GAS GOES GREEN

BRITAIN'S HYDROGEN NETWORK PLAN

REPORT

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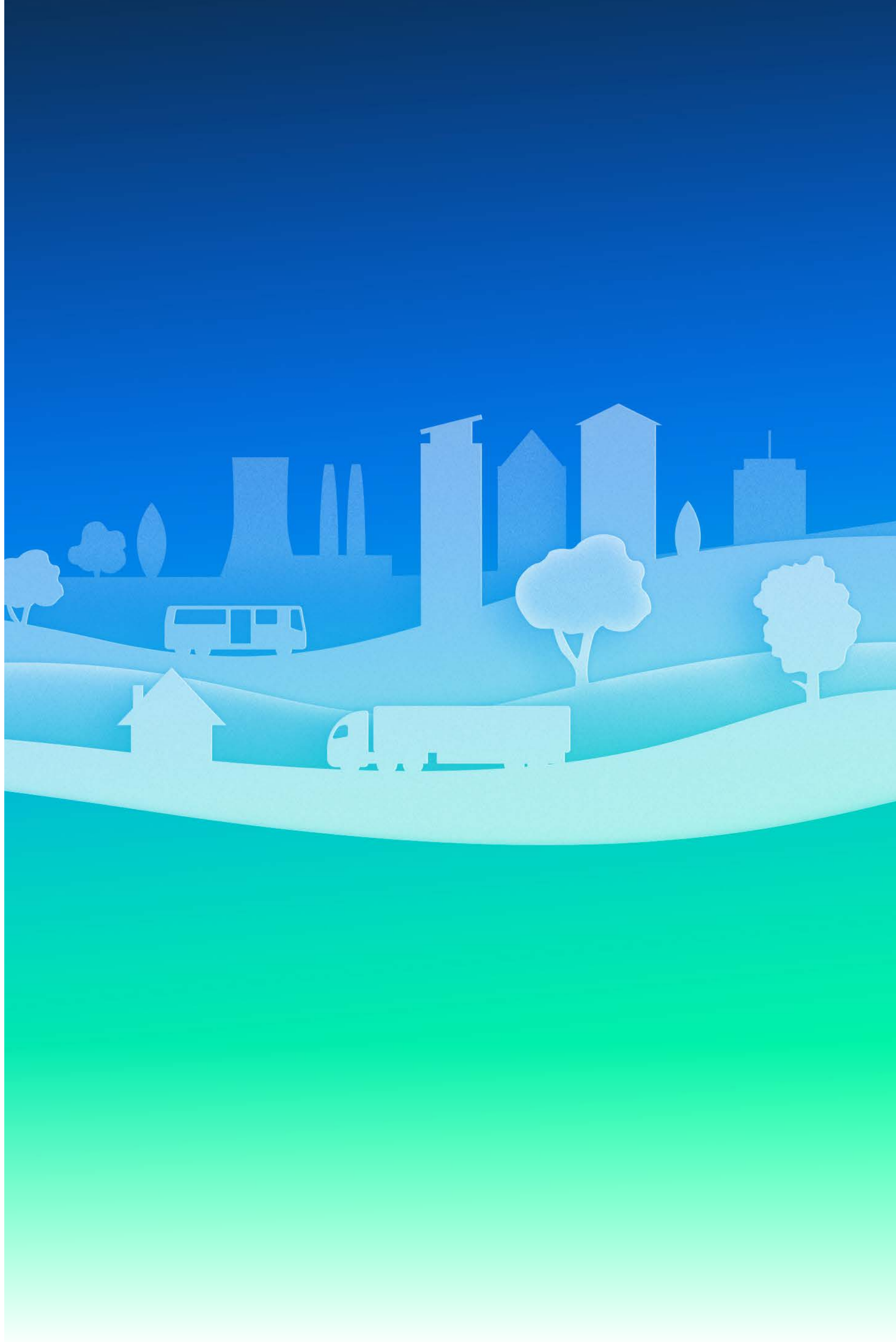
CONTENTS - THE HYDROGEN NETWORK PLAN



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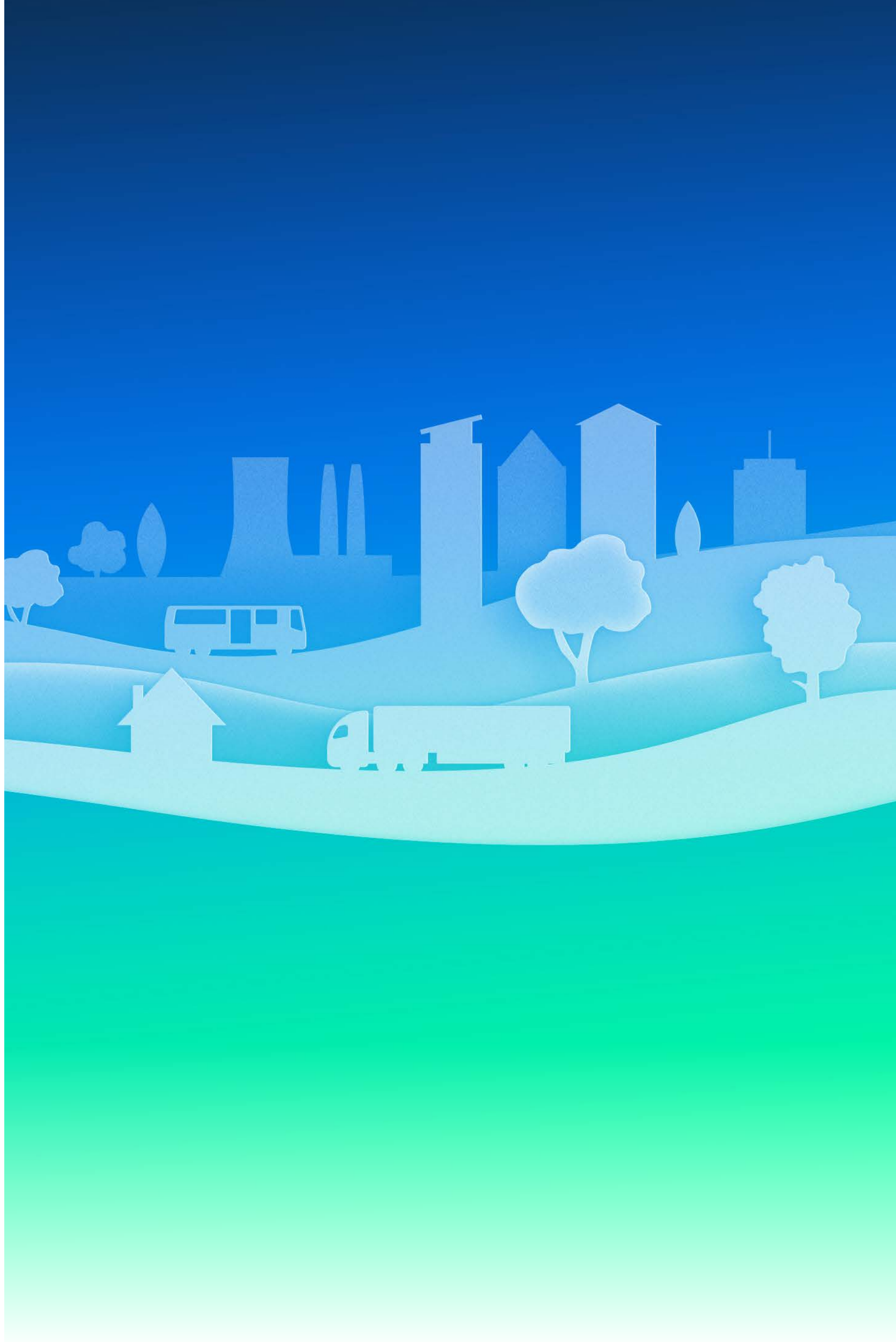

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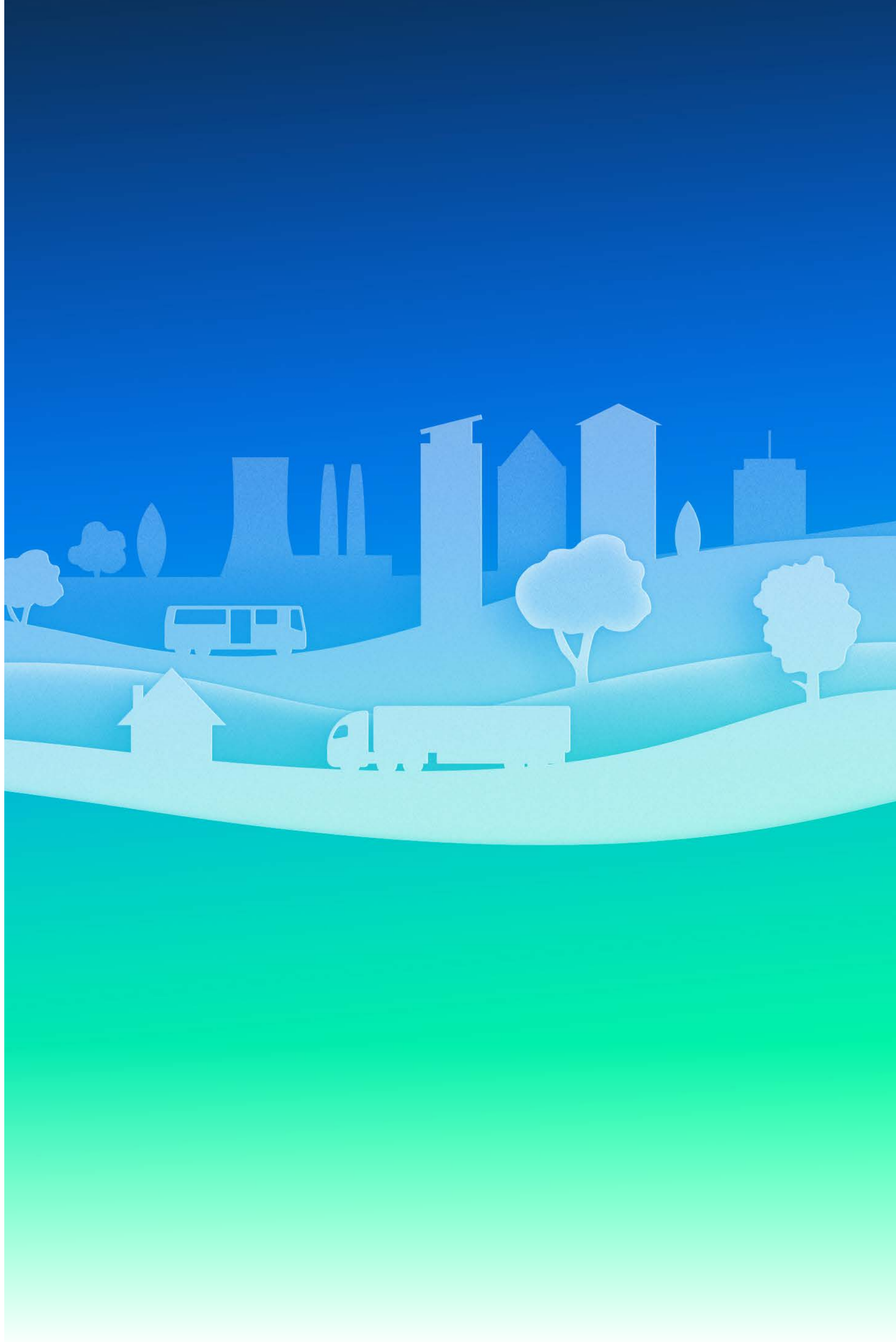

ABOUT

ABOUT ENA

We're the voice of the networks. We're the industry body for the companies which run the UK & Ireland's energy networks, keeping the lights on and gas flowing.

Our members own and operate the wires and pipes which carry electricity and gas into your community, supporting our economy.

The wires and pipes are the arteries of our economy, delivering energy to over 30 million homes and businesses across the UK and Ireland. To do this safely and reliably, the businesses which run the networks employ 45,000 people and have spent and invested over £60 billion in the last eight years.

We're creating the world's first zero-carbon gas grid by speeding up the switch from natural gas to hydrogen for the 85% of UK households connected to the gas grid.

Gas Goes Green, an ENA programme, is our plan to deliver net-zero emissions in the most cost-effective and least disruptive way possible. It is a blueprint for our gas networks to meet the challenges and opportunities of climate change.

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Participating Gas Goes Green members are the gas network companies: Cadent, National Grid Gas, Northern Gas Networks, SGN and Wales & West Utilities.

ABOUT DNV GL

We are the independent expert in risk management and quality assurance. Driven by our purpose, to safeguard life, property and the environment, we empower our customers and their stakeholders with facts and reliable insights so that critical decisions can be made with confidence. As a trusted voice for many of the world's most successful organizations, we use our knowledge to advance safety and performance, set industry benchmarks, and inspire and invent solutions to tackle global transformations.

Since 1864, our Purpose has been to safeguard life, property and the environment.

Our experts work right across the hydrogen value chain, from production through transport to end-use. We understand the technical properties of hydrogen, and work with the networks and a wide range of other organisations to identify the key actions needed to roll-out low carbon hydrogen at scale.

This Hydrogen Network Plan, being delivered by DNV GL, sits within the Gas Goes Green Programme and describes how a viable pathway to 100% hydrogen – alongside other decarbonisation solutions – can be delivered practically.

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FOREWORD

Britain stands on the cusp of a world-leading hydrogen revolution, and one which we are almost uniquely positioned to take advantage of. With an extensive, world-leading gas grid, huge amounts of offshore wind resource and liquid energy markets, there are few other places as well positioned as the UK to lead the international race to build a hydrogen economy.

Published as part of Energy Networks Association's Gas Goes Green programme, *Britain's Hydrogen Network Plan* will play a vital role in delivering the UK's ambitions for hydrogen, as set out in the Prime Minister's *Ten Point Plan For A Green Industrial Revolution.*

This Plan sets out how Britain's gas network companies will enable 100% hydrogen to be transported for use in different sectors of the UK economy. It also identifies the wider actions needed to provide hydrogen production and storage, showing how transitioning the gas networks to hydrogen will allow hydrogen to play a full role in achieving net zero in the hard to decarbonise sectors such as industry, heavy transport and domestic heating, saving an estimated 40 million tonnes of CO2 emissions every year.

All five of Britain's gas network companies, responsible for owning and operating £24bn of critical national energy infrastructure, are committing, through this Plan, to delivering this work. It forms a key part of their ambition to building the world's first zero carbon gas grid, here in the UK.

Britain's Hydrogen Network Plan is founded on four tenets that will underpin the role of Britain's gas network infrastructure in a hydrogen economy. These tenets reflect the breadth and scale of the impact that the transformation of our gas networks will have. They will guide how gas network companies ensure people's safety in a fast moving and changing energy system. They reflect how the companies will maintain security of supply to our homes and businesses, as we move away from the natural gas that has been the bedrock of our energy system for half a century. They will support the public's ability to choose the right technology, so households and businesses can choose the low carbon technologies that are best suited to their needs. And they will deliver jobs and investment, so the transition of our gas networks has a lasting and enduring economic impact in communities across the country.

As we look to the future, the exciting role that hydrogen has to play in delivering a net zero economy is becoming increasingly clear. We look forward to working closely with the customers we serve, the Government and the wider energy industry to turn that ambition into reality.

Chris Train, Energy Networks Association's Gas Goes Green Champion.
December 2020

EXECUTIVE SUMMARY

This detailed and practical plan sets out how Britain's gas network companies will fulfil their commitment to transition the country's gas networks away from delivering natural gas to delivering hydrogen instead. As such, it provides a roadmap for how Britain's five gas network companies will fulfil their commitment to help the UK meet its hydrogen ambitions, including those set out in the Prime Minister's November 2020 Ten Point Plan for a Green Industrial Revolution. That includes how gas network companies will progress to be ready to start blending up to 20% hydrogen into the gas grid by 2023 and how they will help deliver the UK's first 'Hydrogen Town' by 2030.

It shows how this transition will enable Britain to decarbonise 'hard to reach' sectors such as industry, heavy transport and domestic heating, integrating higher volumes of renewable electricity generation and saving an estimated 41 million tonnes of CO_2 a year – eliminating around 12% of the UK's total CO_2 emissions as we move towards net zero.

It sets out the projects that gas networks will, with regulatory approval, carry out to enable 100% hydrogen to be transported for use in different sectors, identifies the wider actions needed to provide sufficient hydrogen production and storage, and highlights the remaining policy gaps that need to be filled.

Conversion of much of the overall gas network to hydrogen is the best way to allow hydrogen to reach all the users who will need it. A full role for hydrogen in decarbonisation is estimated to create 195,000 jobs overall, of which 75,000 jobs and £18 billion of economic value added would be created by 2035, supporting the UK's post-Covid recovery.

The plan meets the need for hydrogen set out in ENA's previous Pathways to Net Zero report. It has been developed following extensive stakeholder consultation, including workshops and interviews, to understand the key barriers and opportunities for different sectors, and the role for gas networks.

This Executive Summary describes our plan to deliver the network elements of a hydrogen transformation. The required capacity of hydrogen is large, and the networks are prepared to transport and deliver it. This Executive Summary has two parts:

PLAN: The projects to deliver the world's first extensive 100% hydrogen network, the wider actions to enable a hydrogen transformation, and the policy gaps that need to be filled.

BENEFITS: Why hydrogen transported through gas networks is needed to reach net zero in the hard-to-decarbonise sectors and the associated emissions reduction and economic benefits.

As we set out below, the task is major, but achievable. But there is no time to waste – ambition must be turned into action at all levels.

Please note that all references are provided in the main report.

DELIVERING BRITAIN'S HYDROGEN NETWORK PLAN

KEY (LEAD NETWORK)

- Others
- Networks
- Regulators
- Governments

	2020-2025 PREPARING FOR TRANSITION	2025-2030 SOLUTION PILOTS	2030-2040 SCALING UP	2040-2050 FULL TRANSITION
SAFETY	Domestic/distribution grid safety case Transmission grid re-purposed or new determination GS (M)R changed to allow H2 blends	UK government heat policy decision New 100% H2 Standard Maintaining a safe H2 network is a business-as-usual activity for gas networks		
SECURITY OF SUPPLY	Network modelling/SO projects H2 production target and H2/CCS business models RAB for H2 storage Industrial clusterFIDs	New H2 pipelines within clusters Sufficient H2 production target Planning application expedited Clusters H2 production- 5GW by 2030 First salt caverns re-purposed for H2	New H2 pipelines within clusters H2 productions connected to networks Clusters H2 productions grows rapidly Other clusters start to convert More H2 storage capacity developed	National H2 networks in place, for H2 cluster and direct network production H2 production grows rapidly with full instrumental roll-out H2 storage at scale, including rough
CUSTOMER FOCUS	Energy content billing 100% H2 domestic trials: Hydrogen Neighbourhood H2-ready appliances mandated Support for hybrid heating RIIO2 sufficiently flexible Compact hybrid boiler technology H2 trucks and buses grow	First 20% blending into gas grid Wider 100% H2 domestic pilots: Hydrogen village and town H2-ready (including hybrid) appliances installed at rate of over 1m a year Gaseous energy bills based on energy content rather than volume, to allow wider range of de-carbonised gases and blends Domestic conversion funding model agreed H2 vehicles grow, inc. first ships First H2 blend in power generation	20% blending into gas grid widened 100% H2 conversion rolled out, for domestic, dispersed industry and transport Fast growth in H2 vehicles for heavy transport, including ships. H2 becomes fuel of choice for part of heavy transport sector, including as input to ammonia and syn fuels H2 use in power generation grows	Significant use of H2 in power
SUPPLY CHAIN	H2 training modules developed Iron mains programme continued until completion H2 transport solutions manufactured at increasing scale	H2 training rolled-out- becomes a business-as-usual gas safety activity H2-ready and H2 (including hybrid) appliances manufactured at scale, for industry and domestic		

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PLAN: DELIVERING A HYDROGEN CONVERSION IN PRACTICE

THE HYDROGEN NETWORK PLAN WILL BE DELIVERED IN FOUR BROAD STAGES:

- Over the next five years, we will be preparing for transition, including continuing the Iron Mains Risk Reduction Programme, completing the safety case, trialling 100% hydrogen in homes, and carrying out network modelling to ensure that security of supply can be maintained. This first stage will give government the information required to make policy decisions on the conversion of networks.

- From 2025-30, we will be carrying out solution pilots, including larger 100% hydrogen domestic pilots; 20% blending in parts of the network; and billing on the basis of energy content rather than volume. The iron mains replacement programme will also continue.

- In the 2030s, we will scale up, building new using hydrogen pipelines between industrial clusters and to connect with storage facilities; connecting hydrogen production to the networks; and, with the iron mains replacement programme completed, rolling out 100% hydrogen conversion for use in homes, dispersed industry and transport.

- In the 2040s, the full transition will occur, with a national hydrogen network in place and hydrogen a normal part of training for Gas Safe engineers.

TENETS

To deliver a 100% hydrogen network, our plan has four key tenets:

SAFETY

Ensuring people's safety: Working closely with the Health & Safety Executive, our innovation projects are making great progress and results have shown that using hydrogen in the natural gas grid is fundamentally safe. Our safety work is developing the right technology and procedures across the GB system, including:
o End-user appliances, such as domestic boilers and industrial burners;
o The low-pressure distribution network;
o The high-pressure transmission network.

SECURITY

Maintaining security of supply: We will deliver a hydrogen network that meets the same high levels of supply security as today, with very rare unplanned interruptions. This includes ensuring:
o Sufficient physical network capacity and resilience to meet demand peaks;
o Effective System Operation;
o Linkages to sufficient hydrogen production and storage capacity;
o Flexibility to connect new sources at more entry points.

CUSTOMERS

Focussing on people's needs: Our hydrogen network will have a strong customer focus, supporting consumers to decarbonise in a convenient and cost-effective way, including through interim steps to enable rapid decarbonisation, covering:
o Domestic convenience and utility;
o Transport sector convenience and utility;
o Industrial sector convenience and utility;
o Interim steps to reduce emissions rapidly and early, including blending and hybrid heating systems;
o Energy-content billing.

SUPPLY CHAIN

Delivering jobs and investment: We will deliver the supply chain to construct and convert the network needed to allow 100% hydrogen to be introduced on time, which includes:
o Equipment, including appliances and long-lead items;
o Skilled people.

The plan sets out to achieve the hydrogen transformation of the network according to these principles, with the networks having projects planned and underway across the country to deliver this. These projects are detailed in the main report.

WIDER ACTIONS NEEDED

Alongside the preparation of gas networks for hydrogen conversion, a set of wider actions are needed for hydrogen to be adopted at scale. These are outside of the networks' control, although projects are being supported by the gas network operators. Building on the Ten Point Plan, the Government's Hydrogen Strategy needs to support work in several areas, to enable Britain's Hydrogen Network Plan – the wider actions are spelt out in detail in the main report, and the key areas include:

HYDROGEN PRODUCTION:

There must be sufficient hydrogen production for a widespread gas network conversion to take place from 2030, which means that production must be expanded beyond the level that is needed for use within clusters. As explained above, this requires GW-scale capacity additions each year, together with the required low carbon electricity generation and/or natural gas and CCS capacity.

HYDROGEN STORAGE:

Alongside sufficient natural gas storage, hydrogen storage capacity needs to be expanded at the level of several hundred GWh per year from 2025. This cannot be solely at the expense of natural gas storage – inevitably some existing storage facilities will be converted to hydrogen, but other facilities must be newly built, to ensure that the methane network maintains its very high reliability.

CCS:

Ensuring that CCS is developed at scale in several clusters by 2030 is critical to network conversion to hydrogen, as it can deliver more hydrogen more quickly than relying on green hydrogen alone. Over time, green will become the production method of choice, as costs decline rapidly, but in the interim, blue hydrogen can deliver the required scale.

POLICY ACTIONS NEEDED TO DELIVER THIS PLAN

Policy support and decisions from government are required for hydrogen development in all sectors. Significant progress is being made, including ongoing work to develop business models for low carbon hydrogen production, but there are several gaps in policy. These gaps need to be addressed in the forthcoming Hydrogen Strategy to deliver on the commitments made in the Ten Point Plan and to deliver this Network Plan – these are set out in more detail in the main report, and the key points include:

HYDROGEN-READY APPLIANCES:

There is no timetable for mandating hydrogen-ready appliances, which are necessary in order to facilitate a network conversion. The earlier hydrogen-ready appliances are rolled out, the smoother the conversion will be. A mandate needs to be in force by no later than 2025, which would mean that most homes would have hydrogen-ready appliances by 2040.

HYBRIDS:

Hybrid heating systems should be supported now, for roll-out at scale.

HYDROGEN PRODUCTION VOLUMES:

The main risk is that insufficient volumes of hydrogen production are supported. As we set out above, GW-scale production capacity needs to be added each year, and business models need to support this scale. While the Ten Point Plan targets 5 GW of low-carbon hydrogen production capacity by 2030 this needs to be increased to 10 GW to enable this Plan.

STORAGE AND CONVERSION SUPPORT:

There are no business models for hydrogen storage or for network conversion, both of which could be funded through the regulated asset base (RAB) framework. A RAB for hydrogen storage should be in place from 2025, and for domestic conversion from 2030.

FLEXIBILITY:

The RIIO2 framework needs to be managed in a sufficiently supportive and flexible way to enable the range of innovation projects and trials to be carried out in a timely way.

PLANNING:

The planning system will need to be able to accommodate a large volume of applications for hydrogen production, storage, pipeline and other facilities. It is not clear whether the planning system will be able to manage this in a timely manner. Planning applications should be prioritised and decisions expedited.

DELIVERY

As we have shown in our time line graphic and description above, delivering our Hydrogen Network Plan requires action on the part of networks, government, regulators and others over the coming years.

BENEFITS: THE EMISSIONS REDUCTION AND ECONOMIC BENEFITS

TACKLING THE HARD-TO-DECARBONISE SECTORS

Hydrogen can make a major contribution to meeting net zero in the hard to decarbonise sectors – domestic heating, heavy transport, and industry – where combined emissions are around 180 million tonnes, 40% of the UK total.

Hydrogen can also help accommodate the growth of renewable electricity, with wind and solar power being used to produce hydrogen, and then the hydrogen being used in a power station to produce electricity during periods when wind and solar generation are low, or stored for use in the gas networks.

As set out in the recent ENA Pathways to Net Zero report, a balanced decarbonisation solution that includes a significant role for hydrogen transformation, alongside biogases and electrification, is the most cost-effective way to decarbonise, saving £13 billion a year when compared with a fully electrified alternative.

REACHING ALL POTENTIAL HYDROGEN USERS

The key benefit of gas network conversion to hydrogen is that it is by far the lowest cost and largest scale way of transporting the hydrogen from where it is produced to the dispersed industrial, domestic and transport users who will need it to decarbonise:

Dispersed users: Dispersed industry accounts for over half of industrial emissions, and gas networks will be needed to transport hydrogen to these facilities. BEIS figures show that the UK's six main industrial clusters have combined emissions of around 33 million tonnes of CO2. But overall industrial emissions are more than twice that, at 76.5 million tonnes.

Cost and feasibility: It is simply not possible to put a hydrogen production unit at the end of every street, or beside every commercial or small industrial building, and nor is it feasible to load 236 TWh of hydrogen onto tankers to drive around the country – the larger road tankers can carry 600kg of hydrogen, or about 23 MWh, so around 10 million tanker loads would be needed.

REDUCING EMISSIONS

Based on hydrogen replacing natural gas in buildings, industry and power generation, and replacing oil products in surface transport and shipping, we conservatively estimate that hydrogen will lead to emissions savings of between 30 million and 105 million tonnes of CO2, depending on the level of hydrogen adoption in the various scenarios put forward by the Committee on Climate Change, National Grid and Aurora. For the level of hydrogen use in ENA's Pathways to Net Zero report, around 41 million tonnes of CO2 would be saved – eliminating around 12% of the UK's total CO2 emissions as we move towards net zero. (Our methodology is explained in full in the main body of the report.)

CREATING JOBS AND ECONOMIC GROWTH

The overall job creation benefits from cross-sectoral hydrogen deployment are large, supporting the UK's post-Covid economic recovery and helping the UK to build back better, right across the country:

- Through to 2050, hydrogen and CCS development for broad based decarbonisation could create 43,000 jobs for industrial decarbonisation alone, 195,000 jobs if hydrogen plays a full role in economy-wide decarbonisation, and 221,000 jobs if the UK also becomes a major hydrogen exporter.
- By 2035, a recent analysis by the Hydrogen Task Force estimated that 75,000 jobs could be created overall, together with £18 billion of GVA, from around 125 TWh of hydrogen. This would include 26,600 jobs in hydrogen production alone, with 12,542 jobs in electrolyser manufacturing and 10,482 jobs in auto thermal reforming.

The economic benefits and protection and creation of jobs are most likely to be felt in less affluent parts of the country, where industry and hydrogen production would be concentrated. Overall, energy intensive industry accounts for £140 billion in economic value added and employs over 1.1 million people.

1. OBJECTIVES AND PLAN OVERVIEW

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Britain's Hydrogen Network Plan sets out how the gas network companies will deliver the world's first extensive 100% hydrogen network. It details the changes the gas network will undergo to deliver the Government's ambition on hydrogen, as set out in the Ten Point Plan for a Green Industrial Revolution. Gas networks will:

- Be ready by 2023 to blend hydrogen into the gas distribution gird up to 20% volume.
- Commence a 'neighbourhood trial' of 100% hydrogen by 2023, a large village trial by 2025 and be ready to convert a large town by 2030.
- Accelerate the shift to low carbon vehicles through a network of refuelling facilities for zero emissions HGVs.
- Connect the renewables production, carbon capture and storage and hydrogen use of industrial SuperPlaces, delivering two clusters by the mid-2020s and two more by 2030.
- And support producers to meet the target of 5GW of hydrogen production capacity by 2030, and 1GW by 2025.

Ensuring that homes and businesses across the country can connect to the world's first Net Zero gas network is one of the best ways to achieve a rapid decarbonisation that consumers can afford.

Six key steps on the pathway to achieve such a transformation have been outlined by the networks, and these will be explored further in this report. The plan will also show how a gas network transformation will enable decarbonisation in domestic, industrial and transport applications, and wider use of renewable energy sources. It also sets out the role the gas networks can play in the green recovery, detailing the economic benefits of a green gas grid.

The diagram below covers the key elements of Britain's Hydrogen Network Plan, including the main actions from the networks, governments, regulators and others.

6 KEY STEPS TO A NET ZERO NETWORK

1. PREPARING FOR TRANSITION

- Strategic, technical and policy planning to enable low carbon gases to play a significant role in GB's transition to net zero, while maintaining safe and reliable operation.

2. FACILITATING CONNECTIONS

- More biomethane plants connect to the gas grid.
- Preparations accelerate for first hydrogen projects.

3. EXPANDING SUPPLY

- First hydrogen projects integrated with CCUS and anchored by baseload consumers, likely industry and transport.
- Continuing scale-up of biomethane supply.

4. EXPANDING THE DEMAND BASE

- Hydrogen use extends to commercial and residential consumers near the first cluster projects, initially via low blends (up to 20%) but developing into 100% hydrogen clusters.
- Consumers in other regions continue to receive natural gas, with increasing biomethane.

5. INCREASING LOW CARBON GASES

- Hydrogen clusters spread and connect to become hydrogen zones, enabled by an evolving, National Transmission System (NTS).
- Greater volumes and diversification of low carbon gas supply as more production methods mature technically and economically.

6. 100% LOW CARBON GASES

- Low carbon gases fully integrated across the GB energy system, with distinct regional solutions.

1. OBJECTIVES AND PLAN OVERVIEW

The need for action to achieve tangible progress on the pathway to net zero has never been greater. The gas networks are ready to support the next transformation, to a greener gas supply, ensuring that homes and businesses across the UK can be connected to the world's first Net Zero gas network. This report sets out the gas networks' view on the pathway to hydrogen in the UK.

The diagram on the following page then shows how the four tenets of the Plan are met through network projects. The tenets, which are explained in more detail in Chapter 2, are:

- **Ensuring people's safety;**
- **Maintaining security of supply;**
- **Focussing on people's needs;**
- **Delivering jobs and investment through the supply chain.**

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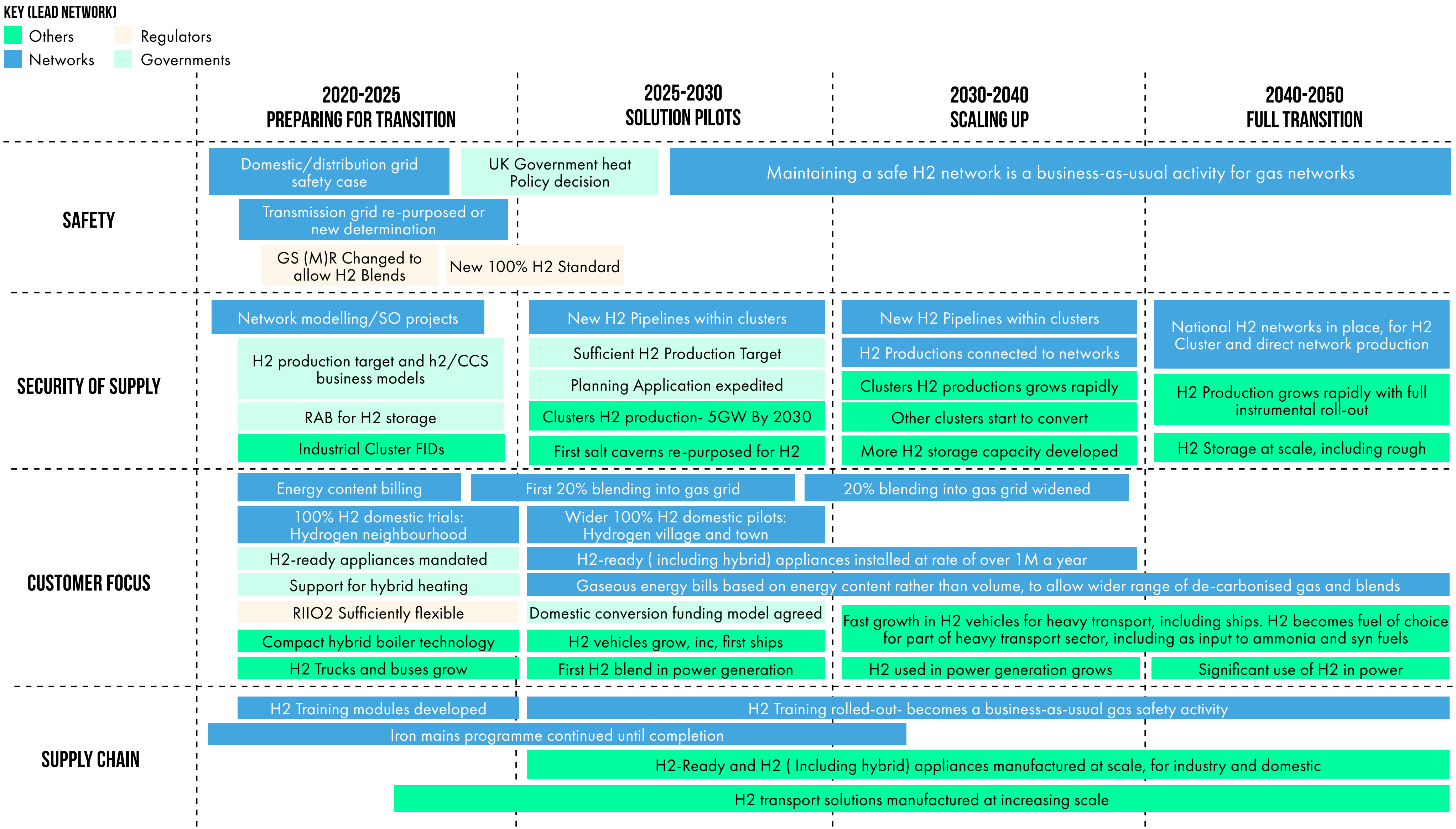
DELIVERING BRITAIN'S HYDROGEN NETWORK PLAN



MEETING BRITAIN'S HYDROGEN NETWORK PLAN TENETS

HOUSEHOLDS | INDUSTRY | POWER | TRANSPORT

SAFETY

- Domestic 100% hydrogen safety case - *Hy4Heat (led by BEIS)*
- Distribution grid 100% hydrogen safety case and other safety studies- H21 and phase 2, H100 FIFE, Network safety and impacts board projects.
- Transmission grid re-purposing safety and feasibility- HyNTS future Grid phase 1

SECURITY OF SUPPLY

- Hydrogen network operation and resilience - transmission modelling. Distribution modelling. System operator transition to Hydrogen
- Market framework for hydrogen - Gas Markets Plan (GMaP)
- New hydrogen networks - Aberdeen vision (new network element) HyNet Homes
- Hydrogen Production directly connected to networks- project Cavendish, H100 Fife, H21 Phase 3 , HyNet homes

CUSTOMER FOCUS

- Cluster Hydrogen - Networks support to industrial cluster projects, including HyNet, zero Carbon Humber, Acorn, Net Zero Teesside, South Wales industrial Cluster and Southampton water
- Domestic use trials: 100% hydrogen Neighbourhood and 100% hydrogen village- H100 Fife. H21 Phase 3, HyNet homes
- Hydrogen de blending for specific customers- De-blending N1A, HyNTS Future Grid Phase 2
- Enabling hydrogen in transport - H2GV, Cadent Gas Transport pathways
- Testing of 20% blending for 2023 start- HyDeploy, HyDeploy2
- Energy content billing to allow blending - future billing, Real Time Networks
- Hybrid Heating and hydrogen - Project Freedom, HyHy, HyCompact

SUPPLY CHAIN

- Mains replacement and readiness for hydrogen, including training- iron mains risk reduction programme, network training programme.
- Entry Connection for decarbonised gas- Entry connection standardisation

Cross- sectoral stakeholder engagement to communicate hydrogen network plan and secure feedback

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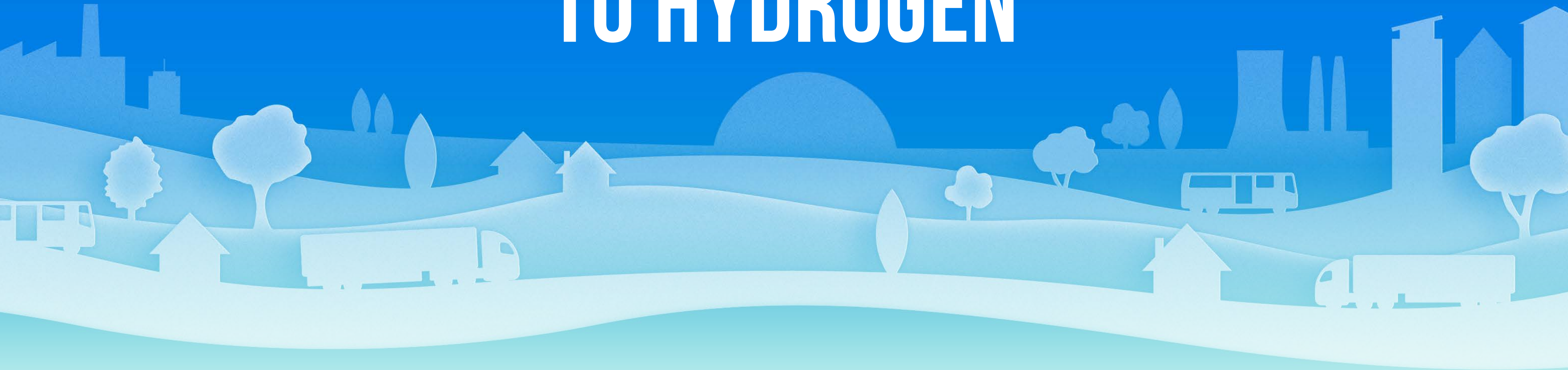
2. TRANSFORMING THE NETWORKS TO HYDROGEN



2. TRANSFORMING THE NETWORKS TO HYDROGEN

Meeting long term targets and near term carbon budgets means taking action now, delivering changes in this decade to set us on the pathway to a greener gas future. The gas networks are ready and able to take the next steps in decarbonising our gaseous energy system.

The Plan follows four steps:

- **2020-25:** Preparing for Transition;
- **2025-30:** Solution Pilots;
- **2030-40:** Scaling Up;
- **2040-50:** Full Transition.

This chapter sets out the overall plan, and the following chapters discuss the implications and benefits for the key sectors which the networks serve. To support the delivery a Net Zero energy system, this plan considers how we can use decarbonised gasses to safely, efficiently and economically replace the role of gas in our energy system today. It recognises the central role gaseous energy plays across the system; the relative cost of energy vectors; and the need to tackle hard-to-decarbonise sectors. Overall, it will save 41 million tonnes of CO2 emissions a year.

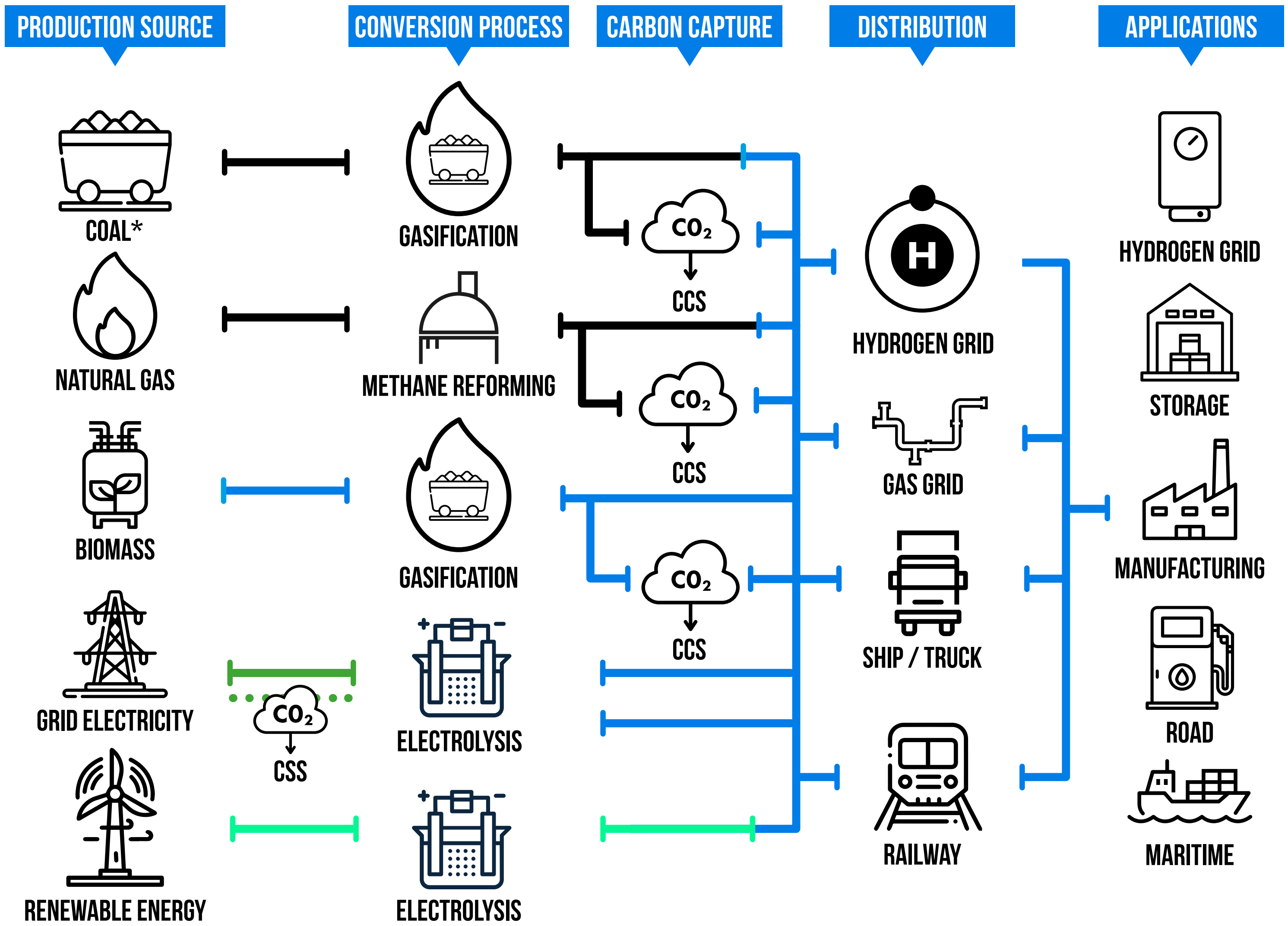
2.1 OVERALL VISION FOR THE NET ZERO GAS NETWORK

The Gas Goes Green vision for a Net Zero gas network is set out in the Pathways to Net Zero report https://tinyurl.com/y34a6dxx, with the gas networks delivering a combination of hydrogen and biomethane in 2050 depending on their location and customer demands. As biomethane is chemically similar to fossil natural gas, this Plan focusses on the changes require for the parts of the network which will be converted to hydrogen.

The diagram to the right summarises for completeness the full range of hydrogen production methods and hydrogen applications.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

KEY:
- Hydrogen from renewables
- Low Cabon gas
- Fossil source no carbon capture
- Unabated grid electricity
- Abated grid electricity



*NB: COAL NOT RELEVANT IN THE UK

2. TRANSFORMING THE NETWORKS TO HYDROGEN

GASEOUS ENERGY IS CRITICAL TO PEOPLE'S LIVES:[1]

- **Domestic:** Gas meets 77% of domestic heating and 65% of total domestic energy use.
- **Services:** Gas meets 63% of heat and 40% of overall energy use.
- **Industry:** Gas meets 59% of heat and 46% of overall energy use.
- **Electricity generation:** Gas is vital to electricity, providing 41% of total power generation.

GASEOUS ENERGY IS LOW COST:

- **Domestic:** Average electricity prices are 16.6 pence per kWh, compared with 3.8 pence per kWh for gas.[2] Households not connected to the gas grid are twice as likely to be fuel poor – in England, 20.4% of households with electricity as their main source were in fuel poverty compared with 10.1% of people who heated their homes with gas.[3]
- **Manufacturing:** The average price of gas for manufacturing is 1.9 pence per kWh, compared with 9.9 pence per kWh for electricity.[4] UK manufacturing has the highest electricity prices in Europe, but amongst the lowest gas prices, maintaining competitiveness.[5]

HYDROGEN CAN HELP TO TACKLE THE HARD-TO-DECARBONISE SECTORS:

Since 1990, the UK has reduced emissions by 43% overall, but this achievement masks very different performances in different sectors:[6]

- **Electricity:** Emissions from generation have fallen by 67% since 1990.
- **Domestic**: Emissions have only fallen by 14% since 1990.
- **Transport:** The sector has seen little reduction, with emissions only falling by 3%, as more efficient engines have been offset by more miles being driven.
- **Industry:** Industrial emissions have fallen, but a large part of this is due to offshoring of manufacturing to other parts of the world. Per capita, the UK is the highest net importer of CO_2 in the world; our net imports from China alone are 80 million tonnes of CO_2 a year.[7]

[1] BEIS, DUKES 2020: Electricity, Table 5.1 https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes; BEIS, Energy Consumption in the UK, 2019, End Use Tables, Table U3 (domestic – heat includes space heating, water heating, and cooking), Table U4 (industry – heat includes high temperature processes, low temperature processes, drying/separation, and space heating), Table U5 (services – heat includes hot water and heating) https://www.gov.uk/government/statistics/energy-consumption-in-the-uk
[2] BEIS, Annual domestic energy bills, Tables 2.2.4 and 2.3.4 https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics
[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829006/Annual_Fuel_Poverty_Statistics_Report_2019__2017_data_.pdf p26
[4] BEIS, Table QEP 3.1.4: Annual prices of fuels purchased by manufacturing industry (p/kWh) https://www.gov.uk/government/statistical-data-sets/prices-of-fuels-purchased-by-manufacturing-industry
[5] BEIS, Quarterly Energy Prices, June 2020, Charts 5.3 and 5.4 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/895143/QEP_Q1_2020.pdf
[6] BEIS, Final UK greenhouse gas emissions national statistics 1990-2018, Table 3 https://data.gov.uk/dataset/9568363e-57e5-4c33-9e00-31dc528fcc5a/final-uk-greenhouse-gas-emissions-national-statistics
[7] Office for National Statistics, October 2019, Figures 11-12 https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/compendium/economicreview/october2019/thedecouplingofeconomicgrowthfromcarbonemissionsukevidence

2. TRANSFORMING THE NETWORKS TO HYDROGEN

2.2 STRUCTURE OF THE GB GAS NETWORKS

The gas networks deliver 900 TWh/year of energy from natural gas. Decarbonisation of this energy vector can be achieved by converting the existing natural gas network infrastructure to hydrogen which burns to produce water and heat with no carbon dioxide.

Over 85% of households in Great Britain choose natural gas for heat – this amounts to about one third of current total gas demand. Industry and power generation use the remaining two thirds, and decarbonisation of these sectors could also be achieved through transition to hydrogen. The gas network pathway to the transport of greener gases must take account of the needs of all consumers.

To transform the network to hydrogen, and recognise the need of the various consumers, it is important to understand the roles of the transmission and distribution systems, as their hydrogen pathways and timescales will be slightly different.

THE ROLE OF THE NATIONAL TRANSMISSION SYSTEM (NTS)

The NTS is the infrastructure that transports natural gas away from the import terminals (such as St Fergus, Bacton, Grain LNG, South Hook, Easington and Dragon LNG) to industry, power generators and domestic consumers. The most efficient way to move gas to consumers is at high pressures and in large diameter pipelines, using compressors at strategic locations to maintain the flows. The NTS currently transports over 97% of the natural gas that flows through the gas distribution networks, the remaining 3% of gas is biomethane which is injected directly into the distribution networks.

THE NATIONAL TRANSMISSION SYSTEM

2. TRANSFORMING THE NETWORKS TO HYDROGEN

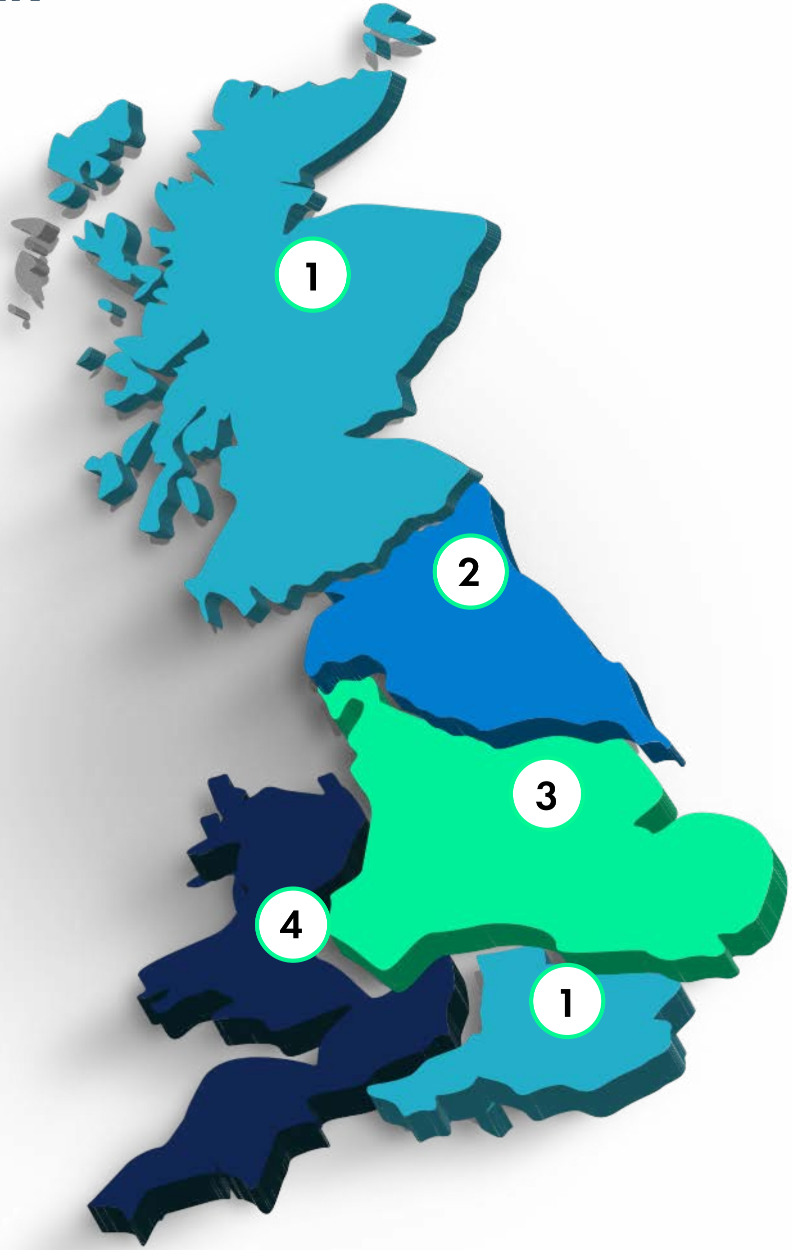
THE ROLE OF THE GAS DISTRIBUTION NETWORKS

The gas distribution networks provide the infrastructure that moves high-pressure gas from the NTS and delivers it to a range of customers. The majority of the original metallic gas distribution mains are being replaced by polyethylene pipes (PE) in the medium and low-pressure networks and by high-density PE in the intermediate pressure network; these PE pipelines are already hydrogen compatible.

GB GAS DISTRIBUTION COMPANIES

The distribution networks transport gas regionally as follows:

1. SGN — SGN supplies all Scotland and South East and South England;
2. Northern Gas Networks — Northern Gas Networks supplies Northern and North East England;
3. Cadent — Cadent supplies East Anglia, East Midlands, West Midlands, North London and North West;
4. Wales & West Utilities — Wales & West Utilities supplies Wales South, Wales North and England in the South West.



2. TRANSFORMING THE NETWORKS TO HYDROGEN

MANAGING TRANSITIONS

Ever since the modern gas industry came into being in the 1960s, the gas networks have evolved to meet the needs of energy consumers. Those transformations took many forms and have required the industry to face and solve several challenges. They included engineering issues, policy and regulatory issues, ownership and organisational issues, and changes to the nature of the gas itself. Today, the industry is looking forward to supporting another transition; that is, to safely and cost effectively transport low-carbon gas to consumers to support the UK's Net zero ambition.

Since 2002, the Iron Mains Risk Reduction Programme (IMRRP) has been delivering the modernisation of the GB gas distribution network. GDNs have already replaced 60,000 km of iron pipelines with polyethylene, representing 62.5% completion of the programme. Polyethylene pipes are fundamentally capable of safely carrying hydrogen.

2.3 DEVELOPING THE PLAN

HYDROGEN APPLICATIONS

To develop this plan, the gas networks have been consulting widely with their customers and broader stakeholders to understand how hydrogen applications and demand will change over the period to 2050. Fundamentally, a 100% hydrogen network will need to:

- Maintain current levels of gas supply security;
- Be funded in a way that continues to be affordable to customers, to minimise fuel poverty and maintain industrial competitiveness;
- Meet net-zero emissions by transporting low- or zero-carbon hydrogen (or biomethane);
- Be demonstrably safe.

As the networks Prepare for Transition in the early 2020s, they will also support near term carbon reductions by connecting hydrogen producers to blend hydrogen in the existing system. The HyDeploy 1 trial is currently injecting up to a 20% blend of hydrogen by volume to 130 homes and faculty buildings at Keele University in Staffordshire. Results show that gas appliances using the blend are functioning normally and householders and campus businesses haven't noticed any differences to their gas supply. The next phase – HyDeploy 2 – will see a 20% blend provided to 670 homes near Gateshead.

In matching customers' expectations for transition, we have developed a programme of work that will demonstrate how networks will make the changes needed to transform to a greener gas infrastructure, moving from delivering natural gas to zero-carbon hydrogen and biomethane.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

HYDROGEN NETWORK PLAN TENETS

To deliver a 100% hydrogen network, our plan has four key tenets:

ENSURING PEOPLE'S SAFETY

Working closely with the Health & Safety Executive, our innovation projects are making great progress and results have shown that using hydrogen in the natural gas grid is fundamentally safe.

Our safety work is developing the right technology and procedures across the GB system, including:

- End-user appliances, such as domestic boilers and industrial burners;
- The low-pressure distribution network;
- The high-pressure transmission network.

MAINTAINING SECURITY OF SUPPLY

We will deliver a hydrogen network that meets the same high levels of supply security as today, with very rare unplanned interruptions. This includes ensuring:

- Sufficient physical network capacity and resilience to meet demand peaks;
- Effective System Operation;
- Access to sufficient hydrogen production and storage capacity;
- Flexibility to connect new sources at more entry points.

FOCUSSING ON PEOPLE'S NEEDS

Our hydrogen network will have a strong customer focus, supporting consumers to decarbonise in a convenient and cost-effective way, including through interim steps to enable rapid decarbonisation, covering:

- Domestic convenience and utility;
- Transport sector convenience and utility;
- Industrial sector convenience and utility;
- Interim steps to reduce emissions rapidly and early, including blending and hybrid heating systems;
- Energy-content billing.

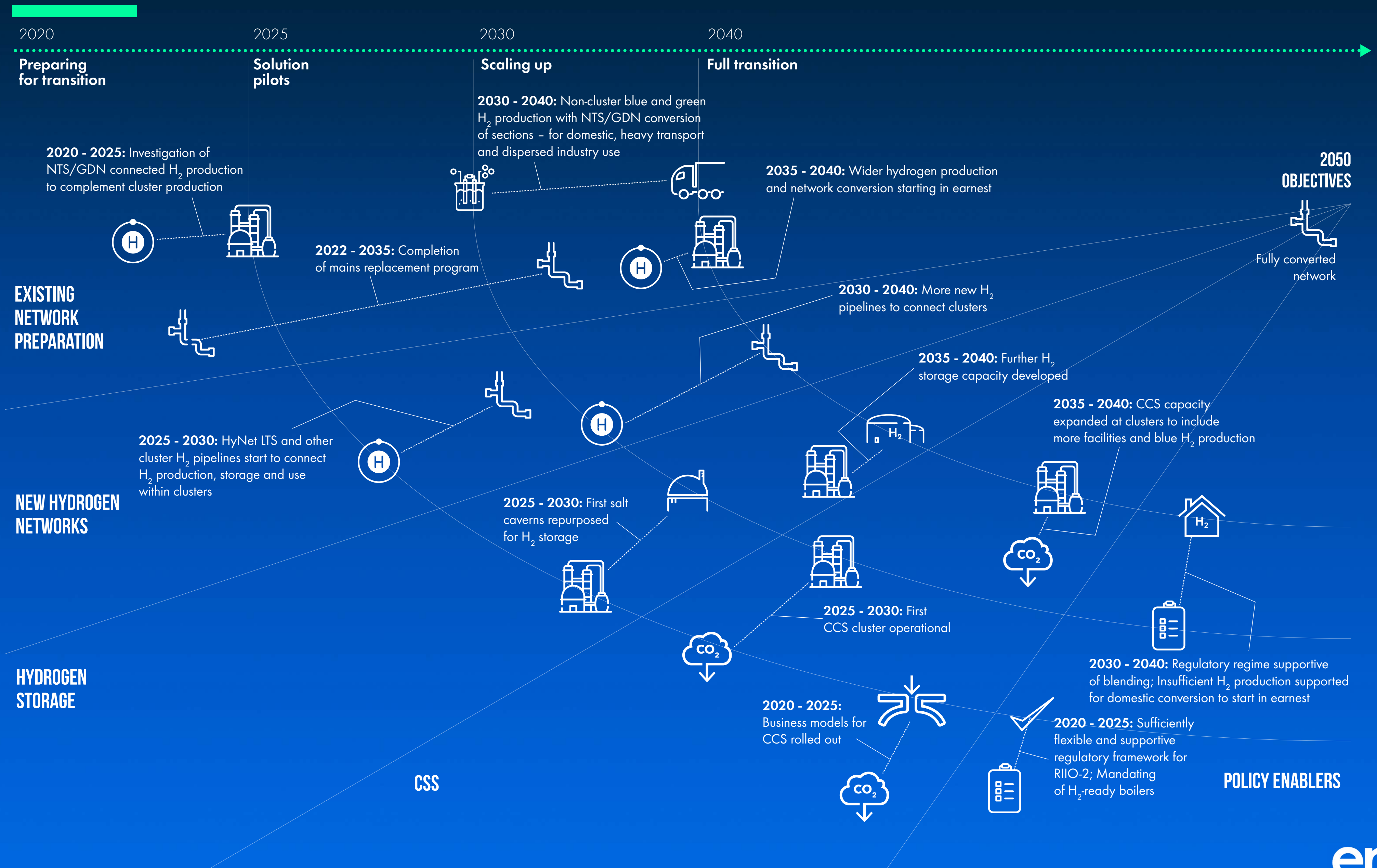
DELIVERING JOBS AND INVESTMENT

We will deliver the supply chain to construct and convert the network needed to allow 100% hydrogen to be introduced on time, which includes:

- Equipment, including appliances and long-lead items;
- Skilled people.

The T-Map on the next page shows how the networks plan to deliver these objectives in parallel between now and 2050. The sections following the T-Map describe the actions that will deliver a whole system hydrogen transformation. The actions set out are ambitious but realistic, and are informed by the stakeholder engagement we have undertaken for this project and across the gas networks' planning and innovation activity.

AMBITION TO ACTION FOR THE NETWORKS



2. TRANSFORMING THE NETWORKS TO HYDROGEN

SECTOR DECARBONISATION PATHWAY THROUGH HYDROGEN

For each of the following sections of the plan that outline actions to 2050, we have adopted a common format. The plans are more detailed for the near-term activities as longer term changes will be shaped by preparatory work, technology development and government policy.

We have developed the actions and network projects in the four end-use sectors:

- Domestic conversion
- Heavy transport
- Industry
- Power generation

We then cover four cross-cutting enablers:

- Hydrogen production
- Existing gas network preparation
- New hydrogen networks
- Hydrogen storage

Finally, we have identified the key gaps in policy required to deliver a broad-based hydrogen transformation and help the UK meet its hydrogen ambitions, including those set out in the Prime Minister's November 2020 Ten Point Plan for a Green Industrial Revolution.

2.4 PREPARING FOR TRANSITION – PATHWAY TO 2025

The period to 2025 will be critical to the achievement of net zero in a number of sectors. Solutions deployed now, will enable us to set out on the pathway to decarbonisation, and crucially, be able to present a common vision to consumers in each sector along that pathway. To enable this, we will need clear policies, supportive regulatory regimes, and consumer acceptance, to rapidly develop and deploy end to end hydrogen value chains.

Many elements of the end to end value chain are not currently the responsibility of the regulated gas networks (e.g. hydrogen production and storage) but are critical to its achievement. This has to be secured in a co-ordinated manner, and the gas networks will work with government, regulators, hydrogen producers and customers to deliver the plan. During the period to 2025, it will be essential for policy decisions and investments to be made to enable dedicated hydrogen production and storage facilities to be available in the 2025-2030 timeframe, and for a clear domestic heat policy to be determined.

In order to ensure that the gas networks are ready for the hydrogen pathway and to demonstrate that it can be completed effectively and efficiently, the gas network companies have already been conducting a significant number of projects to demonstrate safety, enable blending and close any knowledge gaps. In this section of the plan, they are proposing a further set of pathway projects over the next five years. This first stage will give government the information required to make policy decisions on the conversion of networks.

These projects are listed in the table below and described in more detail in the relevant sector chapters later in this document. By its nature, gas network conversion to hydrogen will benefit multiple sectors; we have placed projects in the table in their primary benefit category.

GAS NETWORK HYDROGEN PATHWAY PROJECTS

AREA	EXISTING PROJECTS	PLANNED PROJECTS TO 2025
DOMESTIC CONVERSION	• H21 Phase 1 and Phase 2 • HyDeploy and HyDeploy 2 • H100 • Hy4Heat programme (led by BEIS) • Cadent blending framework report	• H100 • H21 Phase 3 • HyNet Homes
HEAVY TRANSPORT	• H2GV • Cadent Gas Transport Pathways	
INDUSTRIAL CLUSTERS	Network collaboration in cluster projects, including: • HyNet • Grangemouth • Southampton Water • NECCUS • SWIC • Zero Carbon Humber • Net Zero Teesside	Network collaboration in cluster projects, including: • HyNet • Grangemouth • Southampton Water • NECCUS • SWIC • Zero Carbon Humber • Net Zero Teesside
EXISTING NETWORK PREPARATION	Current projects are focused on ensuring the gas networks are ready for a green gas transformation: • HyHy • GMaP – hydrogen workstream • GGG WS4.1 – entry connection standardisation • GGG WS2.1 Strengthening the case for GS(M)R amendment • LTS Futures • Feasibility of hydrogen in the NTS • Aberdeen Vision • Hydrogen deblending • GDNs have already replaced 60,000 km of iron pipelines with polyethylene, 62.5% completion of the mains replacement programme. • Future Billing methodology • Real Time Networks • Optinet • SGN Biomethane • Freedom Project • NGN Hydrogen Conversion Strategy	Planned projects are focused on ensuring the gas networks are equipped to deliver a green gas transformation: • Future LTS • H21 Safety case for trials • IMRP • HyNTS FutureGrid • Common future end states and transition pathways • Assessment methodology • Behavioural change and disruption • System Transformation data project • New modelling tools and capability • Investigation of impacts of purging during conversion • Transmission modelling • Distribution modelling • System Operator transition to hydrogen • System Transformation outputs • Network Safety & Impacts projects
NEW HYDROGEN NETWORKS	• Aberdeen Vision (note elements of this project cover hydrogen blending in the NTS and other elements a new hydrogen pipeline) • Project Cavendish • HyNet Homes	• Aberdeen Vision (ongoing project) • Project Cavendish (ongoing project) • HyNet Homes (ongoing project)

2. TRANSFORMING THE NETWORKS TO HYDROGEN

In this period, BEIS is supporting a range of research, development and testing projects designed to help determine the feasibility of using low carbon hydrogen as an alternative to the use of natural gas for heating in homes, businesses and industry.

BEIS is also working closely with industry and other stakeholders to ensure that the overall programme of work is comprehensive and provides the necessary evidence to assess key issues including safety, feasibility, costs and benefits and the overall consumer experience.

The following tables summarise the key pathway activities and enablers to 2025.

PATHWAY ACTIVITIES TO 2025 IN THE FOUR END-USE SECTORS

DOMESTIC CONVERSION	HEAVY TRANSPORT	INDUSTRY	POWER GENERATION
Network hydrogen safety work and live consumer trials are completed – first Hydrogen Neighbourhood. Hydrogen-ready boilers are mandated and begin to be installed. Hydrogen blending projects ready to start from 2023. Hybrid heating systems are deployed. Consumer engagement and education starts in earnest. Boilers and equipment for commercial users.	Hydrogen trucks appear on the roads. Continued growth in hydrogen buses. Hydrogen ferries and trains are put into use. Vehicles refuel using distributed onsite green hydrogen or hydrogen tankered to refuelling stations. Research into ammonia for zero-carbon shipping. Continued growth in biomethane trucks and buses.	FEED studies at clusters are progressed, funded by schemes such as the Industrial Decarbonisation Challenge and the Industrial Energy Transformation Fund. Final investment decisions are taken at industrial clusters with business models in place. Industrial fuel switching feasibility projects are continued.	Work continues to identify system coupling opportunities across electricity and gas networks. A regulatory incentive framework is established for electrolysis of hydrogen.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

THE KEY PATHWAY ENABLERS TO 2025			
HYDROGEN PRODUCTION	**EXISTING NETWORK PREPARATION**	**NEW HYDROGEN NETWORKS**	**HYDROGEN STORAGE**
2021 – An interim business model is established for hydrogen production with a hydrogen production target set by government through a new hydrogen strategy. 2022 – A final business model for hydrogen production is established, likely to be a CfD based on the gas and CO_2 price with an additional fixed capacity payment. Grant support available for hydrogen production technology from the Low Carbon Hydrogen Production Fund.	Research into NTS blending and deblending is carried out. Network modelling ascertains which sections can convert while maintaining reliability in the natural gas parts of the network. Research into hydrogen production to complement industrial cluster production. The Iron Mains Risk Reduction Programme is continued. PE installation continues.	A programme is developed to connect off-grid communities to gas networks. The System Transformation programme projects proceed.	Assessment of whether existing salt caverns can handle blends of up to 20% hydrogen. Some salt caverns will stay on methane rather than blended hydrogen, depending on whether blending is introduced into the NTS.

POLICY AND REGULATORY ENABLERS BEFORE 2025

The government's Ten Point Plan has set out the overall framework for hydrogen including milestones on business models, enabling blending and trialling hydrogen for heating in the early 2020s. In delivering the Hydrogen Network Plan, the gas networks expect that the following policy developments will be required.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

NATIONAL DELIVERY:

- Coordination of heat decarbonisation efforts to deliver the government's heat strategy.
- Decisions on where carbon capture and storage (CCS) infrastructure will be installed first, as this impacts on blue hydrogen production and therefore network planning.

BUSINESS MODELS:

- A Regulated Asset Base (RAB) financing mechanism for hydrogen storage and a mechanism (CfD or other) to support hydrogen production – for hydrogen production, a consultation is expected in 2021, with a final business model in 2022.
- A funding model for converting domestic properties to hydrogen, with a thorough understanding of the price consumers should be paying for heat decarbonisation, and a willingness to assign additional costs to either consumers or taxpayers.
- A clear signal that dedicated hydrogen production for domestic conversion, as well as for industrial/transport use is needed.
- CCS business models finalised. Likely to be a Contract for Difference (CfD) with a capacity payment for capture and a RAB for transport and storage.

REGULATORY REGIME:

- The RIIO2 framework needs to be managed in a sufficiently supportive and flexible way to enable the range of innovation projects and trials to be carried out in a timely way and ensure networks have the means to continue to prepare for future conversion.
- A regulatory regime that is supportive of hydrogen blending as a precursor to 100% hydrogen, delivering the Ten Point Plan ambition for hydrogen blending from 2023 in practice.
- Mandating of hydrogen-ready boilers.
- Support for hybrid heating solutions.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

The table below presents the gas networks' RIIO2 business plans to facilitate a start on the pathway to a net zero energy system before 2025.

GAS NETWORK RIIO2 NET ZERO PREPARATION COMMITMENTS	
NATIONAL GRID GAS TRANSMISSION[8]	• Lead the development of gas transmission to facilitate the decarbonisation of heat, industry and transport, specifically hydrogen. • Lead the development of the gas markets framework by collaborating to enable the pathway to net zero. • Collaborate across industry on a hydrogen workplan and innovation. • Creating an innovative testing facility through the FutureGrid programme, enabling testing and demonstration of hydrogen within National Transmission System (NTS) assets, leading to live hydrogen transportation on the NTS.
CADENT[9]	• Prepare to deliver clean gas at scale through the HyNet North West project, which will create 5,000 jobs and save 1 million tonnes of CO2 per annum. • Support customers on the clean gas transition, demonstrating the potential for the transportation of a hydrogen blend of gas through our HyDeploy and HyDeploy 2 projects and creating a commercial framework for how this could work in practice.
NORTHERN GAS NETWORKS[10]	• Research into the feasibility and safety case for introducing alternative gases into NGN's network. • Demonstration of safety case for 100% hydrogen for heat. • Increasing volumes of hydrogen blends through delivery of HyDeploy. • First 100% hydrogen community trial delivered.
SGN[11]	• Helping UK Government create a future for heat, power and transport that is low disruption, affordable and reliable, building relevant and impartial evidence towards net zero, including 100% hydrogen. • H100 Fife: Deliver a 100% hydrogen demonstration network in Levenmouth, Fife, that will bring carbon-free heating and cooking to around 300 homes from the end of 2022.
WALES & WEST UTILITIES[12]	• Ambitious whole system plan will decarbonise heat, power and transport in our regions, delivering a net zero ready network by 2035. • The plan is founded on extensive research and live trials.

The work in the next five years will give government the information required to make policy decisions on the conversion of networks. It is critical that a policy decision to allow and support 100% hydrogen conversion is taken in the mid-2020s, which will allow larger hydrogen conversion pilots to take place and meet the ambition in the November 2020 Ten Point Plan for a Hydrogen Village and a Hydrogen Town by 2030. Further policy development will be a critical enabler of the later stages of the plan.

[8] National Grid Gas Transmission, Delivering the future gas transmission system, December 2019 https://www.nationalgrid.com/uk/gas-transmission/about-us/business-planning-riio/our-riio-2-business-plan-2021-2026
[9] Cadent, Transforming experiences: Customers, Communities, Colleagues, December 2019 https://cadentgas.com/about-us/our-company/business-plan
[10] Northern Gas Networks, RIIO-GD2 Business Plan 2021-2026 https://www.northerngasnetworks.co.uk/wp-content/uploads/2019/12/NGN-RIIO-GD2-Business-Plan-2021-2026.pdf
[11] SGN, A plan for our shared future, December 2019 https://www.sgnfuture.co.uk/wp-content/uploads/2019/12/SGN-RIIO-GD2-Business-Plan.pdf
[12] Wales & West Utilities, A sustainable business in a changing and dynamic sector, December 2019 https://www.wwutilities.co.uk/media/3567/3-wwu-business-plan-december-2019.pdf

2. TRANSFORMING THE NETWORKS TO HYDROGEN

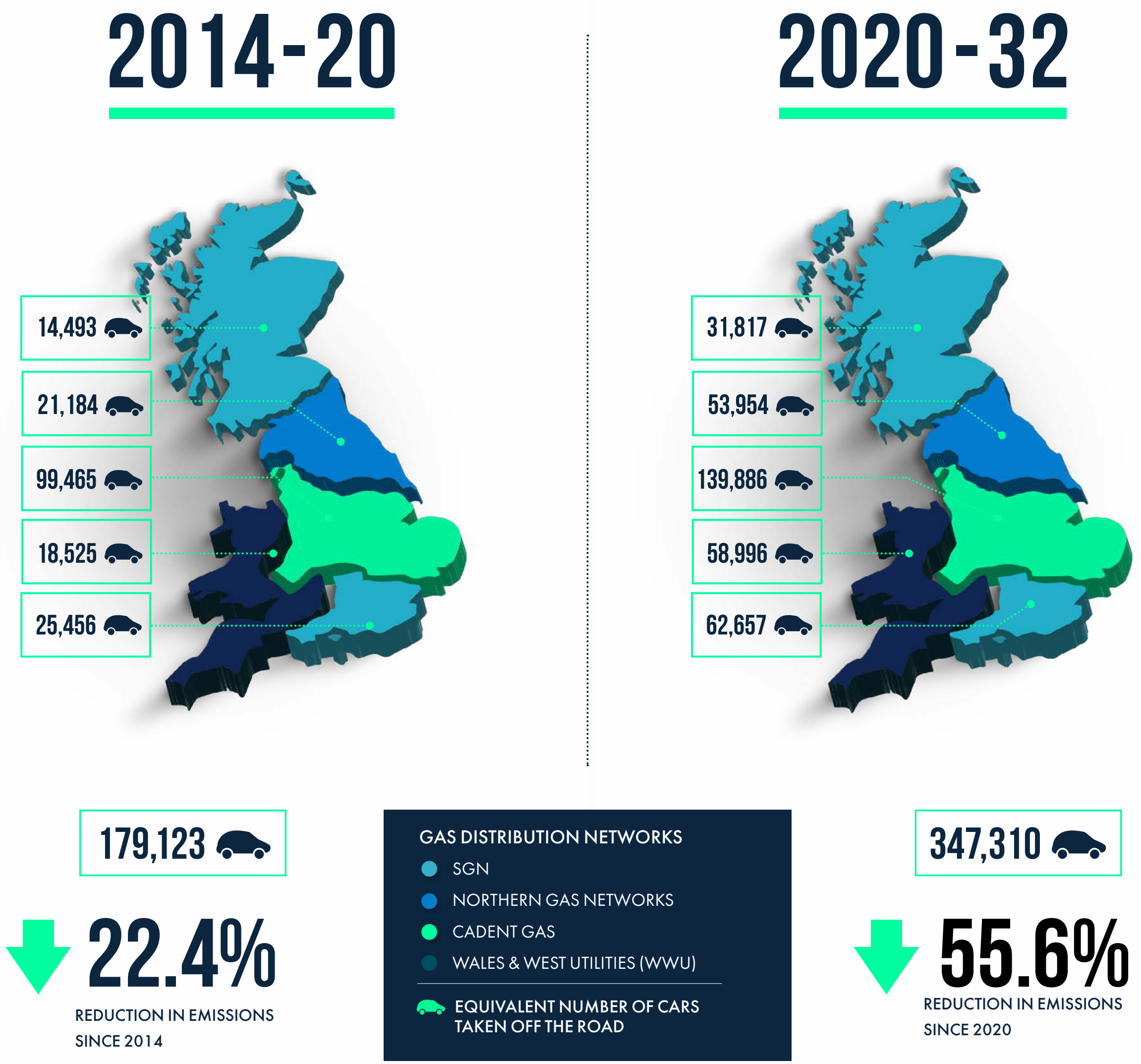
2.5 SOLUTION PILOTS – PATHWAY 2025 TO 2030

During this period, we will deliver the first large scale pilots of 100% hydrogen in domestic properties, including a Hydrogen Town and a substantial ramp-up in the provision of a 20% blend of hydrogen to consumers. The Iron Mains Risk Reduction programme approaches its conclusion, with the majority of the domestic gas network now hydrogen ready. Significant emissions reductions are now being enabled by the greening of the gas network, and by reductions in gas demand driven by improving energy efficiency.

Britain's gas network companies are replacing old iron gas mains with new hydrogen ready pipes, reducing emissions whilst allowing Britain's homes and businesses more choice over which zero carbon technologies they will be able to use in the future for their heating and transport.

526,433 CARS

By 2032 the equivalent of 526,433 cars will have been taken off the road since 2014, thanks to reduced emissions by replacing iron mains.



2. TRANSFORMING THE NETWORKS TO HYDROGEN

BY 2032

WE WILL HAVE

ACHIEVED A

66% REDUCTION

IN CO2e EMISSIONS SINCE 2014.

INVESTED

£28 BILLION

IN REPLACING IRON GAS MAINS WITH HYDROGEN READY PIPES.

Data from Ofgem annual reports or network RIIO2 business plans. tCO2e conversion uses the assumptions and calculation approach prescribed by Ofgem. Greenhouse Gases equivalences use EPA calculations.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

PATHWAY ACTIVITIES 2025-2030 IN THE FOUR END-USE SECTORS

DOMESTIC CONVERSION	HEAVY TRANSPORT	INDUSTRY	POWER GENERATION
Large pilots of 100% hydrogen in homes are undertaken, fed by dedicated hydrogen production – Hydrogen Village and Hydrogen Town. Increasing development of hydrogen blending up to 20% limit. Continuing improvements in energy efficiency to reduce average domestic gas consumption. Hydrogen-ready boilers rolling out around 1.5 million a year, similar to the current level of annual boiler replacements.	Scale up of hydrogen trucks, buses and trains, fed by onsite distributed green hydrogen production, or tankered hydrogen. Hydrogen and ammonia start to be used for shipping. The first hydrogen from industrial clusters starts to be used for heavy transport.	Construction of hydrogen production and CCS is underway, together with industrial fuel switching. Substitution of blue/green hydrogen for existing “grey” hydrogen is started. Hydrogen pipelines between clusters to connect hydrogen production, storage and use.	Hydrogen blends feeding CCGTs in clusters begins. Gas power generation falls as offshore wind increases. The first “system coupling” projects are commissioned.

PROGRESS ON THE KEY PATHWAY ENABLERS 2025-2030

HYDROGEN PRODUCTION	EXISTING NETWORK PREPARATION	NEW HYDROGEN NETWORKS	HYDROGEN STORAGE
Cluster hydrogen production starts – mainly blue with some green and “turquoise” from waste plastic at smaller scale. Distributed green hydrogen production grows for transport, domestic pilots and some dispersed industry. Research continues to scale up the pyrolysis hydrogen production method.	Non-clustered hydrogen production for network injection is started. The Iron Mains Risk Reduction Programme approaches its conclusion. Enabling works are carried out in the networks, including ensuring that valves and compressors etc are ready for hydrogen use.	New hydrogen pipes are starting to connect hydrogen production, storage and use between clusters. The programme of work to connect off-grid communities to hydrogen networks is implemented.	The first salt caverns are repurposed for hydrogen storage, depending on which clusters go first. Other local storage is developed to support hydrogen conversion pilots.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

2.6 SCALING UP THE TRANSITION - PATHWAY 2030 TO 2035

The policies are now clear, and the transition is accelerating. All of the technical challenges have been resolved for hydrogen rollout. Large parts of the distribution networks are carrying a 20% hydrogen blend and we begin to see the arrival of dedicated hydrogen production for domestic consumption.

PATHWAY ACTIVITIES 2030-2035 IN THE FOUR END-USE SECTORS

DOMESTIC CONVERSION	HEAVY TRANSPORT	INDUSTRY	POWER GENERATION
Hydrogen-ready boilers continue to roll out at around 1.5 million a year. Following on from pilots, the first 100% hydrogen conversions take place including hydrogen to fuel district heating.	Wider roll out of hydrogen trucks, buses and trains takes place, partly as a result of bans on new petrol and diesel vehicles coming into effect. Hydrogen and ammonia grow in the maritime sector. Hydrogen in aviation begins. Growth in light fuel cell vehicles.	Hydrogen production in the clusters scales up, including for use in shipping at industrial ports. Dedicated hydrogen production at scale for domestic conversion begins. Industry outside clusters begin to decarbonise using hydrogen from the gas networks. Hydrogen pipelines start to link clusters and support hydrogen in heavy transport in between.	More CCGTs in clusters start to take a hydrogen blend. The first CCGTs in clusters convert to 100% hydrogen. CCGTs outside of clusters decide whether to move to hydrogen or remain on methane and fit CCS. An increasing number of "system coupling" projects are delivered, to support decarbonisation of the electricity sector and increase available renewables capacity.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

PROGRESS ON THE KEY ENABLERS 2030-2035			
HYDROGEN PRODUCTION	**EXISTING NETWORK PREPARATION**	**NEW HYDROGEN NETWORKS**	**HYDROGEN STORAGE**
Cluster hydrogen production grows in earnest, including blue, turquoise, large onshore green, and the start of offshore green. A start is made using pyrolysis production at scale. Hydrogen production dedicated for domestic consumption connected starts in earnest.	The Iron Mains Risk Reduction Programme is completed. The distribution network is now 100% hydrogen ready. Hydrogen blending in the distribution is widespread. Non-clustered hydrogen production starts in earnest, with conversions of sections of the networks – for domestic, heavy transport and dispersed industry use.	More hydrogen pipelines connect clusters to provide greater resilience and ensure the parallel methane network resilience. Development of new NTS and LTS sections dedicated to hydrogen.	Rough is repurposed for hydrogen storage, to allow scale within clusters. LNG increases in importance for methane storage, as more salt caverns switch to hydrogen. Ammonia storage emerges at the LNG import terminals.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

2.7 ACCELERATING THE TRANSITION - PATHWAY 2035 TO 2040

Nearly all domestic properties are now hydrogen ready, with boilers, cookers, and other devices now converted. Dedicated hydrogen production at scale is now available, and widespread conversion of housing to 100% hydrogen is underway.

ACTIVITIES 2035-2040 IN THE FOUR END-USE SECTORS

DOMESTIC CONVERSION	HEAVY TRANSPORT	INDUSTRY	POWER GENERATION
Hydrogen-ready boilers continue to roll out at 1.5 million a year, with the rollout to all properties nearing completion by the end of the decade. Wider domestic conversion starts, changing from a 20% hydrogen blend, to 100% hydrogen.	Hydrogen trucks, buses and trains continue to roll out. Hydrogen and ammonia grow in the maritime sector. Hydrogen in aviation continues to grow. Further growth in light fuel cell vehicles.	Cluster hydrogen production continues to scale up, including for use in industrial ports. Other clusters, which started in the early 2030s, are scaling up. Hydrogen pipelines are now linking clusters and supporting non cluster industry and heavy transport in between.	Continuing CCGT and gas engine switchover to hydrogen or gas with CCS plus new hydrogen CCGTs. Gaseous power generation provides backup power, especially if no new nuclear at scale. If considerable electrification of heat, gaseous power will increase. An increasing number of "system coupling" projects delivered, to support decarbonisation of the electricity sector and increase available renewables capacity.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

PROGRESS ON THE KEY ENABLERS 2035-2040			
HYDROGEN PRODUCTION	**EXISTING NETWORK PREPARATION**	**NEW HYDROGEN NETWORKS**	**HYDROGEN STORAGE**
Cluster hydrogen production grows to support more industry/power switching. Dedicated hydrogen production for domestic consumption fully available.	Wider hydrogen production and network conversion is now continuing in earnest. There is now a significant hydrogen content in the NTS.	Parallel sections of the NTS are converted or built new to allow wider domestic conversion to while maintaining resilience in the methane network. More new or repurposed hydrogen pipelines are connecting clusters.	Further hydrogen storage capacity is developed in a number of forms.

2.8 FULL TRANSITION - PATHWAY 2040S

Conversion of the gas networks to net zero is now complete. Domestic conversion is completed. The gas and electricity networks are interconnected and mutually supportive.

ACTIVITIES IN THE 2040S IN THE FOUR END-USE SECTORS			
DOMESTIC CONVERSION	**HEAVY TRANSPORT**	**INDUSTRY**	**POWER GENERATION**
Widespread domestic conversion with sufficient hydrogen production and storage is now well established.	Hydrogen is an established energy carrier for trucks, buses, trains and ships (includingin the form of ammonia) and is being delivered through gas networks with onsite purification. Hydrogen scales in aviation.	Additional cluster hydrogen production is brought onstream to support the conversion of homes and dispersed industry, with appropriate business models.	Electricity and gas networks are interconnected, and support whole energy system needs.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

PROGRESS ON THE KEY ENABLERS 2040-2050			
HYDROGEN PRODUCTION	EXISTING NETWORK PREPARATION	NEW HYDROGEN NETWORKS	HYDROGEN STORAGE
Large-scale green is increasingly the method of choice for new hydrogen production. Pyrolysis is also established. Sufficient hydrogen is now being produced to use more widely outside of clusters, including larger volumes of NTS/GDN-connected hydrogen.	Existing networks are fully prepared for hydrogen conversion, with hydrogen-ready boilers in all properties.	Further build out of new hydrogen pipelines to connect wider production, storage and use, and conversion of parts of the NTS.	Hydrogen storage widespread, and overall hydrogen system resilience increasing.

2.9 HYDROGEN APPLICATIONS

Alongside the Hydrogen Networks Plan, policy and regulation needs to support the transition for Hydrogen Production and across the end use sectors. Major steps are set out in the T-Plan below, aligned with the Hydrogen Networks Plan.

Chapters 3-6 set out the implications and options in the use sectors in more detail.

HYDROGEN APPLICATIONS ROAD MAP

2. TRANSFORMING THE NETWORKS TO HYDROGEN

2.10 THE HYDROGEN NETWORK PLAN AND STAKEHOLDER ENGAGEMENT

STAKEHOLDER ENGAGEMENT FOR THIS PROJECT

To develop the plan and test the practical transition options in detail, considerable stakeholder engagement has been undertaken. In August and September 2020, we:

- Held two workshops with almost 200 participants – covering producers, transporters, industrial users, consumer groups and policy experts.
- Carried out 17 individual focused discussions with key organisations, including:
    - Producers and industrial clusters: Johnson Matthey, ITM Power, BOC, North West (Progressive Energy), South Wales (CR Plus, Milford Haven Port Authority, Costain, University of South Wales), Humber (Equinor, Centrica), Scotland (Pale Blue Dot, SHFCA), Teesside (BP).
    - Other industrial consumers: Chemical Industries Association.
    - Domestic consumers and appliances: Worcester Bosch, Citizens Advice.
    - Transport: Shell.
    - Power generation and electricity grid: SSE, National Grid ESO.
    - Storage: Storengy.

Appendix A provides a detailed description of what the stakeholders told us, and we also summarise the key points in the relevant sector chapters. Below we highlight a few of the common topics that the stakeholders we spoke to raised with respect to the transformation plan:

LOW REGRETS STEPS: Mandating hydrogen-ready boilers and blending hydrogen into the network to build confidence with consumers, deliver interim carbon savings and make a future conversion smoother.

OVERARCHING RISKS: Managing higher costs and ensuring sufficient volumes of hydrogen production are key risks.

HYDROGEN IN TRANSPORT: To start with, hydrogen is likely to be produced onsite for refuelling stations, but as the use of hydrogen in transport grows, the role of hydrogen in gas networks, with onsite purification, will become more important.

METHANE IN NETWORKS: There will still be a need for methane in the NTS for some time to come, and it is likely that parallel high-pressure hydrogen pipelines will be built.

WIDER PUBLIC OPINION RESEARCH

There has been extensive public opinion research on hydrogen and alternative heat decarbonisation options, including through quantitative and qualitative surveys by the Decarbonised Gas Alliance, Leeds Beckett University for the H21 project, Energy Systems Catapult, the Freedom Project, Ofgem and Climate Assembly UK. The key findings of these surveys are provided in Appendix B and are briefly summarised below:

NET ZERO: There is widespread support for the net zero target, with many people feeling that climate change is one of the most pressing issues of our time. But cost and lifestyle changes are a major barrier, with people unwilling to pay significantly more or face large disruption.

100% HYDROGEN: People tend to be most worried about additional cost and the disruption from a hydrogen conversion, which people tend to think would be major. Most people seem to be relaxed about the decision being made for them, although there was concern about politicians changing their mind – it had not been long, for example, since politicians had actively persuaded people to turn to diesel vehicles.

2. TRANSFORMING THE NETWORKS TO HYDROGEN

2.11 BENEFITS OF A HYDROGEN NETWORK

HYDROGEN SUPPLY AND EMISSIONS SAVINGS

Several different scenarios have been published for meeting net zero in the UK as a whole, which all use hydrogen to a greater extent. These include:

- **Committee on Climate Change (CCC):** The CCC's net zero report envisages up to 270 TWh of hydrogen to meet net zero.[13]
- **National Grid:** The National Grid Future Energy Scenarios set out three scenarios which meet net zero, using between 152 TWh and 591 TWh of hydrogen.[14]
- **Energy Networks Association (ENA):** The ENA's recent Pathways to Net Zero report envisages 236 TWh of hydrogen in 2050.[15]
- **Aurora Energy Research:** Aurora's recent hydrogen report found that hydrogen can play an ambitious role in meeting net zero in the UK, with between 212 and 515 TWh of hydrogen use in 2050.[16]

The following table provides a breakdown of hydrogen use in 2050 in the main scenarios.

HYDROGEN DEPLOYMENT SCENARIOS FOR 2050 (TWH)

SECTOR	ENA Pathways	Committee on Climate Change Net Zero	National Grid Consumer Transformation	National Grid System Transformation	National Grid Leading the Way	Aurora High Adoption*	Aurora Targeted Adoption*
BUILDINGS	140	53	21	319	68		
INDUSTRY	59	120	10	118	67		
SURFACE TRANSPORT	30	25	32	56	45		
SHIPPING (INCLUDING AMMONIA)	-	70	70	70	35		
POWER GENERATION	7	2	20	28	20		
TOTAL	236	270	153	591	235	515	212

* For the Aurora scenarios, a precise sectoral breakdown is not given

In all scenarios, at least 150 TWh of hydrogen is required in 2050. The key contribution that network conversion can make is to enable hydrogen to be transported and used far more widely, including in buildings, non-clustered industry and a full national heavy transport network.

[13] Committee on Climate Change, Net Zero Technical Report, May 2019 https://www.theccc.org.uk/publication/net-zero-technical-report/
[14] National Grid, Future Energy Scenarios 2020 https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents
[15] Energy Networks Association, Pathways to Net Zero, 2019 https://www.energynetworks.org/gas/futures/pathways-to-net-zero-report.html
[16] Aurora Energy Research, Hydrogen for a Net Zero GB: An integrated energy market perspective, 2020 https://www.auroraer.com/insight/hydrogen-for-a-net-zero-gb/

2. TRANSFORMING THE NETWORKS TO HYDROGEN

The table below presents the emissions savings associated with each deployment option. We have assumed that:

- Hydrogen is replacing natural gas for buildings, industry and power generation. Natural gas, if combusted directly, has emissions of 184.2 g/CO_2 per kWh[17], plus an additional 35.3 g/CO_2 per kWh[17] in the natural gas supply chain[18].
- Hydrogen is replacing diesel for heavy surface transport and marine fuel oil for shipping. These have emissions of 249.4[19] and 258.8 g/CO_2 per kWh[20], respectively.
- Lifecycle blue hydrogen production emissions, including emissions of 35.3 g/CO_2 per kWh in the natural gas value chain, are 49.8 g/CO_2 per kWh.[21]
- This gives emission savings of 169.7 g/CO_2 per kWh compared with natural gas, 199.7 g/CO_2 per kWh compared with diesel and 209.1 g/CO_2 per kWh compared with marine fuel oil.

To be conservative, we have also made the following assumptions – in reality, the emissions savings from hydrogen would be higher than we have calculated:

- No supply chain emissions are assumed for diesel and marine fuel oil, and no fuel cell efficiency increase for hydrogen over internal combustion engines is assumed – including supply chain emissions and higher fuel cell efficiency would increase hydrogen emissions savings relative to diesel and marine fuel oil.
- All hydrogen is assumed to be blue hydrogen – green hydrogen from renewables would increase emissions savings, and in reality, a significant proportion of hydrogen will be produced from dedicated renewables.
- Emissions savings in the two Aurora scenarios, where a sectoral breakdown is not given, are related to natural gas only.

EMISSIONS SAVINGS FROM HYDROGEN DEPLOYMENT SCENARIOS FOR 2050 (MILLION TONNES CO2)

SECTOR	ENA Pathways	Committee on Climate Change Net Zero	National Grid Consumer Transformation	National Grid System Transformation	National Grid Leading the Way	Aurora High Adoption	Aurora Targeted Adoption
BUILDINGS	23.8	9.0	3.6	54.1	11.5		
INDUSTRY	10.0	20.4	1.7	20.0	11.4		
SURFACE TRANSPORT	6.0	5.0	6.4	11.2	9.0		
SHIPPING (INCLUDING AMMONIA)		14.6	14.6	14.6	7.3		
POWER GENERATION	1.2	0.3	3.4	4.8	3.4		
TOTAL	41.0	49.3	29.7	104.7	42.6	87.4	36.0
% OF UK CO2 EMISSIONS	11.7%	14.0%	8.4%	29.8%	12.1%	24.9%	10.2%
% OF UK TOTAL GHG EMISSIONS	9.4%	11.3%	6.8%	24.1%	9.8%	20.1%	8.3%

[17] NB: Gross CV measure; natural gas 100% mineral blend, as biomethane would still be used in parts of the network not converting to hydrogen. UK Government GHG Conversion Factors for Company Reporting, 2020 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020
[18] NB: Natural gas supply chain emissions are from 2018 UK natural gas mix (including LNG), and are included in both the total natural gas emissions and the total hydrogen production emissions. H21 North of England, 2018 https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf
[19] NB: Gross CV measure; 100% mineral diesel, as biodiesel would still be used for heavy transport not converting to hydrogen. UK Government GHG Conversion Factors for Company Reporting, 2020 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020
[20] NB: Gross CV measure. UK Government GHG Conversion Factors for Company Reporting, 2020 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020
[21] NB: Natural gas supply chain emissions are from 2018 UK natural gas mix (including LNG), and are included in both the total natural gas emissions and the total hydrogen production emissions. H21 North of England, 2018 https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf

2. TRANSFORMING THE NETWORKS TO HYDROGEN

The table shows that emissions savings from network enabled hydrogen use can be conservatively estimated at between 30 million and 105 million tonnes of CO_2, depending on the level of hydrogen adoption. Based on 2019 UK CO_2 emissions of 351.5 million tonnes and total greenhouse gas (GHG) emissions of 435.2 million tonnes of CO_2-equivalent[22], the table also shows the proportion of UK emissions that hydrogen can remove – hydrogen use as set out in the ENA pathways report would save around 12% of UK CO_2 emissions.

ECONOMIC OPPORTUNITIES

The overall job creation benefits from cross-sectoral hydrogen deployment are large, supporting the UK's post-Covid economic recovery and the Ten Point Plan, and helping the UK to build back better, right across the country.

- Through to 2050, hydrogen and CCS development for broad based decarbonisation could create 43,000 jobs for industrial decarbonisation alone, 195,000 jobs if hydrogen plays a full role in economy-wide decarbonisation, and 221,000 jobs if the UK also becomes a major hydrogen exporter.[23]

- By 2035, a recent analysis by the Hydrogen Task Force estimated that 75,000 jobs could be created overall, together with £18 billion of GVA, from around 125 TWh of hydrogen by 2035. This would include 26,600 jobs in hydrogen production alone, with 12,542 jobs in electrolyser manufacturing and 10,482 jobs in auto thermal reforming.[24]

The economic benefits and protection and creation of jobs are most likely to be felt in less affluent parts of the country, where industry and hydrogen production would be concentrated. Overall, energy intensive industry accounts for £140 billion in economic value added and employs over 1.1 million people.

UK ECONOMIC AND EMPLOYMENT OPPORTUNITIES FROM HYDROGEN (2020-2035)

	JOBS TOTAL	GVA TOTAL
UPSTREAM	28,578	£4,197m
MIDSTREAM	15,197	£5,264m
DOWNSTREAM	30,631	£8,724m

Hydrogen also provides an opportunity to develop UK exports of decarbonised industrial products, together with exports of hydrogen technology and services:

- Overall, the global hydrogen market could reach £1.9 trillion a year by 2050[25], with the global fuel cell market reaching over £140 billion.
- The European electrolyser market will grow rapidly, given the EU Commission's ambitions for 6 GW of electrolysers by 2024 and 40 GW by 2030. The global market for electrolyser exports could reach £250 billion and exports of hydrogen from offshore wind could be worth £48 billion.[26]

[22] 2019 UK greenhouse gas emissions, provisional figures https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2019
[23] Element Energy and Equinor, Hy-impact Study 1: Hydrogen for economic growth, November 2019 http://www.element-energy.co.uk/wordpress/wp-content/uploads/2019/11/Element-Energy-Hy-Impact-Series-Study-1-Hydrogen-for-Economic-Growth.pdf
[24] Hydrogen Taskforce, Economic impact assessment (EIA) of the hydrogen value chain on the UK by 2035 https://www.hydrogentaskforce.co.uk/resources/
[25] Hydrogen Council, Hydrogen scaling up, November 2017, p.8 http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-Scaling-up_Hydrogen-Council_2017.compressed.pdf
[26] Offshore Renewable Energy Catapult and Offshore Wind Industry Council, Offshore wind and hydrogen: Solving the integration challenge, July 2020 https://s3-eu-west-1.amazonaws.com/media.newore.catapult/app/uploads/2020/09/09161500/Solving-the-Integration-Challenge-ORE-Catapultr.pdf

2. TRANSFORMING THE NETWORKS TO HYDROGEN

2.12 THE NETWORK TRACK RECORD

The gas networks have demonstrated the capability to manage the transition to a hydrogen network, including through:

- Managing a very reliable gas network, which provides 99.999% supply reliability. On average, there is an unplanned interruption to gas supply only once every 140 years.
- Replacing 60,000 km of iron pipelines with polyethylene since 2002, helping to make the network ready for hydrogen. The 30-year mains replacement programme, due to finish in 2032, is now 62.5% complete.
- Carrying out major projects as part of their business-as-usual activities, including constructing a new 5 km tunnel 30 metres under the Humber estuary; an extension to the gas network in Northern Ireland, connecting up to 40,000 new customers each year; and a new waste-to-gas project to convert 8,000 tonnes of households waste each year into enough gas to heat 1,800 homes.
- Building new major pipelines in the North of England to distribute natural gas from Norway. The project, which was completed in 2007, saw the construction of two new 48-inch high-pressure gas transmission pipelines, one running for 53km between Ganstead and Asselby in Yorkshire, and the other 94km from Pannal in Yorkshire across to Nether Kellet in Lancashire.

This chapter has set out the overall Network plan for delivering the hydrogen transformation required to meet the challenge of net zero. The following four chapters discuss the implications and benefits for the key sectors of households, transport, industry and power.

3. HOUSEHOLDS

3. HOUSEHOLDS

Converting domestic heating to hydrogen is the lowest cost, least disruptive decarbonisation option for most households. This section outlines how this transition will be enabled by the gas networks and how two major advances are being prepared for:

- By 2023 to blend hydrogen into the gas distribution grid up to 20% volume;
- Deliver a 'neighbourhood trial' of 100% hydrogen by 2023, a large village trial by 2025 and be ready to convert a large town by 2030.

3.1 WHERE WE ARE TODAY

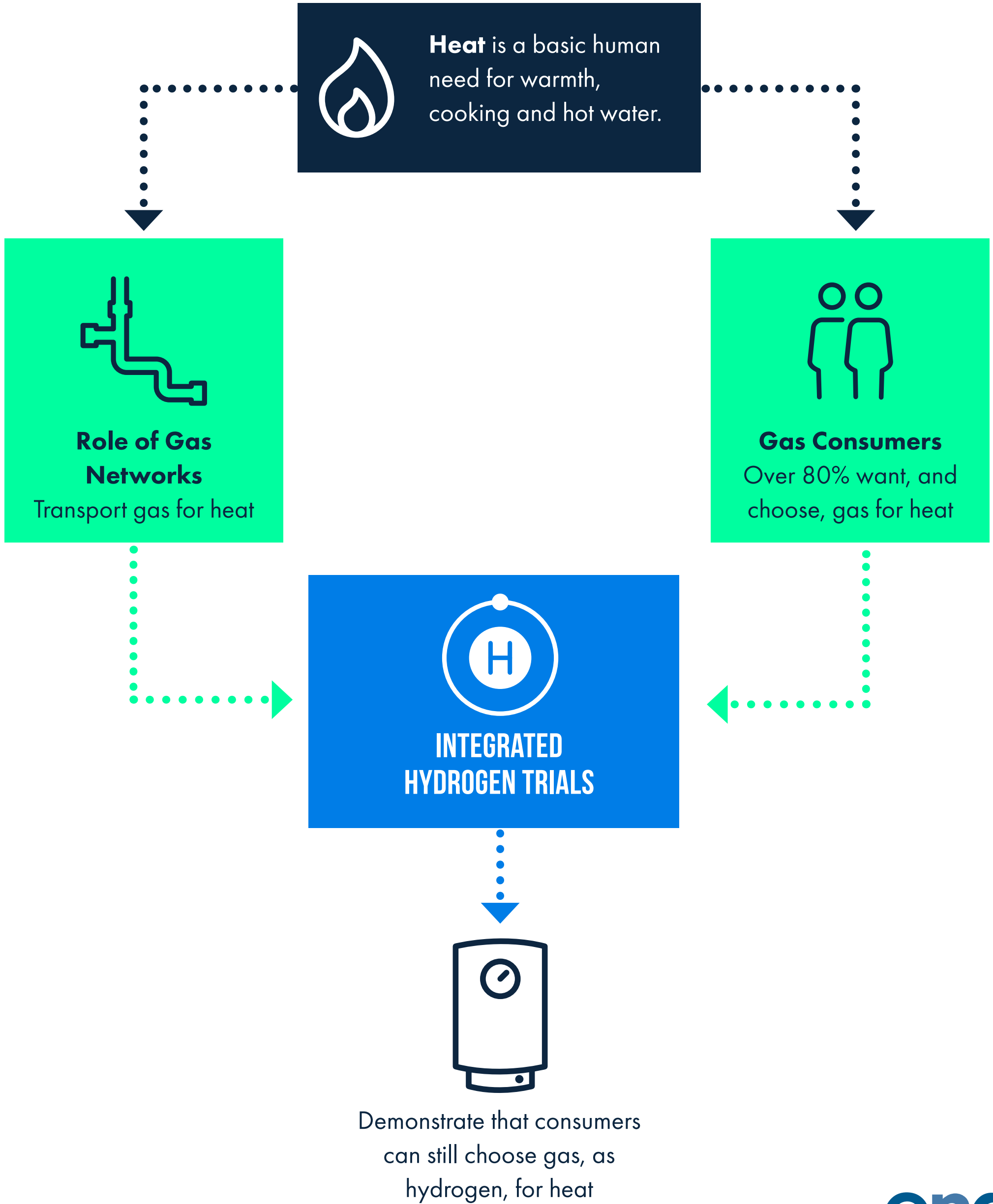
Today, more than 22 million[27] homes enjoy having their heating and cooking requirements delivered from a low cost, safe and extremely reliable gas network.

In 2017, BEIS published a report[28] on gas security of supply and reported that:

- There has never been a gas deficit emergency;
- The strength of the gas system is built on supply diversity;
- There is currently spare capacity on the gas system;
- We are resilient to multiple infrastructure failures.

In the same report it is stated that Ofgem noted in 2012/13 that between 60% and 70% of supply infrastructure would need to fail before supplies to domestic gas customers would be interrupted.

Hydrogen was first used as a domestic energy source in 1792, when William Murdoch lit his house and office in Redruth, Cornwall from towns gas---a mixture of hydrogen, carbon monoxide, and carbon dioxide. The use of towns gas in UK households finished in the early 1970s when the UK transitioned from towns gas to natural gas, from gas fields in the UK sector of the North Sea. By bringing hydrogen back into the gas mix for domestic consumers, and ultimately delivering dedicated hydrogen networks, we can meet the challenges of the 21st century.



[27] Number of homes on the natural gas network https://www.energynetworks.org/energy-networks-explained/
[28] BEIS 2017 report on security of supply: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770450/gas-security-supply-assessment.pdf

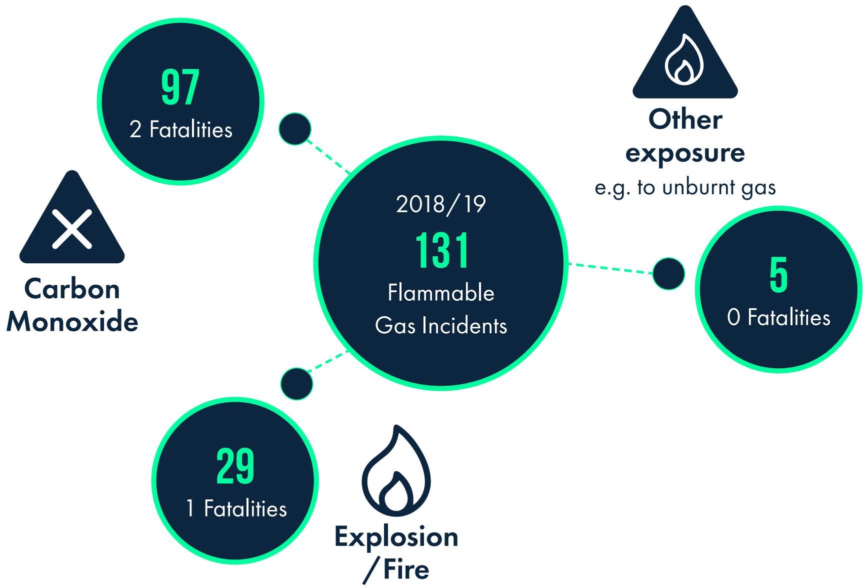
3. HOUSEHOLDS

GAS SAFETY IN HOMES

The gas industry prides itself on excellent performance when it comes to safety and the same high standards will be taken through to a blend of hydrogen on the network and to 100% hydrogen networks.

The industry manages the transportation of a highly flammable material under pressure to more than 24.5 million domestic and industrial connections, while keeping the number of incidents extremely low. In the last dataset (2018/2019)[29] published by the HSE, there were 131 reported incidents, broken down as seen below. Almost 75% of those incidents involved the generation of carbon monoxide from gas combustion, a risk that would not be present with hydrogen. These statistics do not include fatalities arising from cabon monoxide poisoining in off gas grid properties using LPG or solid fuels. All hydrogen appliances would have a Gas Safe check, reducing incident risk.

For comparison, in 2018/2019 in England, there were 2,334 electrical appliance fires, including 926 from microwaves, 523 from washing machines and 479 from tumble dryers.[30]



FUEL POVERTY

The fuel poverty status of a household depends on the interaction between three key drivers – household income, the cost of heat and the efficiency of the home.

In order to move people out of fuel poverty, we therefore need to either raise incomes, improve energy efficiency, or reduce energy cost. The low cost of gas today helps keep many millions of consumers out of fuel poverty.

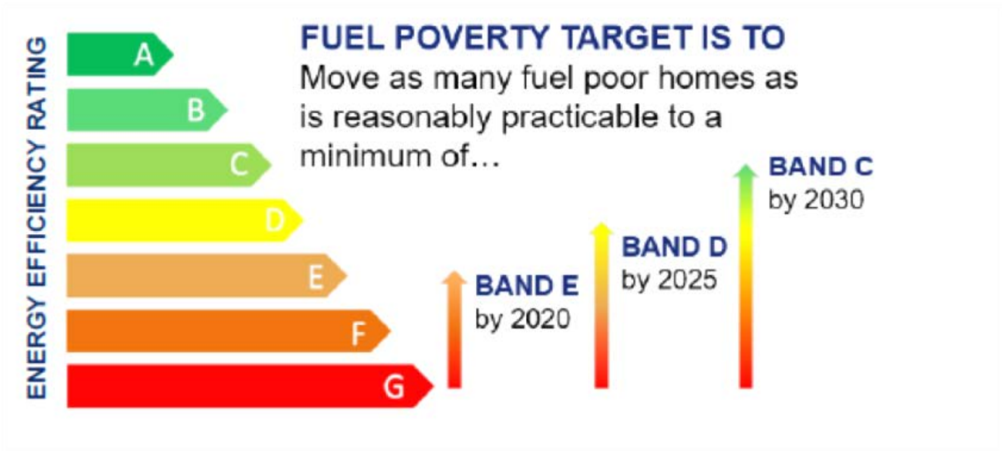
[29] Number of safety incidents associated with natural gas https://www.hse.gov.uk/statistics/tables/index.htm
[30] See https://www.electricalsafetyfirst.org.uk/what-we-do/our-policies/westminster/statistics-england/

3. HOUSEHOLDS

In 2014, the Government put in place a new statutory fuel poverty target for England in order to ensure that as many fuel poor households as reasonably practicable achieve a minimum energy efficiency rating.

In the latest available analysis of 2018 data 10.3% of households in England (2.40 million households) were classed as fuel poor, a reduction of 0.7% (130,000 households) from 2017. The average fuel poor household required an annual reduction of £334 to their fuel costs to move them out of fuel poverty. In 2018, further progress was made towards the interim 2020 fuel poverty target, with 92.6% of all fuel poor households living in a property with a fuel poverty energy efficiency rating of Band E or better, as illustrated below.

Improving energy efficiency in older properties is neither easy, nor cheap. Typically, the cost of improving the energy efficiency of a Band F property to Band C would be over £15,000, and to move a Band E property to Band C would be over £10,000. This does not include the cost of changing the heating solution.



England's statutory fuel poverty target. Image credit: BEIS

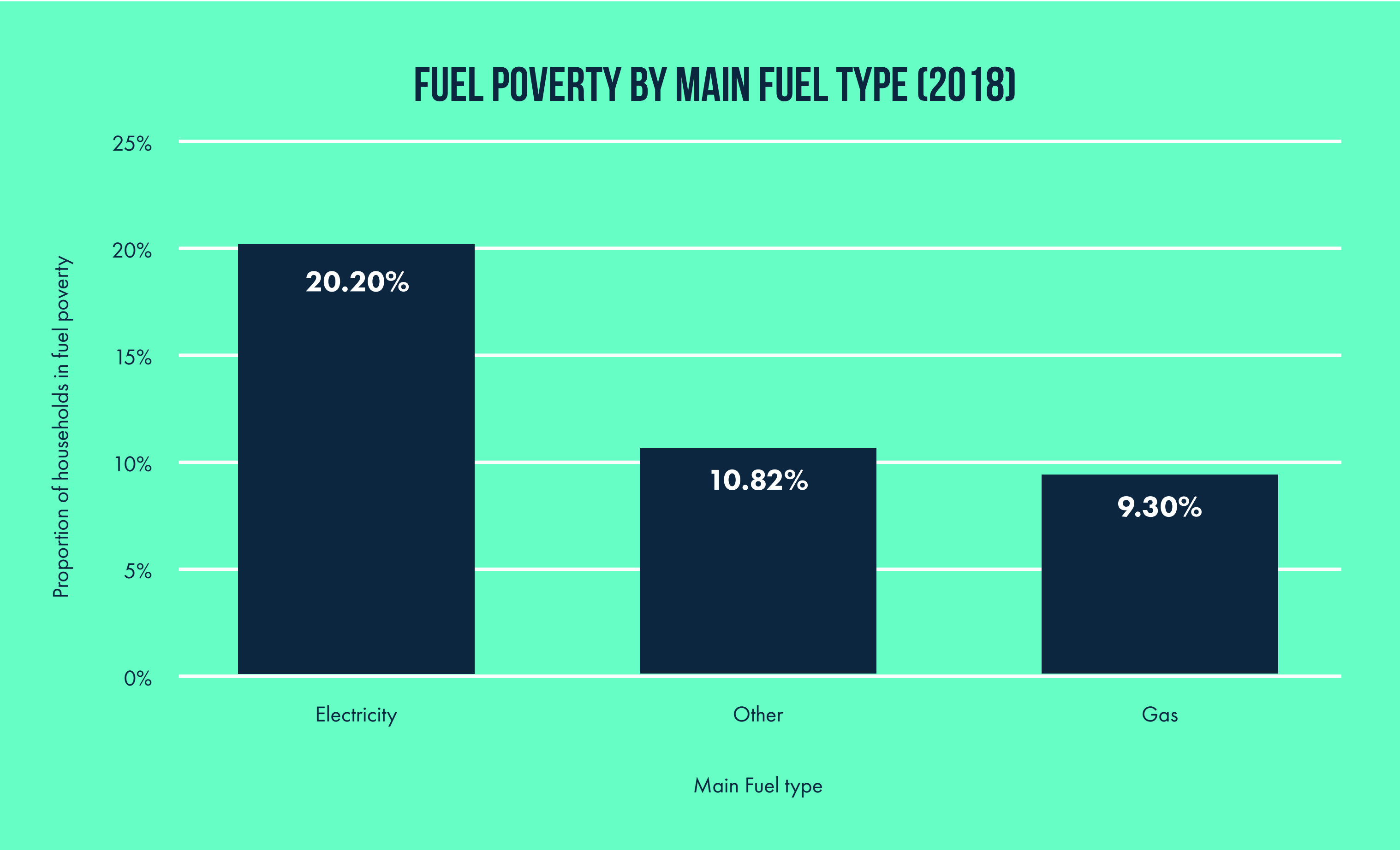
The gas networks play a key role today in helping consumers avoid fuel poverty, and could provide a key solution, to both reducing fuel poverty and CO2 emissions for those not on the gas grid. The affordability of a decarbonised heat network is a critical factor for government to consider when implementing future changes to heat policy.

The latest Government data on energy costs[31] reveals that between Quarter 1 2019 and Quarter 1 2020, in real terms prices (including VAT) there has been an increase of 6.8% for electricity but a decrease of 1.9% for gas. The average price of energy today is 3.8 pence per kWh for gas, and 16.6 pence per kWh for electricity.[32] Clearly, any consideration of domestic fuel poverty must consider the much lower price for gas as opposed to electricity.

Households using electricity as their main fuel for heating have the highest likelihood of fuel poverty at 20.2%, compared to gas at 9.3% according to the government data.[33] Even allowing for the fact that a change to a hydrogen solution could increase domestic gas prices (if the full cost was passed onto consumers), it would still be the case that on a kWh basis, hydrogen would be still be a cheaper option for consumers than electricity.

[31] Energy costs https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/895143/QEP_Q1_2020.pdf
[32] BEIS, Annual domestic energy bills, Tables 2.2.4 and 2.3.4 https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics
[33] Annual Fuel Poverty Statistics in England, 2020 (2018 data).

3. HOUSEHOLDS



In 2018 households using electricity as their main fuel for heating had double the likelihood of being in fuel poverty than those using gas. The Other category in this graph includes off grid properties using heating oil, anthracite nuts, household coal, smokeless fuel, wood, propane, bulk LPG, or community heating from boilers/CHP/waste heat. Many of those properties could also benefit from a connection to a low carbon gas grid, both from a cost, and emissions perspective.

3. HOUSEHOLDS

3.2 HYDROGEN TRANSFORMATION FOR HOMES

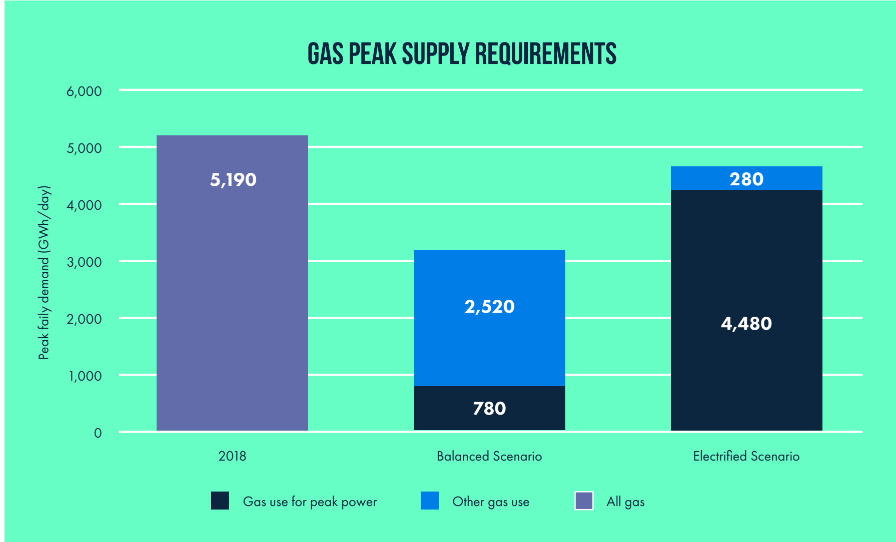
The gas network trials of 100% hydrogen, to a neighbourhood in 2023 and then to a village in 2025, will return crucial learning to enable long term policy decisions to be made. There is no single solution to the decarbonisation of heat, and the question of domestic heat in particular, needs to be considered in the light of the whole system changes that will be taking place in the coming decades. The increased use of renewable energy brings substantial savings in CO2 emissions related to power generation, but the increasing deployment of renewables also brings challenges to the existing electricity network in terms of entry points, system configuration and load balancing. The increase in renewable generation with relatively low annual load factor means significantly more capacity is required to meet demand. National Grid's Future Energy Scenarios[34] report indicates in all scenarios, a substantial increase in demand for electricity transmission and distribution by 2050.

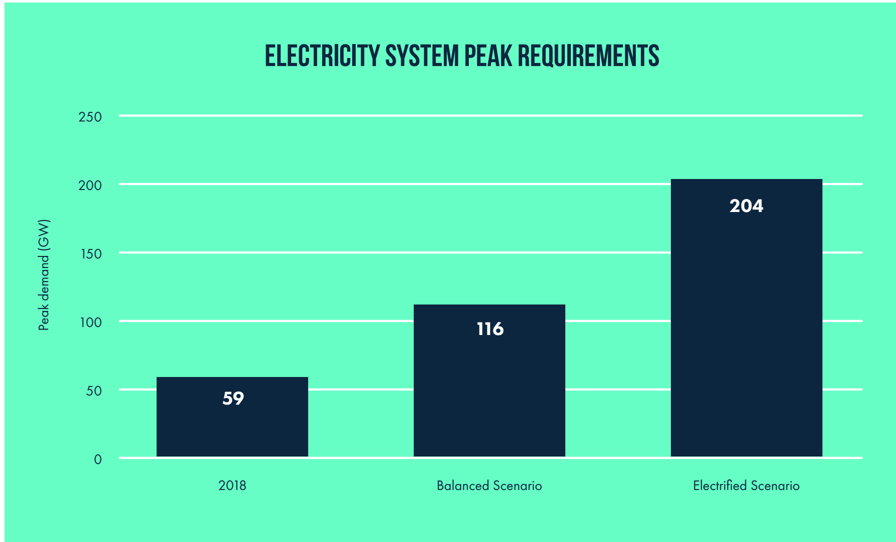
ENERGY SYSTEM BENEFITS

Using hydrogen for domestic heating reduces the need for peak electricity generation and storage capacity to meet peak heat requirements on the coldest evenings, with this added capacity then lying idle for much of the year when heating is not needed.

In the ENA Pathways to Net Zero analysis,[35] a balanced scenario, including 100% hydrogen conversion in parts of the country, would produce far lower energy system peaks than a fully electrified scenario:

- Today, peak gas system daily demand is 5,190 GWh, and peak electricity generation is 59 GW.
- In the balanced scenario, peak electricity generation reaches 116 GW, and peak gas system daily demand falls to 3,300 GWh.
- By contrast, in the electrified scenario, peak electricity generation is 204 GW, and peak daily gas demand (almost all of which is for peak power generation) is 4,760 GWh.





[34] National Grid Future Energy Scenarios 2020 https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents
[35] ENA, Pathways to Net Zero, 2019, Figure 6 https://www.energynetworks.org/assets/images/Resource%20library/ENA%20Gas%20decarbonisation%20Pathways%202050%20FINAL.pdf

3. HOUSEHOLDS

CONSUMER DISRUPTION BENEFITS

Transformation to hydrogen heating would be less disruptive to consumers than many alternatives, as a hydrogen conversion would not need to be accompanies by other home improvements and changes, such as additional insulation and equipment to accommodate low temperature heat, including larger pipework, larger radiators and a need for hot water tanks – it is worth noting that almost 14 million homes in England have no hot water tank.[36]

Heat pumps do present a viable option for decarbonising heat in new build properties where the Energy Performance Certificate (EPC) of the house is C or above.

The 100% hydrogen trials, discussed below in section 3.4, will demonstrate hydrogen as the least disruptive option.

DIFFERENT TYPES OF BUILDING

Different types of building are likely to need alternative solutions. Very well insulated new builds may be suitable for heat pumps, while existing buildings off the gas grid, facing higher heating costs, may benefit from bio-LPG.

For buildings on the gas grid, energy efficient improvements can help to reduce emissions, and biomethane injection can provide further decarbonisation, potentially in combination with hybrid heating systems. The development of low carbon heat networks could potentially use hydrogen as the heat source, and this may be suitable for multi-occupancy buildings (MOBs).

Homes with space constraints may not be able to fit a heat pump and the associated hot water tank, these homes are likely to be better suited to a hydrogen conversion. Older, less well-insulated homes would be decarbonised more cost-effectively through hydrogen, with less expensive retrofitting needed.

Finally, remote communities with their own discrete gas networks (SIUs) would need a bespoke solution, given that they would not be able to access hydrogen from the main grid. In these cases, local hydrogen production and storage, including from local renewable facilities, could be installed.

[36] English Housing Survey 2018: energy report, Annex Table 2.8 https://www.gov.uk/government/statistics/english-housing-survey-2018-energy-report

IF A 20% HYDROGEN BLEND WAS ROLLED OUT ACROSS THE COUNTRY IT COULD SAVE AROUND 6 MILLION TONNES OF CARBON DIOXIDE EMISSIONS EVERY YEAR, THE EQUIVALENT OF TAKING 2.5 MILLION CARS OFF THE ROAD.

CO_2

2.5 MILLION

Greater than **99.9%** supply availability

More than **175,000** miles of gas distribution pipeline

22 MILLION homes use gas for heating and cooking

85% of UK households are connected to the gas grid

Emissions from **residential combustion** represent 15% of UK CO_2 emissions and must be reduced

Compared to electricity, customers on gas are half as likely to be fuel poor

Over 1 million gas boilers are installed each year Mandating hydrogen ready boilers now makes perfect sense

ena energynetworks association

3. HOUSEHOLDS

3.3 ENERGY DEMAND REDUCTION

Whatever options we choose to transform our heating systems, we need to start with a country wide programme of improving the energy efficiency of our housing stock. This is a key "no regrets" step as it reduces both energy related emissions and the cost to the consumer.

Household gas use has been steadily declining for more than 15 years, primarily due to improvements in energy efficiency, including the introduction of condensing boilers. Were these energy efficiency gains to be continued, they could lead to dramatically lower domestic gas use in the future, making a hydrogen transformation more straightforward, reducing the extent of network reinforcement, hydrogen production and storage needs.

2003-2017 – WHAT HAS HAPPENED

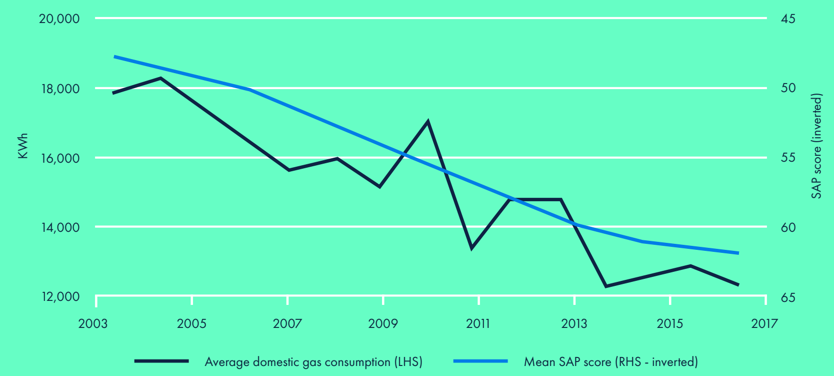
AVERAGE DOMESTIC GAS CONSUMPTION

As the chart below shows, between 2003 and 2017, average building SAP scores (a composite measure recording the overall energy efficiency of the building[37]) have increased from 48 to 62. Over the same period, average domestic gas consumption fell from 18,000 kWh to 12,000 kWh – a decrease of a third. The inverse correlation between average SAP scores and average domestic gas consumption is very strong, at -0.91, meaning that greater building efficiency reduces gas demand considerably.[38]

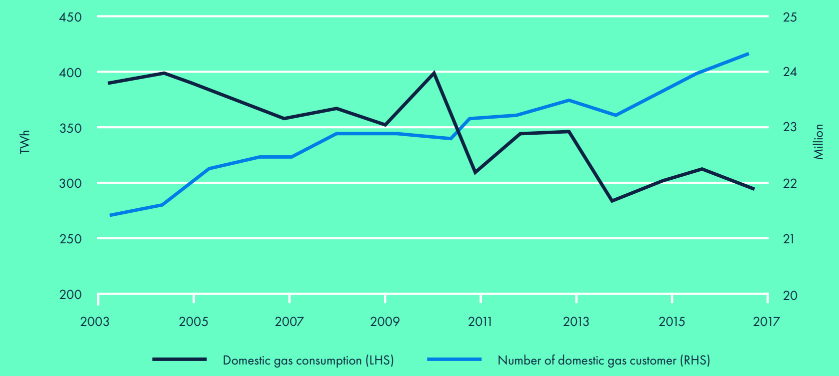
TOTAL DOMESTIC GAS CONSUMPTION

Declining average consumption has meant that, even though the number of domestic gas connections has increased from 21.4 million to 24.2 million over the period, total domestic gas consumption has fallen from 386 to 295 TWh, a decrease of nearly a quarter.[39]

AVERAGE SAP RATING AND AVERAGE DOMESTIC GAS CONSUMPTION



TOTAL DOMESTIC GAS CONSUMPTION AND NUMBER OF CUSTOMERS



[37] An SAP calculation indicates a score from 1 to 100+ for the annual energy cost based on: - The elements of structure, - The heating and hot water system, - The internal lighting, - The renewable technologies used in the home. The higher the score the lower the running costs, with 100 representing zero energy cost. Dwellings with a rating in excess of 100 are net exporters of energy. For more explanation of the SAP system, see https://www.eden.gov.uk/planning-and-building/building-control/building-control-guidance-notes/sap-calculations-explained/#:~:text=Building%20 Regulations%20require%20that%20a,heating%20and%20hot%20water%20system

[38] Total domestic gas consumption – BEIS, DUKES – Natural Gas; Number of domestic gas connections – United Kingdom Housing Energy Fact File to 2011; BEIS, Sub-national electricity and gas consumption summary reports from 2012; SAP score – 2017-18 English Housing Survey Headline Report (assumed similar for Scotland, Wales and Northern Ireland)

[39] Total domestic gas consumption – BEIS, DUKES – Natural Gas; Number of domestic gas connections – United Kingdom Housing Energy Fact File to 2011; BEIS, Sub-national electricity and gas consumption summary reports from 2012; SAP score – 2017-18 English Housing Survey Headline Report (assumed similar for Scotland, Wales and Northern Ireland)

3. HOUSEHOLDS

THROUGH TO 2030 – WHAT MIGHT HAPPEN

DOMESTIC GAS CONNECTIONS

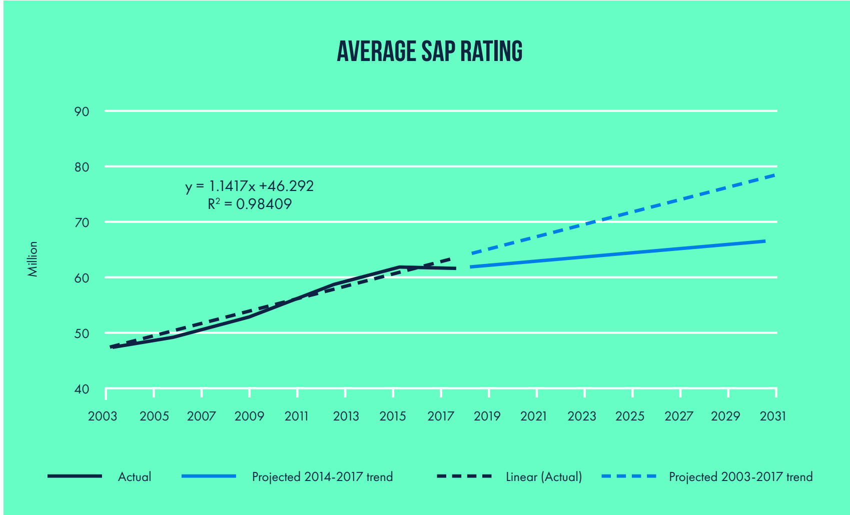
Since 2000, there has been a steady growth in the number of domestic gas connections. If we project the trend forward until 2025, then around 26.5 million households would be connected to gas. We conservatively assume that new connections stop after 2025, although policy in this area has not yet been confirmed.[40]

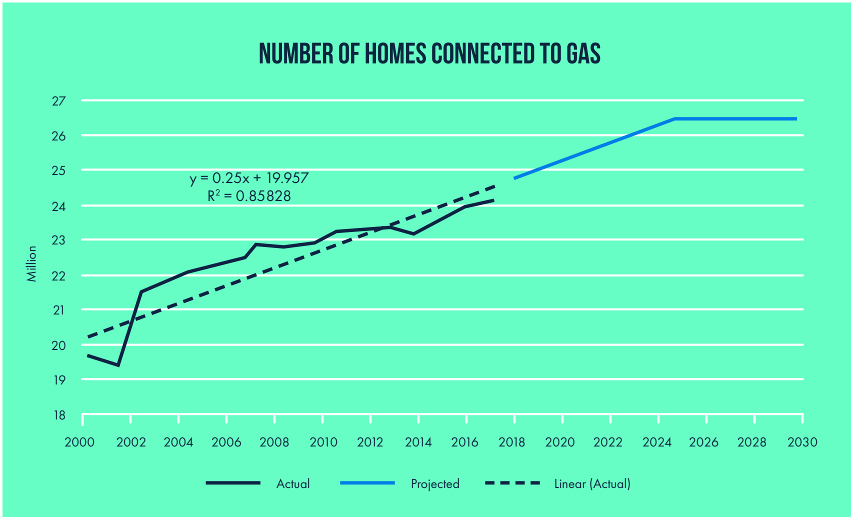
ENERGY EFFICIENCY SAP SCORE

The trend between 2003 and 2017 in average SAP score improvements has been very consistent, apart from a slowing down of improvements between 2014 and 2017. Projecting forward, the 2003-2017 trend would mean that average SAP scores rise to 78 in 2030. On the other hand, projecting forward the 2014-2017 trend would mean that average SAP scores increase to 67. As we show below, this has a significant bearing on projections for gas demand:[41]

- There are reasons to believe that building SAP scores will continue to rise – only 48% of homes have cavity wall insulation and only 38% have 200mm or more of loft insulation. The 2019 Conservative election manifesto pledged to implement energy efficiency measures that would lower energy bills by £9.2 billion for homes, schools and hospitals – if three quarters of the overall saving went to homes, this would equal bill savings of £250 per home.

- On the other hand, other energy efficiency measures are nearing completion, with 85% of homes having double glazing and 74% of homes with condensing boilers.





[40] Number of domestic gas connections – United Kingdom Housing Energy Fact File to 2011; BEIS, Sub-national electricity and gas consumption summary reports from 2012; Projections – assumed trendline of 2000-2017 continues until 2025, when new homes no longer connected to the gas grid, based on government announcements, but not yet legislation
[41] SAP score / energy efficiency measures – 2017-18 English Housing Survey Headline Report (assumed similar for Scotland, Wales and Northern Ireland); Election pledges – Conservative election manifesto 2019

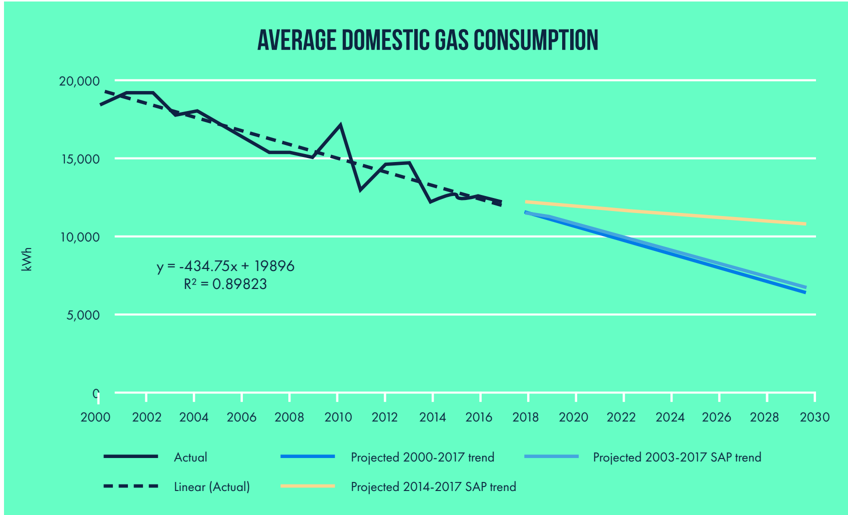
3. HOUSEHOLDS

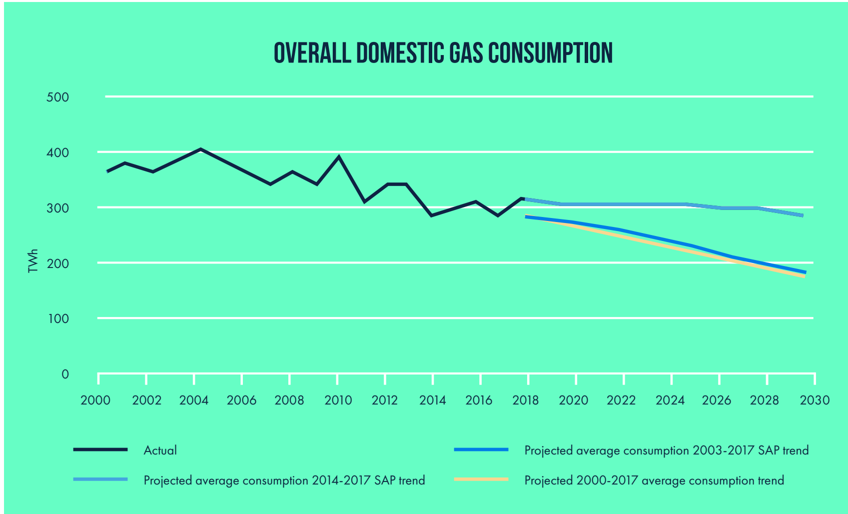
SCENARIOS FOR AVERAGE DOMESTIC GAS CONSUMPTION

The chart below sets out three scenarios for average domestic gas consumption through to 2030 – based on the 2003-2017 SAP score trend (given the very high inverse correlation between SAP scores and average consumption). The scenarios vary widely, with domestic gas consumption falling from 12,000 kWh to around 6,500 kWh if the trends over the last 15 years are maintained, or a much smaller fall to 11,000 kWh if only the last three years' projected trend is followed. The chart shows just how great the impact of energy efficiency can be on future gas demand and emissions reduction.

SCENARIOS FOR OVERALL DOMESTIC GAS CONSUMPTION

Given the projected number of gas connections, as explained above, the chart below shows overall domestic gas consumption through to 2030, based on the three scenarios. If the trend of the last three years is followed, then overall consumption remains at almost 290 TWh, with increasing connections offsetting lower average use. If, however, the previous 15 years' trend is followed, then overall domestic use falls to around 175 TWh.





3. HOUSEHOLDS

3.4 DELIVERING A HYDROGEN TRANSFORMATION

PATHWAYS TO 100% HYDROGEN

Conversion to 100% hydrogen will not be achieved in a single step. However, there are four parallel tracks which combined can deliver the pathway for 100% conversion for the network and meet the ambition of the Government's Ten Point Plan.

BLENDING	HYBRID HEATING	PREPARATION FOR 100% CONVERSION	BILLING
Blending achieves emissions reductions, allows consumers to become familiar with hydrogen without needing to change appliances, and provides a kick start to the market for hydrogen production.	Hybrids reduce gas demand and so reduce emissions. They make a hydrogen conversion easier, by reducing the volume of hydrogen needing to be transported and stored, and they also avoid the need for huge peaks in electricity demand. They can also be delivered with a hydrogen-ready boiler element.	Hydrogen Neighbourhood and Village preparatory demonstration projects and trials are vital to establishing the safety case, demonstrating the practical conversion methodology for a full hydrogen roll out.	Ensuring that the different types of gases in the network are metered based on their energy content rather than volume, is critical to producing accurate bills for consumers, whether in areas seeing hydrogen blending, hybrids or a full hydrogen conversion.

BLENDING AS AN INITIAL STEP

Blending hydrogen into gas networks, at up to 20% by volume, starting in 2023, would allow substantial reductions in emissions without any changes needed to household appliances and pipework, and enable consumers to become familiar with hydrogen.

If a 20% hydrogen blend was rolled out across the country it could save around 6 million tonnes of carbon dioxide emissions every year, the equivalent of taking 2.5 million cars off the road.[42] Rollout of a 20% blend could be achieved in the 2020s, and would make a material impact on emissions, setting us on a clear pathway to net zero. This was acknowledged in the Government's Ten Point Plan, with a target date of 2023 for the testing work to have been completed to enable blending to start.

The HyDeploy 1 trial is currently injecting up to a 20% blend of hydrogen by volume to 130 homes and faculty buildings at Keele University in Staffordshire. Results show that gas appliances using the blend are functioning normally and householders and campus businesses haven't noticed any differences to their gas supply. The research shows that the majority of participants are supportive of the project, with some genuine excitement about being part of it. Consumers value the environmental benefits of the project and appreciate the minimal disruption to their lives and the minimal effort required to 'do something good.'[43] The next phase – HyDeploy 2 – will see a 20% blend provided to 670 homes near Gateshead. These subsequent demonstrations are designed to test the blend across a range of networks and customers so that the evidence is representative of the UK as a whole.

[42] See https://cadentgas.com/news-media/news/may-2020/hydeploy-update
[43] Cadent, Positive results from the UK's first grid-injected hydrogen pilot, May 2020 https://cadentgas.com/news-media/news/may-2020/hydeploy-update

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HYBRID SOLUTIONS

A hybrid heating solution is an integrated solution in which a gas boiler is used to provide back up to a heat pump (usually air sourced). The heat pump provides background heating, and the boiler provides additional energy input to the property during peak demand times such as cold weather, or in the case of a rapid ramp-up in the morning or evening. Trials in the Freedom project [44] illustrated that a hybrid solution can use electricity up to 80% of the time, the remainder being powered by gas. Continuing innovation in this area has now seen the arrival of compact hybrid systems.

A compact hybrid is an integrated boiler and heat pump in a single cased product. The HyCompact project, will trial a 30 kW boiler and completely sealed 4 kW output heat pump in a single compact unit. It can be installed by any registered Gas Safe installer in a single installation process, without requiring an additional F-gas-registered installer[45] to be present. The boiler and heat pump work in tandem, with a Smart Controller, controlling the heating system to optimise the cost to the consumer and reduce the carbon output.

The ongoing HyHy project is providing a better understanding of the relationship between deploying domestic hybrid heating technology – where a smaller heat pump provides most of the heating and a gas boiler provides heating during the coldest periods – and hydrogen supply to achieve an optimised energy strategy, to inform business plan development[46]

A typical HyCompact Hybrid system. Image credit: PassivSystems

[44] Freedom Project https://www.wwutilities.co.uk/media/3860/freedom-project-final-report.pdf
[45] The F-Gas Register is the online F-Gas company certification register, as appointed by the Department for the Environment, Food and Rural Affairs (DEFRA) under the 2015 no310 UK Fluorinated Greenhouse Gases Regulations. This is an approval needed for heat pump installers.
[46] See https://www.smarternetworks.org/project/nia_wwu_060

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PREPARATION FOR 100% CONVERSION – HYDROGEN TRIALS

The gas networks are working together with BEIS, Ofgem and other stakeholders to deliver a set of trials to show that networks can be converted to 100% hydrogen and deliver cost effective heat safely to domestic consumers. The evidence and learning from the trials will be available by 2025 although some trials will continue to run beyond 2025. The hydrogen consumer trials are one step on a five-step evidence pathway that starts with desktop studies and ends with full-scale roll out of conversion to 100% hydrogen. The hydrogen trials will demonstrate that the various transmission and distribution network conversion end-states are safe, secure, affordable, environmentally sustainable and acceptable to stakeholders. These trials and pilots will meet the Government's aim, set out in the Ten Point Plan, for a Hydrogen Neighbourhood, then a Hydrogen Village and a larger Hydrogen Town by 2030.

DESKTOP

- Feasibility study
- Gather evidence
- Gap analysis
- Outline design on project
- Define objectives

OFF-LINE TRIALS

- Laborotory tests
- Detailed design and testing plans
- Build bespoke full-scale test facilities
- Off-line tests of systems and assets
- New safety and mitigation evidence
- Use scientific methods

TRIALS

- On live network
- Build customer base
- Reversible with natural gas back-up
- HSE derogation or exemption
- Fixed time
- Validation risks
- Procedures and standards
- Training and skills
- Inform policy

PILOT

- Live regional or open network
- Nationally coordinated
- Desgined to new standards
- End-to-end conversion
- Not fixed time
- Likely to be clusters
- Develop roll-out logistics
- May stimulate other trials

ROLL OUT

- Hydrogen established as safe low-carbon fuel
- Build out hydrogen production, CCS and skill
- Conversion from fossil methane mandated
- Both natural gas and hydrogen networks required during transition

3. HOUSEHOLDS

There are several key evidence paths that will be demonstrated during the trials. In order to be able to deliver this evidence robustly, more than one trial is needed. The gas networks are therefore working together to deliver the key evidence at sufficient confidence levels to engage with their stakeholders. There are six areas of research evidence that will be delivered by the trials and these are shown below.

REGULATORY AND COMMERCIAL	HYDROGEN PRODUCTION	NETWORK	CONSUMERS	VALIDATE SAFETY	INITIATE MARKETS
• Gas Act • Consumer consent • Ofgem • GT Licence • Billing & Gas (COTE) • HSE • Stakeholders • Planning	• Power • Electrolyzer • Methane reforming • Storage • Injection • Controls • Measure and monitor	• Conversion/new network infrastructure • Operate • Measure and monitor • Analyse • Network trainin and competency	• Service pipes • Meters • Excess flow valves • Appliances • Consumer experience • Billing • Appliance installation trainin and competency	• Implement QRA mitigations • Validate the QRAs with real data	• Supply chain • Hydrogen supplies • Consummer appliances • Training and competency

STAKEHOLDER EVIDENCE AND LEARNING

3. HOUSEHOLDS

Collectively, the networks are working to ensure that trials will provide the evidence required to demonstrate that:

- Current levels of network performance and customer safety will be maintained.
- Current levels of energy security for customers will be maintained, both on the pathway to the system transformation (during conversion) and at the end states.
- Networks can link consumers with sources of green hydrogen or blue hydrogen (centralised or distributed).
- Solutions are cost effective for consumers both during, and after, the transformation by providing data to inform funding models.
- Relevant stakeholders have been fully engaged and consulted.
- Trials are reversible, in other words, consumers can go back to natural gas if needed.
- Evidence is statistically significant.

Three proposals have been developed for hydrogen trials on live gas distribution networks that involve domestic consumers:

H21 PHASE 3A AND 3B will be conversion trials which will follow on from the HyDeploy 2[47] hydrogen blended trials. Phase 3a would involve 50 customers who would be supplied with 100% hydrogen from the electrolyser used for HyDeploy 2. Phase 3b would require additional hydrogen production and storage to be installed and this will enable all customers in the area to be converted. The electrolyser will be powered by green grid electricity

H100 FIFE PHASES 1 AND 2 will provide customers with hydrogen supplied by a new pipeline which will run in parallel with an existing natural gas pipeline. In Phase 1, about 300 customers with homes sited along the new hydrogen pipeline will be able to opt into the trial. In Phase 2, an additional 300 customers, would be converted in small groups such as housing estates or cul-de-sacs. Hydrogen will be produced by an electrolyser powered by electricity from a wind turbine. There are some multiple occupancy buildings within the area giving the opportunity to develop hydrogen options for this critical group of property types.

[47] The HyDeploy2 trial aims to supply up to 20% hydrogen blended with natural gas into the network. This follows the successful delivery of HyDeploy by Cadent at Keele University campus.

3. HOUSEHOLDS

HYNET HOMES will demonstrate the scale, size and complexity of regional and national hydrogen conversion with a much larger group of customers adjacent to the North West industrial cluster – potentially around 2,000 properties, including domestic, commercial and light industrial consumers. This trial will build on the learning from H21 and H100 and is planned to follow once these two trials are well established. The hydrogen will be produced by reforming natural gas supplied from the NTS with carbon capture and storage (blue hydrogen). The trial will involve new hydrogen pipelines and conversion of existing natural gas pipelines.

HYDROGEN PILOTS

Each trial progressively unlocks the ability to run 100% hydrogen conversion pilots, which are the next stage in evidence gathering. The learning and evidence gathered from the Hydrogen Neighbourhood and Village trials will enable decisions to be made on pressing ahead with a Hydrogen Town by 2030. Pilots comprising many tens of thousands of homes are a significant commitment, so it is crucial that the trials progress rapidly to completion to unlock the potential that the pilots will deliver.

Hydrogen trials will have been run by granting regulatory derogations, exemptions and developing bespoke commodity balancing arrangements. For hydrogen pilots, Ofgem, BEIS and HSE will require more permanent regulatory and commercial solutions – some of the learning for this will come from the trials, and their effectiveness at delivering the desired outcomes.

BILLING AND NETWORK OPERATION

The Future Billing and Real-Time Networks projects are developing the methods to enable a wider range of gases to be added to the networks, including biomethane and hydrogen, whilst ensuring that consumers are charged fairly for the energy content, rather than the volume, of those gases. This is a critical enabling step to introducing hydrogen into gas networks, either as a blend or through full 100% conversion.

HyNet North West

REAL-TIME NETWORKS

Future Billing Methodology

3. HOUSEHOLDS

3.5 BENEFITS

HYDROGEN SUPPLY AND EMISSIONS SAVINGS

The ENA Pathways to Net Zero report concluded that, in the balanced scenario, 140 TWh of hydrogen would be supplied to buildings in 2050. If the hydrogen is replacing natural gas, which if combusted directly has emissions of around 185 g/ CO_2 per kWh, plus an additional 35 g/CO_2 per kWh in the natural gas supply chain, then 140 TWh of hydrogen would save around 24 million tonnes of CO_2 per annum.

ECONOMIC OPPORTUNITIES

Looking at domestic end use specifically job creation could be significant:

- A recent analysis by the Hydrogen Taskforce estimated that almost 10,000 new jobs would be created by 2035 through the conversion of buildings to hydrogen, generating £2.5 billion of GVA, with 55 TWh of hydrogen providing residential and commercial heat by 2035.[48]
- The H21 North of England report showed that a widespread conversion of homes to hydrogen would require over 3,000 gas engineers for a number of years, with additional management staff.[49]

3.6 PERSPECTIVES FROM STAKEHOLDER ENGAGEMENT

As detailed in Appendix 1, we have carried out extensive stakeholder engagement for the project, including two well attended workshops and several focused discussions. The stakeholders we spoke to made the following key points for households:

Hydrogen-ready boilers: Mandating hydrogen-ready boilers is a low regrets policy, even for areas that do not convert subsequently. Boiler manufacturers have already received enquiries from consumers interested in purchasing hydrogen-ready boilers, they are ready to tool up their factories to roll out hydrogen-ready boilers from 2025, but they are waiting for a government decision on this. Government needs to act now to mandate hydrogen ready boilers for 2025 or earlier.

Costs: Costs to consumers and the risks of fuel poverty matter, and hydrogen will cost more than natural gas today (as will all other options) – the issue of who pays and how much is therefore critical. Consumer engagement must start now, and lessons need to be learned from previous programmes such as the smart meter rollout.

Blending: Blending up to 20% hydrogen is an ideal way to begin the dialogue with consumers about decarbonisation, as well as delivering interim carbon savings whilst building up hydrogen production and storage facilities and installing hydrogen ready boilers.

Hydrogen availability for domestic conversion: The biggest challenge raised was that in the main, the industrial clusters are planning to produce enough hydrogen for their own use, but not to provide additional production capacity for a domestic conversion. Potential suppliers also felt that there was no business model to produce hydrogen for domestic use, and that government was most interested in hydrogen for industry at present. By the time enough hydrogen is available for domestic conversion – in the mid-2030s and beyond – there is a risk that it will be too late to deliver the decarbonisation pathway outcome. It is therefore important the Government's Hydrogen Strategy, expected in 2021 provides a means of supporting producers to meet the target set out in the Ten Point Plan of 5GW of hydrogen production capacity by 2030, and 1GW by 2025.

Regulation: Consumers need continued protection within a regulated market. There should be a national action plan to achieve net zero, with all technologies on the table.

In addition, the H21 social sciences research project, carried out by Leeds Beckett University, included 12 discovery interviews, a poll of 1,000 people and six deliberative workshops held in Leeds, Manchester and Birmingham.[50] Consumers wanted to know what the changes would mean for them specifically, although many were supportive, for example:

- "If it helps the environment it's a great thing although would need to know if it would affect my hob and boiler."
- "I would want to know what this gas was, how it was better for the environment, where it came from, how long it would last, how much it would cost getting into all UK households."
- "It sounds a bit like a no-brainer."

[48] Hydrogen Taskforce, Economic impact assessment (EIA) of the hydrogen value chain on the UK by 2035 https://www.hydrogentaskforce.co.uk/resources/
[49] H21 North of England, 2018, pp.284-285 https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf
[50] See https://www.h21.green/projects/h21-social-science-research/

3. HOUSEHOLDS

3.7 MEETING BRITAIN'S HYDROGEN NETWORK PLAN TENETS

For households, the four Hydrogen Network Plan tenets are met through the projects focused on households, and the cross-sector network projects, as summarised below:

ENSURING PEOPLE'S SAFETY:

- The Hy4Heat programme (led by BEIS) is putting together the **domestic** 100% hydrogen safety case, including end-user appliances.
- H21 Phase 1 and Phase 2, as well as H100 Fife, are delivering the **distribution grid** 100% hydrogen safety case.
- HyNTS Future Grid Phase 1 is investigating the safety and feasibility of repurposing the **transmission grid** to either a blend of or 100% hydrogen, though a high-pressure test loop at DNV GL's Spadeadam facility (this project is also important for security of supply).
- Other proposed network safety and impacts **safety studies**.

MAINTAINING SECURITY OF SUPPLY:

- The proposed projects on transmission modelling, distribution modelling and System Operator transition to hydrogen projects will ensure that a hydrogen transmission and distribution network **would have sufficient physical network capacity and resilience** to meet demand peaks, including effective **System Operation**.
- The Gas Markets Plan (GMaP) project is investigating **market frameworks for hydrogen** in gas networks.
- The Aberdeen Vision project (new network element) has investigated the requirements of **new hydrogen networks**, and the forthcoming HyNet Homes project will do likewise.
- Project Cavendish and H100 Fife would see **hydrogen production directly connected to gas networks**, as would the forthcoming H21 Phase 3 and HyNet Homes projects.

FOCUSSING ON PEOPLE'S NEEDS:

- H100 Fife will deliver the **Hydrogen Neighbourhood domestic use trial**, and H21 Phase 3 and Hy Net Homes will deliver the **Hydrogen Village** trials.
- Project Freedom, HyHy and HyCompact are trialling **hybrid heating systems** in homes and investigating hybrid heating together with hydrogen.
- HyDeploy is testing **20% hydrogen blends** at Keele University, and HyDeploy 2 will test 20% hydrogen blends in a small part of the public gas grid, to enable widespread hydrogen blending to start in 2023.
- The Future Billing and Real Time Networks projects will together enable consumers to be **billed on energy content**, rather than volume, allowing blends of hydrogen, natural gas and biomethane.

DELIVERING JOBS AND INVESTMENT:

- The Iron Mains Risk Reduction Programme continues to **replace old iron mains** with polyethylene, which will allow 100% hydrogen to be transported – 60,000 km have been replaced so far, 62.5% of the total.
- Network training modules for hydrogen will be developed to ensure that **hydrogen training** becomes a business-as-usual Gas Safe activity.
- Entry connection standardisation will make it easier to **connect hydrogen production to networks**, whether at small or large scale.
- Cross-sectoral **stakeholder engagement** by the networks will communicate Britain's Hydrogen Network Plan and secure feedback.

Overall, hydrogen presents a viable decarbonisation solution for households, and network projects are putting together the safety cases for domestic appliances and the distribution and transmission grids; modelling the networks to investigate security of supply; and testing the user experience of hydrogen in the home.

4. TRANSPORT

4. TRANSPORT

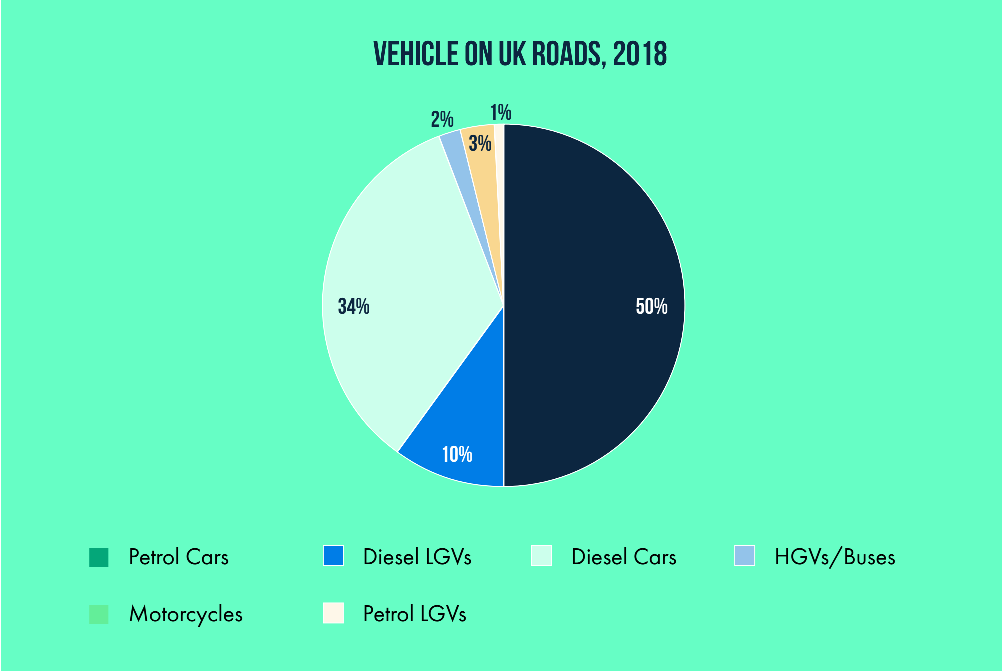
The geographical coverage of the GB gas network makes it an ideal, large scale energy carrier to enable the decarbonisation of several transport sectors. This is recognised in the commitment to zero emissions hydrogen Heavy Goods Vehicles (HGVs) in the Government's Ten Point Plan. This section outlines how converting the gas networks to hydrogen could support the decarbonisation of transport.

4.1 WHERE WE ARE TODAY

Transport is the largest source of UK GHG emissions (27% of the UK total) and, alongside agriculture, is the only sector which saw its emissions rise from 2013 to 2019.[51]

Transport is critical for the UK economy with most businesses reliant on the transport system's ability to rapidly convey goods and personnel. With varied modes of transport, including road, rail, maritime and aviation, this constitutes a wide-ranging opportunity for decarbonisation. The vehicle manufacturing sector and its supply chain also has substantial potential to grow to support the emergence of new energy sources requiring new vehicle designs and fuelling infrastructure.

There are over 38 million licensed vehicles operating on UK roads[52]. Over the last few years there has been a move from diesel cars to petrol cars, but due to their fuel efficiency, and lower fuel cost, the majority of Light Goods Vehicles (LGVs) and HGVs have remained diesel fuelled. The data for 2018 is shown below[53].



[51] BEIS, Provisional UK greenhouse gas emissions, June 2020 https://data.gov.uk/dataset/9a1e58e5-d1b6-457d-a414-335ca546d52c/provisional-uk-greenhouse-gas-emissions-national-statistics
[52] See Department for Transport vehicle licencing statistics: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/882196/vehicle-licensing-statistics-2019.pdf
[53] See data from the Department for Business, Energy and Industrial Strategy https://www.gov.uk/government/statistics/energy-consumption-in-the-uk, especially the Energy Trends special report on transport https://www.gov.uk/government/publications/energy-trends-june-2019-special-feature-article-road-fuel-consumption-and-the-uk-motor-vehicle-fleet

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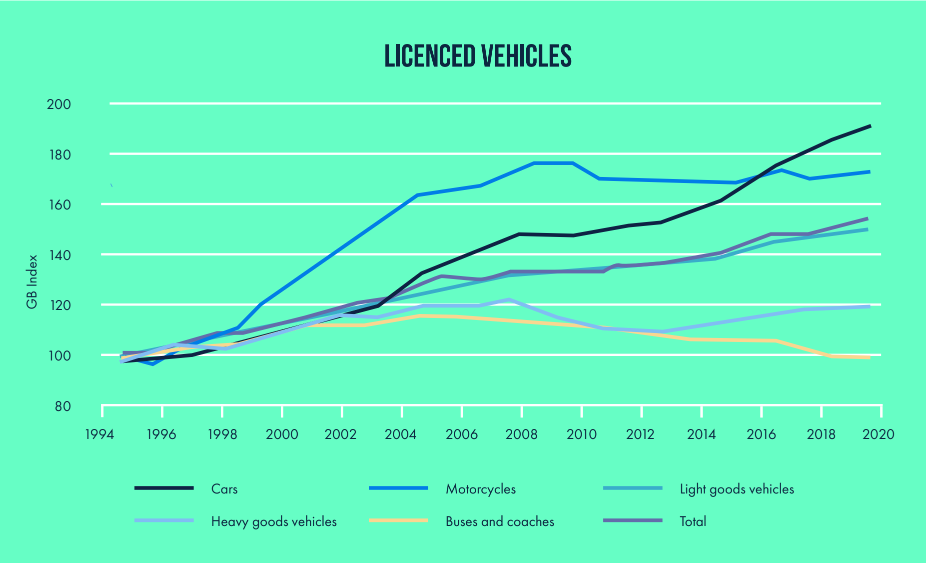
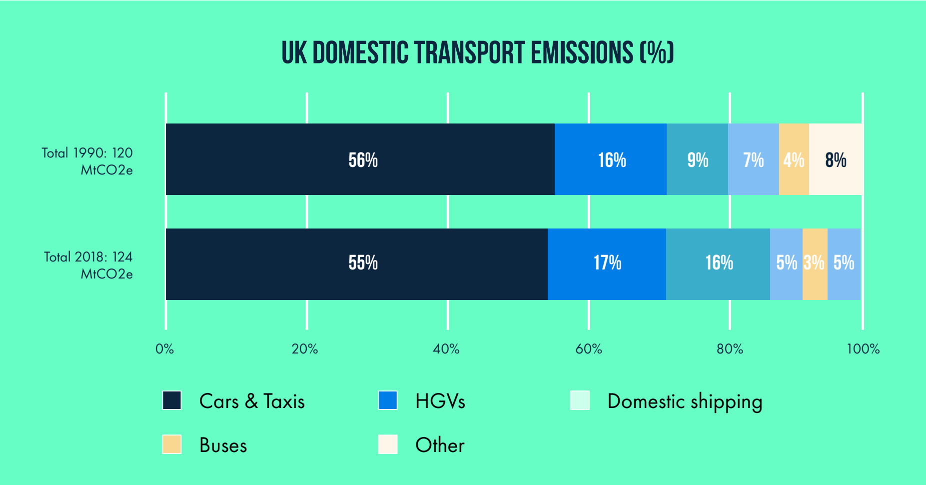
The variation in UK licensed vehicles over the last 25 years is shown in the chart below, based on an index of 100 in 1994.

Even before the COVID 19 impact was felt, with significant increases in home shopping, and a reduction in commuting for work, there was a clear indication that the LGV fleet size was increasing and buses/coaches were declining.

In 2019, out of a total of over 1.5 million vehicles sold, there were 100,000 hybrid electric (HEVs), 17,000 battery electric (BEVs), 18,000 plug-in hybrid electric (PHEVs), and less than 1,000 vehicles using other fuel types. This highlights that the move to low carbon vehicles is starting to increase in but still has a long way to go to begin to dilute the emissions impact of the 37 million vehicles on the road today. The expected future choice for hydrogen conversion in mobile applications is the fuel cell. Measured tank-to-wheel, a fuel cell-based drive train is expected to be more efficient than a gasoline or diesel engine-based drive train.

The distribution of transport types and modes influences the greenhouse gas (GHG) emissions for the sector as shown in the chart below.[54]





[54] For detailed tables on UK transport greenhouse gas emissions see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/850278/env0201.ods

4. TRANSPORT

Around 40% of UK road transport CO2 emissions, are produced by the combined total from light commercial vehicles (LCV), heavy goods vehicles (HGV), buses and coaches. It is in the area of HGVs, that hydrogen is likely to bring the greatest benefits.

Timescales for change can be long and reflect the significant infrastructure changes that will be required and the fact that there is a reluctance from the consumer to be an early adopter of new technologies. The options for change can be classified as:

- **Now** (short - medium term – i.e. by 2025);
- **Soon** (medium – long term – i.e. by 2030); and
- **Future** (long term i.e. by 2040).

	TRANSPORT OPTIONS	CHALLENGES
NOW	Natural gas vehicles for HGVs, LGVs and buses, for both compressed natural gas (CNG) and LNG, with an increasing proportion of biomethane in the mix. Natural gas for marine applications (LNG). Hydrogen in buses and some council vehicles through fuel cells or as a combustion fuel. Hydrogen in limited quantities for cars.	Availability of vehicles and refuelling infrastructure for hydrogen. Availability of LNG bunkering for ships. Expanding options to increase the production of biomethane. Space required for electrolysers.
SOON	Natural gas/hydrogen blends for CNG vehicles. Hydrogen for passenger cars, HGVs and trains. Hydrogen for short sea shipping.	Hydrogen purity standards for fuel cells Acceptability of hydrogen in combustion engines - decarbonisation benefits? Hydrogen storage for shipping.
FUTURE	Hydrogen for aviation and space applications Ammonia or liquid hydrogen for deep sea shipping.	Hydrogen purity standards for aviation. Aviationsafety considerations Safety aspects of ammonia or liquid hydrogen in shipping. Availability of bunkering.

4. TRANSPORT

4.2 THE ROLE OF GAS IN THE TRANSPORT SECTOR TODAY

The global population of gas-powered vehicles (cars, vans, buses and trucks) is over 14 million[55], but the use of natural gas vehicles in the UK has lagged other countries. However, the transport sector has developed to use natural gas in the HGV market (trucks and buses). Today, there are around 700 UK commercial vehicles operating on compressed natural gas (CNG) or LNG, and many of these are now benefitting from the gas pipeline network distribution of biomethane.

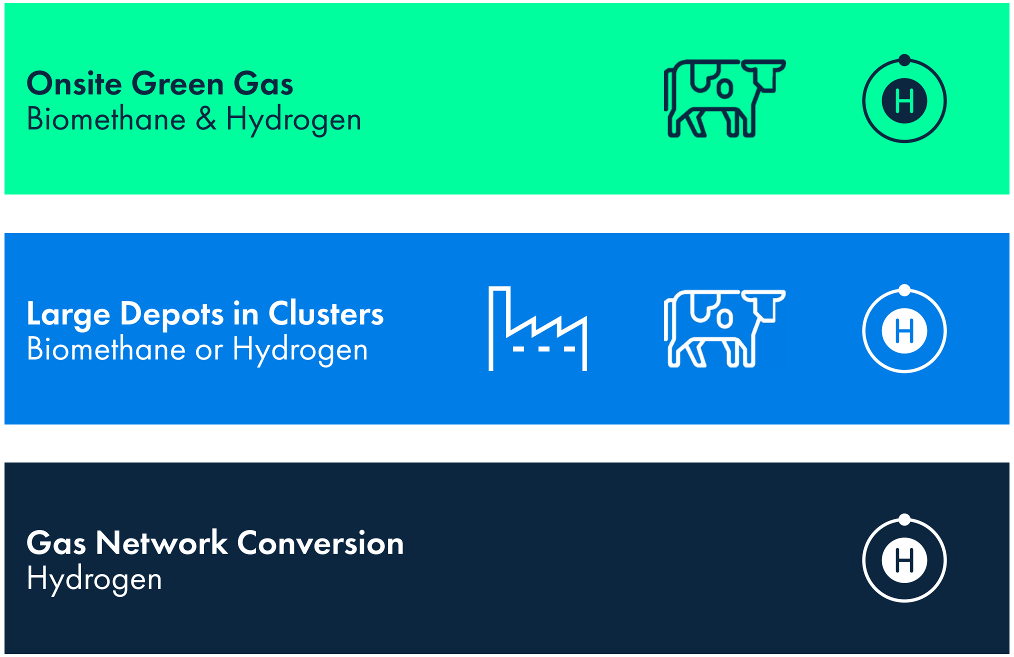
The use of natural gas in transport offers many benefits as an alternative to diesel, and with the expansion to enable greater biomethane use, is already part of the green pathway towards decarbonisation of the transport sector.

4.3 SECTOR SUPPORT FROM THE GAS NETWORKS

The gas networks are already supporting several relevant projects such as the Gas Transport Pathways project, and the Hydrogen Grid to Vehicle (HG2V) project. HG2V was commissioned by Cadent Gas, and was a collaboration between Kiwa Gastec, DNV GL, NPL and Imperial College London, to determine whether the existing gas network could be re-purposed to supply hydrogen for use in fuel cell electric vehicles.

The future deployment of green gases in transport will occur in three models:

1. **Onsite green gas**, in the form of biomethane and hydrogen, where the gas is either generated onsite where space for the electrolyser is sufficient, or delivered via a gas network by road tanker.
2. **Larger depots in clusters** in the form of biomethane or hydrogen. These clusters would suit SuperPlaces and industrial cluster sites, or distribution warehouse complexes. The vehicles being fuelled will typically be LGVs or HGVs but they could also be trains. The presence of a green gas supply on these sites will also enable them to utilise gas for local distribution vehicles, or on-site vehicles such as forklifts, and mechanical handlers.
3. **The provision of hydrogen following gas network conversion** plus onsite purification to achieve the required vehicle hydrogen purity standards for fuel cells and enable a fully national network of hydrogen refuelling stations.



[55] Totals from UK gas vehicle network – see https://www.ngvnetwork.co.uk/natural-gas/gas-vehicles-in-the-uk
Details from the LowCVP workshop can be found at:

4. TRANSPORT

A number of studies have already been completed to evaluate the use of low carbon gases in transport:

- Cenex undertook a trial of gas-fuelled street cleaning vehicles in Camden[56]. The trial evaluated the performance, emissions, reliability and usability of the vehicles fuelled by natural gas and biomethane. The CO2 emission savings when switching from natural gas to biomethane were calculated to be 53%, and there were no significant maintenance issues during the trial.

- Ricardo Energy and Environment investigated the role of natural gas and biomethane in the transport sector focusing on road transport (CNG and LNG) and shipping (LNG). They concluded that for road transport, there were no economic benefits associated with shifting to natural gas, but there were significant benefits to using biomethane.

- In 2019, Cenex published a report[57] entitled "Dedicated to Gas: Assessing the Viability of Gas Vehicles", which formed part of the Low Emission Freight and Logistics Trial (LEFT) project[58]. The project involved extended trials on 20 vehicles fuelled by biomethane, CNG and LNG. The vehicles travelled a combined distance of 2.2 million km and the results demonstrated that compared to diesel there would be at least 17% GHG emission savings with a 25% biomethane blend (B25), and that the use of a 100% biomethane (B100) yielded savings of at least 76% in GHG emissions.

Through the certification of biomethane consumption, it has been reported by the Gas Vehicle Network that almost 80% of the HGV gas refuelling is now from biomethane, based on data from 2019[59]. The European Biogas Association has also highlighted the benefits of natural gas and biomethane use in the road transport sector[60], from both a financial and emissions viewpoint.

CNG Fuels working in close cooperation with Cadent Gas Ltd has built two major HGV refuelling stations in the North West of England at Leyland and Warrington[61]. The refuelling stations are located close to motorway links and distribution centres and this has enabled major companies like John Lewis, Waitrose, Asda, DHL, Argos, Howard Tenens and H Parkinson Haulage to expand their gas-fuelled HGV fleet. Cadent have also committed that all the HGVs in their own operational fleet will be powered by renewable biomethane[62].

Leyland HGV NGV refuelling station. Image credit: Cadent

[56] A copy of the full report can be found at: https://www.cenex.co.uk/app/uploads/2009/07/CENEX-Camden-biomethane-trial-report.pdf
[57] A copy of the full report can be found at: https://www.cenex.co.uk/case-studies/dedicated-to-gas/
[58] Further details of the LEFT project can be found at: https://left.trl.co.uk/
[59] See https://www.ngvnetwork.co.uk/news/renewable-gas-accelerates-hgv-industry-to-carbon-free-destination for a copy of the news article.
[60] Seehttps://www.europeanbiogas.eu/wp-content/uploads/2020/06/EBA_NGVA-Europe_TheEuropeanGreenDeal_FastLaneTransport_20200615_spread.pdf for details.
[61] See information from Cadent Gas website: https://cadentgas.com/news-media/news/january-2018/biogas-demand-triples-at-leyland-cng-station and https://cadentgas.com/news-media/news/april-2020/%C2%A3250,000-boost-to-warrington-s-gas-network
[62] See the following link for more information: https://cadentgas.com/innovation/projects/revolutionising-transport

4. TRANSPORT

4.4 HYDROGEN TRANSFORMATION FOR TRANSPORT

Hydrogen fuel cell vehicles offer drivers a service comparable to conventional liquid fuelled vehicles, with greater range and faster refuelling times than battery electric vehicles. Hydrogen is ideally suited to decarbonise the challenging area of HGVs, trains, ships and buses. The gas distribution networks will provide the infrastructure necessary to enable the delivery of hydrogen to most areas of the UK to support a transport refuelling network under Model 3.

Hydrogen vehicles, potentially, are a more sustainable form of transport than battery power

- Hydrogen refuelling is much quicker
- The energy density of hydrogen is higher as a storage medium
- Lack of refuelling infrastructure is a barrier

The UK Government plans to ban the sale of conventional petrol and diesel fuelled cars by 2030. The Government has also outlined an aspirational plan called "The Road to Zero"[63]. Here it is recognised that there is a significant challenge facing road transport in that:

"More than 60% of UK journeys are by car. More than 75% of the goods we consume travel across the UK in vans and trucks."

[63] To see the full report go to: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf

4. TRANSPORT

The government strategy identifies options including Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) but recognises that there may be benefits from natural gas fuelled vehicles (especially HGVs) in the short term.

In 2018, the Policy Exchange published "Fuelling the Future" to identify the direct and indirect benefits of a switch to hydrogen[64]. The report looked widely at hydrogen from a production and use viewpoint and identified research and investment opportunities to add value for national benefit. The report stated:

"Hydrogen retains certain advantages over electricity as an energy carrier that mean fuel cells can still play a role in the decarbonisation of our transport system. Firstly, hydrogen refuelling is much quicker than charging a battery. Secondly, the energy density of hydrogen is higher as a storage medium than lithium-ion batteries ... hydrogen vehicles, potentially, are a more sustainable form of transport."

Recent announcements from cities such as Aberdeen and Birmingham that they are ordering new fleets of hydrogen fuelled buses has strengthened the case for the use of hydrogen in public transport.

Image credit: Wrightbus Ltd

There is a recurring theme in the available studies on fuel sources in the transport sector which is the lack of an extensive refuelling infrastructure. For natural gas fuelled transport the ability to use the gas network has supported the expansion of CNG refuelling sites. Likewise for hydrogen fuelled vehicles, the ability to utilise a hydrogen based gas network would significantly speed up the adoption of hydrogen as a vehicle fuel. The use of electrolysers and hydrogen refuelling systems has already been demonstrated by several installations designed and built by ITM Power[65], harnessing the benefits of clean hydrogen production by electrolysis to meet the hydrogen purity requirements required for FCEV (as detailed in ISO 16487:2019[66]).

The green gas network of the future will be able to transport hydrogen from large production facilities and deliver it to vehicle refuelling stations where it can be purified to fuel cell standards. Purifying at the point of use will ensure that the cost of hydrogen production is not compromised for general use in boilers, industrial processes or traditional combustion applications. New methods for purification are being developed and form a current area of research[67].

For the transport sector, individual gas network projects like HyMotion and HyNet[68] are leading, with regard to the pipeline delivery of hydrogen to refuelling stations, and the HG2V project[69] has focused on the hydrogen purity requirements. This work also links to the Hy4Heat programme which investigated purity and the required standards for end use[70].

To support the wider adoption of hydrogen in transport, further research and development is underway. The HyTIME (Hydrogen Truck Implementation for Maximum Emission reductions) project led by Ulemco is looking to trial a range of vehicles and associated duty cycles with hydrogen dual-fuel technology[71]. Williams Advanced Engineering is working with Anglo American and DNV GL to develop the powertrain for a mining truck[72] as part of Anglo American's FutureSmart Mining programme. This couples a FCEV with electric drive technology to meet the high-power demands of the mining vehicle and replace the existing diesel engine.

[64] To access the full report go to: https://policyexchange.org.uk/publication/fuelling-the-future/
[65] For details of the sites and designs for the HRS see: https://www.itm-power.com/
[66] The full ISO standard can be reviewed at: https://www.iso.org/standard/69539.html, and is entitled "SO 14687:2019. Hydrogen fuel quality — Product specification
[67] For example, see the current research undertaken by the EU-funded MEMPHYS project: https://www.memphys.eu/
[68] For HyNotion and HyNet information see: https://hynet.co.uk/app/uploads/2019/06/15480_CADENT_HYMOTION_PROJECT_REP.pdf and https://cadentgas.com/innovation/cleaner-greener-future
[69] For information on HG2V see: https://www.smarternetworks.org/project/nia_cad0022 and https://www.kiwa.com/gb/en/areas-of-expertise/hydrogen/kiwa-uk-hydrogen-case-studies/hg2v/
[70] For details see: https://www.hy4heat.info/
[71] For more details on the HyTIME project see: https://gtr.ukri.org/projects?ref=103249#/tabOverview
[72] For further details on the haul truck see: https://www.wae.com/news/2020/02/williams-advanced-engineering-partners-with-anglo-american

ONSITE GREEN GAS

LARGER DEPOTS IN CLUSTERS

HYDROGEN FROM THE GAS NETWORK

REPLACING DIESEL AND FUEL OIL IN HGV'S, TRAINS AND SHIPS WITH 100 TWH OF HYDROGEN WOULD SAVE 20 MILLION TONNES OF CO_2 PER ANNUM

TRANSPORT is now the largest source of UK GHG emissions (27% of the UK total)

Over **38 MILLION** licensed vehicles operating on UK roads

38% of CO_2 emissions from road transport are produced by light commercial vehicles (LCV), heavy goods vehicles (HGV), buses and coaches

More than **60%** of UK journeys are by car

More than **75%** of the goods we consume, travel across the UK in vans and trucks

ena energynetworks association

4. TRANSPORT

4.5 BENEFITS

Hydrogen supply and emissions savings

The ENA Pathways to Net Zero report concluded that, in the balanced scenario, 30 TWh of hydrogen would be used in heavy transport in 2050, although the report did not include the additional benefits of ammonia as a shipping fuel. Other scenarios, including the Committee on Climate Change net zero scenario and two of the National Grid FES scenarios (Consumer Transformation and System Transformation) envisage broadly similar amounts of hydrogen for heavy surface transport, but also up to 70 TWh of hydrogen for shipping in 2050, much of which would be in the form of ammonia.

When hydrogen is replacing diesel and fuel oil, which have emissions of around 250 g/CO2 per kWh, then 100 TWh of hydrogen would save around 20 million tonnes of CO2 per annum.

Economic opportunities

Looking at job creation from hydrogen in transport end use specifically, the Hydrogen Taskforce has found that almost 8,500 jobs and £1.7 billion of GVA could be created by 2035 from 12 TWh of hydrogen use in transport by that date.

4.6 PERSPECTIVES FROM STAKEHOLDER ENGAGEMENT

As detailed in Appendix 1, we have carried out extensive stakeholder engagement for the project, including two well attended workshops and a number of focused discussions. The stakeholders we spoke to made the following key points for transport:

Onsite purification: For hydrogen from gas networks to be used in fuel cell vehicles, onsite purification will be needed. Otherwise the hydrogen will need to be produced by onsite electrolysis or tankered to forecourts. It may also be possible to have central purification and then a dedicated pipe for the last few miles that ensures fuel cell purity levels – this would also mean less hydrogen storage needed at the refuelling station, which may help to manage HSE issues.

Growth: It is likely that the first hydrogen refuelling stations will use onsite electrolysis or have hydrogen tankered, to build the market, and network hydrogen will allow scale-up in the 2030s. However, there will be limited numbers of fuel cell vehicles in the short term, and other counties are likely to see greater penetration in the next few years. Equally, by the time network hydrogen is available at scale – assumed in the mid-2030s – hydrogen refuelling stations may already have secured their supplies.

Clusters or national network: It is not yet clear whether there will be a national network of hydrogen HGVs and refuelling infrastructure, or whether it will be based around industrial clusters, which may help to aggregate demand and link with hydrogen supply. There has been a lack of coordination between the oil and gas industry and the motor industry for liquid fuels, and this may be repeated for hydrogen.

Liquid fuels: Shipping and aerospace were raised, and it was questioned whether gas networks would transport the methane or the hydrogen to make these fuels (ammonia, synthetic fuel, compressed hydrogen or liquid hydrogen). It was thought that ammonia for shipping would take time to break through, and that aircraft manufacturers are starting to move towards cleaner fuels.

Specific uses: Forklift trucks and airport operations lend themselves well to hydrogen, as high utilisation is required, meaning that owners do not want to see their vehicles charging for long periods.

4. TRANSPORT

4.7 MEETING BRITAIN'S HYDROGEN NETWORK PLAN TENETS

For transport, the four Hydrogen Network Plan tenets are met through the projects focused on transport, and the cross-sector network projects, as summarised below:

Ensuring people's safety:

- H21 Phase 1 and Phase 2, as well as H100 Fife, are delivering the **distribution grid** 100% hydrogen safety case.
- HyNTS Future Grid Phase 1 is investigating the safety and feasibility of repurposing the **transmission grid** to either a blend of or 100% hydrogen, though a high-pressure test loop at DNV GL's Spadeadam facility (this project is also important for security of supply).
- Other proposed network safety and impacts **safety studies**.

Maintaining security of supply:

- Proposed projects on transmission modelling, distribution modelling and System Operator transition to hydrogen projects will ensure that a hydrogen transmission and distribution network would have **sufficient physical network capacity and resilience** to meet demand peaks, including effective **System Operation.**
- The Gas Markets Plan (GMaP) project is investigating **market frameworks for hydrogen** in gas networks.
- The Aberdeen Vision project (new network element) has investigated the requirements of new **hydrogen networks**, and the forthcoming HyNet Homes project will do likewise.
- Project Cavendish and H100 Fife would see hydrogen production directly connected to gas networks, as would the forthcoming H21 Phase 3 and HyNet Homes projects.

Focussing on people's needs:

- The H2GV and Cadent Gas Transport Pathways projects are increasing understanding of how networks can enable a widespread **hydrogen refuelling network**.

Delivering jobs and investment:

- The Iron Mains Risk Reduction Programme continues to **replace old iron** mains with polyethylene, which will allow 100% hydrogen to be transported – 60,000 km have been replaced so far, 62.5% of the total.
- Network training modules for hydrogen will be developed to ensure that **hydrogen training** becomes a business-as-usual Gas Safe activity.
- Entry connection standardisation will make it easier to **connect hydrogen production** to networks, whether at small or large scale.
- Cross-sectoral **stakeholder engagement** by the networks will communicate Britain's Hydrogen Network Plan and secure feedback.

Overall, a hydrogen grid would enable wider heavy transport decarbonisation by supplying a national network of refuelling stations. Network projects to prepare for hydrogen transformation are complemented by specific network transport projects to increase understanding of how networks can best enable hydrogen refuelling across the country.

5. INDUSTRY

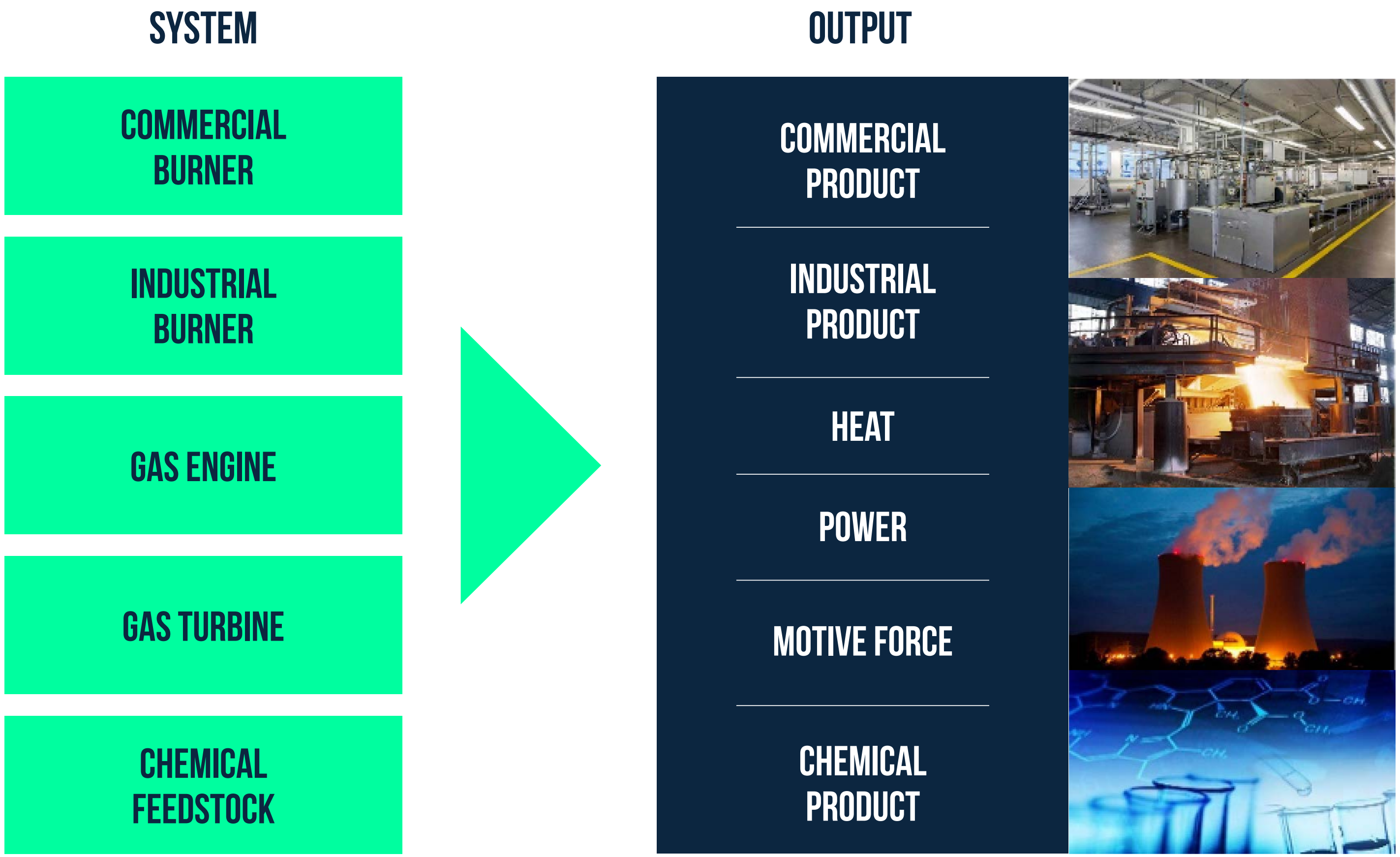
5. INDUSTRY

Almost every industry in the UK today consumes natural gas, either as a feedstock, for process heat, or for space heating. Decarbonising these industries is key to protecting jobs, supporting the economy and enabling exports. It is networks that connect industry with transport, power and CCUS, enabling SuperPlaces and industrial clusters but also non clustered industry throughout Great Britain. This section outlines how a green gas network can help to decarbonise industry.

5.1 ROLE OF GAS IN INDUSTRY TODAY

The figure shows the industrial and commercial systems in which gas is used alongside the outputs it produces.

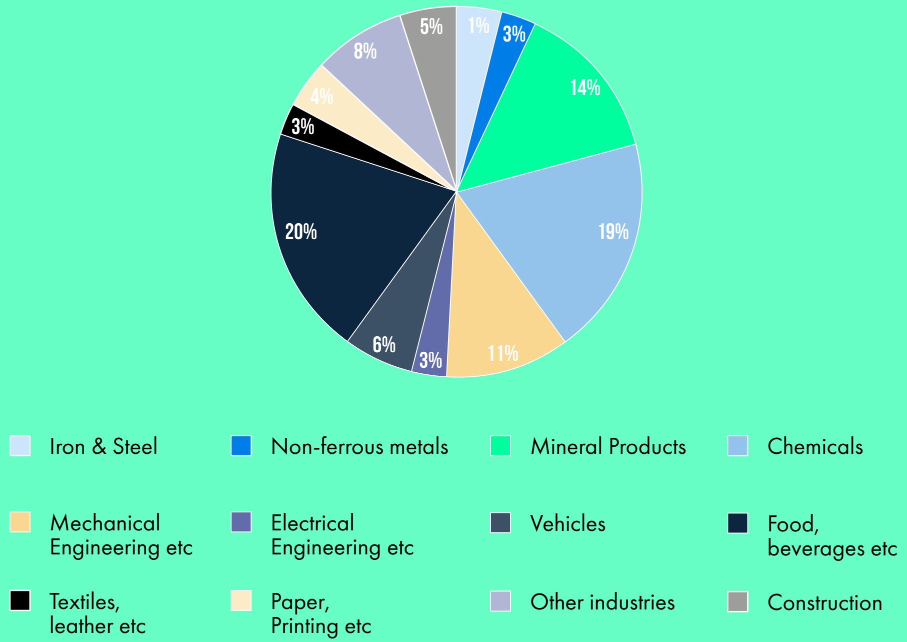
Natural gas is used in a wide variety of industries as illustrated in the chart, which shows the gas use of the industrial sector in 2019.[73]



[73] Digest of United Kingdom Energy Statistics (DUKES) 2020: dataset, Table 1.1 Aggregate energy balance 2019

5. INDUSTRY

NATURL GAS USE BY INDUSTRY SECTOR IN 2019



Industry today uses natural gas predominantly in burners, engines and turbines. It also uses natural gas for space heating and as a feedstock.

GAS BURNERS

Gas quality changes alter flame shape, stability, heat transfer and emissions and all factors could result in a change to the operation of the overall system.

There is a wide range of potential applications for industrial combustion burners. They will be set-up and operated to meet the demands of the process including heat input, efficiency, throughput and stability. Optimum burner performance will be influenced by the gas quality range of the fuel and the variability and time-dependent fluctuations in quality. Hydrogen content of the fuel gas will also impact on the overall process operation.

GAS ENGINES

Natural gas is a clean fuel for use in gas engines, compared with diesel and petrol (gasoline). Gas engines for vehicles and stationary applications are widely available, and the combustion characteristics of natural gas enable it to be used in Spark Ignition (SI) and Compression Ignition (CI) engines.

GAS TURBINES

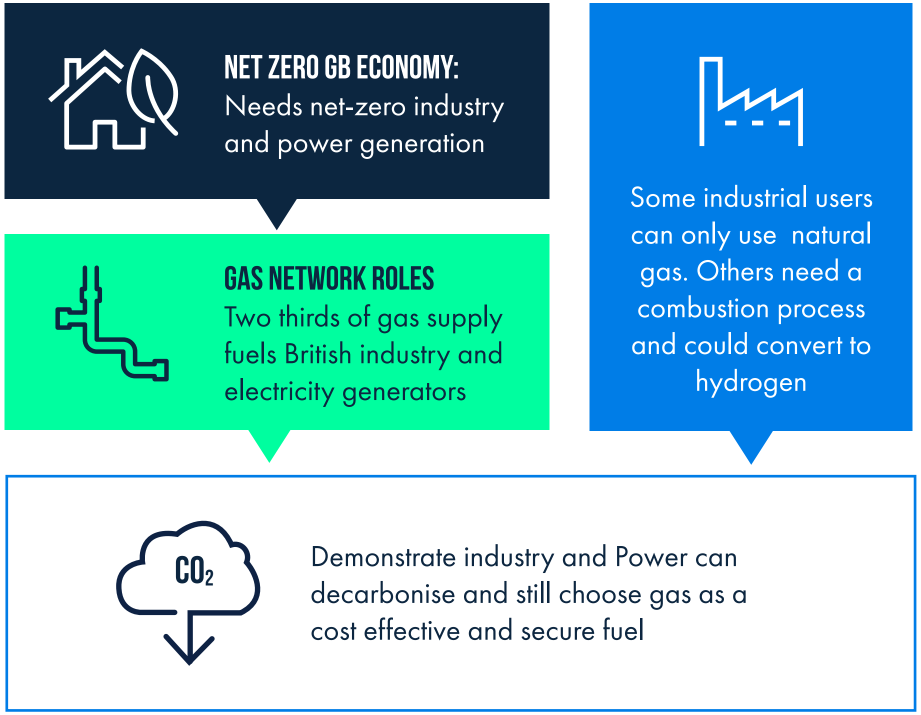
Gas turbines are used extensively for medium and large-scale power generation systems, and for compressors, especially those used to move gas around the high-pressure gas transmission system. They are the favoured technology option for many applications, as they are relatively low polluting.

5. INDUSTRY

5.2 SECTOR SUPPORT FROM THE GAS NETWORKS

Existing network-supported industrial decarbonisation projects

The figure below illustrates the role of gas networks in decarbonisation of heat and power generation in industry.



The role of the gas networks in providing heat to industry and power generation.

The following network-supported decarbonisation projects are of relevance to the industrial sector:

- The Cadent HyNet project is planning to supply a selection of industrial and commercial companies in the North West of England with 100% hydrogen; these cover the food, fertiliser, manufacturing, oil refining, glass and cereals industries.
- Projects at the Isle of Grain (Cavendish) and in Aberdeenshire (Aberdeen Vision) are considering how hydrogen could be made available to industrial users.
- GERG and CEN Hydrogen/H2NG Initiative – Investigating barriers to hydrogen injection in several areas including Industry.
- Burner Control System – DNV GL is in the process of running a Joint Industry Project (JIP) to develop a burner control system that will enable industry to operate on natural gas, hydrogen and all the mixtures in between.
- The SGN, Opening up the Gas Network project looked at widening the GS(M)R network limits. Allowing a wider range of gas quality in the network would increase security of supply and contribute towards decarbonisation by reducing processing.
- National Grid led a project on hydrogen deblending in the gas network to review the techno-economics of utilising existing deblending technology in defined case studies for gas transmission and distribution networks. Working with the GDNs, this project has assessed scales, volumes, purity, gas quality and pressure requirements for each case study. Findings will lead to the identification and scope of a project to demonstrate deblending at scale.

5. INDUSTRY

5.3 HYDROGEN TRANSFORMATION FOR INDUSTRY

HYDROGEN SUPERPLACES AND IN INDUSTRIAL CLUSTERS

The UK currently uses around 27 TWh of hydrogen[74], almost all of which is produced from steam methane reforming or partial oil oxidation, primarily for ammonia production and in petrochemicals.

Although there is considerable industrial capacity dispersed around the country outside these clusters, the large industrial clusters are critical to achieving net zero in practice. This is because their shared infrastructure – including for hydrogen and CO2 – can be developed and used by multiple facilities. The clusters are also major energy supply hubs, with offshore wind cables and offshore gas pipelines coming to shore at these locations. These clusters therefore benefit from major economies of scale to deliver considerable emissions abatement. Networks will help achieve the Government ambition of two industrial clusters by mid 2020s and the aim for four by 2030, but as detailed below networks are supporting all clusters and there is potential for significant emissions reduction.

The UK has six main industrial clusters, as set out in the table below, with their CO2 emissions.[75]

CLUSTER	CO² EMISSIONS (MILLION TONNES)
Zero Carbon Humber	12.4
South Wales Industrial Cluster	8.2
Grangemouth	4.3
Net Zero Teesside	3.1
HyNet	2.6
Southampton Water	2.6

[74] Committee on Climate Change (2018), Hydrogen in a low-carbon economy. https://www.theccc.org.uk/wpcontent/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf
[75] BEIS, What is the Industrial Clusters mission? https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803086/industrial-clusters-mission-infographic-2019.pdf

5. INDUSTRY

Industrial hydrogen production and the gas networks

"Green" hydrogen uses renewable/low carbon electricity to create hydrogen through electrolysis of water. "Blue" hydrogen is produced from natural gas with the use of CCS, e.g. via steam methane reforming (SMR) or autothermal reforming (ATR).

Bulk "blue" hydrogen facilities will be located at industrial clusters, near to existing entry points to the NTS, and/or distribution networks and co-located with CCS facilities. New hydrogen production facilities in clusters can directly connect to distribution networks as they are already embedded in the LDZs and likely have distribution network assets and connections within the cluster.

Each cluster has detailed plans to achieve deep decarbonisation of multiple facilities using shared infrastructure and hydrogen created onsite, or delivered via the gas networks:

HyNet:
in the North West of England would create hydrogen and CCS infrastructure to capture industrial emissions and supply hydrogen (from both natural gas and renewable electricity) for industry to use. By 2026, over 1 million tonnes of CO2 would be saved every year. By 2035, with wider hydrogen supply constructed for flexible power and transport, and negative emissions from bioenergy with CCUS, up to 25 million tonnes of CO2 could be saved per annum.[76]

NECCUS:
Is an integrated plan for hydrogen and CCS in Scotland, incorporating the Acorn project. It would produce hydrogen from natural gas at the St Fergus terminal in North East Scotland for use in the gas network to decarbonise domestic heating, as well as for transportation and industrial use, and would also use a re-purposed pipeline to collect CO2 from Scottish industry. The first phase would capture and store around 340,000 tonnes of CO2 emissions from the St Fergus gas terminal and could be operational in 2024. Subsequent phases would see large additional volumes of CO2 abated each year. The nearby Peterhead port could also receive up to 16 million tonnes a year of CO2 by ship from other clusters and countries, to be stored in the same offshore geological formations.[77]

Net Zero Teesside:
Would create CCS infrastructure to capture emissions from industry and from gas and biomass power generation. The project is currently in the pre-application stage for a Development Consent Order (DCO), which it hopes to gain by the end of 2021. By 2030, up to 6 million tonnes of CO2 would be captured and stored each year.[78]

South Wales Industrial Cluster (SWIC):
Will establish a net zero carbon landscape for industry in South Wales – connecting together mini-clusters along the coastline from Newport to Milford Haven, acting as a catalyst for decarbonisation of other sectors such as rail, heavy surface transport, power generation and home heating. Large-scale hydrogen infrastructure and CCS options will be developed, including an international hydrogen and carbon shipping hub, and process solutions will be identified to reduce carbon emissions at least cost. The cluster is seeking to eliminate over 16 million tonnes per year of CO2 emissions from industry and power generation, which would be further compounded through the coupling of both heat and transport vectors. SWIC is also seeking to support other cluster developments in the Black Country, Southampton, Plymouth and Falmouth.

Zero Carbon Humber (ZCH):
Would create CO2 transport and storage infrastructure, facilitating the Humber's transition to a net zero cluster before 2040. This infrastructure would support a hydrogen fuel switch and post combustion capture decarbonisation programme as well as capturing the 16 million tonnes per annum negative emissions (BECCS) from Drax power station. ZCH incorporates the Hydrogen to Humber Saltend (H2H Saltend) project, planned to be one of the world's first blue hydrogen plants. H2H Saltend will enable industrial customers in the Chemicals Park to fully switch over to hydrogen, and the power plant to move to a 30% hydrogen blend. As a result, total emissions from the Chemicals Park will fall by c.900,000 tonnes to c.2.6 million tonnes of CO2 per year. ZCH has projected that annual CO2 capture rates in 2040 from industry across the cluster (13 million tonnes), hydrogen production (15 million tonnes) and BECCS from Drax power station (16 million tonnes) are achievable. This would result in 44 million tonnes of CO2 stored each year.[79] There are additional opportunities for hydrogen from renewable electricity within the cluster.

Southampton Water:
The Southampton Water cluster emits 2.6mt of CO2 p.a., which needs to fall to zero by 2050. The industrial, commercial and healthcare operations in the vicinity of Southampton Water, are significant, with more than 20 locations emitting significant quantities of CO2. This includes major emitters such as the Fawley Refinery, Fawley Chemicals, the Marchwood and Redlake Power Stations, plus several major hospitals. Blue hydrogen with CCS generated locally, or gas network delivered hydrogen could make a substantial contribution to helping to protect jobs and create new industrial export opportunities.

[76] Hynet, https://hynet.co.uk/
[77] Pale Blue Dot, Acorn CCS and Acorn Hydrogen, https://pale-blu.com/acorn/ and NECCUS, https://neccus.co.uk/
[78] FNet Zero Teesside https://www.netzeroteesside.co.uk/project/
[79] Zero Carbon Humber, Capture for Growth, https://www.zerocarbonhumber.co.uk/wp-content/uploads/2019/11/Capture-for-Growth-Zero-Carbon-Humber-V4.9-Digital.pdf; also see https://www.equinor.com/en/what-we-do/h2hsaltend.html

59 TWH OF HYDROGEN USED BY INDUSTRY IN **2050**, REMOVING **10 MILLION TONNES** OF CO_2 ANNUALLY

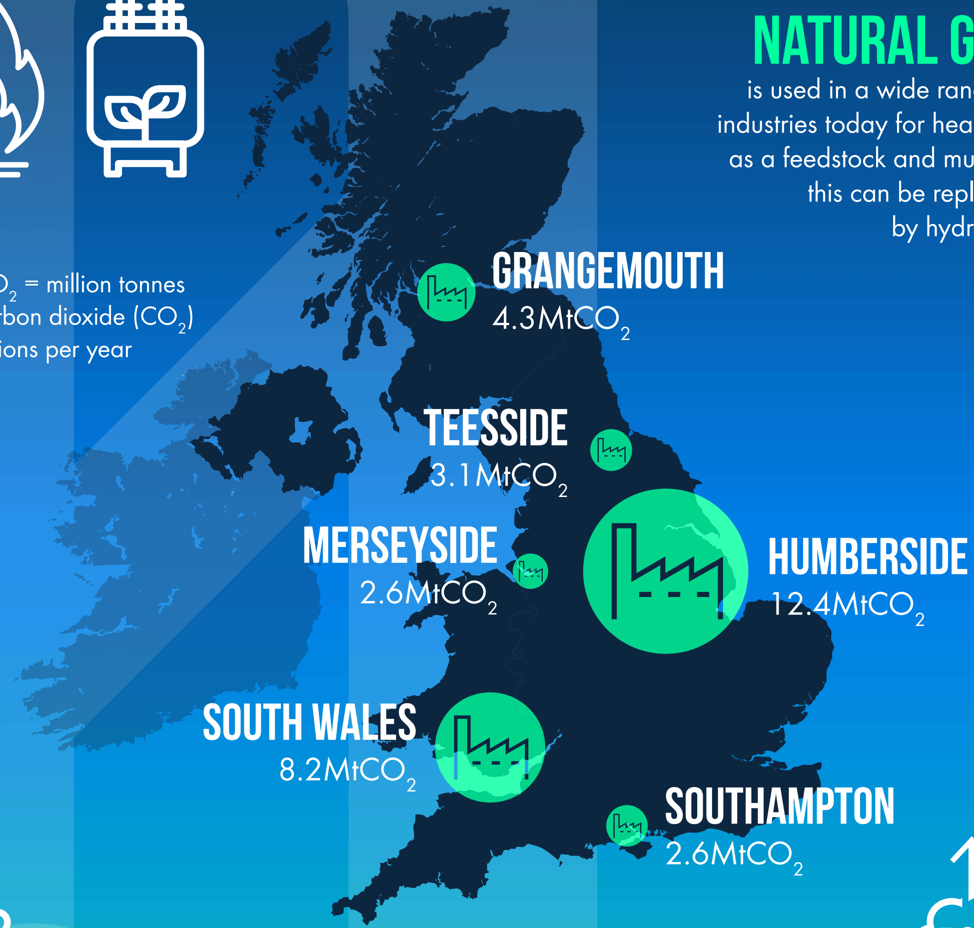
INDUSTRIAL DECARBONISATION COULD CREATE **43,000** JOBS BY **2050**

HEAVY INDUSTRY CONTRIBUTES **£140 BILLION** ANNUALLY TO THE UK ECONOMY, AND SECURES OVER **1.1 MILLION JOBS**

NATURAL GAS

is used in a wide range of industries today for heat and as a feedstock and much of this can be replaced by hydrogen

$MtCO_2$ = million tonnes of carbon dioxide (CO_2) emissions per year



50%

More than 50% of UK industrial emissions are outside the industrial clusters

50%

5. INDUSTRY

UK GOVERNMENT SUPPORT

Funding sources are being made available by the UK government to support industrial decarbonisation, including hydrogen and CCS, as set out in the table below. It is worth noting that some of these schemes have not yet been launched, although firm pledges have been made. Total funding is sizeable, at around £1.5 billion, and industry match funding would increase the overall amount.

The Department for Business, Energy and Industrial Strategy (BEIS) has been consulting on possible business models for hydrogen. A report published in August 2020 narrowed down the options for hydrogen production business models to two: contractual payments to producers and regulatory return models. To manage the risk of low hydrogen demand, a structure was recommended of a grant to cover capital costs, and a variable payment to cover the operating cost of hydrogen production over and above natural gas and carbon prices. Support could be provided through a CfD model, as per renewable generation.[80]

Further work will be undertaken to refine these options, with further consultations. BEIS aims to have final business models for hydrogen production in place in 2022.

PRINCIPAL INDUSTRIAL DECARBONISATION AND HYDROGEN FUNDING SOURCES

FUNDING SOURCE	AMOUNT	SCOPE	STATUS
HYDROGEN SUPPLY COMPETITION[81]	£33 million	Development of low carbon bulk hydrogen supply to reduce costs – feasibility studies and demonstration projects at technology readiness level 4-7	Funding awarded, demonstration projects underway
INDUSTRIAL DECARBONISATION CHALLENGE (IDC)[82]	£170 million	Design and demonstration of industry-scale technologies and shared infrastructure in at least one cluster (approximately £130 million available for pre-FEED and FEED studies)	Phase 1 (£2m) awarded; Phase 2 competition open
INDUSTRIAL ENERGY TRANSFORMATION FUND (IETF)[83]	c.£150 million (total of £315m, of which around half for energy efficiency)	FEED studies and demonstration/deployment of deep decarbonisation technologies on a manufacturing site. Excludes standalone hydrogen production or hydrogen/CO2 transport infrastructure	Phase 1 (£30m) competition open – covers feasibility/FEED studies only for deep decarbonisation
LOW CARBON HYDROGEN PRODUCTION FUND[84]	£100 million	TBC – but expected to cover various low carbon hydrogen production technology deployment	TBC – possibly 2021 opening
CLEAN STEEL FUND[85]	£250 million	Deep decarbonisation options for steel production, including hydrogen	TBC – possibly 2024 opening
CCS INFRASTRUCTURE FUND[86]	At least £800 million (budget to be finalised at Comprehensive Spending Review)	Establish CCS in at least two UK sites, one by the mid-2020s, a second by 2030	TBC opening – but consistent with ambition of CCS in the first site in mid 2020s
TOTAL	£1,503 million		

[80] Frontier Economics, Business models for low carbon hydrogen production: A report for BEIS, August 2020 https://www.gov.uk/government/publications/business-models-for-low-carbon-hydrogen-production
[81] See https://www.gov.uk/government/publications/hydrogen-supply-competition
[82] See https://www.ukri.org/news/ukri-allocates-funding-for-industrial-decarbonisation-deployment-and-roadmap-projects/
[83] See https://www.gov.uk/government/publications/industrial-energy-transformation-fund-ietf-phase-1-how-to-apply
[84] See https://www.gov.uk/government/consultations/creating-a-clean-steel-fund-call-for-evidence
[85] See https://www.gov.uk/government/consultations/creating-a-clean-steel-fund-call-for-evidence
[86] HM Treasury, Budget 2020 https://www.gov.uk/government/publications/budget-2020-documents/budget-2020

5. INDUSTRY

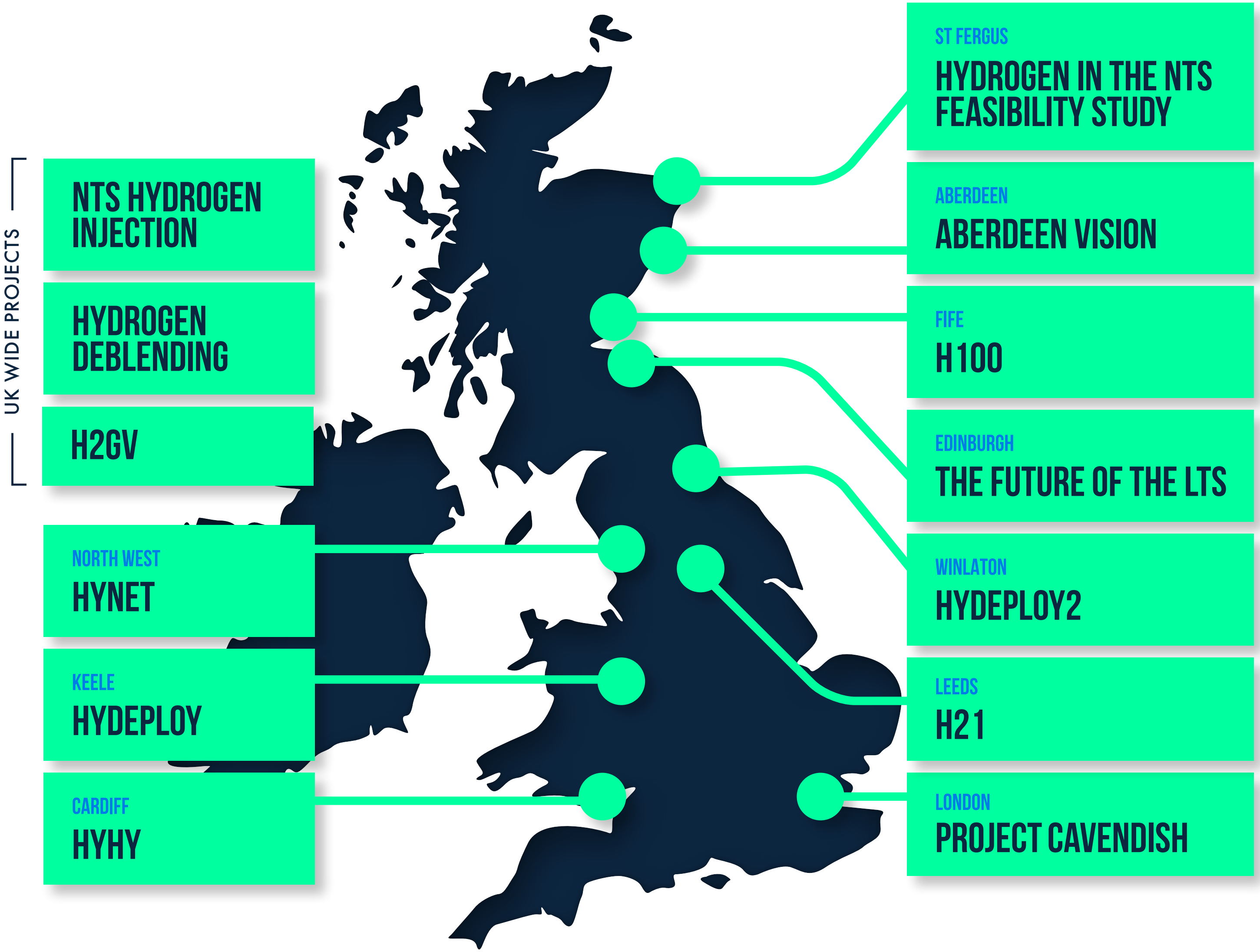
NON-CLUSTERED INDUSTRY

While the industrial clusters are critical to developing hydrogen and CCS infrastructure, non-clustered industry is also vital. According to the BEIS data presented earlier, the large emitters in the main UK clusters are responsible for a combined total of around 33 million tonnes of CO_2, or around 43% of the 76.5 million tonnes of total CO_2 emissions from industry.

For those non-clustered industrial facilities that are suitable for a hydrogen fuel switch, the most cost-effective way to deliver the hydrogen in bulk will be through existing gas networks converted to hydrogen (for some smaller and remote industry, distributed onsite green hydrogen production is another option, but this is unlikely to be the case for much of the non-clustered industry). So, in order to achieve net zero in industry, network conversion will be required.

5. INDUSTRY

5.4 PROJECTS TO DELIVER HYDROGEN TRANSFORMATION



5. INDUSTRY

Deblending projects

All five gas networks, led by National Grid Gas, supported a project[87] to investigate the technical and economic feasibility of deblending hydrogen from natural gas at scale. Four case studies (pressures, flow rates and hydrogen concentrations) were investigated but it was not possible to determine an optimal layout due to the large number of variables. However, in terms of cost and scale, cryogenic separation and membrane separation with pressure swing adsorption were the most promising techniques.

Deblending research will form part of a later phase of the HyNTS FutureGrid project that is proposed to start in April 2021.

Network safety offline trials

The key purpose of these trials is to ensure the safety of hydrogen transportation in gas transmission and distribution networks, to allow the hydrogen to reach large and small industrial users, both within and outside of industrial clusters.

Live trials on gas networks have additional complexity due to the materials, pressure tiers and the quantity of hydrogen required to maintain the flow rates and pressures. Customers directly connected to the transmission networks such as power generators or large industrials may have combustion or other processes that are sensitive to gas quality.

To convert the gas distribution networks and their customers to 100% hydrogen, the metallic NTS and Local Transmission System (LTS) pipelines would be required to move hydrogen at high pressures from the supply points to customers in the lower pressure tiers. The NTS and the LTS are critical for diurnal storage and the need for storage will be increased for 100% hydrogen as the energy content is about one third that of natural gas. Two sets of offline trials are currently proposed to investigate the impact of hydrogen on the NTS and the LTS:

Future of the LTS is investigating the safety, technical and practical evidence for repurposing the 11,500 km system of LTS pipelines to transport 100% hydrogen. The LTS is built mainly of low-strength steels and these are likely to be suitable for 100% hydrogen. Following desktop studies, an off-line trial is planned on a decommissioned section of the LTS between Granton and Grangemouth in Scotland.

FutureGrid is part of the **HyNTS** programme of work. The NTS is constructed of various types of high-strength and large diameter steel pipework and evidence is required to demonstrate that these assets can be repurposed. Following desktop studies, an off-line trial using decommissioned assets is planned in 2021 and a later online trial will follow. National Grid is looking to identify a location to trial a full-scale pilot of hydrogen injection into the NTS (2022-2024). This would require a reliable source of hydrogen and a consumer that can be isolated from the remainder of the NTS. Once injection has been proven, deblending technology could also then be trialled online; this would take place 2024-2025.

[87] Deblending project https://www.smarternetworks.org/cdn/pdf/progress/2b67b5b9-dab2-43d7-b58f-ac0000e51824

5. INDUSTRY

HyNTS FutureGrid Project. Image credit: National Grid Gas

ena energynetworks association

5. INDUSTRY

5.5 BENEFITS

Hydrogen supply and emissions savings

The ENA Pathways to Net Zero report concluded that, in the balanced scenario, 59 TWh of hydrogen would be supplied to industry in 2050. Other scenarios envisage more hydrogen being provided to industry. CCC's net zero scenario sees 120 TWh, and two of the most recent National Grid FES scenarios see 118 TWh (System Transformation) and 67 TWh (Leading the Way) of hydrogen for industry.

Switching to hydrogen would therefore deliver immediate and large-scale emissions reductions, helping to meet interim carbon budgets on the path to net zero – 59 TWh of hydrogen in industry would save around 10 million tonnes of CO2 per annum.

Economic opportunities

For industrial end use, hydrogen would be a significant job creator.

The Hydrogen Taskforce has estimated that around 1,900 jobs and £2.9 billion of GVA would be created from industrial conversion by 2035, with 37 TWh of hydrogen used in industry at this point. Hydrogen and CCS development for broad-based decarbonisation could be a significant job creator, leading to 43,000 jobs for industrial decarbonisation alone.[88]

Many energy intensive industries – iron and steel, cement, chemicals, oil refining, food and drink, pulp and paper and ceramics – are often located in less affluent parts of the country and are the largest employers in the area, offering high quality jobs. Overall, energy intensive industry accounts for £140 billion in economic value added and employs over 1.1 million people.[89]

The UK has experienced emissions reduction through offshoring of heavy industry, and is now the largest per-capita importer of CO2 emissions in the world.[90] The closure of Redcar steelworks in late 2015 led to 2,000 job losses, but was responsible for nearly half the fall in industrial emissions in 2016.[91]

Hydrogen enabled by the gas networks provides an opportunity to develop UK exports of decarbonised industrial products, together with exports of hydrogen technology and services.

5.6 PERSPECTIVES FROM STAKEHOLDER ENGAGEMENT

As detailed in Appendix 1, we have carried out extensive stakeholder engagement for the project, including two well attended workshops and a number of focused discussions. The stakeholders we spoke to made the following key points for industry:

Hydrogen production: Hydrogen production, mainly blue then green, would start at clusters, and hydrogen would be primarily used for industry. It was felt that this was also where government policy was focused. Investment decisions made now are key, as industrial assets last for a considerable period. CCS will be key for hydrogen to start at scale.

Business models and competitiveness: A split CfD, with a fixed payment for capacity and a variable payment for production, was generally seen as the best approach to finance hydrogen production, although it was questioned whether a business model would incentivise production for domestic use. The key issue of industrial competitiveness was raised, and the need to avoid further offshoring of production if energy input prices in the UK rose relative to other countries (including through CfD costs added to gas prices, as per electricity).

Blending and deblending: Most, though not all, stakeholders were uninterested in deblending, seeing it as adding cost, and preferred to see the NTS remain on methane. Blending in the distribution networks was seen by some as providing support for hydrogen supply and building consumer confidence. The issue of blended hydrogen lowering the quality of feedstock was also raised, and the risk of some existing facilities disconnecting from the NTS if this happened, especially in the context of Ofgem's planned changes to the short haul tariff.

Timing: Most industrial stakeholders told us that industrial hydrogen use would scale up in the 2030s, but that there may not be enough "spare" hydrogen for a domestic conversion before the mid-2030s or 2040s, by which time other domestic solutions may have emerged.

[88] Element Energy and Equinor, Hy-impact Study 1: Hydrogen for economic growth, November 2019 http://www.element-energy.co.uk/wordpress/wp-content/uploads/2019/11/Element-Energy-Hy-Impact-Series-Study-1-Hydrogen-for-Economic-Growth.pdf
[89] BEIS analysis using the ONS Annual Business Survey
[90] Office for National Statistics, The decoupling of economic growth from carbon emissions: UK evidence, October 2019, Figure 11 https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/compendium/economicreview/october2019/thedecouplingofeconomicgrowthfromcarbonemissionsukevidence
[91] Cooper SJG and Hammond GP, Decarbonising UK industry: towards a cleaner economy, Institution of Civil Engineers paper 1800007, May 2018, p.3; See https://www.gazettelive.co.uk/news/teesside-news/redcar-steelworks-closure-contributes-sharp-12696855

5. INDUSTRY

Role of networks: It is simpler not to use a gas grid to replace existing grey hydrogen in industry, and most cluster projects are not predicated on a full 100% domestic conversion, with planned cluster infrastructure generally not being oversized for future domestic hydrogen use. There was general, though not complete, agreement that the NTS should remain a methane transporter, including for industry that still needs methane (that may be adding CCS).

New pipelines: Clusters are generally planning to build new high-pressure hydrogen pipelines to connect production, users and hydrogen storage, without relying on full conversion of existing networks.

5.7 MEETING BRITAIN'S HYDROGEN NETWORK PLAN TENETS

For industry, the four Hydrogen Network Plan tenets are met through the projects focused on industry, and the cross-sector network projects, as summarised below:

ENSURING PEOPLE'S SAFETY:

- H21 Phase 1 and Phase 2, as well as H100 Fife, are delivering the **distribution grid** 100% hydrogen safety case.
- HyNTS Future Grid Phase 1 is investigating the safety and feasibility of repurposing the **transmission grid** to either a blend of or 100% hydrogen, though a high-pressure test loop at DNV GL's Spadeadam facility (this project is also important for security of supply).
- Other proposed network safety and impacts **safety studies**.

MAINTAINING SECURITY OF SUPPLY:

- Proposed projects on transmission modelling, distribution modelling and System Operator transition to hydrogen projects will ensure that a hydrogen transmission and distribution network would have **sufficient physical network capacity and resilience** to meet demand peaks, including effective **System Operation**.
- The Gas Markets Plan (GMaP) project is investigating **market frameworks for hydrogen** in gas networks.
- The Aberdeen Vision project (new network element) has investigated the requirements of **new hydrogen networks**, and the forthcoming HyNet Homes project will do likewise.
- Project Cavendish and H100 Fife would see **hydrogen production directly connected to gas networks**, as would the forthcoming H21 Phase 3 and HyNet Homes projects.

FOCUSSING ON PEOPLE'S NEEDS:

- Networks are providing support to all the main **industrial cluster projects**, including HyNet, Zero Carbon Humber, Acorn, Net Zero Teesside, South Wales Industrial Cluster and Southampton Water, many of which also include plans for hydrogen storage and power generation (these projects are also relevant for security of supply).
- The Deblending NIA has found that **deblending hydrogen and methane** for particular customers is feasible, and HyNTS Future Grid Phase 2 will carry out a practical deblending trial.
- HyDeploy is testing **20% hydrogen blends** at Keele University, and HyDeploy 2 will test 20% hydrogen blends in a small part of the public gas grid, to enable widespread hydrogen blending to start in 2023.
- The Future Billing and Real Time Networks projects will together enable all consumers, including industry, to be **billed on energy content**, rather than volume, allowing blends of hydrogen, natural gas and biomethane.

DELIVERING JOBS AND INVESTMENT:

- The Iron Mains Risk Reduction Programme continues to **replace old iron mains** with polyethylene, which will allow 100% hydrogen to be transported – 60,000 km have been replaced so far, 62.5% of the total.
- Network training modules for hydrogen will be developed to ensure that **hydrogen training** becomes a business-as-usual Gas Safe activity.
- Entry connection standardisation will make it easier to **connect hydrogen production to networks**, whether at small or large scale.
- Cross-sectoral **stakeholder engagement** by the networks will communicate Britain's Hydrogen Network Plan and secure feedback.

Hydrogen is a key decarbonisation pathway for industry, and networks will be able to transport the hydrogen from production to storage and end-use within and between the main industrial clusters. Most of the network hydrogen projects are relevant to industry, and the gas networks are also supporting the main industrial cluster decarbonisation projects.

6. POWER SECTOR

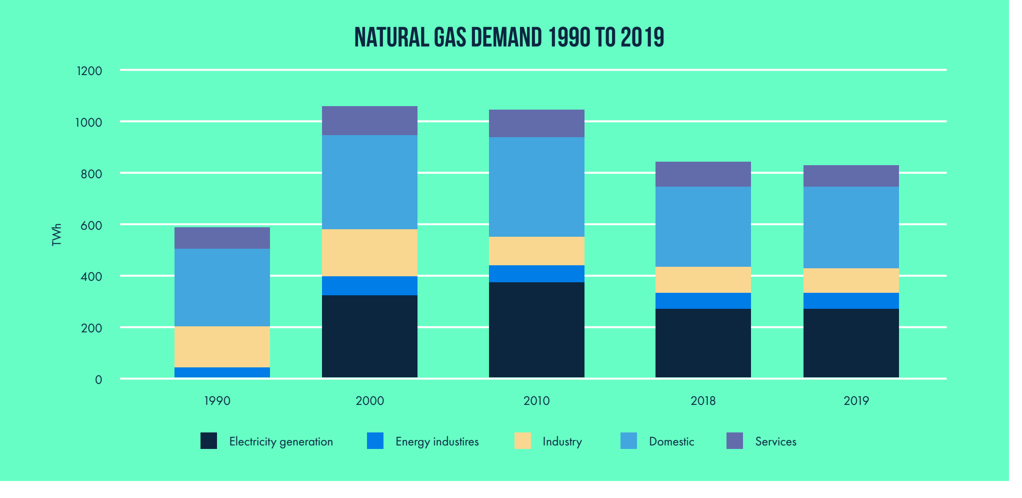
6. POWER SECTOR

In supporting the power sector, hydrogen is one of the leading options for storing variable renewable energy, and in the future, hydrogen and ammonia could also be used in gas turbines to increase power system flexibility. Using a repurposed gas network to transport hydrogen to power stations, or to transport green hydrogen produced from renewables either to consumers, or to storage locations, is crucial to the delivery of a low carbon and resilient electricity network.

This section outlines how the gas networks can work in an integrated fashion with the power sector to accelerate the pathway to net zero.

6.1 THE ROLE OF GAS IN ELECTRICITY GENERATION TODAY

Gas is used today across multiple sectors, but it plays a major role in power generation. Initially, gas played a key carbon reduction role in replacing coal in electricity generation, but even as the UK continues to add low carbon sources to the grid today, gas continues to play a key role in supporting electricity demand. The graph below, based upon data from the BEIS publication UK Energy in Brief 2020[92] shows how gas in electricity generation grew to replace coal in the early 2000s, but still plays a substantial role today. In 2019, gas fired Combined Cycle Gas Turbine (CCGT) generating stations provided 31.5GW of capacity, which is just over 30% of UK electricity generating capacity. When considering peak electricity demand, CCGTs can deliver over 50% of the UK peak.



[92] BEIS, UK Energy in Brief 2020

6.2 THE GAS NETWORKS' ROLE IN ENABLING A LOW CARBON ELECTRICITY SUPPLY

The use of renewable energy in the electricity grid is transforming the way in which our electricity is generated and significantly reducing our carbon footprint. However, the energy transition puts pressure on our power system from both sides: generation and demand. The system needs greater resilience – the ability to adapt electricity load and generation in time to react to changing circumstances.

Resilience will be required on different timescales: for instance, to accommodate short-term hourly, daily, and weekly fluctuations in renewable generation and also the longer-term seasonal variations in renewable generation and electricity demand. The electricity network also needs to be able to match that variable generation with increasing future demands such as heating, electric vehicle charging, electrolytic hydrogen production etc.

For a variety of reasons, it is not always possible to make full use of the electricity generated, at the time is it supplied. As a result, of this, renewable energy sources are currently paid to stop producing excess electricity when the electricity grid cannot utilise it. These constraint payments have been increasing significantly as renewable capacity has grown, and could grow further in future as renewable capacity continues to increase rapidly. Not only does the use of constraint payments place commercial demands on the electricity system operator, it results in substantial amounts of wasted energy.

6. POWER SECTOR

The costs related to constraints in the electricity system are significant, both in terms of excess renewable generation and the lack of available electrical infrastructure to move new renewable electrical energy to where it is needed. The costs of such constraints have increased in recent years from £86 million per annum. during 2005–08 to £303 million per annum during 2014–17. Between 2012 and 2016 the quantity of wind energy curtailed rose substantially, from 45 to 1,123 GWh.[93] Significant ongoing investment in the electricity system is expected to reduce constraint costs over future years, but this investment also needs to be matched to the ongoing scale up of renewable sources.

The absence of a viable storage solution for potentially large amounts of "wasted" energy could be solved by the introduction of a hydrogen transportation and storage solution, which could store excess and low cost renewable energy as hydrogen for distribution via the gas networks to industrial, power, transport or domestic consumers. Coupling electrons and molecules in this way makes perfect sense to accelerate greater uptake of renewables, through using the gas networks as a "battery". In this way, "green" electrons and "green" molecules can work hand in hand to deliver our decarbonisation objectives.

In addition to the role of hydrogen for storage of variable renewables, there will still be a need for gas fired peaking power plants to support the grid in periods of low renewable energy production, peaks of electricity demand, or to balance the electricity system. Several studies, including from Aurora, Imperial College and Pöyry,[94] have demonstrated that annual penetrations of up to 80% of variable renewables in the UK's electricity system are technically achievable, but that still leaves a shortfall that needs to be met by other sources such as nuclear or gas fired generation. A common feature of all of these studies is the need for system flexibility to be enabled through alternative generation or storage solutions.

The CCC, in its 2019 Net Zero Technical Annex,[95] recognised the benefits of hydrogen in power generation when it stated *"Development of a low-carbon hydrogen industry in future would ensure that where back-up generation is needed it is associated only with extra costs, not extra CO2 emissions."*

The Government's recently announced Ten Point Plan also supports the future growth of advanced modular nuclear reactors and highlights their benefits in unlocking efficient production of hydrogen. This builds upon the ambition already stated by projects such as the Cumbria Clean Energy Park[96] and the Hydrogen East initiative[97] to deliver a nuclear based clean energy community, part of which is hydrogen production. In order to realise these visions, and distribute green hydrogen generated in this way, a hydrogen ready gas network will also be an imperative.

6.3 HYDROGEN STORAGE

Hydrogen storage forms an essential link in the overall energy value chain. Without adequate consideration of the needs for storage, it will be impossible to deliver an effective low carbon system transformation.

Gas storage today

Gas storage makes an essential contribution to the UK's energy security of supply.

The demand profile for electricity is relatively consistent during a typical day and over the year, with relatively minor peaks and low ramp-up rates in energy requirements. By contrast the demand profile of the gas network, is highly variable. Daily, it peaks in the early morning as domestic and commercial heating systems begin operating, then drops during the day, and then peaks again in the early evening. During the initial start-up, between 5a.m. and 8a.m. on a winter morning, the ramp rate is extreme, with demand increasing by over 100GW over a period of 2-3 hours.

In order to meet peaks in demand, gas is currently stored in several forms. Short term storage to meet daily peaks is usually dealt with through pipeline linepack. The various pressure tiers present in the gas transmission and distribution systems enable this to be achieved efficiently and safely.

[93] Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany, Michael Joos, Element Energy and Iain Staffell, UK Centre for Environmental Policy, Imperial College London, Renewable and Sustainable Energy Reviews 86 (2018) 45-65
[94] Aurora (2018) System cost impact of renewables; Imperial College (2018) Analysis of alternative heat decarbonisation pathways; Imperial College (2016) Whole-system cost of variable renewables in future GB electricity system; Imperial College (2015) Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies; Pöyry (2011) Analysing Technical Constraints on Renewable Generation to 2050
[95] Climate Change Committee, Net Zero Technical Annex 2019.
[96] https://www.businessgreen.com/news/4017190/moorside-clean-energy-hub-firms-tout-nuclear-hydrogen-plan-cumbria
[97] https://hydrogeneast.uk/

6. POWER SECTOR

There is a far larger seasonal swing in gas demand, with the average winter gas demand being 4-6 times that of the summer demand. This requires other forms of storage beyond linepack, and is generally provided from underground gas stores, pipeline imports, or in the form of LNG.

Following the closure of the Rough storage facility, the UK currently only has eight active underground storage sites with a combined storage capacity of 1.31 billion cubic metres (BCM), and a maximum combined output rate of 106 million cubic metres MCM) per day.

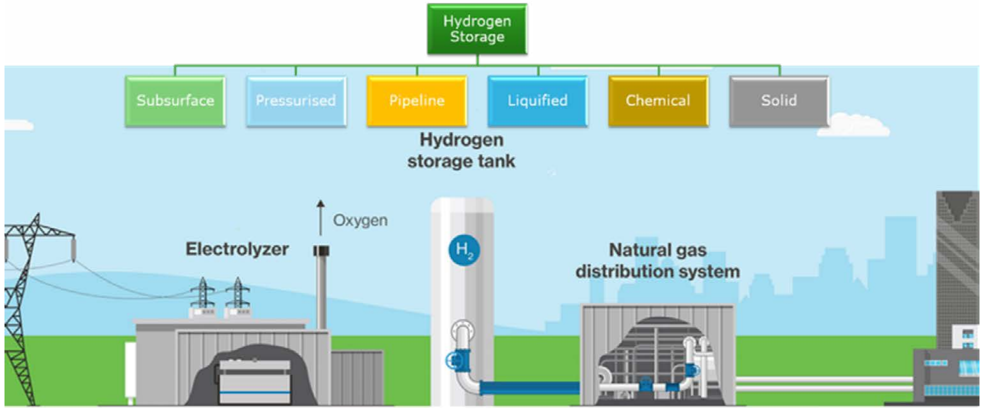
The three LNG storage facilities at Isle of Grain, South Hook and Dragon LNG have a combined storage capacity of 2.075 MCM of LNG (equivalent to 1.2 BCM of natural gas), and a maximum combined output rate of 139 MCM of gas per day.[98] This reduction in available storage has increased the demand for linepack in the gas networks.

Hydrogen storage tomorrow

In the longer term, in order to enable a transition to hydrogen, and support the growth of variable renewables, we need to develop a strategy for hydrogen storage and support its implementation. Hydrogen is generally stored as gas in compressed form because it is very light, with low density of 0.084 kg/m3. The energy density of hydrogen gas at ambient pressure and temperature is however much lower than natural gas, which therefore requires significantly larger storage volumes for a similar energy capacity to natural gas. If adequate attention is not paid to the future needs for hydrogen storage, not only would UK need to secure additional imports of hydrogen, the gas network operators would also need to invest in costly system reinforcement to allow the system to deliver hydrogen to customers with sufficient resilience.

There several existing and emerging technologies that could be used for hydrogen storage. The most likely solutions for the UK, depending upon application, are:

- Underground Storage;
- Pressurised Storage;
- Liquified Storage;
- Chemical Storage.



[98] BEIS, Digest of UK Energy Statistics (DUKES), Chapter 4, November 2019

6. POWER SECTOR

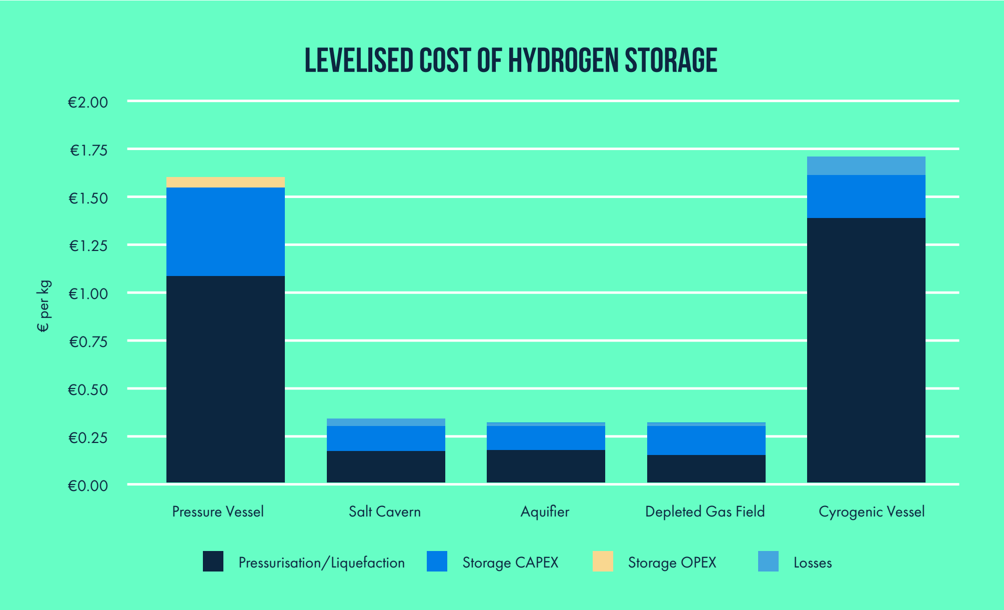
Underground Storage. Pressurised hydrogen can be stored in aquifers, salt caverns, or empty natural gas fields. Storage pressure typically varies between 100-150 bar and may exceed 250 bar for very deep reservoirs or aquifers. Hydrogen storage in salt caverns and depleted oil wells has already been successfully demonstrated in a number of locations for more than 30 years, including Teesside. The UK has approximately 100 salt caverns which are either already being used for natural gas storage or which have gas storage planned, which could be used for hydrogen. The HyStorPor project is investigating the use of underground hydrogen storage in porous rocks. Further studies are planned for Scotland and the south coast of England. The HySecure project will also demonstrate the deployment of grid-scale storage of hydrogen in a salt cavern in the North West of England.

Pressurised Storage. Storage of hydrogen in pressure vessels is also a proven technology with a history of more than 100 years. Composite pressure vessels can withstand pressures up to 1,000 bar. Due to the high pressures involved, the volume of hydrogen per vessel is limited. Banks of vessels can however be deployed to create larger reservoirs. This form of storage will be tested through the initial stage of the H100 and H21 Phase 3 projects which will utilise on site hydrogen storage vessels.

Liquified Storage. Liquefied hydrogen is stored at approximately -253°C, an even lower temperature than LNG. In this form, the liquified gas is at near atmospheric pressure, so the storage tanks do not require pressure strength, but must be heavily insulated. As the tanks do not need to be pressurised, cryogenic storage tanks can be built in large volumes. Typically, a trailer-based storage vessel can hold more than 60 m3 of liquid hydrogen, with stationary tanks as large as 3,800 m3. The energy required to liquefy hydrogen is currently about 47 MJ/kg of hydrogen, but future research will reduce this significantly.

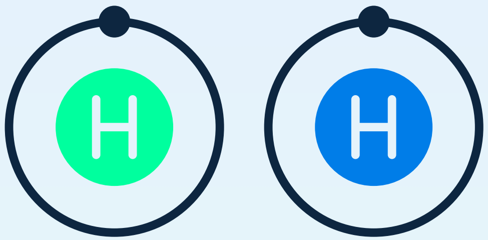
Chemical Storage. Storage of hydrogen by converting it to nitrogen compounds such as ammonia or carbon compounds such as methanol or formic acid is possible, but this is currently more of an option for long distance transportation than storage. Liquid organic hydrides (LOHC) are also being investigated as potential candidates for hydrogen storage and delivery, with the benefits of lower energy penalties for conversion.

Storage Cost Considerations. Recent work by DNV GL on hydrogen storage[99] concluded that pressurised storage in a pressure vessel (700 bar) and cryogenic storage incur the highest costs. The costs for different options for subsurface storage are much lower, and do not differ significantly, but land use issues can be significant, including for infrastructure above-ground (including relating to hazardous areas) and below ground (larger or more cavities needed due to hydrogen's lower energy density).



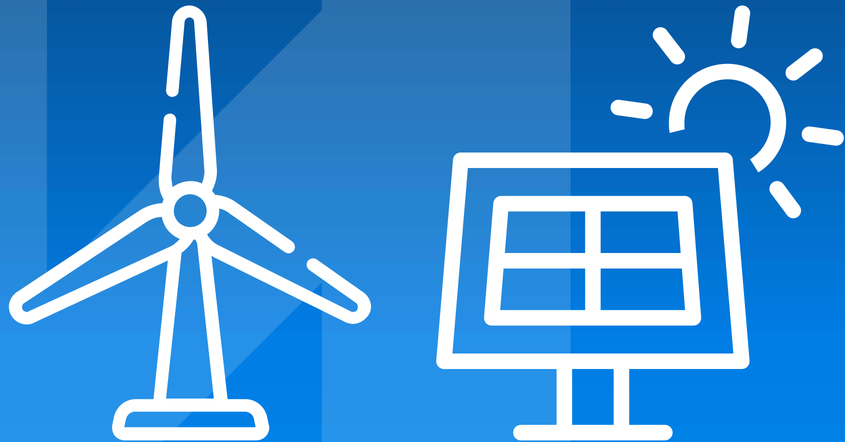
[99] DNV GL, Hydrogen in the Electricity Value Chain, Position paper 2019

BETWEEN **5AM AND 8AM** ON A WINTER MORNING, GAS DEMAND INCREASES BY OVER **100 GW**. THIS IS MUCH HIGHER THAN TOTAL ELECTRICITY GENERATION

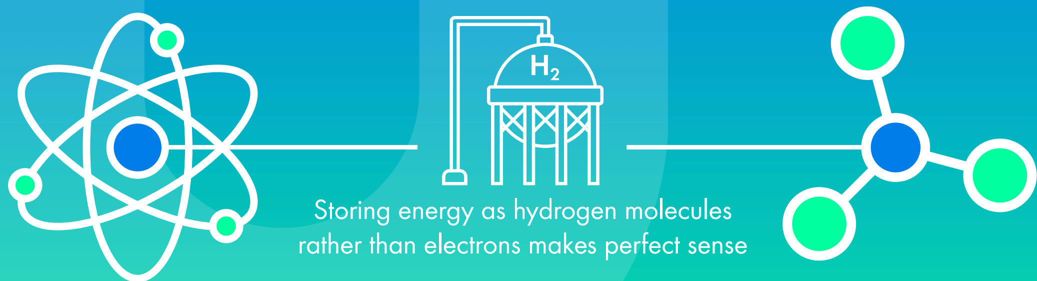


GREEN HYDROGEN WILL BE COST COMPETITIVE WITH **BLUE HYDROGEN** BY THE MID-2030'S

A WHOLE SYSTEMS APPROACH means that variable renewable energy can be stored and used as hydrogen, rather than being constrained.



GAS NETWORKS can store the hydrogen and transport it to be used across the economy.



Storing energy as hydrogen molecules rather than electrons makes perfect sense

energynetworks association

6. POWER SECTOR

6.4 ENA WHOLE SYSTEM INITIATIVES

As the industry body for the companies which run the UK & Ireland gas and electricity networks, the ENA is at the centre of a number of initiatives to promote cross sector solutions to decarbonising our energy systems, increasing collaboration between the gas and electricity networks. These initiatives include:

- **Coordination:** The Open Networks Project includes representation from electricity and gas network companies and key industry bodies, and is sharing data to improve demand forecasting for gas generation customers and improve resilience planning for electricity networks. The project is also considering principles for whole system cost benefit analysis, to ensure best value for whole system investments.

- **Innovation:** The Gas Innovation Governance Group (GIGG) & Electricity Innovation Managers Group are working on a joint innovation strategy that includes whole systems projects. A common approach to the digitisation of the gas and electricity networks is also being developed.

- **Smart meters:** The Smart Meter Steering Group and Smart Meter Operations Group are supported by both gas and electricity teams, and work to improve the smart meter roll out programme, including through reducing the incidence of post-installation issues.

- **Forecasting:** The Electricity System Operator, Transmission Network Owners, Distribution Network Operators, and the Gas Transmission Operator and GasDistribution Operators collaborated to develop a core scenario that enabled a whole system impacts of gas and electricity network business plans to be assessed.

The above examples show how the electricity and gas networks are working together in a series of mutually supportive projects to ensure that the electricity and gas networks of the future can achieve faster progress towards the decarbonisation targets and ensure that the whole-system benefits of hydrogen are realised in practice.

6.5 GAS NETWORK PROJECTS SUPPORTING POWER SECTOR INTEGRATION

The gas networks are undertaking several projects to improve the interface between themselves and the electricity networks, to demonstrate how a whole systems approach could accelerate decarbonisation.

The NTS delivers 881 TWh of energy today, 75% of total GB energy needs, and 39% of that energy is used in supplying gas for power generation. The National Grid Gas **HyNTS FutureGrid** project[100] will investigate whether it is safe to inject hydrogen into the NTS at concentrations of 2%, 20% and 100% hydrogen. FutureGrid, a new hydrogen research facility at DNV GL's Spadeadam site, will be built from a range of decommissioned assets, to create an offline but realistic gas transmission network. Hydrogen has different physical properties from natural gas and this project will test whether the current transmission network is compatible with hydrogen. This will be a key consideration for the ability of gas fired power stations or gas peaking plants to access hydrogen from the NTS.

The SGN **H100 Fife** project at Methil will investigate the link between wind energy, electrolysis, hydrogen storage and network demand in a domestic trial. This initiative is part of a broader H100 Fife project designed to explore the potential for power-to-hydrogen to deliver decarbonisation benefits through a series of projects focussed on the East Neuk of Fife[101].
SGN and Scottish Power Energy Networks (SPEN) are considering an integrated hydrogen energy system as part of this work in which they envisage a coupling of the power and gas networks, where renewable electricity is converted into hydrogen via an electrolyser. The aim is to create a link between the electricity network, fed by renewables from a variety of sources, and the gas network, which would be used to carry hydrogen to a variety of end-use applications including heating, transport and industry.

HyDeploy is a project run by Cadent and Northern Gas Networks. The project sees a blend of up to 20% hydrogen added to the existing gas supply. The use of the blended gas requires no change to appliances and customers do not notice any difference to their gas supply.

[100] https://www.nationalgrid.com/uk/gas-transmission/document/133841/download
[101] SGN, Decarbonising the UK's Gas Network, Realising the green power-to-hydrogen opportunity in the East Neuk August 2020

6. POWER SECTOR

The **H21 Phase 3** project will build upon the earlier HyDeploy project to demonstrate the use of grid electricity to generate hydrogen via an electrolyser before being fed into several hundred homes as part of a network conversion to 100% hydrogen. The chosen area will make history and play an important part in the future of hydrogen use, by becoming the first public network to receive a 20% hydrogen blend provided by a green hydrogen supply.

Wales & West Utilities have been developing the **Freedom Project** in conjunction with Western Power Networks. This £5m innovation initiative developed the Bridgend 'living heat laboratory' in South Wales. Using an air source heat pump and high-efficiency gas boiler hybrid system in 75 residential properties, the project has demonstrated the significant benefits that an integrated whole energy systems approach to deploying smart dual-fuel technologies can deliver. A Freedom installation integrates a small air source heat pump alongside an existing gas boiler central heating system with smart controls. These smart controls are essential and enable automatic switching between gas and electricity based on the affordability and carbon intensity of each vector. The hybrid installation is retrofitted to the existing system with minimal disruption.

6.6 MEETING BRITAIN'S HYDROGEN NETWORK PLAN TENETS

For power, the four Hydrogen Network Plan tenets are met through cross-sector network projects, as summarised below:

Ensuring people's safety:

- H21 Phase 1 and Phase 2, as well as H100 Fife, are delivering the **distribution grid** 100% hydrogen safety case.
- HyNTS Future Grid Phase 1 is investigating the safety and feasibility of repurposing the **transmission grid** to either a blend of or 100% hydrogen, though a high-pressure test loop at DNV GL's Spadeadam facility (this project is also important for security of supply).
- Other proposed network safety and impacts **safety studies.**

Maintaining security of supply:

- Proposed projects on transmission modelling, distribution modelling and System Operator transition to hydrogen projects will ensure that a hydrogen transmission and distribution network would have **sufficient physical network capacity and resilience** to meet demand peaks, including effective System Operation.
- The Gas Markets Plan (GMaP) project is investigating **market frameworks for hydrogen** in gas networks.
- The Aberdeen Vision project (new network element) has investigated the requirements of **new hydrogen networks**, and the forthcoming HyNet Homes project will do likewise.
- Project Cavendish and H100 Fife would see **hydrogen production directly connected to gas networks**, as would the forthcoming H21 Phase 3 and HyNet Homes projects.

Focussing on people's needs:

- Networks are providing support to all the main **industrial cluster projects**, including HyNet, Zero Carbon Humber, Acorn, Net Zero Teesside, South Wales Industrial Cluster and Southampton Water, many of which also include plans for hydrogen storage and power generation (these projects are also relevant for security of supply).
- The Deblending NIA has found that **deblending hydrogen and methane** for particular customers is feasible, and HyNTS Future Grid Phase 2 will carry out a practical deblending trial.
- HyDeploy is testing **20% hydrogen blends** at Keele University, and HyDeploy 2 will test 20% hydrogen blends in a small part of the public gas grid, to enable widespread hydrogen blending to start in 2023.
- The Future Billing and Real Time Networks projects will together enable all consumers, including power generators, to be **billed on energy content**, rather than volume, allowing blends of hydrogen, natural gas and biomethane.

Delivering jobs and investment:

- The Iron Mains Risk Reduction Programme continues to **replace old iron mains** with polyethylene, which will allow 100% hydrogen to be transported – 60,000 km have been replaced so far, 62.5% of the total.
- Network training modules for hydrogen will be developed to ensure that **hydrogen training** becomes a business-as-usual Gas Safe activity.
- Entry connection standardisation will make it easier to **connect hydrogen production to networks**, whether at small or large scale.
- Cross-sectoral **stakeholder engagement** by the networks will communicate Britain's Hydrogen Network Plan and secure feedback.

Hydrogen offers an important option for low carbon back-up power generation, which will enable the growth of renewable generation. Projects are underway to assess the readiness of the transmission grid to transport hydrogen, alongside the possibility of deblending for specific larger consumers, including power stations.

APPENDIX 1
STAKEHOLDER ENGAGEMENT

APPENDIX 1. STAKEHOLDER ENGAGEMENT

A1.1 ACKNOWLEDGMENTS

We would like to thank the various stakeholders we spoke to throughout the project for their time and for their insightful and frank views on the opportunities and challenges of hydrogen transformation – both during the workshops and in the focused interviews. This includes members of the Gas Goes Green Advisory Group. Views were not unanimous on all issues, and we have tried to capture the range of opinions and expertise as best we can.

A1.2 WHO WE SPOKE TO

In August and September 2020, we:

- Held two workshops, the first with around 100 and the second with around 80 participants – covering producers, transporters, industrial users, and consumer and policy experts.
- Carried out 17 individual focused discussions with key organisations, as detailed in the table below.

HYDROGEN STAKEHOLDER GROUP	ORGANISATION/S
Producers and industrial clusters	• Johnson Matthey • ITM Power • BOC • North West (Progressive Energy) • South Wales (CR Plus, Milford Haven Port Authority,Costain, University of South Wales) • Humber (Equinor, Centrica) • Scotland (Pale Blue Dot, SHFCA) • Teesside (BP)
Other Industrial Consumers	• Chemical Industries Association
Domestic consumers and appliances	• Worcester Bosch • Citizens Advice
Transport	• Shell
Power generation and electricity grid	• SSE • National Grid ESO
Storage	• Storengy

APPENDIX 1. STAKEHOLDER ENGAGEMENT

A 1.3 WHAT THEY TOLD US

WORKSHOP 1

In the first workshop we discussed the key opportunities and challenges of transitioning to hydrogen for the major end-use sectors.

HOMES

- **Hydrogen-ready boilers:** Very positive feedback for a nationwide mandate given the small cost differential compared to regular boilers. There were different views on hybrids but the majority were against if the peak heating supply was hydrogen (as opposed to biomethane).
- **Cost to consumers:** The cost differential between hydrogen and natural gas was seen as a crucial issue, but it was pointed out that a doubling of the wholesale price would equal a 40% higher retail price, and natural gas may cost more in 2040 in any case given higher carbon prices. The idea of energy efficiency retrofits at same time as a hydrogen conversion was a possible mitigation, but the issue of who pays cannot be avoided.
- **Consumer engagement:** People felt that, like other energy developments, hydrogen conversion will take twice as long as we think, and so consumer engagement needs to be done in parallel with industrial cluster hydrogen development. Lessons should be learned from smart meters, and there is a risk that consumers may get conflicting advice.

TRANSPORT

- **Onsite hydrogen production or onsite hydrogen purification:** This was the crucial issue. Vehicles will be fuel cell and so it is a straight up choice, with purification needed if the hydrogen is delivered to forecourts via the gas network.
- **Liquid fuels:** Ammonia and aerospace were raised, and it was questioned whether gas networks would transport the methane or the hydrogen to make these fuels.

INDUSTRY

- **Hydrogen source:** There was general agreement that hydrogen would come from either industrial clusters or via the NTS, although there was some support for distributed bottom up hydrogen developments. The point was raised that a new hydrogen network between clusters may be needed to provide resilience.
- **Resilience and storage:** There would only be storage in some industrial clusters, so people felt that there may be a network role to build a link between clusters. If so, it was suggested that the order of cluster development then sets out the network conversion plan. A key question is whether a mainly new or mainly repurposed NTS would be needed.
- **Business models:** Like homes, the crucial question of who pays came up. Networks have less influence but need to see business models/carbon prices to support both hydrogen and CCS.

POWER GENERATION

- **Hydrogen Combined Cycle Gas Turbines (CCGTs) or CCS on gas:** It was generally agreed that for baseload power, it would be best to use CCS on gas; if back-up, then hydrogen would be better.
- **Blending and deblending:** People felt that, while blending can help with resilience, there is a crucial question of whether burners can deal with fluctuating blends, and the cost of upgrades to enable this. This really matters – can a fixed % of hydrogen to a given customer be delivered whatever the weather? If not, then fluctuating blends need to be dealt with.
- **Green hydrogen:** It was agreed that using excess wind is not a big opportunity, and that it is better to think of dedicated renewables, which means higher capex; blue hydrogen on the other hand is mainly an OPEX issue.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

WORKSHOP 2

In the second workshop we discussed possible pathways for transitioning from a methane to a hydrogen network, including considering where hydrogen would be produced and used. Several key issues were discussed in depth, and then there was a straw poll on which pathways were most practical.

HYDROGEN STORAGE

- Storage is vital to deal with supply/demand balancing, and participants thought that hydrogen storage will be needed at each cluster before the clusters can be linked up.
- The North West, Humber and Teesside have salt cavern storage; South Wales could use salt caverns in Somerset; Scotland has no salt caverns. An ongoing University of Edinburgh project (HyStorPor) is looking at porous sandstone reservoirs for hydrogen storage, which can also be found offshore.
- It was questioned whether we could see offshore hydrogen storage located close to CO2 storage, using the same platforms, similar to the offshore energy islands concept. Participants also thought that local storage is an issue, but that we won't see a return of gasholders.
- There was some discussion on flexing ATR production, with an average 55% load factor, and thereby needing less storage and possibly improving the economics. ATRs can flex quite quickly.
- It was also recognised that if existing storage is repurposed for hydrogen, there will be less storage for natural gas, which has knock on security of supply issues.
- Participants felt that planning timescales is a key issue, and that it is hard to get approval for gas storage sites.

BLENDING

- Participants thought that blending reduces the risk of fluctuating hydrogen supply and gets the market going.
- Some issues with blending were recognised, including whether storage salt caverns and compressors can handle a 20% blend, and it was noted that a study on similar sites in France found that they could handle a 10% blend (a 20% blend was not looked at).
- Participants though that blending is also an issue for power generation assets, and people felt that the lower the blend, the easier it would be.
- There was some discussion on whether a lower than 20% blend should be aimed for – it was noted that blends in Europe less than 20%, and it will take some time to get to a 5% blend.
- Blending was a great way to start talking to consumers about hydrogen, getting them familiar and happy with it – HyDeploy was given as a good example.

PIPELINES

- People felt that it makes more sense to build a new hydrogen pipeline from the coast to the city, than a new CO2 pipeline from the city to the coast. The former works for both blue and green hydrogen, whereas the latter only works for blue and so may not last as long.
- Participants agreed that we do not know exactly how much of the NTS can be repurposed for hydrogen – materials work is needed, but also the methane network need to continue during the transition. It was felt that repurposing would be best if possible.
- It was felt that hydrogen at NTS entry points, e.g. Grain and Bacton, is certainly a feasible complement to cluster hydrogen, and it may be that a regional approach with both cluster and NTS hydrogen is a more practical step than a nationwide hydrogen NTS.
- Planning was again cited as a key issue, and it was noted that it took a long time for the new NTS lines from Milford Haven to be approved, and that it also takes a long time for electricity grids to gain approval.
- Participants noted that Europe is looking at thousands of km of repurposed and new hydrogen transmission pipes.

OTHER KEY ISSUES

- **Transport**: Hydrogen for transport was briefly revisited, and it was agreed that it will need onsite purification, and that this can be done alongside the refuelling system. It may also be possible to have central purification and then a dedicated pipe for the last few miles that keeps fuel cell purity – this would also mean less hydrogen storage needed at the refuelling station, which may help to manage HSE issues.
- **Consumers**: It was agreed that consumers are key to all of this. A domestic conversion is needed to get hydrogen beyond the clusters and large users, so there are real problems if consumers do not accept, or indeed if other issues prevent a domestic conversion. The issue of whether consumers would want blue as opposed to green hydrogen also came up.
- **East of England**: The Hydrogen East project is linked to Bacton and Sizewell. It is in its early stages but interesting given the volume of low carbon electricity from offshore wind and nuclear in the region.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

PATHWAY PREFERENCES

PATHWAY	VOTES
Pathway 1 – cluster hydrogen, no blending	9
Pathway 2 – cluster hydrogen with blending	29
Pathway 3 – inland hydrogen	1
Pathway 4 – NTS hydrogen	4
Combination of pathways 2 and 4	36
Combination of pathways 2 and 3	3
The current planning system (for building hydrogen pipelines, storage etc) cannot deliver net zero on time, whether for a hydrogen transformation or alternatives	38 agree 1 disagree

- **Clusters and blending:** The straw poll was clear that hydrogen would primarily be produced at industrial clusters, and that blending was an important interim step. People also felt that some hydrogen would be produced at NTS entry points, as part of a viable transition pathway.
- **Planning:** There was almost unanimous agreement that the current planning system is too slow to allow all the infrastructure – hydrogen pipelines, storage etc – to be built on time to achieve net zero by 2050. People felt that this is the case for other parts of the energy transition as well, including for example overhead power lines.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

FOCUSED INDIVIDUAL INTERVIEWS

The focused individual discussions allowed us to examine issues for particular organisations and sectors in greater depth, and we have grouped the responses into the types of organisations we spoke to. Please note that the views expressed below are those of the organisations we interviewed and may not be representative of the wider stakeholder group.

STAKEHOLDERS — PRODUCERS AND INDUSTRIAL CLUSTERS

HYDROGEN PRODUCTION AND BUSINESS MODELS:

- Hydrogen production must start from industrial clusters, and the view was expressed in some quarters that hydrogen is not needed at NTS entry points like St Fergus or Bacton. The industrial clusters must be supported to go first.
- Blue hydrogen will be needed to kick start decarbonisation with green hydrogen to follow. There is, however, a big difference between the carbon footprint of blue hydrogen from methane extracted from the UK Continental Shelf and imported LNG – we should prioritise indigenous production.
- General view that green hydrogen at scale will not happen before the 2030s. Concerns were raised about the ability to manufacture and install enough electrolyser capacity to provide baseload hydrogen, and the planning, water and infrastructure requirements, even if green hydrogen is cost competitive on paper. Blue hydrogen is seen as meeting the bulk of industrial demand.
- The potential for green hydrogen was expressed. Periods of low electricity prices would enable electrolysers, and integrated offshore wind/hydrogen farms could be developed in the 2030s and 2040s – molecules are the best way to fully harness the offshore wind resource. Already there are enquiries in Europe for 10-100MW scale electrolysers. These can be co-located where offshore wind power comes to shore, with the Port of Cromarty Firth mentioned as an example.
- A whole systems approach was mentioned and a recent report on the North East from Northern Powergrid and NGN was cited, which found that hydrogen could go in at 50MW scale in some locations. It would be helpful for producers to know where the networks need hydrogen at different pressure tiers.
- "Turquoise" hydrogen production is being investigated at Easington via molten metal pyrolysis, which produces a solid carbon by product, which can be used in agriculture or construction.
- Hydrogen produced at blast furnaces should also be considered for early adoption.
- A split CfD, with volume protection for early contracts, was the best business model, with different pots for blue and green hydrogen. Some disappointment was, however, expressed that 2022 is the date set for final business models to be in place, and the hope was expressed that a hydrogen business model consultation would be based on a "minded-to" position.
- The key issue is that the price of hydrogen should be lower than the natural gas plus CO2 price to manage the risk of early adoption – so the reference price should be natural gas excluding the CO2 price. The discovered price for hydrogen should be shared between the producer and government, to build a hydrogen NBP price over time.
- The fixed cost payment should be a bit less than the actual fixed costs, providing an incentive for the producer to find customers, with the fixed costs payment reducing if the plant exceeds expected sales.
- Infrastructure should be built offshore as much as possible as this reduces planning issues. In Scotland, most cities are close to the east coast, so offshore infrastructure is very accessible.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

STORAGE:

- There may be a competition for hydrogen storage. For example, Humber is likely to need 8 TWh of storage.
- Resilience will be needed for each cluster until the clusters are joined up.

POWER GENERATION:

- The Triton power plant is being designed with burners that will accept 40% hydrogen initially and will have to be retrofitted later for 100% hydrogen.
- It may be hard to add CCS onto dispatchable CCGTs.

INDUSTRIAL USE:

- It is most straightforward to grow hydrogen demand for industry. Dispersed industry tends to be smaller – it is important to go for the biggest users.
- At the same time, dispersed industry tends to be SME, and SMEs are important growth centres for the economy – so do not forget the small users.
- According to the Element Energy report, as part of the Hy4Heat programme, a lot of industry can do duel fuel hydrogen and methane. So, a hydrogen trunk line, in addition to the existing methane network, provides flexibility and resilience.
- Investment decisions made now are key, as industrial assets last for a considerable period. Industry cannot install hydrogen-ready equipment as per domestic boilers, and high-temperature conversion to hydrogen would need to be bespoke.
- Ports were also seen as important demand centres, including for HGVs and ships.
- The point was made that there are still a lot of interruptible gas contracts, that are unused because the gas supply has been more resilient.

CCS:

- CCS must come first for hydrogen to succeed – hydrogen may be developed in parallel, but it is unlikely to start without CCS.
- Most industrial consumers want to have post combustion capture, not modifying burners for hydrogen.
- For some clusters, for example South Wales, CO2 shipping is vital.
- For Grangemouth, CO2 could be exported using NTS Feeder 10, or hydrogen could be delivered.

TRANSPORT:

- Which markets will OEMs serve? There is a finite number of fuel cells and given likely market size and fuelling infrastructure, other counties are likely to see greater penetration in the short term.
- Fuel cells will be high purity – they won't get cheaper if you must add technology to handle impurities and manage by-products. At the same time, onsite purification would have to handle the waste stream from the purification process.
- The focus needs to be on cost and public acceptance – it needs to be competitive with diesel. Hydrogen forklift trucks are already cheaper on a total cost of ownership basis, and by 2030, hydrogen could be cheaper than diesel for long distance heavy transport – with a CO2 price.
- It is likely that gas networks will be a long-term solution for transport – and hydrogen will be tankered to fuelling stations or produced onsite to build up the market.
- Industrial cluster projects are planning for a portion of hydrogen production (5% in HyNet) to be used for heavy transport.
- It was suggested that contours of distances from hydrogen production could be established – the closer you are, the cheaper the hydrogen is, and at a certain distance it may be best for onsite electrolysers. For example, the cost of piping hydrogen from HyNet to Birmingham vs the cost on onsite electrolysis or using tankers.
- The key steps could be 1. Short term: Electrolysers on forecourts to enable the sector to develop. 2. Medium term: Centralised, lower cost hydrogen production and tankers to forecourts. 3. Longer term: Pipelines.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

BLENDING:

- In the main, there was little interest in deblending, which is seen as adding cost. Most heavy industry would want to stay on methane and add CCS and would not want to pay more for their deblended methane, then add CCS as well. However, in other clusters deblending was seen as important, including to overcome the efficiency loss from using blended gas. Overall, there was a preference for parallel pipelines for methane and hydrogen.
- The view was expressed that networks need to be 100% hydrogen or 100% methane. Industry cannot afford to handle the uncertainty of blending. On the other hand, while there may be an efficiency penalty from blending, some burners can handle hydrogen blends, and simple cycle turbines are more adaptable than CCGTs. The view was also expressed that it is difficult to build the required hydrogen production capacity to get to 100% without blending as an intermediate step.
- Projects such as Future Billing will allow accurate bills from different CV gases.
- Some cluster projects, e.g. HyNet, are using blending in public gas networks. Blending is seen as providing support for supply and building consumer confidence. Future pilots need to get to thousands of homes.
- Blending could occur with biomethane and syngas, but only if gaseous energy demand falls a lot e.g. with hybrid heating systems.

INDUSTRY VERSUS DOMESTIC:

- Industrial use at scale will happen in the 2030s, but domestic conversion to hydrogen is unlikely at scale before the mid-2030s or 2040s, partly because there may not be enough "spare" hydrogen before then. It is simpler not to use a gas grid to replace existing grey hydrogen in industry, and cluster projects are not predicated on 100% domestic conversion – planned cluster infrastructure is not being oversized for future domestic hydrogen use.
- There is currently no business model for dedicated hydrogen production for domestic use, and until one is in place, no-one will offer to build hydrogen capacity for the domestic market. By the time hydrogen capacity is available for the domestic sector in the mid 2030s, government may well have done something else (demand management, mandating heat pumps etc).
- There may be a BEIS/OFGEM view that seeks to prioritise hydrogen/CCS in clusters, whilst deferring any decisions on domestic heat. Domestic heat is seen as the hardest sector and the one that networks really need.
- Would it be possible to complete the necessary inspection programmes for every house in a 100% conversion? In the HyDeploy trial, every joint in the network and in domestic properties was inspected and leak tested before HSE were happy. This could not realistically be done in a full roll out.
- The risk of increases in fuel poverty is a major one. Do the networks have a target price for hydrogen? There needs to be an early agreement with government on a target price for domestic energy so that the country can understand how much more the transition will cost each consumer, and where subsidy will be needed.
- In the absence of networks, tankering hydrogen to e.g. the SIUs would be possible.

SKILLS:

- The issue of existing gas engineers retiring soon, and the risk of losing skills, was raised. Ensuring enough skilled people is critical.
- Reskilling the oil and gas workforce is critical. The hydrogen economy may not create jobs, except for in the construction phase, but it will sustain jobs.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

ROLE OF GAS NETWORKS:

- Ofgem changes to the short haul tariff might see some sites near gas import terminals disconnect from the NTS and build a direct connection to the terminal.
- The terms of reference for Ofgem need to be reconsidered – it should have a decarbonisation role. Although some competition is good, we need collaboration as well and this is lacking.
- General agreement that the NTS is not needed for hydrogen, and should remain a methane transporter, with the methane still needed by industry. The view was expressed that compression costs for hydrogen for the NTS would be too great, due to the compressibility differences between hydrogen and methane, and the additional energy requirements (8x the power requirement of methane) that results, together with increased interstage cooling.
- However, the alternative view was expressed that the NTS could blend hydrogen from offshore wind production (or from natural gas) at entry points such as Milford Haven, and that this would allow the conversion of existing distribution assets. A 2% blend in the NTS would also be possible from St Fergus.
- Differing views on whether the gas networks should connect the clusters to each other and to storage facilities, or whether a parallel hydrogen network should be built, with possible links to the GDNs. Humber is planning a hydrogen pipeline to Easington, and the CCS pipeline corridor from Drax will include a hydrogen pipeline in the opposite direction (for future expansion). HyNet is planning a new 50 bar LTS. Ultimately, a gas network of some sort is needed to join the clusters together to provide a network with enough capacity.
- In the interim period before a domestic roll out, the networks should focus on getting ready for conversion (network life extension, area reinforcement, sectorisation valves to allow conversion by area etc).
- Notwithstanding the above points on blending, the view was expressed that the networks should focus on growing hydrogen blends in the 2030s. The view was also expressed that the gas sector has been too slow to manage change e.g. a feasibility study for a 3% hydrogen blend was done as far back as 2012.
- Ultimately, the view was expressed that hydrogen can happen without gas networks, but it won't reach its full potential – on cost, security and scale. The UK needs a hydrogen backbone infrastructure like the European hydrogen backbone plans. Dispersed industry, domestic and almost everything else that uses natural gas today depends on a grid.
- Political stability was also mentioned, with an advantage for Scotland in having had fewer energy ministers and a greater ability to take decisions.
- It was also argued that the gas networks need to do more public engagement as there is a risk the future ends up electric.

STAKEHOLDERS → OTHER INDUSTRIAL CONSUMERS

COST AND COMPETITIVENESS:

- There are upfront costs to make assets hydrogen-ready.
- There are ongoing costs of a more expensive fuel compared to that used by overseas competitors. There is a global market for industrial chemicals and other products.
- The biggest energy consumers spend £2-3 billion a year on gas and electricity, which is already a big cost.
- If ammonia costs more from being produced in a decarbonised way, then food will cost more. Farmers cannot pass on higher food costs as consumer won't pay, so farmers would buy cheaper ammonia from overseas and UK ammonia plants would shut.

QUALITY:

- For feedstock, methane is needed, and so there are issues with feedstock quality from a blend of hydrogen, and also whether the blend is consistent. A 5% hydrogen blend would require investment. Otherwise a lower quality feedstock would make the plant trip off.
- Deblending would be OK, but cost is the issue – possibly £100 million CAPEX, although OPEX would be small.
- Quality of heat is also an issue.

CAPACITY:

- Given the lower density of hydrogen, the capacity of pipes, including those going into the chemical plants themselves, is an issue. Bigger pipes may be needed.
- A lot more storage would also be needed, given that plants need a reliable 24/7 supply and cannot flex.

SHIPPING:

- The big issue for ammonia in shipping is that LNG is cheaper than oil and solves the air quality problem – and even with this, the maritime industry has not embraced it. Ammonia will cost a lot more.
- However, the EU is bringing shipping into its decarbonisation targets, so there may be a financial incentive coming.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

BUSINESS MODELS:

- If foundation products are made in the UK, with the lowest global CO2 emissions, then industry needs to be insulated from higher energy costs due to moving to hydrogen earlier than other countries. A carbon border tax is an option, but it would need to be applied as a refund on exports as well as a tax on imports. The UK would need to mirror the EU on this.
- If green gas levies are added to gas prices (as per electricity), there are real risks for industrial competitiveness.
- How would business models for new subsidised hydrogen production affect business models for existing unsubsidised hydrogen, including existing electrolysis? There are sunk costs for existing SMR units, and even with a CfD for hydrogen and CCS, you would still need to spend hundreds of millions effectively building a new ammonia plant.
- Cluster projects are the best ones to subsidise.

ROLE OF THE NTS:

- There is a risk that if the NTS goes into a blend of hydrogen, existing facilities would disconnect from the NTS. Facilities would not want a blend of hydrogen to make hydrogen, and others need methane as a feedstock.
- Most large chemical sites are ex-ICI and located where natural gas comes into shore. They could go off-grid and use the North Sea supplies directly.
- Ofgem's planned new charging arrangement would take no account of geography, so NTS transport costs for gas in clusters would increase, meaning that the payback period to build a new dedicated pipeline would be much shorter – potentially only 6 months. Some clusters may therefore go off grid anyway.
- Large feedstock users account for around 2-3% of NTS use, and an additional 5% goes to large industrial heat users. Industrial burners can, however, do a blend and burner control systems can manage a fluctuating blend.

STAKEHOLDERS — DOMESTIC CONSUMERS AND APPLIANCES

DOMESTIC HEATING:

- Hydrogen ready boilers can be converted to hydrogen by changing out three components which takes about 1 hour. Total cost is £100. Hydrogen-ready boilers would not cost more than regular boilers.
- Hundreds of enquiries have been received from the public about getting hydrogen-ready boilers now.
- It is not possible to convert a natural gas boiler to hydrogen economically although natural gas boilers will run safely on 20% hydrogen blend. Bespoke boilers would have to be made for blends above 20%.
- The first hydrogen boiler was fitted at Spadeadam HyStreet in September 2020. Prototype boilers have been running in laboratories for 3 years now. SGN has placed an order for 100 boilers for H100 Fife.
- Heat pumps have not sold well, and several customers who bought heat pumps have been refunded, with the gas boilers reinstated. 15 million or so homes have a combi boiler and no hot water storage, whereas heat pumps need the hot water storage.
- No preference between green and blue hydrogen, although green would be ideal beyond 2050.
- Some people say that hydrogen is dangerous and expensive but these people tend to have vested interests in competing technologies. The hydrogen industry needs to demonstrate safety and will need continued consumer protection and a regulated market. If gas networks are not converted then they may need to be decommissioned.
- The biggest concern of decarbonisation is cost to consumers.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

TIMING:

- Boiler manufacturers have not yet invested in tooling for mass roll-out of hydrogen appliances, as they are waiting for a policy decision, but they could be ready by 2025-26.
- If hydrogen ready boilers are prescribed from 2025, in 17-18 years all boilers should be ready.
- We have three carbon budgets by 2035 and it is doubtful that that hydrogen conversion would be complete by then. We need to get cracking by injecting some hydrogen into the network asap. A 20% blend is a good way of familiarising customers with hydrogen and buying time whilst building up hydrogen production facilities and installing hydrogen ready boilers.
- There needs to be a national action plan to achieve net zero. 100% hydrogen consumer trials are sensible as the information needs to be provided, but all low carbon options should be available.

STAKEHOLDERS — TRANSPORT

HGVS:

- The OEMs are starting to shift to hydrogen and will use high-purity fuel cells.
- It is not yet clear whether there will be a national network of hydrogen HGVs and refuelling infrastructure, or whether it will be based around industrial clusters, which may help to aggregate demand and link with hydrogen supply.
- Government does not want to put extra taxes on transport, so will not penalise petrol and diesel further.
- There has been a lack of coordination between the oil and gas industry and the motor industry for liquid fuels, and this may well be repeated for hydrogen.

AVIATION:

- Jet fuel could come in the form of synthetic fuel, compressed hydrogen or liquid hydrogen, and Airbus and Rolls Royce are starting to move in this direction.
- Airport operations lend themselves well to hydrogen, where vehicles have high usage rates and therefore charging/refuelling times need to be minimised.

SHIPPING:

- The maritime sector could increase demand for ammonia significantly.
- If there are new ammonia production facilities, these may be located at the port, or the ammonia may be trucked.
- A key issue is who pays. Could there be a ports obligation?

INDUSTRY:

- The chemicals industry needs to decarbonise its feedstocks. It is worth noting that coal (solid fuel) is going, and the EU now wants to clean up oil (liquid fuel).
- Hydrogen may be less efficient than direct electrification, but it is more reliable.

ROLE OF GAS NETWORKS:

- Purification of network hydrogen up to fuel cell standard is not very expensive, and this will be needed for airports as well as HGV refuelling stations.
- However, by the time we see 100% hydrogen in gas networks (2035), fleets will already have moved to hydrogen – they will get the hydrogen from either a private pipe or onsite electrolysis, and therefore won't need to invest in onsite purification. The exception to this would be if bio-CNG is widely adopted as an interim step, before hydrogen fuel cells.
- The sooner networks are ready to take hydrogen, the sooner consumers can use it, and networks need to press on with enabling hydrogen.
- On domestic heating, boiler manufacturers should only be selling hydrogen ready boilers now. The networks should acknowledge that heat pumps play a role, but show to government that it is difficult. Government is sitting in the middle and unsure who to believe.
- Blending is helpful as a sink for hydrogen, providing optionality for producers, and blending should be done if possible as an interim.

APPENDIX 1. STAKEHOLDER ENGAGEMENT

STAKEHOLDERS — POWER GENERATION AND ELECTRICITY GRID

HYDROGEN PRODUCTION:

- Hydrogen may be produced in different ways – blue hydrogen at scale in industrial clusters, green hydrogen located close to consumers, and green hydrogen from dedicated and curtailed renewables, including potential offshore hydrogen production.
- Other forms of hydrogen production, including from biomass (with or without CCS) and nuclear, may be used.
- Clarity from government on policy, business models and regulation are needed before major production decisions can be made.

HYDROGEN STORAGE:

- Hydrogen will be used as seasonal storage, and 17-20 TWh will be needed by 2050. This could include repurposed salt caverns.

POWER GENERATION:

- Views differed from newbuild CCGTs not being needed after 2030, because other solutions such as demand side management, battery storage, interconnectors and overall demand reduction would be sufficient, to gas fired baseload and peak shaving power stations being needed beyond 2050, including new builds, for energy security and system stability.
- Hydrogen fuelled generation is a possibility, and turbine manufacturers are considering large scale machines, but the current focus is on post combustion, rather than pre combustion solutions for decarbonisation.
- Future power stations could be co-located in industrial clusters at blue hydrogen production sites, to ensure a methane feed.

ROLE OF THE NTS:

- Views differed from no need for methane in the NTS for power generation after 2040, to methane being needed from the NTS through to 2050.
- From a system perspective, it would be better to see a parallel hydrogen transmission network rather than hydrogen in the NTS. Deblending to 100% methane might work, but why pay more for this, when it would be best to burn the cheapest fuel and capture the CO_2?

STAKEHOLDERS — STORAGE

BLENDING:

- Existing salt caverns may not be suitable for 20% blending. Studies have been done on similar assets in France, and 10% hydrogen would be OK, but 20% was not studied. A similar study would need to be done for the UK salt cavern sites.

CAPACITY:

- A BEIS led study, HySecure, found that each salt cavern repurposed for 100% hydrogen could hold 50 GWh (1,200 tonnes) of hydrogen on top of the cushion gas.
- The flowrate would be a similar proportion of the working gas volume and would be around 1.3 GWh (40 tonnes) per day, meaning that the cavern would empty in 30 days.
- Each repurposed cavern would cost around £80 million, plus £3 million for the cushion gas, and extra for dehydration. It is expensive but much longer lasting than batteries.

FINANCING:

- A CfD doesn't work for storage, as it is not clear what the reference price would be.
- Leaving it to the market does not work as the winter/summer price differential is too small – it won't deliver either methane or hydrogen storage.
- The best approach is a RAB model, as used in Italy and France, and the RAB can be open to competition, but the insurance value is worth paying for.

APPENDIX 2
WIDER PUBLIC OPINION RESEARCH

APPENDIX 2. WIDER PUBLIC OPINION RESEARCH

Public attitudes to net zero are nuanced. Put simply, the public support net zero, but do not want to experience the cost and disruption that may accompany it. The public are also very open to 100% hydrogen in the home.

The summary below is based on several recent public opinion surveys and practical trials, together with the recent Climate Assembly work, which included focus groups, quantitative polling and equipment installation. Although the fieldwork was done before the Covid-19 pandemic, the results are still relevant, and probably even more so now, when it comes to costs:

- Decarbonised Gas Alliance (DGA): Getting Net Zero Done (May 2020). The research included four focus groups of different incomes and outlook in Warrington and Bushey, together with a nationally representative poll of 2,000 people.[102]
- H21: Public perceptions of converting the gas network to hydrogen (June 2020). The research, carried out by Leeds Beckett University, included 12 discovery interviews, a poll of 1,000 people and six deliberative workshops held in Leeds, Manchester and Birmingham.[103]
- Energy Systems Catapult: Understanding how to increase the appeal and performance of heat pumps (December 2019). The trial involved installing heat pumps as part of smart hybrid heating systems in five homes.[104]
- Freedom Project: Final report (October 2018). The project installed 75 hybrid heating systems in a mixture of private (including off-gas grid) and social housing in Bridgend.[105]
- Ofgem: Deep Dive on Consumer Attitudes Towards Decarbonisation (September 2020): The opinion research involved ten focus groups with domestic energy consumers across Great Britain, covering decarbonisation, climate change and energy consumption behaviours.[106]
- Climate Assembly UK (September 2020). The report brought together the recommendations from the UK's first citizens assembly on climate change.[107]

NET ZERO

- Over 60% of the public think that climate change is either one of the most or the most pressing issue of our time and over 70% support the UK's net zero target. The polling also showed that 57% of the public think Britain should take a lead in dealing with climate change internationally. Although almost half of the population do not know how, people tend to think that meeting net zero will create more jobs than are lost.
- However, when pressed in focus groups, many people associated "net zero" as much with removing plastics from the ocean and air pollution as they did with cutting greenhouse gas emissions, and there was no understanding of the sorts of policies that might be needed to deliver net zero.
- Cost is a major barrier. In the DGA poll, when asked how much of their disposable income people would be willing to lose to help deal with climate change, 37% said none and 38% said less than 5%. In the Ofgem survey, some people were happy to pay a small premium for a green tariff, but for larger purchases such as a new vehicle, new appliances or home insulation, the desire to save money out-weighed the desire to protect the environment.
- From a lifestyle perspective, people were resistant to change. The Ofgem survey found that when deciding when to use appliances, to turn on heating or how to travel, maintaining warmth, minimising effort and fitting around lifestyle were more important than protecting the environment. Taking actions that threatened to disrupt existing habits was a challenge, especially for families.

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APPENDIX 2. WIDER PUBLIC OPINION RESEARCH

100% HYDROGEN

- When asked to rate options to decarbonise industry, heavy transport and home heating, people supported most measures, although with the caveats that they knew little about the options and would not want to pay more.
- For industry, people supported using both electricity and hydrogen for industrial processes, and in heavy transport, people were strongly supportive of electric, hydrogen and biomethane buses and trucks.
- For home heating, people could relate the options to their own lives much more clearly than for the other sectors. In the DGA polling results, the suggestion to blend hydrogen and biomethane into the grid was very well received and converting to 100% hydrogen was met with 50% support and 18% opposition.
- When asked directly in the DGA poll about how they would feel about going off-gas for a few days in the summer to convert to 100% hydrogen, the results were relatively split: 39% unconcerned and 34% concerned. At the same time, 52% were worried about hydrogen safety and 48% about the cost.
- However, in the DGA focus groups, safety was not a big issue – no one brought up safety spontaneously. The main issues in the groups were the disruption of a switchover and the cost, with participants worried about any increase in bills. Most people in the groups were relaxed about the decision being made for them, although there was concern about politicians changing their mind – it had not been long, for example, since politicians had actively persuaded people to turn to diesel vehicles.
- The results were similar in the H21 research, where workshops were held with small groups of people previously unsure about a domestic hydrogen conversion, with some positive and others sceptical. Safety was not a major concern for the participants: they assumed that if their supply is converted to hydrogen then it will have been robustly tested and found to be safe. As in the DGA research, people were more concerned about the safety of storing carbon dioxide (part of the blue hydrogen production process).
- Interestingly, in the H21 research, participants were relatively unconcerned about the estimated 7% by which their gas bill will increase should a conversion go ahead, although they were concerned that other more vulnerable people might struggle. They were, however, concerned about the need to purchase new appliances and wanted reassurance that there would be an incentive scheme to help with the cost. They wanted a decision to be made quickly and to receive enough notice so that they can avoid purchasing expensive appliances that could become obsolete.
- The Climate Assembly strongly supported hydrogen (83%) as part of achieving net zero, with members also supporting heat pumps (80%) and heat networks (80%). Almost all Assembly members (94%) thought that solutions should be tailored to local areas.

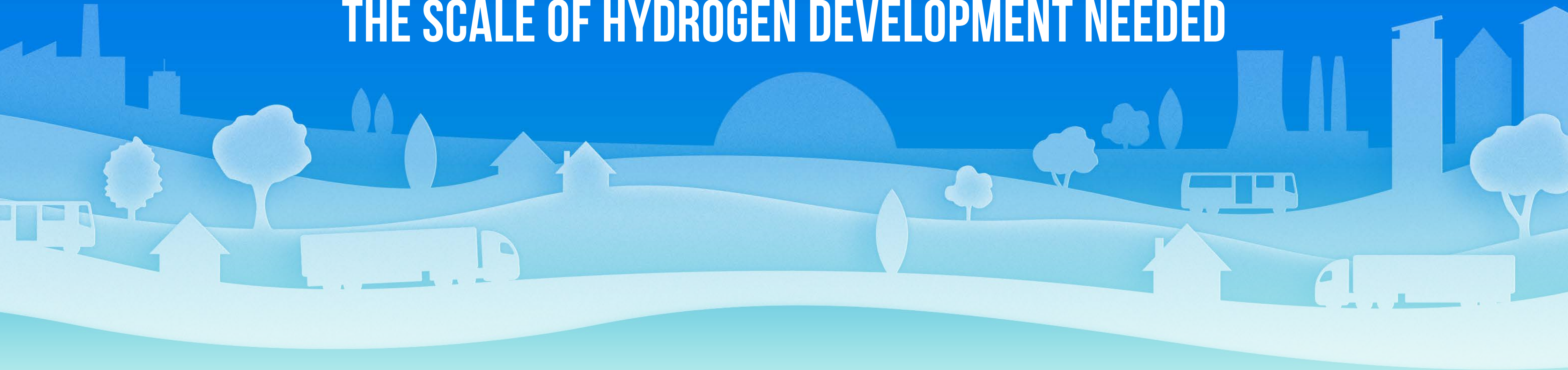
HEAT PUMPS

- In the DGA poll, heat pumps were not as popular as hydrogen, with 40% support and 26% opposition. In the groups, heat pumps got no traction at all.
- There were similar findings from the Energy Systems Catapult work, where five heat pumps were installed as part of hybrid heating systems. It was hard to find homeowners with gas boilers who wanted a heat pump, even though it was being offered free. They worried about energy bills, maintenance costs and, due to a lack of familiarity with the technology, what ownership of a heat pump entailed. Participants in all five properties indicated some surprise at the size of the heat pump and the scale of work required to install the equipment. All participants were reluctant to make expensive investments to improve the energy efficiency of their homes just to enhance the performance of their heat pump.
- The Energy Systems Catapult work also found that people may be more open to removing their gas boilers and relying only on a heat pump to warm their home if they could buy their heat as a service. This might bundle the costs of their heating system, installation, servicing and heat into one fixed weekly cost. They also said they would be more confident heating their home for longer periods to suit a heat pump if they could have cost certainty through a fixed price.

HYBRID HEATING SYSTEMS

- Notwithstanding the Energy Systems Catapult findings, hybrid heating systems were considerably more popular than standalone heat pumps. In the DGA poll, 47% supported and 18% opposed; this was mirrored in the groups. To the extent that people understood the option of combining a heat pump with an existing boiler in a smarter system, they thought it sounded like a good idea.
- Hybrid heating systems also met with more support in the Freedom Project trial, with 74% of respondents saying that they would recommend a hybrid heating system to a friend.
- Respondents were confident the hybrid system was working correctly but were less certain that they were saving energy and money – this highlighted again how important the economic criteria are if customers are to invest in this technology outside of the trial.
- Overall, the Freedom Project found that ease of use, comfort, reliability and up-front and running costs are the primary aspects of a heating system that customers value. The hybrid heating system performed well with respect to ease of use and comfort provided but the up-front costs and operating costs of hybrid heating systems today are likely too high for many customers.

APPENDIX 3 CAPACITY
THE SCALE OF HYDROGEN DEVELOPMENT NEEDED



APPENDIX 3. CAPACITY: THE SCALE OF HYDROGEN DEVELOPMENT NEEDED

HYDROGEN SUPPLY

To get to net zero and tackle the hard-to-decarbonise sectors, scenarios show that we will need substantial quantities of hydrogen. ENA's Pathways to Net Zero report shows that 236 TWh of hydrogen will be needed, including 140 TWh of hydrogen for buildings and 59 TWh for industry. Other scenarios, including from the Committee on Climate Change, National Grid and Aurora, show similar, and in some cases substantially higher, levels of hydrogen.

HYDROGEN CAPACITY

To deliver the 236 TWh of hydrogen set out in ENA's Pathways to Net Zero report, substantial capacity will be needed, including:

PRODUCTION:

- If all hydrogen is produced from natural gas with CCS, then around 33 GW of auto thermal reforming (ATR) capacity would be needed, assuming an 80% load factor.
- If all the production came from electrolysis, then around 67 GW would be needed, assuming a 40% load factor from dedicated renewables.
- In reality, a mix of low carbon and renewable hydrogen production methods will be employed, including hydrogen from waste plastics, but at huge scale. This must be accompanied by the required low carbon electricity generation and/or natural gas and CCS capacity.

STORAGE:

- For an annual usage of around 900 TWh, Great Britain currently has 2.5 billion cubic metres of LNG and underground natural gas storage, equal to around 27 TWh – or 3% of annual usage.
- The equivalent for hydrogen, based on the Pathways to Net Zero report usage, would be 7 TWh of storage – but given that hydrogen is one third the volumetric energy density of natural gas, it would need three times the storage volume.
- Essentially, close to the equivalent of today's natural gas storage space will need to be made available for hydrogen.

GAS NETWORKS:

- Hydrogen: The point made above for storage is also applicable to gas networks, given the lower volumetric energy density of hydrogen. In broad terms, 236 TWh of hydrogen would need around the same grid transportation capacity as 700 TWh of natural gas, and it would need to be sized for peak, not average, demand.
- Methane: At the same time as hydrogen production and use is increasing, the gas networks will need to maintain a resilient methane network, including storage and in some places transporting the methane needed for ATR hydrogen production. The methane network will also be incrementally converting to 100% biomethane.

APPENDIX 3. CAPACITY: THE SCALE OF HYDROGEN DEVELOPMENT NEEDED

HYDROGEN BUILD AND CONVERSION RATES

To ensure that this level of capacity, together with substantial usage, is achieved by 2050, the build and conversion rates will need to be rapid, and will include:

HYDROGEN CAPACITY

To deliver the 236 TWh of hydrogen set out in ENA's Pathways to Net Zero report, substantial capacity will be needed, including:

PRODUCTION CAPACITY:

- To build the required level of ATR capacity would mean 1.3 GW of new ATRs each year from 2025, excluding replacements.
- If the hydrogen was produced solely from electrolysis, 2.7 GW would need to be commissioned each year from 2025, excluding replacements.

STORAGE CAPACITY:

- Based on the storage volumes outlined above, almost 300 GWh of hydrogen storage capacity would need to be brought online each year from 2025.
- This could be a mix of new and repurposed salt caverns as has been demonstrated by, the BEIS-led HySecure study, and larger stores, with existing stores such as Rough having potential for hydrogen storage.

DOMESTIC CONVERSION:

- The Pathways to Net Zero report's 70/30 hydrogen/biomethane split in buildings implies just over 15 million homes converted to hydrogen – a rate of 750,000 homes each year if widespread conversion starts in 2030.
- Overall, the report envisages 22 million homes connected to hybrid heating systems in 2050, primarily through conversions of existing homes.

This path is not only deliverable but is the lowest-disruption and most cost-effective option for consumers, as other studies have shown. And while this is clearly a fast pace of development to maintain, it is in line with other complementary decarbonisation pathways that are needed to achieve net zero. For instance, the Committee on Climate Change's Net Zero report found that, alongside a requirement for 270 TWh of hydrogen by 2050, 9-12 GW of renewable and low carbon electricity generating capacity, together with 2.5-5.8 million tonnes of CO2 storage capacity, need to be built each year over the next three decades. The UK supply chain is keen to deliver this ambitious hydrogen pathway, and there is a real opportunity for UK leadership.

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[105] See https://www.westernpower.co.uk/projects/freedom
[106] See https://www.ofgem.gov.uk/system/files/docs/2020/10/deep_dive_on_attitudes_supporting_decarbonisation_1.pdf
[107] See https://www.climateassembly.uk/report/read/in-the-home.html#in-the-home-summary-of-recommendations

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