ELECTRIC POWER RESEARCH INSTITUTE

Quick Insights

Hydrogen's Role in Decarbonizing Heat in the United Kingdom

RESEARCH QUESTION

What are the drivers for renewed interest in accelerating hydrogen solutions for the decarbonization of heat in the UK and Europe?

KEY TAKEAWAY

Meeting the challenge of decarbonizing heat in the UK, a winter peaking system, is complex. Peak energy demand for heat is significantly higher than that for electricity in winter months. Electrifying heat in the UK has been challenging and would require a significant buildout of the electric system, both generation and wires. The use of hydrogen, delivered via the existing natural gas network, is being investigated as a means of providing low-carbon heat.

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KEY POINTS

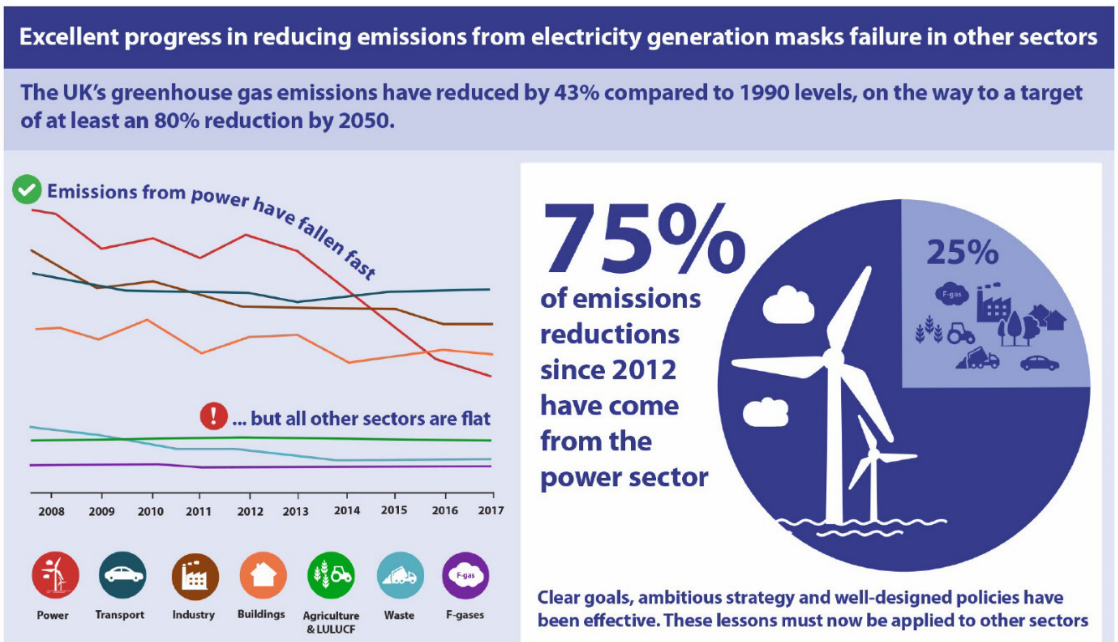
- Space heating accounts for approximately 40% of energy consumption and 20% of all greenhouse gas emissions in the UK. This is largely served by natural gas burned in conventional boilers (furnaces) to drive central heating systems.
- Technologies to decarbonize heat include heat pumps, heat networks,[1] solar thermal, biomass, combined heat and power, and fuel cells—all with challenges to implement at scale. Some have been heavily supported by government policy and incentives without significant adoption at scale.
- Most homes in the UK are connected to (or are located close to) existing gas infrastructure. Attention is turning to low-carbon solutions that may make use of this embedded infrastructure.

1 A heat network is a distribution system of insulated pipes that takes heat from a central source and delivers it to a number of domestic or non-domestic buildings using water or steam as the heat carrier.

- According to the NaturalHy study,[2] up to 10% hydrogen can be blended with natural gas and injected in to the system without adverse effects on the network or end-use appliances. Ongoing research is assessing the feasibility of converting the gas network to accommodate 100% hydrogen.
- The UK's H21 North of England[3] project proposes the conversion of the north of England's gas network to supply clean hydrogen for heat, including a new hydrogen transmission system, repurposing of the gas distribution system, and conversion of end-use appliances for 3.7 million meter points, at an estimated cost of £22.8bn ($28.7bn).

INTRODUCTION

The initial focus for economy-wide decarbonization has been the power system. The general consensus is that clean generation technologies such as hydro, solar photovoltaics (PV), and wind were comparatively easier to visualize and support. There has been significant adoption of these technologies, and a fully decarbonized UK power system is now envisaged sometime in the early 2030s.



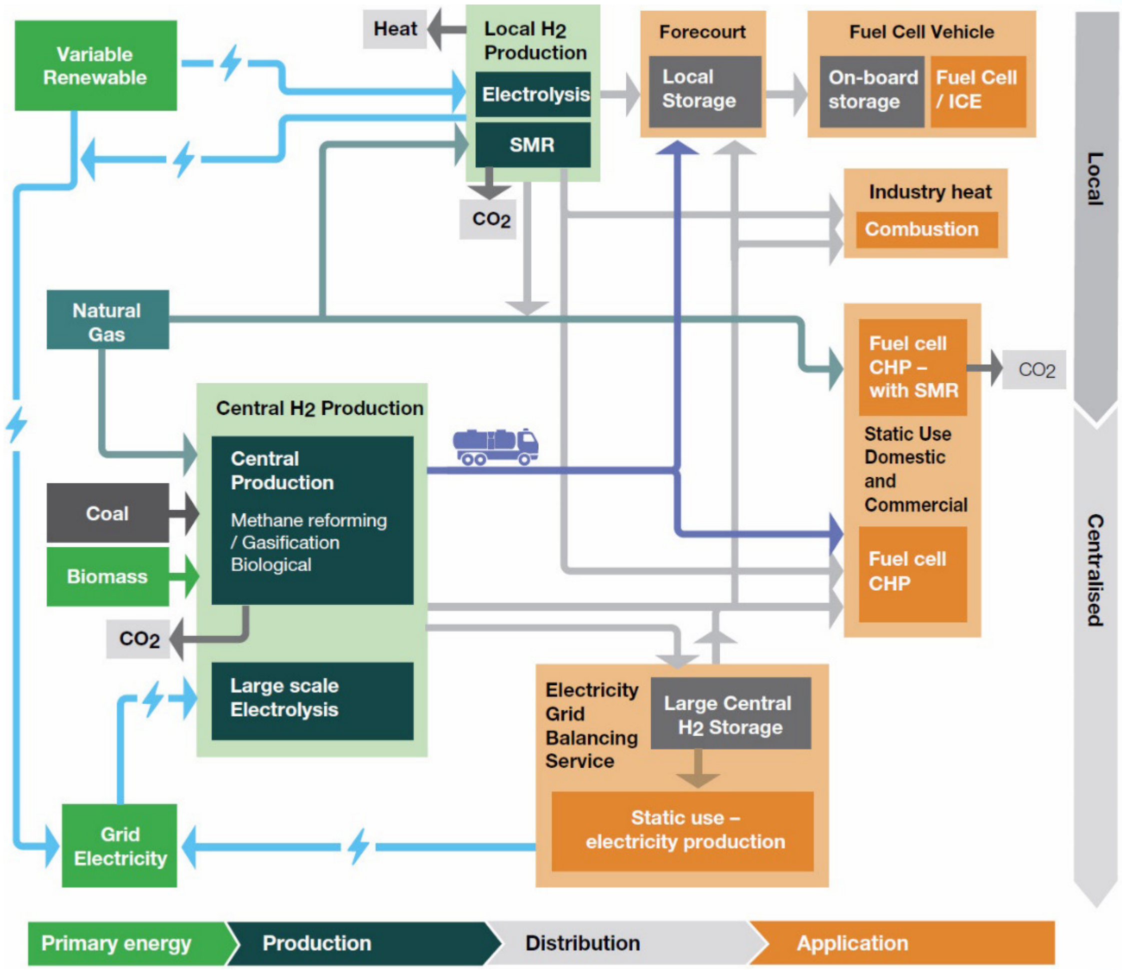
Source: 'Reducing UK Emissions, Progress Report to Parliament' Committee on Climate Change, 2018[4]

The UK's Climate Change Act 2008 sets carbon reduction targets for all energy sources (an 80% reduction in CO_2 emissions by 2050 from 1990 baseline[5]), so attention is now turning to heat, one carbon-intensive sector that has seen little improvement. The initial assumption was that heat pumps would replace conventional boilers in most applications. However, a decade of significant government-funded subsidies and incentives did little to stimulate consumer adoption of heat pumps.

Alternative solutions to heat pumps for decarbonizing heat include heat networks,[1] combined heat and power (CHP) (large-scale and micro), biomass, hybrid (dual-fuel) heat pumps, and hydrogen. Each alternative has distinct challenges and will be difficult to implement at scale.

Recently, there has been renewed interested in the role hydrogen can play in decarbonizing the economy and in particular, through the on-gas grid sector to provide heat.

2 https://cordis.europa.eu/project/rcn/73964_en.html
3 https://www.northerngasnetworks.co.uk/event/h21-launches-national/
4 https://www.theccc.org.uk/publication/reducing-uk-emissions-2018-progress-report-to-parliament/
5 https://www.legislation.gov.uk/ukpga/2008/27/contents



Source: 'The Role of Hydrogen in the UK Energy System', ERP, 2016[6]

A number of challenges exist for creating a scalable hydrogen ecosystem—production, provision of infrastructure, associated carbon capture and sequestration (CCS), and public acceptance. Hydrogen is not widely used today outside of niche industrial settings.

PRODUCTION OF HYDROGEN

There are significant challenges in producing hydrogen economically at sufficient quantities to decarbonize the heat sector. Most hydrogen today is produced from fossil fuels, which also produce CO_2, largely negating any emissions benefit unless CCS is applied to the hydrogen production facility. An alternative means to produce hydrogen is through electrolysis using zero-carbon electricity. This could produce zero-carbon hydrogen but would require a massive deployment of renewable generation and/or nuclear plants.

CONVERSION OF NATURAL GAS DISTRIBUTION NETWORKS TO DELIVER HYDROGEN

In the mid-2000s, when activity addressing climate change began to accelerate, it was envisaged that the natural gas distribution network would become redundant sometime towards the middle of the century. Electrification of heat and transport, coupled with very low-cost renewables and nuclear, would make natural gas a largely obsolete fuel for residential heating (and most industrial heating).

Recently attention has returned to how the gas network could be re-purposed to supply hydrogen and other forms of low-carbon gases for residential heating.

6 http://erpuk.org/wp-content/uploads/2016/10/ERP-Hydrogen-report-Oct-2016.pdf

Hydrogen can be blended with natural gas and injected in to the network. This often is called HENG (Hydrogen-Enriched Natural Gas). This hydrogen-rich gas blend can have an effect on the materials in the pipework, network equipment, and end-use appliances, which were designed for low-hydrogen natural gas.

One of the largest global studies of the effects of HENG on physical pipeline infrastructure was the EU-funded NaturalHy[2] (2008-2013), concluding:

- *The majority of European networks could accommodate up to 10% hydrogen concentration.*
- *Network equipment such as storage facilities, pressure regulators, and compressor stations is not affected.*
- *End-use appliances, (conventional boilers and cookers) can burn a 10% hydrogen blend.*

Higher concentrations (up to 100%) are possible but will require network conversion work and appliance modifications.

Around 25% of the UK gas distribution network is made of iron pipes that are not suitable for hydrogen; the rest is made of hydrogen-compatible polyethylene pipes. The national iron mains replacement program should replace these iron pipes by 2030, which is also considered the earliest feasible date for hydrogen conversion. The gas transmission system is largely made of steel pipes which can only tolerate percentages up to approximately 10%, so a full conversion to hydrogen would require these to be replaced. However, given their placement and the need to inject hydrogen at key network points, a dedicated hydrogen transmission pipeline network may be built in parallel. This would also have the advantage of being able to serve industry and transport applications, ease the cutover transition, and maintain fuel flexibility in the transmission network over time.

Two major UK projects, due to be completed in 2021, are under way to provide critical safety-based evidence for 100% hydrogen conversion:

- Hy4Heat[7] focuses on domestic, commercial, and industrial buildings, including end-use appliances, looking at end-user-owned pipes and equipment.
- H21-NIC[8], led by the UK regulated gas network companies, looking at regulated gas networks.

H21 NORTH OF ENGLAND PROJECT

The goal of the H21 project is to supply hydrogen for heating to all homes and businesses by 2100. This includes hydrogen production, repurposing much of the gas network, and converting end-use appliances. The North of England sub-project[4] (NoE) is the first step and proposes a detailed technical program to convert the north of England by 2034, followed by further phases that would see residential heat in the UK substantially decarbonized by 2050 (helping to meet the UK's climate change goals and commitments to the Paris Agreement). It proposes a natural gas-fired hydrogen production facility with carbon capture and storage (CCS) (from natural gas); a new hydrogen transmission system; a repurposing of the gas distribution system; and conversion of end-use appliances for 3.7 million meter points. The project has an estimated cost is of £22.8bn ($28.7bn), and £250m has been requested for an initial front-end engineering and design (FEED) study.

Technical Aspects of H21 NoE

- Conversion of 86 TWh of gas-based heat demand to hydrogen (representing 14% of all UK heat and 17% of domestic heat)
- 12.1-GW natural gas-based hydrogen production facility based on autothermal reformer (ATR) design with nine 1.35-GW units
- A CCS solution to sequester 94% of the CO_2 emissions from the hydrogen production facility
- New high-pressure hydrogen transmission system feeding into converted local natural gas distribution networks

7 https://www.hy4heat.info/about-us/

8 https://www.ofgem.gov.uk/publications-and-updates/gas-nic-submission-northern-gas-networks-h21

- Infrastructure designed to have 8 TWh of inter-seasonal storage in-built
- Conversion of end-use equipment at 3.7 million meter points to use hydrogen, primarily boilers as there is currently a trend towards electric cooking

***Hydrogen appliances** are expected to cost 10-20% more than natural gas equivalents.[9] "Hydrogen-ready" boilers are expected to be available well before the conversion stage begins (circa 2028). For boilers in which modification is not an option, "drop-in" replacement options are expected.*

Expected Benefits of H21 NoE

- Improve local air quality with associated health benefits
- 92% reduction in carbon emissions from that of the current heating load in the area
- Ensure customers have choice between electric and gas to meet energy needs
- Demonstrate capability to meet large-scale decarbonization targets
- Meet UK and international climate change targets and commitments
- Platform for hydrogen to enable sector coupling among transport, heating, etc.

*The **hydrogen production technologies** considered included ATR, steam methane reforming, electrolysis, coal gasification, and ammonia cracking. ATR was chosen based on a detailed technical and cost comparison.*

Expected Costs of H21 NoE

- Total forecast project capital cost of £22.8bn ($28.7bn)
- Ongoing annual operational cost of £995m ($1.26bn)
- Beginning in 2035, a 7% increase in consumer bills across all domestic customers in the UK

ITEM	CAPEX (£M)	OPEX (£MPA) POST 2035 (ONCE CONVERSION AND COMMISSIONING IS COMPLETE)
Natural gas connection	0 (included in HPF)	0
Hydrogen Production Facility (HPF)	8,520	285
Inter-seasonal hydrogen storage	1,991	63
CO_2 transport and storage	1,340	24
Hydrogen transportation system	3,427	3
Appliance conversion	7,500	0
SUB TOTAL	22,778	375
Additional energy cost for Hydrogen Production Facility	N/A	580 (total annual gas cost is £2,292m based on gas price of £23/MWh)
TOTAL	22,778	955

Source: 'H21 NoE' Report, 2018[3]

A detailed implementation plan has been developed to ensure coordination of aspects of the program over a 12-year period. The conversion process is expected to be carried out with minimal disruption, as the existing distribution network design includes isolating valves to facilitate network conversion, and the network was successfully switched from town gas (gaseous fuel mix manufactured from coal) to natural gas in the 1960-80s.

9 https://www.gov.uk/government/publications/appraisal-of-domestic-hydrogen-appliances

EPRI'S RELATED WORK

In addition to the following in-progress initiatives, EPRI continues to engage with strategic partners, exploring opportunities for collaborative research assessing hydrogen technology and applications:

- Prospects for Large-Scale Production of Hydrogen by Water Electrolysis[10]
- Stationary Fuel Cells in Europe
- Hydrogen Technology Assessment with integrated energy-economics modeling in US-REGEN
- Valuation of hydrogen technology on the electric grid using production cost modeling, in partnership with the U.S. Department of Energy (DOE)[11]

As part of this work in its 2019 Prospects for Large-Scale Production of Hydrogen by Water Electrolysis initiative, EPRI will host an informational webcast. Hydrogen trends (many recent developments) and implications for the power sector (already part of 2019 project scope) will be synthesized in an executive briefing and white paper.

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10 https://www.epri.com/#/pages/product/3002014766/
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