HYDROGEN

CONTENTS

FOREWORD

NOTES

As an industrial raw material, hydrogen has been in use for centuries. Before the 1960s, UK homes were supplied by **Town Gas**[1] which was made with about 50% hydrogen (by volume). Today it is an important ingredient in farm fertilisers, a coolant for electricity generating power stations and an essential component of rocket fuel.

Policy discussions are focusing on hydrogen's potential to back up renewable electricity, replace natural gas to heat buildings, and for use in vehicles and industrial processes.

A key reason for this new interest is that, unlike natural gas, when hydrogen is burned to produce energy, its main by-product is water vapour and no carbon dioxide is produced. That makes hydrogen a potential game-changer when it comes to tackling climate change.

But hydrogen has its challenges. To be useful as a carbon-free fuel, it must be made using zero-carbon electricity or supported by carbon capture and storage in some processes – a technology which exists but is still in its early stages in the UK. Although producing hydrogen is not a problem, scaling up production quickly will be a challenge. Distributing and storing it will need investment in infrastructure. The UK has the know-how owing to its mature gas industry.

For hydrogen to help meet net zero in the UK, some difficult policy decisions will have to be taken sooner rather than later. Avoiding those decisions or getting them wrong will narrow options in the future and risk lost opportunities for the UK. For energy-intensive industries like steel-making, for example, hydrogen could be a lifeline.

There has been a sharp drop in the use of coal in the UK, partly because of the switch to gas, the increased use of renewables and because of the closure of the Redcar steelworks in 2015 – but that came at the cost of over 2,000 jobs[2]. Switching to hydrogen has the potential not only to stop offshoring our heavy industry and our emissions, but to start bringing jobs back to the UK.

This briefing explores whether hydrogen is practical and/or desirable as a potential fuel as part of the energy puzzle, to support renewables in the UK's energy transition to net zero. While the report is non-partisan and takes no stance in the debate, it looks at the positive potential of hydrogen and what would need to be done to make it form part of the UK energy economy.

Natascha Engel
Chief Exective, Palace Yard

1 National Gas and Historic England, *Gas: How was it made?*

2 Carbon Brief, *Analysis: UK carbon emissions fell 6% in 2016 after record drop in coal use*, March 2017

UK ENERGY IN CONTEXT

Carbon emissions from energy use, particularly the UK's continued reliance on **hydrocarbons** (fossil fuels), are under the spotlight in the transition to net zero. Renewable sources like wind, solar and hydro have made great strides in decarbonising electricity which is why switching to electricity (where possible) is a popular low carbon solution.

In 1990, the majority of the UK's electricity was generated in coal-fired power stations (65%) and only a small amount of electricity came from renewables. By 2021, renewables made up 40% of electricity and only 2% was generated using coal.

However, 40% of the UK's electricity is still generated using gas. This is because gas is available when needed (called **dispatchable**) unlike wind and solar which are only available when the wind is blowing and the sun is shining (**intermittent**). In the transition to net zero, we therefore need an energy source that can be stored long-term and this is where hydrogen could play a role.

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Figure 1 1990:

Percentages of energy sources used to generate electricity (1990)

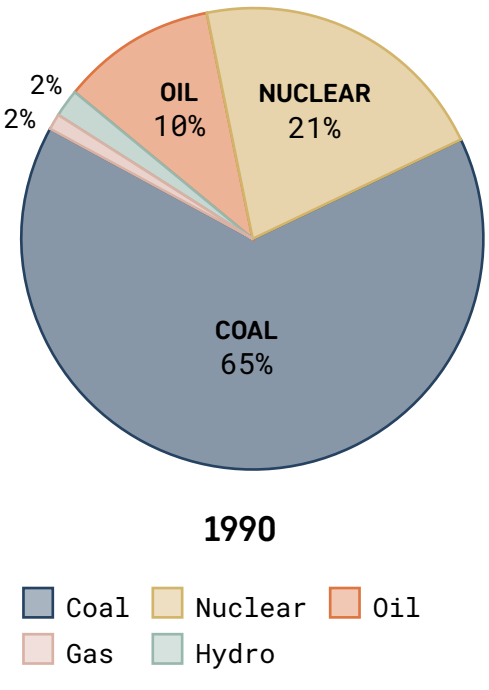
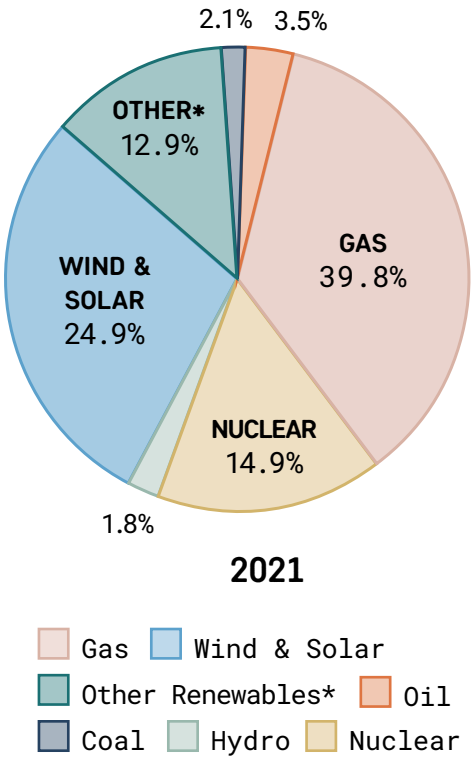


Figure 2 2021:

Percentages of energy sources used to generate electricity (2021)



*Mainly biomass

Source: BEIS, *UK Energy in Brief*, 2022

Words in **green** are defined in the glossary.

UK ENERGY IN CONTEXT // CONTINUED

Overall, **primary** electricity (from nuclear, wind and solar) makes up just over 11% of all the energy used in the UK in 2021. Including electricity generated by natural gas, electricity makes up around 20% of all UK energy[3].

The bulk of the UK's total energy need remains around 80% non-electric – mainly gas (around 40%) and oil (around 35%). Of the energy used in the UK in 2021, nearly 43% was gas, 32% oil (mainly used as petrol and diesel in transport), and just over 3% coal[4].

Alongside electricity, 83% of homes (23 million UK houses) use gas for heating, as do over 200,000 business.

While there has been real progress in decarbonising electricity, areas like industry, transport and domestic heating are still lagging behind partly because they are less easy (or in some cases impossible) to electrify.

The reason why there is so much interest and investment in hydrogen today is because of its potential to help the UK reach its net zero carbon emissions target by 2050 in areas that are hard to decarbonise: industry, domestic and workplace heating, and power generation when renewables are not available.

NOTES

3 BEIS, *UK Energy in Brief*, 2022

4 BEIS, *UK Energy in Brief*, 2022

WHAT IS HYDROGEN?

NOTES

Hydrogen is the most abundant element in the universe. It is a colourless, tasteless, non-toxic gas at room temperature and turns to liquid at -253°C[5]. Unlike natural gas, when hydrogen is burned (or **combusted**), it does not emit carbon dioxide.

Hydrogen is extremely light – 7% the weight of air[6] – which means it quickly rises and disperses. It is usually bonded to another element, such as in water or methane (natural gas) which means that it has to be split away before it can be isolated and used.

When hydrogen is made by splitting it from methane (either in **steam-methane reforming** or **autothermal reforming**), the by-product is carbon dioxide. If the carbon dioxide vents into the air this is called **grey hydrogen** (high carbon). If the carbon dioxide is captured and stored it is called **blue hydrogen** (low carbon). See Figure 3.

When hydrogen is manufactured by splitting it from water (in a process called **electrolysis**), the by-product is oxygen which can safely be vented into the air or captured and used. If the electricity used in the process comes from renewables like wind, then it is called **green hydrogen**. If the electricity comes from nuclear, it is called **pink hydrogen** (both zero carbon).

96% of hydrogen produced in the UK in 2021 was grey[7].

While the different colours of hydrogen are a useful shorthand to understand the process by which hydrogen has been made, a more meaningful calculation is the amount of carbon dioxide emitted during the hydrogen production process.

The UK government has produced the UK Low Carbon Hydrogen Standard[8] for this purpose: to set out how to calculate emissions.

5 Royal Society of Chemistry, *Hydrogen*, 2022

6 Royal Society of Chemistry, *Hydrogen*, 2022

7 Royal Academy of Engineering, *The role of hydrogen in a net zero energy system*, September 2022

8 *UK Low Carbon Hydrogen Standard*, 2022

Words in **green** are defined in the glossary.

WHAT IS HYDROGEN? // CONTINUED

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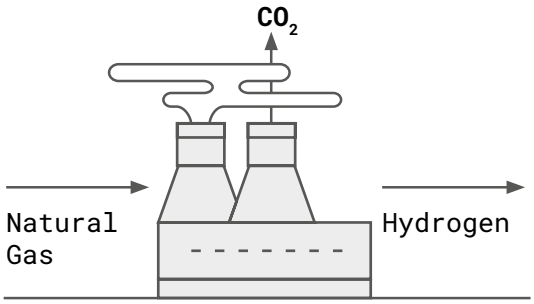
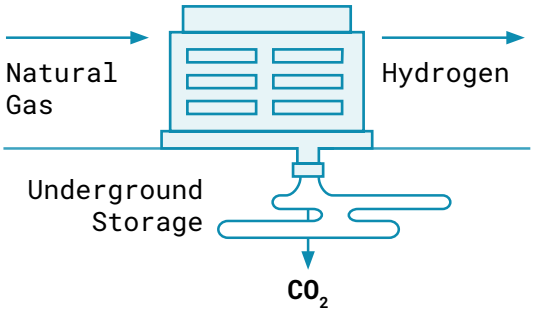
Figure 3:

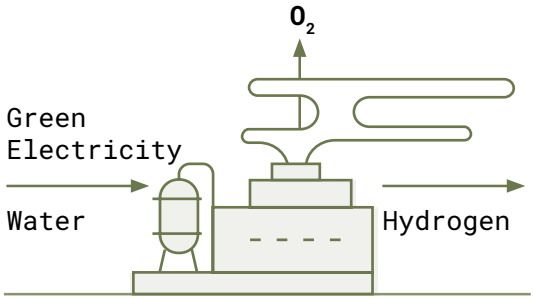
GREY HYDROGEN
(High carbon)



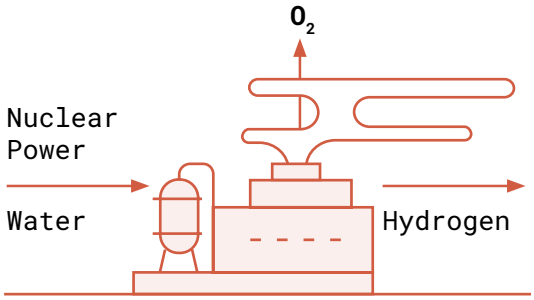
BLUE HYDROGEN
(Low carbon)



GREEN HYDROGEN
(Zero carbon)



PINK HYDROGEN
(Zero carbon)



Hydrogen was discovered by English scientist Henry Cavendish in 1766 who called it 'inflammable air' which produced water when burned. In 1781, it was named 'hydrogen' by French scientist Antoine Lavoisier using the Greek word for 'water maker'.

POTENTIAL USES OF HYDROGEN

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> "Hydrogen could replace natural gas in parts of the energy system, where electrification is not feasible or is prohibitively expensive, for example in providing heat on colder winter days, industrial heat processes and back-up power generation.
>
> "Hydrogen should be viewed as a credible option in the next stage of the UK's energy transition."
>
> Climate Change Committee (2018), Hydrogen in a Low Carbon Economy

Hydrogen has a potential role in the energy transition, especially (but not only) in those areas where electrification is either difficult or impossible.

Hydrogen could support electrification in the total energy system. A report[9] estimated that a combined hydrogen and electricity energy system would save around £13 billion a year compared with a system that ran only on electricity.

TRANSPORT

Hydrogen provides options for heavy transport and fleets of vehicles that cannot afford lengthy re-charging times like ambulances. Batteries for larger vehicles become very heavy and charge times increase. The hydrogen tank in a hydrogen fuel cell vehicle can be recharged more quickly and has longer ranges[10].

> In Britain, Aberdeen has a fleet of 15 hydrogen buses that have passed the million-mile mark[11].

60% of the UK railway network remains unelectrified because of cost[12]: power cables have to be installed and that often means tracks have to be lowered or bridges raised. The Railway Industry Association[13] estimates costs to electrify the rail network range from £750,000 to £1 million per kilometre of track (around £9 billion in total).

A project called HydroFLEX[14] which was part funded by government, the University of Birmingham and Porterbrook has seen the first hydrogen train run on the UK mainline and could see current diesel trains converted to hydrogen.

9 Guidehouse and Energy Networks Association, *Pathways to net-zero: Decarbonising the Gas Networks in Great Britain*, October 2019

10 '*Drive Clean*' is an online tool published by the California Air Resource Board to help car buyers find the greenest vehicles, whether electric or hydrogen powered.

11 Aberdeen City Council, *Projects H2 Aberdeen* 2022

12 Office of Road and Rail, *Rail Infrastructure and Assets 2020-21*, October 2021

13 Railway Industry Association, *RIA Electrification Cost Challenge*, March 2019

14 *HydroFLEX*

POTENTIAL USES OF HYDROGEN // CONTINUED

Germany is pioneering commercial hydrogen-powered passenger trains in Hamburg[15]. The publication Railway Pro says: "The use of hydrogen as a fuel for trains noticeably reduces the burden on the environment, as one kilogram of hydrogen replaces approximately 4.5 litres of diesel fuel."

INDUSTRIAL PROCESSES

Manufacturing cement, ceramics, glass, paper, chemicals processes and steel need temperatures higher than electricity can achieve and/or need a naked flame. In these energy-intensive industries, hydrogen is being developed as a possible carbon-free option.

While there have been dramatic reductions in industry emissions, many UK emissions reductions came at the expense of manufacturing industries closing domestically and moving their operations to other countries.

As a result, the UK in 2021 was the highest net importer of carbon dioxide in the world from importing manufactured goods, many of which used to be made in the UK. The UK imports 80 million tonnes of carbon dioxide every year from China[16].

Steel-making accounts for 7% of global carbon emissions – comparable to the exhausts from all the world's road freight combined[17]. The decarbonisation of steel manufacture would represent a significant contribution to net zero without **offshoring** steel-making.

A Swedish steel-making project using hydrogen has eliminated emissions and created the world's first 'green steel'. The trials have been so successful that the company HYBRIT[18] is planning to shut down its conventional blast furnaces in a conversion to hydrogen in 2030 rather than 2045.

HOME HEATING

83% (23 million) of UK homes are heated with natural gas and over 50% of people use gas for cooking[19]. Gas in homes, hospitals, schools and at work accounts for around 40% of all UK carbon dioxide emissions[20]. Decarbonising building and industrial heating is therefore essential to meet net zero by 2050.

NOTES

15 EVB, *H_2istory in Lower Saxony*, 2022

16 ONS, *The decoupling of economic growth from carbon emissions: UK evidence*, October 2019

17 IEA, *Iron and Steel Technology Roadmap*, October 2020

18 For more details see *SSAB: Reinventing the future of steel*

19 BEIS, *2020 UK Greenhouse Gas Emissions, Final Figures*, February 2022

20 BEIS, *2020 UK Greenhouse Gas Emissions, Final Figures*, February 2022

POTENTIAL USES OF HYDROGEN // CONTINUED

Home heating alone accounts for 17% of UK carbon emissions[21]. Electric heat pumps are not suitable for every home. They are ideal for larger and well-insulated homes with an outside space to sit the heat pump a small distance away from the back wall. They normally need hot water storage tanks.

A report by the Energy and Utilities Alliance (EUA) estimated that heat pumps would not be suitable for between 8 to 12 million UK homes (or 37% to 54%) or would only be suitable with extensive and disruptive wall and home insulation[22].

Estimated costs for heat pumps are between £8,000 to £16,000[23]. Including insulation, changing radiators and/or installing underfloor heating could be as much as £26,000[24]. A hydrogen gas boiler plus installation costs around £3,000 and the disruption would be the same as having a new boiler fitted. Boiler makers have set a price promise to sell hydrogen boilers at the same price as natural gas boilers.

Hybrid heating can combine electricity and hydrogen to make heating more cost effective.

Gas blending: A recent project, HyDeploy [25], blended natural gas with 20% hydrogen to see if this results in any safety concerns. The pilot has found no differ-ence in process or efficiency and that the blending lowered emissions by 6% [26]. HyDeploy was based at Keele's university cam-pus and in 668 houses, a school, several small businesses and a church in Winlaton in Gateshead.

Show homes in the North of England which are fuelled by 100% hydrogen can still be visited. All gas appliances are changed to hydrogen appliances with the normal blue flame of natural gas burning orange with hydrogen.

Read more on potential uses of hydrogen in **Appendix II.**

NOTES

21 HM Government, *Heat and Buildings Strategy*, October 2021

22 Energy and Utilities Alliance, *Decarbonising Heat in Buildings*, April 2021

23 *Homebuilding & Renovating* is an independent website that helps people find the right home heating solution.

24 Committee on Climate Change, *The costs and benefits of higher standards for new buildings*, February 2019

25 For more details see the *HyDeploy* website

26 Blending 20% hydrogen with natural gas reduces carbon emissions by 6% (rather than 20%) because Hydrogen is less energy dense by volume than natural gas

THE HYDROGEN DEBATE

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There is a political divide in the UK hydrogen debate between people who believe that climate change can only be tackled by stopping the exploration and use of fossil fuels altogether, and people who want a 'try-everything' approach to achieving net zero[27].

THOSE WHO ARE SCEPTICAL ABOUT HYDROGEN SAY:
1. Climate change is caused by fossil fuels. Current processes to make hydrogen use oil, gas or coal. Hydrogen is merely an industry excuse to continue using them.
2. Money invested in hydrogen should instead go into developing renewables.
3. Manufacturing hydrogen is expensive, inefficient and it is difficult to store and distribute.
4. Hydrogen is new and untested. Safety concerns have not been fully resolved.
5. It is not possible to make the amount of hydrogen needed for it to make a real difference.

THOSE WHO ARE SUPPORTIVE OF HYDROGEN SAY:
1. Hydrogen is not new. It has been manufactured and widely used for decades.
2. Hydrogen can protect British industries and jobs that use gas in critical processes.
3. Hydrogen is complimentary to renewables and can support energy security.
4. Hydrogen can bring everyone on the journey to net zero through consumer choice and affordability.
5. The UK has an opportunity to lead an international industry and export to the world.

27 See also Michael Liebreich's *Clean Hydrogen Ladder*

WHAT THE PUBLIC THINKS

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Public opinion is important for changes that will need public support – especially those that will cost people extra or that will be disruptive for them.

Although concern over the economy rose in 2022, the public still cared about climate change and the environment. YouGov polling from December 2022[28] showed that after the economy (67%), NHS (49%) and immigration (32%), people's greatest concern was climate change (25%). What people mean by 'climate change', though, is varied. While some are worried about unpredictable weather, most people associate it with plastics in the seas and rivers (67%), harmful effects on wildlife (44%) and air pollution (37%)[29].

However, people's concerns do not necessarily translate into a willingness or ability to pay extra for climate-friendly options. Polling carried out for the Decarbonised Gas Alliance[30] (in 2019, before the rise in inflation and increased living costs) showed that only 25% of people would pay more than 5% of their income towards tackling climate change (37% said they would pay nothing and 38% said they would pay up to 5%).

Cost is therefore a major concern and yet the transition to net zero demands significant changes to people's behaviours and budgets.

Figure 4:

Public opinion issues tracker from YouGov December 2022.

ISSUE	YouGov 2022
Economy	67%
NHS/Health	49%
Immigration and asylum	32%
Climate change/environment	25%
Crime	23%

28 YouGov, *The most important issues facing the country*, December 2022

29 Decarbonised Gas Alliance, *Getting Net Zero Done*, May 2019

30 Decarbonised Gas Alliance, *Getting Net Zero Done*, May 2019

WHAT THE PUBLIC THINKS // CONTINUED

Another issue raised by the BEIS Public Attitudes Tracker[31] showed that knowledge levels of new technologies were equally important, and that unfamiliar heating systems were less popular than the ones that people knew about.

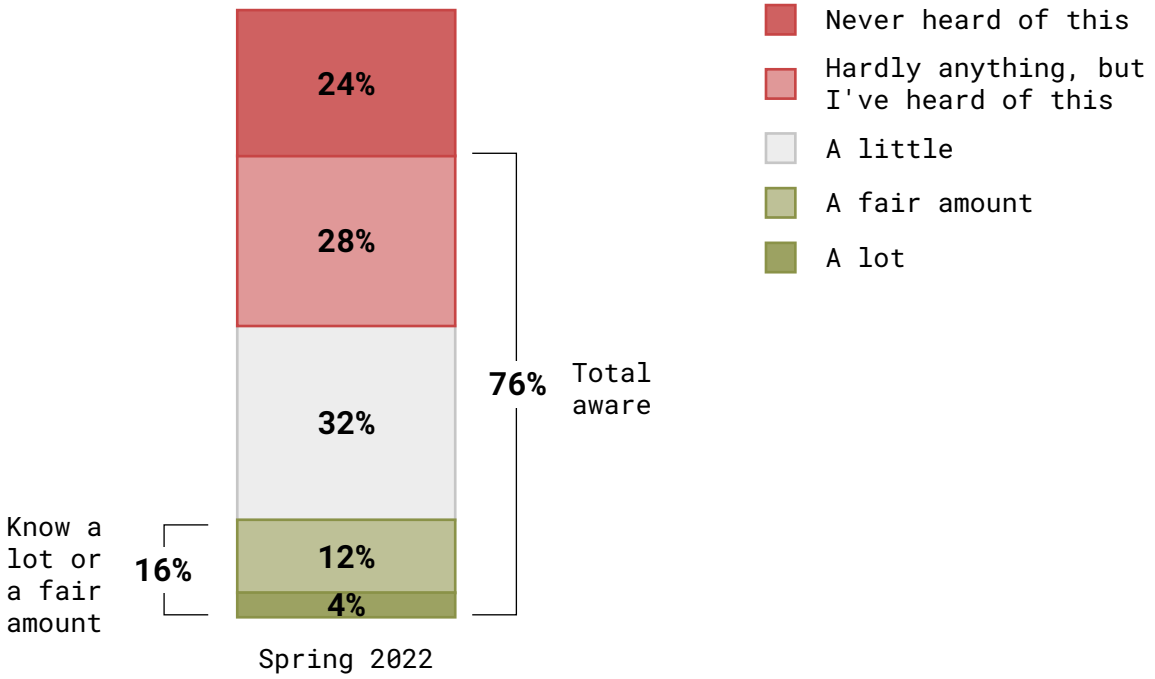
While 76% of people were aware of hydrogen, knowledge levels were very low with 84% of people knowing 'nothing' or 'very little' about it. Information levels about heat pumps are high (at around 70%) and low for hydrogen boilers (40%). See Figure 5.

The trade-offs presented to people in the BEIS Public Attitudes Tracker were not between hydrogen boilers and heat pumps but rather between heat pumps, hydrogen boilers or people's current heating system. 38% said they were unlikely to invest in low-carbon heating systems while 16% said they were likely to. The reasons given for not doing so were cost and disruption.

Read more about public opinion in **Appendix III**.

Figure 5:

Awareness of hydrogen used as a fuel (Spring 2022)



Source: BEIS Public Attitudes Tracker. Totals may not match underlying figures due to rounding.

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31 BEIS, *Energy Infrastructure and Energy Sources*, December 2022

CHALLENGES AND OPTIONS

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COST AND SCALE:

Blue hydrogen needs carbon capture and storage to make it low carbon. Green hydrogen needs electrolysers and renewable electricity. Pink hydrogen needs nuclear power. As with electrification, to make hydrogen happen means significant investment in infrastructure.

Costs are estimated to fall over time. The International Energy Agency (IEA) in their Global Hydrogen Review 2022[32] forecast that the cost of producing green hydrogen could drop by 80% by 2030 from around $5 per kilogram today to $1 per kg in the future, as electrolysers go into mass production. By comparison, grey hydrogen can be made for less than $1 per kg. However, such low costs are likely to be more difficult to achieve in the UK.

OPTIONS:

1. Using wind and solar power from farms that cannot yet connect to the power grid.

2. At the moment, renewable electricity companies are paid not to produce when there is an excess of electricity which cannot be fed into the grid (**constraint payments**) when it is full. This electricity could instead be used to make green hydrogen and either stored or blended into the gas network.

3. Making blue hydrogen from natural gas using carbon capture and storage in the transition to green hydrogen.

4. Siting hydrogen production in industrial clusters to share infrastructure and reduce costs.

STORAGE AND DISTRIBUTION:

Hydrogen can be stored and distributed as a gas or as liquid. Storage and distribution are challenging but not impossible.

OPTIONS:

1. Storage in depleted oil and gas fields or naturally-occurring underground **salt caverns** or tanks.

2. Distribution by pipeline. 80% of the UK's current local has distribution pipes are hydrogen-ready. 100% of these distribution pipes in the **iron mains replacement programme** are due to be converted by 2032[33].

3. Transmission by pipeline. The UK's 7,600km of high-pressure pipes (the **National Transmission System**) are undergoing assessment and testing to be repurposed to hydrogen as part of Project Union led by National Gas.

4. Liquid hydrogen can be transported in ships and HGVs.

32 International Energy Agency, *Global Hydrogen Review 2022*, September 2022

33 House of Lords Debate, *BEIS Written Answers, UIN HL8286*, 2 October 2020

Words in green are defined in the glossary.

CHALLENGES AND OPTIONS // CONTINUED

PUBLIC OPINION AND POLITICS:

Changing heating systems is a matter of cost and disruption but introducing unfamiliar technology into people's homes means ensuring that the safety case has been made.

OPTIONS:

1. Raising information levels and explaining trade-offs.

2. Developing hydrogen for home heating leaves open the option for less expensive and less disruptive hydrogen boilers rather than heat pumps in the future, when natural gas boilers may no longer be available.

3. From 2025, new homes will not be allowed to have gas boilers[34]. This policy position might need revisiting for hydrogen heating.

4. Government is consulting on mandating hydrogen-ready boilers – a **no-regret option**.

5. To ensure that the public is supportive of changing to decarbonised home heating systems, it will be important to give people a choice – whether that's heat pumps, hydrogen boilers, district heating or other options.

OVERCOMING INEFFICIENCIES:

There is a debate about efficiency and cost when hydrogen production and use are compared with electricity but this debate needs to be put into a wider context.

Hydrogen, especially in home heating, may be a more affordable option for low-income households or those where heat pumps are not appropriate. There are also trade-offs to be considered when looking at the amount of new cabling needed for wider electrification and access to enough electricity. Hydrogen at least provides more options for decarbonisation.

Read more on challenges and options in **Appendix IV**.

NOTES

34 National Grid, '*The future of home heating in a net zero UK*', January 2020

GLOSSARY

Abatement	In a climate change context, 'abatement' is usually used to refer to reductions in greenhouse gas emissions.
Aquifers	An aquifer is created when water fills up in rocks that can hold water. The water often travels to wells or springs.
Autothermal reforming (ATR)	Autothermal reforming is similar to steam-methane reforming in that it uses heat to split hydrogen from methane but with ATR, purified oxygen is also used. See also steam-methane reforming.
Baseload	Baseload electricity is the minimum electricity needed at any given time. Nuclear provides constant baseload electricity.
BECCS	Bioenergy with carbon capture and storage. Bioenergy is electricity and gas generated from organic matter (or biomass) like plants or food waste.
Blending	In a hydrogen context, blending is putting hydrogen into the/a natural gas network. Most recently, a pilot project HyDeploy was carried out to blend 20% hydrogen (by volume) in with natural gas in a small, self-contained distribution network.
Blue hydrogen	Low-carbon emitting, this is hydrogen manufactured from coal or gas but with the carbon dioxide captured and stored.
Carbon budgets	Carbon budgets are the amount of greenhouse gases that the UK can emit year-by-year over a five-year period. They are intended to be the maximum amount of permitted emissions if the UK is to reach net zero by 2050.
Carbon capture and storage (CCS)	In a process that emits carbon dioxide, the carbon dioxide is captured, transported and then stored either in underground salt caverns, aquifers or depleted oil and gas wells.
Carbon capture usage and storage (CCUS)	This is where the carbon dioxide is either stored or re-used, for example in greenhouses to help plant growth, fertilisers, for use in abattoirs, or for gas in fizzy drinks.
Carbon leakage	Carbon leakage is when a company moves their production from a country with strict regulations to a country that is more lenient – which then leads to an increase in greenhouse gas emissions.
Clusters	The UK has six industrial clusters where energy-intensive industries work in large industrial zones and take advantage of supporting infrastructure. The clusters are heavy carbon-emitters so the UK is looking to decarbonise the clusters.

NOTES

GLOSSARY

NOTES

Combustion	Combustion is the process of burning fuel to release its energy and drive processes – like in industry or a car. Combustion is the process of combining fuel with oxygen that produces heat and light.
Constraint payments	Payments to wind companies to reduce or stop wind generation at times when there is not the demand on the electricity grid to accept the supply.
Cryogenic	Cryogenic means ultra-cold from -150^{o}C to absolute zero (-273^{o}C). Hydrogen turns to liquid at -253^{o}C.
Decarbonisation	The reduction or removal of greenhouse gases from a process or sector.
Dispatchable energy	'Dispatchable' usually refers to electricity generation which can be used when needed, that is electricity that can be turned on or off depending on the demands of the grid. Coal or gas are dispatchable. Wind and solar are not dispatchable. They are intermittent.
District heating	A local source of heat (a power station or industry) uses its heat by-product to heat water (or steam) which is pumped to a local district on a heat loop to use for room and water heating. The water gets heated in a heat exchanger. The cold water, once it has been used for heating, is then pumped back and reheated.
Electrolysis	A process to produce hydrogen by which electricity is passed through water to split hydrogen from oxygen.
Embodied (or embedded) emissions	Emissions are usually calculated against production (how a product is made) rather than consumption (the total emissions of a product by the time it reaches its end-point). So the emissions from steel produced in the UK are calculated against the steelworks. If steel is produced in China, for example, then the embodied (or embedded) emissions would also include emissions during transportation.
Energy trilemma	All energy is measured for affordability, ease of access (for example, do we have to buy from a hostile power or is it too far underground?), and its impact on the climate. An energy source that has all three elements, ie one that is cheap, easy to access and store and that does not have a negative impact on the climate, has yet to be found.
Feedstock	Feedstock is the raw material to supply or fuel a machine or industrial process.

GLOSSARY

Fugitive emissions	These are emissions which escape during an industrial process because of a leak or accident. They are unintentional emissions.
Gas Distribution Networks (GDNs)	When the Gas Board was privatised, the production and wholesale side was split from the distribution side of the business – the gas pipelines that carried gas to residential, industrial or business users. There are four gas distribution networks (often called GDNs) covering different countries and regions in the UK: Cadent, Northern Gas Networks, Wales & West Utilities, and SGN.
Green hydrogen	Zero-carbon emitting, this is hydrogen manufactured from water using renewable electricity.
Greenhouse gases	The Kyoto Protocol with their 2020 percentage figures for the UK in brackets: Carbon dioxide (79%), methane (13%), nitrous oxide (5%). F, fluorinated or F-gasses (3%) include hydrofluorocarbon, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride. As carbon dioxide is the most abundant greenhouse gas, greenhouse gases collectively are often referred to as carbon emissions.
Grey hydrogen	High-carbon emitting, this is hydrogen manufactured from coal or gas with carbon dioxide vented into the atmosphere.
Hydrocarbons	Hydrocarbons are often referred to as fossil fuels and are chemical compounds made up of hydrogen and carbon. They include crude oil, natural gas and coal.
Hydrogen fuel cell	Hydrogen is stored in a tank and converted when needed into electricity in the fuel cell.
Intermittent energy	Intermittent energy, in this case electricity is energy that is not continuously available or cannot be turned on and off at will because it depends on factors that cannot be controlled. Turbines need wind and solar panels need daylight and sunshine. Electricity that can be turned on and off at will is called dispatchable.
Iron Mains Replacement Programme	The Iron Mains Replacement Programme was started in 2002 and was intended to replace replace all iron gas pipes in the programme with polyethylene up to 30m within a property. Polyethylene is a strong plastic that can carry 100% hydrogen. 80% of the gas pipe network has been replaced and is due for completion in 2032.

NOTES

GLOSSARY

Levelised costs	The levelised costs look at the lifetime total upfront and running costs of a particular technology and divide them over the number of units of energy produced in that time. The levelised costs of energy are an important measurement that allows comparison of costs of different energy sources. LCOE is the Levelled Cost Of Electricity.
Low-regret v no-regret options	A no-regret option adds no extra cost or disruption to a process. Manufacturing hydrogen-ready boilers to replace natural gas boilers is a no-regret option because it wouldn't make any difference even if the boiler never burned hydrogen. A low-regret option is one where a relatively low cost action could reap large benefits in the future.
MtCO2	Million tonnes of carbon dioxide is used as measure to compare different emissions.
Mtoe	Million tonnes of oil equivalent is used as a measure to compare different energy sources.
Natural Gas	Natural gas is mainly methane.
National Transmission System	The network of over 7,000km of high-pressure gas pipelines that act as a backbone of the UK's gas network, connecting gas terminals on the coast to power stations, large industrial users, the Gas Distribution Networks and the interconnectors to Europe and the island of Ireland.
Net zero	Net zero refers to greenhouse gas emissions. The UK has legislated that all processes will either stop emitting greenhouse gases or that their emissions will be offset, for example, by planting trees to absorb carbon by 2050.
Offshoring	In an energy and climate change context, offshoring usually refers to industries and industrial processes that close in the UK and reopen in another part of the world. Usually the product is then imported to the UK but now with additional carbon emissions from transport.
Onshoring	This is the opposite of offshoring and is when industry closes in another part of the world and opens in the UK. Reshoring is when industry, once offshored, returns to the UK.
Pink hydrogen	Zero-carbon emitting, this is hydrogen manufactured from nuclear electricity.
Polyethylene	Often abbreviated to polythene, it is the most widely-used plastic in the world.

NOTES

GLOSSARY

Power	Power is the rate at which work is done or electrical energy is transferred by an electric circuit.
Primary energy	The energy that is directly used before it has been made into something else. Oil, natural gas, coal, biomass, wind, solar, nuclear and geothermic energy are all primary, but when, for example, gas is used to generate electricity, that electricity is secondary energy.
Salt caverns	Naturally-occurring or man-made underground caves which come from the leaching of water of underground salt reserves.
Steam-methane reforming	A process to produce hydrogen by which methane (natural gas) is heated with steam under pressure to split hydrogen from carbon dioxide. See also autothermal reforming.
Sustainable Aviation Fuel (SAF)	Sustainable Aviation Fuel uses fuel generated from waste to replace jet fuel. This waste usually comes from recycled cooking oil and animal fat but can also be waste textiles, food waste, paper or packaging.
Territorial (or inland) emissions	These are emissions which happen within a country. They do not include shipping or aviation.
Town Gas	Town Gas was used to heat and light UK homes until the 1960s. It was made from coal and contained about 50% hydrogen.
Value chains v supply chains	A supply chain is the series of steps that are taken to get a product from the manufacturer to the consumer. A value chain is the process by which a business receives the raw material and adds value to it by working it (in manufacturing processes, for example) to create a new finished product which is then sent through the supply chain to its consumer.

NOTES

APPENDIX I

NOTES

FURTHER READING

Direct links to all of the following documents and information are available on the Palace Yard website, www.palaceyard.co.uk/hydrogen-in-greater-depth.

Digest of UK Energy Statistics (BEIS, 2022) BEIS publishes its Digest of UK Energy Statistics (called DUKES) every year (usually at the end of July). These statistics are updated every quarter and form the most referenced statistics on energy in the UK.

Future Energy Scenarios (National Grid, 2022) FES are widely-respected models, updated annually, which look at options for energy as well as the consequences of pursuing certain courses of action over others to achieve net zero by 2050.

Hydrogen in a low-carbon economy (Climate Change Committee, 22 November 2018) Assesses whether hydrogen is a credible option to help decarbonise the UK energy system.

UK Hydrogen Strategy (BEIS, August 2021) The strategy sets out the UK Government's approach to developing a thriving low-carbon hydrogen sector by 2030. The page includes hydrogen strategy updates to the market.

British Energy Security Strategy (BEIS, 7 April 2022) The strategy came eight months after the Hydrogen Strategy and doubled the Government's target figure for hydrogen production capacity by 2030, from 5GW to 10GW.

Hydrogen Sector Development Action Plan (BEIS 20 July 2022) Following the Hydrogen Strategy and the Energy Security Strategy, the action plan outlines the nature and scale of opportunities focusing on four key areas: investment; supply chains; jobs and skills; and exports.

Decarbonising heat in homes (BEIS Select Committee, January 2022) The report includes hydrogen heating as an option alongside heat pumps and heat networks.

The role of hydrogen in achieving Net Zero (Science and Technology Select Committee, December 2022) Assesses the suitability of the Government's plans for encouraging the growth of low-carbon hydrogen and their current progress.

Hydrogen (International Energy Agency, September 2022) An analysis of progress at an international level in using hydrogen to meet decarbonisation goals.

Hydrogen Demand (Fuel Cells and Hydrogen Observatory, 2021) Data on the current hydrogen demand landscape in Europe by type of industrial end use application.

APPENDIX I

NOTES

Accelerating a UK hydrogen economy (Catapult Network , 2022) Paper summarising the potential role of hydrogen within net zero, current activity.

Path to hydrogen competitiveness: A cost perspective (Hydrogen Council, January 2020) The report provides evidence for cost competitiveness for 40 hydrogen technologies used in 35 applications, to help policy-makers decide what financial and non-financial support needs to be given to hydrogen.

Fugitive hydrogen emissions in a future hydrogen economy (BEIS, April 2022) The study investigates and quantifies the current understanding of potential hydrogen emissions in the different sectors across a future hydrogen value-chain.

How the UK's hydrogen sector can help support the UK's economic recovery (Hydrogen APPG, May 2020) Sets out 15 recommendations to support and accelerate the growth of the UK's hydrogen sector.

ORGANISATIONS

Hydrogen Economy Innovation Network: a non-competitive advisory group to pool knowledge from existing hydrogen projects. See www.ktn-uk.org/energy/hydrogen

Hydrogen Council: a global organisation of CEOs of companies with an interest in developing hydrogen. See www.hydrogencouncil.com/en/about-the-council

Hello Hydrogen: an industry campaign to promote hydrogen heating in the home as a low- or zero-carbon option. See www.hellohydrogen.com

Hydrogen APPG: cross-party group of parliamentarians seeking to learn more about hydrogen and produce reports. See www.connectpa.co.uk/appg-hydrogen

Hydrogen UK: trade association for the industry developing hydrogen – from gas distribution networks to boiler makers. See www.hydrogen-uk.org

Energy and Utilities Alliance: a trade association that represents the gas-users industry, specifically appliance makers. See www.eua.org.uk/about

Energy Networks Association: a trade association that represents the companies which operate the electricity wires, gas pipes and energy system in the UK and Ireland. See https://www.energynetworks.org/about-ena/

APPENDIX II

HYDROGEN IN USE

The Government's UK Hydrogen Strategy[35] states:

Hydrogen is one of a handful of new, low carbon solutions that will be critical for the UK's transition to net zero.

Low carbon hydrogen will be essential for achieving net zero, and ahead of that, meeting our world-leading CB6 target to reduce emissions 78 per cent on 1990 levels by 2035.

The size of the hydrogen economy in 2050 will depend on a number of factors – including

- *the cost and availability of hydrogen and hydrogen-using technology relative to alternatives, such as electrification, biomass and use of CCUS.*
- *Hydrogen can only be considered as a decarbonisation option if it is readily available, at the right price, the right volume and with sufficient confidence it is low carbon.*

HYDROGEN IN TRANSPORT: Transport is a sector that has proven difficult to decarbonise and where hydrogen could play a significant role in reducing and eliminating greenhouse gas emissions. Vehicle emissions have only reduced 5% since 1990 and still produce 27% of UK carbon emissions[36].

Hydrogen is a proven alternative to petrol and diesel combustion engines. Toyota[37] produced the world's first production hydrogen-powered car in 2014, while INEOS[38] is also developing plans for hydrogen fuel cell vehicles.

Germany, South Korea, Japan and the US are ahead of the UK[39] in the use of hydrogen for transport with a total of nearly 26,000 hydrogen-powered cars and 5,600 hydrogen buses.

AVIATION: The JetZero Council[40] is a Government and industry initiative which aims for 10% **sustainable aviation fuel** in the UK by 2030 and zero- emissions transatlantic flights within a generation. Airbus are developing a ZEROe[41] plane with the ambition of having the first zero-emission commercial flights ready by 2035.

NOTES

35 HM Government, *UK Hydrogen Strategy*, August 2021

36 BEIS, *2020 UK Greenhouse Gas Emissions, Final Figures*, February 2022

37 Toyota, *Hydrogen*, retrieved 10 January 2023

38 Ineos, *How Ineos will help drive the hydrogen revolution*, retrieved 10 January 2023

39 Statista, *Number of hydrogen-fueled road vehicles worldwide as of 2020, by type*, February 2022

40 HM Government, *Jet Zero Council*, retrieved 10 January 2023

41 Airbus, *ZEROe: Towards the world's first zero-emission commercial aircraft*, retrieved 10 January 2023

APPENDIX II

SHIPPING: The shipping advisor DNV has brought together 26 of its members to develop the MarHySafe[42] project and produced a handbook for safe hydrogen operations in shipping.

HEAVY GOODS: Johnson Matthey[43] are producers of low- and zero-carbon technologies as well as developing fuel cells for HGVs.

BUSES: Wrightbus[44] are already making fleets of green hydrogen buses some of which are part of the zero-carbon London bus fleet.

RAIL: The University of Birmingham has developed a hydrogen train called Hydro FLEX[45] with rolling stock solutions provider Porterbrook[46]. They believe that by 2023 they will be able to retrofit current trains to hydrogen.

HYDROGEN IN THE HOME: Industry figures on the level of cost and disruption are contested (depending on whether organisations make and/or sell electricity or gas) but electricity is still around three times more expensive than gas for the consumer[47]. This disparity has become less marked as the war in Ukraine has made gas prices more expensive – a situation that may or may not change over the coming years.

Hydrogen has also been extensively tested for the home in a government-commissioned trial called Hy4Heat[48] to establish if it is technically possible, safe and convenient to replace natural gas with hydrogen in residential and commercial buildings and gas appliances. The H21[49] project led by Northern Gas Networks and Arup found that hydrogen can safely be used[50] for heating and for appliances like cookers in the home.

Now that this trial has been successfully completed, SGN will be rolling out a 100% hydrogen network alongside the existing natural gas network to trial its use with volunteers. There is also a competition[51] underway to test hydrogen in residential homes in Whitby (Cadent) and in Redcar (Northern Gas Networks).

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42 DNV, *DNV and industry consortium publish "Handbook for Hydrogen-fuelled Vessels"*, June 2021
43 Johnson Matthey, *Hydrogen for a cleaner future*, retrieved 10 January 2023
44 Wrightbus, *The world's most efficient double deck electric bus*, retrieved 10 January 2023
45 Railway Technology, *HydroFLEX Hydrogen Train*, June 2019
46 Porterbrook, *HydroFLEX*, retrieved 10 January 2023
47 Bloomberg, *Electricity in the UK won't be cheaper than gas anytime soon*, December
48 *Hy4Heat*, retrieved 10 January 2023
49 *H21*, retrieved 10 January 2023
50 BEIS, *Hy4Heat final progress report*, 2022
51 BEIS, *Enabling the Hydrogen Village trial*, December 2022

Words in green are defined in the glossary.

APPENDIX III

NOTES

PUBLIC OPINION RESEARCH IN MORE DETAIL

PUBLIC ATTITUDES TRACKER (BEIS)

The BEIS Public Attitudes Tracker (PAT)[52] is a quarterly survey that collects data on public awareness, behaviours and attitudes on specific policy areas: net zero and climate change; energy infrastructure and energy sources; heat and energy in the home; energy bills and tariffs. Hydrogen falls under energy infrastructure and energy sources which tracks awareness (but not support) for hydrogen.

DECARBONISED GAS ALLIANCE (DGA)

The Decarbonised Gas Alliance commissioned a survey[53] which looked at hydrogen within a climate change context in 2019, before the Covid lockdowns. Climate change was a top-tier concern for most of the UK population. Even in 2022 when the economy is the greatest concern, a YouGov poll from December 2022 still scores the environment high:

Although climate change is an important issue for most of the UK population, what people mean by climate change is highly varied. A 2019 Decarbonised Gas Alliance survey found:

For most people, 'climate change' is as much about plastics in the ocean, protecting green spaces and wildlife habitat as it is about impact on weather.

Plastics in the seas and rivers ...67%
Destruction of wildlife habitat....40%
Air pollution.....37%

People are most worried about:

Harmful effects on wildlife.....44%
Greater risk of flooding.....38%
Impact on food production.....37%

When net zero is explained to people, there is a lot of support, but people do not think the UK is responsible for global greenhouse gas emissions. They put the responsibility with:

Big developing countries like China.. 22%
Big developed countries like USA..... 15%
Medium-sized countries like the UK... 1%

All the same, people generally like the idea of the UK taking a leadership role.

Britain should take a leading role 57%
Britain should only do as much as other countries.....24%

52 BEIS, *Energy Infrastructure and Energy Sources*, Autumn 2022, December 2022

53 Public First poll for DGA, *Energy policy and climate change*, October 2019

APPENDIX III

Cost is the most important factor when people are making decisions about the environment. When asked how much of their disposable income they would/could lose:

None.....37%
0-5%.....38%

Information about which sectors needed prioritising when it came to decarbonisation and greenhouse gas emissions were skewed towards those areas that impacted people least rather than those sectors that were the highest emitters:

Industry.....39%
Airlines and shipping.....21%
Cars and vans.....11%
Public transport..... 9%
Homes.....5%
Don't know.....16%

The public is most concerned about policy changes that impact them and their daily lives. When it comes to changes in heating systems, this goes right to the heart of people's homes. It is therefore vital to understand public attitudes to know which messages are most effectively to encourage people to switch to low-carbon heating options.

Overall, information levels were low about switching to hydrogen home heating. Although none of the following is needed for hydrogen in the home, people thought they would need:

A new tank fitted.....53%
New pipes fitted.....45%
Roads dug up.....37%

In terms of support for hydrogen boilers versus heat pumps, it depended on how the question was phrased. When asked if people were convinced or unconvinced by different arguments, half were persuaded by the idea of blending 20% hydrogen into the gas network with no need to change heating systems:

Convinced 50%
Unconvinced.....7%

When asked about changing to 100% hydrogen with only changing the boiler from gas to hydrogen-ready:

Convinced 40%
Unconvinced.....20%

When compared with heat pumps without mentioning trade-offs or additional information, heat pumps were more popular than hydrogen boilers:

Convinced 57%
Unconvinced.....8%

But when told that heat pumps could not reach such high temperatures, needed bigger radiators and more insulation, they became less popular than hydrogen boilers:

Convinced 36%
Unconvinced.....26%

NOTES

APPENDIX IV

NOTES

CHALLENGES AND OPTIONS IN MORE DETAIL

The Climate Change Committee 2018 report, Hydrogen in a low-carbon economy[54], found that green hydrogen from surplus renewable electricity is unlikely to match the potential scale of demand. They believe that building facilities to make low-carbon hydrogen from natural gas (with carbon capture and storage) would be more cost effective and would help scale the industry.

Low- and zero-carbon hydrogen is in its infancy so in a mature market, prices would be reduced in lower **constraint payments** (where the National Grid pays renewable electricity generators not to produce electricity). A Royal Academy of Engineering report[55], has modelled that with a scale-up of production and declining cost of renewable electricity generation, the cost of green hydrogen could drop as much as 75% by 2030.

There are currently three main ways to distribute hydrogen:

Pipeline This is the easiest and least expensive way to move large volumes of hydrogen around but not all of the UK gas pipe network is suitable. Since 2002 the Health and Safety Executive has led the **Iron Mains Replacement Programme**, replacing the UK's ageing 250,000km iron gas distribution network with durable plastic (polyethylene) which would be suitable for hydrogen. 80% has already been converted and the replacement is due to be completed by 2032[56].

COMPRESSED HYDROGEN IN TANKS

Transported by lorries, rail or ship, this mode of distribution is expensive.

LIQUIFIED HYDROGEN

Hydrogen is cooled to -253°C and pressurised. This is a good way to transport hydrogen over long distances by HGV, rail or ship.

54 Climate Change Committee, *Hydrogen in a low-carbon economy*, 2018

55 Royal Academy of Engineering, *The role of hydrogen in a net zero energy system*, September 2022

56 House of Lords Debate, *BEIS Written Answers, UIN HL8286*, 2 October 2020

ABOUT PALACE YARD

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