Fuel Cells Activity in the UK 2003

Roy Williamson
UK Department of Trade and Industry

September 2003

Introduction

UK innovation in fuel cell technologies is gathering pace. Recent years have witnessed increased activity in the research and development of components, systems and application.

This report provides a picture of the current status of the innovation system in the UK regarding the research and development of fuel cell technologies, as they relate to the wide range of markets that they seem set to impact upon. The information used in this report was gathered from a large though not complete selection of UK fuel cell companies, academia and stakeholders, as summarised below, through interviews, visits and questionnaires;

Survey Coverage	
Academic Institutions	12
Industry	22
Regional Development Agencies and Devolved Administrations	12
Other	3

Global Drivers for Innovation in Fuel Cells

Fuel cells have been in existence for over 150 years, but did not achieve practical application before the US space missions of the 1960s. Terrestrial applications have proved elusive due to the high costs of the stacks and the associated balance of plant. However there is a growing consensus that the long promised commercialisation of fuel cells is finally underway with some markets being predicted to take off within the next 2-3 years.

Driven by the coexistent issues of

1. Low carbon economy goals and rising pollutant levels,
2. Energy security issues, including unstable oil supplies and depleting fossil fuel
3. The growing importance of renewable energy production and the need to tackle reserves

they are now gaining Governmental, academic and industrial attention. Hydrogen and the hydrogen economy are recognised as a suitable solution to these above issues, and associated fuel cell technologies are amenable to both the current dependence on fossil fuels and an envisaged, eventual transfer to a hydrogen based economy. Hydrogen can sourced from reforming natural gas and fuel cell system currently being developed either include an external, natural gas reformer or are of a type that can reform natural gas internally. Research is also being carried out for operation with more alternative fuels such as methanol and LPG. Using natural gas and incorporating CO2 sequestration and storage, this method could make significant removals of carbon from current energy streams, though the economics of this are undetermined. Hydrogen can also be produced via the electrolysis of water which, if powered by renewable energy sources, results in a potentially zero emissions energy chain – the so-called “Hydrogen Economy”. Hydrogen, unlike electricity, may be stored and could therefore also be uses as a means of addressing the issue of intermittency associated with renewable energy supplies. Other drivers for fuel cell innovation include;

- The chemical-reaction nature of fuel cells means that can theoretically extract up to 3 times more energy from their fuel supply than can be achieved through the combustion process/ Otto cycle of petrol engines, although the overall efficiency of

using hydrogen as an energy carrier, the 'well to wheel' efficiency, is an area of debate.

- Fuelled by natural gas or similar, they produce very low levels of SOx and NOx, and fuelled by hydrogen they are produce only water, as a by-product.
- Irrespective of environmental issues or energy security, fuel cells potentially offer benefits over current technologies in terms of high efficiency, lower maintenance costs, and low noise, although these need to be demonstrated if fuel cells are to replace the current, incumbent technologies.

Producing hydrogen using electricity from fossil fuelled power stations enables the displacement of production of carbon dioxide and other pollutants to a simpler, larger (and more efficient) source. This facilitates cleanup and capture on a larger scale. The produced hydrogen can then be used to power fuel cell vehicles, offering significant benefits in urban application. The use of fuel cells could also offer significant gains in reducing and ultimately removing carbon from the transport system, which could have significant health benefits; it is estimated that a large proportion of the 8,000 premature deaths caused by particulates in Britain derives from vehicle emissions in cities.

All the major car manufacturers around the globe are investing in fuel cell research and development, several to the tune of $100M+ per year, and many are publicly trialling fuel cell powered vehicles with fleet operators such as postal workers and Government groups. The requirements of an effective on-board reformer for passenger cars are particularly challenging and current industry thinking is that such vehicles are likely to be fuelled from on-board, stored hydrogen in liquid or compressed-gas form. Research into more compact hydrogen storage techniques is a highly active research area, drawing on the development of current technologies and nanotechnologies.

Market Applications

A recent report for the DTI and Carbon Trust by E4Tech estimated the market potential for fuel cells to be worth over $25Billion by 2011, and significant growth is anticipated to follow as the technology becomes more and more established. The breakdown of this estimate is;

	Application	2011 $B	Longer term
Mobile	Propulsion	3	135
	APU	0.9	9.7
Stationary	DG/ CHP	6	
	Residential/ Small Scale CHP	3	
	Remote Power	2.5	
Portable	Battery/Genset etc Replacement	11	

The fuel cell type currently regarded as most suitable for transport application is the Polymer Electrolyte Membrane (or Proton Exchange Membrane) PEM. These currently operate at relatively low temperature, around 80 C, use platinum as a catalyst and require very pure hydrogen as fuel. Higher temperature operation (80 C-120 C) can be desirable in some applications, such as for vehicles where this enables efficient and compact heat removal, but high temperatures tend to degrade the durability and performance of currently available polymer membrane materials. Hence research into higher temperature membranes, plus pollutant tolerability, are high on the list of topics being researched

Circumventing the issues around using hydrogen, the development of Direct Methanol Fuel Cells (DMFC's) is another area of significant interest.. Methanol is a much simpler fuel to handle and store, and the issues its use raises, such as corrosion, are more easily resolved.

Owing to the much simpler nature of this fuel these systems compete with hydrogen based PEM systems in transport and micro applications. In the latter application there is significant market pull already, looking to replace batteries in laptops, PDAs, mobile phones etc. and significantly extend usage time.

For high efficiency stationary power generation however, at both utility and residential scale and making use of the existing infrastructure, Solid Oxide fuel cells (SOFCs) are ideal. These operate at higher temperatures than both PEMs or DMFCs, and as such can use natural gas directly, without the requirement of a reformer; reformation of fuel is carried out internally. SOFC's are more efficient that conventional power production technologies and also produce high grade heat which can be used in Combined Heat and Power application. They could also be a key technology in distributed generation (DG) networks, a potential solution to the rising issue blackouts in power hungry areas of the world. Power is generated by localised sources, sized according to consumption requirements, alleviating the significant losses incurred through long distance transmission, the problems of mismatches between generation and consumption over large grids, as well as the fragility of single or large, linked networks. Other issues include the inefficient use of land for electricity distribution structures/ pylons and increasing public concerns over radiation from their proximity. Fuel cells are envisaged to play an important part in new, clean power production, in both distributed generation and off-grid, independent power production or uninterruptible power supply (UPS) for banks, hospitals and high value processes. Indeed some business insurers are looking to the benefits of off-grid power sources and consider fuel cells as a key contender for clean, reliable power generation.

In developing countries new industries are growing and power requirements with them. Here, the margins in power generation capacities are being eroded to meet demand and the requirement for new sources of generation is inevitable. New sources are also required for the development remote industries, where generation and infrastructure fundamentally are not existent. For both of these, with growing global awareness of environmental concerns, the links between renewable technologies, hydrogen production and storage and fuel cells have new significance.

In general the markets for the various fuel cells types are;

	Portable	Automotive	Residential	UPS	Utility
PEM	X	X	X	X	
DMFC	X	X			
SOFC			X	X	X

Other types of fuel cells being developed include molten carbonate (MCFC) and alkaline (AFC) though focus is shifting more towards PEM, DMFC and SOFC technologies.

Government Support

DTI Advanced Fuel Cell Programme
The Department of Trade and Industry (DTI) has been supporting industrial research on fuel cells since 1992 under its advanced fuel cell programme, part of the Renewable Energy Programme. During its lifetime the focus of the programme has changed from supporting studies to inform the Department and the industry regarding the prospects for fuel cells to working towards the development of UK capabilities. The programme has supported over 150 projects spending £12.4M with total project value at £92.M. Currently the programme has a budget at around £2M per year.

The Energy White Paper, published in February 2003, described an increasing role for fuel cells in the UK's energy system. A key commitment of the White Paper was for a Government to work with industry to develop a shared vision for how benefits from fuel cell opportunities can be maximised.

The DTI Automotive Unit is also assisting the development of fuel cells. Taking forward recommendations of an advisory group they are working with the Low Carbon Vehicle Partnership, and are investing £15M into two centres of excellence, one to investigate telematics, the other to investigate Low Carbon and Fuel Cells vehicles.

The DTI is involved with several UK Government initiatives, jointly with the Carbon Trust and EPSRC (see Joint Governmental Efforts).

Fuel Cells UK
Launched May 2003, with assistance from DTI, Fuel Cells UK is an industry network body established to:

- foster the development of the UK fuel cell industry
- elevate the UK industry in the international arena
- raise the profile of UK fuel cell activity.

Fuel Cells UK have been responsible for the formulation of a Fuel Cells Vision for the UK, a White Paper commitment, recently announced at the 8th Grove Symposium. They have also prepared Guides to the UK Fuel Cell Industry, and are active in fostering partnerships, both nationally and internationally, between fuel cell researchers and developers. Fuel cells UK also works closely with other initiatives across the UK to build synergies and optimise outcomes for industry and other stakeholders. To ensure maximum relevance for industry, its activities are guided by a high level steering group, consisting of members from academia, industry, the Carbon Trust and DTI.

The Carbon Trust
The role of the Carbon Trust is to support the innovation required to underpin the commercialisation of new and emerging low carbon technologies. Through its Low Carbon Innovation Programme, with a budget of £75M over 3 years and investing in low carbon technologies, it is developing a range of financial instruments to implement this role. In addition, the Carbon Trust uses its influential and impartial position to broker more productive relations in the fuel cells sector and between the sector and Government. The goal is to help build a solid, robust, commercially vibrant industry sector, focussing on those elements of the emerging fuel cell business (including systems design and balance of plant) where the UK can compete successfully.

The Carbon Trust is involved with several UK Government initiatives, jointly with the DTI and the EPSRC (see Joint Governmental Efforts). The Carbon Trust is also looking to support

demonstration projects in fuel cells, seeking to determine and investigate the societal issues and benefits of fuel cells in operation, such as where they will be installed, who will install and maintain them, and public opinion and behaviour.

The Energy Savings Trust
The Energy Saving Trust was established by the UK Government after the 1992 Rio Earth Summit and is one of the UK's leading organisations addressing the damaging effects of climate change. Working with a range of partners, EST focuses on delivering practical solutions for households, small firms and the road transport sector - solutions which save energy and deliver cleaner air. (see Joint Governmental Efforts).

Research Councils
The Engineering and Physical Sciences Research Council (EPSRC) is the UK Government's leading funding agency for research and training in engineering and the physical sciences. It invests more than £400 million a year in research at UK academic institutions and also works with the other Research Councils on issues of common concern through Research Councils UK.
Investment in new and renewable energy generation technologies, including photovoltaics, fuel cells, wind power, wave power, biomass and other approaches such as the hydrogen economy represented a portfolio worth over £26million at May 2003. Since 1994 renewable energy has been an identified priority within the EPSRC Programme, primarily due to the drive to improve the sustainability of energy generation within the UK. As a result, renewable energy research has received support through a number of mechanisms and programme areas. The multidisciplinary nature of renewable energy research, including fuel cells, means that the Engineering, Materials, Chemistry and Physics Programmes within the EPSRC have provided funding for fuel cells.

Support in fuel cell technologies have previously been through targeted activities such as the ‘Fuel Cells’ programme and the ‘RNET’ renewables programme, both of which are now closed. The ‘Responsive Mode’ programme currently provides underpinning support of fuel cells technologies, though non-specifically, through supporting research in the area of membrane and catalyst technologies. This is estimated to add £1M of support per year.

SUPERGEN is the flagship programme currently supporting a consortia of academic groups and users working together to address the broader challenges of sustainable power generation and supply. This initiative will launch a £2M consortium during 2004 specifically to investigate fuel cell technologies and act as a point focus for research activity in the UK.

EPSRC is involved with several UK Government initiatives, jointly with the DTI and the Carbon Trust (see Joint Governmental Efforts)

A new Research Council initiative on energy is being led by NERC in partnership with EPSRC and ESRC. This £28m programme will co-ordinate energy research across the UK and establish the UK Energy Research Centre. The UK Energy Research Centre (UKERC) is being established to improve the coherence of energy RD&D by enhancing co-ordination of the UK energy research agenda. It will be an independent centre within the framework of the Research Councils.

Joint Governmental Efforts

In 2002, the DTI and Carbon Trust commissioned A Review Of The Commercial Potential For Fuel Cells In The UK. The aim of this review was to allow DTI and Carbon Trust to develop a shared understanding of fuel cells, their applications and markets, and to use this as

a basis for complementary, targeted action. The review identified possible opportunities for the UK in the fuel cell supply chain and in early fuel cell markets.

The DTI, Carbon Trust and EPSRC are also committed to coordinating their actions so that they act in a complementary manner so as to provide comprehensive and appropriate support to the emerging fuel cell sector. DTI recently announced the development of a UK Vision for Fuel Cells.

The Low Carbon Vehicle Partnership is an action and advisory group promoting the shift to clean low carbon vehicles and fuels and has a key role in taking forward the low carbon agenda in relation to vehicle technology and road transport fuels in the UK.

The Partnership's tasks are to:
-Encourage industries and other stakeholders to become engaged in the move to low carbon vehicles and fuels;
-Provide a forum in which different groups of stakeholders can work together in overcoming the market barriers to the take up of new low carbon vehicles and fuels;
-Provide a forum for Government industry and other partners to liase on upcoming policy developments and regulatory issues;
-Provide Government with independent advice on the progress and effectiveness of Government programmes.

Whilst independent of Government, the Partnership works closely with the Department for Transport (DfT), the Department of Trade and Industry (DTI) and other departments, plus The Carbon Trust and The Energy Savings Trust, in achieving its goals and help carry through the UK's Powering Future Vehicles Strategy.

The **Fuels Cells Forum** has also been launched [www.fuelcellsforum.com]; a website established by the DTI in conjunction with EPSRC, Fuel Cells UK, The Carbon Trust and DfT, to discuss fuel cell related issues relevant to the UK and provide information on fuel cell activities in the UK and overseas. The Forum includes sections on Breaking News, Patents Applied For and Granted, key International documents, British Embassy Reports on fuel cells and Profiles of UK Research expertise and Companies active in fuel cells.

Regional Activity

All Regional Development Agencies and Devolved Administrations focus on the renewable technologies in their area. Although several view Fuel cell technologies as a longer-term development others are actively studying the potential benefits of fuel cells, and supporting fuel cell development activities.

South East of England Development Agency (SEEDA) has renewables high on their energy agenda, and a target of 14% of power generation from renewables, equivalent to 1600MW, is the aim for 2026. Hydrogen and fuel cells are recognised as key enabling technologies for commercial development of renewables and reducing pollutant emissions. The UK's only fuel cell demonstrator is located in the region, at Woking, producing 250KW to an independent electricity grid, plus heat to a local swimming pool. The USA produced fuel cell is providing real experience of the operation of a fuel cell system.

Scottish Enterprise (SE) has been actively supporting fuel cell activity in Scotland since 2000 when they established the Scottish Fuel Cell Consortium (SFCC). This group, lead by the University of Strathclyde, is an industrial and academic collaboration which has received investment from Scottish Enterprise of approximately £300,000 over the past 3 years,

matching in kind investment from the consortium partners. The focus of the consortium is developing fuel cell systems for transport applications and has included the development of a fuel cell powered sports car, with plans to develop a fuel cell van. Trials of a locally developed fuel cell powered bus on local routes are planned for 2003/2004. The Consortium is already working with Highlands and Islands Enterprise towards the goal of turning Islay into the world's first hydrogen-powered island, with hydrogen being produced by wave power and stored for use in fuel cells.

SE has also separately supported other activities including the development of a novel configuration of SOFC, the SOFCRoll, by St Andrews University, SOFC interconnect development by Fuel Cells (Scotland) Ltd and fuel cell system development, marketing and sales by siGEN Ltd.

Recognising the growing commercial opportunities in fuel cell technologies and the significant potential for 'renewables to hydrogen' production using electrolysis within Scotland, all the main Scottish organisations (with support from SE) have recently established the Scottish Hydrogen and Fuel Cell Association (SHFCA). The SHFCA will represent, promote and advance legislative, technical and commercial aspects of both hydrogen and fuel cell technologies at a Scottish, UK and international level.

Highlands and Islands Enterprise, the Scottish Executive's Agency responsible for social and economic development in the North of Scotland, have significant interest in fuel cells as an enabler of a hydrogen economy, especially given the vast renewable resources available in this region. There are currently two projects at proposal level within the Highlands and Islands. The first project proposal is to produce hydrogen from wave power on Islay, which will then be stored and used for vehicles and power generation. The second proposal is on the Shetland island of Unst where it is proposed to produce hydrogen from wind power.

One Northeast: The Tees Valley Hydrogen Project (TVHP) was initiated by the Centre for Process Innovation, one of 5 Centres of Excellence set up by One Northeast to support pursuit of the regional economic strategy.

The region has a number of special, possibly unique, advantages in the form of immediate access to a fully-fledged hydrogen infrastructure. This includes access to production plants, a large-scale storage system (600Te of hydrogen) and a 30km piped distribution system. Just as importantly, the region has all of the skills and experience required to manage the system, together with access to the specialised support of fully equipped laboratories and pilot plant facilities at the Wilton Centre.

The Project aims to exploit these advantages by reducing both the costs and the risks involved in taking technologies at the prototype stage through to fully commercial application. The project is strongly supported by the communities and public authorities that together comprise the Tees Valley.

Examples of the activities of the TVHP are

1. A range of small-scale Fuel Cell demonstration projects including
   - The Tees estuary Lighthouse
   - An information sign on the well-known Transporter Bridge
   - A remote traffic sign
   - Domestic scale, hydrogen fuel cell driven CHP systems in a visitors centre and a school.

   These provide valuable information for scale up and also offer a vehicle for education of schools and local communities.

2. Plans are being prepared for the development of a ‘Community Energy’ system to power a major urban regeneration project. The latter will be implemented over the next 5 years with physical work starting in early 2004. Provision of the energy scheme is at the Feasibility Study stage. It is proposed that an estimated total energy demand of 15MW will be supplied by a fully optimised CHP system incorporating the facility for the development of large scale fuel cells, fed by the existing hydrogen and low carbon fuel infrastructures. The Fuel Cells will progressively replace the conventional heat engines as their performance (including reliability) meets specified criteria.

3. A Fleet and Fuelling project. As part of a drive to reduce regional carbon emissions over the next ten years, plans have been developed to power certain fleets of municipal vehicles. These will be served by a Green Fuelling Station dispensing compressed natural gas, hydrogen and mixtures of the two.

4. All of the above will be supported by a new Fuel Cell Applications Facility. This will be a national physical resource, the aim of which will be to identify, expedite and facilitate the development of new market applications in fuel cell technologies. The Facility will offer Technical, Project Development, and Management and Information services. It will also provide Training, including safety and awareness courses for engineers and technicians, and comprehensive testing facilities. The Facility will be launched early in 2004.

As well as its interest ion Fuel Cell development, the TVHP is also heavily engaged in the related fields of coal gasification and carbon sequestration.

The Greater London Authority (GLA) have actively supported hydrogen and fuel cell initiatives for several years and later this year Transport for London will take delivery of three hydrogen fuel cell buses as part of a two-year, European-wide trial of the technology. The Mayor of London 's Energy Strategy recognises that hydrogen energy and fuel cells have a key role to play in cleaning up the capital's polluted air, reducing London's impact on climate change, and developing the capital's green economy.

In April 2002 the London Hydrogen Partnership was launched to work towards a hydrogen economy for London, the first partnership of its kind in the UK committed to taking forward fuel cell technology. Its aims are:

- Produce and implement the London Hydrogen Action Plan, now in it’s second draft form
- Establish and maintain dialogue among all sectors/actors relevant to the hydrogen economy
- Disseminate relevant materials
- Provide a platform for funding bids and initiation of projects

The steering group member consisting of Intelligent Energy, Johnson Matthey, Fuel Cell Europe, Air Products, BOC, BP, BMW, Baxi Potterton, Rolls-Royce, Thames Water, Association of London Government, DTI, Greater London Authority, Imperial College, London Development Agency, Transport for London, Carbon Trust, Energy Saving Trust, and London First. Other organisations involved with the partnership include Evobus, Ford, DaimlerChrysler, Merrill Lynch, British Gas, the Energy Savings Trust, some London boroughs, and the Environment Agency,

Advantage West Midlands (AWM) recently published the draft, revised Regional Economic Strategy for comment. One objective of the Strategy is to enable the West Midlands to gain competitive advantage from the development of sustainable technology. Specific tasks include the provision of incubation facilities for Low Carbon technologies, the establishment of a national fuel cell centre and the development of international partnerships to advance work on fuel cell technology. The drivers for these actions are several market studies predicting: 16 000 jobs could be created in the Midlands based on fuel cell technologies by 2010; New business worth £1 billion could be created; The switch from internal combustion engines and drive trains to fuel cell systems could put 24 000 jobs, having significant history in the automotive industry, at risk in the region. AWM has also supported the University of Birmingham, highly active in fuel cell and hydrogen research, in its bid to the EPSRC and Carbon Trust support to be a Centre of Excellence in Low Carbon research, and worked with the university and other regional partners in the development of the regions role in the Low Carbon and Fuel Cell research centre, being developed by the Low Carbon Vehicle partnership and having focus on fuel cells for automotive application. AWM commissioned a report on the West Midlands Hydrogen Economy studying the potential and future benefits in the region. Completed in March this report recommended a series of projects to demonstrate the use of fuel cells in remote power, stationary (buildings) and transport applications. It is proposed that these projects will incorporate the maximum content of commercial components from the West Midlands and provide opportunities to test prototype components manufactured in the region. AWM is organising a stand at the Grove fuel cell conference later this year to enable regional SMEs to exhibit their products.

North West Development Agency (NWDA) is actively supporting renewables and Renewables North West was established in 2002. Fuel cells are gaining focus under this initiative and are a key technology included in proposals for a UK Energy Research Centre and a dedicated, regional North West Centre for Energy. Several institutes in the region are researching aspects of fuel cell technology including hydrogen storage, alternative fuels, SOFC's, DMFC's, fuel cell CFD, as well as studies of small scale CHP. Regional interest in fuel cells is growing at a similar rate to global activity in this technology, and although support is currently more in coordination that direct funding, it is anticipated that future initiatives may be formed for fuel cells as the technology develops and project potential increases.

East Midlands Development Agency (emda) is actively pursuing an agenda of alternative power generation technologies and fuel cells are integral to this. The East Midlands has a long history in the power generation field, including coal mining, power station construction, generation and distribution, and there is a strong power engineering cluster in the region plus the expertise of companies such as Rolls Royce and Alstom. The Agency is keen to assist in the commercialisation of fuel cell technologies, both in large stationary SOFC and mobile/automotive PEM application. Such assistance includes the formation of energy parks, location of premises and identifying suitable future projects such as distributed generation and sustainable villages.

South West Regional Development Agency (SWRDA) have been actively supporting renewables projects for several years, and is currently focusing on demonstration projects in the areas of wave, tidal and biomass power generation. More specifically, SWRDA has established two region organisations, with an interest in hydrogen technologies and fuel cell development. These are RegenSW, the Regional Renewable Energy Agency for the South West and SWRDA's Environmental Technology Sector Group - SW EnviroTech. More specifically support for a Hydrogen Economy 'Active Network ' has been proposed by SW Envirotech, in order to encourage partnership between technology companies, renewable energy companies and Universities in order to exploit the potential of hydrogen technologies that the projected, intense development of renewable energies in the South West makes

possible. Within the South West region plans are already in place for a hydrogen bus service powered by hydrogen generated from wind energy and coordinated by the Gaia Energy Trust.

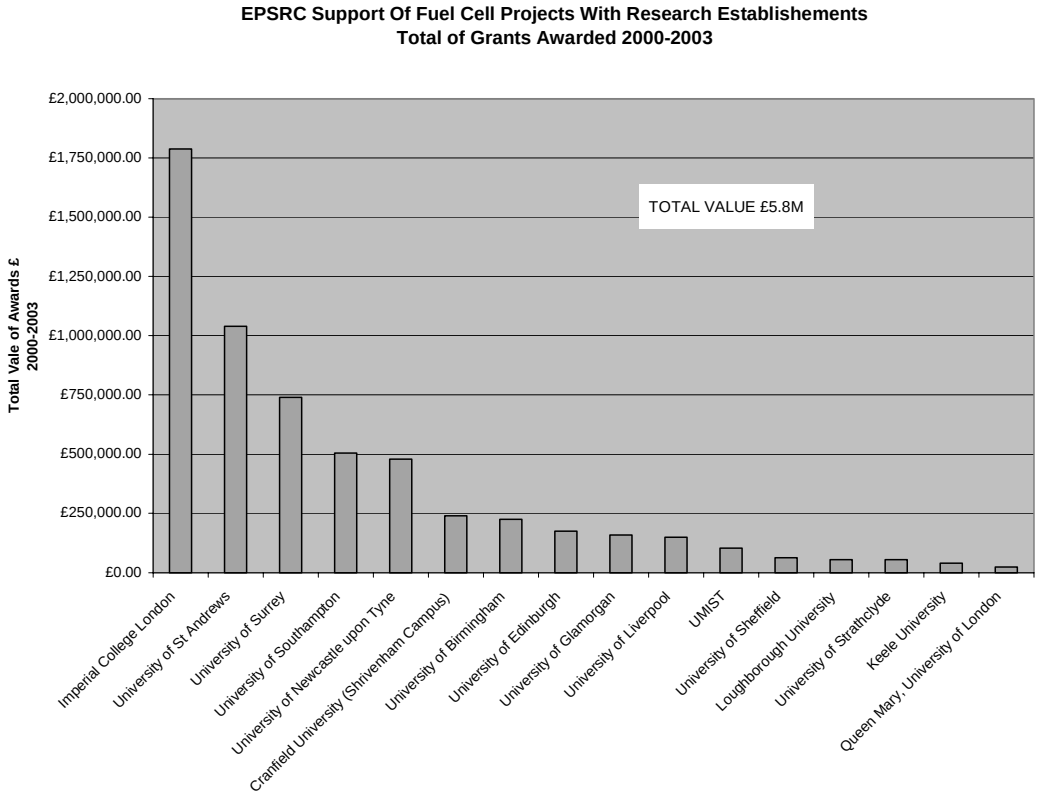
Welsh Development Agency (WDA) initiated the Hydrogen Valley Project early in 2001. The project involves companies from various backgrounds of expertise including hydrogen production, storage and distribution, fuel cells, electric vehicles, batteries and the internal combustion of hydrogen. A feasibility study of a hydrogen infrastructure in Neath Valley has recently been carried out. The aim of the group is to make Wales a hydrogen showcase and to bring hydrogen vehicles to the roads of Wales as soon as possible. This activity is partnered with a major project at the University of Glamorgan researching the social, economic and technical implications of such a move towards a hydrogen economy and deliver a framework through which this can be achieved. The project aims to investigate the potential to develop Welsh industry for the sustainable generation and use of hydrogen, and identify the opportunities for growth in the rural economy through agricultural diversification into hydrogen production.

Yorkshire Forward in partnership with Objective One, and also the Carbon Trust, are looking to establish an Energy Technology Incubator centre of excellence for companies interested in the development and manufacturing of energy efficiency products. The Energy Efficiency Incubator will encompass companies and organisations involved in the design, development, manufacture and commercialisation energy technologies and will focus initially on Fuel Cells, Photovoltaics, Biomass and Energy Storage. The Incubator will be a core contributor for much of the activity around these technologies in the region and there is a proposed energy and environment park planned for the future.

UK Research Activity

Fifteen institutions were identified as highly active in fuel cells research and were surveyed via questionnaires, visits and interviews. This sample encompasses a large majority of the UK's public research activity related to fuel cells.

Support for fuel cell research in the UK is developing and public funding into fuel cell research in 2002 was estimated to be around £3.3M, £3M from the EPSRC, with other sources including Europe, USA and Japan. Over the past three years the EPSRC has awarded nearly £6M towards fuel cell research, the organic growth of expertise and activity at four or five institutions causing them to attract a major share of this, as shown below.



Fuel cell technologies have been proven as a concept in the laboratory and many of the issues being researched pertain to commercialisation issues. These include transient behaviour, longevity and cost, membrane types, performance degradation and levels and types of catalyst coatings. Longer term research into fuel flexibility and optimisation of the technology is also being carried out, but to a lesser degree. The table below summarises the aspects of fuel cell technologies being researched in UK Institutions;

	Cranfield University, Shrivenham Campus	Imperial College, Chemical Engineering	Imperial College, Chemistry	Imperial College, Mechanical Engineering	Loughborough, Aeronautical and Automotive Engineering	Newcastle University, Chemical Engineering	University of Bath, Engineering and Applied Science	University of Birmingham, Chemical Engineering	University of Cambridge, Materials Science and Metallurgy	University of Reading, Chemistry	University of Reading, Chemistry	University of Sheffield, Mechanical Engineering	University of Southampton, Chemistry	University of St. Andrews, Chemistry	University of Strathclyde, Electronics and Electrical Engineering
PEM	■	■	■		■	■		■	■	■	■	■	■		■
DMFC	■		■			■			■						
SOFC		■		■		■	■	■		■				■	
AFC	■					■									■
Other	■														
Improved understanding of cell electro-chemistry and transient operation	■	■	■	■		■	■	■	■			■	■	■	■
Durability and performance	■	■	■	■		■	■	■	■		■	■	■	■	■
Cheaper materials	■	■	■			■	■	■	■		■	■	■	■	
Anode Materials		■	■	■		■	■	■	■			■		■	
Cathode Materials		■	■	■		■	■	■	■			■			
Catalyst Materials		■	■	■		■	■		■	■		■	■		
Alternative fuels	■	■	■		■	■		■						■	■
Catalyst levels		■	■			■	■		■			■	■		
Manufacturing processes	■	■	■	■							■	■	■	■	
Interconnect materials		■	■	■		■	■	■				■			
Design tools for cells		■	■	■				■				■		■	
High-temperature PEMFC membranes	■	■	■			■					■				
Reduced temperature SOFC membranes		■		■			■							■	
Design tools for stacks		■						■				■			■
Design tools for systems		■						■				■			■
Fuel Processing		■						■		■				■	
Hydrogen Storage			■				■			■					■
Optimisation/ miniaturisation		■				■									

Although Loughborough University recently added a fuel cells module to one of their degree courses, fuel cell technologies are still a specialised area of education in the UK. There is growing activity at PhD level, as shown below, but as the technology commercialises and expands a lack of expertise at relevant levels could become an issue: industry currently finds it difficult to recruit graduates with relevant knowledge and settles for more general backgrounds such as materials or electrical engineering.

Post Graduate Research in Fuel Cells 2002.

Master Started	5
Master Running	3
Master Completed	5
PhD Started	18
PhD Running	24
PhD Completed	11

Last year, UK academics published over 100 papers directly related to fuel cells, the majority of these by the more involved institutions, pro rata with activity. Due to the multi-disciplinary nature of fuel cell technologies, and hence the various discipline-specific journals that are relevant, keeping abreast of new developments and highlighting expertise can be difficult, and can require both multi-journal publishing, and acquisition. International conferences provide a more convenient means for gathering and disseminating knowledge, as well as to gain international recognition, though attendance costs can be discordant to academic budgets. Several institutions in the UK are able to draw on well developed and recognised expertise from within their institutes' own faculties however, in such areas as materials, mechanical engineering, electronic engineering etc.

Most institutions are collaborating with other universities within the UK (see UK Fuel Cell Collaboration), aswell as having strong links to Germany, USA, Canada, Japan and China. Indeed it is the general viewpoint that the vast global opportunity that fuel cells presents will be best and eventually addressed by an international research base.

The UK Fuel Cell Industry

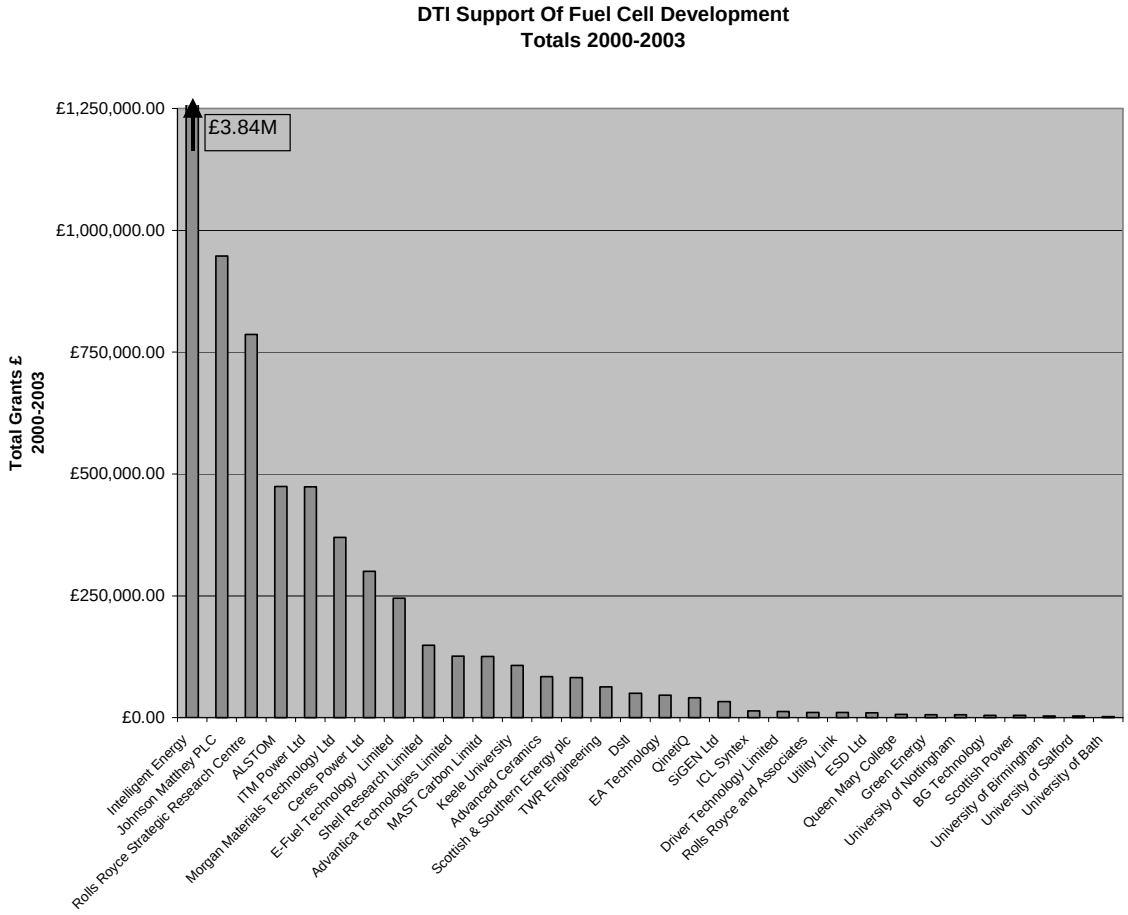
The UK fuel cell industry is spread across all aspects of the supply chain of the popular fuel cell types. Eighteen companies active in the field of fuel cells were surveyed to depict the activity in the UK.

The majority of the UK's interest in fuel cell technologies is relatively new, with involvement beginning in the late 1990's -early 2000's. Exceptions to this are Johnson Matthey with 30 years experience in the supply of fuel cell components, Rolls Royce who have been developing SOFC stack technology for 10 years, Intelligent Energy, formed from Advanced Power Sources, with a 15 year history in developing fuel cell technology, and Morgan Fuel Cell, Advanced Ceramics, and Microponents each with over 10 years in component supply. The table below shows the activity and expertise of the companies surveyed:

	Adelan	Advanced Ceramics	Ceres Power	DT Assembly and Test	Ineos Chlor Ltd	Intelligent Energy	ITM Power	Johnson Matthey	MEL Chemicals	Microponents	Morgan Fuel Cell	Porvair	QinetiQ	Rolls Royce	Fuel Cells (Scotland)	siGEN	Victrex	Voller Energy
PEM				■	■	■	■	■		■	■	■	■			■	■	■
SOFC	■	■	■	■					■	■	■	■		■	■			
DMFC				■	■		■	■		■	■							
AFC				■						■								
Stacks	■	■	■			■	■					■	■	■	■			
Whole Systems	■					■						■	■	■		■		■
Electrode Manufacture	■	■					■	■		■	■	■						
Control Systems	■					■							■			■		■
Fuel Processing/ Cleanup	■					■		■				■	■		■			
Testing		■		■		■		■					■					
Membrane Supply	■	■					■	■									■	
Gas Diffusion Layer		■					■	■				■						
MEA	■	■					■	■										
Power Electronics													■			■		■
Sensors, valves, piping etc.												■						■
Fuel Storage													■					■
Design tools						■		■										
Catalyst Supply						■		■										
Other				Assembly	Bipolar Plates				Raw Materials for SOFC									

The market for fuel cells is forecast to be huge within a couple of decades, of the order of tens of billions of pounds, and it is evident from the activity the industry is aware and believes this. It is reasonable to assume that this faith in the future value of fuel cell related

technologies is strengthened by the commitment of several countries to invest heavily in research, development and demonstration, significantly the pledge of $1.7B over 5 years by the USA for hydrogen economy research including fuel cells, and the long term commitment of Japan to demonstrate and commercialise the technology, around £160M per year. Canada and Germany are also active in this field and have had significant success with more modest budgets, of the order of tens of millions of pounds. Private sector investment, predominantly by the automotive and electronics industry in the USA and Japan, is also significant. Accordingly then, of the companies surveyed, nearly three quarters said that 75-100% of their turnover came from overseas activities, and all but one said at least 50%. The DTI has granted nearly £8M of support for UK fuel cell development in the past 3 years, the major recipients of this are shown below.



This embryonic industry is clearly anticipating significant growth, illustrated by R&D figures (including public funds), for the vast majority of companies, being at levels equal or greater than turnover from fuel cell related business. Such research is, to a major extent, funded internally for large companies, while smaller companies tend to be venture backed. Large, multi -disciplined companies, such as Rolls Royce, also gain useful knowledge and expertise through cross fertilisation of research from across their corporation.

Supply chains in this industry are envisaged to become global as the technologies commercialise, but at present they are still at and early stage and are more localised. Johnson Matthey, a significant player in PEM and DMFC supply chains, has recently opened a dedicated fuel cell component manufacturing facility in the UK, with a local supply chain, permitting greater interaction and clearer information exchange at this early stage in the technologies commercialisation. Johnson Matthey's success in this field has been built on their involvement in catalysts and precious metals for many years, and several other

companies also have significant history with technologies associated with fuel cells. The UK continues to develop significant strength in stacks, components and systems.

The fuel cell markets for larger, predominant companies in the supply chain is, for the main part, unrestricted, only limited by how much investment they choose to risk. For smaller and medium size companies, initially working towards certain niche markets or sections of the supply chain, research activity and hence their interrelated market activity, is reliant on financial backing. With large or small amounts of funding are potentially available but nothing in between, this raises more critical risk issues such as weighing funds for developing R&D capability and expertise against the possible loss of ownership of the company.

Knowledge creation in the supply chain is generally driven from the top down, supplemented by more general insights into where the industry through conferences and Government driven programmes. In many cases, sub-components contain a high level of intellectual property, and due to the nature of this emerging, competitive technology, such components are also both diverse in design and dissimilar in the materials and processes needed to produce them. The result is that whilst developing the capability and expertise of the supply chain to render components for specific customers, the IP developed cannot be carried over or cross fertilised due to customer protection agreements or by the simple fact that component methodologies and particulars are so diverse between customers that knowledge generated is non-applicable elsewhere.

Additionally, across the supply chain, there is general concern regarding increased shortages of suitably qualified personnel, more so as the market for fuel cells begins to expand. This includes graduates and technicians for fuel cells research and development and, just as importantly, trained personnel for their installation and maintenance, plus the installation and maintenance of hydrogen and other fuelling systems. Loughborough University has sought to address this issue and has recently initiated a fuel cells module in one of its degree courses. Air Products have also sought to promote a deeper understanding of hydrogen safety capabilities with training courses. In general though, greater and wider education with regard to fuel cells and associated technologies is viewed as required if the UK is to avoid a shortage of skilled manpower in this area.

UK Fuel Cell Collaboration

The strong research base in the UK is well used by both the national and international fuel cell industry. Several clusters are beginning to emerge based around key companies in fuel cell supply chains and highly active universities. Geographic distances allow UK companies access to many research establishments, each with particular areas of expertise in fuel cell technologies. Many UK institutions and companies have collaborative efforts, both nationally and internationally, and privately and publicly, with associated benefits in both directions. Several have agreements with strict confidentialities.

Demonstrators

Only a handful of fuel cell demonstrators exist in the UK, including an integrated energy park in Woking and the delivery of three fuel cell buses to London later this year, although some companies do have laboratory scale or product demonstrators displaying the capabilities of fuel cells and their operation. As indicated in previous sections, there is interest, both regionally and nationally, to develop and demonstrate automotive, residential and utility fuel cells and hydrogen-based infrastructures, several in conjunction with renewable energy sources, and several initiatives have been launched or are being developed. The Carbon Trust is looking to demonstrate sub-25KW residential CHP technologies including fuel cells, seeking to determine and investigate the societal issues and benefits of fuel cells in operation, such as where they will be installed, who will install and maintain them, and public opinion and behaviour.

Intellectual Property Creation and Protection

The leading UK higher education institutions in fuel cells research hold a handful of patents between them; in the period 2001-2003 around 5 fuel cell related patents were granted to these establishments. Intellectual Property is however becoming an important issue for higher education institutions and some have created specialised departments for the purpose of filing and handling IPR. For most however it is a new area.

UK companies hold around 90 or so patents in fuel cells, almost half held by Johnson Matthey. IPR is of great importance for all sizes of companies, although smaller companies can find the cost of patenting and protection prohibitive. The time required for a patent to be applied for and granted is also be considered a significant obstacle to progressing developments, due to uncertainties around possible patent infringement during the time period, an issue for all sizes of companies. Little or no licensing of IPR either inwardly or outwardly appears evident in the UK, though many envisage that this will develop as the technology is commercialised.

Private Capital

With little market pull currently in the UK, fuel cells are viewed as a risky area for financial backing in the short term. This position is considered to result from a lack of awareness of the technology, reinforced by a lack of demonstrations. The market for fuel cell components, however, continues to develop as fuel cell system developers receive orders and feed orders down the supply chain, and this area is, as would be expected, not considered quite so uncertain in the present, embryonic climate. The UK is viewed to have significant strength in developing low cost, high performance fuel cell components from materials, aswell as world leading fuel cell technologies, although it’s exploitation is still questionable. The development of a UK Vision for Fuel Cells, and the establishment of relevant Health and Safety codes Licences to Operate and Regulations regarding grid connection, are considered as potential confidence builders for investors, and could incite significant financial support for the development of fuel cells in the UK.

Acknowledgements

Appreciation is given to the following organisations, companies and universities is assisting with this report.

Adelan
Advanced Ceramics
Air Products
Ceres Power
Core Technology Ventures
DT Assembly and Test
Evolution Beeson Gregory
IMPAX
INEOS Chlor
Intelligent Energy
ITM Power
Johnson Matthey
MEL Chemicals
Microponents
Morgan Fuel Cell
Porvair
QinetiQ
Rolls Royce
Fuel Cells (Scotland) Ltd
SiGEN
Victrex
Voller Energy

Cranfield University (Shrivenham)
Imperial College London
Loughborough University
University of Bath
University of Birmingham
University of Cambridge
University of Newcastle
University of Reading
University of Sheffield
University of Southampton
University of St. Andrews
University of Strathclyde

The Carbon Trust
EPSRC
DTI
Advantage West Midlands
East Midlands Development Agency
East of England Development Agency
Greater London Authority
Highlands and Islands Enterprise
North West Development Agency
One Northeast
Scottish Enterprise
South East of England Development Agency
South West Regional Development Agency
Welsh Development Agency
Yorkshire Forward