The Department of Energy's Fuel Cell Program

N. Garland[1], T. Benjamin[2]
[1]Department of Energy, Washington, DC
[2]Argonne National Laboratory, Argonne, Illinois

Introduction

The US Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy Fuel Cell Program is developing and demonstrating fuel cell power system technologies for transportation, stationary, and portable applications. The cost of fuel cells must be lowered and durability and performance must be improved to be competitive with current alternative technologies. The Fuel Cell Program is focused on polymer electrolyte membrane (PEM) fuel cells for light-duty vehicles because PEM fuel cells have high power density and potential for quick start-up. The Fuel Cell Program supports the overarching goal of the President's Hydrogen Fuel Initiative to enable technology readiness of hydrogen fuel cells by 2015. DOE-sponsored research and development is being carried out by academia, National Laboratories, and industry. Significant progress has been made recently.

In 2006, DOE selected more than 35 new projects that resulted from two solicitations for proposals that address the 2010 technical and cost targets. New projects were awarded in the following topics: membranes that will conduct protons over the full range of operating temperatures with less than 10% loss of performance by the end of life without external humidification, durable, low cost, low- or non-precious metal cathode catalysts with increased activity and utilization, and new seal materials that are durable and survive over the lifetime of the fuel cell (5,000 hours for transportation applications and 40,000 hours for stationary applications). Additional projects investigate strategies to optimize water management within the fuel cell stack to decrease the complexity and cost of a fuel cell system. The effects of freezing temperatures on fuel cell components and operation are being identified and quantified. Degradation mechanisms of carbon supports are being elucidated. Finally, alternative, innovative fuel cell and stack geometries and configurations with significant potential for increasing power density, specific power, and efficiency are being explored.

To ensure significant and meaningful penetration into the automotive market, fuel cell vehicles must be competitive with conventional vehicles. To achieve this goal, the DOE program is focused on addressing the major technical barriers; namely, performance, durability, and cost. The major cost and technical targets of the DOE fuel cell sub-program are shown below in Table 1.

Table 1. DOE Technical and Cost Targets

Characteristic	Units	2010 target	2015 target
Cost	$/kW	45	30
Durability with cycling	hours	5000	5000
Non-Pt Catalyst Activity per volume of supported catalyst	A/cm^3 @$800mV_{iR\text{-}free}$	>130	300
Pt Catalyst Mass Activity	A/mgPt @$900mV_{iR\text{-}free}$	0.44	0.44

Membranes

Membranes have been a determining factor in fuel cell system durability. Work performed by UTC, DuPont, 3M, and Case Western Reserve University has elucidated membrane decay mechanisms for fuel cell membranes and developed strategies to address the main degradation modes. This effort has resulted in new membranes with increased durability that approaches the 5,000 hour target under cycling conditions. As one example, DuPont has achieved an increase in membrane durability under accelerated testing of almost 40 times compared to their standard baseline Nafion®. The new membrane operated for >4500 hours in accelerated combined humidity and load cycling testing (1). Membrane humidity requirements and temperature limitations are also being addressed.

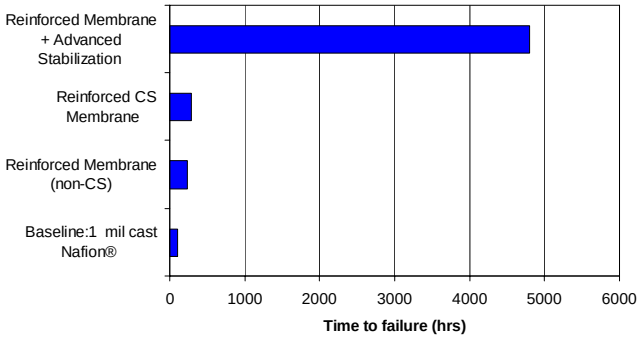

Figure 1. Accelerated durability test results: combined humidity and load cycling operation of DuPont membranes

The DOE program is employing three main strategies in its high temperature membrane research: control of phase segregation, and use of both non-aqueous proton conductors and additives. Initial results indicate phase segregation plays an important role in proton conductivity, and that by controlling phase segregation, one can increase conductivity under low RH conditions while maintaining mechanical strength. McGrath has demonstrated that varying the block sizes in block copolymers affects the phase segregation and the resulting properties, including proton conductivity (2). Another approach that has demonstrated early success is the use of a composite membrane, utilizing an inert polymer matrix or support to provide the mechanical integrity and a low equivalent weight ionomer to provide the proton conduction. With this approach, Giner has been able to demonstrate a conductivity of ~ 0.09 S/cm at 120°C and 50% RH (3).

While these approaches have made improvements in proton conductivity under low RH conditions, they still rely on water for the conduction. DOE is also investigating membranes that employ non-aqueous proton conductors. Membranes using ionic liquids, phosphonic acids and heterocyclic bases such as imidazoles and diazoles are being developed. The success of these systems is tied to the ability to tether the groups responsible for proton conduction in a way that does not interfere with the conduction mechanism. Work at LBNL has demonstrated that these systems can be immobilized without significantly affecting the proton conductivity (4).

Catalysts

To improve catalyst performance and reduce cost, the DOE program is pursuing the following strategies: lowering platinum group metal (PGM) loading by improving catalyst utilization and employing platinum alloys with increased performance and durability compared to platinum; using non-carbon and alternative catalyst supports; and developing non-precious metal catalysts. The 2010 target for catalyst cost is $5/kW, which corresponds to a total cell Pt loading of 0.3 mg/cm^2 at a Pt cost of $15/g.

Low-Pt catalysts. Approaches to reducing the platinum catalyst loading include alloying platinum with base metals or other PGMs such as palladium or ruthenium. Argonne National laboratory, 3M Company, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, and others have demonstrated low PGM loadings with performance and durability exceeding Pt alone. Figure 2 shows the oxygen reduction reaction current densities as a function of oxygen binding energy (5). The graph indicates higher current densities for alloys than for Pt.

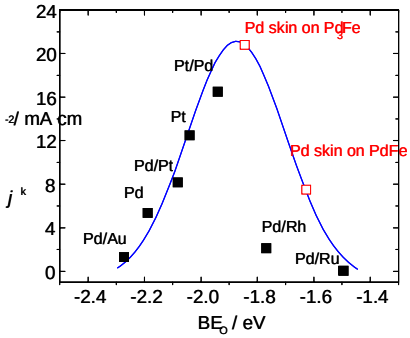

Figure 2 Experimental RDE oxygen reduction data (solid squares) and predicted ORR current densities for Pd over-layer on $Pd_3Fe(111)$ and PdFe(111) (open squares) as a function of the calculated oxygen-binding energy.

Non-PGM catalysts. Progress in cathode catalysts that do not contain precious metals has been impressive although the gap between the performance of non-PGM catalysts and state-of-the-art platinum and platinum alloy catalysts remains large. The University of South Carolina, Los Alamos National Laboratory, Ballard, and 3M Company have addressed the issue. Figure 3 shows the durability of a 3M non-PGM cathode with no irreversible performance loss after more than 1,000 hours of 50 cm^2 cell operation (6).

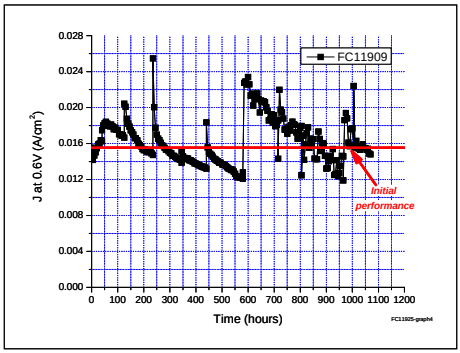

Figure 3 Durability of 3M's Non-PGM Catalyst

Water Management

The Rochester Institute of Technology has begun studying water transport and performance characterization under freezing conditions by identifying new gas diffusion layer materials and design. CFD Research Corporation is studying water transport in PEM fuel cells. Los Alamos National Laboratory is conducting exploratory studies of water transport phenomena. Nuvera Fuel cells is developing a start/stop protocol for an advanced metallic open-flow field fuel cell stack under sub-freezing conditions. All of these developers are using a combination of modeling, experimentation, and characterization.

Other new projects
Other projects from the recent DOE solicitation are discussed below. These projects are just beginning so major progress has not yet been achieved.

Plates Two bipolar plate projects have recently been initiated by DOE to address economic (cost) and technical issues such as corrosion resistance and thermal/electrical properties. GrafTech is developing carbon-based bipolar plates based on an engineered composite of expanded natural graphite and resin. The new plate composite is anticipated to be capable of meeting DOE plate cost and performance targets and enabling PEM fuel cell operation at temperatures up to 120ºC. Oak Ridge National Laboratory is continuing work on metal bipolar plates protected by a nitride layer at the surface. The current focus is on stability and integrity of the nitride layer on stamped plates and the effect of the nitriding process on the plates.

Seals UTC Power is developing a low-cost, durable seal based on liquid injection-molded hydrocarbons to replace the commonly used silicone seals for use in PEM fuel cells.

Innovative designs Case Western Reserve University is developing a stack configuration involving current collection at the edge of the plates instead of from the end plates. Plug Power is developing an adaptive stack with subdivided cells based on a novel flow pattern intended to make flow velocities and currents more uniform across the face of the cell. Argonne National Laboratory is working on a novel PEM stack using patterned aligned carbon nanotubes as electrodes.

Future Solicitations
Contingent on Congressional funding, DOE is planning a major fuel cell solicitation in FY2008 with awards in late FY2009. The technical topics will be designed based on the progress of current projects and new issue that might be identified.

Acknowledgements
Additional details of the DOE program can be found in DOE's 2007 Annual Merit Review Proceedings (http://www1.eere.energy.gov/hydrogenandfuelcells/) and the 2007 Annual Progress Report for the DOE Hydrogen Program (to be published).

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