNZ0097)

476 Energy Networks Association (HNZ0032)

477 British Standards Institution (BSI) (HNZ0048) para 24

478 International Energy Agency, Net Zero by 2050: A Roadmap for the Global Energy Sector, 11 May 2021, p. 112

479 Q47

decarbonise some of the major industrial processes".[480] He added that this could be "up and running quickly, and it has a use case for producing, storing, transporting and using hydrogen".[481]

195. The Government's Hydrogen Strategy announced a consultation on the best business models to encourage hydrogen adoption, with an aim to "finalise the business model in 2022, enabling the first contracts to be allocated from Q1 2023".[482] This did not reflect the need for clarity and support that we have heard from several submissions.[483] For example, National Grid told us:

> If we are to see hydrogen production scaled up in a commercial way, it will be important for the Government to finalise business models at the earliest opportunity […] to provide the best possible chance of achieving its target of two clusters by the mid-2020s and four clusters by 2030.[484]

Since our inquiry finished taking evidence, the Government business model consultation has concluded, and a response published together with Heads of Terms and low-carbon hydrogen standard guidance.[485, 486, 487] The latter "sets a maximum threshold for the amount of greenhouse gas emissions allowed in the production process for hydrogen to be considered 'low carbon hydrogen'".[488] A full certification scheme is expected to follow by 2025.[489] On financing, the Government has said the introduction of a levy to fund the business model is its preferred option, with projects allocated support in the 2022 allocation round to be funded via taxation until the levy is established.[490] The Royal Academy of Engineering has called on the Government as part of its work on the final business model:

> [to] identify areas that require outcome-based market interventions, such as subsidies and auctions to reduce costs, frontload investment, stimulate innovation, development, and deployment, and minimise the risks of investment.[491]

480 Q23
481 Q23
482 Department for Business, Energy and Industrial Strategy, UK hydrogen strategy, CP 475, 17 August 2021
483 The Hydrogen Taskforce (HNZ0045); Centre for Sustainable Road Freight, University of Cambridge; Centre for Sustainable Road Freight, University of Cambridge (HNZ0020); British Glass, Glass Futures Ltd (HNZ0035); Hydrogen Strategy Now campaign (HNZ0024); UK Hydrogen and Fuel Cell Association (HNZ0011) and National grid (HNZ0038)
484 National Grid (HNZ0038)
485 Department for Business, Energy and Industrial Strategy, Design of a business model for low carbon hydrogen, 8 April 2022
486 Department for Business, Energy and Industrial Strategy, Low Carbon Hydrogen Production Business Model: Heads of Terms, 13 December 2022
487 Department for Business, Energy and Industrial Strategy, UK Low Carbon Hydrogen Standard: emissions reporting and sustainability criteria, 8 April 2022
488 Department for Business, Energy and Industrial Strategy, Design of a business model for low carbon hydrogen, 8 April 2022
489 Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market: July 2022, 20 July 2022
490 Department for Business, Energy and Industrial Strategy, Government response to the consultation on a Low Carbon Hydrogen Business Model, 8 April 2022
491 Royal Academy of Engineering and National Engineering Policy Centre, The role of hydrogen in a net zero energy system, 8 September 2022, p. 31

196. The Government has also committed to designing new business models for hydrogen transport and storage infrastructure by 2025,[492] whilst a Net Zero Hydrogen Fund (NZHF) opened for applications in May 2022 and made available up to £240 million to "fund the development and deployment of new low-carbon hydrogen production to de-risk investment and reduce lifetime costs".[493]

197. **As with other low-carbon systems, there are costs associated with the development of infrastructure and the uptake of hydrogen use within every use case. The relatively higher prospective cost of low-carbon hydrogen will increase overall costs of, for example, manufacturing, transportation, or heating. There is a risk that because of these costs and impacts on end user prices, the companies and other entities forming these new hydrogen-based, low-carbon, value chains risk failure from non-competitiveness.**

492 Department for Business, Energy and Industrial Strategy, Hydrogen Strategy update to the market: July 2022, 20 July 2022

493 Department for Business, Energy and Industrial Strategy, Net Zero Hydrogen Fund strand 1 and strand 2, 18 May 2022

7 Conclusion

198. Hydrogen has attracted a growing interest as the UK pursues its legal commitment to deliver a Net Zero economy by 2050, and we have heard a variety of views on its potential prominence in a sustainable future energy system. It has unique features as a clean-burning fuel that can be stored on long timescales with scalable production through several low-carbon means. This enables hydrogen to play a role, not only in decarbonising our energy consumption but also in providing more resilience for our energy system and increasing the UK's energy security.

199. However, whilst hydrogen use has several attractive features, most of the evidence we have received was clear that with current technologies, it does not represent a panacea. As the UK looks to transition to a Net Zero economy, hydrogen will likely have specific but limited roles to play across a variety of sectors to decarbonise where other technologies—such as electrification and heat pumps—are not possible, practical, or economic.

200. There have been recent developments which have affected the energy market in the UK and worldwide, specifically the Russia-Ukraine conflict and an increase in wholesale energy prices. Individuals and households have been put under considerable pressure by rising bills and discussions about sources of energy and the resilience of our energy system have been brought to the fore. These factors could impact the extent to which hydrogen has a role to play in the UK and it will be crucial that an assessment is undertaken of any impacts of its deployment on individuals and households. There is, and will likely continue to be, considerable uncertainty, but as our Report has identified, there are overarching strategic questions which need addressing if the UK hydrogen sector is to continue to grow.

201. The UK Government's Hydrogen Strategy initiated consultations on the role of hydrogen and indicated a timeframe for decisions to be made, and there have been further developments since it was first published in August 2021. However, the UK Government's approach still lacks the clarity that we have heard industry needs.

Conclusions and recommendations

Hydrogen's potential contribution to Net Zero

1. To meet the 2050 Net Zero target, decisions need to be urgently taken by the Government, which will help define hydrogen's place in the UK's overall decarbonisation strategy. These decisions should be integrated across Government, in policy areas such as those identified in the Ten Point Plan for a Green Industrial Revolution. Decisions on hydrogen should be made in an international context and take into consideration the approaches of other countries both in terms of lessons to be learned and collaborations to be pursued. *The Government should, in the next two months, outline a series of decision points between now and 2050 that will determine the role of hydrogen in the UK, in each policy area identified in the Ten Point Plan for a Green Industrial Revolution. This should be accompanied by an outline of the scientific and technological progress that needs to be made to allow hydrogen to play its part in our energy system.* (Paragraph 18)

2. Hydrogen has several distinctive features as a low-carbon gaseous fuel and could contribute to the UK's energy system, including through improving resilience and energy security. Whilst in some applications hydrogen is less efficient compared to alternative low-carbon technologies, the wider energy system benefits of deploying hydrogen must be acknowledged, and we welcome the Government's whole systems approach in its Hydrogen Strategy. *Consideration should be given to broader benefits, such as system resilience and national security, as well as price competitiveness as a fuel, in implementing the Hydrogen Strategy.* (Paragraph 31)

Hydrogen production

3. The Government has chosen at this stage to support the development of both green and blue hydrogen. We heard that the initial adoption of blue hydrogen will be cheaper than green hydrogen, and ready to use in certain niche industrial settings sooner. However, several analysts have argued that green hydrogen will become cheaper than blue hydrogen over time. (Paragraph 44)

4. There is uncertainty about the extent to which blue hydrogen can play a role in a Net Zero economy in the mid to long term, even if it may be cheaper and ready to deploy in certain industrial settings sooner than green hydrogen, as some industrial users already possess the necessary infrastructure. *The Government should not be dependent on either blue or green hydrogen alone in the short-term. The Government's decision to continue using blue hydrogen should be dependent on the standard CO_2 capture rate reaching 95% by 2030 and in excess of 99% well in advance of 2050. In its response to this Report the Government should set out its expectations of how much CO_2 could be captured in hydrogen production and which industrial settings it sees as being ready to utilise blue hydrogen prior to 2050.* (Paragraph 55)

5. *Carbon capture, utilisation and storage (CCUS) technology should be an area of priority research interest for the Department for Business, Energy and Industrial Strategy, and a strategic priority for UK Research and Innovation.* (Paragraph 56)

6. Several countries are prioritising green hydrogen in their hydrogen strategies, and it seems likely that international interest in demonstrably low-carbon hydrogen, including green hydrogen, will continue to grow. This offers an opportunity for the UK to become a leader in green hydrogen production and development. *The Government needs to provide more clarity in its updates to market on the hydrogen strategy, with a view to guaranteeing significant green hydrogen development over the next decade. In its response to this Report, the Government should set out how it intends to support the development in the UK of green hydrogen projects at scale during this decade, to ensure that green hydrogen can be produced in the UK and so it can become cost-competitive with blue hydrogen. This should include additional efforts to reduce the cost of electrolysers.* (Paragraph 65)

7. *The Government should set a 2030 target for green hydrogen production to ensure that full-scale development of green hydrogen is incentivised to take place in the short-term and to make it more likely that the UK develops a green hydrogen production capacity. The Government should be clear whether any targets it sets are for capacity to produce, or are an expectation of how much hydrogen the UK expects to produce and use. The Government should also indicate when grey hydrogen production will be phased out.* (Paragraph 66)

Hydrogen applications

8. Energy storage for electricity generation is widely recognised as an important component of the Net Zero economy, and there are several potential technologies available for energy storage. Hydrogen has unique features as a means of energy storage, since as a clean-burning gas it can be transported through existing infrastructure and stored safely for long periods of time, if necessary. We welcome the Government's recognition of the potential role of hydrogen as an important means of energy storage. *The Government should continue to provide the necessary policy support and infrastructure for grid-scale energy storage technologies. Findings from hydrogen energy storage trials should be recorded and shared between trials to ensure that as much is learned as possible.* (Paragraph 75)

9. Hydrogen can undoubtedly help key UK industrial sectors decarbonise. There is a widespread recognition of the importance of regulatory reform and an effective business model in incentivising a switch to low-carbon hydrogen use. We welcome the Government's use of industrial clusters to trial the use of hydrogen. *The Government must design and establish effective mechanisms to capture and learn the lessons from these trials and demonstrably apply the lessons from the industrial clusters to be set up by 2025 to those which will be in operation by 2030.* (Paragraph 87)

10. Passenger battery electric vehicles for road transport have established a seemingly unassailable lead over other green alternatives, meaning that it looks likely that hydrogen will play in the near future, at most, a small part in decarbonising passenger cars. (Paragraph 94)

11. Whilst there is lower round-trip efficiency compared to electrification, hydrogen vehicles have the advantage of shorter refuelling times and longer ranges. This therefore makes hydrogen a potentially viable alternative to electrification for HGVs, but widespread adoption of hydrogen in HGVs can only be achieved with an

assurance that hydrogen will be widely available across the country. Whilst other countries have given commitments to hydrogen refuelling stations, the UK has been more reticent to date. *More trials for heavy goods vehicles, beyond those already announced and forthcoming as part of the Zero Emission Road Freight demonstration programme, need to take place in the next five years to ensure that a firm decision can be made on the role of hydrogen in HGVs in time to develop the infrastructure needed to deliver carbon emission reductions. Trials could be localised to minimise the initial infrastructure requirements. Any early adoption of hydrogen HGVs is likely to require subsidy by the Government to overcome the higher cost for the operators.* (Paragraph 101)

12. We welcome the trials of hydrogen buses which are taking place in the UK. *The Government should continue to support such trials and come to a rapid view of the contribution that hydrogen-fuelled buses can make. Trials should consider the implications for other applications such as HGVs, and the decisions the trials will help to inform.* (Paragraph 103)

13. Hydrogen has a modest but potentially critical role to play in decarbonising the rail network, where electrification is not suitable or cannot be delivered in time to contribute towards meeting Net Zero. Whilst trials and demonstration projects are underway in hydrogen trains, there is no clear plan to develop the role of hydrogen in this sector. Some countries, such as Austria and Germany, are already using hydrogen trains. In response to this Report, the Government should set out the lessons it has learned from the use of hydrogen trains overseas and how it will use this information in trials of hydrogen trains in the UK. *In response to this Report, the Government should set out the lessons it has learned from the use of hydrogen trains overseas and how it will use this information in trials of hydrogen trains in the UK.* (Paragraph 109)

14. *The Government must identify, with industry, the train lines where it is unlikely that electrification will be viable before 2050 and start trials of hydrogen trains on these lines in the next five years.* (Paragraph 110)

15. Hydrogen has an important role to play in decarbonising shipping and aviation, but parts of the transport industry want more clarity from Government about the intended role of hydrogen since there are significant infrastructure requirements and substantial costs that need to be met. There are also significant infrastructure requirements associated with hydrogen deployment in aviation and shipping but the likely 'winner' from amongst the potential low-carbon technologies in these sectors has yet to emerge and the choice will be internationally, rather than domestically, determined. *In its response to this Report, the Government should set out its strategy for participation in international fora to shape a global outcome on the role of hydrogen in shipping and aviation.* (Paragraph 119)

16. *The Government should use its influence internationally, following its leadership of COP26 and involvement in Mission Innovation, to set standards and timelines for decisions on the role of alternative fuels and hydrogen within aviation and shipping. In these areas the Government should seek to lead the development of standards that can be adopted internationally.* (Paragraph 120)

17. Hydrogen could play a role in domestic heating, but the extent of its potential is still uncertain and looks likely to be limited rather than widespread. We are unconvinced its deployment will prove to be economically viable by the time the Government has said it will determine the role of hydrogen boilers, in 2026. (Paragraph 133)

18. Overall, whilst there are a variety of possible applications of hydrogen technology across every sector of the UK economy, we agree with the Government that on the basis of present knowledge and the technology available it seems that the role of hydrogen will be to decarbonise specific, limited areas where electrification is either not possible or clearly not optimal, such as the industrial clusters currently developing hydrogen capabilities. The clusters may also offer a future production option for some of the hydrogen required in other applications. *The Government should prioritise the use of hydrogen in those sectors where there is a genuine prospect of technical, feasible and economically viable deployment. The Government should work closely with businesses and international partners to set, in the 2020s, a realistic strategy for the adoption and use of hydrogen in these sectors.* (Paragraph 137)

Hydrogen metering and the role of Ofgem

19. Metering is an essential component of any use case for hydrogen in domestic settings. We have heard that the current generation of gas smart meters are designed to measure volume flows of natural gas which are much lower than hydrogen volume flows for the same energy delivery, so are unlikely to be compatible. Larger volume capacity meters, or alternatives which measure mass flow, may be required. (Paragraph 145)

20. The energy regulator Ofgem has not worked on understanding hydrogen domestic metering and has not been able to say whether the current roll-out of smart meters will prove ineffective if hydrogen is used in domestic metering. Ofgem was also unable to provide cost estimates for how expensive a hydrogen-ready smart meter roll-out would be under different scenarios, or what the cost implications would be for the consumer. This has arisen, it was suggested to us, because the responsibility for domestic metering is no longer within the remit of Ofgem. Domestic metering is an issue that has been overlooked, and we are concerned that Ofgem is not fulfilling its specified remit of protecting the consumer. (Paragraph 153)

21. *An urgent project on metering domestic hydrogen use needs to be undertaken. This should include an assessment of:*

- *whether and when the current generation of gas smart meters need to be (a) adapted, or (b) replaced;*
- *what technology could and should be used in new meters to accommodate different fuels and to reflect the timing and pace of different transition scenarios; and*
- *the likely costs of domestic metering under the various scenarios.*

This work should be completed by the beginning of 2024 to ensure that a resilient approach to metering has been developed to underpin the Government's decisions on the role of hydrogen in domestic heating and to lay the foundations for an appropriate pace of change should the decision be to adopt hydrogen for domestic heating. (Paragraph 154)

The Government's hydrogen strategy

22. Several countries including Germany, Japan and Singapore have well developed hydrogen strategies with significant public funding to support the development of infrastructure, production and use of low-carbon hydrogen. Through public-private partnerships, Germany and Japan have structures intended to enable the development of a regulatory framework and provide confidence to consumers for private investment. The UK's main international competitors in this field also tend to have specific bodies responsible for the delivery of their government's targets. *Given the evidence received on the importance of whole systems performance, the Government should designate or create a single department or agency with responsibility and accountability for delivering cross-departmental Net Zero commitments, including those relating to delivering the hydrogen strategy.* (Paragraph 165)

23. The Government's hydrogen strategy and subsequent updates to the market provide a framework with an intention for further consultations rather than early or firm decisions. The Government's understandable desire to keep its options open pending market and technological developments may not provide the clarity that investors require to proceed. The Government needs to trade the risk of failing to meet Net Zero if decisions on how to reach it are not taken soon enough against the risk of pursuing unproven technologies or solutions that are not cost-effective which would then set the UK back at a later stage. *Alongside the series of decision points between now and 2050 required to determine the role of hydrogen in the UK, the Government should, in its response to this Report, set out clear criteria to identify the potential role of hydrogen in each sector.* (Paragraph 177)

24. There appear to be opportunities and advantages in the UK accelerating its decarbonisation of the economy by focusing on hydrogen and becoming a leader in low- carbon hydrogen production, distribution, and deployment for multiple purposes. But, as discussed in this Report there are still uncertainties which entail the risk that technologies do not prove reliable in time, or require excessive costs for consumers and taxpayers. We welcome the Hydrogen Sector Development Action Plan as a step towards making these choices. (Paragraph 184)

25. *The Government should identify its priorities for hydrogen in the economy and recognise the opportunity of hydrogen development in delivering Net Zero and developing a resilient energy system. In its response to this Report, the Government should set out what further work has been done and what more is planned to identify the sectors where the UK has a competitive advantage that it can deploy, and prioritise funding and large-scale deployment in those areas initially.* (Paragraph 185)

26. Whilst much of the technology needed for hydrogen exists and can be scaled up with sufficient policy incentives, innovation in low-carbon hydrogen technology remains important. This includes both the further development of techniques and technologies that are already proven, and the further development, and bringing-to-market, of projects that are less well-known. *Funding bodies, like UKRI, having identified the need for such research, should reflect this in their funding programmes. In many cases, such research is more efficiently funded through our grants system than indirectly through subsidised deployment.* (Paragraph 191)

27. As with other low-carbon systems, there are costs associated with the development of infrastructure and the uptake of hydrogen use within every use case. The relatively higher prospective cost of low-carbon hydrogen will increase overall costs of, for example, manufacturing, transportation, or heating. There is a risk that because of these costs and impacts on end user prices, the companies and other entities forming these new hydrogen-based, low-carbon, value chains risk failure from non-competitiveness. (Paragraph 197)

Formal minutes

Wednesday 14 December 2022

Members present

Greg Clark, in the Chair

Aaron Bell

Rebecca Long-Bailey

Stephen Metcalfe

Graham Stringer

Draft Report (*The role of hydrogen in achieving Net Zero*), proposed by the Chair, brought up and read.

Ordered, That the draft Report be read a second time, paragraph by paragraph.

Paragraphs 1 to 201 read and agreed to.

Summary agreed to.

Resolved, That the Report be the Fourth Report of the Committee to the House.

Ordered, That the Chair make the Report to the House.

Ordered, That embargoed copies of the Report be made available, in accordance with the provisions of Standing Order No. 134.

Adjourned till Wednesday 18 January 2023 at 9.20am.

Witnesses

The following witnesses gave evidence. Transcripts can be viewed on the inquiry publications page of the Committee's website.

Wednesday 3 March 2021

Professor David Cebon, Professor of Mechanical Engineering, University of Cambridge; **Professor Nilay Shah**, Head of the Department of Chemical Engineering, Imperial College London Q1–31

Michael Liebreich, CEO, Liebreich Associates; **Dr Jenifer Baxter**, Chief Engineer, Institution of Mechanical Engineers Q32–55

The Baroness Brown of Cambridge DBE FREng FRS Q56–72

Wednesday 24 March 2021

Professor Marcus Newborough, Development Director, ITM Power; **Tim Dumenil**, Acorn Hydrogen Project Manager, Pale Blue Dot Q73–110

Paul Booth, Chair, Tees Valley Local Enterprise Partnership; **Dr Martin Pei**, Executive Vice President and Chief Technical Officer, SSAB; **Dr Richard Leese**, Director for Industrial Policy, Energy and Climate Change, Mineral Products Association Q111–136

Wednesday 14 April 2021

Gloria Esposito, Head of Sustainability, Zemo Partnership; **Dave Rowlands**, Fleet Engineering Director, Wincanton Q137–163

Dr Helen McAllister, Strategy and Planning Director, Network Rail; **Mike Muldoon**, Head of Business Development, UK and Ireland, Alstom Q164–199

Richard Clegg, Chief Executive, Lloyds Register Foundation; **Morten Bo Christiansen**, Vice President - Head of Decarbonisation, Maersk Q200–217

Glenn Llewellyn, Vice President, Zero Emission Aircraft, Airbus; **Dr Brian Yutko**, Chief Engineer for Sustainability and Future Mobility, Boeing Q218–236

Wednesday 12 May 2021

Carl Arntzen, CEO, Bosch Thermotechnology Ltd; **Professor Jianzhong Wu**, Head of Engineering, Cardiff University Q237–260

Antony Green, Hydrogen Project Director, National Grid; **Angus McIntosh**, Director of Energy Futures, SGN; **Dr Angela Needle**, Director of Strategy, Cadent Q261–293

Professor Jon Gluyas, Executive Director, Durham Energy Institute; **Dr Jonathan Radcliffe**, Reader in Energy Systems and Policy, University of Birmingham; **Professor Clare Grey**, Geoffrey Moorhouse Gibson Professor of Chemistry, University of Cambridge Q294–313

Julian Leslie, Head of Networks, National Grid ESO Q314–332

Wednesday 7 July 2021

Professor Takeo Kikkawa, Distinguished fellow, Graduate School of International Management, International University of Japan.; **Professor Katsuhiko Hirose**, CEO and Chief Consultant, HyWealth Co, Visiting Professor, I2CER (International Institute for Carbon-Neutral Energy Research), Kyushu University Q333–354

Franz Lehner, Head of Division International Cooperation, National Organisation Hydrogen and Fuel Cell Technology; **Eric Heymann**, Senior Economist, Deutsche Bank Research Q355–389

Dr Martin Hanton, Technical Director, TÜV SÜD National Engineering Laboratory; **Dr Jane Dennett-Thorpe**, Deputy Director of Decarbonisation and Energy Transition, Ofgem Q390–421

Wednesday 21 July 2021

Guy Newey, Strategy and Performance Director, Energy Systems Catapult; **Mark Neller**, Director, Energy Business Leader UKIMEA, Arup Q422–459

Professor Paul Monks, Chief Scientific Adviser, Department for Business, Energy & Industrial Strategy; **Sir Patrick Vallance**, Government Chief Scientific Adviser, Government Chief Scientific Adviser, Government Office for Science; **Rt Hon Kwasi Kwarteng MP**, Secretary of State, Department for Business, Energy & Industrial Strategy Q460–533

Published written evidence

The following written evidence was received and can be viewed on the inquiry publications page of the Committee's website.

HNZ numbers are generated by the evidence processing system and so may not be complete.

1 Airbus (HNZ0051)

2 Alstom UK (HNZ0018)

3 Andrews, Professor Gordon (Professor of Combustion Engineering, The University of Leeds) (HNZ0010)

4 Anglo American (HNZ0087)

5 Arcola Energy (HNZ0049)

6 Baxter, Tom (Consultant Chemical Engineer, PDB) (HNZ0012)

7 British Geological Survey (HNZ0026)

8 British Glass; and Glass Futures Ltd (HNZ0035)

9 British Standards Institution (BSI) (HNZ0048)

10 British Steel (HNZ0098)

11 Business Modelling Associates UK LTD (HNZ0017)

12 CMG, Dr Andy Palmer (CEO, Palmer Automotive) (HNZ0008)

13 Cadent (HNZ0099), (HNZ0042)

14 Celsa Steel UK (HNZ0100)

15 Centre for Energy Transition, University of Aberdeen (HNZ0082)

16 Centre for Policy Studies (HNZ0005)

17 Centre for Sustainable Road Freight, University of Cambridge; and Centre for Sustainable Road Freight, University of Cambridge (HNZ0020)

18 Centrica plc (HNZ0073)

19 Christian Aid (HNZ0055)

20 Dalton Nuclear Institute, The University of Manchester (HNZ0071)

21 Davies, Mr Paul (Chair CCS Advisory Group, CCS Adviser to BEIS, CCS Advisory Group, BEIS) (HNZ0006)

22 Department for Business, Energy and Industrial Strategy (HNZ0090)

23 E3G (HNZ0043)

24 EDF (HNZ0065)

25 Energy Networks Association (HNZ0032)

26 Energy Systems Catapult (HNZ0066)

27 Energy and Utilities Alliance (HNZ0070)

28 Enertek International Ltd (HNZ0014)

29 European Marine Energy Centre Ltd (HNZ0039)

30 Flow Measurement SIG, Institute of Measurement and Control (HNZ0013)

31 Green Alliance (HNZ0095)

32 Green, Mr Steve (Ex Chemical Engineer and Technical Authority for it , Retired) (HNZ0009)

33 Greenpeace UK (HNZ0063)

34 Gluyas, Professor Jon (Executive Director, Durham Energy Institute); Dr Jonathan Radcliffe (Reader in Energy Systems and Policy, University of Birmingham); and Professor Clare Grey (Geoffrey Moorhouse Gibson Professor of Chemistry, University of Cambridge) (HNZ0101)

35 Harmer, Ferry (HNZ0092)

36 HyDeploy (HNZ0040)

37 Hybrid Air Vehicles (HNZ0052)

38 Hydrogen Accelerator (HNZ0064)

39 Hydrogen Strategy Now campaign (HNZ0024)

40 Hydrologiq Ltd (HNZ0067)

41 ITM Power (HNZ0093), (HNZ0027)

42 Imperial College London (HNZ0047)

43 InfraStrata plc (HNZ0074)

44 Institution of Chemical Engineers (HNZ0031)

45 Institution of Mechanical Engineers (HNZ0086)

46 JCB (HNZ0083)

47 Johnson Matthey (HNZ0056)

48 Liberty Steel (HNZ0097)

49 Manchester Fuel Cell Innovation Centre - Manchester Metropolitan University (HNZ0023)

50 Maritime UK (HNZ0080)

51 Microcab Industries Ltd (HNZ0075)

52 Mineral Products Association (HNZ0025)

53 National Engineering Policy Centre (NEPC) (HNZ0078)

54 National Physical Laboratory (HNZ0088)

55 National Grid (HNZ0038)

56 Newcastle University (HNZ0089)

57 Nuclear Industry Association (HNZ0036)

58 OGTC (HNZ0016)

59 OGUK (HNZ0084)

60 Ofgem (HNZ0102)

61 PA Consulting Group; and Reaction Engines (HNZ0077)

62 Pale Blue Dot (HNZ0094)

63 Porterbrook (HNZ0007)

64 Powerhouse Energy (HNZ0068)

65 Progressive Energy; and HyNet North West (HNZ0022)

66 RWE (HNZ0085)

67 Riversimple Movement Ltd (HNZ0076)

68 Rolls-Royce plc (HNZ0029)

69 Ryse Hydrogen and Wrightbus (HNZ0057)

70 SGN (HNZ0061)

71 Scottish Carbon Capture and Storage (HNZ0034)

72 Scottish Hydrogen and Fuel Cell Association (HNZ0058)

73 Seymour-Hamilton, Warwick (HNZ0004)

74 Shell UK (HNZ0059)

75 Shetland Islands Council (HNZ0053)

76 Sizewell C (HNZ0062)

77 TRL (HNZ0069)

78 TUV SUD National Engineering Laboratory (part of National Measurement System) (HNZ0003)

79 Tata Steel Europe (HNZ0096)

80 Taylor, Mr Gordon (Consultant, G T Systems) (HNZ0054)

81 Tees Valley Combined Authority (HNZ0081)

82 Thames Estuary Growth Board (HNZ0015)

83 The Geological Society (HNZ0060)

84 The Health and Safety Executive (HNZ0046)

85 The Hydrogen Taskforce (HNZ0045)

86 The International Council on Clean Transportation (HNZ0002)

87 The Royal Society (HNZ0079)

88 UK H2Mobility; and Element Energy (HNZ0033)

89 UK Hydrogen and Fuel Cell Association (HNZ0011)

90 UK Research and Innovation (UKRI) (HNZ0091)

91 Unitrove (HNZ0072)

92 University of Birmingham (HNZ0030)

93 University of Kent (HNZ0001)

94 University of Nottingham (HNZ0021)

95 University of Southampton; University of Southampton; University of Southampton; University of Southampton; University of Southampton; University of Southampton; and University of Southampton (HNZ0050)

96 Vaillant Group UK Ltd (HNZ0037)

97 Wales & West Utilities (HNZ0028)

98 ZeroAvia (HNZ0019)

List of Reports from the Committee during the current Parliament

All publications from the Committee are available on the publications page of the Committee's website.

Session 2022–23

Number	Title	Reference
1st	Pre-appointment hearing for the Executive Chair of Research England	HC 636
2nd	UK space strategy and UK satellite infrastructure	HC 100
3rd	My Science Inquiry	HC 618

Session 2021–22

Number	Title	Reference
1st	Direct-to-consumer genomic testing	HC 94
2nd	Pre-appointment hearing for the Chair of UK Research and Innovation	HC 358
3rd	Coronavirus: lessons learned to date	HC 92

Session 2019–21

Number	Title	Reference
1st	The UK response to covid-19: use of scientific advice	HC 136
2nd	5G market diversification and wider lessons for critical and emerging technologies	HC 450
3rd	A new UK research funding agency	HC 778