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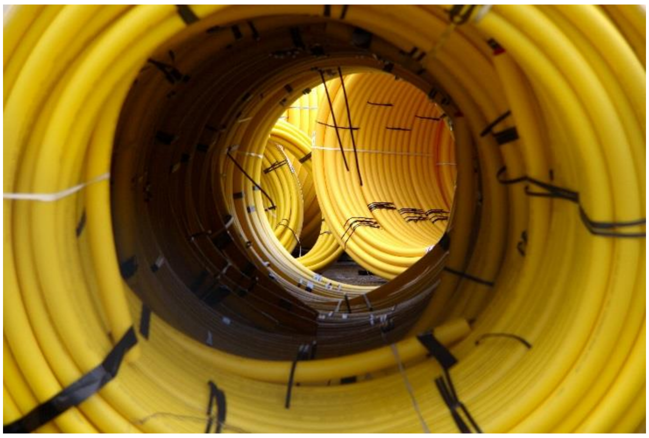
Decarbonising the Gas Network



The burning of natural gas for heating contributes 14% of the UK's greenhouse gas (GHG) emissions. Decarbonising, or reducing the carbon content of the UK gas supply is one option for reducing the emissions from heating. This POSTnote looks at the contribution that two alternative gases, hydrogen and biomethane, could make in achieving this goal.

Overview

- The UK needs new policies on low carbon heating to meet its emissions reductions targets under the Climate Change Act.
- The gas network delivers more than twice the energy of the electricity grid and supplies 23 million consumers. Supplying hydrogen and biomethane in place of natural gas could reduce emissions.
- Biomethane from waste already supplies some gas to the network and could be increased. The amount of available waste material limits future supply potential to 5-20% of current gas demand.
- There is also potential to supply parts of the network with hydrogen in future, but this is reliant on cost reductions, uptake of carbon capture and storage in the UK, and significant changes in network infrastructure.

Background

The Climate Change Act (2008) requires an 80% reduction in greenhouse gas (GHG) emissions relative to 1990 levels by 2050. The UK is on track to meet short-term emissions targets, but is unlikely to meet longer term targets without additional policies (Box 1).[1-4] While emissions from electricity production have fallen significantly, there has been much less progress in reducing emissions from heating.[1-5] In its 2017 Clean Growth Strategy, the UK Government presented electricity and low carbon gases as two possible ways to provide a future low emissions heating system. However, experts do not currently agree on which of these is the best approach.[6-9]

Currently, 70% of heat is provided by natural gas and 13% by electricity.[9] The gas network supplies natural gas to consumers, and could supply low carbon gases in future. This note looks at the prospects for decarbonising the gas network by supplying biomethane and hydrogen in place of natural gas. It covers their production and supply, carbon emissions and costs, and technical and policy challenges.

UK Heating from the Gas Network

Heating from all sources accounts for 20% of UK GHG emissions, with an annual energy demand equivalent to the annual output of 80 million single bar heaters.[1,10,11] Natural gas (which is mainly methane) provides 70% of this energy. It is the largest contributor to GHG emissions from heat.[1,10] Natural gas for heat accounts for 14% of all GHG emissions.

The gas network (Box 2) supplies approximately 90% of UK households,[15] almost exclusively with natural gas. Network operators have recently begun to add small amounts of biomethane, which contributes very little to emissions (see *Carbon Footprint of Biomethane*).[16] The gas network supplies twice the energy of the electricity grid annually, and six times more during winter peaks in demand.[5,17-19]

Biomethane

Biomethane is a purified form of biogas (a mixture of methane, CO_2 and other gases).[20,21] It currently supplies less than 1% of gas within the network, though the number of facilities supplying biomethane to the grid has increased

Box 1. UK GHG Emissions Targets

The Committee on Climate Change (CCC) (an independent statutory body set up under the Climate Change Act 2008) sets five-yearly 'carbon budgets' for reducing the UK's GHG emissions.

- The UK has met its first carbon budget (covering 2008–2012) and is on track to meet its second and third budgets.[12]
- According to the CCC, the UK needs new policies to meet the fourth (2023–2027) and fifth (2028–2032) budgets, reducing emissions to 48% and 43% of 1990 levels respectively.[3,13,14]

Box 2. The UK Gas Network
The current UK-wide gas network evolved from a series of local networks, which distributed hydrogen-rich 'town gas' (derived from coal) at low pressure until the 1960s, when the UK converted to North Sea gas.[25] A series of high pressure steel pipelines, known as the transmission system, now connects these lower pressure tiers.[25] Under the *Iron Mains Replacement Program* (IMRP), polyethylene pipes are replacing ageing iron pipework in lower pressure tiers to reduce leakage.[25,26] The IMRP is due to finish in 2032. Currently, the transmission system can store a significant amount of gas under compression. It is not possible to do so in lower pressure tiers.[25]

in recent years (Box 3).[10,22,23] However, the rate of growth has been lower than previously forecast. Further expansion will depend on continued government subsidies, the availability of organic source material (biomass) and changes to gas network infrastructure and regulations.[24]

Production and Supply
Biomethane can be produced by:[20,21,27]

- **Anaerobic Digestion (AD) facilities**, where wet biomass (such as animal waste or sewage) breaks down in the absence of air (POSTnote 387).
- **BioSNG plants**, which produce a synthesis gas (syngas) from dry organic material, including landfill waste. Further processing converts the hydrogen-rich syngas to biomethane and CO_2, prior to CO_2 removal.

Biomethane from AD is unlikely to provide more than 5% of the UK's current gas demand, due to the limited supply of wet feedstocks.[1,28-30] Because BioSNG uses a wider range of feedstocks, National Grid has suggested that biomethane could in theory supply up to a fifth of the UK's gas demand, although this would leave no biomass to supply other sectors, such as transport.[29,31,32] Currently, there are no commercial BioSNG plants in the UK (Box 3) and all biomethane in the gas network comes from AD plants.

Transporting Biomethane
The gas network has low and high pressure components (Box 2). Currently, production facilities can inject biomethane only into low pressure tiers of the gas grid. The limited storage capacity in this part of the network can prevent them from injecting when there is limited demand for gas.[33,34] Removing this barrier would require network operators to invest in infrastructure upgrades.[35]

Subsidies
The UK Government pays producers to inject biomethane into the network under the Renewable Heat Incentive (RHI). The tariff has been reduced in recent years, and the policy is currently under reform.[36,37] The CCC and industry groups emphasise that subsidy support is important for facilitating biomethane production and grid injection.[1,33,34]

Regulations
Under current regulations, consumers' bills are based on the calorific value (CV), or energy content, of gas in the local network.[38] The CV of biomethane is lower than natural gas and to ensure fair billing, producers must add propane to enrich the CV of their gas before injection. This raises the operating cost of production by up to 30% and increases biomethane's carbon footprint.[20,39] The National Grid's '*Future Billing Methodology'* project investigates alternative billing methods, to avoid the need for propane addition.[39]

Producers must monitor a range of parameters at the point of injection to the grid to comply with current gas safety regulations and if necessary, remove any contaminants.[40] Monitoring costs around £20K per year, per plant.[20]

Hydrogen
Hydrogen combustion produces almost no GHGs.[41] However, like electricity, hydrogen must be produced using other forms of energy, which may be associated with GHGs.[41] Currently, hydrogen gas does not supply the UK gas network, although hydrogen gas pipes supply industrial users in Europe and North America.[25,42] The UK Government Hydrogen Innovation Programme aims to resolve the main technical and safety challenges for hydrogen gas networks and appliances. If successful, it could lead to pilot trials by 2020.[44,45]

Production and Supply
There are roughly 20 methods to produce hydrogen and research is ongoing to make them more cost-effective alternatives to natural gas.[46-48] The methods favoured by industry for supplying a future gas grid are:[25,43]

- **Steam methane reforming (SMR)**, which accounts for 48% of current global production.[48-43] It separates hydrogen from methane at high temperature and pressure.[25,49] Natural gas is the most cost-effective source of methane, but some of its energy is lost during this process.[41,46-48] As a result, natural gas usage could rise by up to a third in areas supplied by SMR plants.[41]
- **Gasification**, which converts organic material to a hydrogen-rich syngas, before further processing to increase the hydrogen content.[43] Gasification of coal and oil account for roughly 48% of global hydrogen production, although a small number of plants have begun using biomass as a lower carbon alternative.[43]
- **Electrolysis**, which uses electricity to separate water into hydrogen and oxygen. It accounts for 4% of global production, and future growth will depend on reducing the high costs.[43] Hydrogen produced by electrolysis can only reduce emissions from the gas network if low carbon electricity is used.[43] If most production occurred

Box 3. Developments in Biomethane to Grid Injection

- **October, 2010**. The first biomethane to grid plant in the UK came online in Didcot, Oxfordshire, using treated biogas from a Thames Water sewage treatment facility to power 200 homes.[50]
- **November, 2012**. The first commercial scale injection plant began operating in Poundbury, Dorset.[51]
- **June, 2017**. A total of 81 biomethane plants were operating under the UK Government's Renewable Heat Incentive (RHI) scheme, which pays producers to inject into the gas grid.[23]
- **Mid 2018**. The UK's first commercial BioSNG plant is due to commence operations in Swindon, following the completion of pilot trials in 2016.[32]

Box 4. Safety
Hydrogen in the gas network is not new; until the mid-1960s, town gas supplies comprised up to 50% hydrogen.[25,41] Methane (including natural gas and biomethane) and hydrogen are both flammable and potentially explosive.[58] Although the overall level of risk is similar for both substances, there are several key differences:[58]

- **Explosion risk.** The *HyHouse* project investigated controlled leakages of hydrogen and natural gas within a domestic setting.[58] It found that fire and explosion risks were similar for both gases; although hydrogen requires less energy to ignite, it disperses more easily, making accumulation less likely.[41,58]
- **Toxicity**. Unlike methane, hydrogen emits no carbon monoxide when burnt. Burning methane and hydrogen in air emits nitrous oxides (NOx), a known class of pollutants. Hydrogen combustion may increase NOx emissions, unless a catalyst is used.[59]
- **Other Safety Issues**. Hydrogen is colourless and like methane, odourless.[41] Detecting leakages may require a new odorant that adheres to hydrogen under all conditions, while appliances may require compounds to make hydrogen flames visible.[41,56]

during periods of excess renewable generation and cheap electricity, it could offer a cost-effective means of augmenting hydrogen stores, which could supply the grid during periods of high demand.[43,49,52-54]

Transporting Hydrogen in the Gas Network
The current high pressure tiers of gas network (Box 2) cannot accommodate hydrogen, as it could cause the steel pipes to become brittle and prone to leakage.[55,56] New polyethylene pipes in the lower pressure tiers should make this part of the network more suitable for hydrogen and hydrogen could be injected into this part of the grid.[4,25,28,56]

New Storage Capacity
Storing enough energy to meet fluctuating and interseasonal heating demand will be an increasing challenge as heating is decarbonised. Hydrogen is easier and cheaper to store in large quantities than electricity, but its energy per unit volume is a third that of natural gas.[25,41,49,43] Because the high pressure network cannot accommodate hydrogen, its significant storage capacity (Box 2) would be lost.[25,41,4943] Additional storage or more flexible production facilities will be necessary to address this. There are several options for storing hydrogen, in either solid, liquid or gas form.[1,25,41,57]

Conversion of Appliances
Current gas appliances, such as boilers and cookers, could not run safely on pure hydrogen without some modification (Box 4).[56] Given the diversity of appliances in the UK, a full replacement programme may be the simplest option, although it would still entail significant costs.[25] A national conversion programme previously occurred during the transition from town gas to natural gas, when the UK Gas Council oversaw more than 40 million appliance conversions from 1966 to 1977.[25]

Potential to Lower Emissions
Both alternative gases could offer significant reductions in emissions compared to natural gas, although the carbon footprint of hydrogen is heavily dependent on the method used to produce it (Table 1).

Table 1: Estimated Carbon Footprints of Gases

Gas	Carbon Footprint (gCO_{2eq}/kWh)*[25,43,60-63,67]
Natural gas	232
Biomethane	-50 to 450
Biomethane injection, RHI eligibility	<125
Hydrogen (SMR, no CCS)	300
Hydrogen (SMR with CCS)	80
Hydrogen (electrolysis)	Typically <100
Hydrogen (biogasification, no CCS)	110
Hydrogen (biogasification, CCS)	Negative

* Carbon footprints are measured in grams of carbon dioxide equivalent per kilowatt-hour (unit of energy).

Carbon Footprint of Biomethane
Biomass absorbs carbon from the air as it grows, which offsets GHG emissions when biomethane is burnt. Individual footprints can vary widely depending on the type of biomass, processing, and accounting method used to produce biomethane.[65,66] However, the carbon footprint of biomethane injected to the grid must be below a threshold (Table 1) to be eligible for RHI subsidy.[66,67] Adding propane before injection (see *Biomethane Regulations*) slightly increases the average footprint, though it remains a lower carbon fuel than natural gas.[64,68]

Carbon Footprint of Hydrogen
SMR and gasification produce CO_2 as a by-product and require carbon capture and storage (CCS) (POSTnote 335) to produce hydrogen with a low carbon footprint (see *The Role of CCS*).[41] Hydrogen from biomass gasification could achieve a negative footprint with CCS, because biomass absorbs GHGs from the air as it grows. The future role of biomass gasification and electrolysis will depend on the respective availability of biomass resources and low carbon electricity.[49,43,54] Electrolysis using most types of renewable electricity produces hydrogen with a lower carbon footprint than natural gas (Table 1).[43]

Transition to a Lower Carbon Network
Many recent studies envisage a role for both biomethane and hydrogen in a transition to low carbon heating.[1,4,9,69-72] The CCC recommends increasing biomethane injection to the grid until 2030 (reaching 4% of current supply) to reduce short-term emissions.[1] Post-2030, a range of measures, including hydrogen, could achieve larger carbon savings.[1] According to most stakeholders, meeting this timescale requires urgent research and trials (Box 5) to understand the costs of and technical issues posed by a hydrogen gas grid.[1,4,25,49,72-74] Government and industry stakeholders advocate one of two broad transition strategies:

- **Hydrogen blending**. Up to 10-20% hydrogen could enter the grid, achieving immediate but small carbon savings without changes to infrastructure.[75] A transition to 100% hydrogen could follow, as technologies mature and the supply chain develops.[49,76]
- **100% hydrogen**. Major carbon savings could be achieved rapidly, via a city-by-city programme of converting appliances from natural gas to pure

Box 5. Technical Assessments of a Transition to Hydrogen
The following projects, run by network operators in partnership with industry, look at converting the grid from natural gas to hydrogen:

- **Leeds H21 City Gate (2016)** presents a wide-ranging analysis of the technical aspects, logistics and costs of converting Leeds to a 100% hydrogen grid from 2026–2029.[25] It includes costs and a timeline to convert every major city to hydrogen by 2052.[25]
- **Liverpool-Manchester Hydrogen Cluster (2017)** promotes an initial transition to hydrogen in energy-intensive industrial areas with steady demand for heat (such as for oil refining and glass manufacture), reducing the need for large storage facilities. It aims to reduce carbon emissions rapidly from major polluters, laying the foundations for a larger scale transition.[82]
- **100% Hydrogen (2017–2018)** will assess the viability of constructing and operating a 100% hydrogen gas network and aims to identify a suitable site for pilot testing.[81]
- **HyDeploy (2017–2020)** will inject up to 20% hydrogen into a local gas grid and assess the impacts on the network and appliances. It aims to promote immediate decarbonisation from blending, facilitating future conversion to 100% hydrogen.[75]

hydrogen, starting in the late 2020s. This scenario requires mandatory switching by consumers and a highly coordinated workforce.[25]

During either transition, producers could modify BioSNG plants to produce hydrogen by gasification instead of biomethane.[1,29,30] This flexibility could make BioSNG plants a useful 'hedging' technology to meet both short-term and long-term emissions targets.[30,41] Converting AD plants to produce hydrogen is unlikely to be viable.

Policy Considerations

Biomethane already supplies the gas grid, although changes to regulations and subsidies could stimulate a small increase in production. By contrast, it is widely agreed that a transition to hydrogen would need extensive government intervention:[1,4,31,77]

- **Developing new gas regulations** on health and safety, design, installation and metering.[38,78-81]
- **Government support** for new infrastructure, appliances and components, until the market develops and they become commercially viable.[1,4,31,41,77,80]
- **Developing a suitable funding mechanism** that minimises the impact on bill payers.[25]
- **Maintaining security of supply** by encouraging a diverse range of hydrogen production facilities.[41,49]
- **Identifying priority areas** where hydrogen offers the most cost-effective means of decarbonisation.[1,82]
- **Standardising appliance components** could facilitate a conversion from natural gas to hydrogen devices. [25,77]
- **Integrating policies** on hydrogen with those on CCS, to lower emissions for most production methods.[1,41]

The Role of Carbon Capture and Storage (CCS)

CCS could lower the carbon footprint of biomethane from BioSNG plants and of hydrogen from SMR and gasification. It is integral to most transition scenarios and the Intergovernmental Panel on Climate Change (IPCC) suggests that decarbonising without CCS could be twice as expensive.[1,13,25,41,73,83-85] There are now 15 large-scale CCS networks globally, although their combined storage capacity is less than 0.1% of annual CO_2 emissions.[86-88] There are currently no CCS networks in the UK and planned CCS initiatives would need rapid acceleration to meet the UK's 2050 target for decarbonisation.[89-92] The UK Government announced £100 million in spending on innovation in CCS and industry as a whole in the Clean Growth Strategy. It aims to develop a deployment pathway for CCS in 2018.[6]

Overall Costs of Decarbonising the Gas Network

Uncertainties around the scale, timing and technology used during a future transition mean that there is a lack of consensus on total costs.[4,9] All of the options for decarbonising heat will require significant investment, whether they involve increased use of electric heating or decarbonising the gas network.[4,9,70-72,93] Economic models of future UK energy systems disagree on the cheapest way to decarbonise heat by 2050, because of different assumptions on the choices and future costs of technology.[4,9,56,70-72,93] Measures to reduce demand, such as insulation and more efficient appliances, are likely to lower the cost of any decarbonisation strategy.[45]

Effects on the Consumer

Using biomethane in the network has minimal impact on consumers,[43] as would blending small proportions of hydrogen. However, the appliance conversions and changes to infrastructure required by a pure hydrogen network would be more challenging.[25,56] Any conversions could take a few days per customer and occur in summer to minimise disruption.[25] Converting a whole city could take several summers.[25]

Natural gas would cease to be available in areas converted to hydrogen, but electric heating would still be available as an alternative.[25] Researchers stress the importance of public information campaigns, help for vulnerable customers and a suitable funding mechanism to support the conversion process.[1,41,59,56,72] Cost and reliability are more important to most consumers than environmental factors. This presents a challenge for any transition to low carbon heating.[94]

Any major capital investments in hydrogen infrastructure will require additional funding.[25] Locally higher bills could occur in regions converting to hydrogen, or the Government could spread costs across the UK.[25] Gas users could pay higher bills over an extended period, to cover the immediate capital investment. This is similar to the current funding mechanism for the IMRP (Box 2).[25] If charges for hydrogen conversion begin around 2032, when costs from the IMRP are due to decline, the impact on consumer bills could be minimised.[25]

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