UK Fuel Cell Development And Deployment Roadmap

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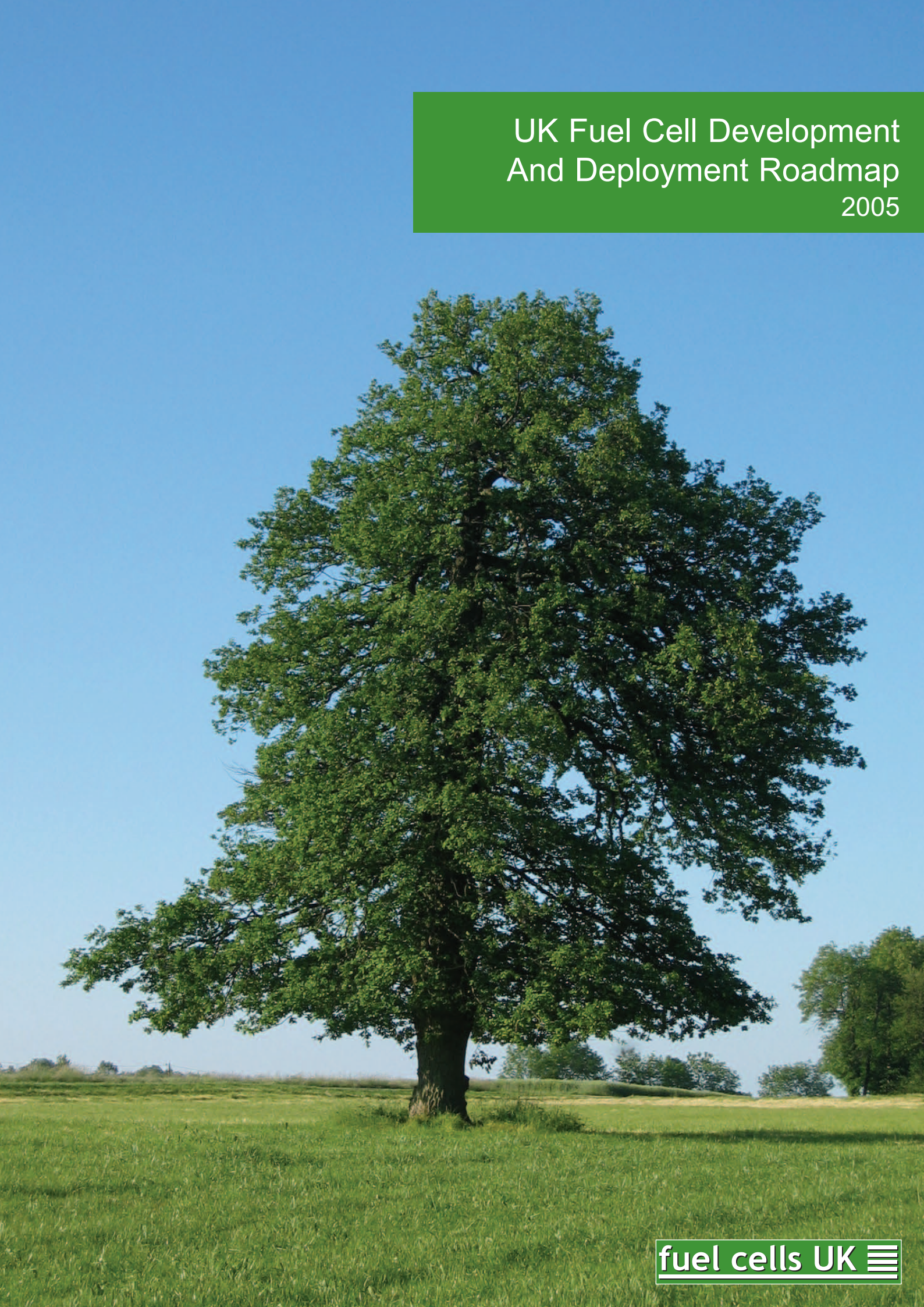

fuel cells UK

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EXECUTIVE SUMMARY

Fuel cells offer the potential to:

- contribute substantially to a global low carbon economy[1];
- improve urban air quality and the health of urban populations[2];
- form the basis of a 21st Century industrial sector that allows sustainable growth of the world economy;
- enhance energy security by allowing a wider choice of fuels;
- contribute to the alleviation of fuel poverty through superior efficiency relative to conventional technologies (particularly in CHP mode)[3]; and
- provide essential intermediate and final components of any future hydrogen economy.

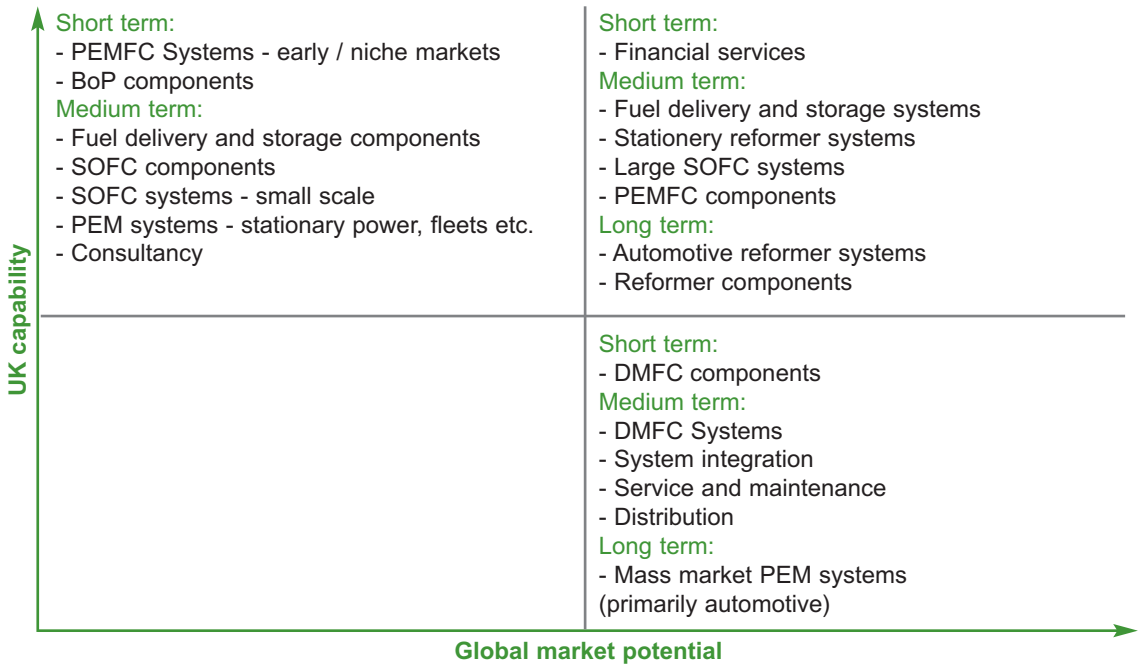
This Roadmap provides a comprehensive framework of actions to help the UK optimise its response to these opportunities and overcome the challenges it faces to:

- Establish a significant market for fuel cells in the UK; and
- Stimulate the growth of a competitive fuel cell industry in the UK.

The development of this Roadmap involved an extensive process of consultation; the importance attached by the UK fuel cell community to this work is reflected in the substantial input from a broad range of stakeholders, with almost 500 hours committed.

Currently, over 100 UK companies are contributing to the creation of the global fuel cell industry. The knowledge and expertise of the UK industry spans the full length of the commercial value chain, from R&D to systems integration, and from finance to servicing. Many of these capabilities have been developed in partnership with companies and organisations from across the world.

An analysis of the UK's position in the global fuel cell landscape reveals the following opportunities:



[1] Fuel cells have the potential to generate carbon savings in the UK of 0.87-1.74 million tonnes by 2020 (Carbon Trust and DTI, 2005). This represents 4-11.7% of the target reduction of 15-25 million tonnes stated in the Energy White Paper.

[2] Fuel cell power plants produce substantially less pollution than conventional plants. Reductions ranging from 40% (summer smog) to almost 90% (eutrophication or magnification of toxic substances along food chains) are achievable, depending on the incumbent technology they are compared to (World Wild Life Fund and Fuel Cell Europe, 2003).

[3] Solid Oxide Fuel Cells can achieve 40-60% electrical efficiency in simple and hybrid combination and, given their high operating temperatures, up to 85% efficiency in combined heat and power applications (Solid State Energy Conversion Alliance, 2004) compared with 30%-38% for conventional boilers.

Future success in responding to these opportunities, and optimising the development and deployment of fuel cells in the UK requires that a number of challenges be addressed. These challenges are:

Regulation and policy

1. Lack of market pull
2. Ensuring that benefits of fuel cell systems are fully accounted for
3. Lack of clear and cohesive policy
4. Overcoming the funding gap (or 'valley of death') between R&D and commercialisation
5. Adapting regulatory framework to enable the introduction of Distributed Generation (DG)
6. Facilitating the deployment of fuel cell vehicles (FCVs) in the UK
7. Insufficient access to market-based mechanisms
8. Ensuring policy develops in line with evolving market conditions
9. Ensuring that opportunities at European level are realised
10. Lack of recognition of UK strengths amongst potential international partners
11. Developing a codes and standards framework
12. Adapting planning consent procedures for fuel cells and related infrastructure
13. De-risking large scale FC projects to encourage private investment beyond demonstration phase
14. Uncertainty around imported versus home-grown technology

Market development

1. Removing barriers to DG
2. Lack of obvious, economical, low-volume, low price-sensitivity early applications
3. Optimisation of UK position in global supply chain
4. Lack of incentives to establish fuel cell supply chain companies in the UK
5. Creating long-term investor confidence
6. Lack of market champion
7. Accelerating the availability of reliable, affordable fuel cells
8. Minimising perceived financial risk
9. Exploiting overlaps with other industries critical to the fuel-cell value chain (e.g. materials development)
10. Lack of unified industry voice to influence policy
11. Optimising the UK position in the global FCV supply chain
12. Integration of distributed generation systems into electricity networks and infrastructure

Education, training and awareness

1. Shortage of advanced skills to foster development of the industry
2. Lack of mechanism to generate certified installation and maintenance professionals
3. Need to educate politicians about benefits of fuel cells
4. Lack of awareness amongst policy makers
5. Lack of coverage of fuel cells in public education
6. Lack of awareness amongst potential procurers and other key stakeholders (e.g. planners and architects)
7. Lack of an informed planning procedure
8. Lack of awareness and credibility among general public
9. Verifying the performance of the product

Technology development - industry

1. Resolving specific technology challenges (see 1-10 below)
2. Optimising manufacturability of all fuel cell types
3. Optimising installability of all fuel cell types

Technology development – research community
1. Achieving acceptable cost levels for stacks
2. Achieving acceptable durability / performance levels for stacks
3. Achieving mass and volume reduction for fuel cell systems where these are important
4. Developing fuel cell systems capable of fuel flexibility (including reforming options)
5. Achieving higher temperature operation for PEM stacks
6. Developing materials for intermediate and high temperature SOFCs
7. Increasing hydrogen storage capability to levels which extend vehicle range to acceptable levels and enhance portable power availability
8. Developing reversible fuel cells to address renewable intermittency
9. Developing effective and affordable balance of plant
10. Ensure cohesion between fuel cell and hydrogen research activities

The strategies and actions needed to overcome these challenges require input from a broad range of stakeholders including Government, industry and researchers, and extend through to 2023 and beyond.

The UK fuel cell community has highlighted five key steps which encompass many of the challenges listed above, and where early action is considered critical; these are:

- **Achieving high level political buy-in** – This will help to ensure that potential policy benefits are fully realised. Action by industry and Fuel Cells UK is needed to stimulate strong political commitment.
- **Supporting fuel cell research and development** – Funding of the order of £10-20m per year is needed if UK research and development capability and effort are to realise their potential to deliver policy objectives, and to support the growth of the industry.
- **Establishing a Fuel Cell Coordination Group within Government** – The Group's role would be to harmonise and unite relevant policies and initiatives, thus facilitating a streamlined and efficient approach to support for the development and deployment of fuel cells in the UK.
- **Fostering significant UK deployment of fuel cells** – The early trial and medium term demonstration of fuel cell applications can help to optimise the technology, encourage the development of supply chains, improve awareness and understanding and, at significantly large scale, help to bring down costs and kick-start mass markets. This, in turn, will help to accelerate delivery of the policy benefits which fuel cells can bring.
- **Introducing a forward public commitment to buy** – Forward commitments by public sector procurers offer a powerful mechanism for the market to deliver innovative solutions to meet policy needs. Such commitments also provide supplier companies and their investors with long-term confidence against which to commit resources for manufacturing scale-up.

This Roadmap provides a starting point in highlighting the actions which need to be undertaken by a broad range of stakeholders if the potential for fuel cells in the UK is to be realised. Early progress is needed both across the five key recommendations listed above, and in relation to the suite of specific actions presented in the Roadmap. This will help to ensure that carbon abatement, pollution reduction, energy security and industrial development outcomes are optimised.

ACKNOWLEDGEMENTS

Many organisations and individuals contributed to the preparation of this Roadmap. A full list is provided in Appendix A. We are particularly grateful to the DTI for funding the work, and to the Fuel Cells UK Steering Group for its ongoing guidance and support.

GLOSSARY

ACE	Association for the Conservation of Energy
AFC	Alkaline fuel cell
APU	Auxiliary power unit
AWM	Advantage West Midlands
BoP	Balance of plant
BRE	Building Research Establishment
BSI	British Standards Institution
CT	Carbon Trust
CAT	Centre for Alternative Technology
Cenex	Centre of Excellence for Low Carbon and Fuel Cell Technologies
CHP	Combined Heat and Power
CHPA	Combined Heat and Power Association
CORGI	Council for Registered Gas Installers
CUTE Project	Clean Urban Transport for Europe Project
Defra	Department for Environment, Food and Rural Affairs
DfES	Department for Education and Skills
DfT	Department for Transport
DG	Distributed Generation
DGCG	Distributed Generation Coordinating Group
DMFC	Direct Methanol Fuel Cell
DTI	Department of Trade and Industry
EC	European Commission
EMDA	East Midlands Development Agency
ENCG	Electricity Networks Coordinating Group
EIU	Environmental Industries Unit
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
EST	Energy Saving Trust
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FCs	Fuel cells
FCVs	Fuel Cell Vehicles
GLA	Greater London Authority
HIE	Highlands and Islands Enterprise
HSE	Health and Safety Executive
IEE	The Institution of Electrical Engineers
IGBT	Insulated Gate Bipolar Transistor
IMECHE	Institution of Mechanical Engineers
IPO	Initial Public Offering
ITI Energy	Intermediate Technology Institute for Energy
ITPs	International Technology Promoters
LECs	Levy Exemption Certificates
LowCVP	Low Carbon Vehicle Partnership
M&A	Mergers and Acquisitions
MCFC	Molten carbonate fuel cell
MEA	Membrane-electrode assembly
NWDA	North West Development Agency
NGOs	Non-governmental organisations
ODPM	Office of the Deputy Prime Minister
PAFC	Phosphoric acid fuel cell
PEMFC	Proton exchange membrane fuel cell
POST	Parliamentary Office of Science and Technology
PRASEG	Associate Parliamentary Renewable and Sustainable Energy Group
QCA	Qualifications and Curriculum Authority
RCs	Research Councils
RDAs	Regional Development Agencies
REGOs	Renewable Energy Guarantees of Origin
RIBA	Royal Institute of British Architects
SE	Scottish Enterprise
SEEDA	South East England Development Agency
SHFCA	Scottish Hydrogen and Fuel Cell Association
SWRDA	South West Regional Development Agency
SECA Program	Solid State Energy Conversion Alliance
SIAM	System Impact of Additional Micro-generation
SOFC	Solid oxide fuel cell
SUPERGEN	Sustainable Power Generation and Supply
UKERC	UK Energy Research Centre
WDA	Welsh Development Agency

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1 INTRODUCTION

1.1 Why fuel cells?

Fuel cells are a technology that can:

- contribute substantially to a global low carbon economy;
- improve urban air quality and the health of urban populations;
- form the basis of a 21st Century industrial sector that allows sustainable growth of the world economy;
- enhance energy security by allowing a wider choice of fuels;
- contribute to the alleviation of fuel poverty through superior efficiency relative to conventional technologies (particularly in CHP mode); and
- provide essential intermediate and final components of any future hydrogen economy.

These issues have a high priority in the UK and a sustained national debate has been taking place on how they can be addressed. As a new and innovative technology, fuel cells can change the rules of this debate and provide attractive solutions to otherwise intractable and complex problems.

Benefits to the UK

Reducing carbon dioxide emissions

It is now widely acknowledged that climate change is happening and this is generally attributed to increased concentrations of greenhouse gases in the atmosphere, the most significant of which is carbon dioxide (CO_2).

There is clear consensus that the widespread introduction of fuel cells for distributed generation and transport has huge potential for reducing CO_2 emissions and improving quality of life. The cost of measures that bring forward the large-scale use of fuel cells to gain the benefits earlier than would otherwise be the case can be balanced against the eventual benefits. These benefits include more rapid UK participation and understanding, earlier large-scale deployment of fuel cells and accelerated efforts to reduce CO_2 emissions.

The UK fuel cell community believes that mechanisms that affect worldwide emissions should have a much higher priority in UK policy. Fuel cells have this dimension. Bringing forward the use of fuel cells in the UK will have the effect of bringing forward international introduction by improving and demonstrating the technology and its benefits. In this way, UK technology and experience would be leveraged to reduce CO_2 emissions worldwide.

Improving urban air quality

The UK faces significant challenges to improve urban air quality. The combination of high population density and a high concentration of pollution sources causes a disproportionate impact on health and results in high health-care costs for those affected.

In the UK, as in other industrialised nations, motor vehicle exhaust emissions cause more air pollution than any other form of human activity. Vehicles account for nearly half of all emissions of oxides of nitrogen, two thirds of carbon monoxide, as much as half of all hydrocarbon emissions and most of the particulate emissions in cities.

The UK Government has set air quality targets for local authorities; however, continuing problems with congestion in urban areas have meant that these are difficult to meet.

The uptake of fuel cells in vehicles will provide relief from this problem since fuel cells can be emission-free at point of use. By taking a leading role in the uptake of fuel cell technology in vehicles, particularly in urban areas, the UK can bring forward these expected benefits, improving urban air quality and relieving the burden on the health service.

A sustainable and competitive economy

The UK has made strong commitments to sustainable economic development. These commitments require the UK to balance continued economic growth with its environmental and social consequences. Fuel cells are a very attractive technology for the stimulation of sustainable growth since they can have positive impacts in both areas.

Fuel cell and hydrogen businesses already support over 800 jobs in the UK. Forecasts of commercial sales give a global market size of above £25 billion in 2011. There is an opportunity for the UK to build a sizeable industry centred on fuel cells and the hydrogen economy, covering all stages of the value chain.

Past experience has clearly demonstrated that industry participants tend to "cluster", preferring to be located near customers or suppliers, and to have an experienced labour pool and infrastructure to draw upon.

The benefits of establishing the UK as an attractive international hub would be to encourage inward investment from key players from all segments of the fuel cell supply chain with the resulting significant benefits to employment and a strong skills base. Significant potential for spin-off developments in related areas such as advanced materials would also ensue.

By taking a leading position on fuel cell development and deployment, the UK will encourage the early flow of inward investment. Showing long-term commitment and support for fuel cells will reduce the risk for companies considering investing in the UK. Such support is likely to represent a better investment than subsidising other industries with less long-term prospects for the UK.

Within the UK a number of regions have demonstrated considerable enthusiasm for fuel cells, and their initiatives provide a promising framework for inward investment. Without national support and coordination, however, these initiatives will struggle to realise their potential.

Contributing to energy security by allowing greater fuel flexibility

As indigenous energy supplies dwindle, the UK is becoming a net energy importer. This makes the country potentially vulnerable to supply interruptions due to regulatory failure, political instability, conflict and price fluctuations.

Supplies of gas, which currently account for 39% of the UK's primary energy demand, are diminishing and it will become net importer by around 2006, with the same applying to oil by around 2010. The UK already imports approximately half of the oil it uses.

Security is best maintained through energy diversity by having different sources, suppliers and supply routes, allowing the existing supplies to last longer than would otherwise be the case.

Fuel cells offer an excellent contribution to the challenges of energy security, as they can be run on a wide and growing range of fuels. Without the introduction of fuel cells in the UK, the impacts of falling indigenous supplies could be significantly greater.

Much of the UK's energy infrastructure needs to be updated in the next 20 years. Substantial investment will be needed to enable a move from the traditional, centralised power operations feeding the electricity distribution network to a system more suited to renewable energy sources (often in peripheral areas of the country or off-shore) and smaller scale distributed energy generation. Additional gas transmission infrastructure will also be needed as the country becomes a net importer of gas. As these changes occur, the need for reliable and 'good quality' energy will increase.

The implications of failure to maintain a reliable energy infrastructure and supply network were illustrated in North America with recent blackouts in large portions of both the USA and Canada. The magnitude of the resulting total costs is estimated to be in the billions of dollars. Recent power failures in London have also raised the profile of this issue.

The hydrogen economy

Fuel cells are widely regarded as the key means for converting hydrogen to energy and, as such, have a clear enabling role in realising any aspirations for a hydrogen economy. The 'hydrogen economy' concept covers a range of ideas where hydrogen plays a major energy vector role in clean energy systems of the future. The ability to operate fuel cells with fuels ranging from fossil fuels, through biomass-based fuels (e.g. landfill gas) to renewable sources means that they could support all steps in the transition to a hydrogen economy based predominantly on renewable energy sources.

1.2 Roadmap objectives and scope

This Roadmap has its origins the 'Fuel Cell Vision for the UK', published by Fuel Cells UK in 2003. The Vision highlighted the benefits to the UK in taking a leading role in fuel cell development and deployment, and defined a pathway for the UK to assume that role. One of the main recommendations emerging from the Vision was:

> *"The key next step is to define the roadmap for realising the vision – specifying routes and milestones for all stakeholders, including government and industry."*

The purpose of this Roadmap is to accelerate the commercialisation of fuel cell technologies within the UK, and to ensure that the UK derives maximum benefit from that process. This applies not only to industry, but also to the research community, Government (national, regional and local) and society at large.

As mentioned above, there are clear and close linkages between fuel cells and the hydrogen economy. Any form of hydrogen economy will be much more successful in delivering policy objectives such as CO_2 abatement if fuel cells have a significant role, and several types of fuel cells require hydrogen as fuel. In the UK, the recently completed 'Strategic Framework for Hydrogen Energy in the UK' sought to determine how the UK could engage with hydrogen economy activities for maximum benefit. Work on that framework was conducted in parallel with the early work on this Roadmap, with close interaction between the authors to ensure complementarity.

The scope of this Roadmap is limited to the fuel cell system and immediate technology (e.g. balance of plant, power conditioning, etc.), plus fuel storage and delivery at the point of use.

The development of this Roadmap involved an extensive process of consultation; the importance attached by the UK fuel cell community to this work is reflected in the substantial input from a broad range of stakeholders with almost 500 hours committed.

Successful progress in the development and deployment of fuel cells will require the full participation of these stakeholders. The outputs of the Roadmap will be of relevance to all those who have an interest in fuel cells in the UK, and its target audience is correspondingly wide.

1.3 Commercial potential

A recent report for the Department of Trade and Industry (DTI) and Carbon Trust estimated the worldwide market potential for fuel cells to be over $25 billion by 2011, with significant growth thereafter as commercialisation progresses. The breakdown of this estimate by technology is as follows:

	Application	Value 2011 $B	Value 2011 £B
Mobile	Propulsion	3	1.6
	Auxiliary Power Units (APUs)	0.9	0.5
Stationary	Distributed generation (DG) / Combined heat and power (CHP)	6	3.2
	Residential / Small-Scale CHP	3	1.6
	Remote Power	2.5	1.3
Portable	Battery / Genset replacement	11	5.8
	Total	**26.4**	**14.0**

This Roadmap highlights ways to help the UK to optimise its response to this opportunity.

1.4 Fuel cell technology

The key features of leading fuel cell technologies are summarised in Figure 1.1 below. R&D concepts of third-generation fuel cell technologies are described in Appendix C.

Figure 1.1 Leading fuel cell technology

Technology	Electrolyte	Power Range	Description, Operating Temperature and Applications	Technology Status
First Generation Fuel Cells – Mature				
Alkaline fuel cell (AFC)	Liquid alkaline, usually KOH	A few watts to tens of kilowatts	Characterised by a liquid potassium hydroxide (KOH) electrolyte. Main issues with this are the possible contamination of the electrolyte by CO_2. Operating Temperature: 90-100ºC Applications: Military, space	Mature technology. Expensive but used in niche applications. Few manufacturers currently active. Technology may still find applications.
Phosphoric acid fuel cell (PAFC)	Phosphoric acid	200kW-11MW	Moderate operating temperature precludes internal reforming of hydrocarbon fuels, and so a separate reformer is required. (True of any low temperature fuel cell.) Operating Temperature: 175-200ºC. Applications: Stationary / distributed power.	200kW systems offered but not commercially competitive with other forms of generation without specialised circumstances.
Second Generation Fuel Cells – Currently Under Development (i.e. concept, prototype, pre-production or early adoption)				
Proton exchange membrane (PEM) fuel cell	Solid polymer	A few watts to many hundreds of kilowatts	Traditional PEMFC direct hydrogen solid polymer fuel cell. Whilst Ballard, Siemens and Babcock have delivered 200kW systems, generally they operate at around the few watts to 25kW (except for vehicle engines at 75kW and bus engines at 250kW) Operating Temperature: 60-85ºC Applications: Transportation, stationary / distributed	"Commercial" products now available although power output limited to 1-2kW. A large number of companies are close to bringing stacks to market but few are offering generator or system products.
Micro direct methanol fuel cell (µDMFC)	Solid polymer	< 50W	Low power PEMFC devices that will compete directly with traditional batteries. Methanol fuel delivered to the PEMFC device as a liquid. Operating Temperature: 60-100ºC Applications: Mobile electronic equipment from phones to computers	Advanced product trials, early commercialisation expected.
Direct methanol fuel cell (DMFC)	Solid polymer; can be alkaline	50-150W	Operating Temperature: 60-100ºC Applications: Larger portable equipment	Early product proof of concept.
DMFC	Solid polymer	500W-2kW	These have significant issues to overcome with regard to efficiency and precious metals content. Operating Temperature: 60-100ºC Applications: Large mobile equipment	Early R&D effort seems to confirm viability.
Molten carbonate fuel cell (MCFC)	Molten carbonate material	25kW-2MW	Hydrocarbon fuels, including coal-derived fuel-gas, may be reformed directly at the anode and an external reformer is not necessarily required. However, sulphur tolerance remains a problem. Possible application areas include power generation, CHP, ship propulsion. Very small MCFC systems are complex due to requirement to re-circulate CO_2 in the system.	Development programmes in Japan, the USA and Europe have produced many small prototype units in the 5-20kW range, and a 2MW plant has been demonstrated in the USA and 1MW one in Japan. 250kW systems are also being demonstrated but further R&D required.
Solid oxide fuel cell (SOFC) – Tubular design	Solid oxide material	100W-10MW	Tubular and planar SOFCs employ similar materials, but differ in terms of fabrication techniques. Natural gas is generally the fuel of choice. Operating Temperature: 600-1,000ºC Applications: stationary centralised and distributed power generation, CHP, APUs, ship propulsion, trains.	SOFC systems of 250kW have been delivered for demonstrations. Costs remain high.
SOFC – Planar design	Solid oxide material	100W-10MW		
High-temperature PEMFC	Solid polymer	Same as PEMFC	Easier heat management, more useful heat output, more tolerant of contaminants in fuel stream. Operating Temperature: 120-160°C	R&D stage

2 OVERVIEW OF FUEL CELL ACTIVITIES IN THE UK

2.1 Introduction

This Section provides an overview of the current UK fuel cell landscape, encompassing the industry and research community, the role of central Government, regional initiatives, funding / support and the UK as a market for fuel cells. There is also a brief summary of the UK's overall position in the global context.

The material presented in this Section provides the context for the more detailed analysis which follows in subsequent parts of the Roadmap.

2.2 The UK fuel cell industry

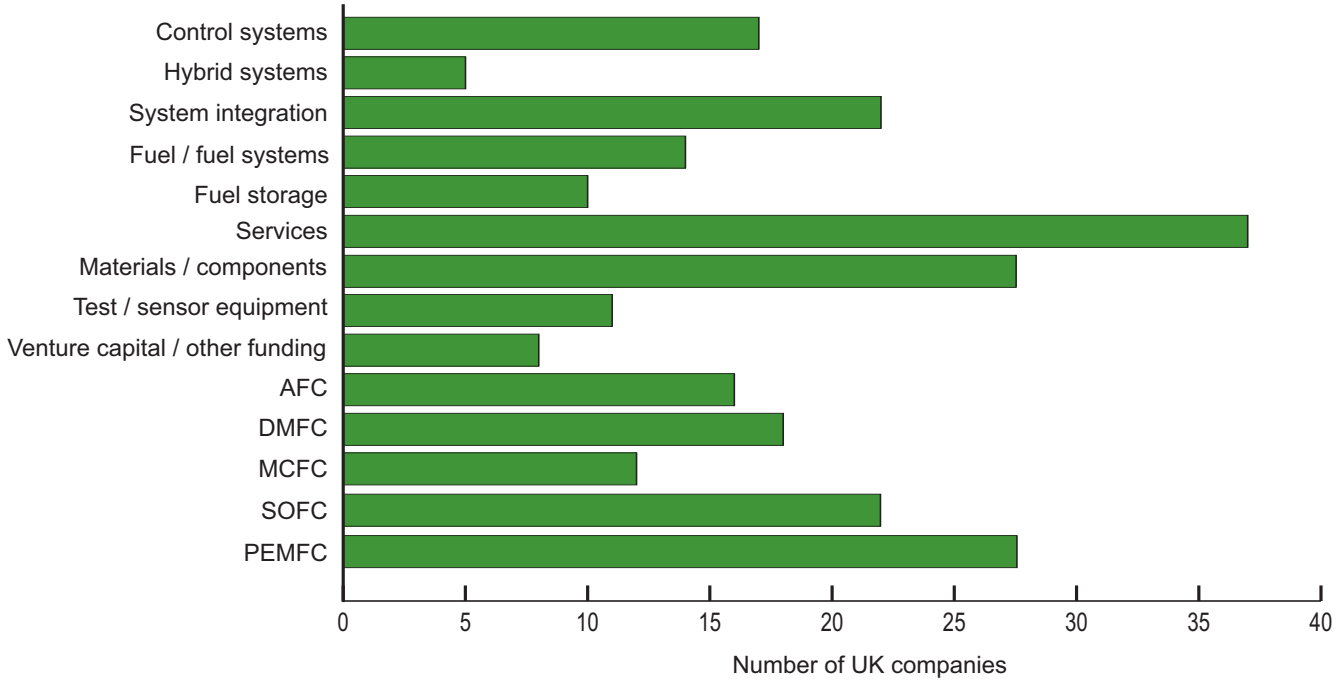
Fuel cell commercialisation is moving forward rapidly across the world. The evolution from research activity to full scale production is generating opportunities for businesses along the supply chain. In the UK, against a backdrop of established players and research activities, recent times have seen the emergence of a number of small entrepreneurial companies and potential suppliers to the industry, all keen to establish a presence in the international market place. An increasing number of entrants are now seeking Initial Public Offerings to inject funds for development and growth; examples of recent successes include ITM Power, Ceres Power and Voller Energy.

Industry structure

Currently, over 100 UK companies are contributing to the creation of the global fuel cell industry. The knowledge and expertise of the UK industry spans the full length of the commercial value chain, from R&D to systems integration, and from finance to servicing. Many of these capabilities have been developed in partnership with companies and organisations from across the world.

The breadth of the UK fuel cell industry's expertise can be illustrated by the number of companies active across the various parts of the supply chain – see Figure 2.1. A more detailed breakdown, based on The UK Fuel Cell Industry Capabilities Guide, is presented in Figure 2.2.

Figure 2.1 Number of UK companies active across different parts of the fuel cell supply chain



Note that these categories are not mutually exclusive. For example, companies developing fuel cell systems might encompass systems integration in their capabilities. Those listed under specfic fuel cell types could include companies supplying materials, components and / services for these technologies.

Figure 2.2 Summary of capabilities of UK companies

	Control systems	Hybrid engines	System intergartion	Fuel/fuel systems	Fuel storage	Services	Materials/components	Test/sensor equipment	Venture capital / other funding	AFC	DMFC	MCFC	SOFC	PEMFC
Accentus plc			•		•									
Adelan UK Ltd			•	•		•	•	•					•	
AEA Technology plc	•		•	•	•					•	•	•	•	•
Air Products plc	•		•	•	•	•	•		•					
Alternative Fuel Systems Ltd	•		•		•	•	•			•				•
AMEC plc	•		•			•								
Aspen Technology				•		•				•	•	•	•	•
Baxi Group Ltd			•											•
BMT Defence Services Ltd	•		•	•		•	•							•
BOC			•	•	•	•			•					
BP				•		•								
Bronkhorst (UK) Ltd	•						•	•						
Cambridge Consultants Ltd						•								
Catal International Ltd	•		•	•		•	•	•						
Ceramic Fuel Cells Ltd													•	
CD Adapco Group						•								•
CERAM Research					•		•	•					•	
Ceres Power Ltd													•	
Chell Instruments Ltd	•		•			•		•						
Conduit Ventures Ltd									•					
Core Technology Ventures Ltd									•					
CPR Automation			•			•								
Dart Sensors Ltd						•	•				•			•
Davis Pneumatic Systems Ltd	•													
Drayton Beaumont Kilns Ltd	•					•								
DT Assembly and Test Europe Ltd						•	•	•		•	•	•	•	•
E4tech (UK) Ltd						•				•	•	•	•	•
EA Technology Ltd	•	•	•		•	•		•	•	•			•	•
ECOTEC Research and Consulting Ltd						•								
Electro-Chem-Technic						•								
Element Energy Ltd						•				•		•	•	•
Elsevier Advanced Technology						•								
Eneco Ltd	•	•	•			•	•	•		•				
Escovale Consultancy Services						•								
Fluent Europe Ltd						•				•	•	•	•	•
Fuel Cells (Scotland) Ltd	•			•				•					•	
Fuel Cell Control Ltd										•				
Gencoa							•							
Generics Group Ltd						•				•	•	•	•	•
Heatric						•	•							
Hudson Shribman Scientific Recruitment						•								
Inco Special Products							•					•	•	•
Ineos Chlor Ltd							•			•	•	•	•	•
Intelligent Energy Ltd			•	•			•	•						•
International Innovation Services Ltd						•			•					
ITM Power plc							•				•			•
Johnson Matthey Fuel Cells				•			•		•		•			•
MEL Chemicals							•						•	•
Microtherm International Ltd							•			•		•	•	•
Oxford Lasers Ltd						•	•							
Parker Hannifin plc IPDE	•		•	•			•							
Porvair Fuel Cell Technology				•			•							
Powergen UK plc			•			•								
Precision Micro							•			•	•		•	•
QinetiQ Ltd	•	•	•		•						•			•
Ricardo UK Ltd	•	•	•	•		•	•	•						
Rolls Royce Fuel Cell Systems Ltd		•	•			•							•	
Scottish and Southern Energy plc						•			•					
siGEN Ltd			•			•					•			•
Stainless Metalcraft Ltd					•		•			•	•	•	•	•
Synnogy Ltd						•				•	•	•	•	•
Technology Interface							•			•	•			•
Turquoise International Ltd									•					
Unitec Ceramics Ltd							•						•	
Voller Energy plc			•	•	•	•								•

As the industry grows and develops there is increasing interaction across its various levels. This is well illustrated by the number of organisations participating in the range of UK fuel cell installations (see Section 2.8 below).

Of the companies active in the UK, more than 20 have a track-record of fuel cell investment of more than 10 years (FCT, 2003a). Materials and catalysts technologies for fuel cells and reformers have been developed by Johnson Matthey for 30 years and Rolls-Royce has been developing SOFC stacks for over 10 years. With a few notable exceptions, most companies in the sector are small.

UK companies generally have extensive international links, whether with customers, development partners or investors. Many of the leading UK players derive a significant proportion (i.e. >50%) of their income from overseas.

The development of local supply chains is seen by many as important for the future development of the industry. Building on its long-term involvement in catalysts and precious metals, Johnson Matthey has recently opened a dedicated fuel cell component manufacturing facility in the UK, within a local supply chain, permitting greater interaction and clearer information exchange at this early stage in the technology's commercialisation.

Employment

In 2003, Fuel Cell Today reported that approximately 850 people were employed in the UK in fuel cell related areas. Around half of these were employed by the ten most active organisations, which included Accentus, Eneco, Imperial College, Intelligent Energy, Johnson Matthey and Rolls-Royce.

2.3 The UK fuel cell research community

This section is primarily concerned with academic research, with some coverage of contract research. Industrial research carried out by companies for their own product development is not covered.

Structure of the community

The UK has over 35 academic and contract research groups highly active in fuel cells and hydrogen research, as well as a number of contract research organisations with relevant experience.

Issues currently being researched include transient behaviour, longevity and cost, membrane types, systems performance, degradation of electrodes, levels and types of catalyst coatings, microbial fuel cell systems and process modelling of biomass-derived fuels for fuel cell systems. There is also research into fuel cell policy and strategy, including issues such as public acceptance. Longer term research into fuel flexibility and optimisation of the technology is also being carried out, albeit to a lesser degree. In 2003, UK academics published over 100 papers directly related to fuel cells and hydrogen.

The UK academic base exhibits a high degree of collaboration, and there are strong links with Germany, the USA, Canada, Japan and China. Academic institutions work closely with industry and several fuel cell companies have been spun out of academic research activity.

Figure 2.3 gives an indication of the levels of interest in specific areas; a more detailed breakdown, based on the UK Fuel Cell and Hydrogen Research Capabilities Guide, is presented in Figure 2.4.

Figure 2.3 Number of UK research organisations active across different parts of the fuel cell supply chain

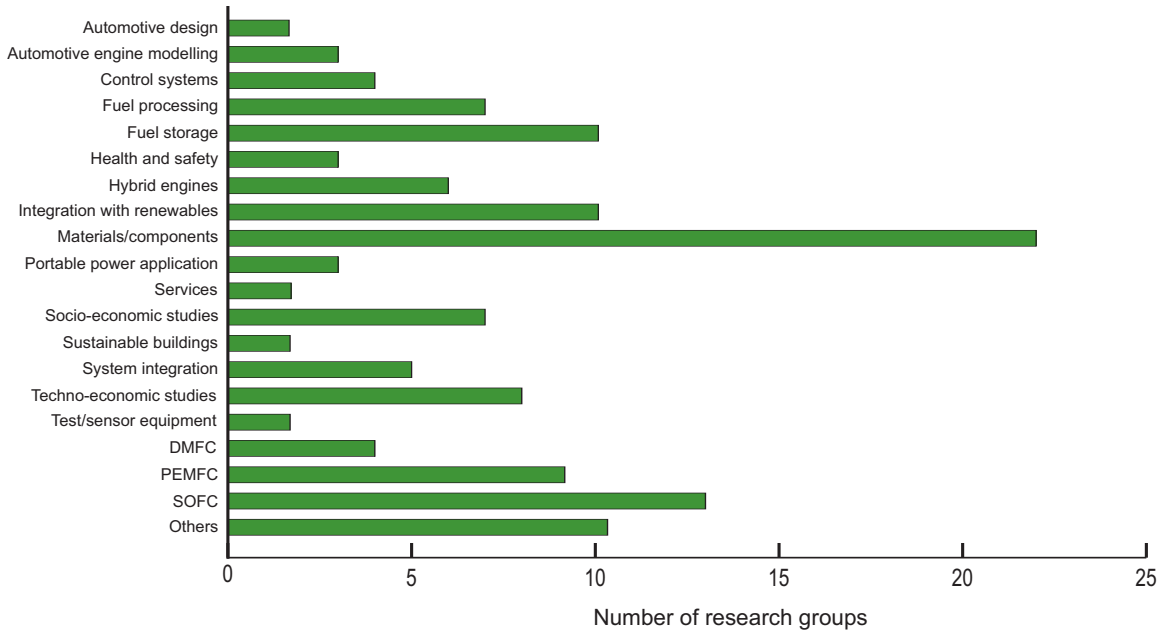


Figure 2.4 Summary of capabilities of UK research groups

Institution	Department/Centre	Automotive design	Automotive engine modelling	Control systems	Fuel processing	Fuel storage	Health and safety	Hybrid engines	Integration with renewables	Materials/components	Portable power applications	Services	Socio-economic study	Sustainable buildings	System integration	Techno-economic study	Test/sensor equipment	DMFC	PEMFC	SOFC	Other fuel cell types
Aston University	Bio-Energy Research Group								•							•					
Cardiff University	Centre for Research in the Built Environment, Welsh School of Architecture											•		•	•						
CCLRC, Rutherford Appleton Laboratory	Energy Research Unit							•	•												
City University	Centre for New Technologies, Innovation and Entrepreneurship												•			•					
City University	Centre for Energy and Environment		•					•					•			•					
Coventry University	Design Institute	•						•													
Cranfield University	Department of Materials and Medical Sciences									•	•							•	•		•
Health and Safety Laboratory	Fire and Explosion Group						•														
Imperial College	Centre for Energy Policy and Technology								•				•			•					
Imperial College	Centre for Ion Conducting Membranes			•	•				•	•			•			•	•		•	•	•
Imperial College	Department of Materials									•										•	
Imperial College	Department of Mechanical Engineering							•												•	
Keele University	Centre for Clean Technology, School of Chemistry and Physics				•				•	•			•							•	
Loughborough University	Centre for Renewable Energy Systems Technology			•		•			•						•						
Loughborough University	Department of Aeronautical and Automotive Engineering		•	•	•	•		•	•	•									•		
Loughborough University	Institute of Polymer Technology and Materials Engineering									•										•	
QinetiQ	Electrochemical Power				•					•	•				•	•		•	•	•	•
Queen Mary University of London	Department of Materials					•															
University of Bath	Department of Engineering and Applied Science									•										•	
University of Birmingham	Department of Chemical Engineering				•					•									•	•	•
University of Birmingham	Department of Metallurgy and Materials				•	•				•									•		

Figure 2.4 Summary of capabilities of UK research groups (continued)

Institution	Department/Centre	Automotive design	Automotive engine modelling	Control systems	Fuel processing	Fuel storage	Health and safety	Hybrid engines	Integration with renewables	Materials/components	Portable power applications	Services	Socio-economic study	Sustainable buildings	System integration	Techno-economic study	Test/sensor equipment	DMFC	PEMFC	SOFC	Other fuel cell types
University of Dundee	Division of Physical and Inorganic Chemistry									•										•	
University of Glamorgan	Sustainable Environment Research Centre, Hydrogen Research Unit								•				•			•					•
University of Manchester	Department of Chemical Engineering (formerly UMIST)					•				•										•	
University of Newcastle upon Tyne	School of Chemical Engineering and Advanced Materials				•					•								•	•		•
University of Nottingham	Advanced Materials Research Group, School Mechanical, Materials, Manufacturing Engineering & Management					•				•											
University of Nottingham	Division of Chemistry, Hydrogen Storage Group					•				•											
University of Reading	School of Chemistry					•				•									•		•
University of Salford	Institute for Materials Research					•															
University of Sheffield	Department of Chemical and Process Engineering					•	•														
University of Sheffield	Department of Engineering Materials									•										•	
University of Sheffield	Department of Mechanical Engineering																				•
University of Southampton	Combinatorial Centre of Excellence, School of Chemistry					•				•									•		
University of St Andrew's	School of Chemistry									•										•	•
University of Strathclyde	Department of Electrical and Electronic Engineering, Centre for Economic Renewable Power Delivery		•	•	•			•	•						•	•					
University of Surrey	Chemistry Division									•										•	
University of Warwick	School of Engineering, Warwick Process Technology Group				•				•	•					•						
University of the West of England	Intelligent Autonomous Systems Laboratory, CEMS Faculty																				•

Major programmes and initiatives

The Engineering and Physical Sciences Research Council (EPSRC)

The EPSRC is the UK Government's leading funding agency for research and training in engineering and the physical sciences. One of its activities is a responsive mechanism which provides support for a wide range of research activities. Support for fuel cells depends, in part, on the level of underpinning technology work supported (e.g. materials science or chemical engineering).

UK Energy Research Centre (UKERC)

The EPSRC, the Economic and Social Research Council (ESRC) and Natural Environment Research Council (NERC) established the UKERC in April 2004. Its mission is to promote an energy system which is environmentally sustainable, socially acceptable and meets energy needs securely and affordably. It aims to achieve this by pursuing its own whole-systems research programme bringing coherence to the diverse range of UK energy research activities through the establishment of a National Energy Research Network. Fuel cells and hydrogen are expected to form an important part of the Centre's remit.

Sustainable Power Generation and Supply (SUPERGEN)

SUPERGEN is an EPSRC initiative to encourage the development of sustainable power generation and supply. It aims to:

- Contribute to the UK's environmental emissions targets through a radical improvement in the sustainability of power generation and supply;
- Promote a significant step change rather than incremental progress; and
- Involve multidisciplinary partnerships working in major programmes of work rather than individual research groups working in isolation.

Across four established Consortia currently operating under SUPERGEN, one focuses specifically on hydrogen. Fuel cells will be covered under a new Consortium.

CCLRC Rutherford Appleton Laboratory

The Energy Research Unit (ERU) of the CCLRC Rutherford Appleton Laboratory operates a testing facility on behalf of the EPSRC for use by UK academic researchers. The laboratory has developed an emphasis on hydrogen-related projects including the co-ordination of the H2NET (UK Hydrogen Energy Network).

2.4 The UK Government

DTI Energy Innovation and Business Unit

The Energy Innovation and Business Unit established an Advanced Fuel Cell R&D Programme in 1992. Since then, the programme has supported approximately 150 projects. It invested approximately £92 million over a decade, £12 million of which came from Government sources.

The DTI's programme has also supported generic studies to address overarching issues, such as:

- Assessment of competing technologies
- Technical prospects for hybrid systems
- Fuel Infrastructure
- Identification of PEMFC R&D issues and priorities
- Fuel Cells niche market applications

The 'Review of Fuel Cell Commercial Potential', published in February 2003, and jointly funded with the Carbon Trust, represents a good example of a generic study which has helped to shape Government thinking on fuel cells.

In spring 2004 the fuel cell programme was subsumed into the wider 'Technology Programme', which, like the previous arrangements, has no ring-fenced or sustained allocation to fuel cells and related hydrogen technologies. This is an issue of concern to the UK fuel cell industry.

On the international front, the Energy Innovation and Business Unit represents the UK on:

- The International Energy Agency's fuel cell and hydrogen Implementing Agreements;
- The International Partnership for the Hydrogen Economy; and
- The EU Hydrogen and Fuel Cell Platform Mirror Group (see below).

DTI Innovation Group

The DTI Innovation Group (http://www.innovation.gov.uk/) works to promote a significant increase in innovation throughout the economy. The Group initiated and provides funding for the Fuel Cells Forum (see below), which was the forerunner for a series of Knowledge Transfer Networks.

Through its Global Watch Services, the Group also provides funding for overseas fact-finding missions aimed at improving UK knowledge of developments and opportunities elsewhere. Over the past three years, three missions focusing on fuel cells, and covering the USA, Canada and Japan have taken place. These missions are typically supported by International Technology Promoters (ITPs) (http://www.globalwatchonline.com), Government-funded technology transfer specialists with extensive networks in the regions and technologies which they cover.

DTI Automotive Unit

The DTI Automotive Unit (http://www.dti.gov.uk/sectors_automotive.html) works to help the UK automotive industry to succeed. It does so by encouraging the spread of best practice in design and manufacture, supporting inward investment and influencing the design of regulations and tax policy so that they reflect the interests of the sector.

The Unit has been instrumental in the establishment of the Low Carbon Vehicle Partnership and the Centre of Excellence for Low Carbon and Fuel Cell Technologies (see below).

2.5 Regional fuel cell activity

Over the past 4-5 years, there has been growing interest across various regions of the UK in the potential for fuel cells to:

- stimulate the development of new industry sectors, and reinvigorate traditional activities;
- support economic growth;
- help achieve sustainable development objectives (e.g. CO_2 abatement, atmospheric pollution reduction); and
- contribute to urban renewal.

Many regions now have initiatives relating to the development and deployment of fuel cell technologies.

Advantage West Midlands (AWM)

AWM's Regional Economic Strategy includes an objective of gaining competitive advantage from the development of sustainable technology. Specific tasks include the provision of incubation facilities for low carbon technologies, the proposed establishment of a national hydrogen and fuel cell centre, the proposed establishment of a domestic CHP fuel cell supply chain demonstrator and the development of international partnerships to advance work on fuel cell technology. A key driver for these initiatives is the potential for job creation, with studies predicting that 16,000 jobs based on fuel cell technologies could be created in the Midlands by 2010 (Advantage West Midlands, 2003).

East Midlands Development Agency (EMDA)

The East Midlands is home to the Low Carbon and Fuel Cell Vehicle Centre of Excellence. EMDA is keen to assist the commercialisation of large stationary SOFC and mobile PEMFC applications through help with location of premises, formation of energy parks and facilitation of distributed generation projects.

The Greater London Authority (GLA)

The GLA has supported fuel cells and hydrogen initiatives for several years. In 2004, Transport for London took delivery of three hydrogen-fuelled fuel cell buses as part of the Clean Urban Transport for Europe project. Earlier, in 2002, the GLA created the London Hydrogen Partnership (LHP) to work towards a hydrogen economy for London and the UK. Its aims are to complete and implement a London Hydrogen Plan, to maintain dialogue between all the local stakeholders and to provide a platform for funding bids and initiation of projects.

Highlands and Islands Enterprise (HIE)

HIE has significant interest in fuel cells as enabling technology for a hydrogen economy based on the vast renewable resources available in the region, notably wind and wave energy. The project 'Promoting Unst Renewable Energy' (PURE) aims to make Unst a centre of excellence for the deployment of hydrogen-fuelled systems in remote locations. PURE intends to balance the intermittency of wind energy generation with the electricity produced by a hydrogen-powered fuel cell (HIE, 2004).

North West Development Agency (NWDA)

Renewables North West was established in 2002 to promote the achievement of governmental renewable energy targets, which will eventually link up with energy conversion and storage solutions. Decision making and feasibility discussions are underway to establish the Joule Centre, with a remit to promote Energy Technology R&D building on existing regional strengths. A feasibility study in early 2005 will examine the potential for creating a Hydrogen Network in the North West.

One Northeast

A key activity for One Northeast is its support for the Fuel Cell Application Facility. A number of local features provide the area with good credentials as a 'trial site' for new energy systems. The Fuel Cell Application Facility undertakes projects, offers technical advice, aims to facilitate supply chain development, and provides information and training. A number of fuel cell systems have recently been installed (see below) and there is an aspiration to develop the components of a local integrated hydrogen community. This could include coal gasification and CO_2 capture and storage, CHP 'private wire' systems (with plans for a large scale fuel system in the medium term), accelerated application of fuel cells of various sizes and the provision of low carbon fuelling for transportation.

Scottish Enterprise (SE)

SE's support for the Scottish hydrogen and fuel cell industry is focused primarily on energy cluster development and the support of early stage technologies through academic research and demonstrator projects. Recently, SE funded the establishment of the Scottish Hydrogen and Fuel Cell Association (see below). It also part-funded the Scottish Fuel Cell Consortium, an industrial-academic partnership focusing on the development of a battery/fuel cell hybrid transport system. Other activities include support for the development of the novel SOFCRoll technology, being progressed by St Andrew's University, and support for the Royal Society of Edinburgh/SE enterprise fellowships, which aim to commercialise technology from higher education institutions. SE is also supporting a number of early-stage demonstrator projects.

The South East England Development Agency (SEEDA)

The UK's first fuel cell demonstrator is located in the region, at Woking; the US-produced PAFC system provides 250kW to an independent electricity grid, as well as heat for a local swimming pool.

South West Regional Development Agency (SWRDA)

The SWRDA is currently reviewing its approach to the environmental technology sector in the South West.

Welsh Development Agency (WDA)

A key recent activity in Wales has been the launch of the Hydrogen Valley Project. This is intended to make Wales a key centre for the development of alternative fuel technologies, a showcase for low or zero emission transportation systems and an attractive centre for investment from companies working in this field.
The Project will be working with its partners to develop a regional micro hydrogen economy in South Wales - a sustainable model that can be replicated in other areas. Initial work involves stimulating demand, influencing public perception and demonstrating viable futuristic vehicles and energy solutions. Within ten years it is envisaged that there will be hydrogen fuelling stations, zero/low emission integrated transport networks, hydrogen powered water taxis and logistics hubs.

Yorkshire Forward

In partnership with Objective One and the Carbon Trust, Yorkshire Forward is looking to establish an Energy Technology Incubator for companies interested in the development and manufacturing of energy efficiency products. The Energy Efficiency Incubator will focus initially on fuel cells, photovoltaics, biomass and energy storage.

2.6 Other key stakeholders and initiatives

There are a number of other quasi-government and independent stakeholders who provide communication, support and coordination for fuel cells in the UK.

Fuel Cells UK

Fuel Cells UK provides a focus for the growing UK fuel cell industry, and works to foster its development. Its role includes:

- raising the profile of the industry both in the UK and overseas;
- acting as a central liaison point for national and international contact;
- catalysing partnering opportunities between UK and overseas organisations;
- improving the positioning of the UK fuel cell industry in the international arena; and
- developing a pan-industry perspective on key issues.

Fuel Cells UK activities include:

The UK fuel cell industry: a capabilities guide: Showcasing the experience and expertise of around 70 companies active in the fuel cells area, with capabilities ranging from materials and components, through fuel cells stacks and integration to investments and finance (see section 2.2 above).

A fuel cell vision for the UK: Highlighting the benefits to the UK in taking a leading role in fuel cell development and deployment, and defining a pathway for the development of fuel cells in the UK; with input from over 150 UK fuel cell stakeholders. (Available in hard copy and on line at www.fuelcellsuk.org).

UK fuel cell and hydrogen research: a capabilities guide: Highlighting the activities and expertise of around 40 research groups with a wide range of fuel cell and hydrogen related interests (see section 2.3 above).

Fuel Cells UK is currently in receipt of seedcorn funding from the DTI. The coming months are expected to see its role evolving to take on a more policy influencing remit, providing a unifying and influential voice for the growing industry.

Low Carbon Vehicle Partnership (LowCVP)

The LowCVP is a partnership of the automotive and fuel industries, Government, academia, NGOs and other stakeholders collaborating to promote the shift to clean low carbon vehicles and fuels in the UK. Its activities are progressed by a number of working groups which encompass areas such as fuels, supply chain development and R&D. These working groups include representatives of the UK fuel cell community. A key initiative of the LowCVP R&D working group is the Centre of Excellence for Low Carbon and Fuel Cell Technologies (see below). Other activities include the development of a supply chain database and a vehicle labelling initiative.

Centre of Excellence for Low Carbon and Fuel Cell Technologies (Cenex)

The centre is being established with funding from the DTI in response to a recommendation of the Automotive Innovation & Growth Team and subsequent stakeholder consultation. Its mission is to stimulate UK business activity in the field of low carbon transport applications by coordinating individual and cluster activities, and raising the level of domestic and inward investment. Its services will range from the provision of knowledge transfer and networking activities through to the management of demonstration, evaluation and, ultimately, product development projects. At the time of writing the Centre was in its launch phase.

Fuel Cells Forum

The Fuels Cells Forum is a website established 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. It was set up by the DTI in conjunction with EPSRC, Fuel Cells UK, The Carbon Trust and Department for Transport (DfT).

Carbon Trust (CT)

The Carbon Trust is an independent company funded by Government. Its role is to help the UK move to a low carbon economy by helping business and the public sector reduce carbon emissions and capture the commercial opportunities of low carbon technologies. This is achieved through a number of support programmes; those of particular relevance to fuel cell development and deployment are shown in Figure 2.5.

Figure 2.5 Examples of fuel cell related activity supported by the Carbon Trust

Programme	Function	Examples of fuel cell related activity
Research, Development and Demonstration	Provides funding for genuine innovation through open calls and the Carbon Vision Partnership	- Low-cost modular PEM electrolysers: a feasibility study (Heriot-Watt University) - Feasibility of developing novel high-volume fuel cell hydrogen storage using thermally restructured Polyacrylonitrile (HILTech Developments Ltd)
Incubator Programme	Provides strategic and business development advice to prepare management teams for further investment	LIFE-IC Incubator: LIFE-IC specialises in fuel cells, buildings, biomass and energy efficiency technologies.
Venture Capital	Identifies and co-invests in early stage technologies	Provision of venture capital support for Ceres Power (prior to its IPO) and CMR Fuel Cells.
Technology Acceleration Projects	Strategic support for projects that fill technological and commercial gaps	Small scale CHP trial, including a 2.4kWe fuel cell unit located at BRE's facilities at Garston, Watford.

The Carbon Trust works closely with other stakeholders, such as the DTI and EPSRC, to ensure synergy of effort and outcome.

Scottish Hydrogen Fuel Cell Association (SHFCA)

The SHFCA aims to promote and develop the hydrogen and fuel cell industry in Scotland. It brings together the expertise and experience of Scotland's fuel cell companies (Fuel Cells Scotland and siGEN), with the Universities of Strathclyde and St Andrew's, a variety of consultants, Scottish Enterprise, and the Defence Diversification Agency. A proportion of its funding is provided by Scottish Enterprise (see above).

Intermediary Technology Institute for Energy (ITI Energy)

The Intermediary Technology Institute for Energy is one of three new initiatives aiming to:

- increase and sustain the birth rate of high-value technology-based companies;
- substantially increase the level of exchange between academia and businesses in Scotland; and
- help to realise the commercial potential of the Scottish science base.

The Institute is a joint activity of Scottish Enterprise (SE) and Highlands & Islands Enterprise (HIE). It has funds of the order of £150m available over 10 years to develop market driven technologies that can be used by companies to develop leading edge products and processes. Fuel cell and hydrogen technologies will undoubtedly form part of its portfolio.

European Union

As a member of the European Union (EU), the UK has access to a variety of funded programmes and projects. Key recent and forthcoming fuel cell related activity is summarised below.

The 1st Call of the European 6th Framework Programme (2003-2006) for R&D lead to a total of €32.9m (~£23m) EU support for fuel cells as follows:

- High temperature fuel cells (4 contracts, €15.1m (~£10m))
- PEM fuel cells (5 contracts, €14.95m (~£10m))
- Portable applications (2 contracts, €2.85m (~£2m))

Coverage of the Call which closed in December 2004 is shown in Figure 2.6.

Figure 2.6 Fuel Cell related topics covered under the European 6th Framework Programme December 2004 Call

Topics Covered	EU Totals
Hydrogen storage; hydrogen production; pre-normative R&D; Fuel cell materials and production; small and large fuel cell systems integration; socio-economic research	€190m (~£133m) (partly)
European partnership 'Hydrogen for transport' and new hydrogen-integrated demonstration projects ('seed' projects for large-scale demonstration) on transport and polygeneration	€132m (~£92m) (partly)
Fuel cell and hybrid vehicle development; generic fuel processor technology; integrated fuel cell systems and fuel processors for aeronautics, waterborne and other transport applications	€35m (~£25m) (partly)
Support of the coordination, assessment and monitoring of research to contribute to the definition phase for a hydrogen communities initiative (HYCOM - see below)	€4.5m (~£3m) (partly)

The UK is represented in the European Hydrogen and Fuel Cell Technology Platform at various levels. The Platform aims to:

"facilitate and accelerate the development and deployment of cost-effective, world class European hydrogen and fuel cell based systems and component technologies for applications in transport, stationary and portable power."

UK engagement encompasses DTI participation in the 'Mirror Group' and company and university representation in groups taking forward the Deployment Strategy and Strategic Research Agenda.

The Platform has links to the development of two key new initiatives of the European Initiative for Growth – "Quick-Start" Programme:

- HYPOGEN – large facility generating hydrogen and electricity from fossil fuels with CO_2 capture and storage (2004-2015; €1.3B (~£1B))
- HYCOM – realisation of hydrogen communities / competence centres demonstrating the generation and utilisation of hydrogen in stationary (CHP) and vehicle applications (2004-2015; €1.5B (~£1B))

Several UK regions and organisations are involved in the initial stages of these initiatives.

2.7 Funding for fuel cells

Many of the organisations described above provide funding for fuel cell development and deployment. Figure 2.7 below summarises the financial support available.

Figure 2.7 Public sector funding for fuel cells in the UK

Source	Value per annum (approx.)	Comments (See Section 2.3-2.6 above for further details)
EPSRC: Responsive Mechanism	£700,000	
The UK Energy Research Centre	£30,000	Funds will be allocated to six areas of research and coordination across a broad spectrum of energy technologies over the next five years. Approximately £30,000 per annum is likely to be deployed in the area of fuel cells. In addition, the Materials Innovation Programme may use part of its resources in fuel cells-related activities.
SUPERGEN 3 Consortium: Fuel Cells Programme	£550,000	There are £2.2m over four years from end of 2004. Work is related to conventional fuel cell technologies, with an emphasis on SOFC.
SUPERGEN and Carbon Trust Co-Funding: Carbon Vision	£375,000	General funds are projected to be £1.5m over four years for biological fuel cells.
SUPERGEN 5 Consortium: Biological Fuel Cells	Level not disclosed	Programme in formation
DTI – Advanced Fuel Cell R&D Programme	£2,000,000	This is now subsumed within the wider Technology Programme. The funding for fuel cells will vary with each call; successful projects in the April 2004 competition included two specifically focused on fuel cells, with a total value (including non-DTI input) of ~£2.4m. There were also several other projects with fuel cell related aspects.
DTI – Overseas Missions	£55,000	Three fuel cell focused Missions have occurred over the past three years.
DTI – International Technology Promoters	£50,000	This represents an estimate of the time/resource allocated to fuel cells and hydrogen.
Scottish Hydrogen and Fuel Cell Association (SHFCA)	£60,000	
Proof of concept projects supported by Scottish Enterprise	Level not disclosed	Since 2000, three fuel cell related projects have been supported to a level of up to £200,000 each.
Scottish Enterprise - Royal Society of Edinburgh: Enterprise Fellowships	£100,000	This is a programme to support commercialisation of technology stemming from higher education institutions. There are currently two fuel cell related fellowships, with a value of ~£50,000 each.

Figure 2.7 Public sector funding for fuel cells in the UK (continued)

Source	Value per annum (approx.)	Comments (See Section 2.3-2.6 above for further details)
Scottish Enterprise supported joint industry projects	Level not disclosed	This covers support for industry partnerships to field-trial new technology. Planned projects include one based on the island of Islay which includes fuel cells.
Welsh Development Agency: Hydrogen Valley Project	Level not disclosed	See above
Welsh Development Agency: Hydrogen Valley Project – Neath Valley	£33,000	WDA recently approved funds at the indicative level of £100,000 over three years to assist the management functions of the project. An initial trial is now part of a broader multi-partner initiative with variable levels of activity and funding every year. Different partners will perform a series of feasibility studies of a hydrogen infrastructure.
One Northeast	£200,000	A total of £500,000 over the past two and a half years has covered the totality of the fuel cell and hydrogen 'campaign' in the region. This comprised a scoping study, project management, business development etc. Funding has been provided by One Northeast, Borough Councils and local companies.
Clean Urban Transport for Europe (CUTE) Project	£243,000	
Centre of Excellence for Low Carbon and Fuel Cell Technologies	Level not disclosed	The overall funding is approximately £7.5m over five years.
DTI – Fuel Cell Forum	Level not disclosed	
ITI Energy	Level not disclosed	The overall funding is £150m over ten years. This will be utilised to evaluate and pursue numerous energy technologies, including storage. The final focus and allocation are not yet defined.
Carbon Trust: R,D&D	£500,000	This represents £1m over 18 months to spring 2004
Carbon Trust: Venture Capital	Level not disclosed	
Carbon Trust: Technology Acceleration	Level not disclosed	The fuel cell CHP unit at Watford forms part of the Small CHP Field Trial to assess the carbon saving potential of small & micro CHP when compared to existing boilers. A broad range of different technologies will be installed in approximately 100 sites with circa £2.5m funding over 3 years. Funding is linked to milestones achieved. No funding has been released yet.
Carbon Trust Incubator	Level not disclosed	The Carbon Trust can channel commercially and technically promising candidates into co-funded incubators. Level applicable to fuel cells is variable.
Total disclosed	**£4,896,000**	

Note that of the 23 sources of funding listed here, monetary values are available for only 12; thus, the funding from public sources could be significantly higher. Furthermore, in many cases, there is linked funding from industry.

Although Figure 2.7 includes activities which are coming to an end, as well as those which are just starting, there is no duplication (i.e. inclusion of fund which is ending, and fund which is replacing it).

The level of disclosed spending compares relatively poorly with many other countries; further details are provided in Section 2.9 below.

2.8 UK installations

The past two years have seen a variety of new fuel cell installations, and this trend is set to continue. By the end of 2004 there were more than 15 units in place. A number of UK regions have been instrumental in the recent growth, with Teesside as a leading example. In all cases, the installations can be considered as mechanisms for trialling, testing or demonstrating the technology.

Implemented and imminent installations are summarised in Figure 2.8 below.

Figure 2.8 UK fuel cell installations (as of end 2004)

Location	Partners	Status	Purpose	Fuel Cell Type	Rating	Fuel	Notes
Middlesbrough Transporter Bridge, Teesside.	CPI, Intelligent Energy, Air Products, Middlesbrough Council	Installed and commissioned 2003. Development work to improve reliability. Prototype system.	Power for variable messaging sign showing whether bridge is open or not	PEMFC	100We	Hydrogen cylinder	
South Gare (Tees Estuary) Lighthouse, Teesside	CPI, Intelligent Energy, Air Products, PD Ports	In final negotiation, December 2004.	Lighthouse primary power	PEMFC	100W	Hydrogen cylinder	
Portable road sign, currently located on Wilton Site, Teesside.	CPI, Intelligent Energy, Air Products, Varitext	Complete. Development in progress to improve fuel efficiency.	Prototype Road Traffic sign for remote locations	PEMFC	<100We	Hydrogen cylinder	Plans for commercial applications well developed
Visitors Centre, Chapel of Rest, Middlesbrough Teesside.	CPI, Plug Power, BOC, Renew Tees Valley, Middlesbrough Council	Installation almost complete.	Back-up power	PEMFC	5kW	Hydrogen cylinder	
Woking Park, Woking	Woking Borough Council, UTC Fuel Cells, US Department of Defence plus others	Delivery to site October 2001. Testing and commissioning December 2001.	CHP used in leisure centre and community housing. Pool In The Park, Leisure Lagoon, Leisure Centre	PAFC	20kW	Natural gas from gas grid, 58m^3/hr	1st UK fuel cell installation
Office location, Aberdeen	AMEC, siGEN, BOC	Commissioning planned for early 2005.	UPS	PEMFC	1kWe	Hydrogen cylinder	Internal installation

Figure 2.8 UK fuel cell installations (continued)

Location	Partners	Status	Purpose	Fuel Cell Type	Rating	Fuel	Notes
London	GLA, EU, Daimler Chrysler, BP, London Bus Services, First Group, Energy Saving Trust	Launch 16th December 2003, in service 1st January 2004	Bus service. 3 buses from CUTE programme	PEMFC	3 x 205kW	Liquid hydrogen storage with fuel dispensed in a gaseous state	Daimler Chrysler Citaro buses
London	LHP, GLA, Mayor of London, Plug Power, BOC, London Development Agency	First application 2004	System available for non-grid connected applications, starting with Christmas Tree light, December 2004	PEMFC	5kW	Hydrogen cylinder	
Black Country Housing Group	Black Country Housing Group, Alternative Fuel Systems, BOC, DTI	System commissioned and trials underway.	CHP	Alkaline	4.4kWe	White spot H_2	
West Beacon Farm, near Loughborough	West Beacon Farm, Intelligent Energy, BOC	Operational	CHP	PEMFC	2kW	Hydrogen cylinder	
West Beacon Farm, near Loughborough	West Beacon Farm, Plug Power, BOC, siGEN	Operational	Power supply	PEMFC	5kW	Hydrogen cylinder	
Garston, Watford	Smart Energy Ltd, Carbon Trust, BRE – Watford, Air Products, Scottish and Southern	Commissioning scheduled for early 2005	CHP	Alkaline fuel cell with lead acid battery storage system	2.4kWe	Hydrogen cylinder	All key system parameters evaluated. Technical and economic factors involved in a hydrogen economy will be investigated

2.9 The UK in the global context

Fuel cells are a global technology, and developments and activities in the UK need to be considered in that context. This section provides an overview of the global landscape and the UK's position therein.

The total number of complete systems built and operated worldwide grew significantly between 2002 and 2003, from approximately 4,000 to 6,800 systems (70% growth). This cumulative number includes all systems built since the 1950s and refers to units capable of independent power generation. As described above, by the end of 2004, the UK had around 15 systems installed, a very small fraction of the total.

As far as international Intellectual Property Rights (IPR) records are concerned, around 5,000 patents relating to fuel cells had been granted worldwide by 2003, of which less than 80 belonged to UK companies. By contrast almost 400 belonged to German organisations and 1,900 to Japanese ones.

In terms of IPR outlook, patent applications over the three years to the first quarter of 2003 reflected a negligible UK share of approximately 1.5%; by comparison, Germany had a 13% share and Japan had a 12% share.

Government support

The world's leading countries in fuel cell development all benefit from substantial and sustained government support. This is helping to accelerate the rate of technology refinement, reduce the timescales for commercialisation and support the development of indigenous industries which are well placed to respond to the growing global market opportunities.

In the USA, there is a long history of federal support for fuel cells, and this has been reinforced in recent times with substantially increased Government funding. In particular, in his State of the Union Address in January 2003, President Bush proposed investment of $1.7B (£0.9B) over the next five years to reverse dependence on imported oil by developing hydrogen powered fuel cells, hydrogen infrastructure and advanced automotive technologies.

Canada has recently made substantial strides in building its fuel cell capability, with numbers employed in the sector up from approximately 200 in 1995/1996 to 1,800-2,000 in 2002. Similarly, R&D expenditure has grown from approximately C$20m (~£8.6m) in 1995/1996 to in excess of C$200m/year (~£86m) in 2002 (a ten-fold increase). The Canadian Government and industry are approaching fuel cell commercialisation and the hydrogen economy in a collaborative manner, which is paying dividends for all parties.

Japanese Government support for fuel cells is of the order of ¥33B (~£0.16B), of which the majority is currently dedicated to the PEMFC programme. The spend is across all sectors, from fundamental research through to demonstrations, which the Japanese Government is able to fund to 100%.

Japan has adopted a policy of target setting, with the following challenging targets in place:

Complete field tests of fuel cell vehicles	by 2005
Complete field tests of residential generators	by 2005
Market 50,000 fuel cell vehicles	by 2010
Market 5 million fuel cell vehicles	by 2020
Market 1.2GW of residential and commercial generation	by 2010
Market 10GW of residential and commercial generation	by 2020.

Overall levels of government funding across these three countries and China are as follows:

Country	Annual funding
US	$US350-450m (Federal and state) (~£185-235m)
Canada	$US20m (Federal plus some regional) (~£10m)
Japan	$US300m (~£157m)
China	$US15m (~£8m)

Although the levels of funding in the US and Japan are significantly higher than those in the UK, this can be partly attributed to the differences in the sizes of the economies and the magnitude of their automotive industry.

2.10 Summary

The UK initiatives described earlier provide a variety of types of support for the UK fuel cell community. Figure 2.9 below summarises this.

Figure 2.9 The roles of UK support organisations / initiatives

Organisation / initiative	Funding for academic research	Funding for indutrial research	Funding for demonstration	VC funding	Research centre	Research programme	Research consortium	Coordination, information etc.	International activity	Comment
EPSRC	•									
UKERC	•				•					Funded by Research Councils
SUPERGEN	•					•				Funded by EPSRC & CT
CCLRC								•		Funded by EPSRC
DTI Technology programme	•	•								
The Regions			•					•	•	
Fuel Cells UK								•		Funded by DTI
LowCVP								•		Funded by DTI
Cenex	•	•						•		Funded by DTI
Fuel Cells Forum								•		Funded by DTI
Carbon Trust (CT): R,D&D	•	•	•							
CT Incubator programme				•						
CT Venture capital				•						
CT Technology Acceleration			•							
SHFCA								•		Partly funded by SE
ITI Energy	•	•								Funded by SE and HIE

3 UK FUEL CELL STRENGTHS

3.1 Introduction

This Section explores areas of strength within the UK fuel cell community. It covers the full supply chain and all fuel cell technology areas. Strengths were identified through an analysis of relevant literature combined with knowledge of the sector.

The results are shown in the Figure 3.1 below. It can be seen that the level of UK activity is defined as either 'strong' (acting at a national or international level) or 'limited' (acting at a local or national level). The rankings for each cell reflect the position of companies within a specific part of the supply chain (defined by the Figure's axes), rather than the number of companies. Thus, wherever an internationally active UK company is present, the overall effect is 'strong activity'; conversely, if there are several national players but no international players the overall effect will be limited activity. Note that the rankings within this analysis take no account of the overall context of activity i.e. level of international competition.

The contents of the matrix were validated through consultation with the Fuel Cells UK Steering Group and wider UK fuel cell community.

A parallel matrix, presented in Appendix D, provides the underlying lists of companies covered by each cell in Figure 3.1.

Section 3.14 below comprises an outline of the UK market for fuel cells. This is included because the context within which supply side organisations (i.e. companies developing fuel cells and related components / materials) could have a significant impact on progress with both development and deployment in the UK.

3.2 SOFCs

The UK has several companies active in the development of SOFC systems. Key players include Rolls-Royce Fuel Cell Systems (medium to large-scale systems for stationary power generation) and Ceres Power (small-scale systems for various applications). There are also strengths in the supply of components and materials, with companies such as Precision Micro, Inco Special Products, Unitec Ceramics and MEL Chemicals all active.

There are particular strengths in SOFC research and development, with around 10 groups working on various aspects across the academic base. This activity has already resulted in the formation of at least two spin-out companies, with more likely to emerge.

3.3 PEMFCs

Intelligent Energy is a UK based PEMFC system developer acting at the international level, and Voller Energy is a manufacturer of portable fuel cell systems for industrial and military use, with distributors in Europe and the USA.

On the components side, Johnson Matthey is recognised as being 'world-class' in the supply of membrane electrode assemblies (MEAs) and catalysts (supplying around one third of all MEAs world-wide). Other component / materials suppliers include Ineos Chlor, ITM Power, Precision Micro and Victrex (note that Ineos Chlor and Precision Micro are active across most fuel cell technologies).

Through CD Adapco and Fluent Europe, both international companies with a UK presence, there is some capability in consultancy services around computational fluid dynamics modelling.

Research into PEMFCs is being undertaken within around eight organisations.

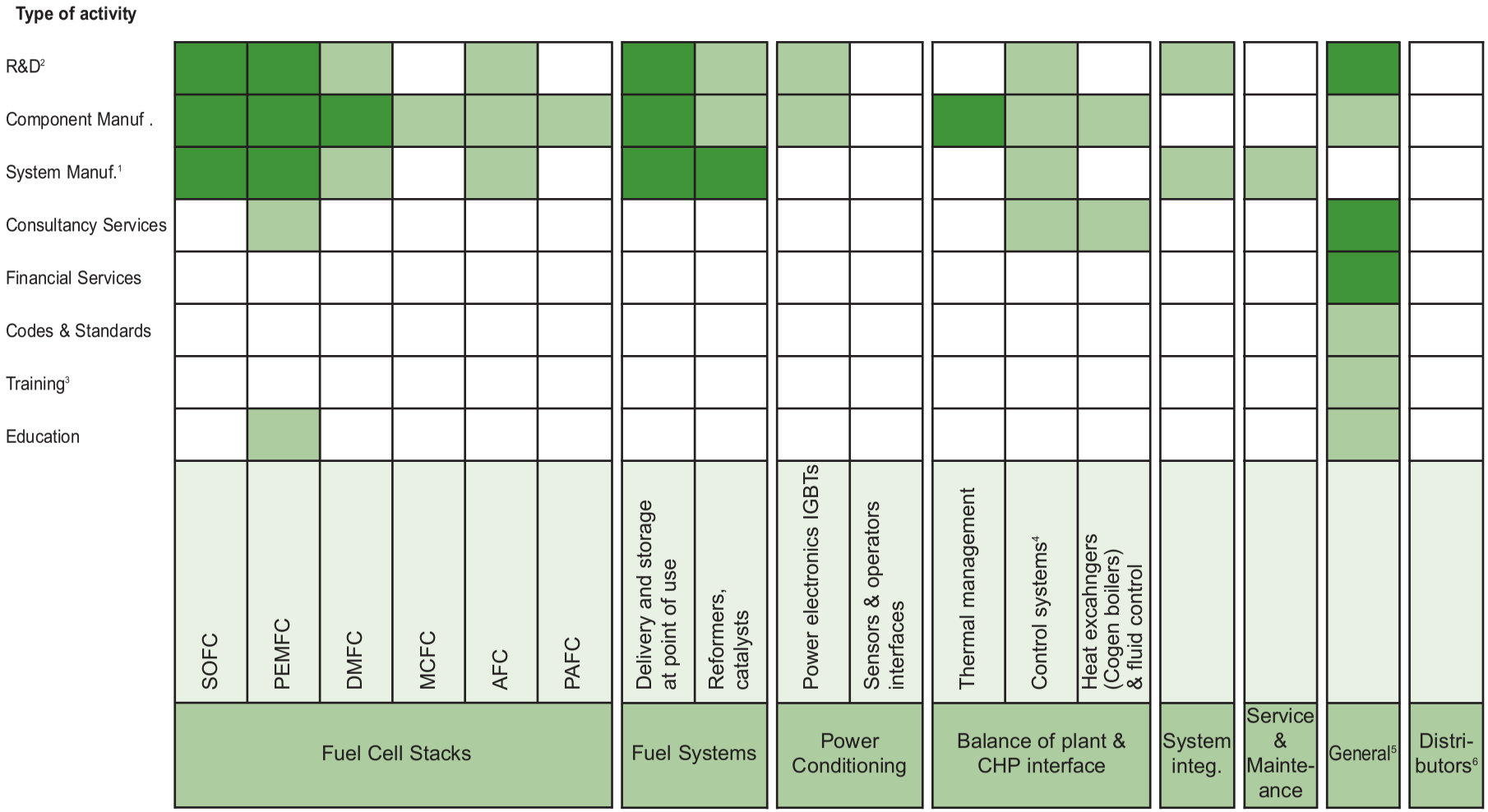
Training in fuel cell vehicles is offered as part of a degree course at Loughborough University.

3.4 DMFCs

The UK has limited activity in the development of DMFCs, with only one active company, CMR Fuel Cells. There are, however, several significant players supplying materials and components, particularly Johnson Matthey and Ineos Chlor. ITM Power and Precision Micro are also active in this area.

On the R&D side, there are around three groups active.

Figure 3.1 UK strengths along the supply chain.



Key

Strong activity (act at a national and international level)

Limited activity (act at a local or national level)

1 Includes developers that do not have large-scale manufacturing
2 Includes contract & academic R&D
3 Training for field engineers, fitters, etc.
4 Includes actuators, sensors & electronics
5 Encompasses organisations active across many parts of the supply chain (e.g. Consultancy for all fuel cell types)
6 Encompasses third party fuel cell distributors (e.g. Utilities)

3.5 MCFCs

Whilst there are no UK developers of MCFC systems, there is limited capability in components supply.

3.6 AFCs

There is limited AFC capability in the UK, with companies such as Alternative Fuel Systems and Eneco active in the development of systems, and a small number of component suppliers.

Among the research community, Cranfield University has interests in Alkaline Methanol Fuel Cells.

3.7 PAFCs

There is limited UK activity in the supply of PAFC components, but no system developers.

3.8 Fuel systems

The UK is home to international supply and storage companies. Stationary gas and liquid fuel storage and handling are strengths of global players such as BOC, BP, Shell and Air Products. There is also significant research activity in these areas, with around eight groups researching various types of fuel storage, including hydrides, nanostructures and other innovative materials.

The UK has a strong base of internationally competitive firms developing reformer systems technology. Intelligent Energy and Accentus are examples of the main proponents. There is also some capability in the supply of components, with players such as CATAL International and Johnson Matthey. Around eight academic groups are researching reformer technology.

3.9 Power conditioning

The UK has limited commercial and research activities around power electronics and insulated gate bipolar transistors (IGBTs).

3.10 Balance of plant (BoP)

The UK has strong activity in the area of thermal management, with Microtherm internationally active in projects with almost all of the major fuel cell manufacturers in Europe and the USA.

There is limited involvement in other aspects of balance of plant. Around five companies are active in control systems, and three in heat exchangers.

There is some research activity around control systems at QinetiQ and Strathclyde University.

3.11 Systems integration

Companies active in systems integration include siGEN and Voller Energy. At least five research groups are also active. This is considered an activity which is best carried out by ‘local’ companies (i.e. those with a presence close to the user).

3.12 Service and maintenance

The current limited servicing and maintenance activity in the UK reflects the development status of the industry.

3.13 General

This Section covers organisations which are active across many parts of the supply chain and / or many fuel cell applications e.g. consultancy for all fuel cell types. It also includes organisations addressing common issues, such as socio-economic aspects, market development etc. In this context, the UK has international recognised activity in research (e.g. Imperial College London, University of Glamorgan), general consultancy services (e.g. E4tech, Element Energy) and financial services (e.g. Conduit Ventures).

There is limited activity in components manufacture (e.g. Porvair, Gencoa), Codes and Standards (through the British Standards Institute and Health and Safety Executive) and education and training (with at least three universities offering general courses, or modules of courses, on fuel cells and hydrogen).

3.14 Distributors

As fuel cell commercialisation progresses, distributors, such as utilities, will play an increasingly important role. Utilities can be considered as one of the prime points at which the market will move forward. At present, however, many UK utilities are adopting a 'watching brief', and are not actively deploying or trialling fuel cell systems. This is, in many ways, a function of the state of development of the industry. It is worth noting that many UK utilities are in non-UK ownership, with greater levels of interest in fuel cell deployment elsewhere e.g. other parts of Europe.

3.15 The UK as a market for fuel cells

As mentioned in Section 3.1, the structure and strength of the early demand for fuel cells in the UK could have a significant impact on progress with development and deployment. This Section considers aspects of the UK as a market, and the general context within which supply side organisations operate.

Stationary applications

Many observers anticipate that stationary applications will represent a key early market for fuel cells in the UK. The UK is considered ahead of many of its counterparts in terms of de-regulation of stationary power, potentially providing greater flexibility for novel solutions. Furthermore, the UK has an extensive natural gas network, providing an established fuel infrastructure for fuel cells able to run on natural gas.

Distributed generation is of particular interest, with drivers such as increased demand for electricity, the need to replace existing infrastructure and infrastructure investment risk (many small installations versus one large one) all being relevant. The UK Government's 2003 Energy White Paper reiterated a commitment to achieve a target of 10GWe of good quality CHP capacity by 2010.

The evolution from a centralised to a distributed power generation infrastructure brings with it many challenges. To address these challenges, OFGEM and the DTI have established the Distributed Generation Coordinating Group (DGCG). Whilst progress is being made in areas such as two-way metering and charging / revenue structures, a number of issues remain outstanding. During its period of DTI funding, Fuel Cells UK has represented the interests of the UK fuel cell community on a DGCG Working Group focused on micro-generation solutions.

In Scotland, there is particular interest in the potential role of fuel cells as a buffer for intermittent renewables. This has yet to be demonstrated, and is likely to be of most benefit under specific conditions, such as remote island communities which currently need to import power.

Balanced against the positive features of the UK, there are a number of uncertainties and barriers:

- as mentioned above, at this stage there appears to be little enthusiasm among utilities to explore the potential of fuel cells;
- the low differential between electricity and gas prices makes the economic case less strong than it might otherwise have been;
- current good electricity grid coverage means that, in comparison with some other countries, there is little demand for remote non-grid connected applications; and
- there are no protocols for installation similar to those in place in relation to gas installations (i.e. CORGI registered installers).

Transport applications

The picture on the transport side is less promising than that relating to stationary applications. The UK is generally considered to be lacking in specific strengths relative to other countries, which are likely to attract deployment of fuel cell vehicles. Furthermore, unlike other countries, public financial incentives to demonstrate fuel cell vehicles are limited. However, the UK has been successful in participating in the European CUTE Project, which has lead to the deployment of three fuel cell powered buses, together with refuelling facilities, in London. It is hoped that this will provide the basis for further trials and demonstration activities.

Factors which might have a positive demand side role include the potential for congestion charging to favour very low or zero emission vehicles, public procurement commitments and rising fuel prices (although these are not unique to the UK).

As discussed above, the Low Carbon Vehicle Partnership is working to accelerate the shift to clean low carbon vehicles and fuels in the UK. During its period of DTI funding, Fuel Cells UK has represented the interests of the UK fuel cell community on the Low Carbon Vehicle Partnership.

Public awareness

There are currently no national public awareness raising activities around fuel cells in the UK. As a consequence, levels of awareness among both the public and decision makers (e.g. town planners) are relatively low.

Other demand side factors

As discussed above, the UK Regions are likely to play an increasingly important role in the deployment of fuel cells. Almost all of the installations to date have been initiated by the regions, and there is enthusiasm to support fuel cells where this is in line with regional objectives.

The UK's membership of the European Union could be a significant factor in the development of the demand side over the coming years. As mentioned above, projects emerging through the Hydrogen and Fuel Cell Technology Platform are likely to be particularly important.

The rate of development of codes and standards could influence the attractiveness of the UK as a location to install fuel cells. Other considerations notwithstanding, developers and promoters are more likely to select sites with clear guidance and requirements than those where the process is complex and unclear. Similarly, where there is a choice of technologies, those with established procedures may well be favoured. The UK has made some progress in this area:

- the Health and Safety Executive has published a guide to the installation of stationary fuel cells 'Fuel cells: Understand the hazards, control the risks'; and
- during its period of DTI funding, Fuel Cells UK represented the interests of the UK fuel cell community on the British Standards Institute's committee GEL/105, Fuel cell technologies, which links into international standards development.

The European Commission's State Aid provisions are often cited as a barrier to demonstration and trial activities in the UK. The types of trials currently in progress in Japan would not be possible under European State Aid rules.

4 UK FUEL CELL FOCUS

4.1 Introduction

This Section explores the UK's position in the global fuel cell landscape, and highlights areas where the greatest potential exists for the UK community to play its role. It specifically addresses the fuel cell industry, rather than the community as a whole.

The UK's potential is a function of UK strength, its global competitiveness and the likely size of the various markets for fuel cells.

The analysis builds on the material presented in Section 3, together with knowledge of global fuel cell activity (e.g. recent Global Watch technology missions to Canada, the USA and Japan) and data on potential future market sizes. To support the assessment of global competitiveness an outline evaluation of levels of global activity across the various elements of the supply chain and types of activity was undertaken. The results of this activity are presented in Appendix E.

The overall results of the analysis are shown in the matrix below (Figure 4.1). Results are disaggregated across three time-frames depending on when the various applications / markets are expected to reach the end of their rapid growth phase. This will differ depending on the technology and the circumstances of its application.

Note that the two axes are not quantified; the purpose is to summarise the position in general terms, and thus highlight the areas of opportunity. Gaps in UK capability – as shown by areas of large potential market size but where the UK has relatively little strength – are shown. Note that the level of UK capability is based on current strength and global competitiveness.

The contents of the matrix were validated through consultation with the Fuel Cells UK Steering Group and the wider UK fuel cell community.

4.2 SOFCs

SOFC applications fall into two main groups:

- Small SOFC systems: Remote power and APU (SOFC-S)
- Large SOFC systems: Large industrial scale and utility scale (SOFC-L)

Small scale systems are anticipated to be a smaller market than large scale systems. There are relatively few international competitors in the large scale market, and the UK is considered to be relatively well placed. Given the developmental status of the technology, the markets for small and large scale applications are expected to develop over the medium term.

UK suppliers of components for SOFCs are considered relatively well placed to compete in the global market place.

4.3 PEMFCs

In this case, a distinction is made between applications emerging in the short, medium and long term:

- Demonstrations and early niche applications (PEMFC System-1)
- Stationary power, CHP and fleets (PEMFC System-2)
- Mass market transport (PEMFC System-3)

The PEMFC supply base is considerably more competitive than that for SOFCs, with many systems developers working to establish a position. Whilst UK companies may be reasonably well placed for stationary power and military / portable applications in the short to medium term, they are expected to face substantial competition for automotive applications in the longer term. The latter are widely seen as the 'ultimate' market for fuel cells, offering very large volumes over time.

UK based PEMFC component suppliers are well placed to continue growing and supplying international systems manufacturers. This is perhaps the greatest area of potential for the UK, with ongoing scope to supply to developers of stationary and automotive applications. It is worth noting that the limitations to the global market size will be determined to some extent by the degree to which global system manufacturers source parts from suppliers or start manufacturing them in-house.

4.4 MCFCs

The UK has limited strength in the supply of components for MCFCs, and this is reflected in a relatively low capability. Furthermore, the market for large scale MCFC systems is expected to be relatively small, and the transition from demonstration to commercialisation is likely to happen after 2010.

4.5 DMFCs

DMFC based portable applications (e.g. PDAs, digital cameras etc.) are viewed by many as likely to be the earliest mass market opportunity for fuel cells, with some (mainly Japanese) companies planning to release products imminently. Furthermore, the market is expected to be relatively large over the medium term.

The UK's single DMFC system developer will face strong competition from major (again mainly Japanese) multinationals investing in this area. Medium to long term outcomes are likely to depend in part on the relative merits of UK based technology, and on the alliances and partnerships which are developed.

The UK has established suppliers of components for DMFCs, and the market for such components is, again, relatively large.

4.6 AFCs

The fuel purity requirements of AFCs imply speciality and niche deployment, with the overall market potential being small. Although the UK has only limited activity, the level of international competition is significantly lower than for other technologies / parts of the supply chain.

4.7 PAFCs

Whilst the UK has no PAFC systems activity, it does have strong activity in components supply. Internationally, the number of companies working on the technology has been decreasing, and it is unclear how cost performance can be improved further; hence the worldwide market potential for PAFC components appears to be limited.

4.8 Fuel systems

The first UK hydrogen refuelling station, opened in 2004 (see Section 2.8), is generating experience and market confidence in fuel delivery systems. Several internationally active UK firms are well placed to play a central role in global markets in this area.

Experience with conventional fuel storage systems implies limited scope for further cost reduction. In contrast, on-board storage is still at the R&D stage. Demonstrating reliable on-board storage systems in the medium term will be crucial for enabling transport fleets.

Whilst UK capabilities based on traditional storage applications are strong, the national long term position will be determined by the extent to which current strengths in research, particularly into aspects of storage relevant to automotive applications, are developed and exploited.

In the medium to long term, the established presence of internationally active companies should enable them to safeguard their competitiveness in delivery and conventional storage systems. Overall, fuel delivery and storage systems are areas of strength for the UK, with significant market potential.

The UK is similarly well placed in components for fuel delivery and storage. Whilst the overall market is expected to be significant, the opportunity for UK companies will depend, in part, on the extent to which existing and potential customers chose to manufacture in-house as the market develops.

Reformer systems represent another area of UK strength. For both stationary and automotive applications, the global market potential is significant; the ultimate size of the market is likely to depend on and be limited by the evolution of fuel production, storage and other fuel conversion technologies.

Reformer components comprise elements common to several applications. UK catalyst firms can create leverage as international component suppliers. Although this is an area of limited strength for the UK, the level of international competition is considered lower than in other parts of the supply chain. The global market potential is significant in the long term.

4.9 Power conditioning systems

Power conditioning systems are an area of limited UK activity. At this stage, it is difficult to evaluate how international competition in this area will develop, as companies currently supplying into other industries may reposition themselves as the market grows. In comparison to other parts of the fuel cell supply chain, the overall market for power conditioning systems is expected to be relatively small.

4.10 Balance of Plant (BoP)

Whilst the UK is well placed to supply thermal management components, there is more limited activity across other aspects of BoP. Given that BoP generally represents a small part of a fuel cell system, its overall global market potential is relatively small. It is worth noting that barriers to entry in this sector are relatively low, making it difficult to anticipate how the market, and the UK's position in it, will evolve over time.

4.11 Systems integration

The current level of UK system integration activity reflects the state of the industry's development. Overall future trends in system integration will vary according to the application, with some integration functions likely to continue to be performed by existing fuel cell and energy companies. The global market potential could be relatively large in the medium term, with activity across various applications.

4.12 Service and maintenance

Although UK service and maintenance activity is currently low, it could be anticipated to grow as the market develops. There is a sizable opportunity over the medium term.

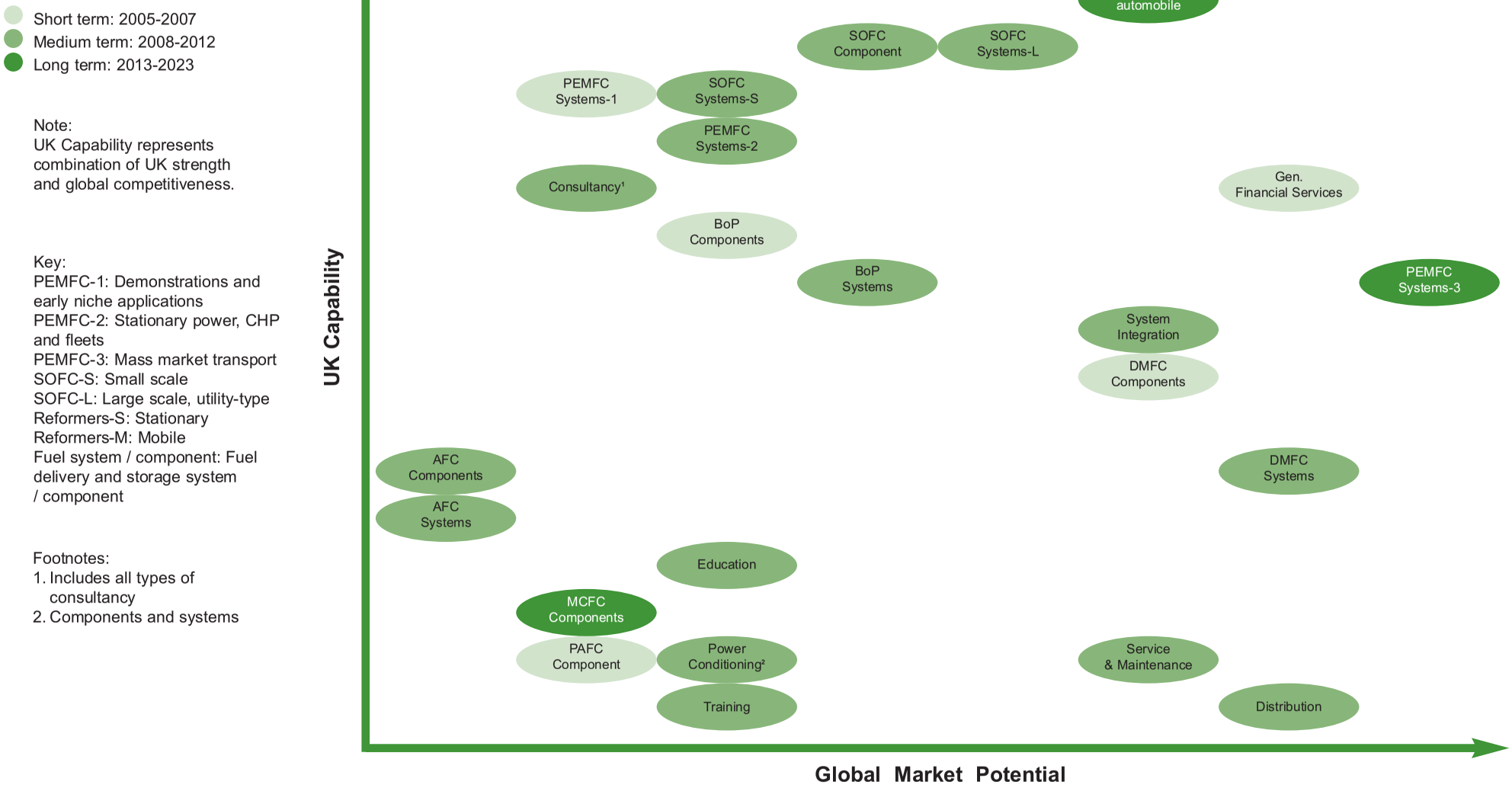
4.13 General

Whilst the UK has strong activity in consultancy and financial services, both areas are highly competitive internationally. Opportunities are expected to extend over the short to medium term, with financial services anticipated to be the more sizable market. Smaller opportunities are expected in the medium term in training and education; these are also areas where the UK is likely to face significant international competition.

4.14 Distributors

Current UK activity in this area is minor at present. However, the potential market size could be substantial and represents a significant opportunity for companies such as utilities. Distributors will form a crucial link in the supply chain which could enable (or hinder) timely deployment.

Figure 4.1 UK Global position



4.15 Summary

This Section highlights some of the key lessons from the analysis above and from Figure 4.1.

There are three areas of particular interest:

1. Areas where the UK has strong activity internationally and where the global market potential is high: these can be considered to represent the most attractive areas for UK activity on the basis of current capability;
2. Areas of high market potential but where the UK has relatively low activity internationally; these might be considered to represent gaps in UK capability; and
3. Areas where the UK has particular strengths which could be exploited in specialist or limited markets.

Strong UK capability and high market potential

The key areas of opportunity are as follows:

Short Term	Medium Term	Long Term
Financial services	Fuel delivery and storage systems	Automotive reformer systems
	Stationary reformer systems	Reformer components
	Large SOFC systems	
	PEMFC components	

High market potential and low UK capability

The following areas represent those which merit further discussion as to whether the UK wants to improve its competitive position, given the scale of the opportunity:

Short Term	Medium Term	Long Term
DMFC components	DMFC systems	Mass market PEMFC systems (primarily automotive)
	System integration	
	Service and maintenance	
	Distribution	

Low market potential and high UK capability

The following areas represent those where the UK is currently strong, and could build on this, albeit in markets with less potential than those highlighted above:

Short Term	Medium Term	Long Term
PEMFC Systems – early / niche markets	Fuel delivery and storage components	
BoP components	SOFC components	
	PEMFC systems – stationary power, fleets etc.	
	SOFC small systems	
	Consultancy	

5 CHALLENGES FACING THE UK, AND STRATEGIES AND ACTIONS TO OVERCOME THEM

5.1 Introduction

Previous sections of this roadmap have explored the current UK position in the global fuel cell landscape. Areas of high UK strength (including some world-class companies) within significant future markets have been highlighted, as have areas with potential due to specific UK expertise, or substantial opportunity.

This Section represents the heart of the Roadmap, and describes in detail the challenges facing the UK fuel cell community and the strategies and actions needed to overcome them. The material represents the result of a comprehensive programme of consultation with the community, combined with analysis and validation.

The resolution of the challenges will require action by the full range of fuel cell stakeholders. Many of the challenges are inter-related, and so a cohesive approach involving concerted effort over the coming years is required.

The challenges facing the UK are, in some cases, common with other countries. However, the context defined by the current state of the UK industry, the policy framework and a variety of other factors highlight the need for a tailored and specific set of actions.

Defining challenges

The challenges facing the UK were defined at a workshop for fuel cell stakeholders. The workshop was designed to be as participative as possible, with attendance reflecting the full range of informed perspectives. Emphasis was placed on building on areas of UK strength and closing gaps in UK capability where appropriate. Preparatory work involved the development of a series of 'Challenge Areas' within which challenges were to be categorised.

Following the workshop, analysis was undertaken to refine challenges, minimise overlaps, improve clarity and confirm grouping. The revised material was the subject of electronic consultation with the fuel cell community, and validation with the Fuel Cells UK Steering Group.

The challenges identified through this process were grouped into four categories:

- Regulation and policy
- Market development
- Education, training and awareness
- Technology development (industry and research community).

Specifying strategies and actions

The routes to resolving the challenges facing the UK cover each of the following elements:

- The desired outcome
- The strategy for its achievement
- The specific actions involved
- The champion or leading stakeholder responsible for the actions
- The anticipated timing of actions.

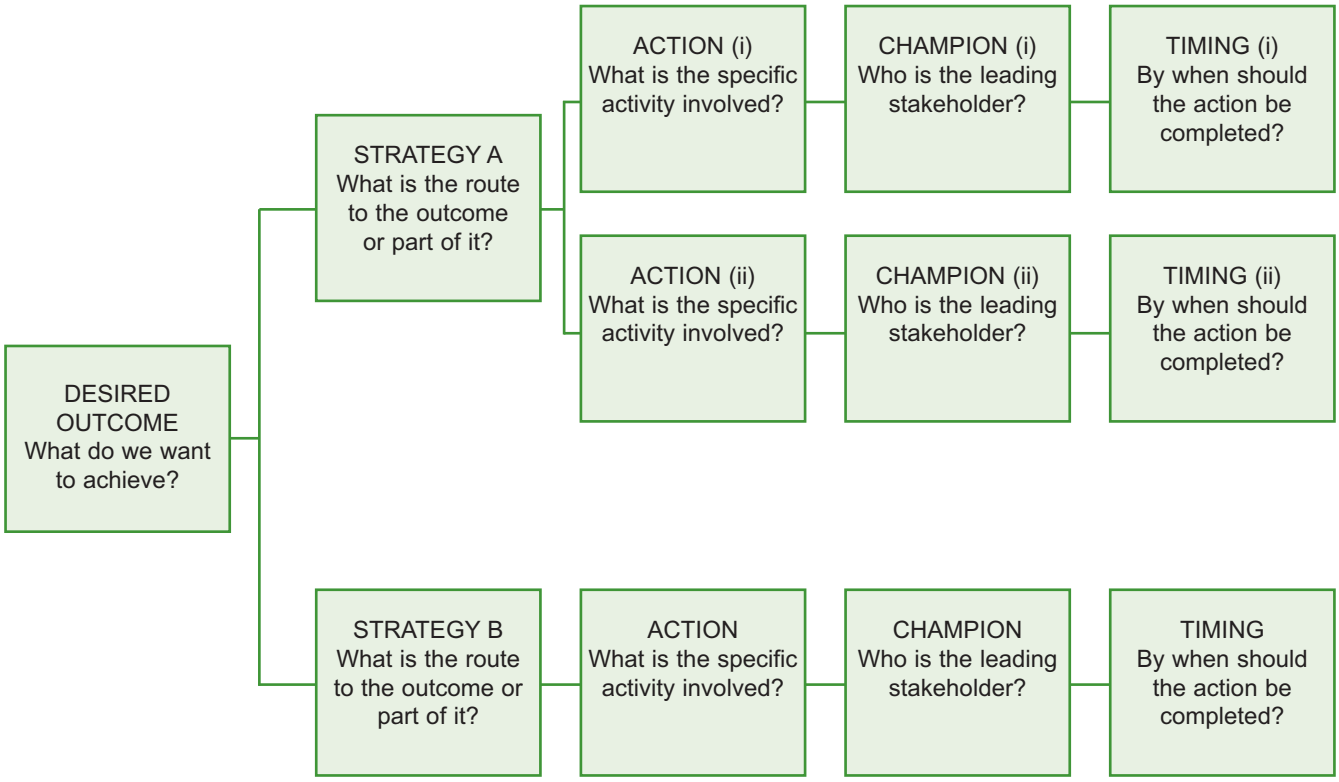
These elements were defined at a second workshop, which built on the first in terms of constituency and groupings. The workshop was designed to draw on the expertise provided by the individual participants. To ensure the highest quality outcomes, some preparatory work was undertaken; this comprised the elaboration of preliminary material for discussion and development.

The outputs from the workshop were consolidated, refined and validated through consultation with other stakeholders where appropriate. The revised material was the subject of a further round of electronic consultation before finalisation.

Note that the nominated champions represented the collective views of the fuel cell community and not any form of commitment on the part of the named organisations.

Figure 5.1 below shows how the various elements defined through the workshop process fit together. For some of the challenges there was more than one strategy for its resolution, and for a proportion of the strategies there were a number of underpinning actions. Time periods are specified as short (2005-2007), medium (2008-2012) or long term (2013-2023), or, where there is either a need for sustained action across periods or for action beyond the long term, ongoing.

Figure 5.1 Linking challenges and routes to their resolution



5.2 Regulation and policy

The regulation and policy challenges facing the UK are:

1. Lack of market pull
2. Ensuring that benefits of fuel cell systems are fully accounted for
3. Lack of clear and cohesive policy
4. Overcoming the funding gap (or 'valley of death') between R&D and commercialisation
5. Adapting regulatory framework to enable the introduction of Distributed Generation (DG)
6. Facilitating the deployment of fuel cell vehicles (FCVs) in the UK
7. Insufficient access to market-based mechanisms
8. Ensuring policy develops in line with evolving market conditions
9. Ensuring that opportunities at European level are realised
10. Lack of recognition of UK strengths amongst potential international partners
11. Developing codes and standards framework
12. Adapting planning consent procedures for fuel cells and related infrastructure
13. De-risking large scale FC projects to encourage private investment beyond demonstration phase
14. Uncertainty around imported versus home-grown technology

Figure 5.2, towards the end of this Section, shows the strategies and actions needed to overcome these challenges, together with timescales and champions.

A key, underpinning challenge is the need to present a compelling case to Government, encompassing politicians and civil servants. As discussed in Section 1, fuel cells have the potential to make a substantial contribution across a range of priority policy areas, namely: CO_2 abatement, energy security, local pollution reduction, fuel poverty and industrial development. The actions needed to deliver high level political buy-in are listed under challenge 3 in Figure 5.2, and include the engagement of a political champion to drive the fuel cells agenda through Whitehall, as well as the establishment of a Fuel Cell Coordination Group. This Group would work across government departments to ensure that discontinuities and overlaps across government are minimised. It should also become the champion (in collaboration with relevant departments and other bodies) for a wide range of actions identified in this Roadmap.

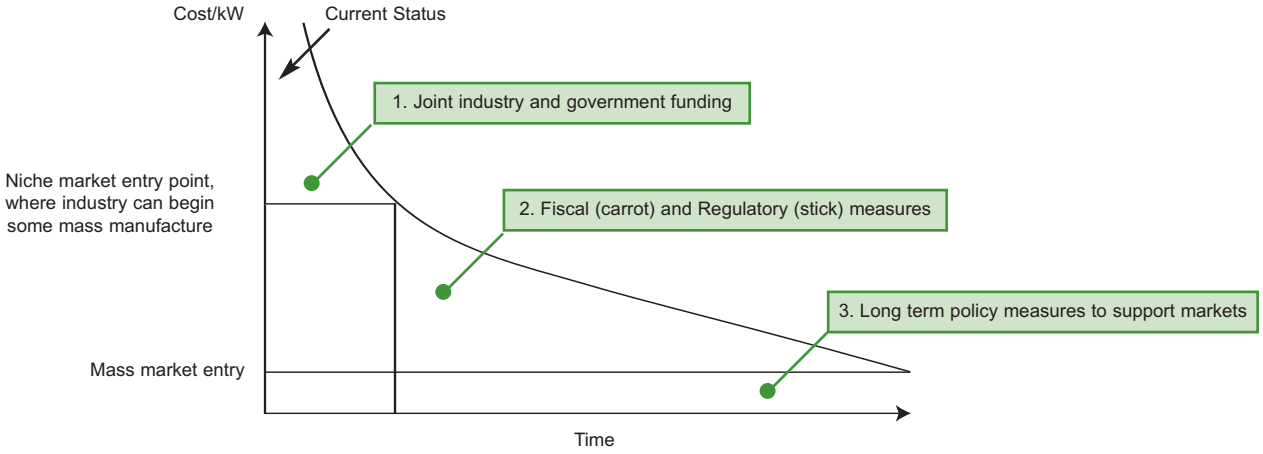
In order to make an effective case for fuel cells, and to optimise its impact, there is a need to clarify the policy mechanisms and support which are required to overcome the current barriers in the UK. In broad terms, the policy framework should help to:

1. Establish a market for fuel cells in the UK in order to achieve energy security and CO_2 abatement policy objectives; and
2. Stimulate the growth of a competitive fuel cell industry in the UK

The required policy framework

Policy requirements, as highlighted by the UK fuel cell community, will change as the industry evolves. This is illustrated in Figure 5.3 (note that different applications will have different entry points, although the overall shape of the curve will be common).

Figure 5.3 Evolving policy requirements



The curve is divided into three regions.

1. The first is the current period, where high costs and immature technology mean that there are very few economically viable markets for fuel cell technology. In order to stimulate production and technology improvement, it is necessary to provide direct funding for research and to allow deployment and learning about products in the field. Without this funding, there will be little incentive for companies to invest in manufacture and product development. Support should be direct and shared between government (to stimulate the industry) and industry (with a view to future profits).
2. The second is the stage where an increasing range of products, extending beyond early niches, becomes competitive. At this stage, industry is prepared to commit to developing manufacturing infrastructure, but needs to see a stable regime which supports the deployment of its product in an increasing number of applications, and where risk is minimised. The support here needs to be regulatory, to force deployment, and fiscal, to incentivise deployment and continued improvements.
3. In the long term, the technology will reach costs which make it competitive in mass markets. To progress towards these markets, it is clearly necessary to have a long term policy commitment, which seeks to ensure that barriers are eliminated.

A key requirement will be for early commitment to appropriate support at all three stages. The specific commitments needed are shown in Figure 5.2.

5.3 Market development

The market development challenges facing the UK are:

1. Removing barriers to DG
2. Lack of obvious, economical, low-volume, low-price sensitivity early applications
3. Optimisation of UK position in global supply chain
4. Lack of incentives to establish fuel cell supply chain companies in the UK
5. Creating long-term investor confidence
6. Lack of market champion

7. Accelerating the availability of reliable, affordable fuel cells
8. Minimising perceived financial risk
9. Exploiting overlaps with other industries critical to the fuel-cell value chain (e.g. materials development)
10. Lack of unified industry voice to influence policy
11. Optimising UK position in the global FCV supply chain
12. Integration of distributed generation systems into electricity networks and infrastructure

As can be seen, these challenges encompass both market pull and optimisation of supply chain elements. Figure 5.4 towards the end of this section shows the strategies and actions needed to overcome them, together with timescales and champions.

Clearly, market development will depend to a significant degree on policy developments, and there are strong cross-linkages. Awareness raising across a broad range of stakeholders will also be important; this is covered below.

5.4 Education, training and awareness

The different types of education, training and awareness challenges facing the UK are shown in Figure 5.5.

Figure 5.5 Education, training and awareness challenges

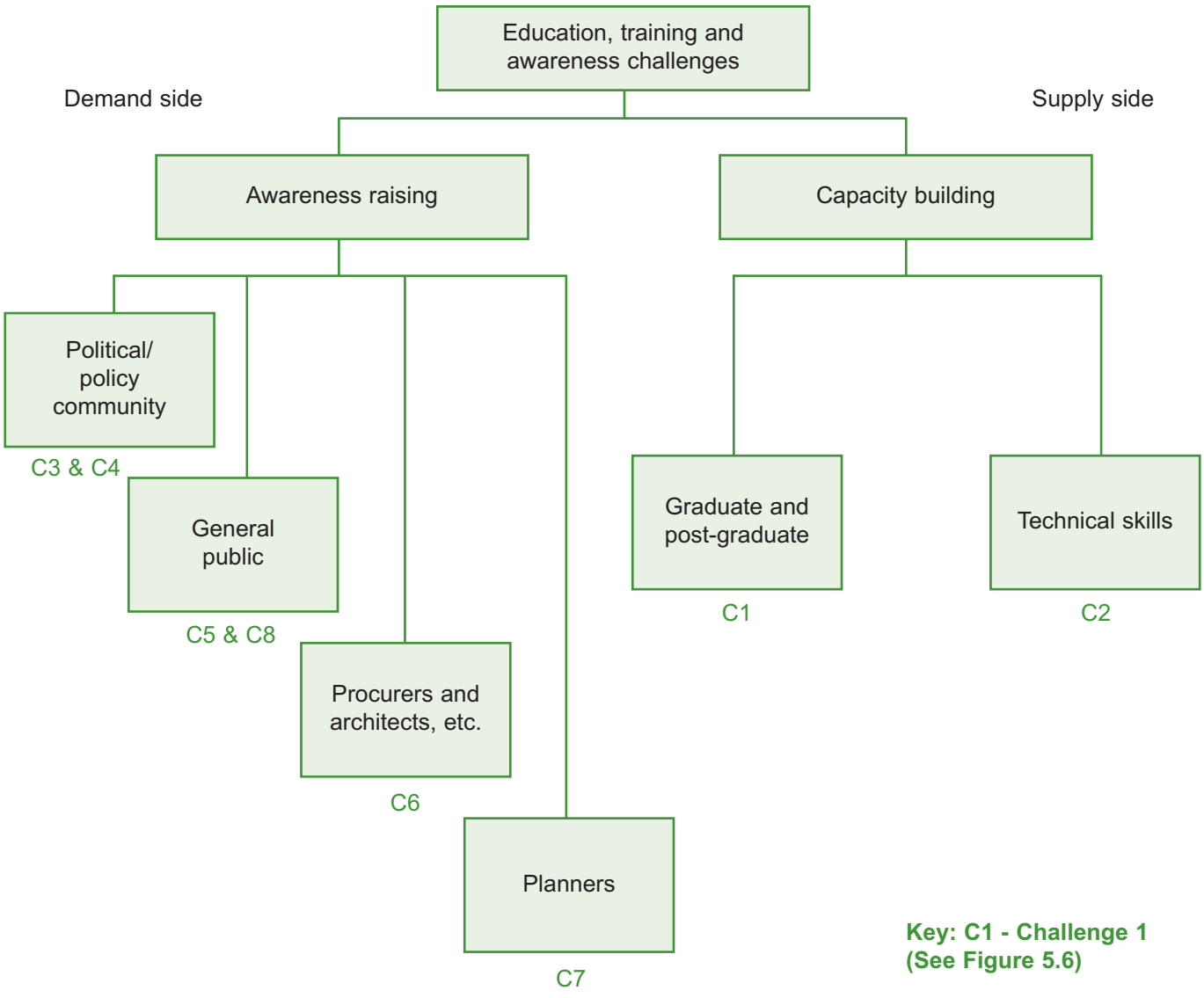


Figure 5.6, towards the end of this Section, shows the strategies and actions needed to overcome both supply and demand side challenges, together with timescales and champions.

In terms of supply side / capacity building, the underlying philosophy is to focus on training required to meet UK needs, taking account of skills that could be acquired from elsewhere.

5.5 Technology development

The technology development challenges facing the UK are:

Industry:

1. Resolving specific technology challenges (see Research community challenges 1-10 below)
2. Optimising manufacturability of all fuel cell types
3. Optimising the installability of all fuel cell types

Research community:

1. Achieving acceptable cost levels for stacks
2. Achieving acceptable durability / performance levels for stacks
3. Achieving mass and volume reduction for fuel cell systems
4. Developing fuel cell systems capable of fuel flexibility (including reforming options)
5. Achieving higher temperature operation for PEM stacks
6. Developing materials for intermediate temperature SOFCs
7. Increasing hydrogen storage capability to levels which extend vehicle range to acceptable levels
8. Developing reversible fuel cells to address renewable intermittency
9. Developing low weight gas regulators
10. Ensuring cohesion between fuel cell and hydrogen research activities

Figures 5.7 and 5.8, towards the end of this Section, show the strategies and actions needed to overcome these challenges, for industry and the research community respectively. As might be expected, there are strong overlaps and linkages; the fuel cell community was particularly keen to see coordination between industrial and academic research.

An overarching strategy and set of actions were defined to cover all challenges for the research community.

It can be seen that the technology challenges are largely aligned with areas where the UK is well placed to compete in potentially significant markets (see Section 4.15 above).

A key success factor was considered to be ongoing buy-in from Government, not only in terms of funding, but also with respect to overall commitment and support.

Note that with the scope of this Roadmap limited to the fuel cell system and fuel delivery and storage at the point of use, the technological challenges around the wider development of a hydrogen infrastructure were explicitly excluded.

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
1. Lack of market pull	A significant market for fuel cells in the UK leading to a competitive UK fuel cell industry	Foster significant deployment of fuel cells in the UK in various applications and situations. The EU has established deployment targets; the achievement of deployment in the UK equal to one fifth of such targets is considered to be a realistic aspiration, assuming an appropriate support framework. It would mean that the following levels were reached: *Niche applications*[1]: By 2006 – Total deployed FCs – 1MW By 2008 – Total deployed FCs – 6MW By 2012 – Total niche FCs – 40MW *Stationary*[2]: By 2008 – Total deployed FCs – 1MW By 2010 – Total deployed FCs – 5MW By 2012 – Total deployed FCs – 120MW *Vehicles:* By 2010 – '00s vehicles By 2015 – '000s vehicles Consider long-term indicative targets, for example: - 5% of electricity generation from FCs by 2020 - 5% of new car sales as FCVs by 2020 - 20% of fleet vehicles as FCVs by 2020	i) Introduce support mechanisms, such as Capital Grants, to offset the risk of early deployment. Such support mechanisms should recognise the contribution of fuel cells to policy objectives and balance the cost of fuel cell technology against established technology. They could build on existing mechanisms (e.g. £3,000/kW for photovoltaics) and be delivered, for example, through the forthcoming Low Carbon Buildings Programme.	i) Fuel Cell Coordination Group in collaboration with Treasury and other relevant government departments (see Challenge 3)	i) Short term
			ii) Ensure that any support mechanisms are technology blind and linked only to certain performance criteria (agreed levels of reliability / efficiency, contribution to policy objectives etc.). iii) Ensure that the opportunities for any support mechanisms to take advantage of the significant budgets being discussed within the EC for stimulating deployment are optimised (See Challenge 9).	ii - iii) Fuel Cell Coordination Group supported by Fuel Cells UK	ii - iii) Short to medium term
			iv) Implement a fuel cells case study as part of the public procurement initiative currently under development (see Section 6).	iv) Environmental Industries Unit (EIU)	iv - v) Short to medium term
			v) Broker the interaction between technology producers, policy objectives and potential stakeholders involved in the public procurement initiative to manage risk.	v) In the case of automotive applications: Cenex; in the case of other applications: RDAs	
			vi) Consider the development of larger scale public procurement commitments to build on the outcomes of the case study.	vi) Fuel Cell Coordination Group (see Challenge 3)	vi) Medium term

[1]Promising niches are those where specific FC attributes become competitive with incumbent systems e.g. rapid response (in UPS) and ability to operate indoors (forklifts)
[2]Encompassing small or large CHP and stationary power generation

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
1. Lack of market pull (continued)			vii) Ensure that market instruments conducive to achieving the significant deployment extend to public procurement and application (See Challenge 7).	vii) Fuel Cell Coordination Group (See Challenge 3)	vii - viii) Short term
			viii) Ensure that low CO_2 targets for new Government buildings contained in Energy Efficiency Action Plans remain challenging but attainable in light of technology development	viii) Central, regional and local Government	
			ix) Implement specific mandates (e.g. air quality zones, curfews, fraction of vehicle fleets) that can be used to initiate uptake (See Challenge 6).	ix) Fuel Cell Coordination Group (See Challenge 3) in collaboration with RDAs	ix) Short to medium term
			x) Incorporate learning from best practice worldwide on measures to support and stimulate the early FC markets (See Challenge 8).	x) Fuel Cell Coordination Group supported by Fuel Cells UK	x) Ongoing
2. Ensuring that benefits of fuel cell systems are fully accounted for	A policy framework which fully reflects benefits that fuel cells can bring	Ensure that policy decision making is based on: - Life cycle analysis costs; and - Evolving methodologies to account for externalities and social benefits of fuel cells.	i) Develop processes to evaluate and weight contribution of policy decisions, including public procurement, to: - CO_2 reduction - Energy security - Job creation/international competitiveness - Pollution reduction - Fuel poverty alleviation	i) Fuel Cell Coordination Group (See Challenge 3)	i - ii) Ongoing
			ii) Ensure that these processes are applied rigorously and transparently.	ii) Fuel Cell Coordination Group in collaboration with Department for Environment, Food and Rural Affairs (Defra), EIU, DfT and DTI	

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
2. Ensuring that benefits of fuel cell systems are fully accounted for (continued)			iii) Formalise procedures for disseminating performance data on new solutions with respect to the parameters listed in (i) (e.g. through a 'New Technology Procurement' website).	iii) Fuel Cell Coordinating Group	iii) Short term
3. Lack of clear and cohesive policy	Buy-in at the highest political levels leading to a cohesive and transparent approach to the development and deployment of fuel cells across government departments and other key public sector stakeholders	a. Foster political leadership. b. Provide focus for government fuel cell related responsibilities. c. Provide coordination of regional fuel cells and hydrogen activities. d. Synchronise activities of fuel cell and hydrogen coordination initiatives. e. Safeguard long term strategic value of policy instruments.	i) Establish a Fuel Cell Coordination Group within government to define and unite government interests in fuel cells. Ensure that such a group has clear linkages to and transparent relationships with all relevant government departments and public sector stakeholders with responsibilities / activities relevant to fuel cells, as well as powers to work with these bodies to ensure that discontinuities and overlaps are minimised. (Strategy: a and b)	i) Government	i - v) Short term
			ii) Engage the Parliamentary Office of Science and Technology in the debate on opportunities for fuel cells. (Strategy: a)	ii) Fuel Cells UK	
			iii) Undertake high level advocacy and communications campaign highlighting CO_2 abatement and energy security benefits. (Strategy: a)	iii) Fuel Cells UK in collaboration with industry	
			iv) Identify political champion at parliamentary level and develop plan for engaging them. (Strategy: a)	iv) Fuel Cells UK	
			v) Establish a Parliamentary Committee on technical solutions to energy security and CO_2 abatement ideally as part of PRASEG. (Strategy: a and d)	v) PRASEG in collaboration with Fuel Cells UK and the Parliamentary Office of Science and Technology	

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
3. Lack of clear and cohesive policy (continued)			vi) Establish regional Task Force to deliver outcomes which are both in line with regional objectives and are optimal for the UK. (Strategy: a and d)	vi) RDAs, Fuel Cells UK	vi) Short term
			vii) Undertake review of current policy and support to highlight opportunities for greater synergy and cohesion. Revise policy as appropriate and in response to this Roadmap and the Fuel Cells Vision for the UK published in 2003. (Strategy: b and e)	vii) Fuel Cell Coordination Group	vii) Ongoing
			viii) Develop fuel cell portal to clarify and provide guidance on support for fuel cell research in the UK. (Strategy: b and d)	viii) Fuel Cells UK in collaboration with Government and funding bodies	viii) Short term
			ix) Ensure demonstrations have maximum impact on public opinion. (Strategy: c and d)	ix) Fuel Cell Coordination Group in collaboration with RDAs, local government and industry, with support from Fuel Cells UK	ix) Medium term
			x) Clarify roles of fuel cell and hydrogen coordination initiatives. Identify and remove duplication. Disseminate guidance for the UK fuel cell community on the roles of and interplay between the various initiatives. (Strategy: d)	x) Fuel Cells UK, Fuel Cells Forum, H2Net and SFCHA	x) Short term
			xi) Develop support measures for fuel cells with clear commitments against specific dates (e.g. define number of installations eligible for Enhanced Capital Allowance within specified time periods). (Strategy: e)	xi) Fuel Cell Coordination Group	xi - xii) Ongoing

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
3. Lack of clear and cohesive policy (continued)			xii) Ensure market mechanisms (see Challenge 7) provide stable market conditions over the long term (e.g. by specifying duration of applicability) (Strategy: e)	xii) Fuel Cell Coordination Group	
4. Overcoming the funding gap (or 'valley of death') between R&D and commercialisation	Trial of prototypes and demonstration of semi-commercial products supported through structured programme.	Provide appropriate support to ensure that viable technologies do not fail due to the 'valley of death' phenomenon.	i) Develop UK trial programme to prove performance in real world conditions, and to input to further product development. See (ii) for process steps (excluding public awareness raising).	i) Fuel Cell Coordination Group (see Challenge 3) in collaboration with RDAs, local government and industry	i) Short term
			ii) Develop UK shared-cost demonstration programme involving central, regional and local government, together with industry, to validate the technology and gain public recognition and acceptance: - Encourage partnering and collaboration as basis for demonstrations. - Explore scope to link into EC initiatives (See Challenge 9). - Minimise planning consent procedural costs for demonstrations using experience from first installations (e.g. Woking and Teesside). - Where appropriate, build on existing fuel infrastructure to create early successes. - Where appropriate, size and locate demonstrations so that they can form part of an evolving network. - Focus early vehicle demonstrations on fleet applications. - Ensure that outcomes from demonstrations feed into codes and standards development, planning policy, and public awareness and education initiatives.	ii) Fuel Cell Coordination Group (See Challenge 3) in collaboration with RDAs, local government and industry	ii) Medium to long term

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
4. Overcoming the funding gap (or 'valley of death') between R&D and commercialisation (continued)			- Implement mechanisms to learn from progress elsewhere (e.g. overseas missions). - Encourage participation by UK companies in all aspects of demonstration.		
5. Adapting regulatory framework to enable the introduction of Distributed Generation (DG)	Barriers to DG understood and overcome	a) Remove infrastructural, institutional and policy barriers to DG. b) Remove disincentives to utilities to become involved in fuel cell supply chain. c) Clarify and communicate benefits of DG.	i) Revise energy trading mechanisms: - Ensure that distribution charges fully recognise the value which DG brings. - Introduce simple standards for metering, settlement and export rewards, together with appropriate enabling mechanisms (e.g. simplified contracting and cost-reflective pricing). - Develop and demonstrate technical solutions to health and safety issues (e.g. around the operation of islanded sections of a distributed network, and separation distances), building on the expertise of utilities and existing technology providers. - Enable simple connection arrangements for domestic and small scale commercial / industrial fuel cell systems. (Strategy: a and b) ii) Introduce an obligation on suppliers to offer terms to stimulate distributed generation. (Strategy: a) iii) Encourage utility involvement, validate technology, establish benefits, test applicability of measures described in (i) and provide basis for further policy revision as appropriate by supporting field trials of fuel cell based DG. Depending on outcomes, consider extension to demonstration programme. (Strategy: a, b and c)	i - ii) DTI supported by 'Distribution Committee' and Electricity Networks Co-ordinating Group (ENCG) (due to replace Distributed Generation Co-ordinating Group DGCG in 2005), Micropower Council and Fuel Cells UK iii) Fuel Cell Coordination Group (see Challenge 3)	i - iii) Short term

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
5. Adapting regulatory framework to enable the introduction of Distributed Generation (DG) (continued)			iv) Ensure that outputs from the Association for the Conservation of Energy (ACE) and the Energy Saving Trust (EST), such as the Strategic Review of the Community Energy Programme, are incorporated into policies to incentivise integration of DG into energy systems. (Strategy: a and b)	iv) Fuel Cell Coordination Group (See Challenge 3)	iv) Short term
			v) Develop specific mechanisms through, for example, EU Emissions Trading Schemes, Enhanced Capital Allowance (ECA), carbon tax (e.g. fuel duty) and market instruments to support DG (See Challenge 7). (Strategy: a and b)	v) Fuel Cell Coordination Group (See Challenge 3)	v) Short to medium term
			vi) Simplify planning consent procedures for fuel cells and related infrastructure (see Challenge 12). (Strategy: a)	vi) Office of the Deputy Prime Minister (ODPM) in collaboration with Fuel Cells UK	vi - vii) Short term
			vii) Disseminate results of Carbon Trust small CHP trial. (Strategy: c)	vii) Carbon Trust, Defra, CHPA	
			viii) Undertake review of Building Regulations to identify any barriers to the deployment of fuel cells and revise accordingly. (Strategy: a)	viii) ODPM with support from Fuel Cells UK and HSE	viii) Now
			ix) Ensure that regulations reflect real world experience by improving liaison mechanisms between Architectural, Civil Engineering and Town Planning professional bodies, Combined Heat and Power Association (CHPA) and its international counterparts, HSE and the fuel cells community. (Strategy: a)	ix) Fuel Cells UK	ix) Short term

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
5. Adapting regulatory framework to enable the introduction of Distributed Generation (DG) (continued)			x) Introduce innovation remits which would require utilities to invest in future technologies and undertake innovative projects. (Although the regulators have significant influence on operating companies, their short time horizon (5 years) can mean that long term new technology options are overlooked.) (Strategy: b)	x) OFGEM	x) Ongoing
6. Facilitating the deployment of fuel cell vehicles (FCVs) in the UK	A significant market for fuel cell vehicles in the UK	Develop mechanisms to support deployment of fuel cell vehicles in the UK (see Challenge 1).	i) See Challenge 1.	i) See Challenge 1	i) See Challenge 1
			ii) Participate in EU funded demonstration projects: - support RDA and private sector involvement (including facilitation and guidance with applications) - provide mechanisms for transfer of learning to UK - explore mechanisms to provide long-term benefit to the UK beyond life of demonstration projects.	ii) Cenex in collaboration with Central government, RDAs, industry and Fuel Cells UK	ii - iii) Ongoing
			iii) Provide long term incentives for low carbon transport, e.g.: - tax incentives or grants for low carbon vehicle ownership (could be administered by EST) - low or zero emission zones and similar (e.g. exemption of low carbon vehicles from Congestion Charging schemes) - maintain zero rate fuel duty on hydrogen and other novel fuels used in FCVs for as long as required - explore opportunities for low carbon fuel obligation - public procurement initiatives (e.g. Government leasing FCVs).	iii) Low Carbon Vehicle Partnership in collaboration with Central government, Energy Saving Trust, regional and local government	
			iv) Explore benefits of and mechanisms for transport to be included in the European Emissions Trading Scheme (EU ETS).	iv) Defra	iv) Short to Medium Term

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
7. Insufficient access to market-based mechanisms	Portfolio of complementary market mechanisms to provide long term support for the development and deployment of fuel cells	Adapt market mechanisms to reflect benefits which fuel cells bring.	i) Explore options for extending the Renewable Obligation Certificate scheme to allow a small proportion of highly innovative electricity generation (beyond renewables), with significant potential to deliver benefit, to receive a greater incentive (e.g. 20p/kW).	i) Defra	i - ii) Short term
			ii) Ensure that fuel cell installations benefit from Levy Exemption Certificates (LECs).	ii) Fuel Cells UK	
			iii) Factor the role of fuel cells into renewable energy systems eligible for Renewable Energy Guarantees of Origin (REGOs) (e.g. biofuels-fuelled systems) as well the potential for emissions trading of bundled installations.	iii) ENCG with support from Fuel Cell Coordination Group (see Challenge 3)	iii) Short to medium term
8. Ensuring policy develops in line with evolving market conditions	Flexible and responsive policy framework	Introduce mechanisms to integrate lessons from national and international experience into the evolving policy framework.	i) Where appropriate adopt international best practice in removing regulatory barriers to fuel cell development and deployment, including fuel infrastructure aspects.	i - ii) Central Government, led by Fuel Cell Coordination Group (see Challenge 3)	i - iv) Ongoing
			ii) Support UK learning from international activity (e.g. demonstrations and procurement initiatives) by funding International Missions etc.		
			iii) Ensure that lessons from trials, demonstrations and research are fully understood and reflected in evolving policy framework through periodic briefings and updates to Departments, Ministries and Parliamentary Office of Science and Technology.	iii) Fuel Cells UK	
			iv) Undertake periodic and systemised review of general and specific policy.	iv) Central Government (led by Fuel Cell Coordination Group)	

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
9. Ensuring that opportunities at European level are realised	Optimal UK participation in EC funded initiatives	Introduce mechanisms to ensure that opportunities for UK participation in EC funded initiatives are maximised.	i) Develop central coordination and guidance point as interface between UK fuel cell community and EC.	i) Fuel Cells UK	i - iii) Short term
			ii) Raise profile of organisations and initiatives well placed to participate in HYCOM, HYPOGEN and other EC activities.	ii) Fuel Cells UK	
			iii) Assist with preparation of applications to participate in initiatives.	iii) Fuel Cells UK	
			iv) Provide appropriate support for UK projects to improve likelihood of success in bidding for EC funds.	iv) Government (national and regional)	iv) Ongoing
10. Lack of recognition of UK strengths amongst potential international partners	UK strengths fully recognised in the international arena; partnering and collaboration opportunities optimised	Promote UK strengths with potential international partners and other stakeholders. Foster inward investment.	i) Ensure that International Technology Promoters are fully aware of UK strengths.	i) Fuel Cells UK	i - vii) Ongoing
			ii) Utilise services of UK Trade and Investment to improve scope for international business.	ii) UK companies	
			iii) Update 'Capabilities Guide' regularly.	iii) Fuel Cells UK	
			iv) Provide single point of contact for UK Fuel cell community.	iv) Fuel Cells UK	
			v) Represent UK fuel cell community at international events.	v) Fuel Cells UK	
			vi) Promote UK community through overseas Embassies and Offices.	vi) Fuel Cells UK with overseas Embassies and Offices	
			vii) Undertake Trade Missions.	vii) UK Trade and Investment	

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
11. Developing codes and standards framework	Clear codes and standards framework within which product design, investment and project specification can take place (encompassing both fuel cells and hydrogen)	Develop clear codes and standards framework which incorporates UK industry input.	i) Ensure UK cooperation in international codes and standards development to inform activity in the UK and deliver outcomes which recognise UK circumstances.	i) Fuel Cells UK	i - iii) Ongoing
			ii) Ensure that codes, standards and health and safety requirements reflect real world experience as identified through improved liaison between system integrators and standards bodies.	ii) Fuel Cells UK in collaboration with HSE, BSI, ENCG and 'Distribution Committee'	
			iii) Provide clear guidance for installers and other personnel (see Education, training and awareness – Challenge 9).	iii) Fuel Cells UK	
12. Adapting planning consent procedures for fuel cells and related infrastructure	Streamlined and transparent planning procedures	a. Adjust planning process to accommodate evolving commercialisation of fuel cells.	i) Assess current planning constraints to highlight areas requiring adjustment. (Strategy: a)	i) Fuel Cells UK in collaboration with ODPM	i) Short term
		b. Ensure appropriate implementation at the local level.	ii) Revise relevant planning regulations and guidance accordingly. (Strategy: a)	ii - iv) ODPM	ii - iv) Short to medium term
			iii) Engage planners in revision process. (Strategy: b)		
			iv) Undertake communication campaign aimed at planners based on outputs of (ii) above. (Strategy: b)		
13. De-risking large scale FC projects to encourage private investment beyond demonstration phase	A more robust project evaluation	Reduce perceived risk through improved understanding among the financial and underwriting communities.	i) Undertake communication campaigns, including specialist workshops, targeted at the financial and underwriting communities.	i) Fuel Cells UK	i) Short term
			ii) Disseminate results from demonstrations to target the financial and underwriting communities.	ii) Fuel Cells UK	ii) Medium term

Figure 5.2 Schedule of challenges and routes to their resolution: regulation and policy (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
14. Uncertainty around imported versus home-grown technology	Clarity on the value of deploying imported technology as a means of learning and developing supporting industries	Allow the inclusion of selected imported solutions in new publicly funded demonstrations and deployment activities where they can enhance local experience, provide the basis for UK industrial development or reduce the perceived risk of evolving UK technology.	i) Ensure that publicly funded demonstration and deployment activities recognise historical support for fuel cell development in the UK relative to elsewhere.	i) Fuel Cell Coordination Group (see Challenge 3)	i - iii) Ongoing
			ii) Recognise that international solutions can contain UK components and include them in publicly funded demonstration and deployment where in line with policy objectives.	ii) Fuel Cell Coordination Group with support from Fuel Cells UK	
			iii) Disseminate progress, findings and achievements of new technology procurement initiatives to the financial and underwriting communities.	iii) Fuel Cells UK	

Figure 5.4 Schedule of challenges and routes to their resolution: market development

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
1. Removing barriers to DG	Clear value proposition for distributed generation	Improve understanding of issues and opportunities among installers and end users. NB See also Regulation and Policy Challenge 5.	i) Disseminate findings of the System Impact of Additional Micro-generation (SIAM) study and other outputs from DGCG and 'Distribution Committee' and Electricity Networks Co-ordinating Group (ENCG).	i) Fuel Cells UK	i) Short term
			ii) Ensure outputs from (i) feed into public procurement planning and policy.	ii) Fuel Cells UK	ii) Ongoing
2. Lack of obvious, economical, low-volume, low price-sensitivity early applications	Economical, price-insensitive markets, which recognise benefits of fuel cells, identified and targeted	a. Identify and respond to early markets where fuel cells will be effective. b. Identify early adopters willing to pay a premium. c. Create more market awareness. d. Provide financial incentives to stimulate early adopter uptake.	i) Undertake market studies (in the UK and abroad) to identify niche markets, early adopters and success criteria. (Strategy: a and b)	i) Individual companies	i - iii) Ongoing
			ii) Collect and disseminate publicly available market information. (Strategy: b and c)	ii) Fuel Cells UK	
			iii) Take advantage of publicly funded mechanisms for building market knowledge (e.g. GlobalWatch Missions). (Strategy: a and b)	iii) Individual companies, with Fuel Cells UK	
			iv) Develop business case, including potential benefits, for early markets (including Government), highlighting CO_2 and Energy Security benefits. (Strategy: a, b and c)	iv) Individual companies	iv) Short to medium term
			v) Identify high profile applications to raise awareness. (Strategy: c)	v) Individual companies	v) Medium term
			vi) Introduce market-based mechanisms to bridge cost gap (see Regulation and Policy Challenge 7). (Strategy: d)	vi) Fuel Cell Coordination Group*	vi - viii) Short to medium term
			vii) Develop leasing proposals to offset high up-front costs. (Strategy: d)	vii) Individual companies	
			viii) Explore feasibility of Government involvement in leasing programmes. (Strategy: d)	viii) Fuel Cell Coordination Group* and Defra	

*See Regulation and Policy Challenge 3

Figure 5.4 Schedule of challenges and routes to their resolution: market development (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
3. Optimisation of UK position in global supply chain	UK company performance in long term global markets optimised	a. Secure financing to build production volumes and associated business activities. b. Develop UK based supply chains. c. Build synergistic relationships with global partners. d. Ensure UK opportunities for early development of UK companies are maximised. e. Raise awareness amongst suppliers currently active in established sectors (e.g. automotive) of the potential opportunities associated with FCs.	i) Raise profile and highlight potential of fuel cell industry with financial community. (Strategy: a) ii) Determine role for Government in bringing investors and partners together. (Strategy: a) iii) Support UK focused collaborative supply-chain based R&D, as basis for long term cooperation. (Strategy: b and e) iv) Develop a database to showcase UK capability in fuel cell vehicle supply chain. (Strategy b, c and e) v) Develop a database to showcase UK capability across other fuel cell applications. (Strategy b, c and e) vi) Foster relationships between UK companies and potential international partners (see also Regulation and Policy Challenge 10). (Strategy: c) vii) Foster UK response to early markets (See Challenge 2 above). (Strategy: d) viii) See Regulation and Policy Challenge 2. (Strategy: e and f). ix) Highlight prospects for fuel cells and related technologies among potential suppliers, for example: - journal articles - contributions to conferences - central contact point and response to interest.(Strategy: e)	i) Fuel Cells UK ii) Fuel Cell Coorination Group* iii) DTI, in collaboration with UKERC and Cenex iv) Low Carbon Vehicle Partnership v) Fuel Cells UK vi) Fuel Cells UK, International Technology Promoters vii) Central Government, individual companies, Fuel Cells UK viii) See Regulation and Policy Challenge 2 ix) Fuel Cells UK	i - ii) Short term iii) Short to medium term iv - v) Short term vi - vii) Short to medium term viii) See Regulation and Policy Challenge 2 ix) Short term

*See Regulation and Policy Challenge 3

Figure 5.4 Schedule of challenges and routes to their resolution: market development (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
4. Lack of incentives to establish fuel cell supply chain companies in the UK	Fuel cell supply chain companies with good prospects view the UK as an attractive location in which to be based	Provide incentives to overseas companies and domestic start-ups to set up in the UK.	i) Offer tax reductions for various desirable activities along the supply chain (e.g. reductions for R,D&D, Enhanced Capital Allowance for testing facilities).	i) Treasury	i - ii) Short to long term
			ii) Provide assistance with services such as location choice and a pre-defined legal package to simplify start-up paperwork.	ii) Fuel Cell Coordination Group* in collaboration with RDAs	
			iii) Ensure world-class skills base. See Education, Training and Awareness Challenges 1 and 2.	iii) See Education, Training and Awareness Challenges 1 and 2	iii) Ongoing
			iv) Highlight opportunities to participate in trial and demonstration programmes, and raise awareness of other UK based opportunities for supply chain companies.	iv) Fuel Cells UK	iv) Short to medium term
5. Creating long-term investor confidence	Clarity on policy frame-work to enable long-term investment commitment	a. Ensure that the financial community is aware of the long term prospects for fuel cells (see Regulation & Policy Challenge 9).	i) Promote long-term prospects, including policy aspects, to financial community. (Strategy: a)	i) Fuel Cells UK	i - ii) Short to medium term
		b. Develop a favourable environment for investors and potential Merger and Acquisition (M&A) partners to be active in the UK Market.	ii) Develop relationships with UK and international investors, and potential partners in related industries. (Strategy: b)	ii) Industry, with support from ITPs and Fuel Cells UK	
			iii) Disseminate progress in IPOs, trade sales, M&As and VC transactions to key members of the insurance and finance communities. (Strategy: a and b)	iii) Fuel Cells UK in collaboration with industry	iii) Ongoing
6. Lack of market champion	Market champion plays key role in increasing public profile and communicating success stories	Identify market champion and support their activities.	i) Nominate charismatic market champion to represent the industry at high-profile business, public and other networking events.	i) Industry with support from Fuel Cells UK	i) Short term

*See Regulation and Policy Challenge 3

Figure 5.4 Schedule of challenges and routes to their resolution: market development (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
7. Accelerating the availability of reliable, affordable fuel cells	Breakthroughs in cost, energy density and fuel storage	a. Support appropriate R&D. b. Expand product testing capability (see also Technology Development). c. Move towards standardisation of key components. d. Identify early markets where cost is less of an issue. e. Increase production volumes as markets develop.	i) See Technology Development. (Strategy: a) ii) Foster development of new testing facilities across industry and academia. (Strategy: b) iii) Undertake study of supply chain harmonisation in the UK. Identify gaps and develop strategy for them to be filled. (Strategy: c) iv) See Challenge 2 above. (Strategy: d) v) Build on experience from other industries, where appropriate, to develop plans for smooth transition from demonstration to early markets. (Strategy: e)	i) See Technology Development ii) Fuel Cell Coordination Group* and RDAs iii) Fuel Cell Coordination Group*, with support from Fuel Cells UK and industry iv) See Challenge 2 above v) Individual companies	i) See Technology Development ii - iii) Short term iv) See Challenge 2 above v) Short to medium term
8. Minimising perceived financial risk	Perceived financial risk does not represent a major barrier	a. Foster cost reduction certainty. b. Develop communication campaign to improve awareness among the insurance and financial community.	i) Develop business plans to respond to short, medium and long term opportunities. (Strategy: a) ii) Provide stable policy framework, including long-term support mechanisms (See Regulation and Policy Challenge 8). (Strategy: a and b) iii) Implement long term strategy for cost reduction – see Challenge 7 above. (Strategy: a) iv) Disseminate experience and technology validation results from trials, demonstrations and other initiatives to the financial and insurance community. (Strategy: b)	i) Individual companies ii) Central Government iii) Industry in collaboration with Government iv) Fuel Cells UK in consultation with industry	i - iii) Short to long term iv) Medium term

*See Regulation and Policy Challenge 3

Figure 5.4 Schedule of challenges and routes to their resolution: market development (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
9. Exploiting overlaps with other industries critical to the fuel-cell value chain (e.g. materials development)	UK companies able to support fuel cell value chain fully aware of opportunities and optimally engaged	Raise awareness of opportunities across other industry sectors and facilitate their realisation.	i) Highlight prospects for fuel cells and related technologies among other industries through, for example: - journal articles - contributions to conferences - central contact point and response to interest. ii) Identify core competencies required of suppliers / partners and seek those among other parts of UK industry. iii) Develop R&D programmes which allow early collaborations to be forged.	i) Fuel Cells UK ii) Individual companies with support from central and regional Government iii) Government, RCs and Carbon Trust	i - iii) Ongoing
10. Lack of unified industry voice to influence policy	Single voice for the industry effectively influencing policy	Develop mechanism through which to deliver unified voice.	i) Build grouping of companies willing to collaborate to form unified voice. ii) Agree areas of focus. iii) Undertake targeted policy influencing initiatives and other activities defined by the group.	i - iii) Fuel Cells UK in collaboration with industry	i - iii) Ongoing
11. Optimising UK position in the global FCV supply chain	UK capabilities adequately incorporated in the global FCV supply chain	Foster collaboration with major international car manufacturers and their suppliers.	i) Consolidate evidence of UK expertise and promote capabilities for collaboration with key suppliers to the major manufacturers. ii) Liaise with major international players to establish part of their operations in the UK. iii) Highlight inward investment opportunities – see Challenge 4 above.	i) Cenex ii - iii) Cenex supported by ITPs	i - iii) Ongoing

Figure 5.4 Schedule of challenges and routes to their resolution: market development (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
12. Integration of distributed generation systems into electricity networks and infrastructure	Distribution networks are able to accommodate DG installations in a variety of locations and applications	a. Facilitate the implementation of islanding systems around DG installations (See also Regulation and Policy Challenge 5). b. Foster experience and technical learning at selected sites covering a mix of domestic and industrial applications.	i) Ensure that a replicable model emerges from first experiences gathered through selected projects. (Strategy a) ii) Enable commensurate investment at secluded and urban settings to accumulate performance data on potential benefits to consumers and network operators. (Strategy b).	i) Distribution Committee and Electricity Networks Coordinating Group (ENCG) supported by Fuel Cells UK ii) Distribution Network Operators in consultation with ENCG	i) Short and medium term ii) Ongoing

Figure 5.6 Schedule of challenges and routes to their resolution: education, training and awareness

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
1. Shortage of advanced skills to foster development of the industry	All UK advanced skills needs met	Support advanced fuel cell skills development in UK Universities.	i) Carry out audit of future UK industry needs to make UK sector internationally competitive.	i) Fuel Cells UK	i - iii) Short term
			ii) Identify gaps and means to fill them: - By improving UK education in key gap areas - By attracting international expertise to fill gaps.	ii) RCs in consultation with Fuel Cells UK	
			iii) Communicate findings of audit to education providers (including auxiliary disciplines e.g. architecture and finance) and to potential funders (e.g. RCs).	iii) Fuel Cells UK	
			iv) Provide funding for targeted advanced research.	iv) RCs and individual companies	iv) Ongoing
			v) Recruit senior research staff to develop research portfolio.	v - vi) Individual universities supported by Research Councils	v - vi) Ongoing
			vi) Adapt and develop teaching provision in line with audit.		
			vii) Update the audit and feed into actions (iii) to (vi).	vii) Fuel Cells UK	vii) Ongoing at 2-yearly intervals
			viii) Undertake in-house training to meet immediate and specific needs.	viii) Individual companies	viii) Ongoing
			ix) Incorporate training into trials and demonstrations, including feedback into emerging codes and standards (See Regulation and Policy Challenge 11).	ix) Industry in collaboration with Fuel Cell Coordination Group*, local government and RDAs	ix) Short and medium term

* See Regulation and Policy Challenge 3.

Figure 5.6 Schedule of challenges and routes to their resolution: education, training and awareness (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
2. Lack of mechanism to generate certified installation and maintenance professionals	Fuel cell professional body responsible for certifying training across all fuel cell applications, types and fuel systems	Initiate process for training and certification of installation engineers and maintenance professionals.	i) Establish professional body, ideally as part of CORGI, to provide certification of installation and maintenance training across all fuel cells types (Note that CORGI reports to the HSE, and has a standing mandate covering its current certification activities, which could be extended).	i) Fuel Cells UK to initiate in collaboration with CORGI	i) Short term
			ii) Develop and implement training courses according to certification requirements and aligned with the general needs of DG.	ii - iv) Public and private training providers supported by Certification body (e.g. CORGI)	ii - iv) Short to long term
			iii) Ensure that training and certification processes incorporate up-to-date computer training necessary for control systems and integration with other technologies.		
			iv) Introduce apprenticeship scheme in maintenance.		
			v) Develop process to provide resources for teaching at different levels in cooperation with industry.	v) Certification body (e.g. CORGI) in collaboration with industry	v) Ongoing
3. Need to educate political decision makers about benefits of fuel cells	Awareness of benefits which fuel cells can bring among political decision makers	Implement awareness raising / education campaign aimed at politicians and focusing on CO_2 and Energy Security benefits.	i) Identify political champion at parliamentary level and develop plan for engaging them.	i - ii) Fuel Cells UK	i - ii) Short term
			ii) Develop and implement awareness raising campaign targeted at key political stakeholders.		

Figure 5.6 Schedule of challenges and routes to their resolution: education, training and awareness (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
3. Need to educate political decision makers about benefits of fuel cells (comtinued)			iii) Provide dedicated briefings for key political groups e.g. PRASEG and Parliamentary Office of Science and Technology (POST).	iii) Fuel Cells UK	iii - iv) Short term
			iv) Explore and learn from lessons elsewhere on building political awareness.	iv) Fuel Cells UK in collaboration with International Technology Promoters	
			v) Showcase tested products in high-profile locations.	v) Industry in collaboration with Fuel Cells UK, local and regional government	v) Medium term
4. Lack of awareness amongst policy makers	Increased knowledge of fuel cells and their benefits among decision makers	Implement awareness raising campaign among policy makers focusing on the key messages of CO_2 and energy security advantages.	i) Develop and implement series of workshops across Government departments to educate and inform officials of the CO_2 and energy security benefits of fuel cells and how these can be realised.	i) Fuel Cells UK	i) Short term
5. Lack of coverage of fuel cells in public education	Fuel cells are explicitly included in the curriculum, with coverage increasing as children progress through their education	a. Raise awareness amongst individuals setting public education curricula. b. Develop tools to incorporate FCs into curriculum.	i) Carry out awareness raising campaign (e.g. via workshops) at Department for Education and Skills. (Strategy a)	i) Fuel Cells UK	i) Short term
			ii) Develop regional / national competition / challenge for schools to trial or deploy small units. (Strategy b)	ii) Fuel Cells UK in collaboration RDAs, local education authorities and industry	ii) Medium term
			iii) Develop support material for lesson plans approved by the Qualifications and Curriculum Authority. (Strategy b)	iii) Qualifications and Curriculum Authority in collaboration with Fuel Cells UK and industry	iii - iv) Short and medium term
			iv) Provide focused information and training resources for different educational levels at energy education centres throughout the UK (e.g. Centre for Alternative Technology). (Strategy b)	iv) Fuel Cells UK supported by Central Government, RDAs and existing installation/training centres (e.g. Teesside, CAT)	

Figure 5.6 Schedule of challenges and routes to their resolution: education, training and awareness (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
6. Lack of awareness amongst potential procurers and other key stakeholders (e.g. architects and planners)	Key stakeholders aware of opportunities for, benefits of and issues around fuel cells and hydrogen	Raise awareness through various channels.	i) Maximise opportunities for increased awareness through high profile demonstrations (see Regulation and Policy Challenge 4).	i) Fuel Cell Coordination Group*, RDAs and industry	i - ii) Medium term
			ii) Disseminate results from demonstrations widely e.g. produce fact sheets for RIBA, IMECHE, CORGI and IEEE.	ii) Fuel Cells UK	
			iii) Undertake communication campaigns aimed at key procurer groups (e.g. through specialist magazine articles etc.).	iii) Fuel Cells UK	iii) Short to medium term
7. Lack of an informed planning procedure	Planning procedure reflects specific attributes of fuel cells	Undertake awareness raising amongst developers of planning policy and guidance, and local planners.	i) Ensure lessons from small trials and subsequent demonstrations feed into evolving planning guidance.	i - iii) ODPM in consultation with Fuel Cells UK, the HSE, PRESAG and Defra	i) Short and medium term
			ii) Produce guidance for developers on how to successfully gain planning permission.		ii - iii) Medium term
			iii) Ensure that HSE input to new guidance is optimised.		

* See Regulation and Policy Challenge 3.

Figure 5.6 Schedule of challenges and routes to their resolution: education, training and awareness (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
8. Lack of awareness and credibility among general public	Positive public image of fuel cells and related technologies	Implement awareness raising and education activities, including, in the medium term, demonstrations.	i) Implement coordinated outreach campaign to communicate benefits of fuel cells.	i) Fuel Cells UK with industry	i) Short to medium term
			ii) Maximise opportunities for increased awareness through high-profile demonstrations (See Challenge 5 above).	ii) Fuel Cell Coordination Group* in collaboration with RDAs, local government and industry	ii) Medium term
			iii) Carry out specific profile / awareness-raising initiatives (e.g. automotive industry sponsored, fuel-cell powered motor sports; school / university competitions).	iii) As appropriate, facilitated by Fuel Cells UK	iii) Short to medium term
9. Verifying the performance of the product	Accreditation and testing mechanisms and facilities in place	Develop an independent product accreditation and testing scheme validated against key requirements.	i) Establish the mechanism and legal structure for distributing accreditation / verification licences.	i) Central Government in collaboration with CORGI, HSE and Fuel Cells UK	i) Short to medium term
			ii) Establish licensed facilities entitled to verify products.	ii) Central Government in collaboration with CORGI, HSE and Fuel Cells UK	ii) Medium term
			iii) Disseminate the results and purpose of the scheme to fuel cell purchasers as well as the financial and insurance communities.	iii) Fuel Cells UK	iii) Short and medium term

* See Regulation and Policy Challenge 3.

Figure 5.7 Schedule of challenges and routes to their resolution: technology development (industry)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
1. Resolving technology challenges (research community) (see 1 - 10 below)	See technology challenges (research community) below	Facilitate industrial R&D appropriate to UK position (See Sections 3 and 4 above).	i) Support industrial R&D on a rolling specific and targeted basis with short, medium and long term goals (see below).	i) DTI	i - ii) Ongoing
			ii) Ensure that support for industrial and academic R&D is coordinated, with shared overall objectives where appropriate (see below). (This should not preclude independent basic research within academia, or independent applied R&D within industry; instead, it should focus on better promotion of ultimate exploitation.)	ii) Fuel Cell Coordination Group*, RCs, CT	
			iii) Establish thematic working groups involving industry and academia to explore research priorities and exploit opportunities for collaboration.	iii) UKERC with support from Fuel Cells UK	iii - iv) Short to medium term
			iv) Develop and support collaborative research activities through the DTI's Technology Programme, with enhanced funding, preferably to a level of £10-20m per year. These activities should build on the outputs from the thematic working groups and be mod-elled, as far as practicable, on the US SECA Program.	iv) DTI	
			v) Where UK needs to collaborate, make international partnerships a requirement for support.	v) DTI and Fuel Cell Coordination Group*	v - vii) Ongoing
			vi) Assist UK companies to find appropriate overseas partners for joint R&D activity.	vi) DTI, ITPs and Fuel Cells UK	
			vii) Identify and exploit opportunities for UK-US collaboration through UK-US Memorandum of Understanding on Energy.	vii) Fuel Cell Coordination Group* in collaboration with industry	

* See Regulation and Policy Challenge 3.

Figure 5.7 Schedule of challenges and routes to their resolution: technology development (industry) (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
2. Optimising manufacturability of all fuel cell types	Mass producible fuel cells at acceptable cost (See also market development challenge 3 and 7)	Transfer knowledge from related sectors.	i) Identify industrial sectors with similar mass production processes etc. ii) Develop joint initiatives to transfer learning and expertise.	i - ii) Industry with support from Fuel Cells UK	i - ii) Short to medium term
3. Optimising installability of all fuel cell types	Fuel cell systems easy to install and compliant with all legal requirements	a. Transfer knowledge from related sectors. b. Build on lessons from demonstrators. c. Ensure compliance with Codes and Standards requirements.	i) Identify industrial sectors with similar installation issues. (Strategy: a) ii) Develop joint initiatives to transfer learning and expertise. (Strategy: a) iii) Ensure that lessons from demonstrators are fully disseminated to optimise learning. (Strategy: b) iv) Maximise engagement of manufacturers and integrators in C&S groups (e.g. HSE, BSI). (Strategy: c)	i) Industry with support from Fuel Cells UK ii) Industry with support from Fuel Cells UK iii) Fuel Cells UK iv) Fuel Cells UK	i - iv) Short to medium term

Figure 5.8 Schedule of challenges and routes to their resolution: technology development (research community)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
1. Achieving acceptable cost levels for stacks	Achievement of entry level costs[3]: larger stationary applications: ~€2,000/kW (~£1,400/kW) in 2008 PEMFC system for transport applications: ~€100/kW (~£54/kW) by 2015 Achievement of cost levels to allow competition with incumbent technologies in mass market applications: PEMFC stack: ~$45/kW (~£24/kW) by 2010 ~$30/kW (~£16/kW) by 2015[4] SOFC Stationary power system: ~$400/kW (~£214/kW) by 2010[5]	Build on existing UK research activity to achieve desired outcomes across identified challenges. Where UK has strong position take a lead; otherwise ensure cooperation with international partners.	i) Undertake audit to confirm existing UK activity, expertise and level of international collaboration for each challenge. ii) Establish thematic working groups involving industry and academia to explore research priorities and exploit opportunities for collaboration. iii) Ensure a cohesive, simple and focused support framework able to adopt a long term approach. iv) Recast existing programmes (e.g. SUPERGEN) to accommodate complementary areas of research, where appropriate. v) Develop new and transparent research programmes to address challenges which cannot be accommodated within existing programmes (See industry Challenge 1 above). vi) Undertake regular reviews to ensure relevance of research. vii) Provide funded mechanisms for collaboration between academia and industry, ensuring that research directions are in line with commercialisation activities (See industry Challenge 1 above). viii) Ensure results of R&D can be fully exploited, and that benefit to the UK can be maximised.	i) UKERC with support from Fuel Cells UK, and in collaboration with RCs and CT ii) UKERC with support from Fuel Cells UK iii) RCs, DTI, Scottish Executive, DfT, Defra, EST and CT iv - viii) RCs, DTI and CT	i) Short term ii) Short to medium term iii) Short to long term iv) Short to medium term v) Medium to long term vi) Ongoing vii) Short term viii) Medium to long term
2. Achieving acceptable durability / performance levels for stacks	Achievement of lifetimes of: - 20,000-40,000hrs for stationary applications - 5,000-8,000hrs for transport applications[6]				
3. Achieving mass and volume reduction for fuel cell systems where these are important	For 100kW systems, without electric drive and hydrogen storage, achievement of: 1.5kg/kW 1.5l/kW by 2015[7]				

[3] In line with The European Hydrogen and Fuel Cell Platform Strategic Research Agenda
[4] In line with US Department of Energy, Energy Efficiency and Renewable Energy, Freedom CAR Initiative
[5] In line with US Solid State Energy Conversion Alliance (SECA) Program Strategy
[6] In line with The European Hydrogen and Fuel Cell Platform Strategic Research Agenda
[7] In line with The European Hydrogen and Fuel Cell Platform Strategic Research Agenda

Figure 5.8 Schedule of challenges and routes to their resolution: technology development (research community) (continued)

Challenge	Desired outcome	Strategy	Actions	Champion	Timing
4. Developing fuel cell systems capable of fuel flexibility (including reforming options)	New fuel cell systems with fuel flexibility (including reforming options) are available for testing and deployment				
5. Achieving higher temperature operation for PEM stacks	PEM stacks capable of operating at 120-160°C				
6. Developing materials for intermediate and high temperature SOFCs	Materials for use in intermediate temperature SOFCs available and in use				
7. Increasing hydrogen storage capability to levels which extend vehicle range to acceptable levels and enhance portable power availability	Achievement of hydrogen storage capability of >6wt% in the short to medium term and >12wt% in the long term				
8. Developing reversible fuel cells to address renewable intermittency	Development of reversible fuel cells suitable for operation with intermittent renewable technologies				
9. Developing effective and affordable balance of plant	Development of effective and affordable pressure regulators, blowers, pumps, flow controllers, power conditioning, control systems, etc.				
10. Ensure cohesion between fuel cell and hydrogen research activities	Underpinning technologies and areas of commonality, where multiple benefits could accrue, are co-ordinated rather than performed in isolation				

6 RECOMMENDATIONS

Fuel cells offer the potential to:

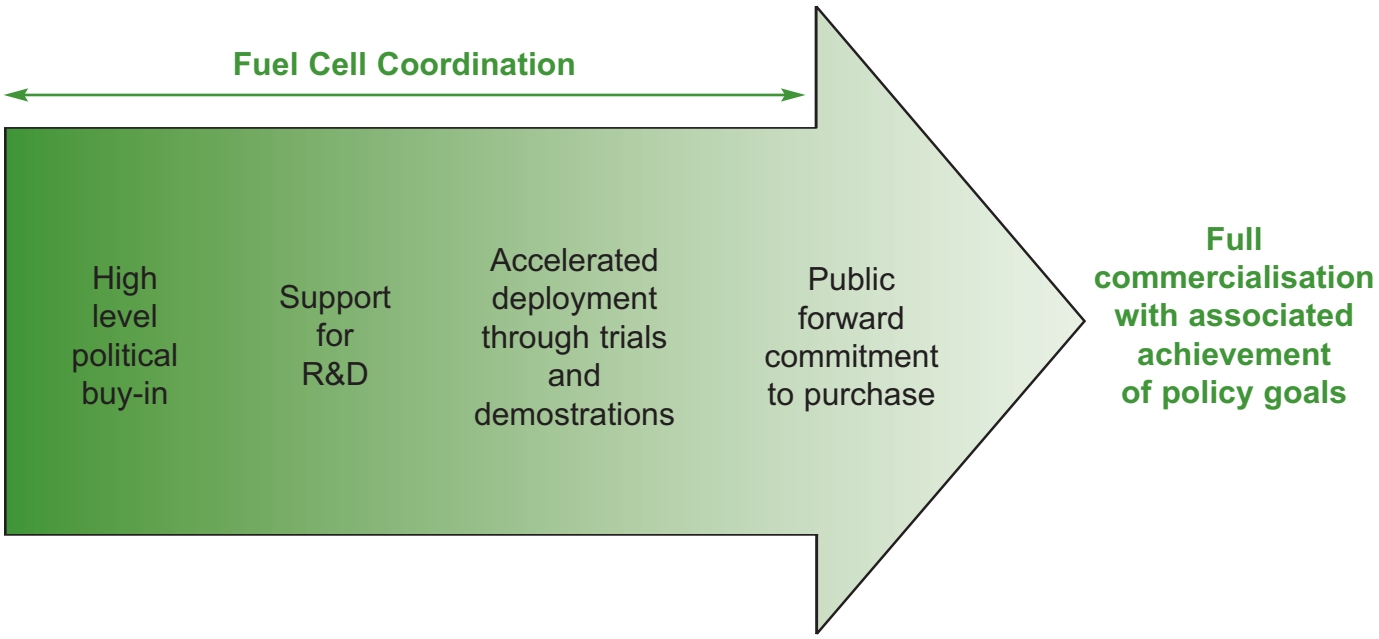
- contribute substantially to a global low carbon economy;
- improve urban air quality and the health of urban populations;
- form the basis of a 21st Century industrial sector that allows sustainable growth of the world economy;
- enhance energy security by allowing a wider choice of fuels;
- contribute to the alleviation of fuel poverty through superior efficiency relative to conventional technologies (particularly in CHP mode); and
- provide essential intermediate and final components of any future hydrogen economy.

This Roadmap provides a comprehensive framework of actions to help the UK optimise its response to these opportunities and overcome the challenges it faces to:

- establish a significant market for fuel cells in the UK; and
- stimulate the growth of a competitive fuel cell industry in the UK.

It has been prepared to reflect the views and aspirations of the UK fuel cell community, and is intended to inform the thinking and activities of a broad range of stakeholders including Government, industry and researchers.

The community has highlighted five key areas where the need for early success is considered critical. These are clearly linked, with progress in each case having implications for subsequent stages:



These are summarised below, with further details provided in Section 5.

Achieving high level political buy-in

The policy benefits listed above will only be maximised if there is strong political commitment to the development and deployment of fuel cells in the UK. Furthermore, the need for buy-in at the highest political level is urgent if the UK is to maintain and build its competitive position.

Action by the industry and Fuel Cells UK is needed in several key areas:

- high-level advocacy and communications campaign highlighting carbon abatement and energy security benefits;
- identification of a political champion at parliamentary level and development of a plan for engaging them;
- provision of dedicated briefings for key parliamentary groups e.g. Parliamentary Renewable and Sustainable Energy Group (PRASEG) and Parliamentary Office of Science and Technology (POST); and
- engagement of POST in the debate on opportunities for fuel cells.

Supporting fuel cell R&D

The UK has experienced considerable growth in fuel cell activity over recent years, with established players building their positions in the market, and a number of new companies emerging. As the industry has evolved, so has the scale of the opportunity, with a commensurate impact on the need for R&D. Government support for R&D will have an important role in realising the potential contribution of fuel cells to a range of policy objectives, and help to optimise outcomes from deployment.

It is recommended that the DTI's Technology Programme give greater recognition to the value of new, more sustainable energy technologies, including fuel cells. Government support to the value of £10-20m per year is considered appropriate to optimise outcomes and reflect the substantial increase in privately funded fuel cell R&D over the past few years. This £10-20m should be exclusively for R&D, with separate support being available for trials and demonstrations (see below).

The DTI's Technology Strategy Board should adopt the strategies and actions described in Section 5 to drive calls. Provision of a medium term commitment to industry led consortia, with the scope of R&D activities being developed in consultation with thematic working groups, is considered particularly important. A potential model on which to build is the US SECA Program; key elements of this are:

- industry led consortia supported by the research community;
- clear targets and early deadlines across fuel cell types covered; and
- sufficient financial support to make a significant impact.

Section 5 also includes proposed strategies and actions to support R&D within the academic research community, through channels such as the Research Councils.

Establishing a Fuel Cell Coordination Group

As a consequence of the many and varied opportunities for fuel cells, their development and deployment will be influenced by activities across a wide range of Government departments, from ODPM, DTI and DfT to the Cabinet Office and the Treasury. At present, there is no formalised direct coordination and linkage between these various interests. This has the potential for inconsistency of approach, discontinuity and overlap.

It is recommended that a Fuel Cell Coordination Group is established to harmonise and unite relevant policies and initiatives. This Group should develop clear linkages to and transparent relationships with other Government departments and public sector stakeholders with responsibilities / activities relevant to fuel cells. It would then take the lead on a wide range of the actions identified in this Roadmap.

Fostering significant UK deployment

The early trial and medium term demonstration of fuel cell applications can help to optimise the technology, encourage the development of supply chains, improve awareness and understanding and, at significantly large scale, help to bring down costs and kick-start mass markets. This, in turn, will help to accelerate delivery of the policy benefits which fuel cells can bring.

Trials and demonstrations will ensure that the outcomes of R&D activity are fully exploited (see above); they will also enable life cycle benefits to be determined, which will be invaluable in facilitating commitments to public purchase (see below).

It is recommended that central and regional government works with industry and other stakeholders to foster significant deployment of fuel cells in various applications and situations.

A whole suite of actions will be required to achieve this. Full details are provided in Section 5; examples include:

- the development of UK based trial and demonstration programmes;
- the introduction of support mechanisms, such as capital grants, to offset risk. (Delivery routes might include the forthcoming Low Carbon Buildings Programme);
- participation in EC-funded activities;
- the development of appropriate skills to support large scale deployment – in particular, through training and certification of installation engineers and maintenance professionals;
- the removal of institutional barriers (e.g. to the introduction of distributed generation);
- the introduction of innovation remits across regulators such as OFGEM, which would require utilities to invest in future technologies and undertake innovative projects (although the regulators have significant influence on operating companies, their short time horizon (5 years) can mean that long term new technology options are overlooked); and
- the introduction of a portfolio of market-based mechanisms.

Implementation of the measures outlined above on a significant scale, and with appropriate coordination and commitment from public bodies, should provide technology providers and the supply base with the confidence to invest in manufacturing scale-up and achieve substantial deployment over the coming years. The following are considered to represent realistic aspiration levels for deployment:

Total Deployment	2008	2010	2012
Niche applications (MWs)[1,2]	1	6	40
Stationary applications [1,3]	1	5	120
Vehicle (numbers)		‘00s	‘000s

Notes:

1. The levels for niche and stationary applications represent one fifth of the overall EC targets for deployment.
2. Early niche markets include portable generators, back-up / UPS and remote power, as well as specialist vehicles (e.g. forklifts, airport tugs, industrial vehicles) and APUs for recreational vehicles and boats.
3. Stationary applications encompass small or large CHP and stationary power generation.

Introducing a forward commitment to buy

The DTI has recognised the importance of public sector commitments to purchase technology as a driver of markets for innovative goods and services. Where these support technologies that can deliver CO_2 benefits and improve energy security, such as fuel cells, they can align with and help to deliver wider Government objectives. Such commitments also provide supplier companies and their investors with long-term confidence against which to commit resources for manufacturing scale-up.

The DTI / Defra Environmental Industries Unit (EIU), together with its Environmental Innovations Advisory Group, has analysed the ways in which public procurement can support innovation and is pioneering some examples to establish good practice in this area. Their findings show that:

- Policy teams struggle to include innovative solutions into their plans, as they are relatively invisible or very risky.
- Purchasing professionals need specifications for tenders and are, quite rightly, risk averse, militating against innovative technologies.
- Forward commitments to buy provide supplier companies, their suppliers and their investors with long-term confidence against which to commit resources for demonstration and manufacturing scale-up.
- Forward commitments by public sector procurers offer a powerful mechanism for the market to deliver innovative solutions to meet policy needs that is particularly appropriate in the environmental sector where consumer driven mechanisms are weak.

It is recommended that the EIU includes a fuel cells case study in its programme, and that consideration be given to the development of larger scale commitments.

A fuel cells case study would involve an agreement to buy a pre-defined number of units at an agreed price, subject to the technology fulfilling certain techno-economic criteria. Such criteria could be developed for each type of application, and could be based on the results of early trials and demonstrations. The commitment would not be valid if the criteria were not met, although alternative arrangements could be explored if agreed by both parties.

There is a need for a broker to link technology producers, policy objectives and potential procurers, and help to manage risk. Such a broker would help to formulate the terms of each forward commitment and, if appropriate, develop pan-application performance criteria. In the case of automotive applications, it is recommended that Cenex perform this function. For stationary applications, the RDAs could have a significant role to play.

Although funding may be required to facilitate this activity, this would be relatively small, and primarily relate to support for the determination of appropriate criteria against which to commit and to manage risk.

Next steps

The next few years will be critical in determining the UK's ultimate position in the global fuel cell landscape. This Roadmap provides a starting point in highlighting the actions which need to be undertaken by a broad range of stakeholders if the potential is to be realised. Early progress is needed across each of the five recommendations presented here, and in relation to the specific actions described in Section 5.

APPENDIX A
CONTRIBUTORS TO THE ROADMAP

Fuel Cells UK is grateful to the many organisations and individuals who contributed to the development of this Roadmap. In addition to the DTI, which funded the work, particular thanks are due to members of the Fuel Cells UK Steering Group (shown in **bold** below), workshop attendees and those who provided individual perspectives for the validation process or useful data (with the latter shown in *italics*).

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GLA / LHP	*Lambros Antoniou*
Highlands and Islands Enterprise	*Elaine Hanton*
Imperial College London	*Alan Atkinson*
Imperial College London	Alexei Kornyshev
Imperial College London	*John Kilner*
Imperial College London	Anthony Kucernak
Imperial College London	*Stephen Skinner*
Intelligent Energy	***Dennis Hayter***
Intermediary Technology Institute for Energy	*Jackie Doyle*
Johnson Matthey	***Jack Frost***
Johnson Matthey	Martin Green
Loughborough University	*Rupert Gammon*
Loughborough University	Amitava Roy
Micropower Council	*Dave Sowden*
North West Development Agency	*Joe Flanagan*
Ofgem	*Michael Byrne*
Porvair	Ian Stirling
Renewables North West	*Julian Carter*
Rolls-Royce Fuel Cells	**Johnathan Lewis**
siGEN	*Dave McGrath*
Scottish and Southern	Garth Graham

Scottish Enterprise	*Melanie Hay*
St Andrew's University	*John Irvine*
South East of England Development Agency	*Graham Tubb*
South West Regional Development Agency	*Dominic Vincent*
Tees Valley Hydrogen Project	*Graham Hillier*
Transport for London	*Anna Rickards*
Turquoise Associates	Mark Cropper
UK Energy Research Centre	*Nigel Brandon*
UK Hydrogen Energy Network	Geoff Dutton
Unitec Ceramics Ltd	Gordon Bennett
Unst Partnership	Sandy Macaulay
Welsh Development Agency	*Anthony Armitage*
Welsh School of Architecture	*Ian Knight*
Yorkshire Forward	*Michael Smith*

APPENDIX B

INFORMATION SOURCES

Advantage West Midlands, 2003. Fuel Cells, Current and Planned Activities in the West Midlands. *Presentation by Advantage West Midlands at the UK Fuel Cell Vision Workshop*, 20 August 2003, London

Carbon Trust and DTI, 2005. *Renewables Innovation Review*. London. Available from: http://www.dti.gov.uk/energy/renewables/policy/fuelcells.pdf (accessed on 28 February 2005)

Ceramic Fuel Cells Limited, 2005. *Benefits of Solid Oxide Fuel Cells.* Available from: http://www.cfcl.com.au/html/body_benefits_of_sofc.htm (accessed on 8 March 2005)

Cropper M, Geiger S & Jollie D (Fuel Cell Today), 2003a. *Fuel Cells in the United Kingdom: A survey of current developments*. London

Cropper M, Geiger S & Jollie D (Fuel Cell Today), 2003b. *Fuel Cell Systems: A survey of global activity.* London

Defra and DTI, 2001. *The UK Fuel Poverty Strategy.* London.

Department for Transport, 2002. *Powering Future Vehicles.* London

DTI, 2002. *Major Photovoltaics Demonstration Programme.* Available from: http://www.est.co.uk/solar/ (accessed on 7 January 2005)

DTI, 2005. *Renewable Energy Capital Grants.* London. Available from: http://www.dti.gov.uk/renewables/renew_4.3.2.htm (accessed on 03 March 2005)

DTI Global Watch Service, 2002. *Global Watch Mission Report: Fuel Cells – the Canadian Experience.* London

DTI Global Watch Service, 2003. *Global Watch Mission Report: Fuel Cells – the US Experience.* London

DTI Global Watch Service, 2004. *Global Watch Mission Report: Fuel Cells – the Japanese Experience.* London

E4Tech, 2003. *Review of Fuel Cell Commercial Potential for DTI and The Carbon Trust.* London

E4Tech, Element Energy and Eoin Lees Energy, 2004. *A strategic framework for hydrogen energy in the UK.* London

Eaton R & Ereaut P, 2002. *The DTI's Advanced Fuel Cells Programme: Past, Present and Future.* London

ETSU, 2002. *Prospects for Fuel Cells Component Suppliers.* London

European Commission, 2003. *Hydrogen energy and Fuel Cells – A vision for the future.* Brussels: EC (EUR 20719 EN)

European Hydrogen and Fuel Cell Platform, 2004. *Strategic Research Agenda – Draft Report.* Available from: http://www.euractiv.com/Article?tcmuri=tcm:29-136906-16&type=News (accessed on 4 March 2005)

Fuel Cell Europe, 2004. http://www.fuelcelleurope.org/home-fce.fcm?subsite=479 (accessed on 16 September 2004)

Fuel Cell Today, 2001. *2001 Grove Fuel Cell Symposium Review.* London

Fuel Cells Canada, Industry Canada & PWC, 2003. *Canadian Fuel Cell Commercialization Roadmap*

Fuel Cells UK, 2003. *The UK Fuel Cell Industry: A Capabilities Guide*

Fuel Cells UK, 2004. *UK Fuel Cell and Hydrogen Research: A Capabilities Guide*

Highlands and Islands Enterprise, 2004. *Ambitious hydrogen energy project in Unst*. Available from: http://www.hie.co.uk/ (accessed on 25 October 2004)

FreedomCAR and Fuel Partnership, 2004. *Partnership Plan*. Available from: http://www.eere.energy.gov/vehiclesandfuels/pdfs/program/fc_fuel_partnership_plan.pdf (accessed on 9 March 2005)

Johnson Matthey, 2004. *Acquisition of Synetix*. Press release. Available from: http://www.matthey.com/AR03/cstate.html (accessed on 6 October 2004)

Johnson Matthey, 2004. Presentation. Available from: http://www.matthey.com/media/Presentations/32, (accessed on 15 September 2004)

Larminie J & Dicks A, 2003. *Fuel cell systems explained.* 2nd Edition, Chichester, England: John Wiley & Sons Ltd.

PWC & Fuel Cells Canada, 2002. *Fuel Cells – The opportunity for Canada*

US Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), 2004. *Hydrogen, Fuel Cells and Infrastructure Technologies Program*. Available from: http://www.eere.energy.gov/hydrogenandfuelcells/news_fuel_processor.html (accessed on 14 September 2004)

Solid State Energy Conversion Alliance, 2002. SECA Program Overview. *Third Annual SECA Workshop*. 21-22 March 2002, Washington, D.C. Available from: http://www.netl.doe.gov/publications/proceedings/02/SECA/SECA3Strakey.pdf (accessed on 7 March 2005)

Solid State Energy Conversion Alliance, 2004. *A Vision for Sustainable, Highly Efficient Energy Production.* Available from: http://www.seca.doe.gov/overview.html (accessed on 22 February 2005)

Stuart Energy, 2004. *Stuart Energy Signs Exclusive Global Distribution Agreement*. Press release. Available from: www.stuartenergy.com/main_media_center.html (accessed on 9 October 2004)

Surdoval W, 2002. The Solid State Energy Conversion Alliance. In US Department of Energy, ed. *Fuel Cells for Buildings and Stationary Applications Roadmap Workshop.* 10-11 April 2002, College Park, Maryland. pp. 26-37

Van Honacker H (European Commission – DG Research), 2004. Research on Fuel Cell and Hydrogen Technologies. In *European Union Presentation at Fuel Cell Seminar 2004*

Williamson R (DTI), 2003. *Innovation in the Energy Sector – Case Study of Fuel Cell Technologies in the UK.* London

World Wildlife Fund and Fuel Cell Europe, 2003. *Fuel cells for distributed power: benefits, barriers and perspectives.* London

APPENDIX C

THIRD GENERATION FUEL CELL TECHNOLOGIES – R&D CONCEPTS ONLY

Technology	Electrolyte	Power Range	Description, Operating Temperature and Applications	Technology Status
Third generation technologies – R&D Concepts Only				
Direct H_2S SOFC	Solid oxide material	100s of kilowatts and above	Taking H_2S as the fuel, the heat of the anode dissociates the hydrogen and sulphur.	Conceptually proven, embarking on fund raising to commercialise (2-5 years to market).
Liquid acid DMFC	Liquid acid	1kW –5kW	Claims better technical performance over PEM DMFC devices but has drawback of a liquid electrolyte. Given that it is a Kordesh technology its currency is coincident with AFC (1st generation) but has not enjoyed widespread exposure and deals with inherent problems with DMFC.	Early R&D work, theoretical characterisation leading to prototyping during 2003, 2-3 years away from pre-production stage.
Micro SOFC (µSOFC)	Solid oxide material	<10W	• Integrated µSOFC and micro-reformer on a silicon chip using some Micro Electro Mechanical Systems (MEMS) technology from the integrated circuit industry • Extremely high energy densities theoretically possible • Targeting battery replacement market for next generation of portable electronics	Early R&D work, theoreti-cal characterisation leading to prototyping during 2003, 2-3 years away from pre-production stage.
Micro PEMFC (µPEMFC)	Solid polymer	<100W at present	Uses micro-fabrication techniques to build up very small PEMFC systems, hence high energy densities possible	Early R&D work
High-temperature PEMFC	Solid polymer	Same as PEMFC	Easier heat management, more useful heat output, more tolerant of contaminants in fuel stream. Operating Temperature: 120-160°C	R&D stage

APPENDIX D

UK ORGANISATIONS ACTIVE ALONG THE FUEL CELL SUPPLY CHAIN

	SOFC	PEMFC	DMFC	MCFC	AFC	PAFC
R&D	Ceram Research; Imperial College; Keele University; Loughborough University; QinetiQ; University of Manchester; University of Bath; University of Birmingham; University of Sheffield; University of St Andrew's; University of Surrey	QinetiQ; University of Birmingham; Cranfield University; Imperial College; Loughborough University; Newcastle University; University of Reading; University of Southampton	QinetiQ; Cranfield University; Newcastle University		Cranfield University	
Materials & Components Supply	MEL Chemicals	Inco Special Products; **Ineos Chlor**; **ITM Power**; **Johnson Matthey**; Precision Micro; Victrex	**Ineos Chlor**; Precision Micro; **Johnson Matthey**; **ITM Power**	Inco Special Products; Ineos Chlor	Ineos Chlor; Precision Micro	Ineos Chlor
System Manufacture	Adelan; Ceres Power; Fuel Cells Scotland; **Rolls-Royce Fuel Cells**	**Intelligent Energy**; Voller Energy	CMR Fuel Cells		Alternative Fuel Cell Systems; Eneco	
Consultancy Services		CD Adapco Group				
Financial Services						
Codes & Stds						
Training						
Education		Loughborough University				
Fuel Cell Stacks	SOFC	PEMFC	DMFC	MCFC	AFC	PAFC

Organisations active at an international level are shown in **bold**.

	Fuel Systems		Power Conditioning		Balance of plant & CHP interface		
	Delivery and storage at point of use	Reformers, catalysts	Power electronics, IGBTs	Sensors & operator interfaces	Thermal Management	Control systems	Heat exchangers (Cogen) & fluid control
R&D	QinetiQ; CCLRC; Queen Mary University of London; University of Birmingham; University of Nottingham; University of Reading; University of Salford; University of Southampton; Loughborough University; University of Manchester; University of Sheffield	QinetiQ; Keele University; Loughborough University; University of Birmingham; University of Strathclyde; University of Warwick	University of Strathclyde			QinetiQ; University of Strathclyde; Imperial College; Loughborough University	
Materials & Components Supply	**Air Products**; **BOC**; **BP**	Catal; Precision Micro; **Johnson Matthey**	Eneco		Microtherm; Heatric	Eneco; Dart Sensors	Parker Hannafin; Precision Micro; Heatric
System Manufacture	**Air Products**; **BOC**; **BP**; HILTech Developments	**Air Products**; **Intelligent Energy**; **Johnson Matthey**; **Accentus**	HILTech Developments			Bronkhorst Ltd; Chell Instruments; Alternative Fuel Cell Systems	
Consultancy Services						Cambridge Consultants	
Financial Services							
Codes & Stds							
Training							
Education							

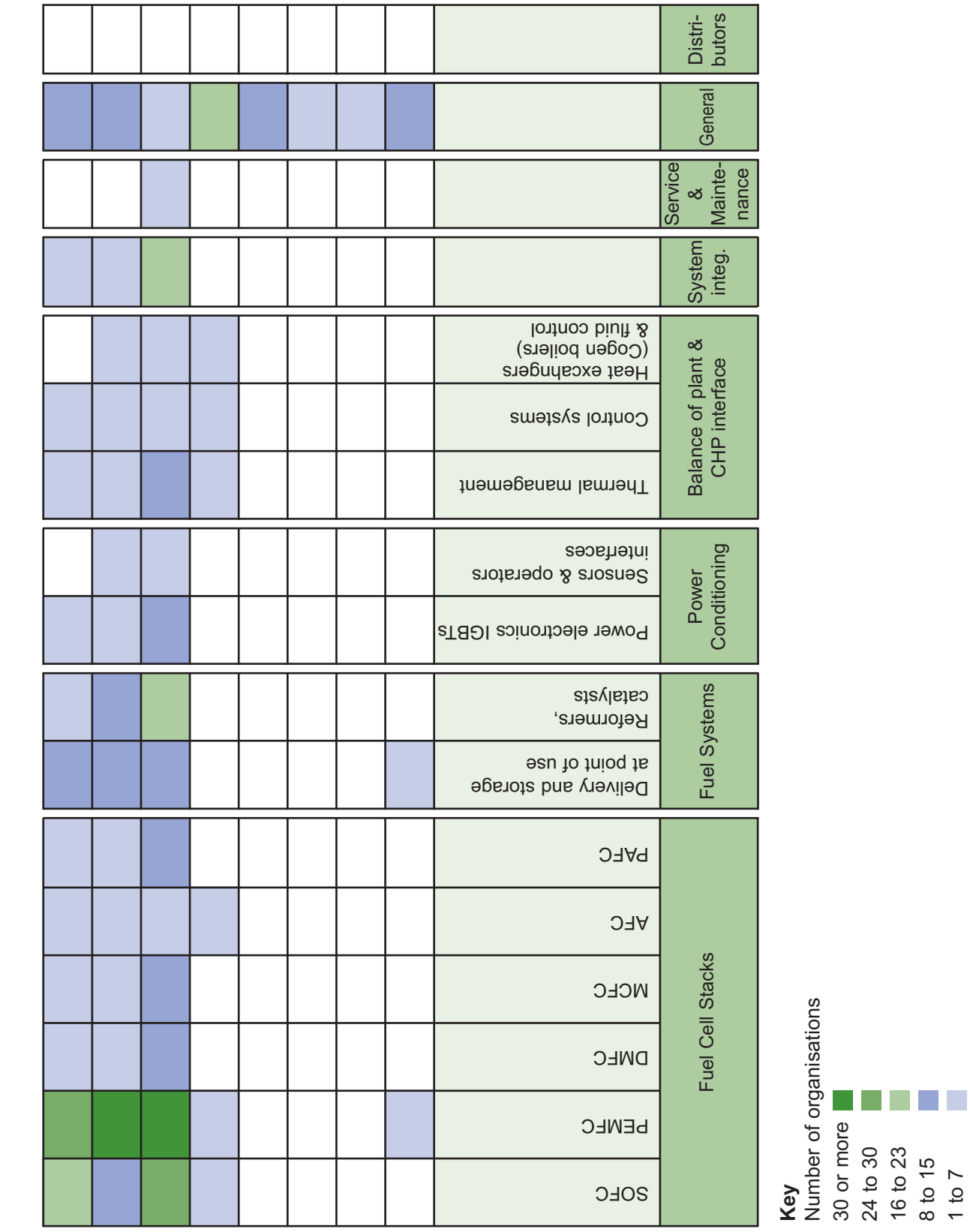
Organisations active at an international level are shown in **bold**.

	System integration	Service & Maintenance	General	Distributors
R&D	QinetiQ; Cardiff University; City University; Coventry University; Loughborough University		City University; Imperial College; University of Glamorgan	
Materials & Components Supply			Gencoa; Porvair Fuel Cell Technology	
System Manufacture	siGEN; Voller Energy; Fuel Cell Control Ltd	siGEN		
Consultancy Services			E4tech; EA Technology; Ecotec; Element Energy; Escovale; Aspen Tech; Fluent Europe; LIFE-IC; Ricardo; Scottish & Southern; Synnogy; Generics Group	
Financial Services			Conduit Ventures; Turquoise International	
Codes & Stds			Health & Safety Laboratory; BSI; HSE	
Training				
Education			Elsevier; Electro-Chem-Technic; Imperial College; Loughborough University; University of Birmingham	

Organisations active at an international level are shown in **bold**.

APPENDIX E

LEVELS OF GLOBAL INDUSTRIAL ACTIVITY ALONG THE FUEL CELL SUPPLY CHAIN



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