Spatial hydrogen infrastructure development in a low carbon UK energy system

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In response to climate challenge, the UK Government adopted a 60% CO2 reduction target from 1990 levels by 2050 (DTI 2003). The same document specifies that these reductions should be achieved without hampering the competitiveness of the economy, reliability of energy supplies and fuel affordability. In this regard, hydrogen (H_2) infrastructures and technologies offer the possibility of deep cuts in CO_2 emissions as well as contributing to security of supply objectives (DfT 2004). Moreover, they have the potential to make these reductions in sectors such as transport which have been shown to be hardest to decarbonise (IEA 2006). Hence, the aim of this paper is to explore what roles hydrogen can play in moving to a low carbon economy and in particular how H_2 network might develop spatially as part of the future UK energy system. This study is carried out under a project funded by the Department for Transport's Horizons Research Programme.

In analyzing possible hydrogen pathways, a whole energy system view needs to be taken into account as H_2 is not a primary fuel on its own; rather it competes with other parts of the energy system (Joffe and Strachan 2007). Also, unlike the gasoline/diesel infrastructure, the optimal H_2 infrastructure system will likely vary in different regions, according to the availability and cost of resources and the scale and density of demand (Yang and Ogden 2006). In this study, we address these key issues by extending the UK MARKAL model with geographic information systems (GIS) tools.

MARKAL is a dynamic technology-rich energy systems economic optimisation model (see Loulou et al 2004). It has been widely used for both policy and academic research (e.g., IEA 2006; Rafaj and Kypreos 2007). The UK MARKAL model as a partial equilibrium energy system and technologically detailed model, is well suited to investigating the cost and physical trade-offs between long-term divergent energy scenarios. The new UK model has been substantially rebuilt and enhanced including detailed sectoral (industry, transport, commercial, residential, agricultural) representation, fossil and renewable resource supply curves, and explicit depiction of key energy processes including the refining sector, hydrogen and biomass chains, nuclear fuel cycle and centralized-decentralized electricity grids (see Strachan et al, 2006, 2007). It has provided significant analytical contributions to the Energy White Paper (DTI 2007) and has been developed under the UK Energy Research Centre's Energy Systems Modelling theme.

For this analysis, the UK MARKAL model is linked to a Geographical Information Systems (GIS) based interface of plausible gaseous and liquid H_2 infrastructures and delivery systems. We defined twelve demand regions (nine key urban areas, and three aggregated areas), based on GIS analysis of population and economic drivers. Energy service demand and technology data for hydrogen and other transport pathways was then disaggregated to these regions. Similarly, six UK H_2 supply points were defined based on GIS analysis of UK energy resources, sites for carbon capture and sequestration (CCS), and liquid H_2 and LNG terminals. H_2 infrastructures options for combinations of transport and stationary applications were then mapped onto the supply-demand regions. Future H_2 infrastructures (liquid delivery by tankers, gaseous pipeline networks, and small scale production) were modelled using discrete or integer investments to recognize the minimum operational size for economic H_2 infrastructure components as these are sequentially built up in the coming decades.

The modelling results highlight numerous energy system trade-offs on supply side, between use of carbon storage in domestic hydrogen production versus power generation and import of liquid hydrogen. If liquid H_2 import is limited, then large scale production from renewables become viable. On the other hand, demand centres are clustered together within infrastructure options, even though this incurs longer transmission distances. Overall, total energy system costs get larger when spatial variation is accounted than a geographically averaged model due to higher hydrogen infrastructure costs.

References

DTI (2003) Energy White Paper Our energy future- creating a low carbon economy, Department of Trade and Industry, February 2003, available at http://www.berr.gov.uk/files/file10719.pdf

DTI (2007) Energy White Paper: Meeting the Energy Challenge, Department of Trade and Industry, 23 May 2007, available at http://www.dtistats.net/ewp

DfT (2004) The Future of Transport: a Network for 2030, Department for Transport, London

IEA (2006) *World Energy Outlook*, International Energy Agency, Paris.

Joffe D., and N. Strachan (2007) *Review of modelling approaches to the development of a 'hydrogen economy'*, UKSHEC Social Science Working Paper No. 30, available at www.psi.org.uk/ukshec

Loulou R., G. Goldstein and K Noble (2004) Documentation for the MARKAL family of models, Energy Technology Systems Analysis Programme (available at http://www.etsap.org/tools.htm)

Strachan, N., R. Kannan, N. Balta-Ozkan, S. Pye, P. Taylor (2006) Development of the UK MARKAL Energy Systems Model - 2nd Interim Report, Report for DTI/DEFRA, October 2006, available at http://www.ukerc.ac.uk

Strachan N., R. Kannan, and S. Pye (2007) Final report for the DTI-DEFRA Scenarios and Sensitivities, Using the UK MARKAL and MARKAL-MACRO Energy System Models, available at http://www.ukerc.ac.uk

Yang, C. and J. Ogden (2006), *Determining the lowest cost hydrogen delivery mode*, International Journal of Hydrogen Energy, Volume 32(2): 268-286.

Rafaj, P., and S. Kypreos (2007) *Internalization of external cost in the power generation sector: Analysis with Global Multi-regional MARKAL model*, Energy Policy, 35(2): 828-843.