V.0 Fuel Cells Sub-Program Overview

INTRODUCTION

The Fuel Cells sub-program supports research, development, and demonstration of fuel cell technologies for a variety of transportation, stationary, 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 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. In the mid- to long-term, development of fuel cells for transportation applications is a primary goal due to the nation's significantly reduced energy and petroleum requirements and the subsequent increase of available high-efficiency fuel cell electric vehicles. Development of fuel cells for distributed power generation (e.g., combined heat and power (CHP) for residential and commercial applications) is also underway. The sub-program's portfolio of projects covers a broad range of technologies including polymer electrolyte membrane (PEM) fuel cells, direct methanol fuel cells, alkaline membrane fuel cells, and molten carbonate fuel cells.

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, sub-systems, and systems; supporting analysis; and testing, technical assessment, and characterization activities.[1] 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, and for the development of innovative concepts for fuel cell systems.

GOAL

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

OBJECTIVES[2]

The sub-program's key objectives include:

- 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 ($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.
- 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 by 2020.

FISCAL YEAR (FY) 2014 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

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.

[1] http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-16

[2] 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. The cost analysis in 2014 was based on similar technologies as used in 2013, including a Pt-Co-Mn nanostructured thin film cathode catalyst developed through an earlier DOE-funded project, and therefore the 2014 costs status of $55/kW is the same as the 2013 status, as depicted in Figure 1. Examination of more advanced catalyst technology developed more recently by the sub-program, including de-alloyed PtNi catalysts, is planned for future year analyses.

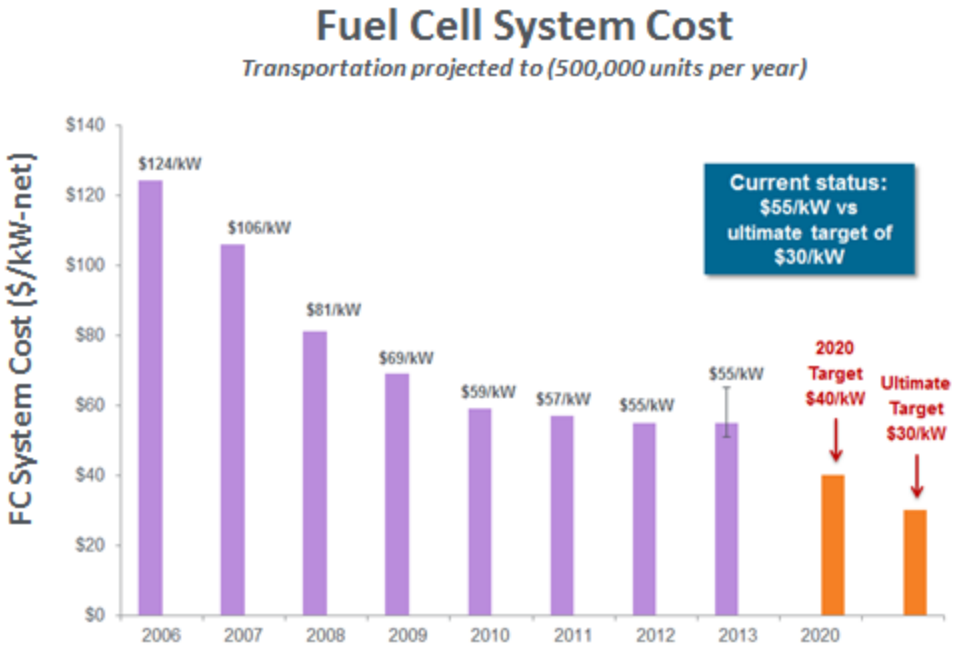


FIGURE 1. Modeled cost of an 80-kW automotive fuel cell system based on projection to high-volume manufacturing (500,000 units/year).[3]

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.

The sub-program sponsors technical working groups on the topics of durability, transport modeling, and catalysis. These working groups, composed of representatives from DOE-funded R&D projects, met in 2014 to exchange information, create synergies, share experimental and computational results, and collaboratively develop methodologies for and understanding of further R&D needs in the topical areas. Additional issues addressed in 2014 include an examination of non-platinum-grade metal (PGM) catalyst targets by the catalysis working group, which led to development of a new non-PGM activity target adopted by the Fuel Cell Tech Team and planned for adoption by the Fuel Cell Technologies Office.

Catalysts

Argonne National Laboratory (ANL) adapted a synthetic procedure originally developed at Lawrence Berkeley National Laboratory (LBNL) to produce a new platinum-nickel (Pt-Ni) catalyst with unprecedented activity. Scientists at LBNL initially created Pt-Ni crystalline polyhedra particles that were left under ambient conditions in a solvent exposed to air for two weeks. Surprising changes in the structure and composition were noted—the particles had spontaneously dealloyed into a more Pt-rich alloy and transformed into hollow nanoframe structures. Recognizing the potential relevance of these new structures for catalysis, the LBNL researchers teamed up with electrochemical experts at ANL. ANL optimized the synthesis process, resulting in a catalyst that can be prepared in only a few hours with an

[3] DOE Hydrogen and Fuel Cells Program Record #13012, http://hydrogen.energy.gov/pdfs/13012_fuel_cell_system_cost.pdf.

activity that outstrips all previous fuel cell catalysts in ex situ testing. Encapsulating a protic ionic liquid inside the nanoframe catalyst resulted in a further increase in activity, yielding more than 30X the mass activity of a conventional platinum catalyst in rotating disk electrode (RDE) testing. The nanoframes showed no decrease in activity after 10,000 cycles of accelerated stress testing, demonstrating high durability. ANL is now scaling up synthesis of the catalyst for testing in a fuel cell, a critical step to assess viability in practical applications (Figure 2). (ANL)

In 2014, advances in catalyst synthesis and electrode optimization allowed PtCo and PtNi dealloyed catalysts, which have already met DOE targets for mass activity and durability of mass activity, to achieve good durability of high-current performance for the first time. These catalysts achieved the same H_2/air fuel cell performance as a 0.4 mg_{Pt}/cm^2 electrode, but with only one-fourth the PGM loading. The performance improvements were confirmed in a full-active-area automotive stack. Up to 60,000 cycles between 0.6 and 0.925 V were performed with only 20 mV loss at 1.5 A/cm^2 (Figure 3). (General Motors)

Anode-protection catalysts based on the oxygen evolution reaction (OER catalysts), which prevent oxidative degradation of anode catalysts and supports under-cell reversal, have been developed by 3M, but until now these catalysts were degraded by typical startup/shutdown conditions, in which H_2/air fronts move through the anode. In 2014 this problem was solved by incorporating a refractory metal interlayer between the anode catalyst and the OER catalyst, serving to isolate the OER catalysts from the localized destructive effects of H_2/air fronts. These interlayer-modified catalysts have demonstrated the ability to continue protecting the anode during more than 10 hours of cell reversal even after being exposed to 200 cycles of hydrogen/air switching (Figure 4). (3M)

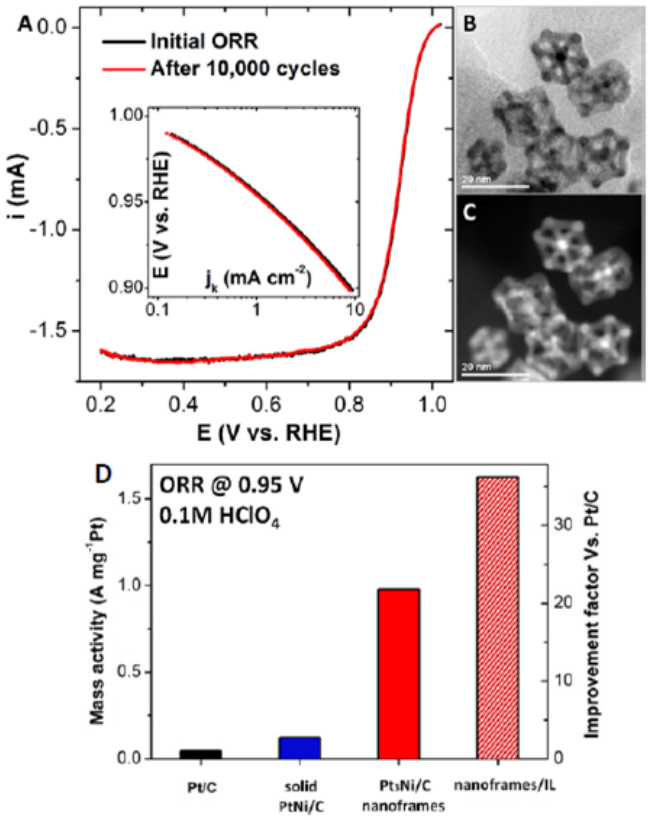


FIGURE 2. Multimetallic nanoframes with three-dimensional surfaces: (A) Oxygen reduction reaction (ORR) performance before and after 10,000 cycles between 0.6-1.0 V (reference hydrogen electrode, RHE); (B-C) preserved morphology of nanoframes after durability test; (D) superior mass activity.

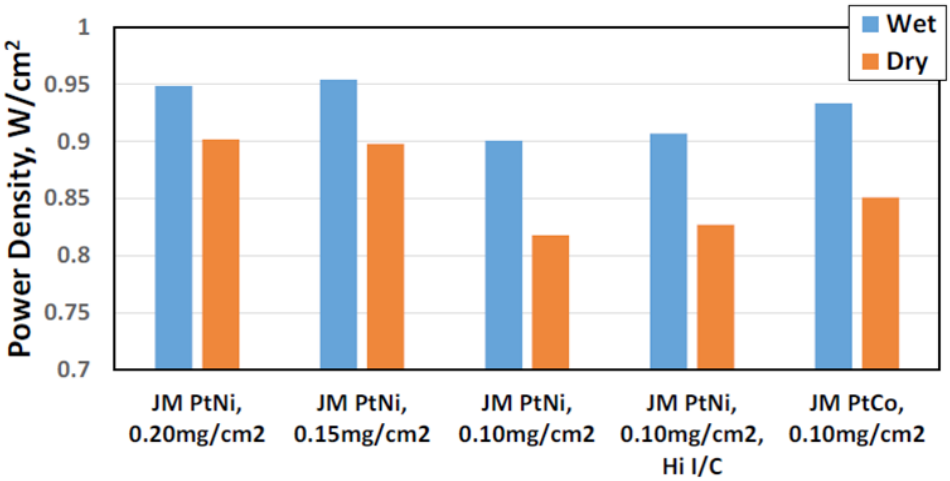


FIGURE 3. Full-active-area stack high-power performance of the dealloyed $PtNi_3$ and $PtCo_3$ catalysts under Fuel Cell Tech Team recommended conditions.

Protocols and best practices for RDE catalyst testing were prepared. Initial screening of fuel cell catalyst activity is typically performed ex situ using an RDE. RDE experiments are performed with little standardization between laboratories, leading to large discrepancies in reported activity values for the same catalysts and undermining the validity and usefulness of RDE data. Improvements in technique that allowed for higher and more reproducible activity have been reported recently, but have not yet been widely adopted. Therefore, Fuel Cell Technologies Office issued a request for information on RDE best practices, discussed the issue at meetings of the catalysis and durability working groups, and supported a collaborative effort between researchers at ANL and the National Renewable Energy Laboratory (NREL) to use the resulting input to develop protocols and best practices for RDE testing. This effort established a standard protocol and test methodology for measurement of electrochemical area (ECA), ORR activity, and durability, and evaluated three electrocatalysts using identical protocols and electrode preparation in three laboratories. Comparison of the results verified the reproducibility of measured ECA, ORR activity, durability between the labs, demonstrating the validity of the newly issued protocols (Figure 5). (ANL and NREL)

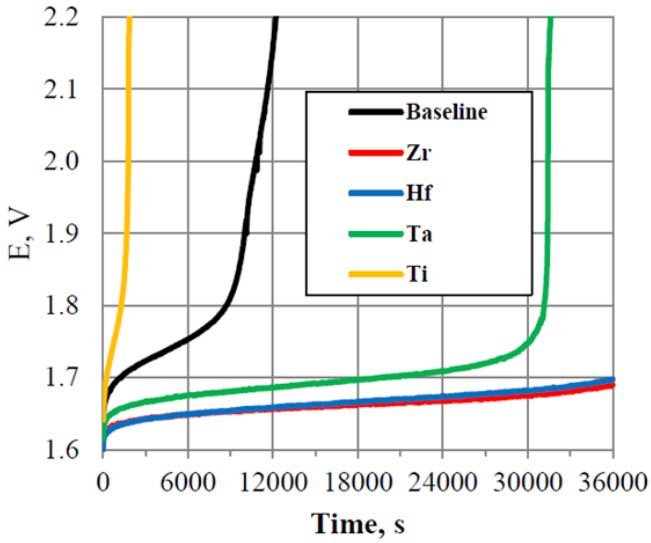


FIGURE 4. Cell reversal durability after 200 gas switches in addition to 200 pulses at 200 mA/cm^2. Reversal potential of the four refractory metals added as a sandwich between Pt and the Ir OER catalyst.

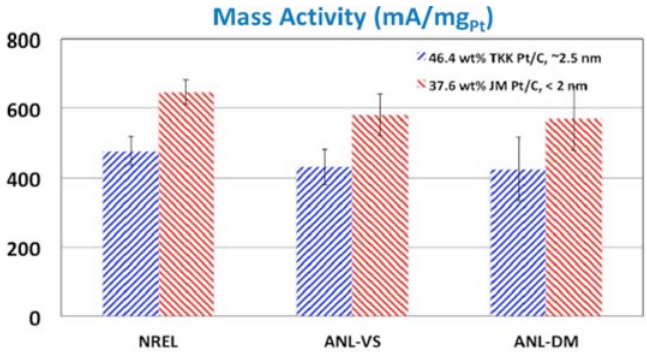


FIGURE 5. Comparison of mass activity between laboratories of two Pt/C electrocatalysts in 0.1M $HClO_4$ at 25°C and 100 kPa conducted at 20 mV/s in the anodic sweep.

Membranes

A new project begun in FY 2014 is further advancing performance and durability of membranes under hot and dry operating conditions by improving and combining components developed under earlier projects. Perfluoroimide acid ionomers previously developed have met many performance and durability targets, but ionomer improvement and membrane thickness reduction are required to simultaneously meet all DOE membrane targets. Modifications to the ionomer chemical structure, combined with incorporation of inert nanofiber supports developed by Vanderbilt University, has enabled the new membranes to meet chemical and mechanical durability targets while approaching all membrane resistance targets. (3M)

Membrane Electrode Assembly (MEA) Integration

Improvements in MEAs containing PtNi nano-structured thin film catalysts have enabled performance improvement at high current densities, resulting in PGM total content levels as low as 0.16 g/kW at 150 kPa_{abs}. This measurement was obtained at a high operating temperature of 90°C and voltage of 0.69 V, conditions that satisfy the DOE heat rejection target, $Q/\Delta T \leq 1.45$. When compared to PGM total content measured at 0.69 V in previous years, this year's results mark a 25% and a 6% improvement since 2012 and 2013, respectively. Further development is required to achieve DOE's target level of 0.125 g/kW, and to simultaneously meet durability targets (Figure 6). (3M)

BUDGET

The FY 2015 budget request calls for approximately $33.0 million for the Fuel Cells sub-program, which is at approximately the same level as the FY 2014 appropriation.

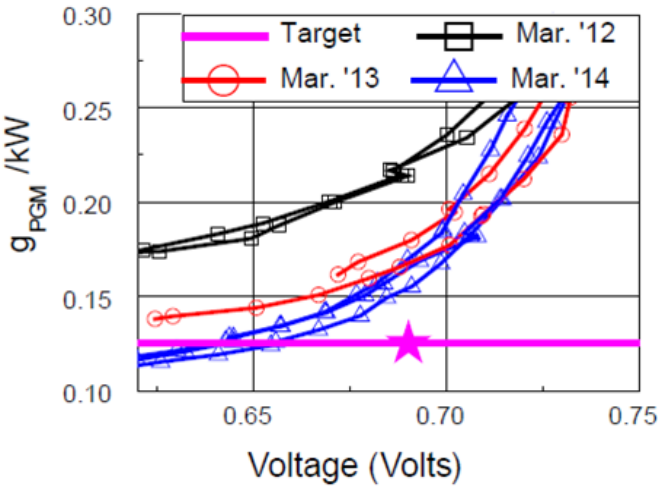
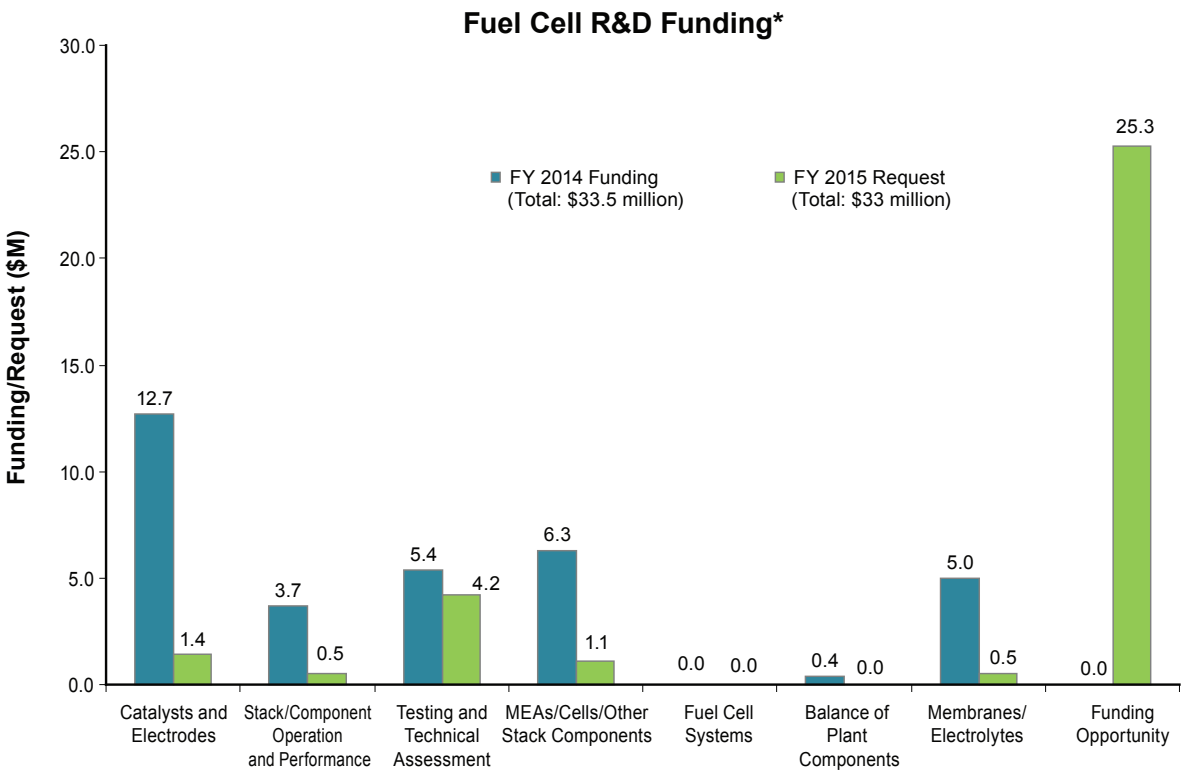


FIGURE 6. Total PGM content in PtNi nano-structured thin film-based MEAs operating at 90°C. At this temperature, an operating voltage of 0.69 V or higher is required to meet the DOE heat rejection target.

Figure 7 shows the budget breakdown by R&D area for the FY 2014 congressional appropriation of $33.5 million and the FY 2015 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 2014 for R&D on membranes, and molten carbonate fuel cells. In FY 2015, the Fuel Cells sub-program plans to facilitate the development of non-



* 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.

FIGURE 7. Budget Breakdown for FY 2014 and FY 2015

PGM catalyst containing MEAs through a center of excellence approach addressing improved modeling for materials development, high-throughput screening, and advanced characterization. The Fuel Cells sub-program plans to issue a funding opportunity announcement for awards funded in FY 2015.

FY 2015 PLANS

In FY 2015, 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 bio-derived renewable 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 and stack level, as well as on integration and component interactions at the system 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 PEM fuel cell technology for transportation applications, as well as PEM fuel cell and alternative technologies for distributed power generation systems (including CHP) and systems for emerging markets; further detailed results of these analyses are expected in FY 2015. 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 2015.

Dr. 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) 586-9995
Email: Dimitrios.Papageorgopoulos@ee.doe.gov