II.B.5 Solid Oxide Based Electrolysis and Stack Technology with Ultra-High Electrolysis Current Density (>3A/cm²) and Efficiency

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Subcontractor:
Versa Power Systems, Ltd., Calgary, Alberta, Canada

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Overall Objectives

Develop solid oxide electrolysis cell (SOEC) technology capable of:

- Operating at ultra-high current density (>3 A/cm^2).
- Operating with a cell voltage upper limit of 1.6 V, equivalent to 77% efficiency, lower heating value (LHV).

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(F) Capital Cost

(G) System Efficiency and Electricity Cost

(J) Renewable Electricity Generation Integration

Technical Targets

- Develop a solid oxide electrolysis cell platform capable of operating with current density up to 4 A/cm^2 at or below a voltage of 1.6 V (2020 Stack Energy Efficiency Target: 77% LHV).
- Demonstrate stable SOEC operation with high current density of 3 A/cm^2 for 1,000 h.
- Design a solid oxide electrolysis stack platform capable of operating with the high current density (>3 A/cm^2) cell technology at an upper voltage limit of 1.6 V/cell (2020 Stack Energy Efficiency Target: 77% LHV).
- Demonstrate stable solid oxide electrolysis stack operation with high current density of more than 2 A/cm^2 for 1,000 h.
- Complete a solid oxide electrolyzer process and system design that accommodates the ultra-high operating current density platform, all to meet the Department of Energy (DOE) 2020 target for advanced electrolysis technologies (2020 System Energy Efficiency Target: 75% LHV).

Fiscal Year (FY) 2016 Accomplishments

- Developed and demonstrated a high power density (HiPoD) solid oxide cell platform in electrolysis mode capable of operating with current density more than 4 A/cm^2 at a voltage of 1.6 V at 750°C, meeting the DOE 2020 stack energy efficiency target of 77% LHV. In particular, two HiPoD cells were further tested to a current density of 6 A/cm^2 at 800°C.
- Demonstrated stable SOEC operation with high current density of 3 A/cm^2 for 1,000 h with a degradation rate of 1.81% per 1,000 h.
- Demonstrated a solid oxide electrolysis stack platform capable of operating with the high current density of 3 A/cm^2, at an average cell voltage of only 1.493 V/cell. This corresponds to a demonstrated stack efficiency of 83% LHV, which exceeds the DOE 2020 Stack Energy Efficiency Target of 77% LHV.
- Demonstrated stable solid oxide electrolysis stack operation with high current density of 2 A/cm^2 for 1,000 h with a degradation rate of 1.2% per 1,000 h.

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INTRODUCTION

Hydrogen, a valuable commodity gas, is increasingly recognized as an important fuel and energy storage pathway of the future. Demand for hydrogen as a fuel for fuel cells, in both transport and stationary applications, will continue to grow alongside hydrogen for energy storage (including power-to-gas and power-to-liquids pathways). The renewed interest in developing electrolysis systems is driven, in part, by burgeoning solar and wind industries and the need for an energy conversion and storage technology that can serve as the vehicle for converting intermittent solar and wind energy into the production of hydrogen. Although current electrolysis systems have the potential to integrate with wind and solar energy sources, the key challenges are low system efficiency and high capital costs. This project aims to address these barriers with an innovative solid oxide fuel cell (SOFC)-based electrolysis cell and stack technology with ultra-high steam electrolysis current (>3 A/cm^2) for potentially ultra-low-cost, highly efficient hydrogen production from diverse renewable sources.

APPROACH

FuelCell Energy (previously Versa Power Systems) has a strong solid oxide cell and stack development history through its previous Office of Energy Efficiency and Renewable Energy sponsored project and through over 15 years of cell and stack advancements from previous efforts (DOE, Solid State Energy Conversion Alliance, and Defense Advanced Research Projects Agency projects). Leveraging this experience, the project objectives will be met by executing the following scope:

- Addressing high current density electrolysis cell performance limitations by conducting multiple materials development and cell design-of-experiments, integrating them with cell production technology development.
- Developing SOEC stack engineering modeling and process fabrication designs to address high current density operating requirements and identifying key operating parameters for the design of an integrated, SOEC-based energy conversion and storage system for renewable energy sources (wind and solar).
- Down-selecting cell technology developments and demonstrating high current density SOEC operation via single cell and stack tests.
- Investigating a high current density solid oxide electrolyzer system, including the option of integration with renewable energy sources, to meet DOE 2020 Advance Electrolysis Technologies targets.

RESULTS

In this project, solid oxide based HiPod cells have been developed such that, when run in electrolysis mode, they are capable of operating at ultra-high electrolysis current density. Those *cathode-supported cells* have been developed using conventional SOFC materials comprising a nickel oxide and yttria stabilized zirconia cathode and 8 mol% yttria-stabilized zirconia electrolyte. (Note: electrolysis electrochemical nomenclature is used here. In fuel cell mode, these same cells are called *anode supported;* in electrolysis mode they are technically accurate to be referred to as *cathode supported*.) The cell utilizes an all-ceramic anode with no noble metals. Electrochemical testing (current-voltage response) of the cells was performed up to 6 A/cm^2 in electrolysis mode as shown in Figure 1. The steam and air are supplied in the horizontal plane, perpendicular to one another, in what is termed a cross-flow geometry. The test housing (and current collection) is made from low-cost ferritic stainless steel and the current collection and seal materials used are the same as those used in SOFC stacks. The cell voltage includes all interfaces and the stainless steel current collection jigs; and, as such, is believed to be representative of the unit cell of an electrolysis stack. The cell platform dimensions are 5 cm x 5 cm x 0.03 cm with an active electrode area of 16 cm^2. This area requires a current input of 96 A to reach a current density of 6 A/cm^2 during electrolysis testing. Gas flows and compositions are as annotated in the figures and consistent across all temperatures tested. Figure 1 shows cell voltage plotted against current density for four different temperatures up to 6 A/cm^2 in electrolysis mode. A remarkable cell voltage of 1.67 V at 6 A/cm^2 was achieved at 800°C. Even at 750°C, the cell exceeded the project performance target of 4 A/cm^2 at 1.6 V. Recently, a HiPoD cell has been operating for more than 1,000 h at 3 A/cm^2 current density with a low degradation rate of 1.8% per 1,000 h.

A 20-cell electrolysis stack was built using HiPoD cells and an ultra-compact, low-cost stack design platform. A photograph of the stack installed in a test stand with thermocouple and voltage lead instrumentation attached can also be seen in Figure 2.

This stack was used to explore the boundaries of high current density electrolysis operation and achieved a very high stack current density of 3 A/cm^2 (67 A) with an average cell voltage of only 1.493 V. Figure 2 shows the load-up, tuning, and operation at this current density over a five-hour

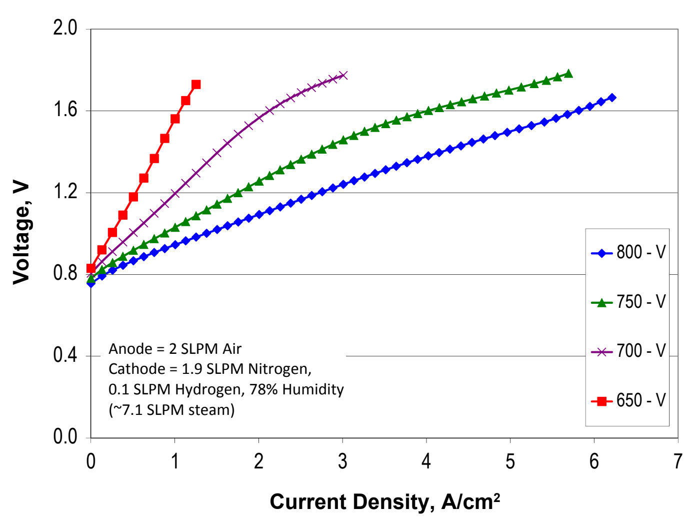

FIGURE 1. Voltage–current density curves for HiPoD cell electrolysis operation 650–800°C

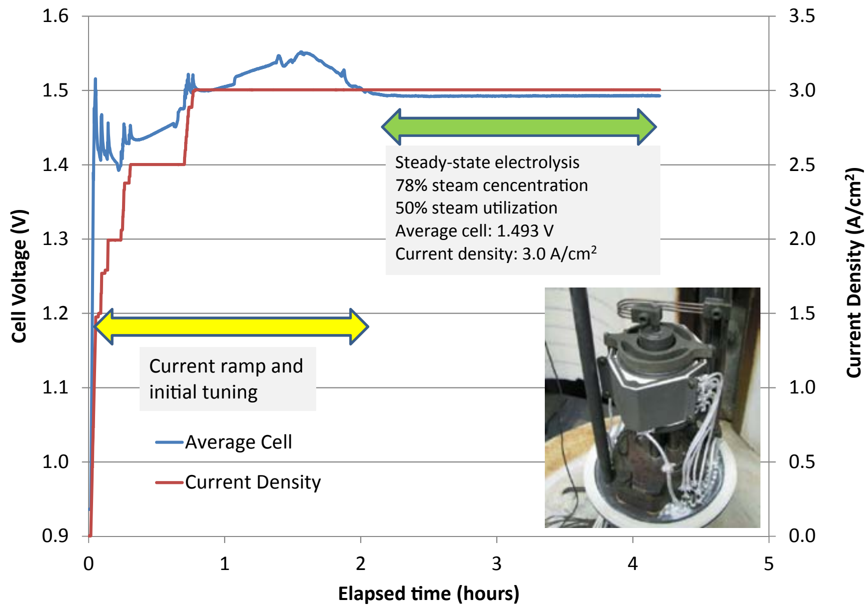

FIGURE 2. Load-up, tuning, and high current density operation of a 20-cell SOEC stack

period. The cathode composition is 78% water and 22% hydrogen (20.11 slpm water, calculated, 5.672 slpm hydrogen, steam utilization is 50.0%). After load-up and tuning, stack voltage is 29.856 V (1.493 V/cell) and stack current is 67 A (3.004 A/cm^2). At this test condition, the stack is producing 50.3 g/h hydrogen with a stack volume of only 200 cm^3 using 2 kW input. This equates to 2.5 kg H_2 per day for a 225-cell stack of this platform design. The stack was further operated in steady-state electrolysis at 2 A/cm^2 for more than 1,000 h. Early in the testing there were three unplanned and uncontrolled test interruptions which resulted in full thermal cycles. The degradation appears to have increased for a period after the first interruption, but the overall degradation for the test period was relatively low at 7.2 mV per 1,000 h per cell or 0.57% per 1,000 h.

A preliminary system design was developed by integrating the inputs from electrochemistry, cell/stack performance data, and system level implications of configuration and operational parameters. Several variations were hypothesized and modeled and the most promising were iterated several times in order to determine the best-case baseline system. The resulting system design is yet to be fully optimized; however, it provides excellent insights to the potential of a high current density, high temperature water splitting system.

CONCLUSIONS AND FUTURE DIRECTIONS

The project team will continue on the current development path. This includes:

- Complete 10 kW rated SOEC stack design freeze incorporating final design changes suggested by stack test results and any further modeling effort as well as final design elements that permit stacking into a 10 kW stack package.
- Complete in-depth SOEC hot module configuration design.
- Demonstrate stable operation of an SOEC stack with a hydrogen production rate of 250 g/hr at a current density of more than 2 A/cm^2.
- Complete a comprehensive techno-economic study of an ultra-high current density SOEC system integrated with renewable energy sources.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Oral presentation at the 2016 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting in June 2016.

2. "Solid Oxide Electrolysis Development at Versa Power Systems," Tony Wood, Hongpeng He, Tahir Joia, Mark Krivy, Dale Steedman, Eric Tang, Casey Brown, Khun Luc; 12th European SOFC & SOE Forum 2016.

3. "Performance Evaluation of Solid Oxide Electrolysis Cells at Versa Power Systems," H. He, A. Wood, T. Joia, M. Krivy, and D. Steedman; 229th ECS Meeting, San Diego, 2016.

4. J. Electrochem. Soc. 2016 Volume 163, Issue 5, F327-F329, Communication—"Electrolysis at High Efficiency with Remarkable Hydrogen Production Rates," Anthony Wood, Hongpeng He, Tahir Joia, Mark Krivy, and Dale Steedman.