V.0 Fuel Cells Sub-Program Overview

The Fuel Cells sub-program supports research, development, and demonstration of fuel cell technologies for a variety of stationary, transportation, and portable applications, with a primary focus on reducing cost and improving durability. These efforts include research and development (R&D) of fuel cell stack components, system balance-of-plant (BOP) components, and subsystems, as well as system integration. The sub-program seeks a balanced, comprehensive approach to fuel cells for near-, mid-, and longer-term applications. Existing early markets and near-term markets include portable power, backup power, auxiliary power units, and specialty applications such as material handling equipment. Mid- and longer-term applications with more stringent technical and cost requirements include distributed power generation (e.g., combined heat and power [CHP] for residential and commercial applications) and transportation (e.g., light-duty vehicles and transit buses). The sub-program's portfolio of projects covers a broad range of technologies, including polymer electrolyte membrane fuel cells, direct methanol fuel cells, alkaline fuel cells, and solid oxide fuel cells (SOFCs).

The Fuel Cells sub-program's tasks in the *Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan* are organized around development of components, stacks, sub-systems, and systems; supporting analysis; and testing, technical assessment, 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.

Goal

The sub-program's goal is to advance fuel cell technologies for stationary, portable, and transportation applications to make them competitive in the marketplace in terms of cost, durability, and performance, while ensuring maximum environmental and energy-security benefits.

Objectives[1]

The sub-program's key objectives include:

- By 2015, develop a fuel cell system for portable power (<250 W) with an energy density of 900 Wh/L.
- By 2017, develop a 60% peak-efficient, direct-hydrogen fuel cell power system for transportation, with 5,000-hour durability, that can be mass produced at a cost of $30/kW.
- By 2020, develop distributed generation and micro-CHP fuel cell systems (5 kW) operating on natural gas or liquefied petroleum gas that achieve 45% electrical efficiency and 60,000-hour durability at an equipment cost of $1,500/kW.
- By 2020, develop medium-scale CHP fuel cell systems (100 kW–3 MW) that achieve 50% electrical efficiency, 90% CHP efficiency, and 80,000-hour durability at a cost of $1,500/kW for operation on natural gas and $2,100/kW when configured for operation on biogas.
- By 2020, develop a fuel cell system for auxiliary power units (1–10 kW) with a specific power of 45 W/kg and a power density of 40 W/L at a cost of $1,000/kW.

Fiscal Year (FY) 2011 Technology Status

The need for cost reductions and improvements in durability continue to be the key challenges facing fuel cell technologies. In addition, advances in air, thermal, and water management are necessary for improving fuel cell performance; some stationary applications would benefit from increased fuel flexibility, and, while fuel cells are approaching their targets for power density and specific power, further progress is required to achieve system packaging requirements necessary for commercialization.

One of the most important metrics is the projected high-volume manufacturing cost for automotive fuel cells—the Program tracks this on an annual basis. The 2011 estimate of this cost is $49/kW, which represents

[1] Note: Targets and milestones are under revision; therefore, individual progress reports may reference prior targets.

a 33% decrease since 2008 and an 82% decrease since 2002, as depicted in Figure 1. The 33% decrease in projected cost since 2008 stems in part from a reduction in precious grade metal loading and an increase in cell power density, allowing the design of smaller and less expensive stacks. The 2011 cost analysis estimated the cost of the fuel cell stack to be $22/kW. BOP cost has also been reduced during this time. Major sources of the reduction in BOP cost include reconfiguration of the ejector system based on stakeholder input, redesign of the system controller, and reduction of the radiator size. The reduced radiator size was enabled by improvements in stack components, allowing a higher stack operating temperature.

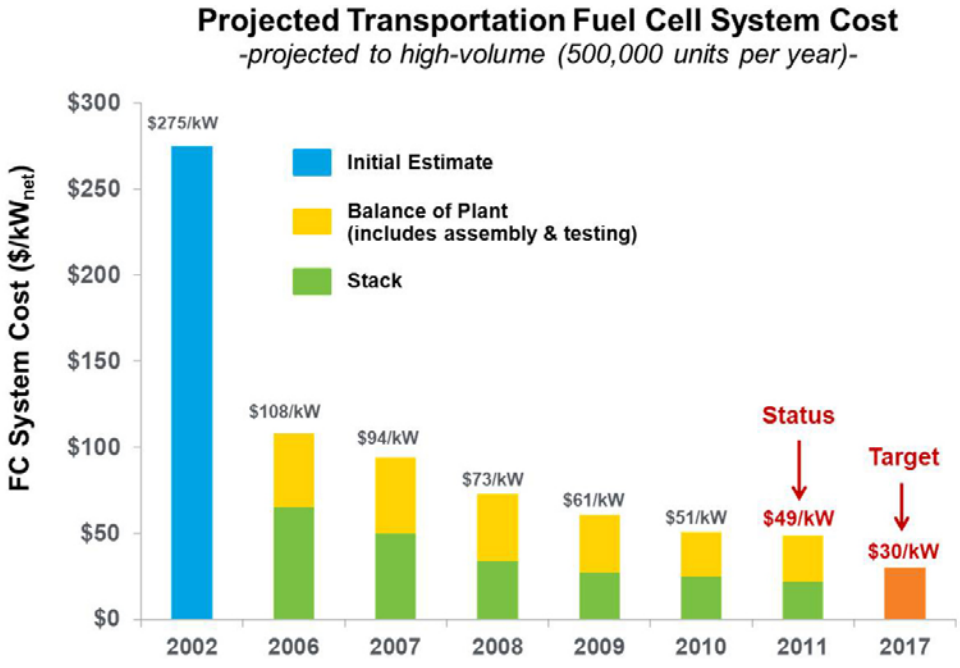


FIGURE 1. Current Modeled Cost of an 80-kW Automotive Fuel Cell System Based on Projection to High-Volume Manufacturing (500,000 units/year)[2]

FY 2011 Accomplishments

In FY 2011, continued progress was made toward meeting 2017 technical and cost targets. Notable technological advances in several component areas have led to significant improvements in performance and durability, with decreased cost. Key advances in FY 2011 include the following:

- **Nano-segregated binary and ternary catalysts demonstrated performance more than 6X that of platinum:** Following on the discovery of the exceptionally high activity of the $Pt_3Ni(111)$ surface for the oxygen reduction reaction, which has specific activity two orders of magnitude higher than that of Pt/C,[3] Argonne National Laboratory (ANL) is working to develop nanosegregated Pt/Ni catalysts that can achieve similar activity in a catalyst suitable for incorporation in fuel cells. Pt/Ni catalysts synthesized thus far at ANL have mass activity six times that of Pt/C (Figure 2), approaching the DOE target activity of 0.44 A/mg. The Pt/Ni catalysts also have better durability than conventional Pt/C. ANL is also developing a variety of ternary catalysts in which an Au core is encapsulated by an FePt shell. These ternary catalysts also exhibit better activity and stability than conventional Pt/C.

[2] DOE Hydrogen and Fuel Cells Program Record #11012, http://hydrogen.energy.gov/pdfs/11012_fuel_cell_system_cost.pdf.
[3] Nenad Markovic et al., "Nanosegregated Cathode Catalysts with Ultra-Low Platinum Loading," 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review11/fc008_markovic_2011_o.pdf.

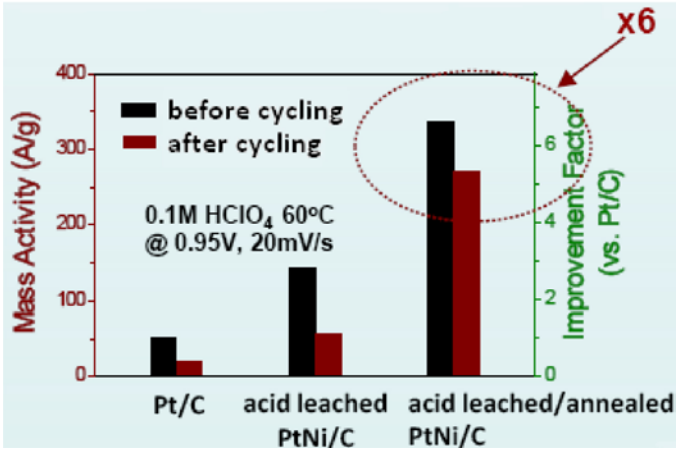


FIGURE 2. Mass Activity of Several Pt-Based Catalysts for the Oxygen Reduction Reaction[4]

- **New cathode and anode catalysts demonstrated durability under startup/shutdown:** Significant progress has been made in addressing degradation that can occur under startup, shutdown, and fuel-starvation conditions. Work led by 3M has resulted in development of new cathode and anode catalysts to increase durability.[5] 3M has incorporated a highly active and highly durable oxygen evolution catalyst on the cathode, based on Ru and Ir. By enhancing oxygen evolution, these catalysts suppress excursions to high voltage, and thus mitigate corrosion of catalysts and supports. In collaboration with 3M, ANL has developed calixarene-modified anodes, on which the oxygen reduction reaction is suppressed without inhibiting hydrogen oxidation. Use of the modified cathode and anode catalysts has enabled successful achievement of 10,000 simulated startup/shutdown cycles with only 2 μg/cm^2 more precious grade metal content, in addition to the 0.15 mg/cm^2 total Pt content (Figure 3).

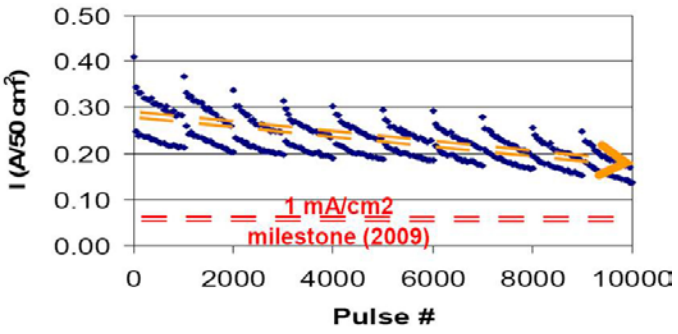


FIGURE 3. Oxygen Evolution Performance Of A Modified Cathode Catalyst – Performance Remains Higher than the Target even after 10,000 Cycles[6]

- **Degradation studies enabled design of more durable electrodes:** Los Alamos National Laboratory has demonstrated the relationship between electrode structure and cell durability.[7] They found that the degree of ordering and agglomeration of perfluorosulfonic acid (PFSA) ionomer during electrode preparation is

[4] Ibid.
[5] Radoslav Atanasoski et al., ""Durable Catalysts for Fuel Cell Protection During Transient Conditions," 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review11/fc006_atanasoski_2011_o.pdf.
[6] Ibid.
[7] Rod Borup et al., "Durability Improvements Through Degradation Mechanism Studies," 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review11/fc013_borup_2011_o.pdf.

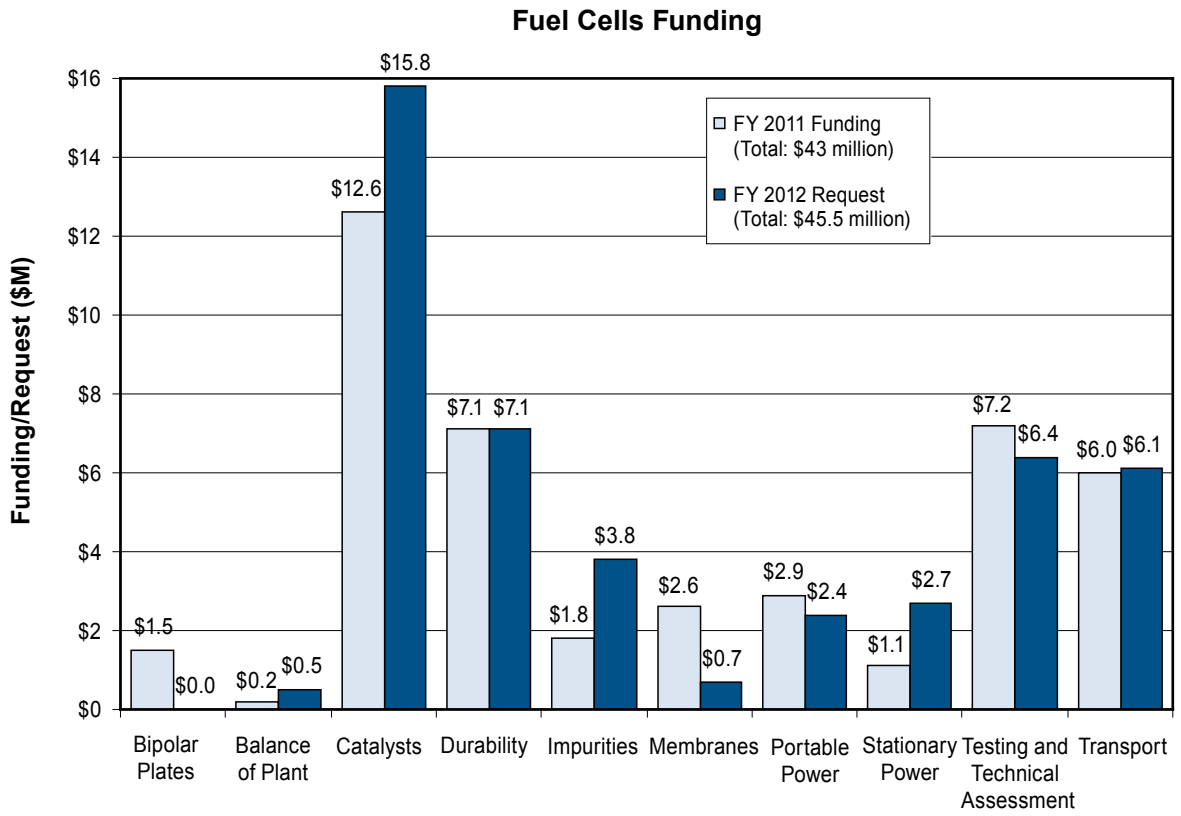
related to the long-term stability, with a higher degree of ordering correlating with lower stability. They also discovered that ionomer aggregation in solution leads to poorer mechanical properties in cast ionomer films, suggesting that the observed electrode stability differences are related to the mechanical properties of the ionomer in the electrode. Electrodes prepared from glycerol-based inks, in which little ionomer agglomeration occurs, demonstrated high stability, with less than 30 mV loss at 0.8 A/cm^2 after 70,000 cycles, exceeding the DOE target of 30,000 cycles. In contrast, electrodes prepared from water/alcohol-based inks, in which ionomer agglomeration occurs, were shown to suffer from severe degradation.

- **Innovative membranes demonstrate high conductivity at low relative humidity:** Progress in development of perfluoroimide acid (PFIA) membranes has enabled 3M to meet most DOE targets for high-temperature membranes, and 3M is close to fulfilling the final target of 0.02 ohm-cm^2 area specific resistance at 120°C and 40 kpA of water vapor.[8] The 3M PFIA ionomer is related to conventional PFSA ionomers, but it incorporates two superacid sites per side chain–an imide acid site in the middle of the chain, and a sulfonic acid site at the end of the chain. This configuration allows use of a lower equivalent weight ionomer with a more highly acidic acid group. The multi-acid side chain approach allows preservation of the perfluorinated backbone crystallinity at lower equivalent weights than with conventional PFSA. This enables higher conductivity under dryer conditions without sacrificing mechanical properties, and it is expected to lead to better performance and durability than conventional PFSAs.
- **Performance and durability of SOFC systems improved:**
  - Reversible SOFCs under development at Versa Power Systems have made significant progress, meeting resistance, degradation, and current density targets.[9]
  - In addition to the increase in SOFC system power density achieved in FY 2010, Acumentrics has demonstrated increased durability, with more than 12,000 hours of operation.[10] Acumentrics also increased system electrical efficiency from 35% to 40%, through enhancements made in reforming technology and generator design. These advances represent a significant step toward production of an SOFC system for widespread commercialization.

Budget

The President's FY 2012 budget request calls for approximately $45.5 million for the Fuel Cells sub-program. The following figure shows the budget breakdown by R&D area for the FY 2011 congressional appropriation of $43 million and the FY 2012 budget request. The sub-program continues to focus on reducing costs and improving durability with an emphasis on fuel cell stack components. The funding profiles for FY 2011 and the FY 2012 request are very similar, with some projects in membranes and bipolar plates ending in FY 2011.

[8] Steven Hamrock et al., "Membranes and MEA's for Dry, Hot Operating Conditions," 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review11/fc034_hamrock_2011_o.pdf.
[9] Randy Petri et al., "Advanced Materials for RSOFC Dual Mode Operation with Low Degradation," 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review11/fc042_petri_2011_o.pdf.
[10] Norman Bessette et al., "Development of a Low Cost 3-10kW Tubular SOFC Power System," 2011 DOE Hydrogen and Fuel Cells Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review11/fc032_bessette_2011_o.pdf.



FY 2012 Plans

In FY 2012, the Fuel Cells sub-program will continue R&D efforts on fuel cells and fuel cell systems for diverse applications, using a variety of technologies (including polymer electrolyte membrane, solid oxide, and alkaline fuel cells) and a range of fuels (including hydrogen, diesel, natural gas, and bio-derived renewable fuels). Support will continue for R&D that addresses critical issues with electrolytes, catalysts, electrodes, and modes of operation. The sub-program will also continue its emphasis on science and engineering at the cell and stack level and on integration and component interactions at the system level. Significant emphasis will be placed on BOP component R&D (such as humidifiers and air compressors) that can lead to lower cost and lower parasitic losses. Ongoing support of modeling will guide component R&D, benchmarking complete systems before they are built and enabling exploration of alternate system components and configurations. Cost analysis efforts have been expanded to include distributed power generation systems (including CHP) and systems for emerging markets for a variety of fuel cell technologies; detailed results of these analyses are expected in FY 2012.

FY 2012 will see the continuation of most existing projects, as well as the initiation of new projects. A fuel cell R&D solicitation closed in FY 2011, and a small number of new R&D projects from the solicitation are expected to begin in FY 2012, subject to appropriations.

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