II.B.8 Multi-Scale Ordered Cell Structure for Cost Effective Production of Hydrogen by HTWS

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Contract Number: DE-EE0007645

Subcontractors:
- Palo Alto Research Center, Palo Alto, CA
- Gaia Energy Research Institute LLC, Arlington, VA

Project Start Date: October 1, 2016
Project End Date: September 30, 2019

Overall Objectives

- Develop and test advanced high temperature water splitting (HTWS) stacks to demonstrate pathways to hydrogen production cost goal of <$2/kg.
- Demonstrate ability to operate on intermittent renewable energy as the input.

Fiscal Year (FY) 2017 Objectives

- Fabricate structured button cells.
- Demonstrate button cell area specific resistance of ≤0.4 ohm-cm^2.

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

(I) Grid Electricity Emissions

(J) Renewable Electricity Generation Integration

Technical Targets

This project is developing a novel architecture for HTWS cells. Development and testing of stacks will be conducted using cells with the structured design to meet the following DOE hydrogen production targets for HTWS.

- Area Specific Resistance ≤0.3 ohm-cm^2
- Operating Voltage 1.2 V (endothermic)
- Operating Temperature ≤800°C
- Electrical Efficiency >95% lower heating value H_2
- Degradation Rate <0.5%/1,000 h
- Levelized Cost of H_2 Production $2/kg
- H_2 Delivery Pressure Capability

FY 2017 Accomplishments

- Baseline electrolyte and electrode compositions are finalized.
- Thick electrolyte-based button cell tests show that total electrode polarization losses are within 10% to the target 0.2 ohm-cm^2.
- Button cell stability of ~1% current density degradation per 1,000 h at 1.2 V.

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INTRODUCTION

High temperature water splitting process efficiently produces hydrogen from steam using electric energy. In order to achieve commercial cost target for hydrogen production, the performance of the device must be improved and the hydrogen production must remain stable during the device life time. This project will demonstrate high performance and high efficiency hydrogen production by the use of a novel structured cells that increases the production capacity of the device. By judicious choice of materials, the device performance will show minimal degradation during its lifetime. The combination of these two advances will allow the device to consume less electrical energy which will favor low cost hydrogen production.

APPROACH

The project will implement approaches to address the limitations of current HTWS technology through the use of a novel cell design that introduces macro-features to provide mechanical support of a thin electrolyte and micro-features of the electrodes to decrease electrode losses. The set of features will enable a high performance stack that is robust to handle intermittent electric load. The materials set that would be used for cell and stack fabrication will provide operational stability to decrease levelized hydrogen production cost. The approach also utilizes a combination of fabrication options that are scalable to achieve manufacturing cost objectives.

RESULTS

A novel cell structure has been designed to address the challenges of current cell design. A schematic of the structure is shown in Figure 1. The cell design incorporates a multi-scale ordered structure to improve cell performance. A thin, high conductivity electrolyte provides low electrical resistance to increase cell performance. In contrast to current state-of-the-art cell design where fuel electrode constitutes the mechanical support for the cell, a macro-featured honeycomb support is used on the oxygen electrode side. By the use of thin hydrogen electrodes, the steam diffusion limitations of fuel support are decreased. The hydrogen electrode features an ordered structure of differing materials compositions to provide a high reaction zone area where steam is reduced to produce hydrogen.

Improvements in cell lifetime is targeted through the use of thermochemically stable electrodes. For the oxygen electrode, a composition with stable dopant chemistry is selected. The composition is shown to provide stable electrode/electrolyte interface to eliminate electrode delamination on the oxygen evolution interface. A 1,000 h test of a symmetric cell tested at the target current density of 1 A/cm^2 showed no evidence of delamination as shown in Figure 2.

Electrode polarizations were studied using symmetric cells and full button cells using thick electrolyte cells in order to verify the selected compositions. Impedance measurements using reference electrodes were made to isolate contributions from anode and cathode. Typical average anode and cathode polarization values are shown in Figure 3. The combined electrode contribution averaged at about 0.2 ohm-cm^2 close to the target value for FY 2017.

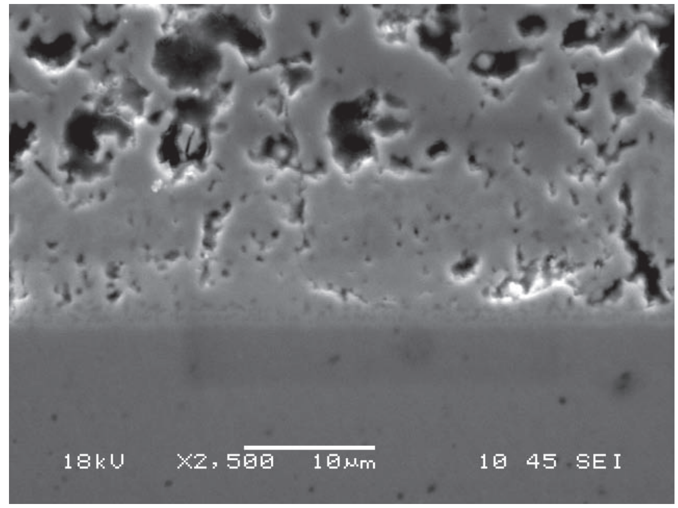


FIGURE 2. Scanning electron micrograph of delamination resistant oxygen electrode

Several button cells were tested to evaluate performance at various operating voltages (1.3 and 1.2 V) and steam conversion ranging from 10% to 60%. Cells were operated for typically 1,000 h under constant applied voltage to study the degradation. Cell performance degradation of 1% per 1,000 h is achieved at 1.2 V. The performance of a button cell is shown in Figure 4. The cell was tested for 1,000 h under varying loads and steam utilizations. The final 1,000 h performance at a specified operation is shown.

Palo Alto Research Center completed ink formulation for electrode and support structure printing evaluation. Printing trials of hydrogen electrode features and oxygen electrode support are in progress (Figure 5).

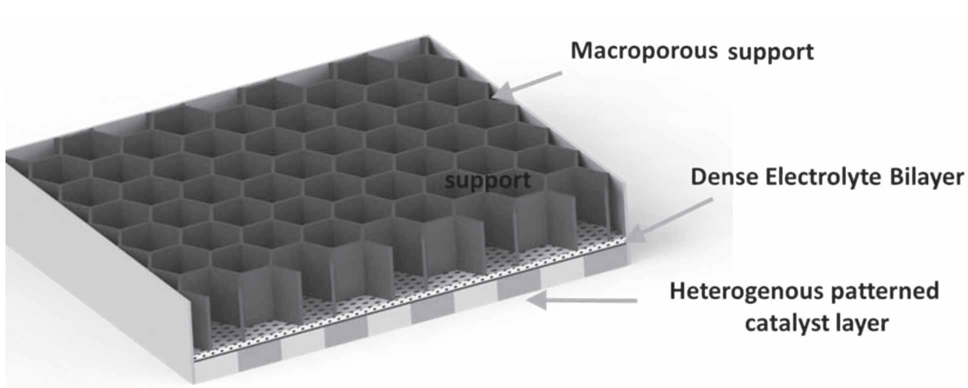
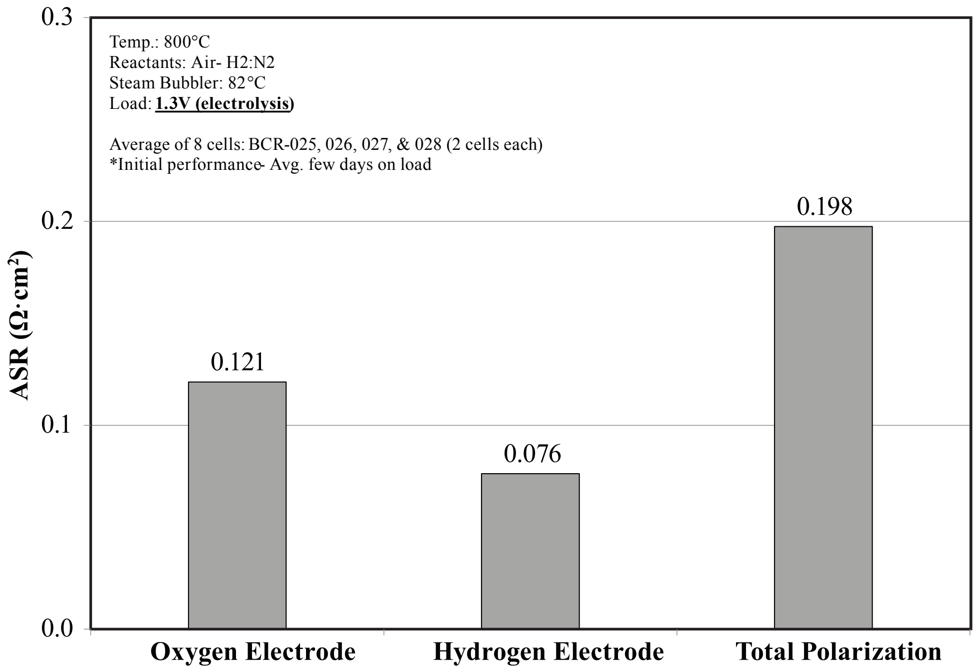


FIGURE 1. Schematic of ordered cell structure



ASR – area specific resistance

FIGURE 3. Electrode polarization resistance

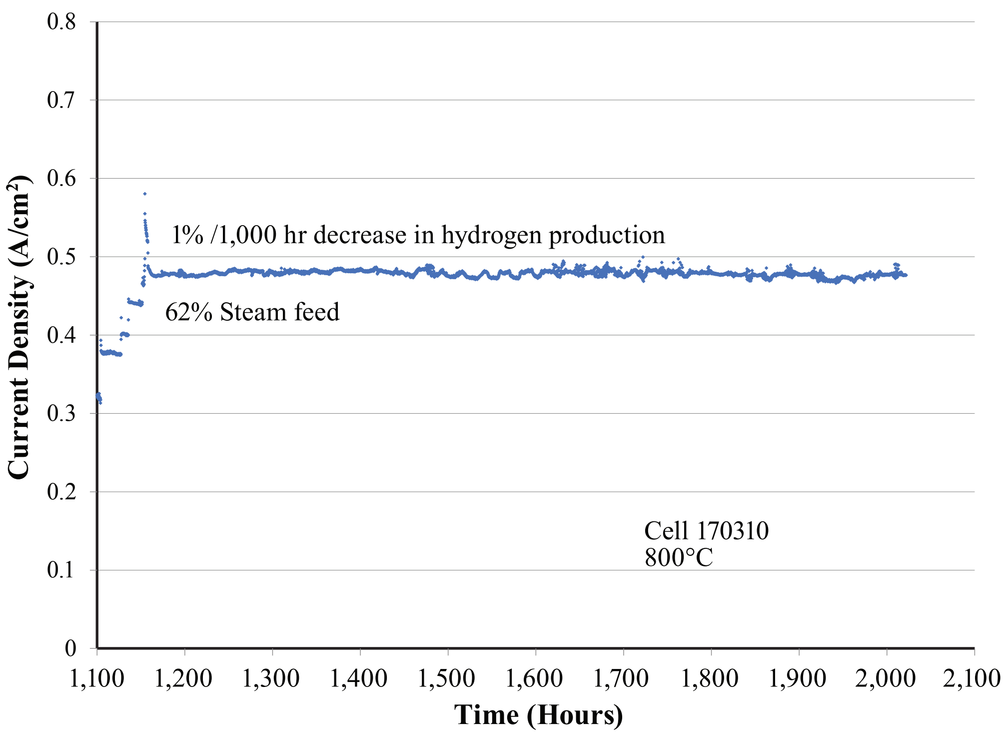


FIGURE 4. Button cell performance

(a)

(b)

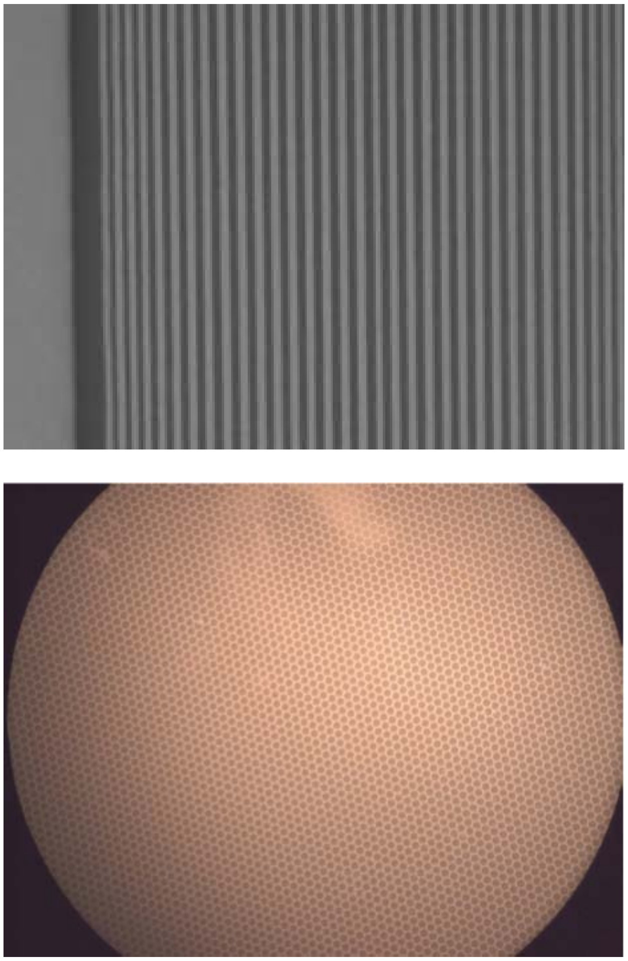


FIGURE 5. Fabrication trials of electrode features: (a) patterned fuel electrode, (b) honeycomb oxygen electrode support

CONCLUSIONS AND UPCOMING ACTIVITIES

Work conducted to date shows that the electrode compositions selected are suitable for achieving target cell performance with the structured cell. Electrode compositions also show long term stability that is indicative of their potential to meet the overall objective of levelized hydrogen production cost.

During the remainder of the project, button cells with the featured electrodes will be fabricated and tested to validate the concept to achieve high performance, robustness, and durability. Following fabrication process optimization, larger cells will be fabricated to validate stack performance to meet the end of project goal of testing a stack that is capable of 1 kg/d of hydrogen production.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Hartvigsen, Joseph J., "Sustainable Transportation Fuels as a Store of Nuclear and Renewable Energy," Johns Hopkins University, Washington D.C., November 17, 2017.

2. Colella, Whitney G., "Advanced High Temperature Water Electrolysis and Competing Hydrogen Generation Technologies," American Institute of Chemical Engineers (AICHE) 2017 Spring Meeting and 13th Global Congress on Process Safety, San Antonio, TX, March 26–30, 2017.

3. Elangovan, S., "Solid Oxide Technology: Materials and Operational Challenges," Plenary Lecture, 13th International Conference on Catalysis in Membrane Reactors, Houston, TX, July 10–13, 2017.

4. J. Hartvigsen, S. Elangovan, J. Elwell, and L. Frost, "High temperature electrolysis performance maps and extension to techno-economic analysis for hydrogen cost optimization," World Hydrogen Technology Convention, Prague, Czech Republic, July 9–12, 2017.

5. J. Hartvigsen, S. Elangovan, J. Elwell, and L. Frost, "Synthetic fuels as a store of renewable energy enabled by co-production of H2 and CO in a SOEC system," World Hydrogen Technology Convention, Prague, Czech Republic, July 9–12, 2017.

6. Colella, Whitney G., "Life Cycle and Techno-Economic Analysis of State-of-the-Art Solid Oxide Electrolyzer Systems," Fifteenth International Symposium on Solid Oxide Fuel Cells (SOFC-XV), Hollywood, FL, July 23–28, 2017.