V.J.3 Advanced Materials for Reversible Solid Oxide Fuel Cell (RSOFC), Dual-Mode Operation with Low Degradation

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Fiscal Year (FY) 2012 Objectives

The objective of project is to advance RSOFC cell stack technology in the areas of endurance and performance.

Technical Barriers

This project addresses the following technical barriers from the Production section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan [1]:

(G) Capital Cost
(H) System Efficiency
(I) Grid Electricity Emissions (for distributed power)
(J) Renewable Electricity Generation Integration (for central power)

Technical Targets

This project includes RSOFC materials development, and reversible stack design, and demonstration. The project objectives include meeting the following performance and endurance targets in a kW-class RSOFC stack demonstration:

- RSOFC dual-mode operation of 1,500 hours with more than 10 SOFC/solid oxide electrolysis cell (SOEC) transitions.
- Operating current density of more than 300 mA/cm^2 in both SOFC and SOEC modes.
- Overall decay rate of less than 4% per 1,000 hours of operation.

Meeting those performance and endurance technical targets will be the key RSOFC cell stack technology development step towards meeting DOE's technical targets for distributed water electrolysis hydrogen production by an RSOFC system.

FY 2012 Accomplishments

- Over 20 types of RSOFC cells were developed in the project. Many of those exceeded the performance (area-specific resistance <0.3 Ω-cm^2) and the endurance (degradation rate less than 4% per 1,000 hours) targets—in both, fuel cell and electrolysis modes.
- Down-selected and demonstrated RSOFC-7 in a single-cell Go/No-Go milestone test which included:
  - Steady-state electrolysis with a degradation rate of about 1.5% per 1,000 hours.
  - Ultra-high current electrolysis over 3 A/cm^2 at 75% water electrolysis efficiency voltage of 1.67 V.
  - Daily SOFC/SOEC cyclic test of 500 days, that is 1.37 years, with a similar degradation rate of 1.5% per 1,000 hours
- Validated cell material systems via a dual metric—fuel cell/electrolysis—cyclic metric. Over 6,000 SOFC/SOEC cycles were demonstrated in accelerated cycling. The degradation obtained was less than 3% per 1,000 cycles.
- Completed stack design and component down-select, and conducted a number of kW-class RSOFC stack development tests to demonstrate:
  - Steady-state electrolysis operation of over 5,000 hours.
  - Daily SOFC/SOEC cyclic test of 100 cycles.
  - Scale up capability of using large area cells with 550 cm^2 active area.

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Introduction

RSOFCs are devices which enable the energy conversion, storage, and re-conversion to power. They are capable of operating in both power generation mode (SOFC) and electrolysis modes (SOEC). RSOFC can integrate renewable production of electricity and hydrogen when power generation and steam electrolysis are coupled in a system, which can turn intermittent solar and wind energy into “firm power.” In order to address the technical and cost barriers, DOE funded a number of research projects over the past ten years [2]. Although significant progress was made in those projects, it was concluded that further development was required, especially in the areas of RSOFC performance and endurance. In this project, Versa Power Systems Inc. (VPS) is addressing those performance and endurance issues for RSOFC cells and stacks.

Approach

VPS has identified four task areas in an effort to improve the performance and endurance of RSOFC systems: degradation mechanism study, cell material development, interconnect material development, and stack design and demonstration. A stage-gate project management process is employed with a quantitative Go/No-Go decision point. The scope of the work has been carried out by:

1. Building on VPS’ strong SOFC cell and stack baseline, and leveraging cell and stack advancements from the DOE State Energy Conversion Alliance (SECA) program.
2. Carrying out parallel materials development activities and integrating them with cell production technology development.
3. Developing RSOFC stack and process designs to address durability, performance, and cost in both fuel cell and electrolysis operating modes.

Results

The development path for RSOFC cell technology at VPS can be summarized in Figure 1. More than 20 material systems have been developed in the project. At the project Go/No-Go milestone test, one of the best cell material system—RSOFC-7—demonstrated 223 and 224 mΩ-cm^2 ASR values in electrolysis and fuel cell modes, respectively, at 750°C compared with the target of less than 300 mΩ-cm^2. The same materials system also demonstrated ~1.5% per 1,000 hours degradation rate as compare with the target of 4% per 1,000 hours. To further explore the performance capability in electrolysis mode, a single stack repeat unit with one RSOFC-7 cell was tested to ultra-high electrolysis current. The DOE’s water electrolysis FY 2017 efficiency target of 75% was used to establish the electrolysis operating voltage of 1.67 V. As shown in Figure 2, the cell demonstrated excellent performance of exceeding 3 A/cm^2 at 75% water electrolysis efficiency, with an operating voltage of 1.67 V.

The project initially focused on performance improvement; then the emphasis for RSOFC materials system development switched to endurance—for both SOEC steady-state and SOFC/SOEC cyclic, transient conditions. Twelve material systems, highlighted in yellow in Figure 1, were developed based on the RSOFC-7 cell. RSOFC cell material systems have been further validated in fuel cell/electrolysis cyclic operation. A cyclic test profile was designed to simulate an integrated reversible SOFCEL/solar power system. The test runs a 24-hour cycle with 10.5 hours in electrolysis, 12.5 hours in fuel cell operation, and the balance in transitions. One SOFCEL daily cyclic test of an RSOFC cell completed over 11,900 hours (~500 days) as shown in Figure 3; the degradation in fuel cell mode is about 0.6% per 1,000 hours. The SOEL mode testing was conducted at twice the current density in as that in SOFC; the SOEC degradation is slightly more than double—at about 1.5% per 1,000 hours. This is similar to the steady-state SOEC degradation rate at

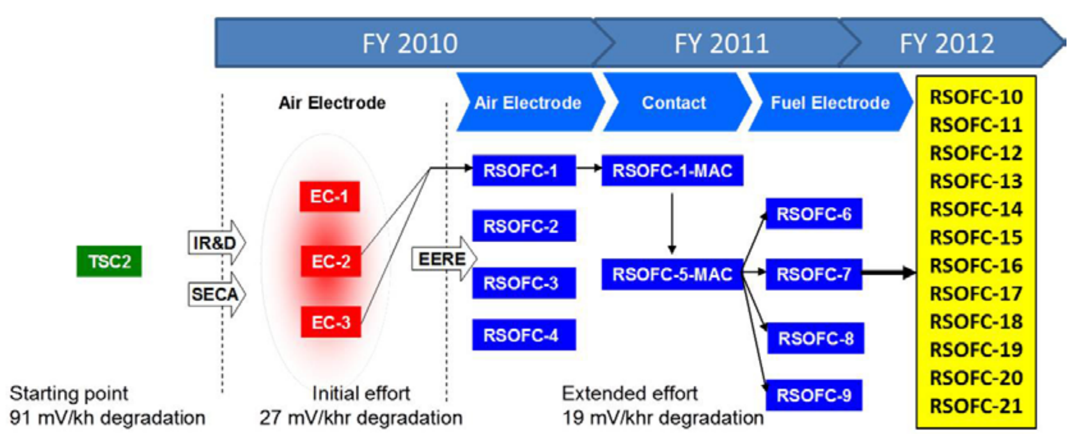

FIGURE 1. RSOFC cell development path at VPS

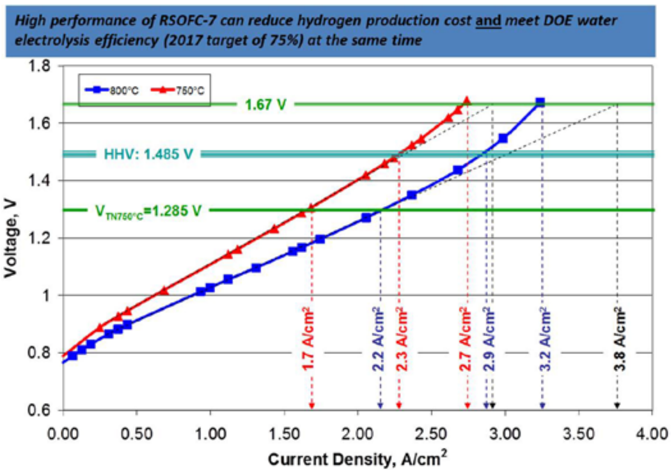

FIGURE 2. Single-cell test of a RSOFC-7 cell performance at ultra-high electrolysis current density of over 3 A/cm^2

the same current density. In both cases, the degradation rate of the RSOFC-7 bettered the project target of less than 4% per 1,000 hours for over 1,000 hours. To further validate the SOFC/SOEC cyclic capability of the VPS materials systems, a single-cell stack repeat unit with one RSOFC-7 cell was tested in an accelerated cycling test—to more than 6,000 SOFC/SOEC cycles. This is equivalent to daily cycles for more than 15 years. Most of the transients in this accelerated test were conducted over a 20 minute duration (8 minutes in SOFC, 8 minutes in SOEC, and 4 minutes in transient). The cyclic degradation rate is identical to that of daily cycle, at 3 mV/100 cycles.

Finally, in FY 2011, the improvement in steady-state SOEC degradation was verified in a long-term steady-state electrolysis test of a kW-class stack for over 5,000 hours—with less than 4% per 1,000 hours degradation rate. Last, in FY 2012, the project team has focused on the cyclic operation capability and scale up potential of the RSOFC stack. A kW-class stack with 20 RSOFC-7 cells (Figure 4) demonstrated over 100 SOFC/SOEC cyclic operations. The cyclic degradation in SOFC and SOEC were 13 mV and 64 mV per 100 cycles, respectively. This degradation rate is substantially higher than the degradation rate from the single stack repeat unit test. It was identified that the gap is mainly due to thermal management issues in an RSOFC stack. Improving thermal management in RSOFC stacks for SOFC/SOEC transient will be the main focus in the remaining of the project.

In addition, one scaled up kW-class stack with large area 25 cm x 25 cm cells (550-cm^2 active area) developed under the DOE SECA program, was built and tested in both steady-state electrolysis and cyclic SOFC/SOEC modes for over 1,500 hours. The results demonstrated the potential for large-scale RSOFC stack development in the future.

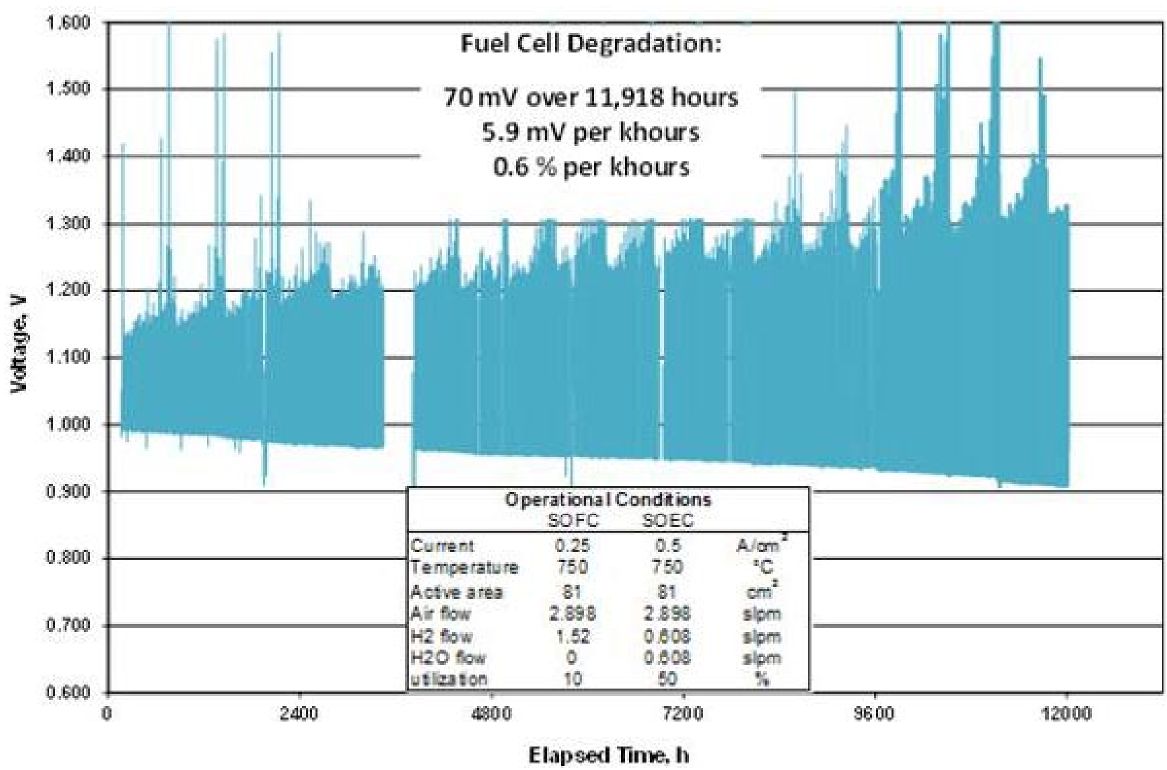

FIGURE 3. Daily cyclic operation of a RSOFC-7 in a single-cell test for ~500 days

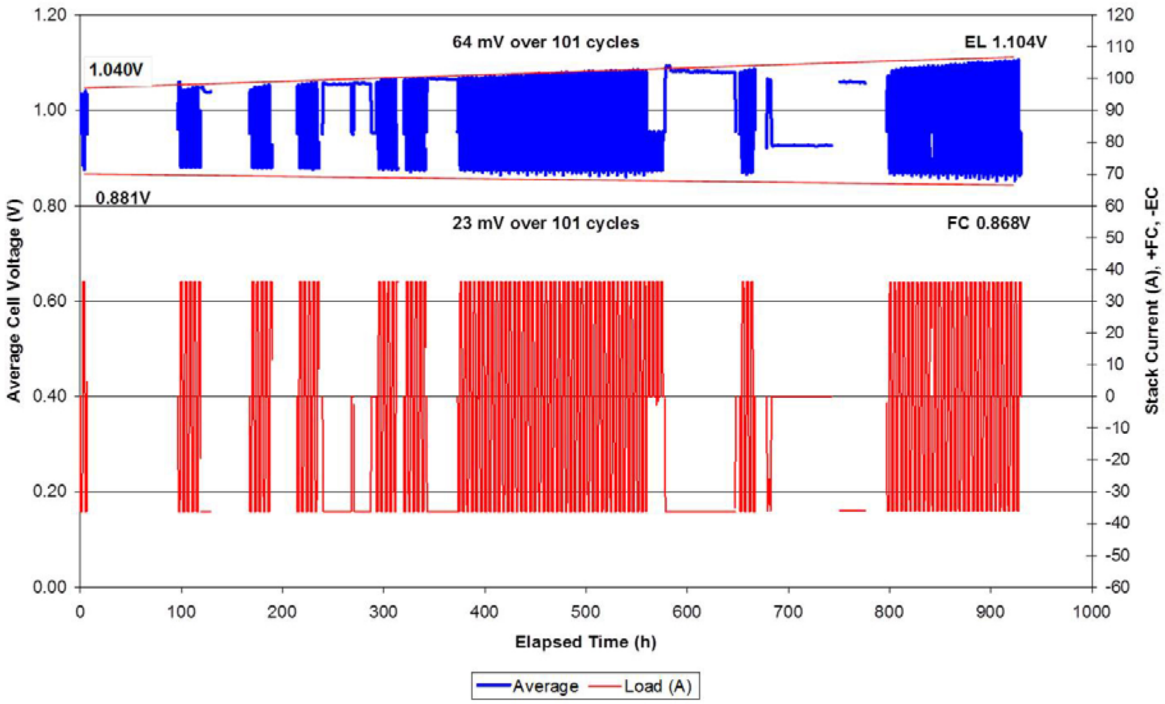

FIGURE 4. SOFC/SOEC cyclic test of a kW-class stack with RSOFC-7 cells

Conclusions and Future Directions

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

1. Continuation of the RSOFC cell and stack development and testing
2. Complete the end-of-the-project kW-class RSOFC stack metric test

FY 2012 Publications/Presentations

1. An oral presentation for this effort was made at the 2012 DOE Hydrogen and Vehicle Technologies Programs Annual Merit Review and Peer Evaluation Meeting.

References

1. DOE EERE Multi-Year Research, Development and Demonstration Plan, Page 3.1-7 (2007).

2. J. Guan et al., High Performance Flexible Reversible Solid Oxide Fuel Cell, Final Technical Report, DOE DE-FC36-04GO14351.