The H2FC Hub: Identifying the opportunities for Hydrogen and Fuel Cells in the UK

Zeynep Kurban, PhD
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H2FC SUPERGEN
Aims and Objectives

The Hydrogen and Fuel Cells (H2FC) SUPERGEN hub, funded by the Research Council’s UK Energy Programme (May 2012-April 2019).

Three primary functions:

- **Transformational Research**: that enables the application of hydrogen and fuel cells in the energy landscape
- **Informing Stakeholders**: of the roles and benefits of hydrogen and fuel cell technologies
- **Building Networks**: between the academic research base and industry, builds partnerships across the sector

SUPERGEN is part of the UK Energy Programme’s Sustainable Power Generation and Supply initiative (SUPERGEN).
21 UK + 8 International Universities, £20m over 7 years

### Core Hub Research Universities

- Imperial College London
- University of Bath
- UCL
- Ulster University
- University of Birmingham
- University of St Andrews
- Newcastle University

### Other UK Universities with Hub Projects

- University of Liverpool
- University of Surrey
- University of Oxford
- Lancaster University
- University of Exeter
- The University of Nottingham
- University of Strathclyde
- University of South Wales

### International Partner Universities

- University of Cape Town
- Zhejiang University
- DTU
- MIT
- Yonsei University
- HANBAT National University
- Soongsil University
- Kyushu University
H2FC Supergen Research Hub

Multidisciplinary Collaboration

Low Carbon Technology

Linking Industry & Academia

Policy and Socio-economics

Solid Oxide Fuel Cells (SOFC) and Electrolysers (SOEC)

Research Synthesis

Hydrogen Electrolyte Fuel Cells

Hydrogen Storage

Hydrogen Production

Hydrogen and Fuel Cells Safety

Education and Training

Hydrogen and Fuel Cell Systems
Four evidence based White Papers

To inform key stakeholders, especially policy makers, of the roles and potential benefits of hydrogen and fuel cell technologies for meeting UK energy objectives.

Launched at the London City Hall in March 2017
Methods

1. Reviews of the technical, academic and commercial literature.

2. Engagement with core industry stakeholders.

3. Targeted analyses (e.g. comparative analysis of heating technologies complemented by scenario building using UK Times Model)

**UK CO2 reduction Targets (compared to 1990 levels):**
- 80% CO2 reduction by 2050
- 50% reduction by 2025 and 57% by 2030.
Decarbonising Heat...

Demonstration Studies

Hy4House

HyDeploy (Keele Uni.)

Hydrogen Upstream of the meter

H21 Leeds City Gate Study

£10m NIC award to GDNOs led by NGN

Hy4Heat

£25m BEIS research and Innovation Programme
Future energy systems

Examine the potential contribution of hydrogen and fuel cell systems to:

- Transport.
- Heat.
- Electricity.

Consider the infrastructure requirements.

How might a transition to these systems occur?

Concludes that hydrogen and fuel cells:

- are too important to neglect;
- make decarbonisation easier; and,
- need greater policy visibility.
Scenarios

∗ **Least Cost:** the lowest-cost method of achieving the GHG target based on input assumptions.

∗ **Critical Path:** the hydrogen option is kept open to 2030 through small investments in infrastructure and road vehicles; deployment ramps up in 2050 for strategically important end uses (transport and electricity).

∗ **Gas Conversion:** gas networks are converted to deliver hydrogen; homeowners choose between low-carbon heating and transport technologies primarily on cost.

∗ **Full Contribution:** hydrogen is taken up across the economy; hydrogen boilers and hybrid heat pumps heat most houses by 2050; almost all road vehicles use fuel cells; substantial contributions from hydrogen in industry and electricity generation as well.

∗ **No Hydrogen:** a counterfactual scenario that is the same as Least Cost, except that no hydrogen technologies are available.

∗ **Electrification:** a counterfactual scenario with widespread electrification of end-use technologies that relies primarily on renewable generation.
Hydrogen consumption by sector, in the six scenarios to 2050

Targeted analyses using **UK Times Model**

**Least Cost**: the lowest-cost method of achieving the GHG target based on input assumptions.

**Critical Path**: deployment ramps up in 2050 for strategically important end uses (transport and electricity).

**Full Contribution**: hydrogen is taken up across the economy; 50% of end-use demand is met by hydrogen in 2050.

**No Hydrogen**: a counterfactual scenario that is the same as Least Cost.

**Electrification**: a counterfactual scenario with widespread electrification of end-use technologies that relies primarily on renewable generation.
Final UK energy consumption in 2050, in the six scenarios
Energy conversion costs for different scenarios

Table S2 Total discounted costs of the energy systems in each scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Basic scenario</th>
<th>No BECCS</th>
<th>No CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least Cost</td>
<td>1.0</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Critical Path</td>
<td>1.2</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Gas Conversion</td>
<td>1.5</td>
<td>2.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Full Contribution</td>
<td>2.3</td>
<td>2.6</td>
<td>3.0</td>
</tr>
<tr>
<td>No Hydrogen</td>
<td>1.1</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Electrification</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

All costs are relative to the difference between the Least Cost scenario cost and the cost of an unconstrained reference scenario with no GHG emission targets. The Least Cost scenario therefore has a cost = 1. BECCS is bioenergy with carbon capture and storage (CCS).
How might hydrogen and fuel cells affect energy security in the UK energy system? Can they improve it? Would they worsen it?

Conclusions:

* Using hydrogen would not greatly change energy security, as measured by various indices – and the diversity of the energy system could increase.
* Using hydrogen could reduce the impacts of volatile energy import prices.
* The resilience of the UK electricity system could be increased by reducing the impacts of infrastructure damage (by natural incidents as well as malevolent interference).
Energy Security Definition(s)

- Resilience: robust to incidents
- Robustness: long-term stability
- Long-term perspective: secure investment framework
- Cost to consumer
- Cost to society (taxpayer)
- Affordability
- Reliability
- Security
- Availability
- Sustainability
- Economy
- Cost to consumer
- Cost to society (taxpayer)
- ECONOMY
- LCOE
- Annual bills
- Fuel poverty
- Affordability
- Network costs
- System adequacy
- De-rated capacity margin
- Shock resilience
- Response and reserve
- Supply diversity
- Internal disruption
- External disruption
- Supply disruption
- Materials depletion
- Fuel scarcity
- Water intensity
- Carbon emissions
- Environment
- SHORT-TERM
- LONG-TERM
<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>High diversity</th>
<th>Independence</th>
<th>High diversity and independence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full contribution</td>
<td>2.3</td>
<td>2.3</td>
<td>6.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Critical path</td>
<td>1.2</td>
<td>1.2</td>
<td>4.8</td>
<td>5.0</td>
</tr>
<tr>
<td>No hydrogen</td>
<td>1.1</td>
<td>1.2</td>
<td>4.8</td>
<td>5.0</td>
</tr>
</tbody>
</table>

All costs are relative to the smallest increase in costs required to meet the UK 80% GHG reduction target in 2050 in an unconstrained scenario in the UK TIMES Model (UKTM), relative to the reference scenario with no GHG targets. So this unconstrained scenario has a cost = 1.0.
Economic Impacts

- An early assessment of the scale and type of impact hydrogen and fuel cell technologies could have on the UK macro-economy.
- Uses **input-output modelling** to examine economy-wide impacts of building new supply chains for these technologies and reducing supply chains for incumbent systems.
- Considers economic (£m) and employment impacts (with **Consumer Road Transport as an exemplar**).
- Wider issues such as skills and industrial clusters are also examined.
- This is a preliminary study – there is much scope to develop the methodology to examine economic implications of energy technologies and an industrial strategy in the future.
What is a Multiplier?

- Input
- Output

Multiplier Diagram

- Value £
- HYDROGEN INDUSTRY
- Direct=Final spend (£1)
- Final consumers spend money

Industries need to buy inputs from other industries

Industries employ people who spend money

Total benefit
You are a potential hydrogen supplier

- We burn hydrogen for heat (assume 100% conversion efficiency)
- Apply approximate fuel cell conversions (losses) to generate relative values for electricity production and transport applications

That gives a modified *hydrogen value ratio set* of:

<table>
<thead>
<tr>
<th></th>
<th>Heat</th>
<th>Electricity</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Energy (based on efficiency of device)</td>
<td>4.18p /kWh</td>
<td>13.86p /kWh</td>
<td>41p /kWh</td>
</tr>
<tr>
<td>Relative H2 value</td>
<td>1</td>
<td>1.6</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Based on what you know consumers expect to pay for heat, electricity and transport,

**In which market space are you most likely to make a good margin?**

*Not indicative of what H₂ might cost*
Input-output data are produced as part of the UK National Accounts (ONS 2016), under United Nations System of National Accounts (SNA 1993).

The UK (industry by industry) input-output tables (2010): is a matrix describing the structure of the economy in a given year in terms of 103 industries (identified by the Standard Industrial Classification, SIC 2007).
A significant move away from current UK use of refined fuels in private transport towards hydrogen can yield a valuable increase in GDP and employment.

- The likely gains will come not only from the production and distribution of hydrogen in the UK but also from the range of service sector activities, including finance, involved in a potentially strong domestic supply chain.

- Key driver of findings: the current supply chain for petrol and diesel is highly import-intensive.
Where will H2 come from?
Importance of *domestic (UK) supply chain linkages* in delivering economic expansion through multiplier effects

*If* hydrogen supply could *replicate the strong domestic upstream supply linkages of the current UK gas and electricity supply sectors*, opportunities for economic expansion through a hydrogen transport economy

However, much will depend on the *continued role of fossil fuel extraction* from the UK oil and gas extraction industry

Attention in development of the skills base in UK *service industries*

Potential additional impacts from private and public investment targeted at R&D, construction etc., but impacts may be time-limited (as opposed to on-going operational)
The role and status of hydrogen and fuel cells across the global energy system

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Abstract

Hydrogen technologies have experienced cycles of excessive expectations followed by disillusion. Nonetheless, a growing body of evidence suggests these technologies form an attractive option for the deep decarbonisation of global energy systems, and that recent improvements in their cost and performance point towards economic viability as well. This paper is a comprehensive review of the potential role that hydrogen could play in the provision of electricity, heat, industry, transport and energy storage in a low-carbon energy system, and an assessment of the status of hydrogen in being able to fulfil that potential. The picture that emerges is one of qualified promise: hydrogen is well established in certain niches such as forklift trucks, while mainstream applications are now forthcoming. Hydrogen vehicles are available commercially in several countries, and 225,000 fuel cell home heating systems have been sold. This represents a step change from the situation of only five years ago. This review shows that challenges around cost and performance remain, and considerable improvements are still required for hydrogen to become truly competitive. But such competitiveness in the medium-term future no longer seems an unrealistic prospect, which fully justifies the growing interest and policy support for these technologies around the world.
## H2 & FC Uptake targets

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</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>1.4m</td>
<td>5.3m</td>
<td>40,000</td>
<td>200,000</td>
<td>800,000</td>
<td>160</td>
<td>320</td>
<td>900</td>
</tr>
<tr>
<td>Germany</td>
<td>–</td>
<td>–</td>
<td>100% ZEV&lt;sup&gt;(a)&lt;/sup&gt; by 2040</td>
<td>400</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>China</td>
<td>–</td>
<td>–</td>
<td>3,000&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>50,000</td>
<td>1m</td>
<td>100</td>
<td>300</td>
<td>1,000</td>
</tr>
<tr>
<td>US</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>3.3m</td>
<td>–</td>
<td>100&lt;sup&gt;(c)&lt;/sup&gt;</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>South Korea</td>
<td>–</td>
<td>1.2 MW</td>
<td>10,000</td>
<td>100,000</td>
<td>630,000</td>
<td>100</td>
<td>210</td>
<td>520</td>
</tr>
<tr>
<td>UK</td>
<td>–</td>
<td>–</td>
<td>100% ZEV&lt;sup&gt;(a)&lt;/sup&gt; by 2040</td>
<td>30</td>
<td>150</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

<sup>(a)</sup> Zero Emission Vehicle

<sup>(b)</sup> Shanghai only

<sup>(c)</sup> California only

- UK in top 10 countries globally in terms of numbers of hydrogen and fuel cell publications
- 2nd only to Germany in terms of average citations per article.
ISCF – Innovate have issued an EOI (closing date 18 April) inviting proposals on the potential future challenges to get support through the Industrial Strategy Challenge Fund

Mission based innovation:
Prof Marina Mazzucato (UCL)

IEA Hydrogen Tasks:
1) Market Deployment & Pathways to Scale
2) Hydrogen in Industry and Buildings
Thank you!

Download the four White Papers:
www.h2fcsupergen.com

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