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CHANGING WHAT'S POSSIBLE

PROTON-CONDUCTING FUEL CELLS FOR STATIONARY POWER

Updated: December 11, 2017

TITLE: Low-Cost Intermediate-Temperature Fuel-Flexible Protonic-Ceramic Fuel Cell and Stack

PROGRAM: Reliable Electricity Based on ELectrochemical Systems (REBELS)

AWARD: $3,997,457

TEAM: Colorado School of Mines (Lead), FuelCell Energy

TERM: October 2014 – September 2020

PRINCIPAL INVESTIGATOR (PI): Ryan O'Hayre

MOTIVATION

Large, centralized power plants are the most efficient way to convert fuels such as natural gas to electricity. However, current 25 kilowatts (kW) natural gas generators are typically only 25-30% efficient and expensive to maintain. Fuel cells with an electrical efficiency of 50% could displace generators of 25kW or less in remote power, telecommunications, and residential cogeneration uses. Furthermore, fuel cells could provide valuable grid services, such as ramping power up or down to match load conditions. The challenge to adoption is that both low- and high-temperature fuel cells are very expensive. Moreover, low-temperature fuel cells can be started up quickly, but require highly pure hydrogen fuel and expensive catalysts. High-temperature fuel cells can operate on a range of fuels, but they have costly system components and can degrade rapidly.

TECHNICAL OPPORTUNITY

Recent advances in fuel cell materials and manufacturing present an opportunity to develop an intermediate temperature (200-500°C), high-efficiency system. This operating range requires new materials for the electrolyte and the electrodes. High-temperature solid oxide fuel cells (SOFCs) perform poorly at temperatures less than ~650°C, in part because the transport of oxygen ions in the electrolyte is sluggish at lower temperatures. New materials based on barium-zirconium-cerium-yttrium oxide now make it possible to employ a mixed proton and oxygen-ion conducting ceramic electrolyte to create a fuel-flexible fuel cell. Protons can move through solid electrolytes more quickly, thus lowering the resistance at intermediate temperatures. Researchers at the Colorado School of Mines (CSM) had previously discovered a solid-state reactive sintering (SSRS) process that combines materials-synthesis and fuel-cell-fabrication processes within a single step,[1] thereby reducing manufacturing costs. Significant work remains to translate these technical advances into large area proton-conducting fuel cells (PCFCs), assemble them into stacks, and test them on fuels.

INNOVATION DEMONSTRATION

The CSM project focused on creating commercially relevant, proton-conducting ceramic fuel cell stacks capable of operating on natural gas fuel. The project team's initial phase was cell scale-up and stack integration, and the team is under a second phase of scaling up from laboratory-scale to pre-commercial stacks (Figure 1).

The team, through a new fabrication process, increased the active area 40-fold (from 0.1 to 4 cm^2). They modified their SSRS process to create a thin, uniform, and dense protonic-ceramic electrolyte and composite anode, achieving a first in proton-conducting cells beyond a "button cell" (~1 cm^2).[2] CSM also was able to increase

1 Tong, J., Clark, D., Bernau, L., Sanders, M., & O'Hayre, R. (2010). Solid-state reactive sintering mechanism for large-grained yttrium-doped barium zirconate proton conducting ceramics. Journal of Materials Chemistry, 20(30), 6333-6341.

2 C. Duan, J. Tong, M. Shang, S. Nikodemski, M. Sanders, S. Ricote, A. Almonsoori, R. O'Hayre, "Readily Processed Protonic Ceramic

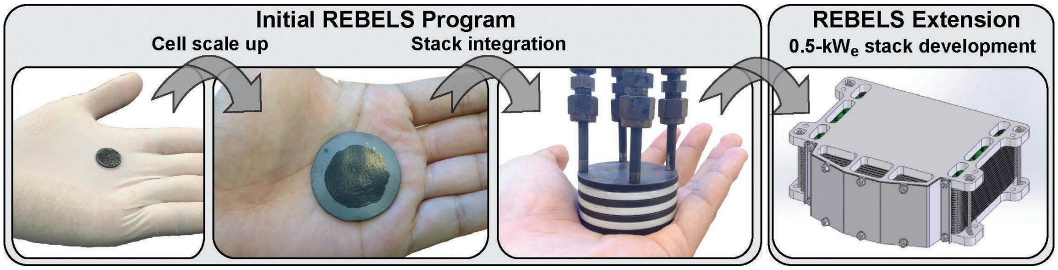

Figure 1: Technological road map for CSM's protonic-ceramic fuel cells.

power density, and, in particular, develop nano-structured materials that provide high performance while being stable at about 500°C. The ultimate cell chemistry enabled an increase in the peak power density at 550°C on methane fuel from 100 mW/cm^2 to approximately 250 mW/cm^2. Furthermore, the cells could operate directly on methane at 550°C or less without degradation, avoiding the tendency for carbon deposits that degrade performance (coking) at these temperatures. Finally, the new PCFCs were robust and could be operated on a variety of fuels—pure methane, methanol, natural gas with impurities, ethanol, propane, ammonia, and hydrogen—for thousands of hours with minimal degradation.

The cells were integrated into a stack with frames, interconnects, and seals. Overcoming the many challenges of stack design, the CSM team built a three-cell stack with a power density of approximately 200 mW/cm^2. Techno-economic models were developed to estimate technology cost at scale. Existing cost studies for traditional SOFCs operating at 800°C assume a fuel cell stack cost of $300-340/kW. In contrast, the PCFC operating at 550°C is projected at approximately $235/kW.[3] The PCFC power density is 15-25% lower than SOFCs, but analysis shows substantial cost savings at the stack and system level, related to the cell materials, current collectors, seals, interconnects, and balance-of-plant components at lower temperatures.

IMPACT PATHWAY

The CSM team partnered with FuelCell Energy to further scale up their cell area, create a 500 W prototype operating on natural gas, and quantify the degradation behavior under different types of fuels. Working with FuelCell Energy will allow CSM to further prove the commercial viability of the PCFC with more data and better cost models to compare its benefits to the state of the art. A particular area of focus is whether the PCFC material set has the mechanical strength and properties needed to create larger area cells and stacks.

LONG-TERM IMPACTS

The typical electrical efficiency of a small, stationary generator operating on a fuel such as natural gas is 25-30%. The target efficiency for the PCFC technology is 50%—an improvement that would reduce fuel consumption and emissions. A potential entry market is the electrification of off-grid oil and gas wellpads that currently rely on the pneumatic pressure of natural gas for power, with the concomitant atmospheric release of gas. In the long term, the PCFC technology could be used for residential or commercial heat and power—with heat utilization increasing the system's overall energy efficiency to 85% or higher. The fuel flexibility of the PCFC system means that it could be operated on low-carbon fuels such as biogas, ammonia, or ethanol.

INTELLECTUAL PROPERTY AND PUBLICATIONS

As of December 2017, the CSM project has generated two invention disclosures to ARPA-E. One U.S. Patent and Trademark Office (PTO) patent application has been filed on the disclosed inventions. The CSM team has also published six times the scientific underpinnings of this technology in open literature.

Fuel Cells with High Performance at Low Temperatures," Science 349, 1321-1326 (2015).

3 A. Dubois, S. Ricote, R. J. Braun, "Benchmarking the expected stack manufacturing cost of next generation, intermediate-temperature protonic ceramic fuel cells with solid oxide fuel cell technology," J. Power Sources 369, 65-77 (2017).