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# Hydrogen and Fuel Cells: For a Low Carbon Future

HIGHLIGHTS FROM THE FOURTH HYDROGEN AND FUEL CELL CONFERENCE

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The Hydrogen and Fuel Cells: For a Low Carbon Future conference and exhibition was again held at the Gallery Suite, the National Exhibition Centre (NEC), Birmingham, U.K., on the 2nd April 2008 (1) and was sponsored by Advantage West Midlands (AWM), East Midlands Development Agency (*emda*) and the Hydrogen Technology Transfer Project (HYTETRA). This conference, the fourth in the series, attracted over 250 delegates from eleven countries and the attendance was higher than in 2007 (up by 30%). While the Grove Fuel Cell Symposium remains the largest fuel cell gathering in Europe (2), the Hydrogen and Fuel Cells conference at the NEC is now gaining interest among hydrogen and fuel cell stakeholders in the U.K., Europe and worldwide.

The conference, officially launched by Birmingham City Council and Professor Stuart Palmer (The University of Warwick, U.K.), was split into four main sessions: Session 1 on 'European Progress on Hydrogen and Fuel Cells'; Session 2 on 'Regional European Activities on Hydrogen and Fuel Cells'; Session 3 on 'Hydrogen Generation and Storage'; and Session 4 on 'Fuel Cells for Transport and Buildings'. During lunchtime, consortium building was organised by Alex Mauser (Coventry University, U.K.) and an exhibition and poster session was organised by Dr Bruno G. Pollet and Professor Kevin Kendall (Fuel Cells Group, The University of Birmingham, U.K.).

## Highlights of the Conference

There has been a surge of interest in clean and efficient energy generated locally through fuel cells and hydrogen. The Joint Technology Initiative (JTI) is part of a €1 billion European Union (EU) programme to roll out this technology, and the Energy Technologies Institute (ETI) is a £1 billion U.K. project aimed at accelerating the development of low carbon energy technologies. The conference explained the reasons behind these investments, outlined progress made to date within the U.K. Midlands region and at international level, and sought to bring together interested parties across Europe for the development of future collaborative projects. More information on the participants and background to the conference can be found in the Conference Programme (1), and links to the individual presentations can be found through The University of Birmingham Fuel Cells Group website (3).

## European Progress on Hydrogen and Fuel Cells

Session 1 was chaired by Professor Kevin Kendall (The University of Birmingham, U.K.). In the first presentation, Professor Jim Skea (U.K. Energy Research Centre, London) explained 'Hydrogen and Fuel Cells for a Low Carbon Future' and focused on the current importance of climate change and energy security, which are two of the most pressing issues of the early 21st century. He emphasised that the urgent need to reduce carbon emissions and secure diverse, reliable energy supplies does not sit easily alongside current business-as-usual trends and models. The Stern Review (4) identified the nature of the failures in current U.K. energy markets and the steps required to remedy these. In his talk, Skea explained why action is urgently required, outlined the options available for moving forward and described the rapidly changing policy environment at the U.K., EU and wider international levels.

Dr André Martin (European Joint Technology Initiative for Fuel Cells and Hydrogen, Brussels, Belgium) explained in detail the JTI, which is the result of many years of campaigning for industry to undertake and take control of hydrogen and fuel cell development programmes in the European Framework. He explained that over a hundred stakeholders have invested more than €100 million in preparation for the JTI, starting with the original vision in 2003, moving on to the strategy in 2005 and ending up with the implementation plan in March 2007. Those documents are available on the HFP website (5). Martin highlighted that the council gave its approval in February 2008 and the EU Parliament's agreement was anticipated by the end of April 2008, with final adoption in May 2008. The interim structure was funded by the industry partners. The work programmes were expected to start later in 2008, and handover to the JTI was scheduled to occur at the end of 2008. The outcome will be an industry-led development project with a large number of European collaborators participating in projects worth €1 billion, up to 2013. Martin's talk highlighted the direction of the projects and the expected budget breakdown.

Professor Richard Green (The University of Birmingham, U.K.), on behalf of Dr David Clarke (ETI, U.K.), outlined 'The Energy Technology Institute: Prospects' and its main role in the U.K. The ETI was established in late 2007 as a £1.1 billion public-private partnership with its headquarters at Holywell Park, Loughborough University, U.K. Green explained that the ETI has a vision to secure sustainable and affordable energy for present and future generations, with a mission to accelerate development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies and services, which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals. Both 'supply-side' and 'demand-side' will be addressed in projects delivered through multi-partner consortia, which will be both national and international. The outputs are to be made available as widely as possible following delivery, in line with partner needs and agreed ETI outcomes.

Jeremy Harrison (E.ON UK) explained the role of the utility company in the race for a low carbon future. Climate change has created some significant challenges for the energy industry, in combination with aspects of the U.K. Government's energy policy. Harrison emphasised that achieving a goal of 80% reduction in $CO_2$ by 2050, while cost-effectively ensuring security of energy supplies, all within a very competitive market, means that the company is working hard to find new ways of delivering energy to its customers. Harrison pointed out that recent experience has shown that gas cannot be relied upon at a secure low price. He added that the utility company is looking to play an important part in replacing the U.K.'s ageing electricity generating infrastructure through the construction of a variety of plants: renewable, nuclear and even new coal plants with carbon capture and storage. He explained that the company needs to do this if generating assets are not to become 'stranded' and too expensive to run in a market which demands low carbon solutions. Within this context, fuel cells offer the potential to deliver heat and power at very high conversion efficiencies from a range of primary fuels, even at the relatively low power levels appropriate for distributed generation. The use of fuel cells in distributed generation further enhances their performance by minimising distribution losses for both the heat and electricity generated. E.ON UK is currently engaging in a range of fuel cell development and evaluation activities, aimed at gaining a deeper understanding of the technical and commercial challenges of bringing this technology to a promising market.

## Regional European Activities on Hydrogen and Fuel Cells

Session 2, formally opened by Ralph Hepworth (AWM, U.K.), focused on hydrogen and fuel cell activities at the European regional level. The first talk in this session was delivered by Dr Frank Koch (The Fuel Cell and Hydrogen Network, Germany), who outlined the 'Fuel Cell and Hydrogen Network North Rhine-Westphalia'. The network, a non-profit organisation, is supported by the Ministry of Economic Affairs and Energy, and the Ministry of Innovation, Science, Research and Technology of the State of North Rhine-Westphalia and is co-funded by the EU Regional Development Fund. Currently, the network consists of more than 300 members including companies (70%), research institutes (20%) and other stakeholders such as industrial chambers of commerce and government institutions (10%).

The main role of the network is to initiate projects, for example, the North Rhine-Westphalia (NRW) region of Germany is following an 'early market strategy' for fuel cell technology and hydrogen infrastructure. The network is pushing early markets for the deployment of fuel cells, for instance in the logistics, leisure, military and power supply markets. To date, eighty-one fuel cell and hydrogen projects have been funded by the state's government (partially co-funded by the EU), with a total budget of €210 million. Within the main industrial area of the Rhine-Ruhr valley, a 230 km hydrogen pipeline exists, connecting many chemical plants and producers as well as hydrogen users. Koch emphasised that this hydrogen pipeline could be the 'nucleus' for a German or even a European wide hydrogen infrastructure. Finally, he added that the City of Essen, located in North Rhine-Westphalia, will be hosting the 18th World Hydrogen Energy Conference (WHEC) in 2010 and he is hoping that the region will become an international platform and showcase for hydrogen and fuel cell technology.

Professor Kevin Kendall (Fuel Cells Group, The University of Birmingham, U.K.) gave an overview of hydrogen and fuel cell activities at the University (under the Supply Chain Research Applied To Clean Hydrogen (SCRATCH) project) and in the English West Midlands region. The SCRATCH project is aimed at the future hydrogen economy, which many analysts believe will be dominating the energy structure of the U.K. by 2050 as a result of the high efficiencies, zero emissions and easy conversions that can be attained with hydrogen technologies. He pointed out that the chemical industry already operates 'mini-hydrogen economies' on its sites; for example, the Teesside plant in the North East of England produced up to 100,000 tonnes of hydrogen in 2005, operated a twenty-one mile hydrogen pipeline, used salt caverns to store hydrogen, and set up several demonstrations of fuel cell power including road signs and a lighthouse. The main aim of SCRATCH is to make such hydrogen economies available to consumers to drive vehicles, power homes and run portable appliances. At present, hydrogen vehicles are not generally used in the U.K., as the supply chain is not yet implemented. There is an urgent need for hydrogen filling stations and for hydrogen vehicles (see for example Figure 1). However, at The University of Birmingham, a fleet of five hybrid hydrogen fuel cell vehicles (Figure 2) has been introduced on campus, and the various component supply chain companies have been signed up to a £2 million development project. These are zero emission vehicles (ZEVs), which are currently being tested for efficiency compared to the standard diesel and 'purely' electric fleets on campus. Preliminary results show that the hydrogen fuel cells can achieve an energy efficiency of 1 km $MJ^{-1}$.


*Fig. 1 Hydrogen refuelling station and a hydrogen fuel cell vehicle at The University of Birmingham, U.K. (Courtesy of Dr Bruno G. Pollet, The University of Birmingham, U.K.)*

Kendall emphasised that homes in the U.K. do not have hydrogen supplies in place to run combined heat and power (CHP) systems. At Birmingham, hydrogen infrastructure has been installed in a building to test the use of proton exchange membrane fuel cell (PEMFC) CHP. In addition, Baxi Innotech has installed two of their PEMFC CHP units running on pipeline natural gas through a reformer. One of these is operating in a family home (in Lye, West Midlands, U.K., with the help of the Black Country Housing Association), and the other at The University of Birmingham Fuel Cells Laboratories. Other types of fuel cell CHP systems based on solid oxide fuel cells (SOFCs) are also being installed at present to compare the technological options.

*Fig. 2 Five hybrid hydrogen-powered fuel cell cars at The University of Birmingham, making it the only university in the U.K. to run a fleet of vehicles powered in this way (Courtesy of Dr Bruno G. Pollet, The University of Birmingham, U.K.)*

However, a key question is the supply of 'green' hydrogen. The SCRATCH project has brought together a consortium which is working to build and extend the supply chain, from the sources of green hydrogen, through its production, storage and supply, to utilisation and products in the market. Kendall added that the main weaknesses in the hydrogen economy need to be considered, including the lack of current renewable sources, storage issues, market demand and economic barriers. The University of Birmingham is focusing on innovative systems and on the ways in which these can be spread from chemical industry sites. A particular objective is to design a zero-emission campus based on a hydrogen economy. £1.5 million of funding from EPSRC and £0.5 million from AWM are currently supporting five research associates over a three-year period, from 2007 to 2010, to carry out research in the technical areas prioritised by the industries. This revenue project fits in with the £6.5 million capital project on hydrogen funded by AWM as part of the AWM Birmingham Science City. This provides test equipment, CHP systems, fuel cell vehicles and a hydrogen refuelling station on the university campus.

'Review of U.K. Regional Activities on Hydrogen and Fuel Cells' was presented by Dr Jon Helliwell (Centre for Process Innovation (CPI), Wilton, U.K.). He highlighted a variety of hydrogen and fuel cell related projects that have been established in the U.K., covering a number of regions. His presentation reviewed these projects in a regional context and commented on the regional and national strategies supporting them. A great emphasis of the projects was the context of the hydrogen supply chain itself, including hydrogen production, storage, distribution and use. Having reviewed the current picture of hydrogen activity in the U.K., Helliwell raised the important question of whether or not these projects offered a coherent demonstration and development strategy.

Ian Williamson (Air Products PLC, U.K.) gave a talk on 'Hydrogen Development', giving a vision of hydrogen and fuel cells in Europe. His presentation covered the role of Air Products in this growing market and gave some examples of urban scenarios and short-term demonstrations. Air Products is the world's largest producer of commercial hydrogen (~ 50% market share). Their capacity amounts to around 1.75 million tonnes per annum, which could eventually support seven to eight million hydrogen-powered vehicles. Air Products has been active in this market since 1993, having built over eighty hydrogen station projects and supplied over 50,000 fuellings in fourteen countries. Future hydrogen infrastructure will include pipelines delivering hydrogen, similar to those in existence for natural gas, plus a multitude of hydrogen feed sources, from biomass to geothermal, wind, solar, nuclear and coal and methane reforming. Williamson also listed the main hydrogen fuelling station requirements, such as:

(a) Safety;
(b) Capacity, as per the U.S. Department of Energy's (DoE) H2A Model (1,500 kg per day, utilisation of 70% and flexibility to meet daily, weekly, seasonal or growing demand);
(c) Dispensing capability (350 bar and 700 bar with a fill time of three to seven minutes);
(d) Reliability (> 99.9%);
(e) Location, for example urban;

(f) Small footprint, i.e. a transparent operation to the consumer.

Some examples of successful projects were shown, for example, the seventeen mile Los Angeles basin hydrogen pipeline through an urban area and Air Products' operation of over 500 miles of hydrogen pipeline worldwide.

Tommaso Giunti (Fiat Powertrain Technologies (FPT), Centro Ricerche Fiat ScpA (CRF), Italy) gave an overview on the 'State of Art for Automotive Fuel Cell in Northern Italy'. Many Italian regions located along the Po Valley suffer from pollution and environmental damage. These are caused by the presence of heavy or 'dirty' industries, as well as an increasing population density which leads to a growing number of vehicles on the road. Together with poor weather conditions, these factors combine to cause problems that require immediate action through an integrated sustainable mobility and energy strategy.

In 2007, the regions of Piemonte and Lombardia (13 million residents and 9.3 million vehicles) signed a strategic agreement for the deployment of hydrogen and fuel cell technologies, in line with European Seventh Framework Programme (FP7) hydrogen and fuel cells JTI programmes on sustainable energy and mobility (the REGIO-ISEM programme). The agreement is open to other Italian regions, and to countries located along the fifth corridor in the Mediterranean area which are willing to share research and technological development (RTD) programmes and infrastructures. It aims to achieve a common energy and mobility strategy, with an effective critical mass in the European Research Area (ERA) context.

Currently, the Fiat Group are operating and testing three Panda Hydrogen fleet vehicles under real conditions. The main objectives of this project are to improve on the vehicles' performance, power (aiming to improve from 7 kW to 75 kW) and load (from two to four seats including a full luggage compartment).

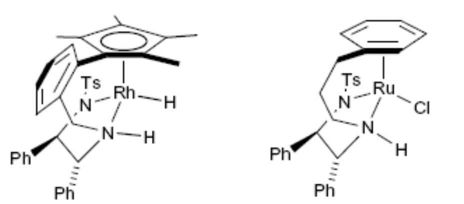
## Hydrogen Generation and Storage

Dr Rupert Gammon (British Midlands Hydrogen Forum (BMHF), U.K.) opened Session 3 by announcing the British Midlands Hydrogen Ring (MHR). The MHR is an initiative launched by the BMHF to establish a cluster of hydrogen refuelling facilities across the West and East Midlands regions of the U.K. The MHR will include trials of a variety of hydrogen vehicles in controlled environments, such as university campuses, vehicle testing centres, airports and visitor attractions. As confidence in the hydrogen and fuel cell technologies grows, the vehicles will be trialled on the open road, allowing them to travel between refuelling stations. Each hydrogen refuelling station will be strategically situated and will incorporate other examples of sustainable energy systems (solar, wind etc.). All these facilities will build upon the Midlands' knowledge base in the relevant technology areas. Gammon concluded that the Midlands could become the centre of a U.K.-wide network of hydrogen highways, with a significant part of this initiative being the fostering of links with neighbouring regions and those active in the development of hydrogen technologies. A number of locations for the refuelling stations have been proposed.

Professor Pieternal Claassen (Agrotechnology and Food Sciences Group (AFSG), Wageningen University and Research Centre, The Netherlands) presented on 'Non Thermal Hydrogen Production from Biomass'. In order to support the sustainability of the future hydrogen economy, hydrogen should be produced from renewable primary energy. The main methods for the production of 'green' hydrogen are either by electrolysis using electricity from renewable resources (such as sunlight, wind and hydropower), or from biomass. Currently, there are two methods for hydrogen production from biomass: the thermochemical method (for example gasification) and the biochemical method using microorganisms. For the latter method, the composition of the biomass is paramount – for example, its water content governs the suitability of the technology. One of the many advantages of the biochemical route is the production of 'green' hydrogen with no carbon footprint.

Professor Claassen showed that many microorganisms are able to produce hydrogen from mono- and disaccharides, starch and cellulose or hemicellulose under full anaerobic conditions. Claassen went on to say that, by uncoupling hydrogen production from methane production, hydrogen becomes available for recovery and exploitation. For example, during fermentation organic acids are produced together with hydrogen. In subsequent photofermentation, these organic acids can also be converted to hydrogen using light. Combining these fermentation methods leads to complete conversion of carbohydrates to hydrogen and $CO_2$.

Professor Martin Wills (The University of Warwick, U.K.) gave a presentation on 'Chemical Catalysts for Hydrogen Generation', in which he featured examples of the use of organometallic catalysts for the generation of hydrogen from organic compounds, including formic acid and alcohols. He gave examples of developed catalysts based on rhodium and ruthenium (Figure 3). Professor Wills showed that the catalysts are believed to work through a mechanism in which hydrogen atoms are removed 'in pairs' from the organic compounds, through a transition state. Loss of $H_2$ then regenerates the catalytic complex for another cycle. There is a precedent for this mechanism in asymmetric transfer hydrogenation chemistry.



Rhodium catalyst Ruthenium catalyst

*Fig. 3 Transfer hydrogenation catalysts based on rhodium and ruthenium for generation of hydrogen from alcohols (Courtesy of Professor Martin Wills, The University of Warwick, U.K.)*

Professor Duncan Gregory (University of Glasgow, U.K.) presented his current work on 'Solid State Storage Solutions: Hydrogen Storage in Nitrogen-Containing Materials'. He explained that inorganic nitrogen-containing compounds (nitrides, imides and amides) are becoming increasingly important as potential materials for sustainable energy applications. For example, lithium compounds with nitrogen could be extremely useful, both in power generation and conversion (for example in rechargeable batteries) and also as hydrogen storage devices. He conclusively showed that materials containing lithium and nitrogen can offer high capacity reversible storage with potentially fast sorption (ad-/desorption) kinetics and good cycleability. Nitrides, imides and amides present a multitude of opportunities for doping, catalysis and control of morphology and size. Professor Gregory concluded that nitrogen-containing materials could potentially solve solid-state hydrogen storage problems and reach targets set by the U.S. DoE.

Dr Torgeir Nakken (Norsk Hydro ASA, Norway) presented on 'Experiences from the Wind-Hydrogen Plant at Utsira'. He explained that the use of hydrogen fuel cell systems employed as stand-alone energy devices in remote locations (where traditional power supply is mainly based on diesel) is thought to be one of the most promising early markets for stationary applications. In order to demonstrate the feasibility of such autonomous energy systems, from 2003 to 2004 the Norwegian energy company StatoilHydro, together with German wind turbine manufacturer Enercon, built a wind-hydrogen plant on the island of Utsira, Norway. The system produces hydrogen through an electrolyser when an excess of wind energy is available. It provides electricity to local domestic customers *via* a fuel cell and a hydrogen internal combustion engine (ICE) when the wind turbine slows or stops. Nakken emphasised that Utsira is the only operational full-scale autonomous wind-hydrogen system in the world. During the first three years of operation, the project has shown that it is possible to supply local customers with reliable power using this type of system. However, Nakken added that one of the many challenges of the technology has been the high number of interfaces in the system, necessary to control a grid with a large wind turbine supplying a relatively small load, together with the operation of the fuel cell, electrolyser and hydrogen engine.

## Fuel Cells for Transport and Buildings

The final session of the conference was opened by Professor Martin Wills (The University of Warwick, U.K.) and focused on fuel cells for transport and buildings. Professor Andreas Züttel (EMPA, Swiss Federal Laboratories for Materials Testing and Research, Zurich, Switzerland) described 'Hydrogen for a Low Carbon Future'. He outlined that much emphasis is currently being placed on the use of hydrogen and fuel cells for vehicular applications. This presents problems with regard to the use of solid-state hydrogen stores, particularly in the case of compact motor vehicles, due to their size and weight. However, in marine transport applications, these factors are less important as the weight of the solid-state hydrogen stores can be a positive advantage in terms of the ballast required in the vessel. Professor Züttel described the hybrid canal boat project being carried out at The University of Birmingham (under Professor Rex Harris).

Following the presentation from Professor Züttel, Professor Rex Harris (The University of Birmingham, U.K.) presented on 'Hydrogen, Magnets and the Protium Project', focusing on the Hydrogen Hybrid Canal Boat project. The zero-emission hydrogen hybrid canal boat was developed by Professor Rex Harris and engineers at the University of Birmingham. The canal boat, called The Ross Barlow (Figure 4), is fully operational and demonstrates how a combination of magnet and fuel cell technologies could be used to power inland waterways craft.

The Ross Barlow has been created by converting a standard maintenance boat which was donated to the university by British Waterways. The diesel engine was removed and replaced by a zero-emission propulsion system and the central part of the boat was converted into a covered demonstration area. The hydrogen is stored on board in a large-scale metal hydride storage system which was developed by The University of Birmingham Hydrogen Materials Group (headed by Dr David Book) with Swiss collaborators at the EMPA laboratories in Zurich. This provides an effective means of storing large amounts of hydrogen at room temperature and moderate pressure (around 10 bar). The hydrogen is released from the hydride by decreasing the pressure, providing the platinum group metal (pgm)-catalysed PEMFC with ultra-pure hydrogen. The metal hydride system weighs 130 kg and is thought to be the only store of its kind in the U.K. Rare earth permanent magnets are used in the highly efficient motor and rudder system. There is a synergy between the magnets and hydrogen as they are manufactured by a hydrogen-based process invented by the Birmingham research group.

Harris recognises that the world has no more than twenty years to meet the urgent challenges of climate change and oil depletion. Much can be gained from the operation of hydrogen-based demonstrations, and the canal boat project

*Fig. 4 The Ross Barlow Hydrogen Narrow Boat developed by Professor Rex Harris at The University of Birmingham, U.K. (Courtesy of Professor Rex Harris, The University of Birmingham, U.K.)*

represents one step in the journey towards a hydrogen society.

Renewable electricity can be stored as hydrogen by splitting water using electrolysis. Hydrogen can subsequently be converted back to electricity and water by using a gas turbine or fuel cell. 'Green' hydrogen is considered a clean fuel as it has minimal impact on the environment and could reduce emissions of $CO_2$ and other greenhouse gases.

The conference ended with two presentations, one from Jonathan Lewis (Rolls-Royce Fuel Cell Systems Ltd, Derby, U.K.) on 'Stationary Fuel Cells and More Efficient Distributed Power', and one from Dr Jack Frost (Johnson Matthey Fuel Cells Ltd, Swindon, U.K.) on the 'Vision/Review of Hydrogen Fuel Cell Future'. Both talks gave an overview on fuel cell technologies, covering the challenges of energy security, efficiency and emissions as well as current challenges in fuel cell technology.

## Conclusions

Hydrogen and fuel cells are likely to be one answer to the consumer's demand for energy replacement and increased power, along with current environmental issues. Furthermore, it is evident that fuel cells are currently playing an important role in moving towards a low carbon future and are gradually being accepted for other applications. This is an exciting time for the hydrogen and fuel cell community, as on a U.K. and EU level, funding towards programmes and projects is being channelled through research institutions, universities and directly or indirectly to industry and local companies to 'catalyse' hydrogen fuel cell R&D and demonstrations. Furthermore, the use of pgms for fuel cell applications has a promising future for both transport and domestic applications as demand is likely to increase.

The Fifth Annual Hydrogen and Fuel Cells Conference: Building the Hydrogen & Fuel Cells Future was scheduled for 25th March 2009 at the Gallery Suite, NEC, Birmingham, U.K. The conference was to focus on the application of low carbon built environment EU and U.K. programmes. Further information can be found on the Climate Change Solutions website (6).


## Acknowledgements

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**The Reviewer**

Dr Bruno G. Pollet, Lecturer in Hydrogen Energy and Fuel Cell Technologies, and Head of the Proton Exchange Membrane Fuel Cell (PEMFC) Group, Fuel Cells Group (FCG), The University of Birmingham, is an expert in the areas of PEMFCs, electrochemical engineering and sonochemistry. He is currently responsible for the £1.3 million U.K. government DECC HFCCAT Hydrogen Fuel Cell Vehicle project and PEMFC and MEA activities within the FCG. He is also the coordinator of the recently awarded £5.5 million EPSRC Doctoral Training Centre in Hydrogen, Fuel Cells and Their Applications, the first of its kind in the U.K. He has successfully implemented a Hydrogen and Fuel Cell Supply Chain (EPSRC and AWM projects) within the West Midlands with currently fifty small and medium enterprises (SMEs) involved in the development and manufacturing of hydrogen and fuel cell components (SCRATCH: http://www.hydrogen-wm-scratch.info/). For further information, please visit: http://www.fuelcells.bham.ac.uk/Pollet.shtml