CAN WE USE HYDROGEN AS A STORAGE VECTOR TO REDUCE THE COST OF INTERMITTENT RENEWABLES?

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(1) Overview

Hydrogen has long been identified as a zero-carbon energy carrier for transport applications. Yet there are other potential roles for hydrogen in low-carbon energy systems that have received relatively little attention. One option is power-to-gas, in which excess intermittent renewable generation is used to produce hydrogen that can be stored for subsequent electricity generation or injected into the natural gas network to avoid supply-demand imbalances. For countries that currently rely on piped high-carbon natural gas for heating buildings, hydrogen is a low-carbon heating fuel that could be delivered using the existing gas networks as an alternative to electrifying heat. The electricity and gas networks, which currently operate independently, could be integrated in the future, with the gas network providing an important short-term energy storage medium to cope with periods of peak energy demand. Larger storage (e.g. salt caverns) could be used for inter-seasonal storage of hydrogen to deal with winter peaks in heat demand.

The UK is a candidate for all of these uses of hydrogen. The UK Climate Change Act 2008 requires the UK government to reduce national greenhouse gas emissions in 2050 by 80% relative to 1990 levels (HM Parliament 2008). In response, 8.5 GW wind generation has been deployed and this will increase substantially as further large offshore wind farms are connected, leading to large supply-demand imbalances in the future. Meanwhile, the UK gas network currently supplies around 22.9 million customers (DECC 2011), including 84% of homes.

We have examined the potential for hydrogen to be a storage vector in the UK electricity and gas systems. First, using the UK MARKAL energy system model, we have examined the cost-optimal long-term use of hydrogen to decarbonise the gas network, through injection (Dodds and McDowall 2012; Dodds and McDowall submitted) or through conversion to deliver only hydrogen (Dodds and Démoullin in press). This model is not able to represent inter-seasonal hydrogen storage so we have created a new energy system model that is based on the TIMES platform to examine the potential benefits to the UK of these technologies. This new model also includes all greenhouse gas emissions, an improvement from UK MARKAL which represents only CO_2 emissions, so it also allows us to assess the benefits of avoiding methane leakages from the gas networks. The representation of power-to-gas technologies is also much improved. In this paper, we discuss the prospects for using hydrogen as an energy carrier in the UK gas networks using UK MARKAL. We then introduce the new UK TIMES model and consider the potential for power-to-gas and inter-seasonal storage to contribute to the planned large-scale deployment of renewables in the UK in the future.

(2) Methods

MARKAL is a widely-applied bottom-up, dynamic, partial equilibrium economic optimisation model (Loulou et al., 2004). The UK MARKAL model (Kannan et al. 2007; Anandarajah and Strachan 2010) has been developed over the last decade and portrays the entire UK energy system from imports and domestic production of fuel resources, through fuel processing and supply, explicit representation of infrastructures, conversion of fuels to secondary energy carriers (including electricity, heat and hydrogen), end-use technologies and energy service demands of the entire economy. We have updated UK MARKAL with a new representation of the natural gas networks that includes hydrogen injection and conversion for the first time (Dodds and McDowall submitted). We implement UK climate policy by constraining CO_2 emissions to reduce in linear steps between 2000 and 2050 to achieve an 80% reduction relative to 1990 emissions. This assumes that an 80% reduction in non-CO_2 greenhouse gas emissions is realistically achievable. We examine separate scenarios with options for hydrogen injection and for conversion of the gas networks. We use the MARKAL elastic demand variant in this study in which welfare (defined as the sum of producer and consumer surplus) is maximised, and hence demand and supply reach equilibrium. Behavioural change in response to increasing energy costs is simulated endogenously using reductions in the energy service demands.

TIMES follows the same paradigm as MARKAL but is a much more flexible model. Our new UK variant of the model, UK TIMES, is based on UK MARKAL but with several notable improvements including a representation of all greenhouse gas emissions. We have introduced seasonal and inter-day timeslicing of hydrogen and natural gas as well as electricity so that the benefits of different types of storage, on different timescales, and the interactions between electricity and other energy carriers can be assessed more accurately. TIMES includes several new storage mediums including inter-seasonal storage of hydrogen in salt caverns and the use of the gas network for energy storage. The model is calibrated to DUKES and NAEI data in the year 2010.

(3) Results

In UK MARKAL, hydrogen injection to the gas system peaks in 2035 but falls to only 17 PJ from 2050 (Figure 1) because gas consumption is very low and because hydrogen injection is limited to 7% of the total delivered gas for safety and operational reasons. Hydrogen injection is a niche technology which is most important during the transition to a low carbon economy as the amount of hydrogen in the natural gas is insufficient to enable natural gas to be used to fuel heat in the long-term in the optimum economic scenario, although 60 PJ of hydrogen continues to be injected beyond 2050 if the model is constrained to require natural gas use for heat in the long term. Figure 2 shows that hydrogen conversion is a cost-optimal option for the UK, particularly if the conversion costs (represented as a percentage of the cost of building a new pipeline, and including building conversion costs except in the “None” scenario) are low. The level of hydrogen consumption is sensitive to the capital cost of heat technologies, particularly air heat pumps.

We are in the process of testing the UK TIMES model will shortly commence our assessment of the potential long-term benefits of power-to-gas and inter-seasonal storage technologies on the UK energy system. We hope to introduce this model to the international scientific community for the first time at this conference.

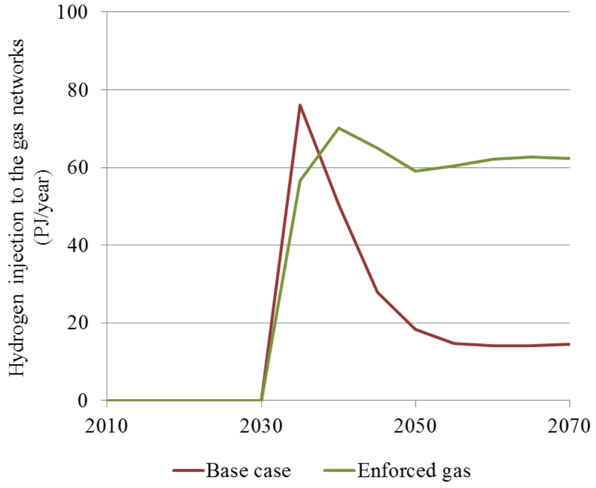

Fig. 1: hydrogen injection to the gas networks for two scenarios with an 80% reduction in CO2 emissions in 2050. The ‘enforced gas’ scenario requires 85% of homes to continue using natural gas for heating.

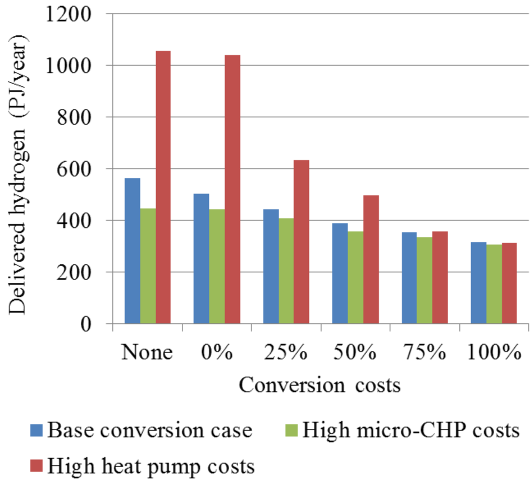

Fig. 2: hydrogen delivered to UK buildings in 2050 following gas network conversion, as a function of the conversion costs and the cost of key heat technologies (air heat pumps and hydrogen micro-CHP fuel cells).

(4) Conclusions

We have shown that hydrogen could have an important role in decarbonising the UK natural gas system both through hydrogen injection, for example from power-to-gas, and by converting the gas system to deliver hydrogen instead of natural gas. Building on this work, we have designed a new model, UK TIMES, with the aim of assessing the potential benefits to the UK of power-to-gas and inter-seasonal hydrogen storage technologies. The integration of the gas and electricity systems using these technologies could potentially minimise the temporal supply-demand imbalances that could otherwise occur from the high level of intermittent renewables that are currently being deployed.

References

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