

Fuel Cells Science and Technology 2008

SCIENTIFIC ADVANCES IN FUEL CELL SYSTEMS

Reviewed by Donald S. Cameron

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Following meetings in Amsterdam, Munich and Turin (1–3), a fourth gathering was held on 8th and 9th October 2008 at the Confederation of Danish Industry in Copenhagen, Denmark, with the theme ‘Scientific Advances in Fuel Cell Systems’ (4). These conferences alternate with the Grove Fuel Cell Symposium, with greater emphasis on the latest technical developments in the field. The two-day programme was compiled by the Grove Symposium Steering Committee (5) from oral papers and posters submitted from around the world, and the conference was organised by Elsevier. Many of the papers will be published in full in a special edition of *Journal of Power Sources* (6).

The meeting was attended by delegates from universities, research organisations and the fuel cell industry, numbers being limited to 280 by the capacity of the venue. A total of 32 countries were represented, with 18% of delegates from Scandinavia, 60% from the rest of Europe, and 16% from Asia, as well as others from the Middle East and Africa. Surprisingly, only 4% of delegates were from the U.S.A.

The conference represents the state of the art in research and development topics on fuel cells and their applications and, as well as 56 oral papers, there were almost 140 high-quality poster presentations. There were eight oral sessions on fuels and fuel processing, modelling, systems and applications, membrane science, materials science, and finally cell and stack technology, the latter two categories each occupying two sessions. Since the topic of fuel cells covers such a wide area, for this review only papers involving use of the platinum group metals (pgms) and possible alternative materials have been selected.

Delegates were welcomed to the headquarters of the Confederation of Danish Industry, situated at the edge of the world-famous Tivoli Gardens,

by the Deputy Director General, Ole Krog. The Confederation represents 11,000 companies in Denmark employing 500,000 workers. Thomas Egebo (Permanent Secretary of State at the Ministry of Climate and Energy, Denmark) officially opened the proceedings, and spoke of the need to improve security of energy supply, partly by improving the efficiency of utilisation of existing supplies, as well as increasing renewable energy generation. The transport sector accounts for 25% of greenhouse gas emissions, and hydrogen and fuel cell powered vehicles have been granted exemptions from Danish government registration taxes to encourage their implementation.

Egebo ended by presenting the 2008 Grove Medal to Subhash C. Singhal, who is a Battelle Fellow and Director of Fuel Cells at the Pacific Northwest National Laboratory (PNNL) in Richland, Washington, U.S.A. (Figure 1). Singhal is an acknowledged world leader in solid oxide fuel cells (SOFCs), having joined PNNL in April 2000 after working at Siemens Power Generation (formerly Westinghouse Electric Corporation) for nearly thirty years, playing a key role in bringing SOFC technology from a few-watt laboratory curiosity to fully integrated 200 kW power generation systems. 100 kW systems have been demonstrated in The Netherlands, Germany and Italy as well as the United States, while technology demonstration programmes are in progress worldwide. The Solid State Energy Conversion Alliance (SECA) project is addressing the challenges to be faced, where cost reduction remains a major factor, together with interconnects and gas seals which are compliant with differential thermal expansion.

Plenary Presentation

One reason for the high level of interest in fuel cells in Denmark was explained by a plenary presentation entitled ‘Massive Integration of Renewable



Fig. 1 The 2008 Grove Medal was presented to Dr Subhash Singhal (centre), a world authority on solid oxide fuel cells, by Thomas Egebo, the Danish Permanent Secretary of State at the Ministry of Climate and Energy (right), and Professor Lars Sjunnesson, Chairman of the Grove Symposium Steering Committee (left)

Energy in the Power System with Fuel Cells as Virtual Power Plants', given by Inger Pihl Byriell (Energinet.dk, Denmark). This company is owned by the Danish state and was set up by Act of Parliament in December 2004 to operate the electricity and gas grids, but has no power production capacity.

Twenty-five years ago, fifteen large thermal electricity generating plants supplied all Danish power requirements. Today, there are still fifteen large plants, but there are also 700 combined heat and power (CHP) units generating local power and currently 5000 wind turbines rated at up to 3000 MW. National annual demand is 35.3 TWh, which must be balanced against the 47.3 TWh actually generated by marketing the surplus. On some windy days, turbines and CHP can meet all of Denmark's power demands. However, this generating capacity fluctuates widely, depending on wind strength, which cannot be accurately forecast.

To bridge the wide gaps between supply and demand, 'spinning reserve' must be maintained in the coal-fired thermal power stations, which have relatively slow response times to changing loads. Excess power is sold to neighbouring Sweden and Germany, but electricity prices vary widely depending on availability. Stores of electricity, or generators with fast response times, would considerably ease the difficulties in balancing supply and demand, and alternatives such as batteries, fuel cells and

electrolysers, as well as compressed air storage and heating systems, are being considered.

A distributed energy generation system consisting of large numbers of connected fuel cells forming a 'virtual grid' is seen as a possible solution, particularly since these generators operate at increased efficiency under partial loads. Danish wind turbine generating capacity is expected to double from 3000 MW to 6000 MW by 2025, posing a considerable challenge. Denmark is one of the leading exponents of renewable energy generation, but this supply and demand problem will soon be encountered by other countries as their proportion of renewable energy increases.

Fuels and Fuel Processing

Most fuel cells rely on a supply of gaseous hydrogen which may be provided by several means, including storage under pressure, reforming hydrocarbons or electrolysis. Huge volumes of hydrogen are generated as byproducts from industrial processes, one of the largest sources being from chlorine or caustic soda production. A high proportion of electrolysis is still carried out using mercury amalgam cells, which leads to contamination of the hydrogen with mercury.

The effect of this has been investigated, as explained by Karel Bouzek (Institute of Chemical Technology, Prague, Czech Republic) in his talk 'Influence of the Hydrogen Contamination by Mercury on the PEM Type Fuel Cell Life-Time'.

Brine electrolysis in mercury-type cells typically results in hydrogen contaminated with between $10 \mu\text{g m}^{-3}$ and $40 \mu\text{g m}^{-3}$ of mercury, which over long periods may be adsorbed on the platinum catalysts of PEM fuel cells to form platinum amalgams. Small (50 cm^2) fuel cells with electrodes supplied by E-TEK, New Jersey, U.S.A. (now BASF Fuel Cells), with 5 mg Pt cm^{-2} content, and Nafion[®] membranes were supplied with hydrogen containing between $0 \mu\text{g m}^{-3}$ and $1000 \mu\text{g m}^{-3}$ mercury over extended periods. Although there was some performance recovery during periods when the cells were switched off, there was a 20% power reduction over 10,000 hours which was not recoverable. X-Ray photoelectron spectroscopy indicates that the mercury is in a changed chemical state, suggesting that an amalgam is formed with the highly dispersed platinum catalyst. This effect was reproduced using platinum foil electrodes exposed to mercury vapour. Overall, results indicated that with hydrogen containing $10 \mu\text{g m}^{-3}$ of mercury, polymer electrolyte membrane (PEM) fuel cells are likely to be able to operate for 10,000 to 20,000 hours without catastrophic poisoning by the mercury.

Two papers were presented on storage of hydrogen in the form of ammonia. The first of these, 'Solid Ammonia as Energy Carrier: Possibilities and Technology Development', was presented by Debasish Chakraborty (Amminex A/S, Denmark). Ammonia itself is more dangerous than gasoline, since it is toxic and has a high vapour pressure at room temperature. However, in the form of a metal ammine, such as with magnesium, $[\text{Mg}(\text{NH}_3)_2\text{Cl}_2]$ or copper, $[\text{Cu}(\text{NH}_3)_8\text{Cl}_2]$, ammonia can be stored in solid form, from which gaseous ammonia can be recovered and cracked to release hydrogen.

Amminex have developed 'Hydramine'TM, which includes $\text{Mg}(\text{NH}_3)_6\text{Cl}_2$ and $\text{Ca}(\text{NH}_3)_8\text{Cl}_2$ and has a volumetric hydrogen content similar to liquid ammonia ($\sim 110 \text{ kg H}_2 \text{ m}^{-3}$), but does not necessitate pressurised storage, and is non-hazardous for road transportation. The company is actively integrating this solid ammonia technology with a SOFC, in collaboration with Topsoe Fuel Cell, Denmark, and Risø National Laboratory at

the Technical University of Denmark, since the SOFC operating temperature is sufficient to decompose the ammine and to generate hydrogen from the resulting ammonia. A thirty-cell, 450 W SOFC stack has been operated directly on ammonia, and the work is being extended to intermediate temperature (673 K to 773 K) fuel cells.

A prototype compact ammonia cracker capable of producing 0.7 l min^{-1} of ammonia with 99.9% conversion has also been developed, incorporating a ruthenium-based catalyst to reduce the reaction temperature. It will be operated in conjunction with a PEM fuel cell built by Intelligent Energy, U.K. For this purpose it is necessary to incorporate an absorber to remove any residual ammonia and prevent membrane contamination.

Further work on metal ammine complexes was reported by Asbjørn Klerke (Technical University of Denmark, Lyngby). In his paper 'Indirect Hydrogen Storage in Metal Ammine Complexes for Portable Devices', it was emphasised that ammonia is produced for agricultural purposes on a huge scale (125 million tonnes per annum) worldwide. It can be converted to stable compounds such as calcium, manganese or nickel amines, with energy densities comparing favourably with other forms of hydrogen storage such as liquid or compressed gas or metal hydrides. The group has investigated the effect of temperature programmed desorption of various amines, releasing gaseous ammonia which may be either used directly in a SOFC or decomposed to form hydrogen and nitrogen. The calcium form $[\text{Ca}(\text{NH}_3)_8\text{Cl}_2]$ decomposes completely below 550 K, while the manganese form $[\text{Mn}(\text{NH}_3)_6\text{Cl}_2]$ decomposes below 650 K, and the magnesium $[\text{Mg}(\text{NH}_3)_6\text{Cl}_2]$ and nickel $[\text{Ni}(\text{NH}_3)_6\text{Cl}_2]$ forms below 670 K.

On heating the nickel form, the blue solid becomes a cream solid with a more open structure of composition $[\text{Ni}(\text{NH}_3)_2\text{Cl}_2]$, before finally decomposing to yellow NiCl_2 . Catalysed cracking of ammonia to hydrogen and nitrogen has also been investigated, with best results being obtained using supported ruthenium catalysts (3% Ru on titania) at temperatures as low as 700 K.

The use of fuel cells in small-scale decentralised energy generation requires hydrogen to be produced on site from hydrocarbons such as natural gas, propane and liquefied petroleum gas (LPG). Although poison-tolerant pgm fuel cell catalysts have been developed, low-temperature fuel cells still require hydrogen with very low carbon monoxide (CO) content to avoid impaired performance due to catalyst poisoning. Conventional hydrogen generator systems consist of a reformer operating at 1073 K to 1273 K, followed by a high-temperature water-gas shift reactor (HT-WGS) at 570 K to 770 K, and a low-temperature shift reactor (LT-WGS) at 453 K to 573 K. Finally a preferential oxidation (POX) catalyst is used to oxidise CO to CO₂ at 353 K to 423 K in the presence of hydrogen, preferably to less than 10 ppm CO. Heat for the endothermic reformer reaction can either be provided by heat transfer through the reactor walls, or generated *in situ* by oxidising a proportion of the fuel. Work is in progress to simplify this process by making multifunctional reactor vessels.

Feyza Gökalliler (Bogaziçi University, Turkey) in a talk entitled 'Oxidative Steam Reforming Performance of Pt-Ni Catalysts' described the use of platinum-nickel alloy catalysts on alumina supports for oxidative steam reforming as the first stage, followed by the water-gas shift reaction. By optimising the Pt:Ni ratio of the catalyst and reaction parameters, it is possible to use a single reactor vessel to combine the reforming and high-temperature shift reactions. Parameters examined included the Pt:Ni ratio of the catalyst and the overall metal content, the hydrocarbon feed rate, and the steam:carbon and carbon:oxygen ratios in the feed stream. These showed that the platinum-nickel system is a promising catalyst for the oxidative steam reforming (OSR) reaction. During this reaction, exothermic oxidation and endothermic steam reforming are catalysed by Pt and Ni sites respectively, with the catalyst acting as a micro heat exchanger. Using this catalyst, hydrogen production could be carried out at temperatures as low as 673 K with 100% conversion of the hydrocarbon feed. The hydrogen production rate increases with increasing temperature and no carbon is

deposited on the catalyst surface. Selectivity (the H₂:CO ratio) is highest at low temperature and tends to decrease with increasing temperature. Similarly, the proportion of hydrogen in the product increases with decreasing residence time in the reactor.

Hydrogen can be generated by decomposing metal hydrides, as explained by Carmen M. Rangel (Instituto Nacional de Engenharia, Tecnologia e Inovação, Lisbon, Portugal) in her talk 'Hydrogen Generation and Storage System Using Sodium Borohydride at High Pressures for Operation of a 100 W-Scale PMFC Stack'. Sodium borohydride (NaBH₄) contains 7.3% hydrogen by weight, corresponding to an energy density of 1.38 kWh kg⁻¹. To prevent spontaneous decomposition of the material in aqueous solution, sodium hydroxide (NaOH) is normally added to maintain the pH above 14, although even under these conditions there is a slow release of hydrogen above 333 K. Decomposition is accelerated by the presence of a catalyst, and ruthenium or nickel on a metallic foam support is frequently used. Typical hydride fuels consist of 10% NaBH₄ plus 1% NaOH, or 20% NaBH₄ with 3% NaOH, often with carboxymethyl cellulose or polyacrylamide gelling agents to render the mixture thixotropic. Other direct oxidation types of borohydride have also been developed. Applications are likely to be limited to relatively low-power devices by the energetics of manufacturing the sodium borohydride, but the technology appears feasible for small, hand-held devices.

Membrane Science

Intense development efforts on polymer electrolyte membrane fuel cells have resulted in technology improvements on a broad front. It has long been recognised that the limiting factor in PEM fuel cell durability was due to the membrane. Peter Gray (Johnson Matthey Fuel Cells, U.K.) outlined some of these developments in his talk 'Advances in MEA Durability in PEM Fuel Cells'. Membranes with increased chemical stability, incorporating reinforcing materials as well as additives to reduce chemical attack have resulted in membrane electrode assemblies (MEAs) able to

meet current durability targets, achieving lifetimes up to five to ten times those obtained using previously available commercial materials. Emphasis has therefore moved to catalysts with improved stability, particularly under the arduous conditions of cell reversal. This may occasionally occur due to hydrogen starvation at cell anodes during fuel cell start-up and shut-down, particularly in automotive applications. This can result in loss of electrochemical surface area due to oxidation of the catalyst carbon substrate, and also possible sintering of the platinum catalyst. Significant improvements in MEA durability have been obtained by incorporating advanced membranes with oxidation resistant catalysts, even when subjected to extreme voltage cycling test regimes.

Cell and Stack Technology

Direct methanol fuel cells (DMFCs) are being sold in significant numbers as portable electric power sources for civilian as well as military applications (7). In order to reduce parasitic power losses, passive-feed DMFCs, without external pumps for feeding methanol or air to the fuel cell are being investigated. Air reaches the cathodes by diffusion, while methanol diffuses to the anodes due to a concentration gradient from a reservoir, and by capillary action through the electrode pores.

In his talk 'Electrochemical Characterisation of a Passive Monopolar DMFC Mini-Stack Operating at Room Temperature', Antonino S. Arico (CNR-Institute of Advanced Technologies for Energy (ITAE), Messina, Italy) described how three different designs of passive monopolar three-cell mini-stacks of this type have been investigated. This work forms part of a programme aimed at building a 500 W system for the European Commission-sponsored MOREPOWER project, in collaboration with several other organisations. Using various platinum metal loadings, optimum power density was reached using 4 mg Pt cm⁻² at 294 K. Preferred catalysts are carbon supported platinum-ruthenium alloys for the anode and platinum on carbon for the cathode. Cell performance decreased during prolonged operation, although this could be restored by shaking the cells. This

was attributed to dislodging carbon dioxide gas bubbles which build up within the structure. One challenge still to be overcome is a high level of methanol crossover to the cathode, which could be substantially reduced or eliminated by using an improved membrane.

Under the European Commission-funded Sixth Framework research initiative, Airbus Industrie are coordinating the CELINA project to develop auxiliary power units for aircraft to take over many of the functions of the present hydraulic system. Erich Gülzow (German Aerospace Center, Institute of Technical Thermodynamics, Germany) in his talk 'Investigation of Low Pressure Operation of PEFC Using CO Contaminated Gas' described how PEM fuel cells can be operated at pressures as low as 200 mbar when standard fuel cells normally run at around 1.2 bar.

Since air compression is energy intensive, it is advantageous to operate at low pressure: 200 mbar which corresponds to a height of 10 km. As a preliminary to designing a reformer system for kerosene, a special fuel cell test station has been constructed to operate at pressures as low as 50 mbar, using single 150 cm² format PEM cells. Typically, anodes contain 0.30 mg Pt-Ru cm⁻² alloy catalysts, while cathodes contain 0.55 mg Pt cm⁻². Typical gas mixtures used at the anode consist of hydrogen plus 5 ppm, 10 ppm, and 20 ppm CO, with between 1.5 and 2.5 stoichiometric fuel flow. Conclusions to date indicate that a pressure between 1000 mbar and 500 mbar does not have a dramatic effect on performance, with a more pronounced effect below 500 mbar with a minimum of 62% relative humidity in the inlet gas. The maximum permitted carbon monoxide content was 20 ppm, since pronounced performance effects were found at concentrations above this level.

Various attempts to eliminate or minimise the amount of pgms used in PEM fuel cells are in progress. One of these was presented by Andrew M. Creeth (ACAL Energy Ltd, U.K.) in his talk entitled 'FlowCath™ Technology – A Route to Precious Metal-Free Cathodes for PEM Type Fuel Cells'. This system is aimed at producing portable fuel cell generators, CHP systems for the home

and automotive applications. Each individual cell incorporates a three-dimensional cathode which is immersed in a homogeneous aqueous mediator, consisting of an undisclosed transition metal redox catalyst. This can be regenerated in an external reactor vessel by bubbling atmospheric oxygen through it. Currently about 300 ml of redox medium is required per 1 kW output, although this may be reduced to 200 ml kW⁻¹, and water management can be achieved within the regenerator. The cathodes, which may be carbon based or metal meshes, are combined with conventional MEAs with platinum-catalysed anodes. Due to the facile nature of the hydrogen oxidation reaction, a very low anode pgm loading is permissible.

Peak powers of up to 440 mW cm⁻² have been observed with durability in excess of 1500 hours. Due to the relatively large volume of catholyte, no humidification is required for the inlet gases. As a DMFC, an open circuit voltage of 0.7 V can be obtained with power densities in excess of 90 mW cm⁻² and no impact is observed due to methanol crossover at concentrations below 8 M. A ten-cell stack of 5 cm² cells has been demonstrated, providing 60 W of power, and a 1 kW system is being constructed.

A second means to minimise the platinum content of fuel cells was proposed by Stuart Gilby (CMR Fuel Cells, U.K.) in his talk 'CMR Fuel Cells: Development of Novel DMFC Fuel Cell Technology for the Portable Market'. The company is developing a range of DMFC stack products for the portable electronics industry. This application requires small, compact stack designs with high voltage efficiency and power density to minimise stack volume. By using alkaline solid polymer electrolyte membranes, a wide range of catalysts may be used, such as silver, perovskites, and pyrochlore materials. An added advantage of alkaline membranes is that electro-osmotic effects tend to move water molecules from the cathodes to the anodes, inhibiting crossover of other species. Methanol permeability therefore decreases with increasing concentration, so that higher concentrations can be used at the anode. Unfortunately, alkaline membranes are less well developed than their acid equivalents, and also exhibit a lower

mass transfer rate for hydroxyl ions compared to protons, so that their conductivity is roughly one tenth of those obtained for acidic membranes. This is partly offset by the high reactivity for the oxygen reduction reaction under alkaline conditions. In addition, soluble forms of membrane material are not yet available. These are essential to mix with the catalysts to produce an optimum high area three-phase interface between gas, liquid and solid when preparing electrodes.

In a talk entitled 'Fuel Cell Cathodes Studied with Density Functional Theory', Jan Rossmeisl (Center for Atomic-scale Materials Design (CAMd), Technical University of Denmark, Lyngby) described the use of the density functional theory (DFT) model to examine the oxygen reduction reaction on platinum and its alloys. Having developed a framework to deal with the potential in electronic structure calculations, and by applying a quantitative version of the Sabatier principle, together with a database of DFT calculations, they are able to predict trends in activities for different electrode materials. Comparing the predictions of the Sabatier model with experiments on Pt and Pt₃Ni {111} surfaces, most of the polarisation curve features seen in experiments can be explained in terms of the Sabatier analysis. Also, CAMd have developed a kinetic model which allows them to study the effect of hydroxyl ion coverage and the pressure of oxygen, based directly on *ab initio* calculations.

Microbial fuel cells are capable of transforming chemical energy directly to electrical energy *via* electrochemical reactions. Beate Christgen (Newcastle University, U.K.) in a talk entitled 'Advances in Microbial Fuel Cells through Cathode, Anode and Membrane Development' explained that they may be used to treat materials such as waste water to obtain clean water and electrical energy. Generally a catalysed, air depolarised cathode is used in conjunction with an anode system in which organic matter is oxidised by anaerobic bacteria acting as biocatalysts, producing electrons which are transferred to a solid anode. To date, platinum-catalysed cathodes have been used, although less expensive alternative materials such as metal phthalocyanines supported

on carbon, or manganese dioxide on carbon have also been examined. Due to the low current densities obtained from microbial fuel cells, it will be necessary to use cells with large surface areas to produce a useful current output, implying that inexpensive membrane separators will also need to be developed.

Poster Exhibits

Two poster sessions were held, with almost 140 posters. These included several featuring applications of the pgms in fuel processing, fuel cell catalysis and sensors.

Eini Puhakka (VTT Technical Research Centre of Finland) presented a poster entitled 'Comparison of Pt-Based PEMFC Cathode-Catalysts Using Modelling Approach'. Density functional methods and rotating ring disc platinum electrode measurements have been used to investigate reasons for the potential loss which takes place at the cathodic oxygen reduction reaction.

Julia Melke (Fraunhofer Institute for Solar Energy Systems ISE, Germany) presented a poster entitled 'Investigation of Reaction Mechanism and Structural Changes in Direct Ethanol Fuel Cell Electrodes Using X-Ray Absorption Spectroscopy'. The ethanol oxidation reaction has been investigated using carbon supported platinum, platinum-ruthenium, and platinum-tin alloys in half cells and fuel cells using the $\Delta\mu$ X-ray absorption near edge structure ($\Delta\mu$ XANES) technique, while structural changes to the catalysts have been studied using conventional extended X-ray absorption fine structure (EXAFS) spectroscopy.

Janet M. Fisher (Johnson Matthey Technology Centre, U.K.) presented a poster entitled 'PdRu Alloy Nanoparticles as Anode Catalysts in Direct Methanol Fuel Cells' aimed at developing more cost effective catalysts for small portable power units. The individual components of the catalyst show relatively poor activity on their own, but for the methanol oxidation reaction, palladium-ruthenium anode catalysts have the same activity at 353 K as commercial platinum-ruthenium anode catalysts at 333 K.

Berker Fıcılcar (Middle East Technical University, Ankara, Turkey) reported on the 'Effect of Pd Loading in Pd-Pt Bimetallic Catalysts Doped into Hollow Core Mesoporous Shell Carbon on Performance of Proton Exchange Membrane Fuel Cells'. Catalyst substrates were synthesised by template replication with sub-micrometre-size core mesoporous shell silica spheres, yielding supports with surface areas as high as $1290 \text{ m}^2 \text{ g}^{-1}$ with a uniform, narrow pore size distribution centered around 3.0 nm. A microwave synthesis route was used to prepare carbon supported palladium-platinum alloy catalysts and testing was carried out in 5 cm^2 single-cell PEMFC tests in conjunction with a range of physical characterisation techniques.

As the range of applications for PEMFCs increases, there is more awareness of the potential for poisoning. One example of poison tolerance testing was reported by Won-Yong Lee (Korea Institute of Energy Research (KIER), Daejeon, South Korea) in a poster entitled 'Influence of NaCl Vapor on Performance and Durability of a PEFC'. Experiments involved monitoring single cell performance while running the cathode on air contaminated with sodium chloride vapour, and post-test examination of the cell components. The results were discussed in terms of poisoning of platinum catalysts by Na^+ ions and H^+ ions in the ion exchange membrane exchanged with Cl^- ions.

Satoshi Ohara (Osaka University, Japan) presented an interesting paper on the use of 'Palladium-Polymer Hybrid Nanoparticles for Hydrogen Sensors in Fuel Cells'. DNA strands have binding sites for metal ions and cation molecules on the nucleoside bases and backbone. Metal (Pd)-polymer (DNA) hybrid nanoparticles were created by a combination of metallisation and DNA compaction. Directly bound Pd(II) complexes were produced and then reduced to metal causing a morphology change in the DNA strands, producing a spherically shaped moss-like hybrid. The palladium can still absorb hydrogen to become PdH_x , which increases the electrical resistance and volume of palladium materials. The result is a highly sensitive hydrogen sensor or hydrogen switch device.

Poster Prizes

Posters were judged by panels of members of the Grove Symposium Steering Committee for content and presentation, and four awards were made to:

- (a) Xiaohui Tian, Steffen Eccarius and Carsten Agert (Fraunhofer Institute for Solar Energy Systems ISE, Germany) for their poster 'Computational Geometry Design and Modeling for a Vapor-Fed Direct Methanol Fuel Cell' (Poster 1.28)
- (b) Timo Kurz, Anne Grundmann and Carsten Agert (Fraunhofer Institute for Solar Energy Systems ISE, Germany) for their paper 'Modelling Heat Management in a High Temperature PEM Fuel Cell System with Adsorption Heat Storage' (Poster 1.54)
- (c) Satoshi Ohara, Kazuyoshi Sato, Mitsuo Umetsu and Tadafumi Adschiri (Osaka and Tohoku Universities, Japan) for their presentation 'Palladium-Polymer Hybrid Nanoparticles for Hydrogen Sensors in Fuel Cells' (Poster 2.16)
- (d) Samuel Georges, Jean-Marie Klein and Yann Bultel (Laboratoire d'Electrochimie et de Physicochimie des Matériaux et des Interfaces (LEPMI), Grenoble, France) for their paper 'Gradual Internal Reforming of Methane with Electro-Catalytic Dissociation in Planar SOFC: From Model to Operation' (Poster 2.48)

Summary

Findings from the Fuel Cells Science and Technology 2008 conference were summed up in a talk by Professor Søren Linderøth (Risø National Laboratory, Technical University of Denmark, Roskilde). Fuel cells continue to find new applications as auxiliary power supplies in aircraft, and as a means to utilise renewable energy sources such as landfill gases and wastewater while generating useful electrical power. In the area of fuel processing and fuels, interest is moving to novel fuels such as landfill gas, ammonia and ethanol. Alternative methods of storing hydrogen

such as metal amines and sodium borohydride are also being investigated. The importance of fuel purity has been recognised and is being intensively examined. In the area of membrane science, higher operating temperatures, reduced requirements for hydrating the input fuels, and improved durability are being sought and achieved. DuPont Nafion[®] remains the standard membrane by which others are judged.

While platinum remains the standard catalyst material for low-temperature fuel cells, cost reduction efforts are in progress, either by replacing it (generally with a substantial performance penalty) or seeking other electrode structures or membrane materials to minimise its use. The pgms are used in a wide range of applications as well as the electro-catalyst.

The Eleventh Grove Fuel Cell Symposium will take place at the Queen Elizabeth II Conference Centre in Westminster, London, U.K., from 22nd to 24th September 2009 (5), while the next conference in the Science and Technology series is likely to be held in Spain during 2010. See the Fuel Cells Science and Technology website for updated information as it becomes available (4).

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The Reviewer

Don Cameron is an independent consultant on fuel cells and electrolysers. As well as scientific aspects, his interests include standardising and commercialising these systems. He is Secretary of the Grove Symposium Steering Committee.