Fuel Cell R&D Subprogram Overview

INTRODUCTION

The Fuel Cell Research and Development (R&D) subprogram supports R&D of fuel cell technologies for transportation, stationary, and cross-cutting applications. The subprogram mainly focuses on reducing cost and improving durability and efficiency to allow fuel cells to compete with incumbent and advanced alternative technologies. Research areas include catalysts, membranes, and fuel cell performance and durability. The subprogram seeks a balanced, comprehensive approach to fuel cells for near-, mid-, and long-term applications. The development of fuel cells for transportation applications is a primary focus due to the nation's goal of significantly reducing its energy and petroleum needs and the benefits inherent in fuel cell electric vehicles (FCEVs) such as high efficiency, long driving range, and zero emissions. Transportation applications also include medium- and heavy-duty trucks, rail, and marine fuel cell propulsion.

The Fuel Cell R&D subprogram has expanded its focus to heavy-duty applications, which have more stringent durability requirements compared to light-duty vehicle applications. Stationary applications include the development of fuel cells for distributed power generation, including combined heat and power (CHP) for residential and commercial applications. Existing early markets and near-term markets generating market traction for adoption of FCEVs include primary/backup power for critical infrastructure such as data centers, auxiliary power units, and specialty applications such as material handling equipment. The subprogram's R&D portfolio is primarily focused on polymer electrolyte membrane (PEM) fuel cells but also includes longer-term technologies, such as alkaline membrane fuel cells, and low- and high-temperature reversible fuel cells for energy storage applications.

Durability and cost are the primary challenges to fuel cell commercialization. Also, life cycle cost reduction dictates further enhancements in efficiency. Improvements in multiple components are required to concurrently meet these challenges. The subprogram's fuel cell tasks are delineated in the Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan, with R&D focused in the key areas of fuel cell components and materials, as well as fuel cell performance and durability.

GOAL

The Fuel Cell R&D subprogram goal is to advance fuel cell technologies for transportation, stationary, and cross-cutting applications.

OBJECTIVES

The subprogram supports R&D to enable fuel cell power systems to be competitive with incumbent and alternative technologies. Key objectives of the Fuel Cell R&D subprogram include:

- Develop a 68% peak-efficient (ultimate 72%), direct hydrogen fuel cell power system for heavy-duty trucks that can achieve 25,000-hour durability (ultimate 30,000 hours) and be mass produced at a cost of $80/kW by 2030 (ultimate $60/kW).
- Develop a 65% peak-efficient, automotive direct hydrogen fuel cell power system that can achieve 5,000-hour durability (ultimate 8,000 hours) and be mass produced at a cost of $40/kW by 2025 (ultimate $30/kW).
- Develop medium-scale CHP systems (100 kW–3 MW) by 2025 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 2019 TECHNOLOGY STATUS AND ACCOMPLISHMENTS

One of the most important metrics used to guide the subprogram's R&D efforts is the projected high-volume manufacturing cost for automotive fuel cells, which is tracked on an annual basis. The subprogram is targeting a cost reduction to $40/kW by 2025. Long-term competitiveness with alternative powertrains is expected to require further cost reduction to $30/kW, which represents the subprogram's ultimate cost target. In Fiscal Year (FY) 2019, the preliminary cost projection for an 80-kW_{net} automotive PEM fuel cell system based on next-generation laboratory technology and operating on direct hydrogen is $50/$kW_{net}$ (2016 U.S. dollars) when manufactured at 100,000 units/year and $45/$kW_{net}$ when manufactured at a volume of 500,000 units/year.[1] The estimated cost of automotive PEM fuel cell systems that are based on currently deployed commercial technology in 2018 is approximately $210/$kW_{net}$ if manufactured at a volume of 1,000 units/year and $116/$kW_{net}$ if manufactured at a volume of 100,000 units/year. On-road technology is not warrantied for the ultimate lifetime target of 150,000 miles (8,000 hours), suggesting a shortcoming in stack durability that would likely be addressed by replacing the stack. In order to account for this in the cost of a fuel cell system, a single stack replacement is included in the durability-adjusted cost of $75/$kW_{net}$ at a manufacturing volume of 100,000 units/year. Future plans for system analysis include more rigorous testing of state-of-the-art membrane electrode assemblies (MEAs) to refine the durability-adjusted cost.

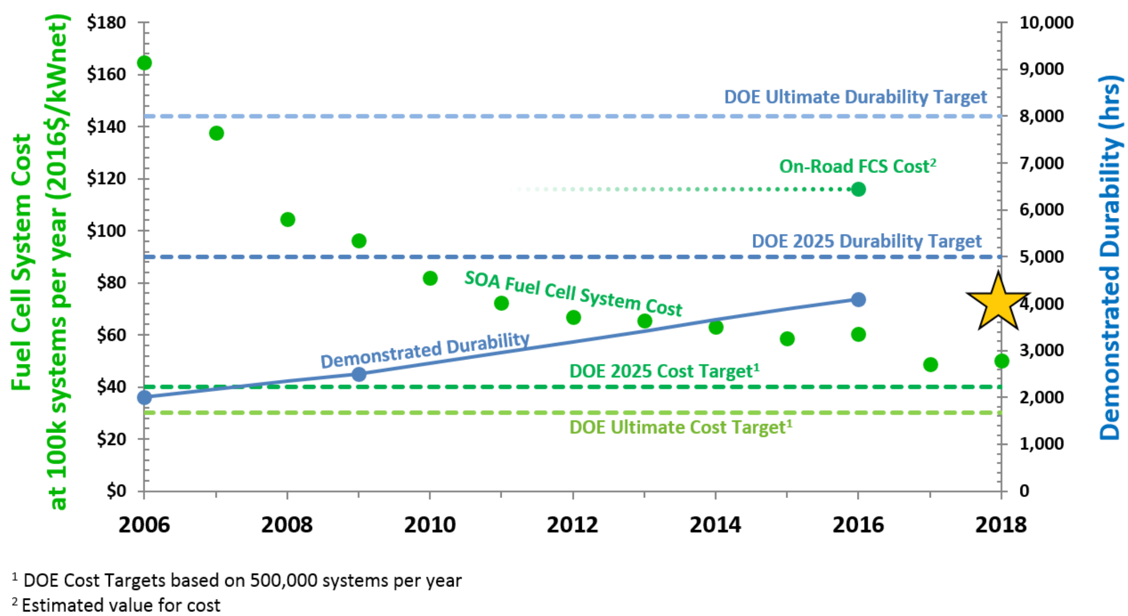

Figure 1. Modeled cost of an 80-kW_{net} PEM fuel cell system based on projection to high-volume manufacturing (2016 U.S. dollars, left axis) and on-road demonstrated fleet average durability (durability record).

Note: Yellow star indicates the $75/kW status for durability-adjusted cost in 2018.

In FY 2019, the subprogram completed its first-ever full cost analyses of direct-hydrogen fuel cell systems suitable for medium- and heavy-duty automotive applications. A two-stack system generating 170 kW_{net} was chosen to represent medium-duty fuel cell applications (e.g., delivery trucks and buses), while a three-stack 330 kW_{net} system was chosen to represent the needs of a system for heavy-duty long-haul trucks. Parameters for stack design (e.g., catalyst loading), system operation (e.g., heat rejection requirements), and other factors differ from the light-duty automotive fuel cell system because of the rigorous performance and durability requirements for medium- and heavy-duty systems. The estimated 2019 costs of the fuel cell systems manufactured at high volume (100,000 units/year) are $108/$kW_{net}$ for the medium-duty system and $97/$kW_{net}$ for the heavy-duty system.

Subprogram-Level Accomplishments

- Achieved platinum group metal (PGM)-free cathode MEA performance in an H_2-O_2 (hydrogen-oxygen) fuel cell of 29.6 mA/cm^2 at 0.90 V (*iR*-corrected) at 1.0 bar partial pressure of O_2 and cell

[1] Based on 2018 draft Fuel Cell System Cost record.

temperature 80°C, exceeding the 2019 target of 29 mA/cm^2. This was an 85% improvement in PGM-free catalyst activity over the 2016 baseline of 16 mA/cm^2.

- Finalized and disseminated PGM-free fuel cell catalyst test protocols through the Electrocatalysis Consortium (ElectroCat), harmonizing testing and best practices across the research and stakeholder community.
- Initiated efforts to model cost and performance of heavy-duty truck fuel cell systems providing key strategic analysis to guide target development and R&D approaches for heavy-duty fuel cells to be competitive in the marketplace.
- Hosted a Membrane Working Group meeting to discuss progress; consider future R&D needs; and develop testing protocols and milestones for alkaline exchange membranes (AEMs), MEAs, and system and stack components. The meeting provided a strategic approach to AEM fuel cell advancement; it was attended by over 50 industrial, academic, national laboratory, and government experts.

New Project Selections

Reversible Fuel Cell (RFC) Development and Validation Projects

- FuelCell Energy, Inc.—High Efficiency Reversible Solid Oxide System
- Proton Energy Systems—A Novel Stack Approach to Enable High Round Trip Efficiencies in Unitized PEM Regenerative Fuel Cells

Innovative RFC Component Projects

- Giner, Inc.—Reversible Fuel Cell Stacks with Integrated Water Management

High-Durability, Low-PGM MEAs for Medium- and Heavy-Duty Truck Applications Projects

- General Motors, LLC—Durable Fuel Cell MEA through Immobilization of Catalyst Particle and Membrane Chemical Stabilizer
- Nikola Motor—Durable MEAs for Heavy-Duty Fuel Cell Electric Trucks
- Carnegie Mellon University—Durable High Power Density Fuel Cell Cathodes for Heavy-Duty Vehicles

Project Level Accomplishments

Low-PGM MEAs

- Demonstrated mass activity as high as 0.79 A/mg$_{PGM}$, with 37% loss after 30,000 accelerated stress test cycles in MEA testing with ordered intermetallic PtCo nanoparticles supported on N-doped hydrogel carbon (Los Alamos National Laboratory—Advanced Electrocatalysts through Crystallographic Enhancement).
- Demonstrated mass activity as high as 0.60 A/mg$_{PGM}$, with 40% loss after 30,000 accelerated stress test cycles, in 4-nm particle diameter ordered intermetallic PtCo nanoparticles (Los Alamos National Laboratory—Advanced Electrocatalysts through Crystallographic Enhancement).
- Increased PGM utilization (to 12.1 vs. target of 8 kW/g$_{PGM}$ at 150 kPa) by reducing Pt amount in both anode and cathode (General Motors—Highly Accessible Catalysts for Durable High-Power Performance).

Fuel Cell Performance and Durability (FC-PAD)

- Examined the durability performance of low-PGM-loading MEAs as a function of ultra-low loading and upper potential limit with recovery protocols to be fed into catalyst models and inform future catalyst development.

- Examined the effect of radical scavenger (Ce) migration through the membrane and ionomer on fuel cell performance and durability.
- Correlated how solvent\ionomer interactions within the catalyst ink impact catalyst-layer structure and resultant high-current-density performance.

PGM-Free Catalysts (ElectroCat)

- Characterized oxygen reduction reaction activity and atomic structure of 75 high-throughput-synthesized Fe-dopant-phenanthroline-zeolitic imidazolate framework catalysts using X-ray absorption and multi-channel flow double electrode cell, identifying materials with half-wave potential ($E_{½}$) greater than 0.80 V.
- Defined advances needed in catalyst activity and electrode properties to achieve 1,000 mW/cm² power density while meeting Q/dT target.
- Calculated a density functional theory database of vibrational spectra with and without probe molecules for identification of stretching frequencies observed using nuclear resonance vibrational spectroscopy.

BUDGET

The FY 2019 appropriation is $30 million for the Fuel Cell R&D subprogram. In FY 2019 the subprogram funded early-stage R&D efforts in key areas focusing on fuel cell stack components to increase performance and durability while reducing cost, broken down into five areas represented in Figure 2.

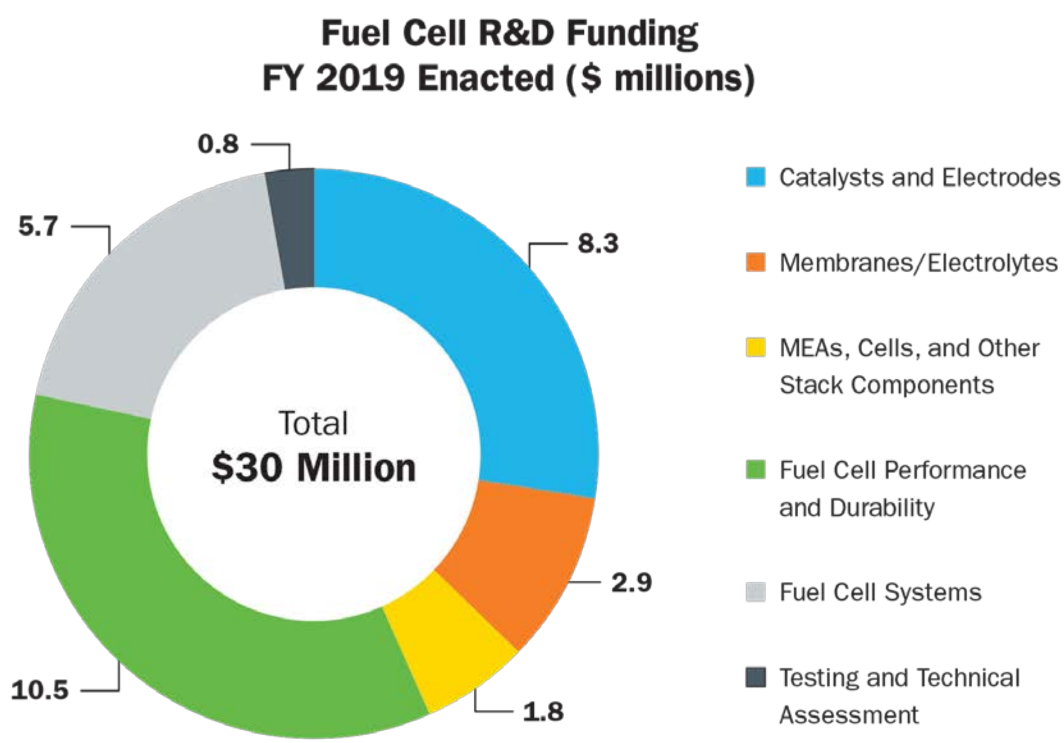

Figure 2. Fuel Cell R&D subprogram FY 2019 enacted budget

Awards made for new funding opportunity announcement (FOA) projects accounted for $12 million in funding and included those awarded in two topics: high-durability, low-PGM MEAs for medium- and heavy-duty truck applications, and RFC development and validation. A significant amount of the remaining funding was dedicated to the two national laboratory consortia: FC-PAD, designated as its own category in Figure 2, and ElectroCat, which contributes to the $9 million in funding of catalyst and electrode development. The balance is made up by work in membrane R&D, testing and technical assessment (primarily performed by Argonne National Laboratory and Strategic Analysis, Inc.), and work on other stack/MEA components that includes gas diffusion layers and bipolar plates, among others.

UPCOMING ACTIVITIES AND PLANS

In FY 2020, the Fuel Cell R&D subprogram will focus R&D in the key areas of fuel cell components and materials, as well as fuel cell performance and durability with an emphasis on cost reduction and durability and efficiency improvement. Fuel cell components of interest include high-temperature membranes (up to 120°C) and low-PGM catalysts and MEAs for heavy duty applications (trucks, marine, rail), which require much more aggressive durability targets—more than five-fold higher than automotive durability targets. The subprogram's consortia will continue fostering national lab capabilities and collaborations with stakeholders and the research community. The subprogram continues to support the development of PGM-free catalysts and electrodes, utilizing unique experimental and advanced computing capabilities at the national labs, through ElectroCat. The work of FC-PAD will be increasingly focused on applying the insights achieved over its first several years' work in low-PGM fuel cells to meet the challenges of high efficiency and high durability needed for heavy-duty applications, including work with new FOA partner projects. ElectroCat and FC-PAD will engage the FOA partners to further increase the cooperativity and effectiveness of R&D progress on PGM-free and low-PGM fuel cells. The subprogram will continue to support collaboration on membrane electrolyte materials through the Membrane Working Group, partnering with the National Renewable Energy Laboratory, Los Alamos National Laboratory, and Advanced Research Projects Agency–Energy.

Ongoing support of modeling guides component R&D, benchmarking complete systems before they are built and enabling exploration of alternate system components and configurations. The subprogram will pursue fuel cell technology and manufacturability at the stack and system level, with efforts to enable low-cost, domestically manufactured standardized stacks and systems for multiple heavy-duty applications. This approach will enable building a domestic heavy-duty fuel cell supply chain, prioritizing American manufacturing capability, and will provide further insight on critical early-stage R&D needs for heavy-duty fuel cell systems and approaches to strengthen the domestic supply chain.

In addition to efforts pertaining to PEM fuel cell R&D, the subprogram will foster component innovation for longer-term AEM fuel cells and for unitized RFCs to meet the needs for grid-scale energy storage, and also support the efforts of recently selected RFC development and demonstration projects. The subprogram will explore the potential of stationary fuel cells to supply primary/backup power to data centers.

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