V.0 Fuel Cells Sub-Program Overview

INTRODUCTION

The Fuel Cells sub-program supports research, development, and demonstration of fuel cell technologies for transportation applications, as well as stationary and early market applications, with a primary focus on reducing cost and improving durability. Efforts include research and development (R&D) of fuel cell stack components, system balance of plant 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. The development of fuel cells for transportation applications is a primary goal due to the nation's requirements for significantly reduced energy and petroleum consumption and the subsequent increase of available high-efficiency fuel cell electric vehicles (FCEVs). Stationary applications for fuel cells include distributed power generation, including combined heat and power (CHP) for residential and commercial applications. Early market and near-term market applications for fuel cells include backup power, auxiliary power units, and specialty applications such as material handling equipment. The existing market traction that fuel cell technologies have achieved in these applications provides support for adoption of FCEVs in the transportation sector. The sub-program's R&D portfolio is primarily focused on polymer electrolyte membrane (PEM) fuel cells but also includes longer-term technologies, such as alkaline fuel cells and higher temperature fuel cells like molten carbonate fuel cells (MCFCs) for stationary applications.

The sub-program's fuel cell tasks in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan are organized around development of components, stacks, subsystems, and systems; supporting analysis; and testing, technical assessment, and characterization activities.

GOAL

The sub-program's goal is to advance fuel cell technologies with a focus on transportation, as well as enabling stationary and early market applications.

OBJECTIVES[1]

The sub-program's key objectives include the following.

- Develop a 65% 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 (\$40/kW by 2020)
- Develop distributed generation and micro-CHP fuel cell systems (5 kW) operating on natural gas or liquid 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) by 2020 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

FY 2015 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

Reducing cost and improving durability while maintaining performance continues to be the key challenge facing fuel cell technologies. Reduction in platinum group metal (PGM) loading and increase in membrane electrode assembly (MEA) areal power density are required to reduce material costs. Current state-of-the-art MEAs with very low cathode PGM loading experience higher than expected reduction in performance when operating at high power (e.g., near the rated power point), but significant progress has been made in FY 2015 to address this performance loss. Commercial fuel cells are expected to use PGM-based catalysts in the near term, but in the long term, developing PGM-free fuel cells would reduce cost and improve competitiveness with incumbent and alternative technologies. Advances in FY 2015 have brought non-PGM catalysts significantly closer to parity with conventional PGM-based catalysts. Major advances in FY 2015 were also made in development of durable, high performance membranes that will allow fuel cells to operate for longer periods of time under harsh conditions.

---

[1] Note: Targets and milestones were recently revised; therefore, individual project progress reports may reference prior targets.

One of the most important metrics is the projected high-volume manufacturing cost for automotive fuel cells, which the sub-program tracks on an annual basis. This year, the cost of an 80-kW_{net} automotive PEM fuel cell system based on next-generation laboratory technology and operating on direct hydrogen was projected to be $53/$kW_{net}$ when manufactured at a volume of 500,000 units/year. For comparison, the expected cost of automotive PEM fuel cell systems that are based on current technology and planned for commercialization in the 2016 timeframe is approximately $280/kW when manufactured at a volume of 20,000 units/year.

The 2015 cost estimate was based on Argonne National Laboratory's projected stack performance for a de-alloyed $PtNi_3$ catalyst (d-PtNi), a change from the nanostructured thin film (NSTF) cathode catalyst selected for last year's analysis. With this change as well as other modifications incorporated into modeling, including a decrease in the cell active-to-total-area ratio, a re-examination of machinery size and procedures utilized at low production volumes, and improved estimates of air humidifier system size, the net change in system cost from 2014 to 2015 was approximately $2/kW. Practically, the use of the d-PtNi catalyst permits the use of relatively less expensive catalyst application processes and offers a higher likelihood of achieving DOE catalyst lifetime targets. The results of the current year's cost analysis are compared to previous years in Figure 1.

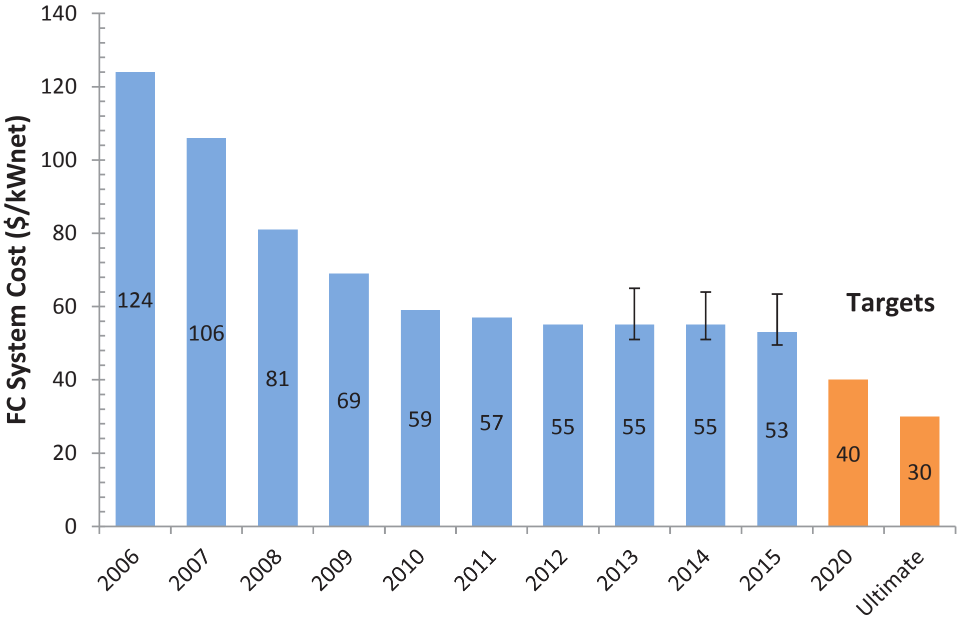


FIGURE 1. Modeled cost of an 80-kW_{net} PEM fuel cell (FC) system based on projection to high-volume manufacturing (500,000 units/year).

To enable vehicle commercialization, the sub-program is targeting a cost reduction to $40/kW by 2020. Long-term competitiveness with alternative powertrains is expected to require further cost reduction to $30/kW, which represents the sub-program's ultimate cost target.

Several new R&D projects were awarded in FY 2015 to explore innovative, off-roadmap ideas that could have a major impact on fuel cell cost, performance, and durability. New approaches being explored through these initiatives include the use of high temperature MEAs for liquid fuel utilization; development of advanced catalysts and MEAs for reversible alkaline membrane fuel cells; development of non-PGM hydrogen oxidation catalysts for alkaline membrane fuel cells; development of anion-exchange membranes for redox flow batteries; and development of non-PGM cathode catalysts for high temperature MEAs.

Performance and durability remain as major technical barriers to fuel cell commercialization. A new initiative announced in FY 2015, Fuel Cell Performance and Durability (FC-PAD), will directly address these topics through an R&D consortium led by a team of national laboratories. This core lab team will work with competitively selected industry and academic partners to advance the science and engineering of fuel cells, with a particular focus on development of durable, high performance electrodes.

Examples of R&D advancements achieved in FY 2015 are described below, including major improvements in fuel cell catalysts, membranes, and MEAs.

Catalysts

Several approaches to developing non-precious oxygen reduction catalysts were pursued in FY 2015, resulting in improvements in fuel cell activity measured at 0.9 V on pure oxygen and at 0.8 V measured on air. Current densities of 14–24 mA/cm^2 and 90–110 mA/cm^2 were achieved in the 0.9 V and 0.8 V testing, respectively, representing an improvement from 9–15 mA/cm^2 and 25–75 mA/cm^2 in FY 2014. The FY 2015 performance measurements indicate good progress toward achieving the targeted performance levels of 44 mA/cm^2 at 0.9 V and 300 mA/cm^2 at 0.8 V (which are equivalent to DOE targets for platinum-based catalysts). Catalysts investigated in FY 2015 were based on metal atoms or particles (typically iron) coordinated in a carbon-nitrogen matrix structure, including iron incorporated in metal organic framework structures and iron incorporated in a matrix of pyrolyzed cyanamide and polyaniline (CM-PANI-Fe-C) (Figure 2). Durability studies of these materials are underway, but the CM-PANI-Fe-C catalyst has already demonstrated high stability in ex situ testing, surviving 30,000 cycles from 0.2–1.0 V with only 30 mV decline in half-wave potential. (Los Alamos National Laboratory [LANL], Argonne National Laboratory, and Northeastern University)

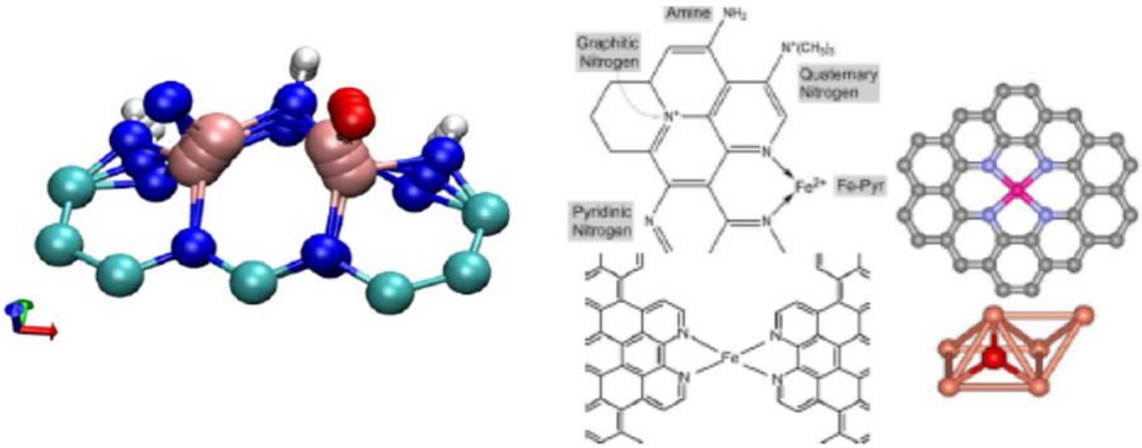


FIGURE 2. Left: Model active site in a CM-PANI-Fe-C catalyst. Right: Proposed structure of an iron metal organic framework catalyst.

Electrolytes

Improved nanofiber-supported fuel cell membranes containing multi-acid side chain ionomers were developed in FY 2015 (Figure 3). These membranes meet DOE durability targets and have better performance under hot and dry conditions than state-of-the-art conventional membranes. The new membranes, which combine low equivalent weight (EW) ionomers with electrospun nanofiber supports and chemical stabilizers, are promising candidates to improve fuel cell performance robustness and decrease humidification requirements. The inclusion of multiple acid sites on each side chain enables the new ionomer to have the high conductivity of a low-EW ionomer while retaining the good mechanical properties of a high-EW ionomer. Up to four acid groups were incorporated into each side chain, leading to unprecedented levels of conductivity in a stable perfluorinated ionomer. Mechanical testing of the electrospun membrane supports indicated that they already have strength similar to conventional expanded polytetrafluoroethylene supports, but further work is ongoing to achieve even higher strength. (3M)

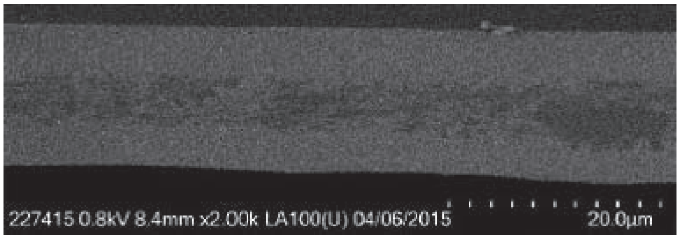
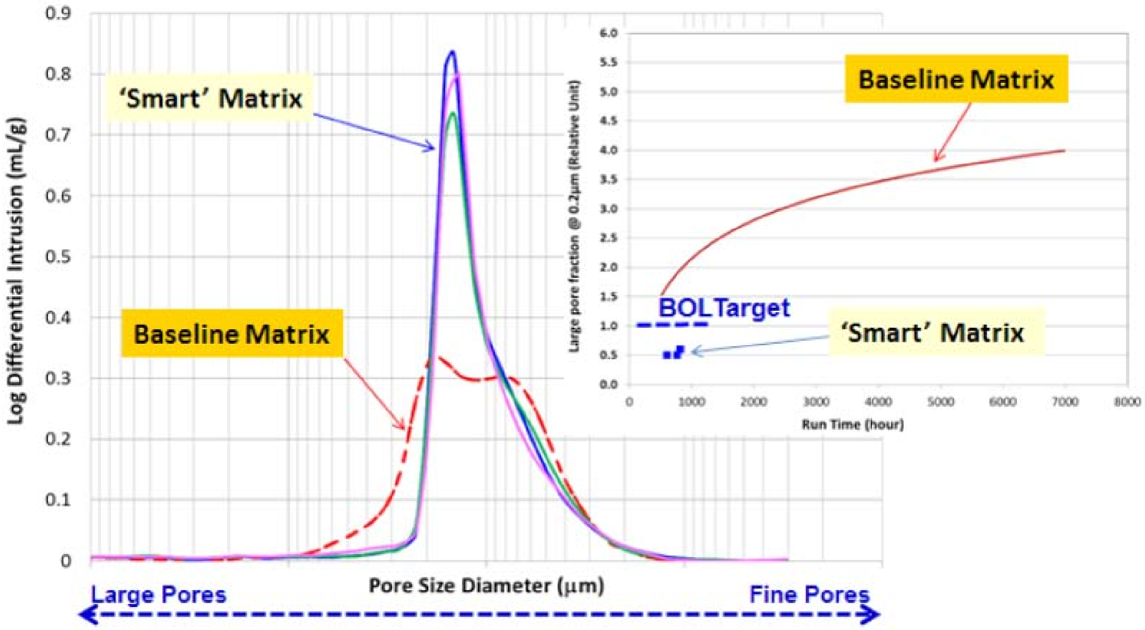


FIGURE 3. Cross-section of an advanced composite membrane showing an internal nanofiber-based support layer surrounded by a multi-acid side chain ionomer.

An improved electrolyte matrix for MCFCs with increased porosity and improved pore size distribution was developed in FY 2015. The new matrix has porosity more than 20% higher than the baseline matrix, enabling a higher electrolyte concentration with lower ohmic resistance. The new matrix has a narrower pore size distribution (Figure 4), with the fraction of undesirable large pores (larger than 0.2 µm) decreased by more than 30% in a cell that was verified over a 2,000-hour test. A 25% increase in mechanical strength of the matrix was also demonstrated. These improvements are part of a “smart” matrix development project that is expected to increase rated stack power by more than 20% while doubling stack lifetime. Successful achievement of these goals, which will be verified through accelerated testing of a full-area 30 kW demonstration stack, will enable larger scale deployment of MCFCs for distributed generation and CHP applications. (FuelCell Energy)



BOL – beginning of life

FIGURE 4. A new MCFC electrolyte matrix developed in FY 2015 has improved pore size distribution, enabling higher performance and longer lifetime.

Membrane Electrode Assembly Integration

Improved integration of fuel cell components based on NSTF catalysts into high performance MEAs enabled a substantial increase in performance in FY 2015. Power output per gram of PGM at rated power increased to 6.5 kW/g_{PGM} (improved from 2.8 kW/g_{PGM} in 2008 and 6.2 kW/g_{PGM} in FY 2014) under conditions that satisfy the DOE heat rejection target (Figure 5). The performance of this MEA at 0.8 V surpassed the DOE target of 300 mA/cm^2, while the performance at rated power of 855 mW/cm^2 fell just short of the DOE target of 1,000 mW/cm^2. The inclusion of a platinum nanoparticle-based cathode interlayer in this MEA represents a major improvement in enabling higher operation robustness and tolerance to non-ideal operating conditions. Development of a new ionomer

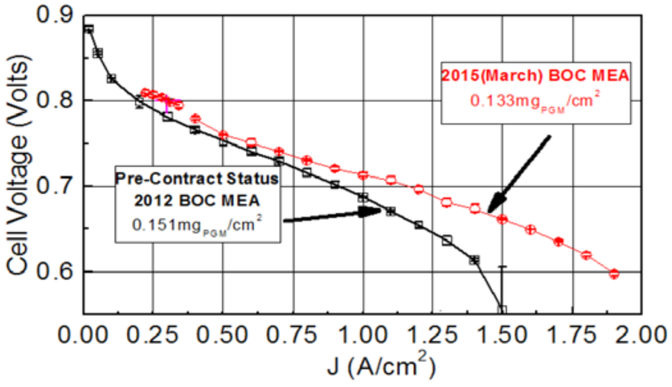


FIGURE 5. Reduction in PGM loading and improvement in MEA performance have enabled performance levels as high as 6.5 kW/g_{PGM} in NSTF-based MEAs.

membrane that reduces the extent of catalyst poisoning by ionomer degradation products also led to a 30% decrease in rated power degradation versus the 2014 baseline. (3M)

A new fuel cell fabrication method was developed in FY 2015 in which the fuel cell cathode has higher performance with lower platinum catalyst loading. This improvement was enabled by incorporating carbon nanotubes covered by a thin layer of Nafion® into the cathode, thereby providing a continuous pathway for transport of protons between the fuel cell membrane and the catalyst particles. Inclusion of this continuous pathway enables the use of thinner coatings of Nafion® on the platinum catalyst particles, making the particles more accessible to reactant oxygen and improving performance. Fuel cells containing these engineered cathodes had performance similar to state-of-the-art commercial fuel cells despite having a lower surface area of platinum. (LANL)

Improved Characterization Techniques

Development of improved visualization techniques has enabled physical mapping of fuel cell structures with unprecedented resolution. High spatial resolution images of fluorine distribution obtained through energy dispersive spectroscopy (Figure 6) have enabled mapping of ionomer content across an entire 5-µm cathode catalyst layer, data that is helping modelers to better understand electrode structure and resulting transport properties. (Oak Ridge National Laboratory)

Similarly, high resolution cryo-electron tomography (Figure 7) has enabled visualization of the heterogeneous domain structure of ionomer membranes, enabling better understanding of transport within the membrane and at interfaces. (Lawrence Berkeley National Laboratory)

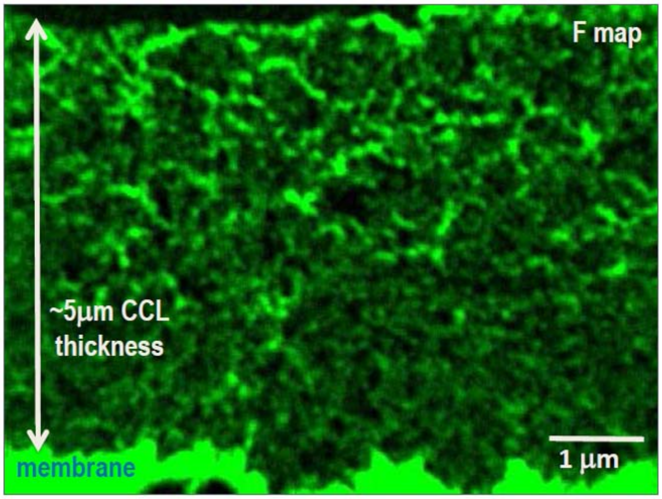


FIGURE 6. Ionomer distribution (fluorine X-ray map) across full thickness of 5-µm cathode catalyst layer.

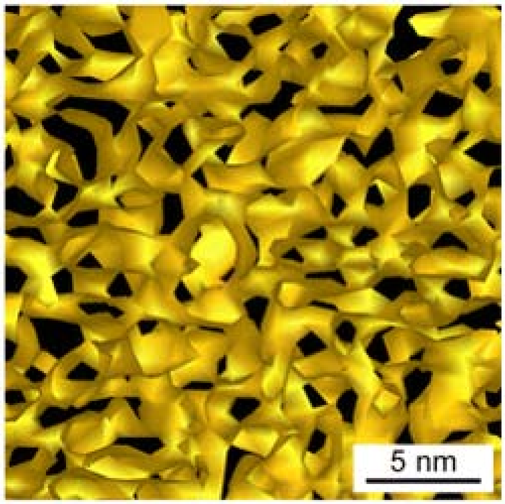


FIGURE 7. Cryo-electron tomography of hydrated Nafion® reveals a connected locally-flat network.

BUDGET

The FY 2016 budget request calls for $36 million for the Fuel Cells sub-program, which is a slight increase from the FY 2015 appropriation.

Figure 8 shows the budget breakdown by R&D area for FY 2015 and the FY 2016 budget request. The sub-program continues to focus on reducing costs and improving durability with an emphasis on fuel cell stack components. New projects were initiated in FY 2015 for R&D on several advanced off-roadmap concepts, and a new lab-led consortium tasked with coordinating and harmonizing fuel cell performance and durability R&D was selected. In FY 2016, the sub-program plans to issue funding opportunity announcements for awards funded in FY 2016.

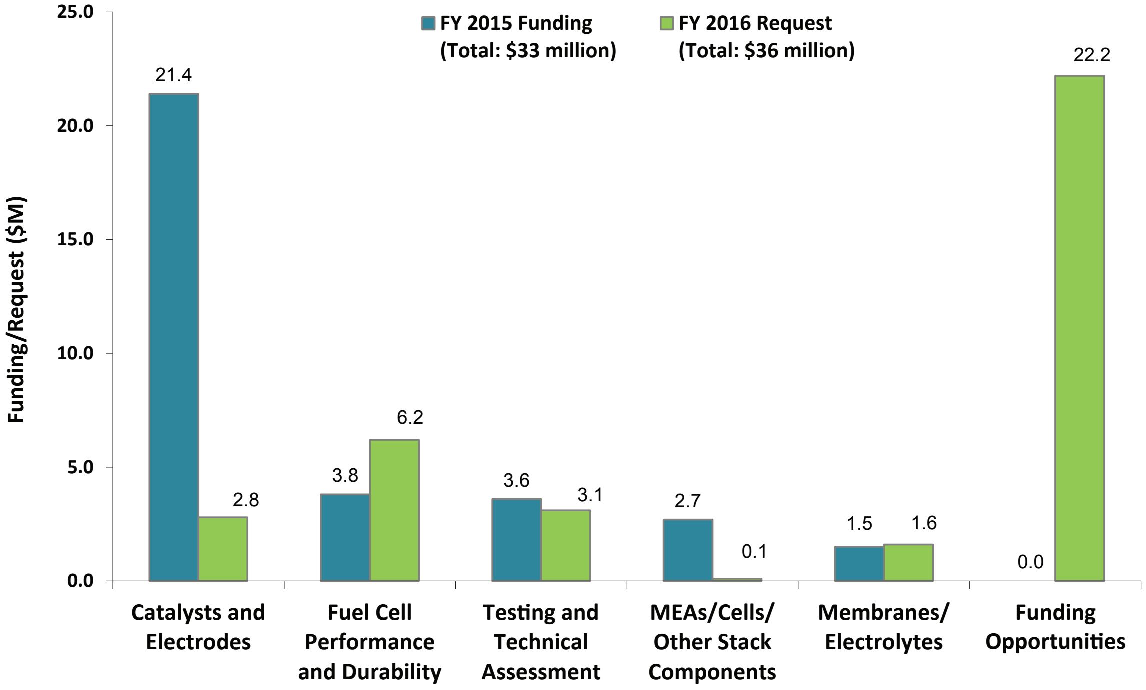


FIGURE 8. Fuel Cell R&D Funding. Subject to appropriations, project go/no-go decisions, and competitive selections. Exact amounts will be determined based on research and development progress in each area and the relative merit and applicability of projects competitively selected through planned funding opportunity announcements.

FY 2016 PLANS

In FY 2016, 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 PEM and alkaline membrane fuel cells) and a range of fuels (including hydrogen, natural gas, and liquid fuels). Support will continue for R&D that addresses critical issues with electrolytes, catalysts, electrodes, and modes of operation, with an emphasis on cost reduction and durability improvement. The sub-program will also continue its emphasis on science and engineering with a focus on component integration at the cell level. 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 include studies of fuel cells for transportation applications as well as distributed power generation systems (including CHP) and systems for early markets; further detailed results of these analyses are expected in FY 2016. Updates to target values will be released in a revision of the Multi-Year Research, Development, and Demonstration Plan, which is scheduled for release in FY 2016.

Dimitrios Papageorgopoulos
Fuel Cells Program Manager
Fuel Cell Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, D.C. 20585-0121
Phone: (202) 586-5463
Email: Dimitrios.Papageorgopoulos@ee.doe.gov