UNRESTRICTED REPORT

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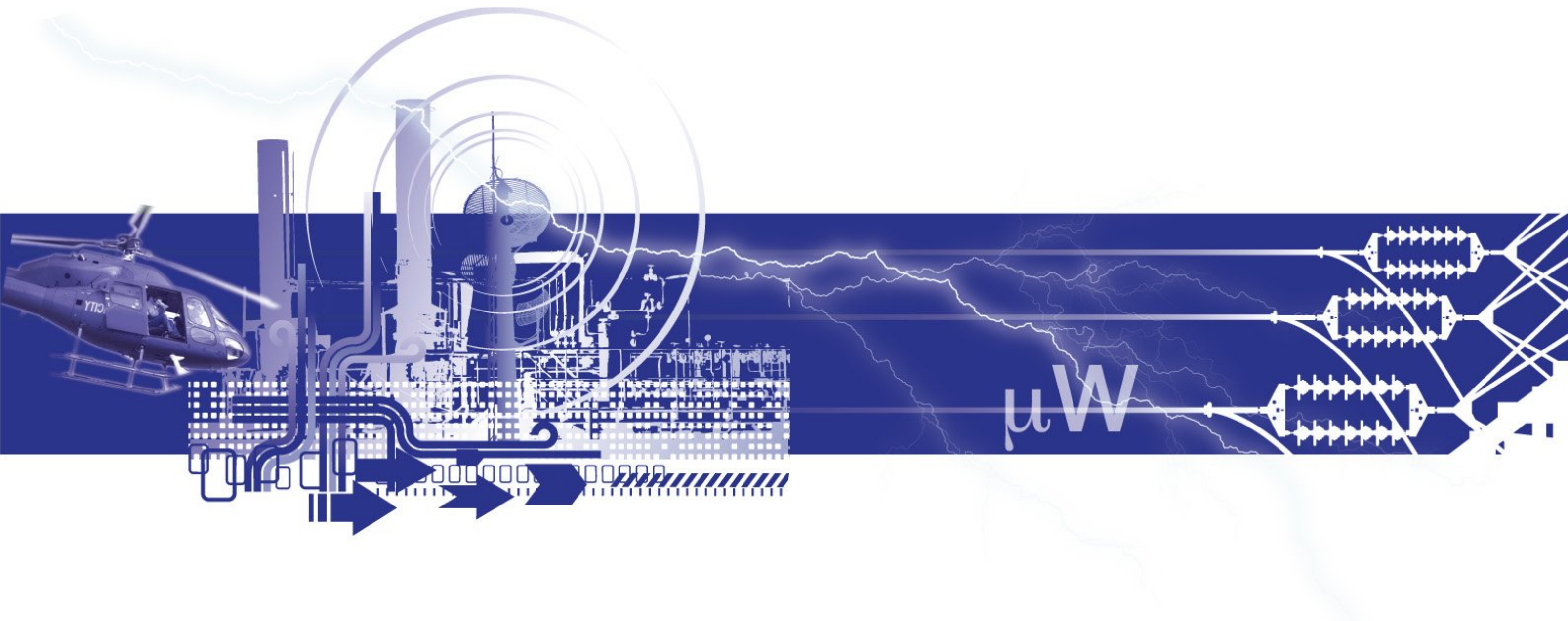

Review of UK Hydrogen Capabilities

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Review of UK Hydrogen Capabilities

Client

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Review of UK Hydrogen Capabilities

by

Mary Gillie & Jen Carter

Summary

The UK is a participant in the International Energy Agency's Hydrogen Implementing Agreement Task 18 which studies the development of hydrogen demonstration schemes. Through participation in the Task and the reports from other countries it became clear that there has not been a comprehensive study of the areas within the field of hydrogen and fuel cells where the UK is particularly active or a study of the barriers or gaps preventing the development of hydrogen.

This aim of this work is to:

- Survey the types and size of hydrogen research, development and demonstration projects being carried out in the UK, the sources of funding and locations.
- Evaluate the current funding initiatives in terms of their effectiveness.
- Summarise best practice from overseas and compare it to the UK's performance.
- Identify the key areas where the UK has expertise on which to build and how this can best be facilitated through funding and other measures.

Hydrogen is an energy vector that can integrate all energy sectors within a complete low-carbon energy system. At the same time as offering a controllable load for grid balancing, the production of hydrogen also provides a flexible fuel for the following end-use applications:

- transport;
- electricity;
- heat;
- all three above energy uses for remote communities.

The report gives an overview of these uses. It then breaks down the projects currently being undertaken in terms of funding, areas of focus, location, and stage of development. There is significant clustering of projects. This is partly due to regional funding in certain areas but also due to a tendency for areas that develop expertise to attract new companies and projects that wish to share facilities and knowledge.

Compared to world leaders, the UK lacks a clear goal for developing hydrogen systems and a strategy with targets and timescales. This is urgently needed and should be developed in collaboration with industry and academia. It would appear unwise for the UK to try to

develop expertise in all areas. The following topics have been identified as areas in which the UK should consider build on existing expertise. In research and development:

- The development of cheaper, more common catalysts to replace platinum;
- Work to find metal hydrides to provide high density, low mass storage;
- Electrolysers that can work with intermittent energy sources and at part load.

At the demonstration stage the UK should consider concentrating on:

- The development of test facilities and filling stations for hydrogen vehicles and the use of internal combustions engines as a stepping stone to fuel cell vehicles;
- Biohydrogen systems for rural areas in the UK and abroad;
- Applications for remote communities;
- System design and integration.

Contents

1 Introduction

The UK is a participant in the International Energy Agency's Hydrogen Implementing Agreement Task 18 which studies the development of hydrogen demonstration schemes. Through participation in the Task and the reports from other countries it became clear that there has not been a comprehensive study of the areas within the field of hydrogen and fuel cells where the UK is particularly active or a study of the barriers or gaps preventing the development of hydrogen within a low carbon energy system.

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- Evaluate the current funding initiatives in terms of their effectiveness.
- Summarise best practice from overseas and compare it to the UK's performance.
- Identify the key areas where the UK has expertise on which to build and how this can best be facilitated through funding and other measures.

2 Potential Uses of Hydrogen and Key Challenges

Before considering the UK's current activities in relation to hydrogen, it is beneficial to consider the potential applications for hydrogen that are currently being examined, both in the UK and internationally. This section therefore outlines the potential uses of hydrogen and the key challenges limiting the development of hydrogen as part of a low carbon energy system. Where appropriate, it also highlights work done, or being done, to address these areas on an international level.

2.1 Potential Uses

Hydrogen's central role within a low carbon energy system is as a means of managing grids with high penetrations of renewable energy and/or less flexible generation such as nuclear or 'clean coal'. At the same time as offering a controllable load for grid balancing, the production of hydrogen also provides a flexible fuel for the following end-use applications:

- transport;
- electricity;
- heat;
- all three above energy uses for remote communities.

Thus hydrogen is an energy vector that can integrate all energy sectors within a complete low-carbon energy system. This section gives an overview of these potential applications.

2.1.1 Transport

Potentially, hydrogen could be used to fuel road transport such as passenger vehicles (cars), service vehicles with a fixed route, or public transport (buses or taxis). The possibility of other modes of transport, such as trains[1] and planes[2], running on hydrogen are also being seriously considered.

There are two main options for the use of hydrogen for transport: either internal combustion engines that run on hydrogen, rather than diesel or petrol; or electric vehicles that are powered by an onboard fuel cell, rather than needing to be ‘plugged in’. Both options are currently being developed by different players. As far as passenger cars are concerned, ITM Power has converted a conventional Ford Focus to run on hydrogen, with the option of reverting to petrol if one ran out of hydrogen[3]. Honda, on the other hand, is trialling a ‘sedan-type’ electric car in California that uses a hydrogen powered fuel cell[4]. Following successful involvement in a European Trial, Transport for London will be running ten hydrogen-fuelled buses in London by 2010, with half using an internal combustion engines and half a fuel cell technology[5]. As highlighted in the last report to the IEA Task 18[6] Experts' Meeting in Denmark and Sweden, the municipality of Malmo, Sweden, has a programme to run its bus fleet on compressed natural gas and hydrogen[7]. The target is to migrate to a fleet fuelled by hydrogen produced from electrolysis from excess wind power and sewage gas.

2.1.2 Electricity Sector

A number of possible applications for the use of hydrogen in the electricity sector have been proposed. These include using hydrogen to generate electricity and as an alternative method for storing electrical energy, by converting excess electricity into hydrogen that can be used to generate electricity at times of peak demand.

More recent variations suggest that hydrogen could be incorporated into renewable generation schemes. Typically, fluctuations in wind power mean that generators are exposed to significant risk in the current trading and imbalance arrangements. Hydrogen could be produced, for example, when wind exceeds a certain threshold as is illustrated in Figure 2.1.

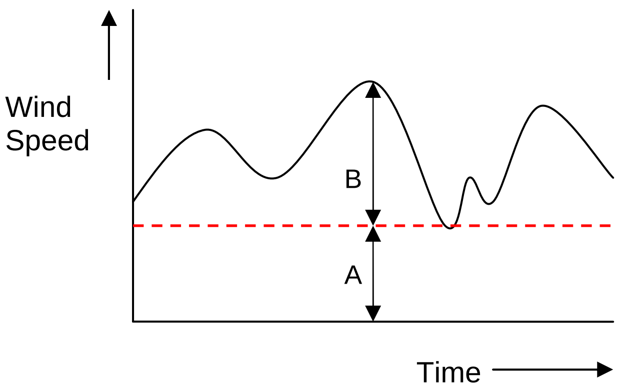

Figure 2.1 Trading Wind

[1] For example, http://www.hydrogentrain.eu/Default.aspx?ID=328
[2] For example, http://www.boeing.com/aboutus/environment/alt_energy.html
[3] More information available at http://www.itm-power.com/news/63.pdf
[4] More information available at http://automobiles.honda.com/fcx-clarity/
[5] http://www.tfl.gov.uk/corporate/projectsandschemes/environment/8444.aspx
[6] Task 18 of the IEA Hydrogen Implementing Agreement (hereafter, Task 18)
[7] Malmo Hydrogen and CNG/Hydrogen filling station and Hythane Bus Project http://www.cder.dz/A2H2/Medias/Download/Proc%20PDF/PARALLEL%20SESSIONS/%5BS26%5D%20Deployment/13-06-06/339.pdf accessed 19th January 2009

Power generated under the red line, marked A, could be traded with relative certainty on the existing power markets. The additional power under the curve, marked B, could be used to generate hydrogen which could be used for a number of applications, such as transport fuel or electricity generation as required. Theoretically, this type of approach would enable hydrogen to be produced with a minimal carbon footprint, for relatively low cost, whilst ensuring that wind generation remains economical, even with high levels of renewable integration. Such schemes have also been proposed in relation to electrical energy storage technologies such as batteries and flow cells.

Hydrogen systems have also been proposed for providing more general grid management services. Alongside, or as an alternative to, energy storage devices, a hydrogen system could assist in controlling frequency and voltage, both locally and nationally, by converting excess electricity into hydrogen which could in turn be converted into power when the system is short.

There are, however, efficiency issues with converting electricity into hydrogen and back again. Where there is a plentiful supply of renewable electricity this may be of less concern, but for many applications it is likely to be preferable to minimise the losses. In a low carbon economy approach, rather than reconverting to electricity for the power system, the hydrogen produced could be used for transport. Use in transport replaces more carbon intensive diesel or petrol and improves security of energy supplies. Loughborough University, Intelligent Energy, Bryte Energy and other companies are currently researching this type of synergy between applications and it is an area of interest to the Midlands Hydrogen Ring, in general.

The technical and economic issues of wind-hydrogen integration via electrolysis are studied in Task 24 of the IEA Hydrogen Implementing Agreement. The Institute for Energy's 2006 report[8] gives different scenarios for wind-hydrogen integration in Europe. The report predicts that improved efficiencies and reduced costs could reduce the cost of hydrogen from wind by 30% over the next 30 years.

2.1.3 Heat Generation

One of the side effects of generating electricity is that heat is also produced. In conventional power generation, the majority of this heat is lost. Combined Heat and Power (CHP) in contrast tries to match it to a local heat demand, either from industrial consumers (usually as steam) or to meet space or hot water heating for domestic, community or SME consumers. This is also possible for hydrogen-fuelled CHP schemes and the UK already has a commercial CHP plant running off hydrogen (with an integrated natural gas reformer) that provides power, heat and cooling to a Leisure Centre in Woking[9] for a number of years. Other examples are CHP in housing on Orkney[10], in Berwick[11] and in the Hydrogen Office in Fife[12]. Some of these use reformed natural gas as a stepping stone to using hydrogen. Fuel cells have the advantage of a low heat to power ratio and are therefore ideal for applications where the heat demand is smaller than that which is viable with conventional CHP units.

[8] Bridging the European Wind Energy Market and a Future Renewable Energy Hydrogen-Inclusive Economy S Shaw and SD Peteves, Institute for Energy 2006
[9] More information can be found at http://www.woking.gov.uk/environment/Greeninitiatives/sustainablewoking/fuelcell.pdf
[10] http://www.freesen.de/hydrogenexpo/2008/PURE_press_release.pdf accessed 26th November 2008
[11] http://www.bhagroup.org.uk/
[12] www.hydrogenoffice.com, accessed 26th November

The possibility of developing smaller schemes, suitable for use in domestic properties, is also being investigated by some boiler manufacturers like Baxi. These could potentially convert natural gas into hydrogen and thereby operate on the existing natural gas infrastructure, minimising the disruption to the householder. Such schemes will deliver a large amount of the household's electricity demand but consumers are likely install them as an alternative to a boiler upgrade, rather than as a generator and therefore the cost to the consumer will need to be similar to a boiler.

As highlighted in the report to the September 2008 Task 18 Experts' meeting, there are trials of hydrogen fuelled domestic CHP fuel cells on the island of Lolland, Denmark. The hydrogen will be produced from excess wind energy and supplied to domestic properties by the local distribution network operator, who will also control the CHP units remotely to supply electricity when required. This demonstrates how hydrogen fuelled CHP could deviate from conventional applications and be electricity led to allow it to be used for grid balancing. A heat store is required to save excess heat when there is insufficient heat demand at the same time as electricity demand. This project is a good example of the potential benefits from combined use of microCHP and active electricity network control.

2.1.4 Remote Communities

This potential application would probably combine some or all of the above applications. These locations are the most technical challenging however, due to location, the economics of a scheme for a remote/island community are likely to be different from the majority of the UK. In many of these remote communities, fuel prices are significantly higher than the national average due to the need to import fuel and likely dependence on diesel generators or similar for electricity generation. The geographical location of such communities, both in the UK and internationally, means that they tend to have above average renewable energy resources.

Proposed schemes are likely to generate electricity to meet the community's demand, with any surplus being used to produce hydrogen which can then be used for transport, heat or power at times of peak demand and/or low supply. The IEA Hydrogen Task 18 is currently studying the experiences of communities who are pioneering hydrogen-renewable schemes. This work identifies the drivers, barriers and methods in which such schemes can be replicated or modified to become more mainstream.[13] The benefits are not only in terms of reduced fuel bills and energy security but community pride, job creation and additional tourism.

2.2 Key Challenges

The key technical challenges that have been highlighted as limiting the development of a hydrogen economy in the UK are:

- Production;
- Storage and distribution of hydrogen;
- The integration of hydrogen into a low carbon economy.

This section gives an overview of these challenges.

[13] Benefits and Barriers of the Development of Renewable/Hydrogen Systems in Remote and Island Communities, Shannon Miles and Mary Gillie. 2008 Draft Report for the IEA HIA Task 18. To be released 2009.

2.2.1 Hydrogen Production

It is possible to use a number of methods to produce hydrogen. These include steam reforming, partial oxidation, electrolysis of water and a number of biological processes, including fermentation. Of these, steam reforming is the most common technique used at present for mass production of hydrogen for industrial applications but this and partial oxidation are heavily dependent on hydrocarbons.

Electrolysis of water is an alternative method of production that has the potential to produce 'green' hydrogen. However, the level of the carbon emissions and the costs that are associated with hydrogen produced by electrolysis are heavily dependent on the energy source used to generate the electricity, so can vary significantly according to the electricity fuel mix. The use of electricity generated from renewable sources would reduce both the carbon footprint and the cost of hydrogen produced by electrolysis. Production of hydrogen using electrolysis should aim to use excess power from non-dispatchable generation. If electricity from renewable sources is used to displace fossil fuel for transport or heat requirement it will increase the country's overall electricity demand and, consequently the amount of renewable energy projects[14]. Hydrogen could be the energy vector from electricity to transport fuel or heat but an alternative is to use electricity directly with battery storage. Apart from conversion losses, hydrogen itself will not increase amount of energy required overall.

In order to incorporate hydrogen within a low carbon energy system in the UK, hydrogen needs to be produced at a competitive cost and with a minimal environmental impact. There are some new methods currently being developed, as an alternative to electrolysis including:

- the use of algae (via photosynthesis);
- bacteria (via fermentation);
- photoelectrolysis (where a solar cell is used to split water directly without the use of electricity).

Some of these systems are at the demonstration stage at the University of Glamorgan. As part of the Supergen Sustainable Hydrogen Energy Consortium, the University of Glamorgan is running reactors to obtain hydrogen from crops typically grown on 'set aside' land[15]. Other demonstration or lab projects are using wheat starch industry co-products and sewage sludge. [16]

2.2.2 Hydrogen Storage

Being able to store hydrogen in a way that is safe, economical and practical is critical for many of the applications detailed above, but particularly in relation to transport. Current techniques for storing hydrogen are as compressed gas, as liquid hydrogen or using types of chemical storage where hydrogen is contained within the chemical structure of another compound.

The type of storage that is most appropriate may vary between applications. For transport, in particular, it is important that the storage adds minimal additional weight to the vehicle as this will affect the vehicle's efficiency. There are also likely to be misconceptions about the safety of hydrogen vehicles and it may be necessary to demonstrate the safety of the storage element of the vehicles is to allay public concerns.

[14] As discussed in BERR's Consultation on the UK Renewable Energy Strategy, published June 2008.
[15] http://www.serc-wales.org.uk/Assets/shecleaflet.pdf
[16] http://www.tsec-biosys.ac.uk/index.php?p=2&pp=0&pt=5

2.2.3 Hydrogen Distribution

Unless hydrogen is produced locally at the point of use, widespread usage of hydrogen applications, especially for transport, will require a new infrastructure of fuelling stations to distribute the hydrogen for vehicles or other applications, as was recognised by the King Review[17]. To date, relatively little has been done in this area. As Smith[18] has commented, "*Customers will be reluctant to buy a hydrogen car until the infrastructure exists, yet investment in such an infrastructure will depend upon a growing demand*." There may be a need for governmental intervention to promote investment in such infrastructure.

The use of hydrogen as a grid balancing tool heavily favours its production at distributed level, close to the point of delivery, rather than at centralised facilities or close to the point of primary energy production. This obviates the development of extensive hydrogen pipeline infrastructure, but places the burden on the electricity transmission and distribution network instead. Given this situation, the issue of introducing hydrogen infrastructure is largely about provision of production, storage and dispensing facilities at garage forecourts (or, potentially, small domestic refuellers).

There are some localised or regional schemes to establish a network of filling stations, such as those being developed by the British Midlands Hydrogen Ring, for example, but these are limited at present.

2.2.4 Competition between Low Carbon sectors

To date, hydrogen and other low carbon technologies for power generation have tended to be considered as separate sectors. This has led to competition between the two for resources, including funding, skilled personnel, and knowledge. Whilst some of this competition has probably been beneficial, it has focused low carbon technologies on competing against each other rather than replacing carbon intensive technologies. Indeed, only an integration of various technologies will be the winning solution. For example, electric, biofuel and hydrogen vehicles have vied against each other. This is despite the fact that hydrogen vehicles will, in reality, be mainly hydrogen-electric hybrids and biogas and hydrogen could be mixed and used in an internal combustion engine. Electric vehicles, too, have often been seen to be in competition with hydrogen vehicles in that they are transferring energy from the grid to the transport sector and should do so in response to the grid balancing requirements. It is likely that electric vehicles will be more appropriate for short-range, lightweight applications and hydrogen technologies (or more likely, hydrogen-electric hybrids) are more appropriate for larger long range vehicles. Another alternative is battery-petrol hybrids often referred to as 'plug in-hybrids'. The Department of Business, Enterprise and Regulatory Reform (BERR) and the Department of Transport (DfT) sponsored a project to look at the viability of switching to electric and plug-in hybrids (see reference 19).

For the UK to move forward with hydrogen and renewable energy, it would seem appropriate to combine all these areas into a single sector with a combined national strategy.

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[17] 'The King Review of Low Carbon Cars – Part I: the potential for CO_2 reduction', (October 2007), p.33

[18] 'Energy for Transport: the 95th Thomas Hawksley Lecture' Prof R A Smith November 2008 para 32.

[19] 'Investigation into the Scope for the transport Sector to Switch to Electric Vehicles nad Plug-in Hybrid Vehicles' October 2008, CENEX, Ove Arup for the Department of Business Enterprise and Regulatory Reform and the Department of Transport

3 Analysis of Current UK Hydrogen Projects

This section considers current projects in the UK. The information sources for this review are primarily the responses to the requests for information for the UK database, established under Subtask A of Task 18 of the International Energy Agency Hydrogen Implementing Agreement. In addition, readily available public domain sources were also searched and used to provide supplementary or supporting evidence. The website of the Engineering and Physical Sciences Research Council (ESPRC) was particularly useful in providing information relating to academic research currently being undertaken in this area. Other sources of national government funding over the last few years have been:

- The Technology Programme – this issues competition calls twice a year for project within particular themes. Hydrogen and fuel cell systems have been amongst these themes as well as work in material science.[20]
- The Hydrogen, Fuel Cells and Carbon Abatement Demonstration Programme offered £15 million for hydrogen and fuel cells over 4 years.[21]
- Advanced fuel cell programme offered £2 million a year.

The Low Carbon and Fuel Cells Knowledge Transfer Network offers a useful forum to publicise news developments, reports and events[22]. Unfortunately, there does not appear to be summary of the projects funded under the programmes above. New funding initiatives through the Energy Technologies Institute and The Technology Strategy Board and regional funding are described in section 4.3.

Please note, that there may be projects that have not been included in this analysis. This has particularly been a concern for projects that are being developed by commercial organisations that are 'under wraps' for reasons of commercial sensitivity. The authors have endeavoured to include as many projects as possible using the information available.

3.1 Analysis of Developmental Stage of Projects

Information was collected on 90 projects currently being undertaken in the UK and Table 3.1 shows the breakdown of these projects across the different stages of development from Research and Development to Commercial Deployment. This breakdown illustrates that current UK projects are significantly weighted towards the Research end of the Development spectrum.

Table 3.1 Stage of Development of Current UK Projects

Stage of Development	Total
R & D	61
Demonstration	26
Commercial	3
Support Mechanism	3
Grand Total	93

20 http://www.berr.gov.uk/dius/innovation/technologystrategyboard/tsb/technologyprogramme/index.html accessed 19th January 2009

21 http://www.hfccat-demo.org/ accessed 19th January 2009

22 www.fuelcellktn.com accessed 19th January2009

Figure 3.1 illustrates the number of projects different types of organisation in the UK are carrying out. This suggests that the significant majority of projects are being carried out in an academic environment. This supports the analysis above that the majority of projects are at the early stages of potential product development, rather than at the demonstration or commercialisation stages.

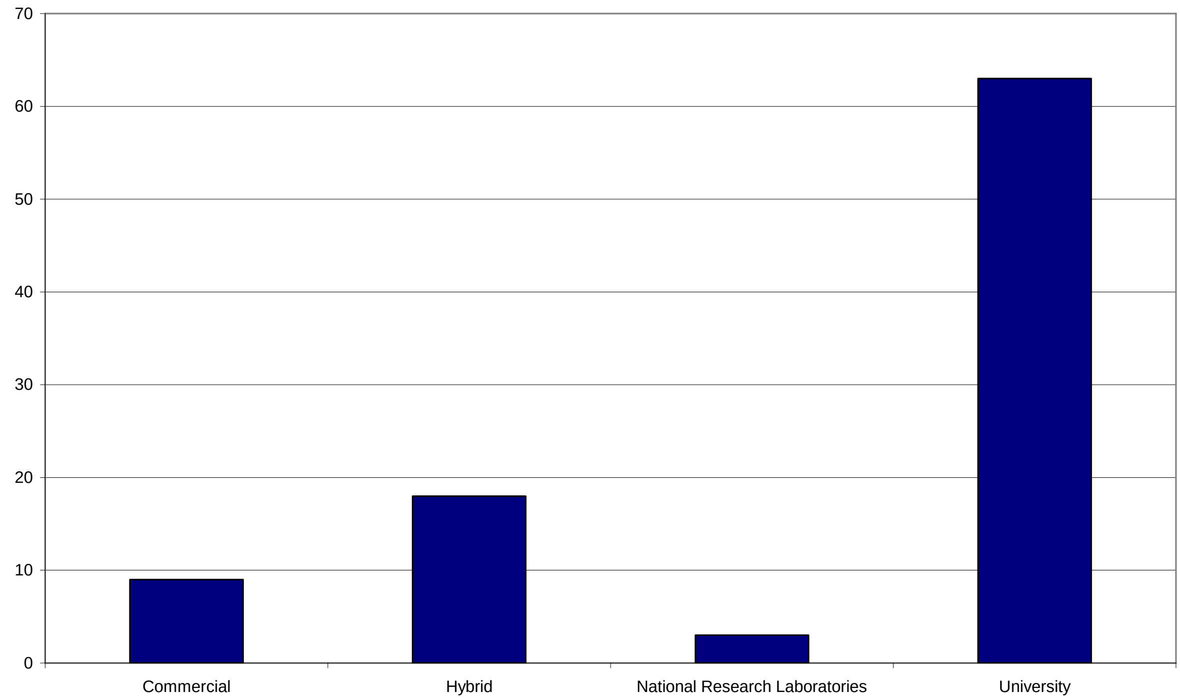

Figure 3.1 Breakdown of Projects by Organisation carrying out work

Table 3.2 shows the source and value of funding from public bodies. Where information on the source or value of any funding was unavailable or not disclosed, it is shown as ‘Unknown’. Over 70% of the projects have received some public funding, with the majority of these projects receiving between £100,000 and £500,000. In line with the majority of projects being carried out in an academic environment, almost three quarters of the projects that declared the source of any public funding have been funded through EPSRC.

Table 3.2 Breakdown of public funding by source and value of funding

Government Funding Source	£0>£ 100k	£100k>£ 250k	£250k> £500k	£500k> £750k	£750k> £1m	£1m> £5m	£5m+	None	Unknown	Grand Total
Carbon Trust									1	1
EPSRC	7	20	19	3	2	5	1		2	59
EST									1	1
EU			1	1		1			1	4
None								1		1
RDA						1	1		4	6
Scottish Govt		2	1			1				4
TSB									2	2
UK Govt						1			1	2
Unknown									12	12
(blank)									1	1
Grand Total	7	22	21	4	2	9	2	1	25	93

3.2 Regional Analysis of Projects

Table 3.3 shows the breakdown of projects by geographical region of the UK. This table suggests that there is a widespread interest in hydrogen development, although there are areas with significantly more projects than others at present. Of these, the Midlands is the clear leader, with strong interest also in Scotland, the North East and London. The North West has the least activity at present with just 2 current projects.

Table 3.3 Regional Analysis of Projects

Region	Total
East Anglia	4
London	12
Midlands	25
North East	14
North West	2
Scotland	19
South East	4
South West	4
Wales	9
Grand Total	93

One possible reason for this regional representation is illustrated in Table 3.4. Whilst all the regions have some projects being carried out by universities, the regions with a stronger representation also have projects being carried out by, or in conjunction with, other types of organisations. Some of these, for example, are as a result of successful research projects being spun out to develop into demonstration projects run by spin-off companies from the universities. Others have been developed through relationships between universities and their local or regional authorities. Some regions may be better at creating the conditions for development as identified by Porter in his Dynamic Diamond model such as strategy, demand, infrastructure, knowledge exchange, skills and education.

Table 3.4 Regional Breakdown by type of Organisation

Stage of Development	East Anglia	London	Midlands	North East	North West	Scotland	South East	South West	Wales	Grand Total
R & D	4	8	16	7	2	13	3	4	4	61
Demonstration		3	7	6		5	1		4	26
Commercial			1	1		1				3
Support Mechanism		1	1						1	3
Grand Total	4	12	25	14	2	19	4	4	9	93

The differences in public funding available in different regions may be another reason for the distribution of hydrogen projects. The regions with the greater proportion of current projects also have significantly higher contributions of public funding, in the region of £6 million upwards. The exception to this is the South West, as the United Kingdom Sustainable Hydrogen Energy Consortium is based at the University of Bath and attracts significant EPSRC funding.

This also highlights the difficulties in this type of analysis. One large project in a region costing several million pounds, for example, may be as productive as many small projects and lead to similar levels of employment and opportunities for that region.

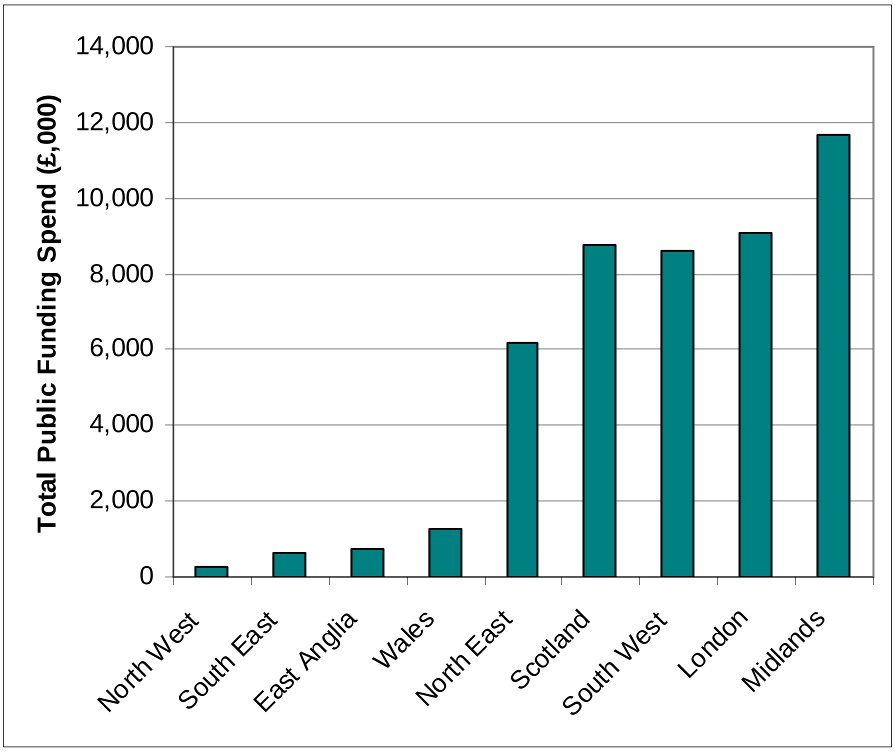

Figure 3.2 Total Public Spending by Region

Table 3.5 shows a breakdown of the projects by region and funding source, excluding those that have received funding through EPSRC. Approximately half of the projects that have received public funding have used regional funds (including from the Scottish Government). Projects therefore often cluster in regions where there is funding. Examples of clusters of activity are given in Case Study 1 and 2.

Table 3.5 Non-EPSRC funding by region (project numbers)

Government Funding Source	London	Midlands	North East	Scotland	South East	Wales	Grand Total
Carbon Trust						1	1
EST						1	1
EU				2		2	4
RDA	1	1	3		1		6
Scottish Govt				4			4
TSB	1	1					2
UK Govt	2						2
No Public Funding		8	4	1		1	14
Grand Total	4	10	7	7	1	5	34

However, this may not always be the case. Of these projects, almost half have not received, or declared, any public funding so are presumably drawn to the area by other factors. They may be attracted by other organisations already working in that region or may be keen to locate close to their parent organisation, laboratory or test facilities. Spin-off companies that have come out of academia are keen to maintain the link with the university.

Case Study 1 British Midland Hydrogen Forum
The British Midland Hydrogen Forum has attracted funding from the Development Agencies in the East and West Midlands and has universities active in the field of hydrogen (particularly Loughborough University and the University of Birmingham but also Nottingham, Warwick and Leicester). This has attracted involvement and funding from industry. CENEX (Centre for Hydrogen and Low Carbon Technologies) is an industry led public private partnership supported by the Department of Business, Enterprise and Regulatory Reform. SCRATCH (Supply Chain Research Applied to Clean Hydrogen) is an £8 million project funded by EPSERC and industry. It is run by the Universities of Birmingham and Warwick and focuses on:

- hydrogen production,
- storage,
- refuelling and pipeline infrastructures,
- fuel cells and
- economic barriers

Case Study 2 Renewable Hydrogen and Fuel Cell Support Scheme
The Renewable Hydrogen and Fuel Cell Support Scheme has provided £1.5 million for demonstration schemes using hydrogen and renewable energy in Scotland. Combined with its abundant renewable resources and remote communities, this has resulted in a number of demonstration schemes in Scotland. The projects include:

- A facility to produce hydrogen from biogas run by Western Isles Council.
- A fuel cell and electrolyser at Myers Hill wind turbine test site, near East Kilbride, to demonstrate how hydrogen can be used to strengthen an area of constrained grid.
- A micro renewable powered hydrogen fuel cell in a house in Ayton owned by Berwickshire Housing Association to provide a constant supply of green energy.
- Further research on their solid oxide fuel cell for use with biogas by St Andrews Fuel Cells.

Analysis of the Types of Project

To analyse the types of project being conducted, the projects were categorised by their area/s of focus. This is shown in Table 3.6. The total in this table exceeds the number of projects above as some focus on more than one area. Development of fuel cells and the associated technologies is the most prevalent area of work at present with storage of hydrogen a close second.

Table 3.6 Projects by Category

Categories	
Fuel Cell Development	39
Hydrogen Storage	30
Production of Hydrogen	25
Transport Applications	12
Renewables Integration	8
Distribution of Hydrogen	4
Other	5
Education	3
Total	**126**

Table 3.7 breaks this analysis down further into the stages of development of the projects. The number of projects being carried out in Fuel Cell Development suggests that this area is progressing well towards commercialisation, whilst the projects in Hydrogen Storage are mostly at the research stage.

Perhaps interestingly, projects looking at Hydrogen Applications for Transport and the use of Hydrogen to support Renewables Integration are predominantly in the demonstration and commercialisation stages. Transport is being targeted for support in the Midlands Hydrogen Ring and in London. The Scottish government has focused on hydrogen and renewables for remote and off-grid communities. These types of projects are also able to use the developments from some of the other categories, such as fuel cell development or storage, allowing them to miss the early stages of research and go straight to integrating the technologies into a vehicle or system for integrating renewables. A combination of these factors is likely to explain why these projects are the most advanced.

Table 3.7 Projects by Category and Stage of Development

Categories	R&D	Demonstration	Commercial Deployment	Support Mechanism	Total
Fuel Cell Development	21	16	2	0	**39**
Hydrogen Storage	24	5	1	0	**30**
Production of Hydrogen	18	6	1	0	**25**
Transport Applications	1	10	1	0	**12**
Renewables Integration	0	7	1	0	**8**
Distribution of Hydrogen	1	2	1	0	**4**
Other	0	2	0	3	**5**
Education	0	1	0	2	**3**
Total	**65**	**49**	**7**	**5**	**126**

3.2.1 Areas of International Expertise

Japan, USA and Canada all have advanced demonstration programme with which it will be very difficult for the UK to compete directly. For example the US has 4 car fleets under demonstration. The Japanese have 2187 fuel cell microCHP units installed in homes. These examples are discussed further in section 5.1. The Strategic Framework for Hydrogen Energy in the UK, proposed in 2004[23], commented specifically that the UK was lagging behind the USA and Japan in fuel cell development. However, the UK Fuel Cell Development and Deployment Roadmap[24] in 2005 did highlight areas where the UK is active on an international level. Rolls Royce and Johnson Matthey are highlighted as two companies with a long track record in materials and catalysts for fuel cells and reformers, along with 21 universities that are active in this area. There are also 10 companies and 11 universities identified as involved in hydrogen storage. Other areas of expertise are integration with renewables and hybrid engines.

3.3 Completed Projects 1999 – 2008

In addition to the analysis discussed above, a survey was also carried out on the projects listed on the Research Register maintained by the UK Energy Research Centre of projects in the area of Hydrogen and Fuel Cells[25]. The Register lists 246 projects in this field that have received funding grants since 1999, including 6 projects where funding has been agreed already but the project is not due to commence until later in 2009. Projects funded by the Regional Development Agencies or Devolved Governments do not appear in the Register.

The Register lists projects by the funding source and, similar to the research carried out above, just over 75% of the projects have been funded through the EPSRC. This is slightly distorted, however, as the Register does not lists any projects with alternative funding sources that have been started since April 2007.

[23] A Strategic Framework for Hydrogen Energy in the UK, Eoin Lees Energy, E4Tech, Element Energy, December 2004
[24] UK Fuel Cell Development and Deployment Roadmap 2005 Fuel Cells UK (Funded by the DTI)
[25] Available at http://ukerc.rl.ac.uk/ERCR000.html

As at 1st January 2009, 111 of the projects listed have been completed. Table 3.8 shows the breakdown of funding sources of these projects, with the majority being funded through a Research Council. Of the remainder, there is a relatively even split of funding between the former DTI, the DfT and the Carbon Trust.

Table 3.8 Numbers (C) of Completed Projects with Funding Sources for[26]

Funding Source	C
BBSRC	1
Carbon Trust	19
DfT	13
DTI	21
EPSRC	57
Grand Total	111

Of these completed projects, 68 have been carried out in an academic environment and the remainder by private organisations. This is also reflected in the breakdown of the stage of development of the projects, as shown in Table 3.9. The stages, as characterised by the Register, do differ slightly from those used above but do show a similar bias towards the earlier stages of research. The Register is restricted towards research projects and consequently any examples of demonstration or early deployment projects are not included. The use of broad sectors in the Register limits the ability to consider the projects in relation to the area that they are attempting to address.

Table 3.9 Numbers (C) Completed Projects by Stage of Development

Type of Research	C
Basic & Strategic Applied Research	70
Applied Research & Development	40
Final Stage Development & Demonstration	1
Grand Total	111

For these completed projects the Register provides access to the resulting publications or final report where these are publicly available. It does not list papers that have been published in academic journals. Of the completed projects, one project funded by the DfT and 7 funded by the DTI list a publication[27] and a further 4 projects (one funded by the DfT and 3 by the DTI) include a Final Report. For one DTI funded project, it is possible to access both a short publication and the lengthier final report.

This analysis would seem to support the conclusions above that funding tends to be focused on projects in the early stages of development. Consideration of the projects included suggests that there is little information fed into the public domain on the results of the research projects that have been funded. This thereby limits the lessons that can be learnt from this research to the parties involved or able to access papers published in academic journals.

3.4 Conclusions

There are 90 projects in the UK at present looking at the use of hydrogen as a fuel. Of these, the majority of projects are at the research and development stage, with relatively few

[26] BBSRC – Biotechnology and Biological Science Research Council
[27] Publications are short documents (approximately 4-6 pages in length) whilst the Final Reports are much longer documents (>50 pages in length).

projects yet achieving commercial deployment. This is reflected in the fact that much of the work is carried out in universities and is supported by a consideration of completed projects.

There are a few regions in the UK which have a stronger involvement with the development of hydrogen. This may be due to a number of factors, but targeted regional funding and established research centres, usually around universities, are significant influences.

Given the numbers of current projects and their associated levels of funding, it would seem that the majority of work is focusing on the production and storage of hydrogen and its use in fuel cells. As highlighted above, care must be taken, however, with figures on the number of projects in this section as one large project costing several million pounds may be as productive as many small projects .

The ability to produce hydrogen economically for use as an alternative to fossil fuels is probably one of the biggest barriers to its use in the UK. Current techniques for mass production of hydrogen are typically energy intensive and expensive. Some of the techniques using biological waste products that are currently being developed, along with advances in electrolysis, could offer options for production with lower costs and less of an environmental impact. Presently, mass produced hydrogen is uncompetitive when compared to more traditional fuels such as natural gas, coal or petrol. An alternative production method would make hydrogen a more attractive alternative to existing fuels for transport applications.

Less attention has been given to how hydrogen may be distributed and the infrastructure required to facilitate this. Presently, there is very little infrastructure to distribute hydrogen in much of the UK, especially for transport applications. There are a few pipelines in the north east and west of England and south Wales but these are designed to feed industrial processes not to service transport. With no consistent ability to ‘fill up’ with hydrogen, consumers are unlikely to consider hydrogen as an alternative to mainstream transport fuels. This is particularly the case for longer journeys or to less familiar parts of the country where the risk of not being able to find a fuelling point and the subsequent possibility of running out of fuel will be perceived as much higher. One way of getting around this is the use of hydrogen in an internal combustion engine, which can be switched back to petrol if the hydrogen runs out where there are no refuelling facilities, an area currently being developed.

The possibility of hydrogen being used to facilitate the integration of renewables has significant potential, especially in more remote areas with good natural resources for generating electricity but where demand does not match generation, electricity networks are weak or islanded and transport fuel is also a priority. Petrol and diesel prices are significantly higher for these communities who are dependent on imports from the mainland. Producing their own hydrogen, may enable such communities to be more self-sufficient and have less exposure to soaring fuel bills or fuel insecurity.

Whilst all of the projects contribute to our knowledge and understanding of how hydrogen might be used, it will be the ability to produce hydrogen economically that ultimately determines its viability. Some of this cost reduction should be achievable as a consequence of mass production, but much of it must be achieved through technical development (e.g. of low cost electrolysers capable of operating at low capacity factors).

The importance of knowledge transfer between completed and current or future projects should not be underestimated. The analysis above, especially in relation to completed projects, would suggest that more could be done in this area to ensure that lessons learnt through publically funded projects are accessible in the public domain. The Low Carbon and Fuel Cells Knowledge Transfer Network has been set up to exchange information in this field. It could be used to publish results and chart how projects link together within a formal and robust reporting regime.

This section has focused on the projects that are ongoing in the UK at present and the next section will consider the potential gaps that the analysis has highlighted. One other critical factor in addition to those highlighted by this analysis is the role of political support. The EU sponsored Roads2Hycom project, for example, reported that when comparing progress in different regions and cities in Europe, success in developing hydrogen to date has been as much about political and co-ordinated support as much as finance.[28] A clear, co-ordinated UK policy as to the role of hydrogen within a low carbon economy will encourage developers and investors alike to pursue work in this area as their investment is more likely to pay off.

[28] Roads2Hy com workshop with IEA/HIA Athens 4th November 2008 Simon Vinot, Marcel Weeda, Manfried Kiell

4 Gaps and UK expertise highlighted by preceding analysis

The previous section has analysed the state of current UK Hydrogen projects and highlighted a number of gaps in the current arrangements for developing hydrogen focussed technologies. This section will consider these gaps and areas of UK expertise in a little more detail, considering what may have caused them, whether they are already being addressed by overseas organisations and how the UK might address them in the future.

4.1 Lack of coordinated strategy to progress projects through the Innovation Chain

One significant gap is the lack of co-ordination for the development of hydrogen in a low carbon economy in the UK. As a consequence very few projects make it through the Innovation Chain shown in Figure 4.1.

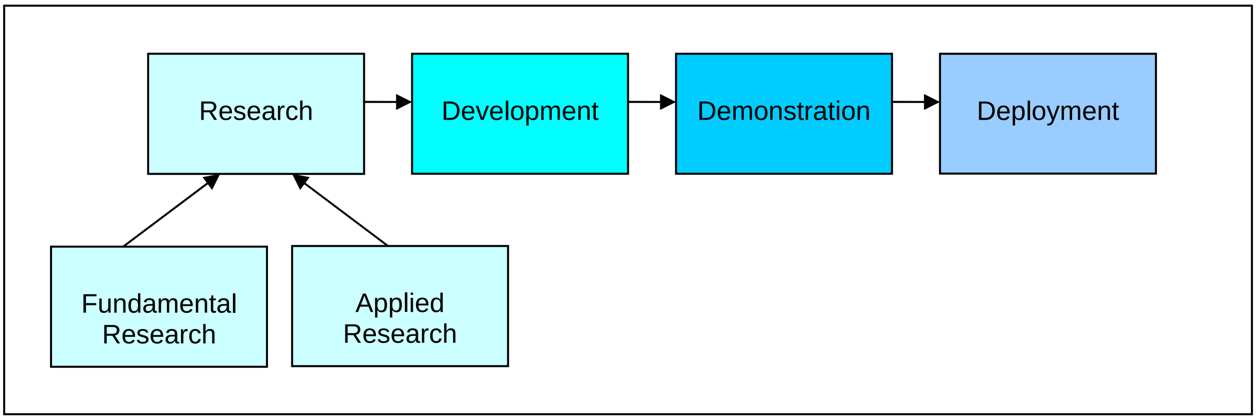

Figure 4.1 Innovation Chain

Two-thirds of the current UK projects related to hydrogen fall within the Research and Development phases of the innovation chain, many of these falling within the area of Applied Research. Less than 4% of the projects are achieving the early stages of commercial deployment. This suggests that there is a significant gap between the number of projects being started at the research end of the chain and those achieving commercial viability.

Such a gap is always to be expected in the development of new technologies from 'blue-skies' ideas. Many will prove unviable or initial research projects point to further areas of work that are needed to develop the technology. Such a gap can also disguise other barriers limiting technologies from achieving commercialisation, such as

- lack of funding for demonstration projects and commercialisation. The 2005 roadmap[24] showed that there were very few organisations providing funding for demonstration or venture capital funding for fuel cell (although since 2005 other programmes have been developed);
- lack of alternative components to replace expensive materials that would make the finished project uneconomic;
- shortage of suitably skilled personnel; and
- lack of suitable locations for manufacturing and delays in the planning and health and safety processes as highlighted in the 2005 Roadmap[24] and in case studies carried out under the IEA HydrogenTask 18.

A co-ordinated approach to funding research could help to minimise this gap by reviewing research outputs across a number of organisations and making recommendations for the next stage of development that is required. This could also highlight any of these barriers and ensure research is appropriately directed to address these.

There is also limited information on historic projects, restricting the ability of interested parties to learn from the past. Research that leads to a positive conclusion is more likely to be published than that which has shown what does not work. Sometimes this is due to funding frameworks that cut finance to 'blind alleys' before publication. There is also sometimes a fear that negative results will be perceived as failure and jeopardise further funding. However, both positive and negative results are equally valuable to minimise repetition and ensure the most effective use of time and resources. Competition between universities, and also between universities and commercial organisations, also limits the sharing of information and the amount of detail that a research group is likely to be willing to publish.

The need for a co-ordinated research programme in the UK was recognised by 2002[29], although it has not really materialised yet. However, support mechanisms such as the British Midlands Hydrogen Forum and the London Hydrogen Partnership have attempted to address this for their region and are responsible for the strength of interest in hydrogen in these regions. There have also been a few research projects set up in this period that bring together researchers from a number of different universities in a collaborative effort[30]. Such support mechanisms and collaborative research projects should definitely be welcomed and encouraged. However, a clear, national strategy for the commercialisation of hydrogen, with contributions from academia, manufacturing organisations and other relevant stakeholders, would help to prevent overlap and ensure that lessons learnt are not repeated unnecessarily.

There is currently a process underway attempting to create a co-ordinated, UK-wide hydrogen project. This is being lead by the British Midlands Hydrogen Forum, the UK Hydrogen Association and CENEX and has strong support from the Scottish Hydrogen and Fuel Cell Association, Centre for Process Innovation (representing the North East), the London Hydrogen Partnership and the University of Glamorgan (representing Welsh hydrogen stakeholders). The aim of this initiative is to formulate a project that is big enough to compete on the world stage, while still allowing the regions their own autonomy. It will enable economies of scale through joint procurement, promote shared learning and avoid unnecessary duplication of effort.

These problems are discussed in the next section.

4.2 National Strategy

Comparing the UK's approach to that of countries that have been more successful in developing hydrogen and fuel cells, demonstrates the flaws in the UK's approach. A more detailed analysis is given in reference 31. Here, the German and American programme

[29] DTI Sustainable Energy Programmes Project Summary 006, "The Global Status of Hydrogen Research", March 2002
[30] Examples include the Supergen Module on "Delivery of Sustainable Hydrogen", coordinated by Professor Metcalfe at Newcastle University, and the 'Supply Chain Research Applied to Clean Hydrogen (SCRATCH)" project which brings together the potential supply chain for a hydrogen economy in the West Midlands, coordinated by Dr Pollet at the University of Birmingham.
[31] Survey of Support Mechanisms for the Development and Demonstration of Hydrogen Systems, M Gillie and K Platt, Report by EA Technology for the IEA HI Task, report number 6250 18th Ocotber 2008. Unrestricted.

structures are studied as examples, together with work carried out by the EU project Roads2Hycom.

4.2.1 German and American Programme Structures

Countries such as Germany and the USA have a clear strategy for development of different aspects of hydrogen. Firstly there is a clear 'raison d'être' for the programme. For example the American National Renewable Energy Programme states:

> *"NREL is working to develop and demonstrate advanced hydrogen and fuel cell technologies to reduce our nation's dependence on foreign oil, improve our air quality, and maintain our economic competitiveness."*[32]

As a result it is supporting Hydrogen Fuel Cells and Infrastructure Programme which has the following goal:

> *"The goal of this program is to help industry develop technologies to produce, store, transport and use hydrogen made from renewable resources in quantities large enough, and at costs low enough, to compete with traditional energy sources such as coal, oil and natural gas*[32]*."*

In Germany it is recognised that the development of hydrogen will

> *"…secure jobs in Germany as a centre of innovation and will make a major contribution to developing efficient energy and less-polluting supplies and usage"* [33],.

For both the German and American programmes, there are clear targets and timescales for projects in each area. For example, in transport, these cover factors such as weight reduction, demonstration of fleets and distance travelled before refuelling. In both programmes there are R&D projects and demonstration projects allowing the two areas to be co-ordinated.

The targets are agreed with industry, who then collaborate to produce detailed projects to reach the targets. In the case of Germany, the regional governments are heavily involved. In return for funding, whilst protecting commercial sensitivity, the results are publicised. In the USA there is an annual peer review process[34], [35].

Examples of targets for vehicles in the USA are:

- 2000 hours fuel cell durability by 2009 and 5000 hours by 2015.
- Vehicle range of 250 miles by 2009 and 300 miles by 2015.
- Hydrogen costs at filling station of $3/gallon by 2009 and $2-3/gallon by 2015.

Examples of Germany's targets for domestic stationary fuel cells are:

- 450 units by 2010 with electrical efficiencies of greater than 30-33%.
- Total efficiencies of 84-90% by 2010.
- More than 10,000 running hours for fuel cell stacks by 2010.

These targets are all part of a wider strategy to have 72,000 units installed at 1700 euros/kW by 2020.

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[32] http://www.nrel.gov/hydrogen/ accessed 26th November 2008
[33] http://www.nkj-ptj.de/datapool/filelistvoll3//300407NIP2.1_english_final.pdf
[34] http://www.hydrogen.energy.gov/pdfs/hydrogen_posture_plan_dec06.pdf
[35] DOE Hydrogen Program overview 4th November 2008 Roads2hycom workshop Carole Read

4.2.2 Targets and Gaps in Europe

The Roads2Hycom project has carried out work to assess the present gaps and suitable targets from a European perspective[36]. The targets for cost and weight reduction could form the basis of a document for the UK, similar to the programme documents of Germany or the USA. Opportunities that it highlights are:

- Electrification of transport, with more flexibility than batteries;
- CO_2 reductions in mass - market transport systems and natural gas fuelled mini-CHP fuel cell systems.

Its recommendations are to aim for mass-markets to minimise costs. This would ideally be done by developing systems and storage that can be used for more than one application.

The perceived threats the project identifies are:

- The cost of hydrogen production, storage and fuel cells;
- The availability of ‘green’ hydrogen;
- The advances in battery technology; and
- Energy conservation versus CHP.

Priorities the project concludes should therefore be:

- Cost reduction;
- Identification of markets where cost is less of an issue (e.g. remote communities);
- Demonstration of reliability; and
- Complementary policies, such as low limits on the emissions from all road traffic vehicles.

4.3 Present UK approach

Although funding is available, the approach in the UK is much more piecemeal and contrasts to the approaches described above. Four examples are studied here:

- The Technology Strategy Board;
- The Energy Technologies Institute;
- The Midland Hydrogen Forum; and
- The Scottish Renewable Hydrogen and Fuel Cell Support Scheme.

Despite strategies being commissioned for hydrogen and fuel cells in 2004 and 2005[23,24] these are not clearly referred to in the literature on these programmes nor are there clear goals or targets. If such a structure were in place, the Low Carbon and Fuel Cells Knowledge Transfer Network could be used for report against it. Whilst the amounts of funding may be significant, similar issues are also present in previous schemes such as calls with the Technology Programme[20], the Hydrogen and Fuel Cell and Carbon Abatement Demonstration Scheme[21] and the Advanced Fuel Cells Programme.

4.3.1 The Technology Strategy Board

The Technology Strategy Board (TSB) is a recent development, established in 2007. It has collaboration and funding from different government departments and regional development agencies as well as industry input. This has improved the focus of national funding compared to previous initiatives. However, although the calls for projects are themed, compared to more successful programmes abroad, there is:

- No overall strategy,

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[36] A summary can be found at http://www.ricardo.com/Downloads/Roads2HyCom%20R2H6017PU%20Review%20of%20Hydrogen%20Community%20R&D%20Agendas.pdf

- No clear indication of how projects or themes are linked, and
- Few SMART (Specific, Measurable, Achievable, Realistic and Time-bound) objectives.

Whilst some projects do have targets, there is no clear indication of how the projects will be evaluated, their results disseminated or the results fed into further projects.[37]

The TSB has recently published its strategy for 2008-2011[38], in which it assesses a number of energy technologies against four criteria for investment, namely UK Capability, Market Opportunities, Timeliness & Impact and Added Value, to determine where investment can best be directed. Hydrogen is rated as an area of high priority against all four criteria. The report recognises the need for a roadmap in this area and suggests that the TSB will play a role in "*seeking to take this forward*."[37] Unfortunately, the strategy section of the report, whilst recognising the needs within the sector, gives little information as to exactly how the TSB will progress this area[37].

A new competition for funding for Fuel Cells and Hydrogen Technologies will be opened in March 2009, with decisions due in July[39]. It is to be hoped that this will be underpinned with SMART targets and a strategy as to how to build on previous work to ensure that the lessons that have already been learnt are not repeated.

4.3.2 Energy Technologies Institute

Another new organisation, the Energy Technologies Institute (ETI) is a joint government industry initiative, that was established in 2006 with a potential budget in excess of a billion pounds (only a small proportion is for hydrogen related technologies). The involvement of industry in development of the areas for funding and selection of projects is a good step forward. Large firms such as power utilities and petrochemical companies are involved as well as EPSRC, DBERR and DfT. Projects are funded as milestones are reached which is a relatively unusual approach but should be welcomed and encouraged.

Unfortunately, there does not appear to be an overall strategy for milestones for each programme area or a clear indication of how lesson learnt can be fed into new projects. Whilst it is intended that projects should be ready for commercialisation at the end of the support process, it is unclear if there is funding for the commercialisation process.[40]

4.3.3 British Midlands Hydrogen Forum

The British Midlands Hydrogen Forum has led to successful collaborations between industry and academia with regional and national funding. Examples of projects are the Midlands Hydrogen Ring of filling stations and associated vehicle development, the SCRATCH project, the Hydrogen and Renewables Integration (HARI) project and CENEX. There is still no overall strategy however, apart from promoting the region as any area of expertise and innovation and creating a cluster of hydrogen refuelling infrastructure, known as the Midlands Hydrogen Ring, as a foundation for capacity building in the region.

A view from a participant is that piecemeal funding weakens the forum. It is addressing this issue by seeking to put its funding from the two Regional Development Agencies (RDAs)

[37] http://www.innovateuk.org/ acessed 12th January 2009
[38] ETI 'Energy Generation & Supply – Key Application Area 2008-2011,' May 2008, available from the ETI's website
[39] http://www.innovateuk.org/_assets/pdf/competition-documents/fuel%20cells%20and%20hydrogen%20technologies_071008.pdf
[40] http://www.energytechnologies.co.uk/Home.aspx

concerned (East Midlands Development Agency and Advantage West Midlands) on a firmer footing based upon a 3-year business plan that is currently under development.

4.3.4 Scottish Renewable Hydrogen and Fuel Cell Support Scheme

After consultation and research, the Scottish administration focused its support on demonstration schemes of the use of hydrogen in remote areas, although this remit has been rather stretched. Whilst this gave the funding a clear scope, there is no clear evaluation process or indication of how the projects are linked. Nor is there a clear strategy for how these demonstration projects will be built upon.[41]

[41] http://www.scotland.gov.uk/News/Releases/2007/03/26123223

5 Recommendations for the UK

The UK needs to have a clear vision for why hydrogen is important and how it wants to make use of it. The UK should consider developing an overall strategy based on those of Germany and US and the information from EU projects. This will require collaboration from industry to set SMART targets and input from regional governments and agencies so that their regional programmes map onto and are mutually beneficial to the overall strategy. It is not therefore appropriate for this document to provide the targets and milestones as these must be agreed by the parties involved. This process has already been started with the initiative by the main regional players to develop a UK wide project (see section 4.1). National Government should consider supporting this project financially in return for a strategy with targets and timescales being developed onto which the UK project maps.

The TSB and ETI could both play important roles in bringing together the relevant stakeholders. The UK Environmental Transfer Fund[42] (ETF) that overseas work in funding pre-commercialisation through bodies such as the Carbon Trust and the Energy Saving Trust must also play a key role. The establishment of the ETF to co-ordinate work at the pre-commercialisation stage indicates a recognition of the importance of such co-ordination and this is welcomed. However, to achieve the UK's potential, agreement on how projects are linked, evaluated and the results used must also be reached. We suggest that one way in which a dialogue between academia and industry could be supported and maintained would be through the increased use of industry experts to peer review academic work in applied research areas. This could help to build relationships between the disciplines and ensure that such applied research is set in the broader context of the needs of industry. The Knowledge Transfer Network could be a forum to publicise the results of a more robust reporting and evaluation process for all stages of development.

The two strategy documents[23],[24] are another way in which a number of stakeholders can be brought together to set the direction for work to take. The capabilities, actions and high level targets in the 2005 Roadmap[24] would benefit from being updated and expanded to include all aspects of hydrogen. This could form the basis of agreeing review structures, priorities and targets for hydrogen within a low carbon energy system. These reports also highlight the softer issues of health and safety regulations and public acceptance. The wealth of information provided by Roads2Hycom should also be used. Work Package 6 of Roads2Hycom in particular, provides technical targets for different areas that could be adopted. For example, for compressed storage systems, the state of the art energy density at present is 0.5kWh/litre; this should be 0.7kWh/litre by 2015 and 0.8kWh/litre by 2020.

The following sections describe areas that we recommend that the UK considers focuses on.

5.1 Areas of Focus and Regional Differences

From the programmes in the US, Germany and Japan, it is clear that these and other countries are more advanced in many aspects of hydrogen and fuel cell development. This is demonstrated in a survey of funding and support mechanisms of participating countries carried out by Task 18[43]. The spend over the last 5 years on hydrogen and fuel cells per GDP in Japan, Germany and USA is hundreds of times greater than in the UK (Figure 2).

[42] UK Environmental Transfer Fund Strategy September 2008
http://www.berr.gov.uk/files/file47575.pdf accessed 19th January

[43] Survey of Support Mechanisms for the Development and Demonstration of Hydrogen Systems. M Gillie and K Platt EA Technology for IEA HIA Task 18, Report No. 6250, October 2008.

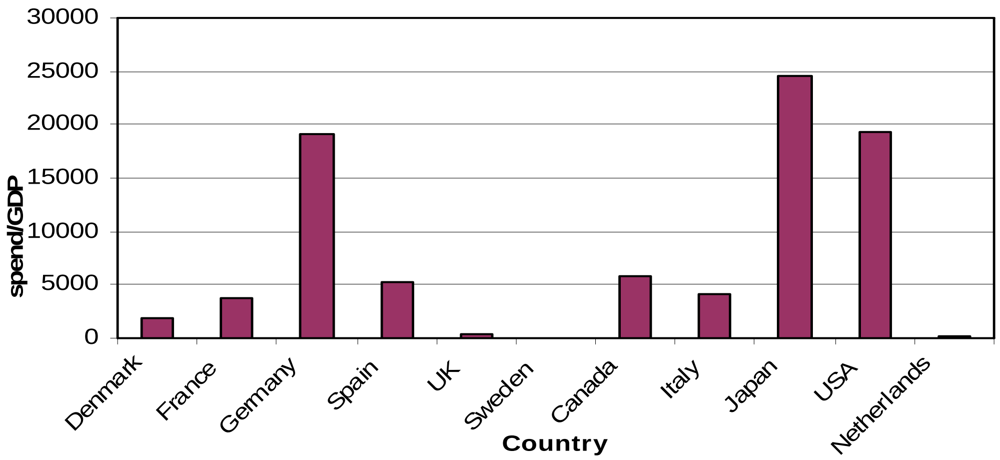

Figure 2 Comparison of government spending over 5 years on demonstration hydrogen projects/GDP by country (Euros)

As a result, Germany for example already has over 300 vehicles on the road and the USA in excess of 200, whilst Japan has 2 187 microCHP fuel cell installed in homes. The targets highlighted above demonstrate the ambitions of the programmes.

It would probably be unwise at this stage for the UK to attempt to compete in all areas of the field but rather to focus on the areas where it has expertise. This should be born in mind when formulating the strategy. The analysis below highlights areas that may be good to focus on. In addition certain regions have expertise in particular fields.

5.1.1 Possible Areas for Focus

Areas of focus can be broken down into 2 types:

- Research & Development and
- Demonstration.

5.1.1.1 Areas for Research and Development

These areas are key to reducing the price of hydrogen systems and making them more practical. They should feed into and support areas for demonstration. As emphasised above these are not the only areas where work is needed but where the UK has significant expertise that it can build on.

Catalysts
Many fuel cell designs use platinum as a catalyst. It is however a very scarce and expensive metal. An alternative material for the cheaper, more common catalyst could reduce the cost significantly. As highlighted earlier, this is an area where the UK has recognised expertise both commercially and in academia.

Storage
The UK should build on it expertise in metal hydrides and framework materials to develop suitable compounds that store hydrogen at high density and low mass. As highlighted earlier, this is also an area where the UK has recognised expertise both commercially and in academia.

Electrolysers
Presently, the PURE electrolyser is one of the few electrolysers that can withstand an intermittent input of power[44]. There is great potential for more efficient, cheaper electrolysers for renewable energy applications using expertise from PURE and Loughborough University and local companies such as Bryte Energy.

As discussed above, the introduction of electrolysers into renewable electricity schemes could increase their economic viability. This could be through using hydrogen either:

- to maximise the use of renewable energy resources in areas with weak or islanded electricity networks.
- by enabling the trade of the 'firm' electricity output with the uncertain element used to produce hydrogen.

However, in order to achieve this, it is essential to have electrolysers available in different sizes and that can cope with fluctuations in the power source and can be efficient when running at low capacity factors.

5.1.1.2 Area for Demonstration

Transport
The Midlands Hydrogen Ring is developing the first network of hydrogen filling stations to facilitate the development of hydrogen fuelled vehicles. This could be extended to link to South Wales and London. Whilst fuel cell vehicles are still expensive and under development, hydrogen fuelled internal combustion engines could be developed as a stepping stone to encourage the installation of hydrogen refuelling infrastructure. A network of filling stations would also attract manufacturers from abroad to trial fleets in the UK and thus increase inward investment. In addition, there are companies in the UK (e.g. Rouch) that are already able to convert internal combustion engines to run on hydrogen. Exploiting this expertise and the UK's automotive supply chain has the potential to create a sizeable transition market ahead of the widespread introduction of fuel cell vehicles.

Biohydrogen Systems
South Wales is developing expertise and demonstration of biohydrogen. This has numerous applications for processing industry waste products and for agriculture including in the developing world. Targets for this area should therefore aim for the export as well as the domestic market.

Application for Remote Communities
Scotland has focused on applications for renewable energy in remote communities. The PURE consultancy is an obvious success story where an island community has built a business from the expertise they have developed. The UK can rightfully claim expertise in this area. This area can solve energy security problems both at home and abroad. The market is however finite and a strategy in this area should aim to build on the expertise and projects to develop grid balancing systems for electricity networks and vehicles. The plans for the Hebridean Hydrogen Park is a good example of this approach[45].

5.1.2 System Expertise

The areas for demonstration indicate that there is great potential for the UK to expand on its existing world-leading expertise in system design and integration. Even if the components

[44] http://www.fuelcellmarkets.com/3,1,11952,17,27572.html
[45] Hebridean Hydrogen Park
http://www.fuelcellmarkets.com/energy_innovation_zone//5,1,14514,1538.html?subsite=14514&language=1 accessed 17th December 2008

are produced overseas, the UK has the skills to design and integrate systems to maximise their potential.

There is a parallel here with the wind industry. Whilst the UK lost the manufacturing of wind turbines to other countries, it still retains a large wind energy consultancy base (for example Garrad Hassan, RES, Dulas and IT Power).

5.1.3 Regional Differences

The analysis in previous sections showed some significant differences in the number of projects being carried out in different regions.

As many of the projects are carried out in, or are linked to, universities, the research background of these organisations is obviously significant in attracting funding and collaboration opportunities. It seems likely that clusters of related projects will continue to develop in those regions where there is an established knowledge and experience base.

The availability of targeted funding within regions is also likely to lead to the development of projects. There may be a number of reasons for RDAs to choose to promote the development of hydrogen technologies within their area. Many of the existing projects do have links with other projects and local clusters are more likely to explore the potential synergies between their products than dispersed organisations. The development of a national strategy should consider the benefits of regional 'cluster funding' to promote the development of hydrogen technologies, as well as recommendations for collaborative working across regions.

Three regions with particular expertise are:

- South Wales: biohydrogen.
- Midlands: hydrogen transport, hydrogen production for grid management, hydrogen storage.
- Scotland: Renewable hydrogen for remote communities.

5.1.4 Other issues

At a wider level, as with any new technology there is a need to ensure that the path to commercialisation is smoothed with funding but also by ensuring that:

- Skill shortages are addressed;
- Planning and safety assessment processes are uniform, clear and not unduly onerous;
- Procurement and/or locations for manufacturing are available;
- There is increased collaboration between industry and academia, to support and facilitate applied research, demonstrations and ultimately early-stage commercial deployment of technologies.