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Canada–USA PEM Fuel Cell Network Research Workshop: Report

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The 'Canada–USA PEM Fuel Cell Network Research Workshop' was held on 16–17 February 2009 in Vancouver, Canada, at the Institute for Fuel Cell Innovation (IFCI), one of the institutes of the National Research Council of Canada (NRC). This workshop is one of a series of fuel cell related workshops held at the IFCI, following the workshop 'Vancouver to Northeast USA Fuel Cell and Hydrogen Cluster Connection', which was held on 17–18 March 2008. This brief review summarizes the main themes of the event and key presentations made at the workshop.

The Institute for Fuel Cell Innovation of the National Research Council of Canada organized this workshop in order to promote networking among the hydrogen and fuel cell clusters in Canada and the US.

There were 50 participants, representing national laboratories (such as Los Alamos National Laboratory, the Naval Research Laboratory, US Army Research Laboratory, and NRC-IFCI), universities (such as the University of Alabama, University of Central Florida – Florida Solar Energy Center, University of Waterloo, University of South Carolina, University of Connecticut, University of California – Riverside, University of Hawaii – Hawaii Natural Energy Institute, University of British Columbia, Dalhousie University), the US Department of Energy, INRS (Institut National de la Recherche Scientifique, Canada), and fuel cell companies (General Motors, Automotive Fuel Cell Cooperation Corporation (AFCC), Ballard, 3M and DuPont).

In total 28 presentations were made during the workshop, followed by panel discussions on R&D collaborations.

Workshop organizer

NRC is the Canadian government's premier organization for research and development. NRC is the home of more than 20 research institutes and several national programs, spanning a wide variety of disciplines and offering a broad array of services.

Figure 1. The NRC-Institute for Fuel Cell Innovation is based in Vancouver, BC.

NRC's Institute for Fuel Cell Innovation (NRC-IFCI) is Canada's premier applied research organization dedicated to supporting the nation's fuel cell and hydrogen industry (**Figure 1**). NRC-IFCI works independently and in partnership with companies, research organizations, universities and government agencies on projects focused on the research, development, demonstration and testing of hydrogen and fuel cell systems.

This mandate delivers on the Government of Canada's climate change and innovation priorities, and responds to Canada's Fuel Cell Commercialization Roadmap, which identified critical areas of research necessary for Canadian industry to overcome the cost, performance and reliability challenges of hydrogen and fuel cell technologies.

IFCI's culture and business practices are collaborative. The institute works closely with industry, academia and other government agencies, both domestic and international, on projects focused on the research, development, demonstration and testing of hydrogen and fuel cell systems.

IFCI has built its core competency in the following areas:

- Advanced materials and processing.
- Modeling and numerical simulation.
- Novel architecture design.
- Unit and integrated system testing.
- Sensors and diagnostics development.

IFCI's technology foci are proton-exchange membrane (PEM) fuel cells, solid oxide fuel cells (SOFCs), hydrogen and alternative fuels, integrated technology and demonstrations. The institute is well equipped to carry out its cutting-edge research. The facilities include nine fuels-safe labs, a hydrogen environmental chamber (HEC), an advanced fuel cell testing center, more than 20 fuel cell test stations and various analytical equipment.

Objectives

This workshop was one of a series of workshops organized by IFCI to promote collaborations among Canadian and US researchers in the area of fuel cell research and development. The previous workshop – 'Vancouver to Northeast USA Fuel Cell and Hydrogen Cluster Connection', co-hosted by NRC-IFCI and the University of Connecticut – was held on 17–18 March 2008 in Vancouver. In that workshop, a framework for mutual partnership between Canadian and US fuel cell developers was established, and areas of mutual interest and capability were successfully identified, such as PEM fuel cell contamination and catalysis.

That workshop was limited in scope in discussing and establishing formal partnerships and joint research proposals in the areas of PEM fuel cell contamination and catalysis, where each respective hydrogen and fuel cell cluster in Canada and the US is seen to have world-leading capabilities and technologies.

The objective of the latest workshop was to bring together the leading researchers in Canada and the US to exchange information in the areas of PEM fuel cell contamination and catalysis, and to seek opportunities for joint R&D between industries, academia and government within and between the fuel cell clusters in Canada and the US.

PEM fuel cell contamination

The effects of impurities on fuel cell performance, often referred to as fuel cell contamination, are closely associated with PEM fuel cell durability and reliability, both of which are important factors in the development and commercialization of PEMFCs.

NRC-IFCI's Contamination Consortium

Hui Li introduced NRC-IFCI's capabilities in contamination and durability-related areas, including contamination modeling, contamination fuel cell testing, electrochemical studies of contamination mechanisms, and fuel cell durability studies. Because of the competencies NRC-IFCI has and the strong industrial interest in contamination research, a Contamination Consortium was formed on 1 April 2007, which currently has four members: NRC-IFCI, Ballard Power Systems, Hydrogenics, and Angstrom Power.

The Consortium has completed its Phase I research work, including the experimental testing and semi-empirical modeling of air-side toluene contamination. The Consortium now is in its Phase II – the study of metal ion contamination effects on the cathode side. The Consortium offers NRC-IFCI opportunities to expand its contamination research capabilities, leverage resources with industries, accelerate research progress, and stimulate broader collaboration with both national and international partners.

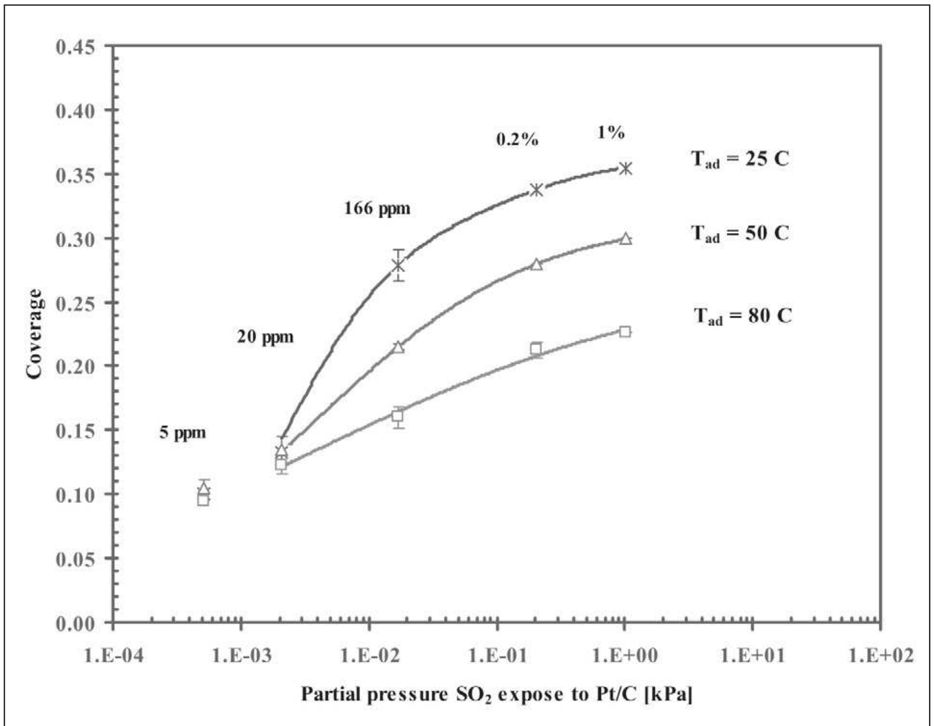

Figure 2. Effect of temperature and partial pressure on adsorption of SO_2 species on Pt/C (0.1 g Pt/cm^2).

Contamination testing and evaluation

John Van Zee (University of South Carolina) studied the mechanisms of SO_2 and NH_3 accumulation and transport in a PEM fuel cell, and the interaction of water with NH_3 and SO_2 contamination. SO_2 adsorption and desorption mechanisms on Pt were proposed, and the effects of temperature and partial pressure on SO_2 adsorption were also experimentally investigated (**Figure 2**).

Fernando Garzon (Los Alamos National Lab) presented a comprehensive study of H_2S, SO_2, CO and NH_3 contamination. His research group experimentally studied H_2S adsorption, the impact of H_2S exposure on fuel cell performance, the effects of relative humidity (**Figure 3*a***) and temperature on H_2S poisoning (Figure 3*b*), the effects of air bleeding and open-circuit voltage (OCV) on sulfur poisoned cathodes and anodes, co-adsorption of CO and H_2S, NH_3 effects on the anode, and impurity mixture effects on membrane conductivity.

Trent Molter (Connecticut Global Fuel Cell Center) reported the evaluation of the effects of gas-phase impurities (CH_4, C_2H_6, CH_3CHO, and CHOOH) on fuel cell performance and integrity. He also reported on the effects of cationic impurities (Li^+, Na^+, K^+, Cs^+, Mg^{2+}, Ca^{2+}, Fe^{2+}) on membrane properties, such as fluids permeability, water content, ion-exchange capacity, conductivity and mechanical strength.

Guido Bender from the Hawaii Natural Energy Institute (HNEI) presented a comprehensive contamination study of fuel-side CO and air-side SO_2. The effects of contaminants at various operating conditions were investigated using constant-current discharge, CV stripping and H_2 pump experiments, with full gas analysis to check the molar flow balance for the contaminants. A segmented cell with spatial data acquisition system was employed as a diagnostic tool to assist in the contamination study.

Contamination modeling

Datong Song (NRC-IFCI) introduced the PEM fuel cell contamination modeling research work conducted at NRC-IFCI over the last few years. Three theoretical models have been developed: a general fuel-side contamination model, a transient kinetic model for fuel-side H_2S, and a general air-side contamination model. All of these are based on the kinetics of the surface and electrochemical reactions of the contaminants at the

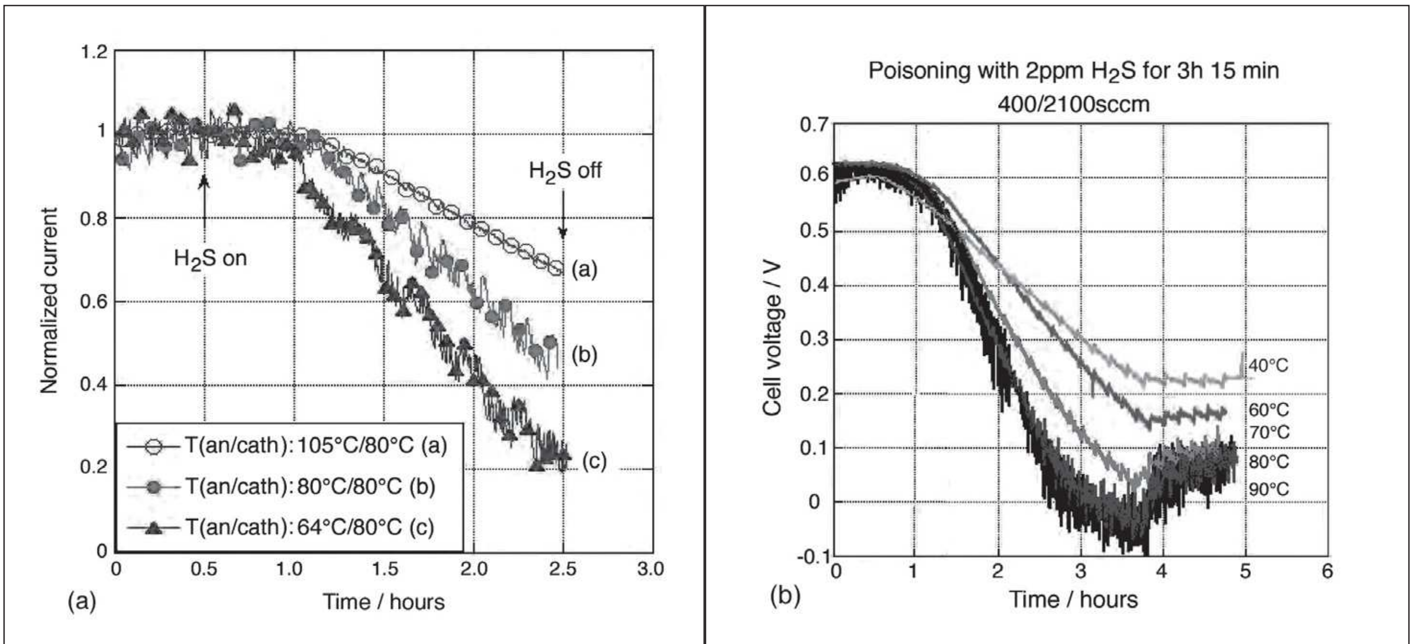

Figure 3. (a) Effect of relative humidity on H_2S poisoning: H_2S concentration = 2 ppm, cell temperature = 80°C, cell voltage = 0.5 V; (b) effect of temperature on H_2S poisoning: H_2S concentration = 2 ppm, current density = 0.8 A/cm^2, cell temperature = 80°C.

anode or the cathode. The models have been validated with experimental data (**Figure 4**), and can be used to simulate both transient and steady-state fuel cell performance.

Thomas Springer (Los Alamos National Lab) presented his work on modeling cation contamination effects in polymer electrolyte membranes. With the guidance of the model, hydrogen pump experiments were designed and conducted to obtain membrane conductivity data that can be applied to fuel cells contaminated by cations.

Xianguo Li (University of Waterloo) reported a PEM fuel cell contamination model that includes H_2, CO and O_2 adsorption, desorption, electro-oxidation and heterogeneous oxidation kinetics. This model was validated with experimental data in the literature on CO poisoning effects, and excellent agreement was achieved. The model was also used to simulate the effects of O_2 and air bleeding on CO poisoning of the fuel cell performance at various current densities.

Other issues pertinent to PEM fuel cell contamination were also discussed. For example, Cunping Huang (University of Central Florida – Florida Solar Energy Center) and Karen Swider Lyons (Naval Research Lab) reported on mitigation and recovery methods of sulfur contamination. And Gerald Voecks (US Department of Energy) addressed the need for a hydrogen fuel quality specification.

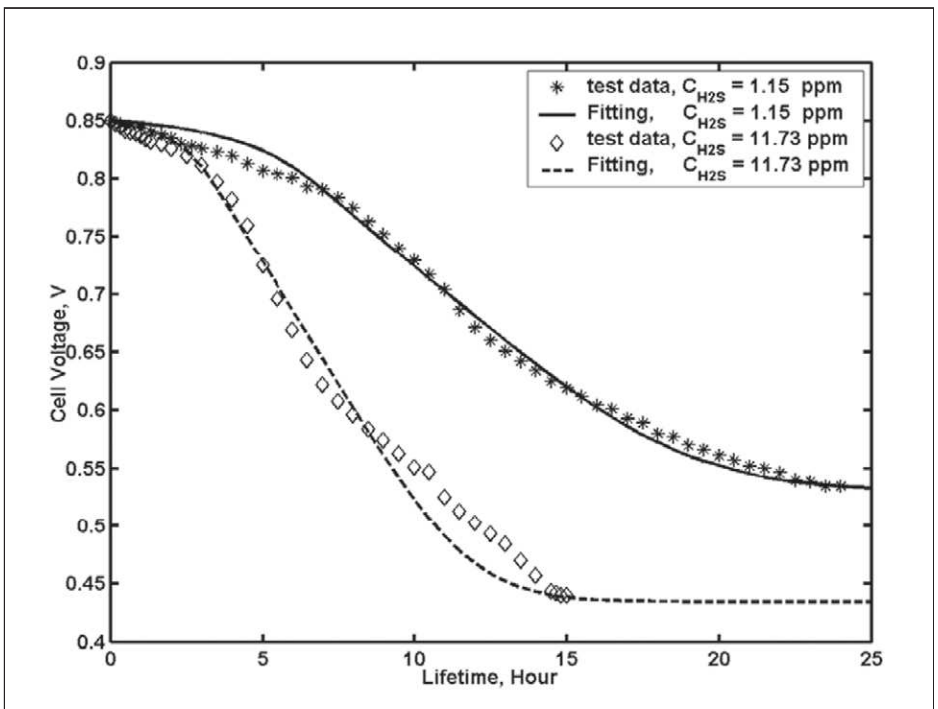

Figure 4. Model-predicted and experimentally tested cell voltages as a function of time at 0.1 A/cm^2 with various levels of H_2S in the fuel stream.

PEM fuel cell catalysis

The second theme of the workshop was PEM fuel cell catalysis, which included a variety of topics, covering catalyst materials, screening methodologies for fuel cell catalysts, low-Pt catalysts and non-noble metal catalysts, CO-tolerant catalysts and so on.

Research activities at various research organizations

The research activities on PEM fuel cell catalysis at various research organizations were introduced by several speakers. Jiujun Zhang presented on the catalysts research focus at NRC-IFCI, which includes supported Pt alloy catalysts, such as $PtBi_2$, Pt-Co/C, Pt-Ru-Ir-Sn/C, Pd-Co/C, Ir-Co/C, Pt/MC and PtRu/MC, and supported non-noble catalysts, such as Co-TMPP/C, Co-PPY/C, $Fe\text{-}N_4$/C, Mo-N/C, Ir-Se/C, W-Co-Se/C and Fe-N/C. Researchers at NRC-IFCI have developed a template-assisted ultrasonic spray pyrolysis (USP) technique that can produce a new type of carbon support material, called Porous Carbon Sphere (PCS). The PCS is a versatile carbon material with consistent controllable surface area and porosity. **Figure 5** shows the Porous Carbon Sphere supported Pt catalyst.

Piotr Zelenay introduced the Advanced Cathode Catalysts project currently being undertaken at Los Alamos. This project involves several US national laboratories (Brookhaven, Argonne and Oak Ridge) and universities (Illinois, New Mexico and UC Riverside), with multiple research areas in novel cathode catalysts and novel electrode structures for cathode catalysts, including catalysts with ultra-low Pt content, chalcogenide-based catalysts, precious metal-free catalysts, open-frame catalyst structures, nanostructures for maximum catalyst utilization and mass transport, catalyst fabrication and scale-up, and so on.

In Piotr's talk, he mainly focused on the synthesis of PANI-derived non-precious transition metal catalysts, with discussions on the RED and RRDE analysis of the synthesized catalysts, the effects of heat-treatment, acid leaching, catalyst loading and metal content. **Figure 6** shows the fuel cell testing results with a PANI-Fe_3Co/C catalyst synthesized by Piotr's group.

David A. Stevens introduced a variety of research projects conducted at Dalhousie University (Halifax, Canada), including non-noble metal catalysts for ORR, improved Pt-based ORR catalysts, hydrogen oxidation catalysts with improved CO tolerance, alternative catalysts for ethanol oxidation, and high-surface-area catalyst supports for high-temperature studies. Most of their catalysts were deposited on 3M's nanostructured thin-film support, using the sputtering deposition technique to create any composition desired (metals, polymers, oxides etc.).

Low-Pt and non-Pt catalysts

Low-Pt catalysts and non-Pt catalysts were the main theme of the workshop on PEM fuel cell catalysis. Apart from the above-mentioned speakers whose talks partially covered low-Pt and/or non-Pt catalysts, a few other speakers focused specifically on low-Pt and/or non-Pt catalysts.

For example, Frédéric Jaouen from INRS (Institut National de la Recherche Scientifique, Canada) reported on the synthesis of non-noble metal catalysts (NNMCs) conducted by Jean-Pol Dodelet's group, using the Fe precursor + N precursor + carbon support + pyrolysis procedure. There were extensive discussions on the importance of several factors, including the nitrogen content on the catalyst surface, the choice of disordered carbon, the pyrolysis duration in NH_3, the microporous surface area created during pyrolysis in NH_3, and so on. It was concluded that, during the heat treatment, an active site for ORR could be formed only if the four requirements (Fe ion, micropore of specific size, disordered carbon, and N source) were simultaneously met. And it was claimed that non-noble metal (Fe) catalysts with activity very close to the US DOE target of 2010 can now be synthesized.

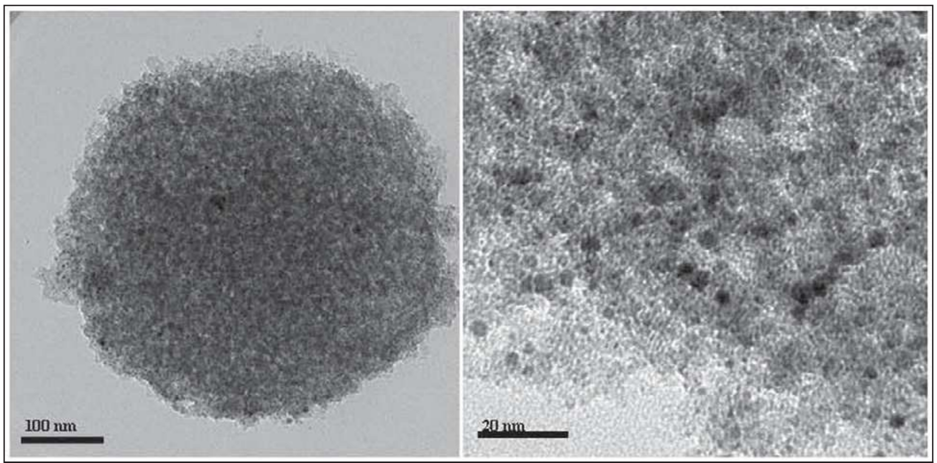

Figure 5. Porous Carbon Sphere (PCS) supported Pt catalyst.

Yushan Yan (University of California – Riverside) introduced studies on low-Pt Pt/CNT catalysts (Pt supported on carbon nanotubes, CNT), low-Pt Pt/NT catalysts (supportless), and non-Pt catalysts (Co-PPY-C). CNT as catalyst support was reported to be attributable to improved Pt utilization, improved catalyst activity and improved corrosion resistance. **Figure 7** shows a Pt/MWCNT (multi-walled carbon nanotube) catalyst, and **Figure 8** gives the performance of a Pt/MWCNT catalyst with a loading of 12 μg Pt/cm^2.

Alevtina Smirnova from the University of Connecticut presented a supercritical fluid technique, which was used to deposit mono, binary and ternary PtIrCO catalysts with good morphology, high electrochemical surface area (ECSA) and high metal surface area nanostructures. This supercritical fluid technique was also used to synthesize the carbon aerogel carbon support, which was claimed to have the benefit of narrow size distribution (±1 nm), high surface area

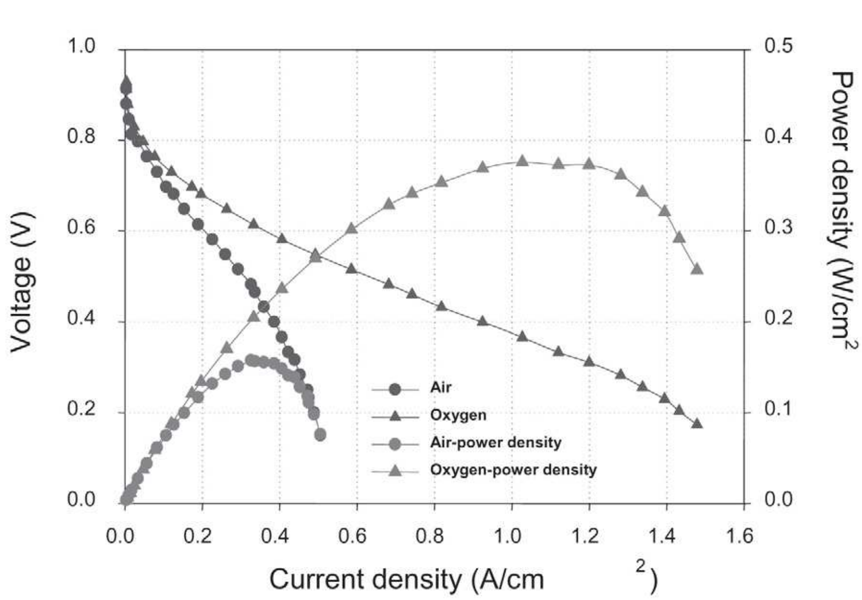

Figure 6. Cell voltage and power density as a function of current density. Anode: 0.25 mg/cm^2 Pt, 30 psig H_2. Cathode: 4.0 mg/cm^2 PANI-Fe_3Co/C, 30 psig O_2. Cell temperature: 80°C.

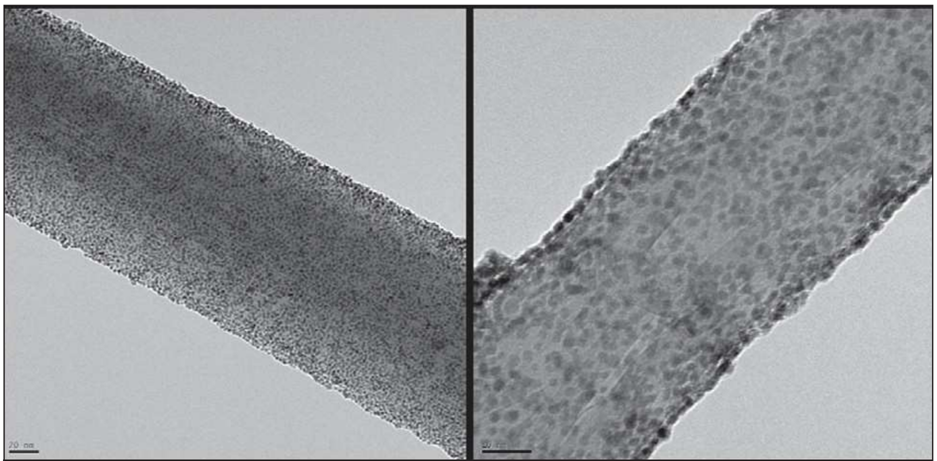

Figure 7. Pt supported on multi-walled carbon nanotube (Pt/MWCNT).

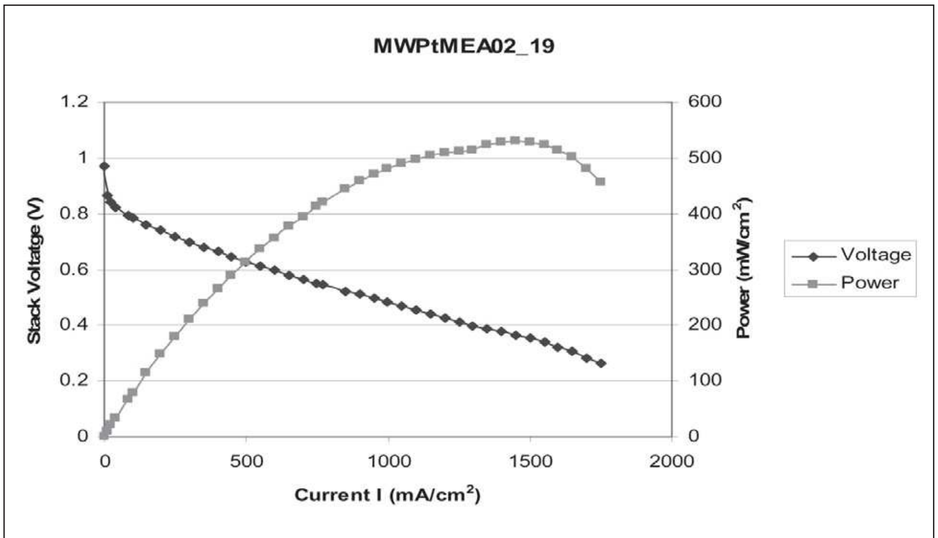

Figure 8. Cell voltage and power versus current density. Anode: sprayed E-Tek 200 µg Pt/cm^2; cathode: Pt/MWCNT 12 µg Pt/cm^2; H_2: 0.2 l/min, O_2: 0.2 l/min, RH: 80–100% on both sides, cell temperature: 70°C, back pressure: 35 psig.

(500–3000 m^2/g), high electric conductivity, high crystallinity and stability, and the absence of ionic impurities.

Other presentations related to PEM fuel cell catalysis included atomistic computation-assisted fuel cell catalyst material design by Heath Turner from the University of Alabama; optimization of fuel cell electrode structure and composition by Christina Johnston from Los Alamos; the effect of catalyst/electrode properties on PEM fuel cell performance by Jo-Ann Schwartz (DuPont Fuel Cells); and a combinatorial method for high-throughput screening of fuel cell catalysts.

Input from industry

Representatives from the Canadian fuel cell industry attended the workshop as well, and expressed their needs during fruitful discussion sessions. According to the Automotive Fuel Cell Cooperation Corporation, the following issues need to be addressed in the automotive industry for the large-scale commercialization of hydrogen fuel cell technology:

- The cost of the membrane-electrode assembly (MEA) needs to be reduced.
- The mass activity of the ORR catalyst needs to be increased by at least a factor of four.
- The MEA durability needs to be improved considerably, to address catalyst degradation.
- The PEM ionic conductivity at low relative humidity (RH%) needs to be increased.
- The gas permeability of the PEM (to hydrogen and nitrogen) needs to be reduced.
- A fundamental understanding of the cathode catalyst layer structure–performance relationship is required to enable high-current-density operation.

Summary

The workshop provided opportunities to connect the Vancouver/Canada fuel cell and hydrogen research providers to their counterparts in the US, especially those located in the East Coast clusters around the universities of Connecticut and South Carolina, as well as the various US national laboratories active in the field. The workshop also promoted the exchange of information, identified research and development opportunities, built a consensus on priorities, and explored near-term funding opportunities to conduct joint R&D activities that will benefit the R&D communities and their stakeholders in industry.

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