II.A.3 High-Performance, Low-Cost Hydrogen Generation from Renewable Energy

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Subcontractors:
- Entegris, Inc., Chaska, MN
- The Electrochemical Engine Center at Penn State, University Park, PA
- Oak Ridge National Laboratory, Oak Ridge, TN

Project Start Date: September 1, 2009
Project End Date: September 30, 2013

Overall Objectives

- Improve electrolyzer cell stack manufacturability through:
  - Consolidation of components
  - Incorporation of alternative materials and manufacturing methods
  - Improved electrical efficiency
- Reduce cost in electrode fabrication through:
  - Reduction in precious metal content
  - Alternative catalyst application methods
- Design scale up for economy of scale including:
  - Scale up of the design to a large active area cell stack platform
  - Development and demonstration of a robust manufacturing process for high volume plate production
- Quantification of the impact of these design changes via the H2A model.

Fiscal Year (FY) 2013 Objectives

- Verify low-cost manufacturing processes
  - Capability to meet dimensions
  - Structural testing
- Perform operational testing and stack scale up
- Develop manufacturing process (to scale) and qualify production level parts

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

Technical Targets

The technical targets are presented in Table 1.

TABLE 1. Proton Energy Systems Progress Towards Meeting Technical Targets for Distributed Water Electrolysis Hydrogen Production

Characteristics	Units	2012 Target	2017 Target	Proton Status
Hydrogen Cost	$/gge	<3.70	<3.00	3.46
Electrolyzer Capital Cost	$/gge	0.70	0.30	0.64
Electrolyzer Energy Efficiency	% (LHV)	69	74	67

gge - gasoline gallon equivalent; LHV - lower heating value
Note: Estimates are based on H2A v2.1, for electrolysis only (compression-storage-delivery not included). Model assumes $0.05/kWh.
Electrolyzer cost based on 1,500 kg/day capacity, 500 units/year; efficiency based on system projections, technology which could be implemented within five years, and demonstrated stack efficiency of 74% LHV efficiency.

Advanced Bipolar Plate Manufacture and Cell Stack Scale Up

This project is bringing low-cost bipolar plate technology to production implementation. Two stack designs will be completed to leverage these advancements, with the following targets:

- Cost reduction of baseline stack: 40%
- Scale up to >5 times active area
- Additional 40% cost reduction based on scale

FY 2013 Accomplishments

- Implemented intermediate treatment process for 50% improved embrittlement resistance (cost share)
- Production scale stack at 0.1 ft^2 level demonstrated to >5,000 hours with advanced coatings which provide >99% reduction in hydrogen uptake
- Scale up and validation of advanced stack design to >500 cm^2 active area
  - Completed mechanical stress and flow modeling
  - Pilot run of >50 parts
- Demonstrated single cell prototype operation at large active area
- Production tooling ordered for large active area parts

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INTRODUCTION

This project addresses the DOE Hydrogen Program objective for distributed production of hydrogen from proton exchange membrane water electrolysis. The DOE technical targets for hydrogen cost as well as electrolyzer efficiency and capital cost will be directly addressed through the advancement of key components and design parameters. When added together, the bipolar assemblies and membrane electrode assemblies (MEAs) constitute over half of the total cell stack cost. Significant cost reductions of these components are required in order to reach the targets. This project focuses on cost reduction of the bipolar assembly through improved design and manufacturing methods, as well as scale up. Additional feasibility work was conducted on cost-reduced MEA configurations and transitioned to other projects, as described other summary reports.

The efforts of the last year culminated in the build of a >0.6 ft^2 prototype stack utilizing the selected materials, coatings and manufacturing methods for the bipolar assembly. This achievement was based on extensive modeling of mechanical stress and fluid flow in the proposed part design as well as collaboration with the supplier. Cost reductions for the new design vs. the legacy design at the same active area as well as for scale up were documented. Additional subscale stacks will be built and tested as part of the design validation effort. The scaled-up stack will form the basis for megawatt scale electrolysis systems.

APPROACH

The scope of work for this project allowed for research and development in several key areas relating to cell stack cost reduction. Topics included 1) catalyst formulation, 2) flow field design and materials, 3) computational performance modeling, and 4) flow field coating development.

Advancements in flow field design are intended to be advantageous for low-cost, high-volume manufacturing. Alternatives to the current flow field design included either 1) composite bipolar plates or 2) unitized flow fields, which consolidate parts and reduce the amount of required precious metal plating. The early investigations into the cost and manufacturability of the various design alternatives resulted in a final down-select to a unitized flow field. This approach integrated the function of several components into a single low-cost component, which also reduced the assembly labor. Computational modeling of an electrolyzer cell will allow for optimization studies to be performed around flow field material and architecture. Cell performance can be quantified in ways not typically possible with standard physical test experiments. Alternate coating strategies are also being investigated which eliminate metal plating. Validation of all of the previously mentioned design changes will be achieved through cost analysis based on the H2A model.

RESULTS

Accelerated hydrogen uptake experiments and analysis of residual stress were continued at Oak Ridge National Laboratory as a function of process steps and order of operation (Figure 1). While the long-term goal is to implement alternative coatings for cost reduction, the analysis also showed the potential for near-term improvements based on process order. Residual stress was significantly reduced depending on the current steps used to treat the plate. Based on these results, Proton leveraged non-federal funding to implement these near-term improvements. In parallel, continued validation of various nitride coatings continued. Minor loss of the coating is observed in the water channels, but the layer contacting the MEA appears

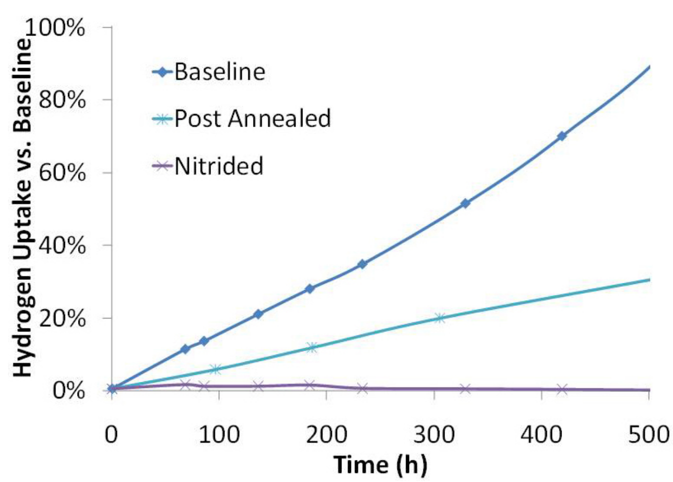

FIGURE 1. Accelerated H_2 Uptake as a Function of Surface Treatment

stable, and over 10,000 hours of performance have been demonstrated with no change in voltage. With these advanced coatings, no detectable hydrogen uptake is observed even after hundreds of hours on the accelerated uptake test. Initial plans to move forward with implementation at smaller stack sizes are underway.

For the plate design, based on the initial success and 5,000 hour validation run for the prototype stack, scale up in cell count was performed to a commercially relevant level. The first stack was disassembled to analyze the coatings discussed above. The second stack has also operated for several thousand hours and continues to operate (Figure 2). Based on these builds and quotes for parts at the 100-1000 piece level, the cost reduction of 40% vs. the baseline stack was validated, even for low production volumes. A key advantage of the manufacturing approaches chosen were the relatively low tooling costs, allowing rapid payback on the design and fewer stacks required to amortize any required design changes.

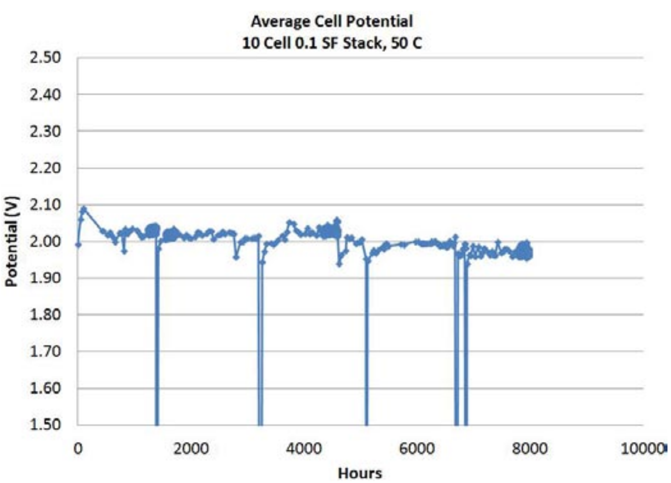

FIGURE 2. Operational Data (Average Cell Voltage), Commercial Scale Cell Stack

Detailed design work was also continued for the large active area version of the new stack design. This format required re-design of the flow features to avoid warping of the part during manufacture due to long, narrow features. A novel solution was developed to add tortuosity to the flow field while providing exceptional flow distribution. Computational fluid dynamics (CFD) modeling was performed to simulate fluid flow on the oxygen-water side of the cell to insure acceptable water distribution across the MEA. Design refinement was then performed for the large active area stack, which resulted in enabling a 15% increase in the active area vs. the original design intent, while maintaining equivalent cost reductions. Design tasks included finite element analysis of critical load-bearing components such as flow fields, frames, and endplates, as well as additional CFD analysis on sensitivity to flow rate variations at the cell level and the impact of cell count in the stack to fluid flow for each cell (Figure 3). Manufacturing considerations such as orienting features for improved registration and error-proofing during assembly were also included.

Design verification included load testing of individual parts as received to check for deformation under the design loads, and hydrostatic testing of the assembled cell configuration to verify sealing capability. Flow testing was also performed to verify the results of the CFD single-cell modeling. Once this testing was completed, final tooling was ordered and a production level run of the plates was performed. Acceptance test procedures were drafted based on similarity to existing cell stacks, including short testing, gas permeation testing, and cell resistance measurements. A single-cell stack was assembled and tested (Figure 4). The stack passed the initial acceptance test procedures and successfully operated within the expected cell voltage range. A multi-cell stack will replace this stack once an acceptable amount of run time has been achieved (1,000 hours) and the single cell stack disassembled for analysis.

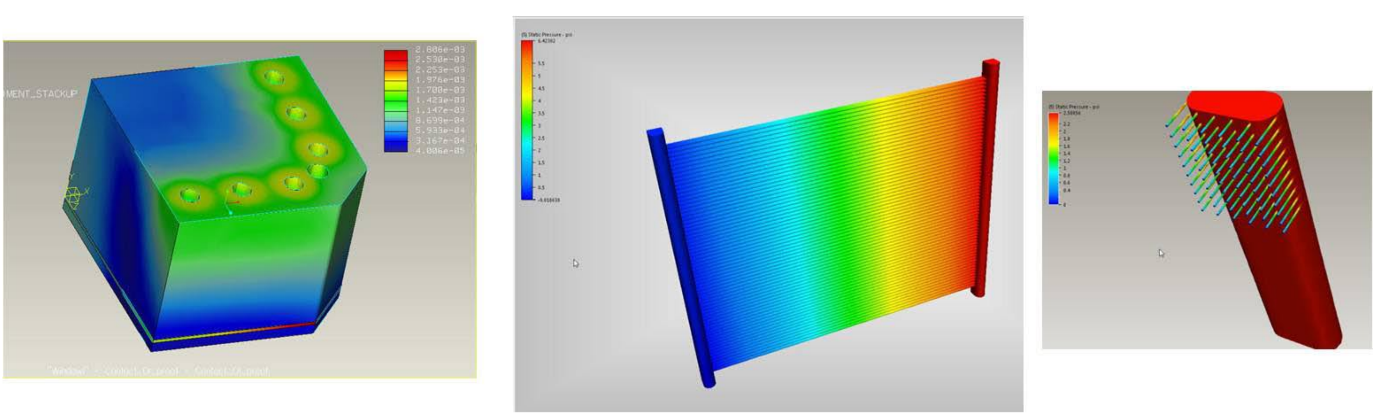

FIGURE 3. Single Cell Stack Performance, Large Active Area Stack

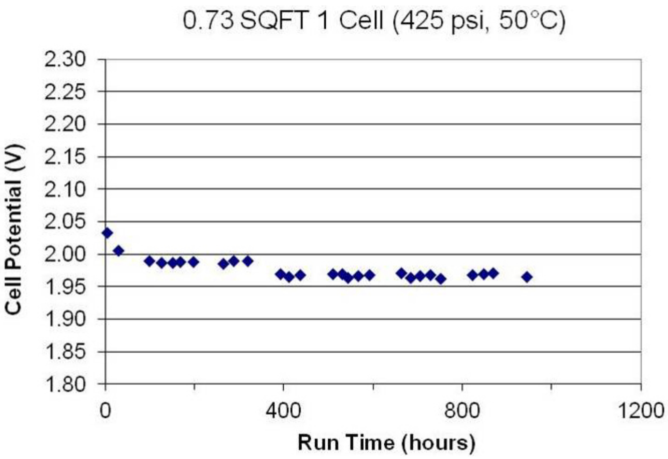

FIGURE 4. Single-Cell Stack Test

CONCLUSIONS AND FUTURE DIRECTIONS

- Initial single-cell testing has been verified at commercially relevant stack heights. Single- and multi-cell stacks have been operated for thousands of hours. Part costs for these stacks validate the 40% cost reduction target vs. the original project baseline.
- Detailed design work and modeling was completed on the large active area stack. Analysis of form factors and design limits enabled a 15% increase in active area vs. the original design intent.
- Initial testing on prototype parts for the large active area stack have matched the modeling results and electrolysis was demonstrated at 430 psi. Cost analysis for the large active area stack also validates the 40% cost reduction for this stack platform. The stack scale up contributes approximately an additional 40% in $/kg vs. the smaller active area stack.
- Alternative coatings and processes are being qualified for production vs. the baseline plate treatment. These processes have been demonstrated to reduce hydrogen uptake while providing consistent voltage performance.
- For the remainder of the project, the next step in scale up of stack count will be performed for the large active area stack. This stack will be tested in a system capable of full scale stack testing. Additional work will be performed through internal funding to release the stack to production manufacture. A final cost analysis will be provided with the final report.

FY 2013 PUBLICATIONS/PRESENTATIONS

Presentations

1. "Fueling Vehicles from Sun and Water", Fall ECS meeting, Honolulu, October 2012.

2. "Bridging the Infrastructure Gap: Cost Effective Generation of Hydrogen from Water", Department Seminar, Colorado School of Mines, November 2012.

3. "Material Advancements for Cost Effective Hydrogen Energy Storage: Megawatt Electrolysis Development", Spring ACS Meeting, Esther Takeuchi Award Symposium, New Orleans, April 2013.

4. "Development of Megawatt Scale PEM Electrolysis: A Culmination of Cell Design and System Advancements", Spring ECS Meeting, Toronto, Canada, May 2013.