V.0 Fuel Cells Sub-Program Overview

Introduction

The Fuel Cells sub-program supports research, development, and demonstration of fuel cell technologies, focusing on the development of fuel cells and fuel cell systems for use in a variety of stationary, portable and transportation applications, with a primary focus on reducing cost and improving durability. Efforts are balanced to achieve a comprehensive approach to fuel cells for near-, mid-, and longer-term applications. Early market penetration is targeted through the development of fuel cell technologies and systems for portable-power applications, auxiliary power units (APUs), and specialty applications such as material handling equipment. Fuel cell technologies already provide sufficient performance and durability to be competitive with alternative technologies in some of these applications, while in others relatively modest improvements are required. The expansion of fuel cells into applications and markets that have more stringent technical and cost requirements is also being pursued. The sub-program pursues the development of fuel cell technologies and systems for distributed power generation–including combined heat and power (CHP) for residential and commercial applications–and for light-duty vehicles, in the longer-term, to allow fuel cell technologies to have significant economic, energy security, and environmental benefits on a national scale.

The sub-program's portfolio of projects covers a broad range of technologies including polymer electrolyte membrane fuel cells (PEMFCs), direct methanol fuel cells, alkaline fuel cells, and solid oxide fuel cells (SOFCs). Efforts support research and development (R&D) of fuel cell stack components, fuel processors for stationary and off-road transportation applications, and system balance of plant (BOP) components. Along with ongoing efforts, funding allowed for nine new projects, following a 2008 solicitation/lab call, to be initiated in Fiscal Year (FY) 2010. These projects include R&D of catalysts and membrane electrode assembly (MEA) structures with reduced platinum group metal (PGM) content, PGM-free catalysts, portable power, as well as degradation and durability studies, and fuel cell mass transport studies. The DOE funding for these projects is approximately $33 million.

Goal

Develop and demonstrate fuel cell power system technologies for stationary, portable, and transportation applications.

Objectives

- Develop a 60% peak-efficient, durable, direct hydrogen fuel cell power system for transportation at a cost of $45/kW, by 2010; and at a cost of $30/kW, by 2015.[1]
- Develop a fuel cell system for consumer electronics (<50 W) with an energy density of 1,000 Wh/L, by 2010.[1]
- Develop a distributed-generation PEMFC system operating on natural gas or liquefied petroleum gas that achieves 40% electrical efficiency and 40,000 hours durability at $750/kW, by 2011.[1]
- Develop a fuel cell system for APUs with specific power of 40 W/kg and power density of 35 W/L, by 2015.[1]

FY 2010 Technology Status

Major challenges in the advancement of fuel cell technology are reduction of cost and improvement of durability. Air, thermal, and water management are also key issues for enhancing fuel cell performance. Fuel cells are approaching their targets for power density and specific power, but further progress is required to achieve system packaging requirements necessary for commercialization. Efforts continue to evaluate, understand, and mitigate degradation mechanisms through modeling and experimental validation by the national laboratories, universities, and fuel cell developers. While

[1] Objectives are from the Multi-Year Research, Development and Demonstration Plan, which is under review.

hydrogen is the fuel of choice for automotive applications, stationary applications would benefit from technology improvements permitting fuel flexibility.

The tasks in the *Multi-Year Research, Development and Demonstration Plan*, to be updated in 2010, are organized around components (membranes, electrodes, MEAs, gas diffusion layers, bipolar plates, seals, and BOP components), supporting analysis, and benchmarking and characterization activities. Task areas for fuel cell system and fuel processor sub-system development for stationary power generation applications are included, as are those for early market fuel cell applications, such as portable power, and for the development of innovative concepts for fuel cell systems.

The Fuel Cells sub-program maintains a portfolio of R&D projects specifically aimed at meeting technical and cost targets that will allow fuel cells to compete in the marketplace. With cost a prime driver, analysis of the cost status on an annual basis is required for progress to be gauged. As shown in Figure 1, the cost of a hydrogen-fueled 80-kW_e fuel cell power system projected for high volume production (500,000 units/year) has been estimated to be $51/kW (assuming 2010 technology), a $22/kW (30%) reduction from the 2008 cost of $73/kW and $10/kW (16%) reduction from the 2009 cost of $61/kW. Cost reductions resulted from simplified architecture and reduction in stack component costs through ongoing R&D efforts. The cost of the fuel cell stack has been estimated to be $25/kW.

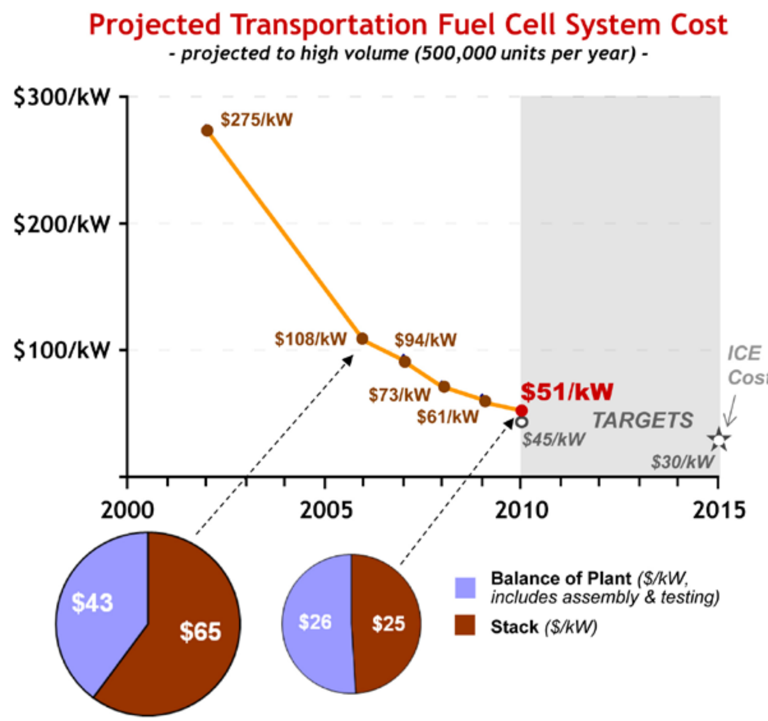


FIGURE 1. Current Modeled Cost of an 80-kW System Based on Projection to High-Volume Manufacturing (500,000 units/year)[2]

FY 2010 Accomplishments

Continued progress was made toward meeting 2010 and 2015 technical and cost targets during FY 2010. Notable technological advances in several component areas have led to significant improvements in performance and durability, with decreased cost.

Advanced Catalysts Enable Reduction in Precious Metal Loading

The high cost of catalysts based on platinum (Pt) and other PGMs presents a major impediment to widespread commercialization of fuel cell technology. Reducing the loading of Pt and other PGMs, without compromising performance, is therefore a key path to decreasing system cost.

3M continues to develop advanced cathode catalysts based on nanostructured thin film (NSTF) technology. In late FY 2009, 3M reported results from testing of 400 cm^2 short stacks with NSTF-based PtCoMn catalysts with total PGM content as low as 0.19 g_{PGM}/kW. In FY 2010, 3M increased PtCoMn mass activity 30%, reaching 0.24 A/mg_{PGM} at 0.9 V, and demonstrated Pt_3Ni_7 alloy with mass activity of 0.40 A/mg_{PGM}. 3M developed a post-fabrication treatment process that is roll-good compatible and increases oxygen reduction reaction mass activity up to 50% for PtCoMn and the Pt_3Ni_7 alloy. Further

[2] DOE Hydrogen Program Fuel Cell System Cost Record–2010, under development.

work promises to yield even greater improvements, allowing NSTF catalysts to approach activity levels observed with idealized model catalysts.[3]

3M operated a membrane over 5,000 hours with load cycling with an MEA based on a non-stabilized 20-µm membrane and catalyst loading of 0.15 mg_{PGM}/cm^2, meeting the DOE 2010/2015 durability target of 5,000 hours. (The 7,300 hours reported previously was with a higher PGM loading.) With the use of chemical stabilizers in the membrane, 3M exceeded the 200-hour DOE target for stability under open-circuit voltage hold in H_2/air by more than 300%.[3]

Development of novel core-shell catalysts at Brookhaven National Laboratory (BNL) has contributed to efforts to decrease PGM loading. In FY 2010, BNL improved its core-shell catalyst by using an interlayer of gold (Au) to separate the Pt shell from the PdCo core. Rotating disk electrode testing of the new catalyst has demonstrated mass activity as high as 1.10 A/mg_{PGM} and specific activity as high as 1,170 $\mu A/cm^2$ at 0.9 V,[4] suggesting a high probability of meeting DOE MEA-level and stack-level targets of 0.44 A/mg_{PGM} and 720 $\mu A/cm^2$. Scale-up of core-shell catalysts has also been demonstrated, with production of a Pt/Pd core-shell catalyst in batches up to 20 g at Cabot Fuel Cells.

These and other advancements in PGM-based catalysts represent significant progress in FY 2010 toward improvement of fuel cell performance and reduction in fuel cell cost through minimization of PGM loading.

Non-Precious Metal Catalysts Demonstrate Potential for High-Performance, Low-Cost Fuel Cells

Continued work at Los Alamos National Laboratory (LANL) on PGM-free catalysts yielded significant performance improvements in FY 2010, with volumetric current density as high as 60 A/cm^3 measured at 0.80 V (iR-free) during fuel cell testing with Fe-cyanamide-C catalyst, representing a 64x improvement over the past two years.[4] Extrapolation to correct for mass-transport limitations suggests that current density as high as 165 A/cm^3 is achievable with this catalyst, in excess of the DOE 2010 target of 130 A/cm^3. Progress also continues on PGM-free polyaniline-based catalysts at LANL, with activity as high as 31 A/cm^3 measured at 0.80 V, a 36x improvement over the past two years.[4]

Innovative Polymer Chemistry Produces New Membrane Materials for Hot and Dry Conditions

3M developed new polymer electrolyte membranes with higher proton conductivity and improved durability under hotter and dryer conditions compared with previously produced membranes, as shown in Figure 2.[5] The new multi-acid side-chain polymer membranes have better mechanical properties than conventional single acid side chain perfluorosulfonic acid (PFSA) membranes. In FY 2010, 3M developed innovative polymers in which side chains contain both sulfonic acid and sulfonamide groups. These new perfluoroimide acid (PFIA) polymers have higher tetrafluoroethylene backbone crystallinity than PFSAs of the same equivalent weight, and thus have better mechanical properties, including lower swelling and lower water

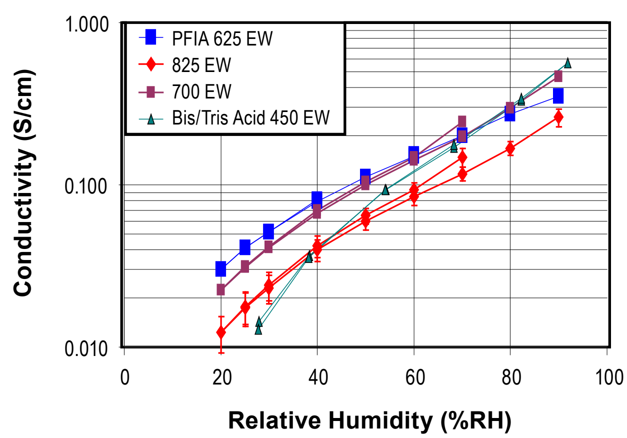


FIGURE 2. Conductivity of 3M ionomers at 80°C[5]

[3] Mark K. Debe, 3M, "Advanced Cathode Catalysts and Supports for PEM Fuel Cells," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc001_debe_2010_o_web.pdf
[4] Piotr Zelenay, "Advanced Cathode Catalysts," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc005_zelenay_2010_o_web.pdf
[5] Steven Hamrock, 3M, "Membranes and MEA's for Dry, Hot Operating Conditions," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc034_hamrock_2010_o_web.pdf

solubility. Efforts continue to produce PFIA membranes of lower equivalent weight and higher conductivity under dry conditions.

Degradation Studies Reveal Pathways to Increased Durability

Improvements in durability of fuel cell systems will facilitate user acceptance of fuel cells to replace conventional power generation technology. Argonne National Laboratory is investigating the role of electrocatalyst degradation in fuel cell durability, and has thus far highlighted the effect of catalyst particle size on degradation rates, revealing that performance of catalysts with small initial particle size moves toward that of larger particles during operation with cycling, as shown in Figure 3.[6] Work at LANL has demonstrated the critical role of electrode processing on durability. Electrodes formed by an ink-painting technique are strongly sensitive to the nature of the solvent used in the ink. Electrodes prepared from glycerol-based inks demonstrated excellent durability (less than 30 mV loss at 0.8 A/cm^2 after 70,000 cycles, (exceeding the DOE target of 30,000 cycles), while electrodes prepared from water/alcohol-based inks suffer from severe degradation.[7]

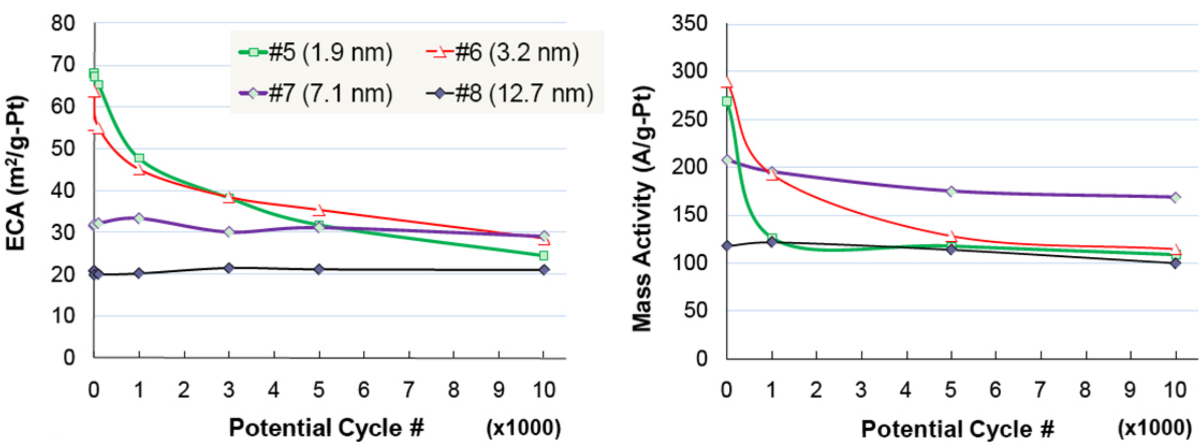


FIGURE 3. Cycling Degrades Performance of Catalysts with Small Initial Particle Size toward that of Larger Particles[6]

Metal Bipolar Plate Development Demonstrates Corrosion Resistance at Low Cost

Since bipolar plate corrosion and high cost have a negative impact on fuel cell stack cost and durability, sub-program activities support development of novel materials and fabrication methods for bipolar plates. TreadStone Technologies demonstrated coating approaches that allow for the development of low-cost, corrosion-resistant, metal bipolar plates, with an FY 2010 cost estimate well below $5/kW, achieving the FY 2010 target.[8] The approach relies on the use of small, conductive, corrosion-resistant materials as conductive points to cover a small portion of metal surface, together with the use of non-conductive, corrosion-resistant materials to cover the majority of the surface of the metal plates.

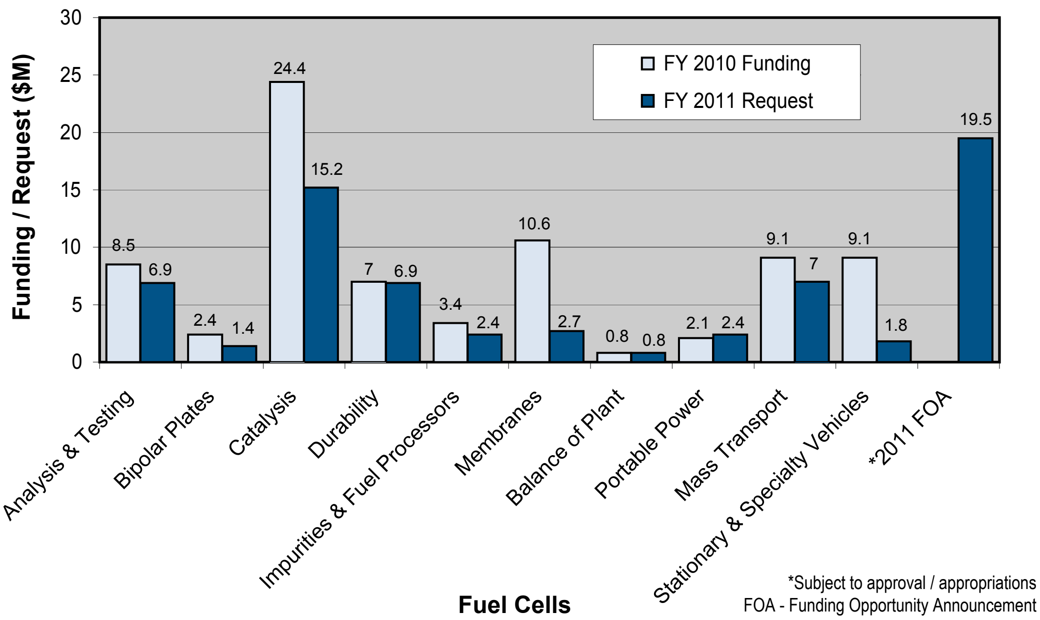
[6] Deborah Myers, "Polymer Electrolyte Fuel Cell Lifetime Limitations: The Role of Electrocatalyst Degradation," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc012_myers_2010_o_web.pdf
[7] Rod Borup, "Durability Improvements through Degradation Mechanism Studies," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc013_borup_2010_o_web.pdf
[8] Conghua Wang, "Low Cost PEM Fuel Cell Metal Bipolar Plates," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc023_wang_2010_o_web.pdf

CHP Operation Demonstrates Capability for Energy and Cost Savings

DOE is developing distributed energy and CHP systems based on several technologies. Acumentrics Corporation is funded to develop micro-CHP systems based on tubular SOFC technology. In FY 2010, Acumentrics achieved a 24% increase in system power density, enabling a 33% reduction in stack volume and a 15% reduction in stack weight. A low degradation rate of 0.86%/1,000 hours during 1,500 hours of testing was demonstrated.[9]

Budget

The President's FY 2011 budget request calls for approximately $67 million for the Fuel Cells sub-program, with emphasis on R&D of materials, fuel cell stack components, and system BOP components, targeting lower cost and enhanced durability for stationary, portable, and transportation applications. Further emphasis is placed on R&D for integrated fuel cell systems for distributed power, including CHP applications, where a 'technology-neutral' approach is pursued. The FY 2011 request also includes approximately $19.5 million for a potential solicitation, subject to approval and congressional appropriations. The figure below shows the budget breakdown by sub-program R&D area for the FY 2010 congressional appropriation and the FY 2011 budget request.



FY 2011 Plans

In FY 2011, the Fuel Cells sub-program will continue R&D efforts on fuel cells and fuel cell systems for several key applications, with a focus on further developing multiple fuel cell technologies using various fuels, which involves improving component properties. Support will continue for R&D that addresses critical issues with membranes, catalysts, electrodes, and modes of operation. The sub-program will continue to place emphasis on the science and engineering at the cell and stack level and, from a systems perspective, on integration and component interactions.

The sub-program will also place significant emphasis on BOP component R&D (such as water transport, sensors, and air compression) that can lead to lower cost and lower parasitic losses. Continued support of modeling will guide component R&D, to benchmark complete systems before

[9] Norman Bessette, "Development of a Low Cost 3-10kW Tubular SOFC Power System," 2010 DOE Hydrogen Program Review. http://www.hydrogen.energy.gov/pdfs/review10/fc032_bessette_2010_o_web.pdf

they are built and explore alternate system components and configurations. Cost analysis efforts will be expanded to include distributed power generation systems (including CHP) for a variety of fuel cell technologies.

FY 2011 will see the continuation of existing projects and of those awarded in FY 2010, as well as a new initiative. A planned solicitation, subject to approval and congressional appropriations, is expected to lead to the awarding of new projects in FY 2011.

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