WHITE PAPER 3

Imperial College London | SUSTAINABLE GAS INSTITUTE

A greener gas grid: What are the options?

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BACKGROUND

Gas networks are used in many countries to deliver natural gas to industrial and domestic consumers, supplying energy for a range of services such as heating and cooking. However, the future for gas networks is uncertain mainly due to the carbon dioxide (CO_2) and methane emissions associated with natural gas systems.

The emissions from natural gas systems and the difficulty in capturing them is a problem for global carbon reduction ambitions.

While electricity and heat pumps could be used to decarbonise domestic and commercial energy services, there are significant technical, economic and consumer barriers to electrifying heat. Low-carbon gas networks could therefore still play a significant role in the future energy system and contribute significantly to decarbonisation.

In the third report in the Sustainable Gas Institute White Paper Series, we review the evidence on the options for the future use of gas networks. The paper focuses on the use of **biomethane** and **hydrogen**, and their technical potential, carbon intensity and the costs associated with decarbonisation.

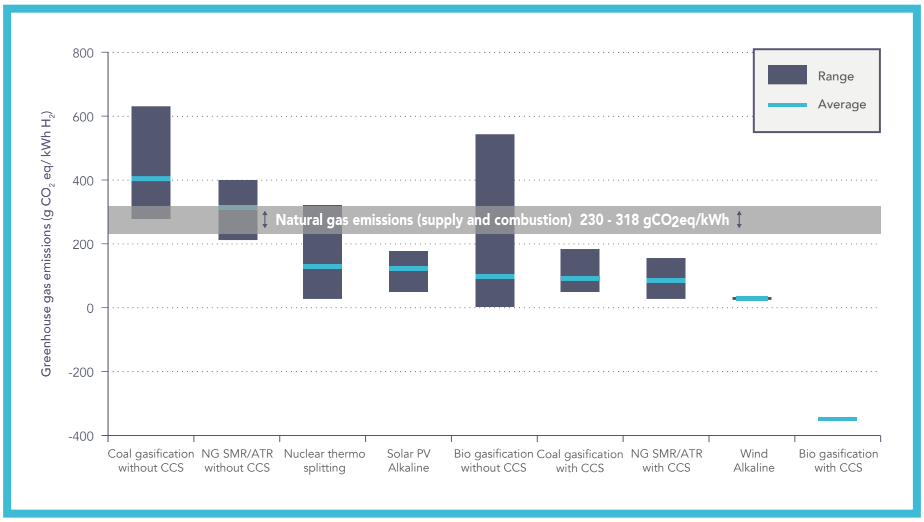

Figure 1 Ranges of estimates of total greenhouse gas (GHG) emissions associated with hydrogen production from different technologies and feedstocks, expressed in gCO_2eq/kWh hydrogen produced. Notes: NG = natural gas, ATR = Autothermal Reformer, SMR = Steam Methane Reformer, CCS = Carbon Capture and Storage

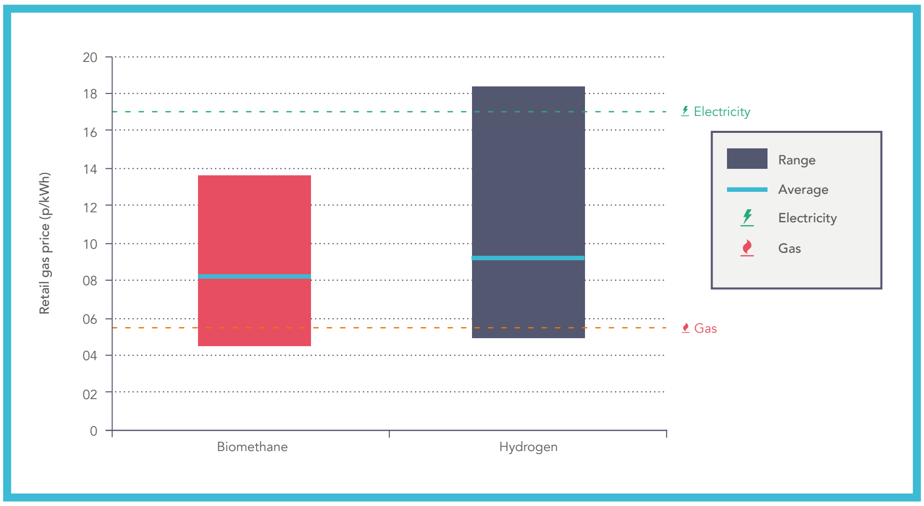

Figure 2 Estimate of retail price of decarbonised hydrogen and biomethane compared to the EU average retail prices of natural gas and electricity in 2015.

KEY FINDINGS:

1. Gas networks could **play an important role in decarbonising** the future energy system.
   - There are significant benefits to decarbonising the gas network. For example, there is value to the existing assets, and in the inherent flexibility of gas. There is also a general consumer preference for gas appliances; and it is relatively low cost and easy to install gas-fired heating systems.
   - However, the technical capabilities of existing networks, and the level of decarbonisation achievable, still need to be explored, and resulting costs remain uncertain.

2. The **storage potential** of low carbon gas offers a significant advantage over electricity networks.
   - Gas has relatively low-cost flexibility, particularly for seasonal fluctuations in energy demand.
   - Future decarbonised gas also has this flexibility but this is more technically challenging and expensive for an electricity system. Per kilowatt-hour the cheapest forms of electricity storage are approximately four times more expensive than the highest cost estimates for hydrogen storage (salt caverns). However, the value of this flexibility is unclear and depends on the future balance of decarbonised gas and electricity demand.

3. Decarbonised gas offers a range of advantages, but there is **no 'best option'**.
   - **Biomethane** is the most compatible with existing gas networks and may deliver negative emissions. However, there are limitations on the future availability of biomass, used to generate biomethane.
   - **Hydrogen** could be delivered through electrolysis from renewable energy without the need for carbon capture and storage (CCS). However, electrolysis is currently expensive relative to other methods, although it is likely that costs will decrease. Producing hydrogen through steam methane reformers (SMR) is scalable at relatively low cost. But using natural gas to generate hydrogen in SMR could increase

gas demand by 15% to 66% per unit of energy delivered to consumers, relative to direct use of natural gas.

4 The range of **CO_2 emissions** estimates for the different methods to produce low carbon gas is extremely large.

- This is -371 to 642 gCO_2eq/kWh for hydrogen and -50 to 450 gCO_2eq/kWh for biomethane.
- The highest and most variable emissions come from fossil fuel routes to produce hydrogen that do not include CCS. These technologies are likely to produce carbon intensities greater than current gas networks. CCS is therefore needed to ensure this gas is low carbon.
- Emissions estimates for SMR with CCS are between 23 to 150 gCO_2eq/kWh, while for electrolysis using renewable electricity sources the range is from 25 to 178 gCO_2eq/kWh. The carbon intensity of heat might be between 26 and 167 gCO_2eq/kWh for methane based hydrogen and 27 to 198 gCO_2eq/kWh for hydrogen from electrolysis, assuming a 90% efficient hydrogen boiler. Heat pumps with 250% efficiency using the same electricity might deliver heat with a CO_2 intensity of 10 to 71 gCO_2eq/kWh.

5 The **cost** estimates for different decarbonised gas options vary significantly.

- The resulting retail price estimate for biomethane might be 4.4 to 13.6 p/kWh (average 8.1 p/kWh) compared to an estimate for hydrogen of 4.9 to 18.4 p/kWh (average 9.3 p/kWh). This can be compared to an EU average retail price in 2015 for natural gas of 5.4 p/kWh, and electricity at 17p/kWh. *Prices are in pence per kilowatt hour [p/kWh].*
- If the future efficiency of methane or hydrogen-fired boilers is 90%, the costs of delivered heat ranges from 4.9 to 15.1 p/kWh heat for biomethane and 5.4 to 20.4 p/kWh heat for hydrogen.
- For comparison, at heat pump efficiencies of 250% and a retail electricity price of 17 p/kWh, heat pumps could produce heat for 6.8 p/kWh.
- Converting consumers to hydrogen gas networks may cost over £3,000 per household including appliances and supporting equipment. This can be compared to the cost of installing air source heat pumps at between £4,000 to £11,000 or ground source heat pumps at £13,000 to £20,000.

6 **Countries with mature gas networks** may find decarbonisation options attractive given the value of their existing assets (e.g. Netherlands, UK and USA)

- Existing low-pressure gas networks are compatible with biomethane, and the cost of converting networks to carry hydrogen is expected to be small relative to total system costs.
- Countries with gas networks connected to less than 50% of consumers may continue to develop low-pressure networks and may be able to design those assets to be compatible with future hydrogen conversion.
- Where low-pressure gas distribution networks are very small or non-existent the cost of building may be significant, but not prohibitive. For example, to build a new hydrogen low-pressure distribution network similar in length to the networks existing in the UK or Japan might cost £145 billion. Spread over 20 million domestic gas consumers (UK) this is £7,250 per household, which is similar to the cost of installing air or ground source heat pumps. This can be compared to an estimated cost for repurposing an existing natural gas network of the same length to transport hydrogen of £2 billion or £10,000 per km.

7 There is **limited real-world evidence** on the capability of low-pressure gas networks to transport 100% hydrogen gas streams effectively.

- Several studies have tested the durability, integrity and safety of existing low-pressure gas distribution infrastructure in a small number of countries. They found increased, but manageable gas leakage rates and safety concerns.
- However, this evidence often focusses on hydrogen/methane blends and not on 100% hydrogen gas streams. The diversity of materials and variable quality and age of existing low-pressure gas networks is an issue for extrapolating these findings to real-world gas systems.

8 Key considerations for **policy** include:

- *Setting gas decarbonisation standards.* The carbon intensity of decarbonised gases differs due to a range of factors. Policy approaches should ensure these systems are sufficiently low carbon which could include a standard for low carbon gas or a market based mechanism.
- *Developing consumer awareness approaches for network conversion.* Choosing areas of the existing gas network to convert to hydrogen will be challenging. Questions will arise around what rights consumers have, and how to ensure equity between all network consumers and what this means for competitive energy markets.
- *Advancing the evidence and standards for hydrogen safety.* While there is evidence that the safety of hydrogen networks is not a barrier, there is, currently, little demonstration evidence. An evidence base on safety issues should be developed before significant commitments are made on hydrogen networks.

9 Future research is needed to develop **practical demonstration** projects, and **new whole-system modelling** that incorporates evidence from practical experience and quantifies the system-wide impacts.

- Future demonstration projects could include examining the options to understand real world efficiencies, carbon intensities and costs achievable. In addition, it is important to test hydrogen safety, in households, commercial premises and in the existing low-pressure gas network. Research should also be undertaken into consumer and system-level impacts associated with new technologies such as hybrid gas/electric heat pumps, fuel cells or gas heat pumps.
- Better whole-systems modelling analysis is also needed. This could involve examining the conditions and locations under which gas networks may be competitive in addition to modelling the interactions between gas, electricity and other energy infrastructures to better quantify the system value of gas flexibility.

SUPPLY CHAIN EMISSIONS

Supply chain emissions are increasingly important as emissions from decarbonised gas production decrease. This includes methane and CO_2 emissions in the natural gas supply chain, the embodied CO_2 emissions in electricity generation, and the negative emissions associated with biomass cultivation.

For further information on this subject please contact the lead author at **SGI@imperial.ac.uk**

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The Sustainable Gas Institute at Imperial College London aims to explore the role of natural gas in the world energy mix.

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