INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 7189–7200

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/he

Conversion of the UK gas system to transport hydrogen☆

Paul E. Dodds [a,*], *Stéphanie Demoullin* [b]

[a] *UCL Energy Institute, 14 Upper Woburn Place, London WC1H 0NN, UK*

[b] *Department of Civil, Environmental and Geomatic Engineering, University College London, London, UK*

ARTICLE INFO

Article history:
Received 16 January 2013
Received in revised form
2 March 2013
Accepted 6 March 2013
Available online 9 May 2013

Keywords:
Natural gas conversion
UK MARKAL
Energy system model
Hydrogen networks
Gas decarbonisation

ABSTRACT

One option to decarbonise residential heat in the UK is to convert the existing natural gas networks to deliver hydrogen. We review the technical feasibility of this option using semi-structured interviews underpinned by a literature review and we assess the potential economic benefits using the UK MARKAL energy systems model. We conclude that hydrogen can be transported safely in the low-pressure pipes but we identify concerns over the reduced capacity of the system and the much lower linepack storage compared to natural gas. New hydrogen meters and sensors would have to be fitted to every building in a hydrogen conversion program and appliances would have to be converted unless the government was to legislate to make them hydrogen-ready in advance.

Converting the gas networks to hydrogen is a lower-cost residential decarbonisation pathway for the UK than those identified previously. The cost-optimal share of hydrogen is sensitive to the conversion cost and to variations in the capital costs of heat pumps and micro-CHP fuel cells. With such small cost differentials between technologies, the decision to convert the networks will also depend on non-economic factors including the relative performance of technologies and the willingness of the government to organise a conversion program.

1. Introduction

Most UK buildings are currently heated by boilers using natural gas transported by extensive transmission and distribution networks that service 84% of UK households. In 2010, UK households emitted 85 $MtCO_2$ by direct combustion of natural gas for heat and another 0.2 Mt of methane escaped from the gas networks [1]. Several studies [2,3] have concluded that these emissions must reduce in the future if the UK is to reduce greenhouse gas emissions in 2050 by 80% relative to 1990 levels, as mandated by the UK parliament [4].

Electric heating, particularly using heat pumps, is increasingly identified as a low-carbon alternative to natural gas [5–7]. This has provoked a number of studies funding by the gas industry to identify scenarios in which the gas networks continue to have a role in a low-carbon economy [8–10]. Yet one option not considered by these studies is to decarbonise the gas supply by delivering hydrogen rather than natural gas to homes through the existing gas networks. The UK government mentions this option in the heat strategy framework that it published in March 2012 [11] but notes that there are many uncertainties about this strategy.

Dodds and McDowall [12] take a first step towards assessing the potential benefits of hydrogen conversion by showing that it would be part of the cost-optimal decarbonisation pathway for the UK if conversion could be achieved at zero cost. In this paper, we greatly expand on this exploratory work by assessing the costs of a conversion program and

* *Corresponding author*. Tel.: +44 (0)203 108 9071.
E-mail addresses: p.dodds@ucl.ac.uk, pedodds@hotmail.com (P.E. Dodds).

0360-3199/$ – see front matter Copyright © 2013, The Authors. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijhydene.2013.03.070

identifying technical issues surrounding conversion. We make a first assessment of the technical feasibility of transporting hydrogen in the gas networks in Section 2 and we make a first estimate of the costs of conversion in Section 3. This enables us to make a much more authoritative assessment of the economic benefits to the UK in Section 4.

2. Technical feasibility of transporting hydrogen using the gas networks

Transporting hydrogen using the gas networks is not a novel activity. Until around 1970, 'town' gas rather than natural gas was delivered by the gas networks. Town gas was manufactured from coal and contained a mix of hydrogen, carbon monoxide, methane and other gases [13]. In the 1960s, large deposits of natural gas were discovered under the North Sea and the UK Gas Council decided to switch the entire country from manufactured town gas to natural gas in a national program over a 10 year period [14]. New high-pressure transmission and distribution pipeline networks were built but the low-pressure pipes were mostly unchanged. In this section, we consider the technical feasibility and issues of a second national conversion program to transport 100% hydrogen in the gas networks.

2.1. *Methodology*

We assessed the technical feasibility of transporting hydrogen in the gas network through semi-structured interviews with 14 experts from industry, academia and government, underpinned by a literature review. These experts were chosen to examine both the feasibility of transporting hydrogen and the costs and complexity of converting the network. Table 1 summarises the interviewees; since some requested anonymity, we have grouped our findings by sector throughout this paper. We were particularly interested in experts who understood hydrogen behaviour, safety systems and other technological challenges, those with knowledge of the specifications and operational requirements of the natural gas network, and those with experience of using hydrogen for energy purposes (whether for existing industrial plants or demonstration projects for new technologies).

Our aim was to address the following broad questions:

Table 1 – Summary of interviewee backgrounds and expertise.

Sector	Number	Backgrounds
Government	3	Hydrogen policy, experience of deployment and safety
Industry	7	Directors, managers and engineers in companies producing and supplying natural gas, industrial chemicals and infrastructure products
Academia	4	Safety, gas pipes, fuel cells and the economics of hydrogen

- Will hydrogen transportation adversely affects pipeline integrity?
- Is hydrogen a safe energy carrier for use in homes?
- Can the existing gas networks deliver sufficient energy in the form of hydrogen to meet demand?
- Can end-user appliances perform correctly and safely using hydrogen?
- Would the conversion process be similar to the previous conversion from town gas to natural gas or are there additional factors that must be considered?

2.2. *Pipeline integrity*

Natural gas is transported to customers throughout the UK by numerous interconnected pipeline networks. A national transmission network supplies high-pressure gas from import terminals to 13 regional distribution networks [15,16]. The gas pressure is gradually lowered in each of these networks by pressure reduction stations until delivery from the low-pressure distribution network to buildings via millions of short service pipes. Pipes in different parts of the networks are constructed of different materials, with the variations mainly reflecting the operating pressure and age of the pipes. Table 2 summarises the characteristics of each part of the network. The suitability of pipes for transporting hydrogen depends on a number of factors including the material, operating pressure, age and overall condition [17].

2.2.1. *High-pressure transmission and distribution pipes*

At ambient temperature and pressures below 100 bar, the principal integrity concern for high-strength steel is hydrogen embrittlement. Hydrogen will diffuse into any surface flaws that occur due to material defects, construction defects or corrosion, resulting in a loss of ductility, increased crack growth or initiation of new cracks. These will ultimately lead to material failure [20–23]. Higher pressures are thought to increase the likelihood of material failure although no threshold value has been defined independently of other factors [24–26]. Hydrogen can be transported at high pressures using pipes constructed of softer steels that reduce the rate of embrittlement, and there is much industrial experience in this area spanning many decades [27]. This means that existing high-pressure natural gas pipelines are not suitable for hydrogen transport, but that a new national network of high-pressure pipelines could be constructed to transport hydrogen around the UK.

2.2.2. *Lower-pressure distribution and service pipes*

Steel and iron pipes, which were used prior to 1970, are susceptible to embrittlement if the hydrogen gas pressure is high enough. There is uncertainty about the threshold pressure below which the pipes can be safely used with hydrogen [21,26]; it will almost certainly vary according to the type of steel or iron, as well as the pipeline microstructure, stress history and the type of welding used [24]. Conversely, the integrity of polyethylene pipelines, which have been used since 1970, should not be affected by the use of hydrogen [28,29]. An "Iron Mains Replacement Programme" is currently underway which aims to replace all of the low-pressure iron distribution pipes near buildings with polyethylene pipes for