Leeds
City
Gate

H21

Northern
Gas Networks

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Executive Summary

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The UK, as with most other countries around the world, recognises the importance of meeting the challenge of climate change and has resolved, by 2050, to reduce carbon emissions by 80% of the level in 1990 under the terms of the Climate Change Act. This is the biggest energy challenge facing the world today although, to date, there has been little investigation or thought leadership around the opportunity to decarbonise the UK distribution gas network by specifically focusing on large cities.

Even natural gas (predominantly methane), the lowest carbon dioxide emitter per unit of energy of any fossil fuel, produces about 180 gm/kWh CO_2 equivalent whereas hydrogen emits zero (at the point of use). The change over from natural gas to hydrogen has the potential to provide a very deep carbon emission reduction. The true carbon footprint of hydrogen depends on its source. For example, grid power electrolysis has very high emissions whereas hydrogen made from stripping the carbon atom from natural gas has about 50 gm/kWh CO_2 equivalent including indirect emissions, a large reduction over the existing unabated natural gas fuel. Renewable based electrolysis could be used, but for the foreseeable future the required quantities do not look realistic.

This report suggests that we can significantly decarbonise parts of the existing gas network at minimal additional cost to consumers. This would significantly contribute to the UK's 2050 and Paris Agreement commitments, remove the risks of carbon monoxide poisoning, increase energy storage, potentially remove air pollution from vehicles, and enable new product development and innovation for manufacturing and industrial businesses.

The UK gas industry is over 200 years old. For the first 150 years the gas used was locally manufactured town gas which contained circa 50% hydrogen with smaller quantities of carbon monoxide and methane. In the early days this was made by distilling coal and, later, oil. Following the initial discovery of natural gas in the North Sea, made up predominantly of methane, during the 1960/70s the UK undertook a nationwide gas conversion programme converting 40 million appliances, reaching a peak of 2.3 million per year. Over 80% of the UK population now use this gas network for heating and cooking. A hydrogen conversion would follow a similar process to the original town gas to natural gas conversion undertaken so successfully and within living memory. The process will involve minimal disruption for the customer (domestic or commercial) and require no large scale modifications to their property.

Since 2002, the UK has been undertaking the Iron Mains Replacement Programme (IMRP), upgrading the majority of its distribution pipes to polyethylene. This is a risk prioritised, Health and Safety Executive mandated initiative due to complete in 2032. These polyethylene pipes are considered to be suitable for transporting 100% hydrogen.

The H21 Leeds City Gate project is a study with the aim of determining the feasibility, from both a technical and economic viewpoint, of converting the existing natural gas network in Leeds, one of the largest UK cities, to 100% hydrogen.

The project has been designed to minimise disruption for existing customers, and to deliver heat at the same cost as current natural gas to customers.

The project has shown that:

- The gas network has the correct capacity for such a conversion
- It can be converted incrementally with minimal disruption to customers
- Minimal new energy infrastructure will be required compared to alternatives
- The existing heat demand for Leeds can be met via steam methane reforming and salt cavern storage using technology in use around the world today

The project has provided costs for the scheme and has modelled these costs in a regulatory finance model.

In addition, the availability of low-cost bulk hydrogen in a gas network could revolutionise the potential for hydrogen vehicles and, via fuel cells, support a decentralised model of combined heat and power and localised power generation.

The Results

The results of the Project are as follows:

Demand vs. Supply (Section 2)

The energy demands calculated for the area of conversion are:

1. Average yearly gas demand = 678 MW (derived from DECC data)
2. Maximum peak yearly demand = 732 MW (temperature corrected DECC data)
3. Maximum peak hour demand = 3,180 MW (NGN 1 in 20 peak hour demand)
4. Peak day average demand = 2,067 MW (derived from NGN 1 in 20 peak hour demand design parameter)
5. Total average yearly demand = 5.9 TWh
6. Total peak year demand = 6.4 TWh

This demand would be serviced by the following hydrogen production and storage facilities: Hydrogen production capacity of 1,025 MW_{HHV} (305,000 Sm^3/h) provided by four Steam Methane Reformers (SMRs) located at Teesside, fitted with 90% carbon dioxide capture. This CO_2 is then compressed to 140 bar and assumed to be exported 'over the fence' to permanent sequestration deep under the North Sea. Such hydrogen production at large scale is fully proven, with worldwide production standing at about 50 million tonnes per annum compared to 0.15 million tonnes per annum for the proposed area of conversion.

Additional intraday storage, which together with the SMRs and inter-seasonal storage, will supply a maximum 1 in 20 peak hour demand of 3,180 MW_{HHV}. This will be in the form of salt cavern storage located at Teesside, some which may be repurposed from already existing caverns.

Inter-seasonal storage of 702,720 MWh_{HHV} (40 days of maximum average daily demand (coldest year), 209 million Sm^3 hydrogen). This will be in the form of salt cavern storage located on the East Humber coast.

A Hydrogen Transmission System (HTS) will connect the SMRs and salt caverns to the proposed area of conversion (Leeds) and will be capable of transporting at least the peak supply requirement of 3,180 MW.

Gas Network Capacity (Section 3)

Both the Medium Pressure (MP) and Low Pressure (LP) gas distribution networks within the area of conversion have been modelled for hydrogen conversion using the network analysis software and data currently used by Northern Gas Networks. The conclusion of this modelling is that the gas networks have sufficient capacity to convert to 100% hydrogen with relatively minor upgrades.

Gas Network Conversion (Section 4)

It is possible for the existing gas network to be segmented and converted from natural gas to hydrogen incrementally through the summer months over a three-year period. This approach would mean minimal disruption for customers during the conversion.

Appliances Conversion (Section 5)

Hydrogen appliances and equipment for domestic, commercial and industrial sectors can be developed. There are already a few models on the market, although sales are extremely low, due to an absence of piped hydrogen. Just with the knowledge of this study, several manufacturers are showing real enthusiasm for their development. A firm long-term plan and significant stimulus would be needed to provide the motivation to develop and produce the wide range of equipment required. This could potentially be in the form of a national heat policy.

Hydrogen Transmission System (Section 6)

High pressure hydrogen transmission pipelines are operating around the world today. Similar pipelines have been proposed for carrying hydrogen from the SMR site to the conversion area and hydrogen storage sites. In addition a connection between the natural gas transmission system and the SMR has been proposed along with a pipeline from the SMR to CCS. Costs for these have been estimated at £230 million with ongoing OPEX costs of £0.5 million per annum.

Carbon Capture and Storage (Section 7)

The H21 Leeds City Gate project would give the following savings in CO_2 emissions:

	gm/kWh NG	gm/kWh H_2	% Reduction
UK Carbon budget basis (Scope 1)	184.0	27.0	85%
Including electricity for sequestration (Scope 1+2)	184.0	49.5	73%
Including embodied CO_2 from the production and importation of natural gas (Scope 1+2+3)	209.3	85.8	59%

The H21 Leeds City Gate project would sequester 1.5 million tonnes per annum CO_2.

Scope 1, net CO_2 savings for the area of conversion is 927,000 tonnes per year.

Carbon capture and storage technology is well established alongside SMR operations. An example of which can be seen in the Port Arthur SMR plants operated by Air Products in the USA.

Financial Model (Section 8)

Total costs associated with the Project are summarised in the table below.

Cost Summary (£m)	Cost incurred (£m)	Ongoing costs each year (£m)
Network Capacity and Conversion Preparatory Work (Section 2.2)	10	
Hydrogen Infrastructure/Conversion Costs		
Steam Methane Reformer (SMR) Costs (Section 2.1)	395	
Intraday Salt Caverns (Section 2.1)	77	
Inter-Seasonal Salt Caverns (Section 2.1)	289	
Appliance Conversion (Domestic, Commercial and Industrial users within area of conversion) (Section 2.3)	1,053	
Hydrogen Transmission System (HTS) (Section 2.4)	230	
Ongoing OPEX Costs		
Carbon Capture and Storage		60
SMR/Salt Cavern/HTS Management		31
SMR Efficiency loss (30%)		48
Total	**2,054**	**139**

If the H21 Leeds City Gate project was funded using the current UK regulatory business plan it would have negligable impact on customers total gas bills.

Next Steps, Programme of Works and H21 Roadmap (Section 9 and 10)

The earliest practical date for the initial hydrogen conversion of a UK city is 2025. In order to achieve this, several preparatory actions need to have taken place these are:

1. **2017 to 2022 –** Provision of finance to deliver the 16 work packages identified in this report with an estimated value of between £60m and £80m (See Section 10).
2. **2016/17 –** Establishment of the H21 Programme Team to co-ordinate and deliver the 16 identified work packages.
3. **2018 –** Provision of funding to begin the FEED/detailed design of the hydrogen production, storage and pipeline systems.
4. **2018 –** Clear direction by OFGEM that gas distribution networks need to allow provision within their GD2 business plans (2021–2029) to facilitate the conversion of the first cities.
5. **2021/22 –** A policy decision committing to the strategic, incremental material conversion of the UK gas grid over an agreed timescale.

The H21 Vision (Section 11)

The H21 Leeds City Gate Project has focused on the provision of heat through a 100% hydrogen gas network conversion for Leeds. Additionally by utilising gas industry expertise some thought leadership has been provided around the impact of an incremental rollout of such a system across UK cities and/or regions. This has also considered the potential impact of establishing the first commercial hydrogen economy in the world.

Two rollout options have been presented and, alongside efficiency savings, both options could be developed with minimal impact on customers overall bills

General Considerations

1. The H21 Leeds City Gate Project has shown that the conversion of the UK gas distribution network to hydrogen would enable a dramatic reduction in UK emissions with circa 73% reduction from heat but also from transport and power generation.
2. Converting the UK gas network avoids the need to persuade householders to raise the funds and give up the space to install other complex low carbon technology. The absence of hassle for the customer is considered to be very important in the likely success of any decarbonisation strategy.
3. Leeds with circa 1% of the UK's population is a sensible starting point because of its size and geographical location, near to both Teesside (with its existing hydrogen infrastructure) and the salt beds north of Hull.
4. The use of hydrogen storage addresses inter-seasonal storage, one of the known problems of trying to use only electricity as the energy vector for heat, This inherently smooths out:
   - The UK's large variation in inter-seasonal energy demand as hydrogen is produced and stored 'downstream' at a relatively constant rate throughout the year.
   - The production of CO_2 thereby simplifying sequestration.
   - The wholesale natural gas purchases as the demand is relatively constant over the year for hydrogen production and storage and therefore this reduces the volume of natural gas required at periods of high demand (and therefore cost).
5. Low cost pipeline quality hydrogen (99.9%) can be purified to the very high quality gas required by fuel cells. Therefore a UK gas grid conversion to hydrogen could provide feedstock for automotive use, and via fuel cell combined heat and power open up the opportunity for an alternative to centralised power generation.
6. All of the individual steps in the hydrogen supply train (except for some appliances) are proven and widely available by competitive tender.
7. The project could stimulate the Northern Powerhouse bringing economic benefits to both the North and the UK economy as a whole.

The H21 Leeds City Gate project provides evidence that converting the UK gas network to hydrogen is technically possible and economically viable. A UK hydrogen conversion strategy could make a significant contribution towards meeting the challenge of the Climate Change Act as well as establishing the world's first hydrogen economy. It could also create a significant impact on UK GVA and establish a real anchor project around the Northern Powerhouse concept.

The Results

This section details the results of the H21 project. It provides a clear description of how the work was undertaken, what assumptions were made, what data was used and the conclusions.

For ease, the results have been split into the following sub-categories:

Section 2: Demand vs. Supply

Section 3: Gas Network Capacity

Section 4: Gas Network Conversion

Section 5: Appliance Conversion

Section 6: The Hydrogen Transmission System

Section 7: Carbon Capture and Storage

Section 8: Financial Model

Section 9: The Next Steps – Programme of Works

These are illustrated on the next page.

H21 Leeds City Gate System Schematic