II.D.2 High Performance, Low Cost Hydrogen Generation from Renewable Energy

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Contract Number: DE-EE000276

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

Fiscal Year (FY) 2012 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.

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:

(G) Capital Cost
(H) System Efficiency
(J) Renewable Electricity Generation Integration

Technical Targets

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 and demonstrated stack efficiency of 74% LHV efficiency

FY 2012 Accomplishments

- Over 3,000 cells utilizing the new flow field design resulting in >20% part cost savings (12% stack cost savings) have been fabricated and assembled into production stacks.
- Composite bipolar plates from Entegris exhibited stability over >3,000 hours of operation.
- Alternative flow field manufacturing methods were validated and an additional 50% cost reduction in the subassembly was realized for an overall stack cost reduction of 40% vs the 2008 baseline.
- Penn State comprehensive electrolyzer cell model was utilized to characterize updated flow field geometry.
- Achieved >5,000 hrs of stable performance with a 3-cell prototype stack utilizing alternate electrode structures and new flow field components.
- Nitrided separators showing stable in cell performance at >5,000 hrs.
- Initiated design effort to scale up existing 0.1 ft^2 stack up to 0.6 ft^2.

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Introduction

This project addresses the DOE Hydrogen and Fuel Cells Program objective for distributed production of hydrogen from proton exchange membrane (PEM) 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 as demonstrated with this research are required in order to reach the targets. Further optimization of cell stack components results in efficiency gains at the system level and ultimately a reduction in the cost to produce hydrogen. The efforts of the last year culminated in the build of a 0.1 ft^2 prototype stack utilizing the selected materials, coatings and manufacturing methods for the bipolar assembly. The prototype 0.1 ft^2 cell stack design has operated with stable performance for >5,000 hrs (Figure 1). Based on the performance of the prototype stack, and the projected cost savings of this cell stack architecture, the decision was made to scale this architecture up to 0.6 ft^2. Lessons learned during the prototype design and build will be leveraged during the scale up design activity.

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.

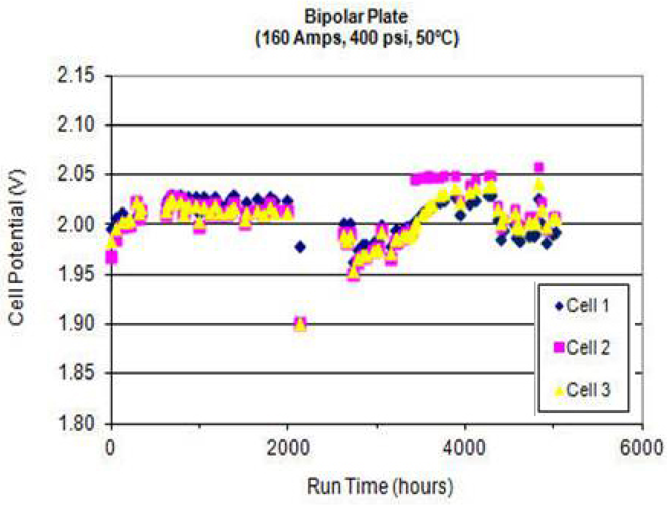

FIGURE 1. Voltage Trend for Composite Bipolar Assembly

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

The comprehensive computational model of an electrolyzer cell developed at Penn State was previously shown to be capable of predicting performance parameters based on the geometry of the flow fields and specified operating conditions. Learnings from this model were used for refinement of the updated flow field geometry for improved water flow distribution within the cell and better thermal management.

The down-selected design from the manufacturing study was utilized to make prototype parts and were inspected according to print before assembly into a 0.1 ft^2 test stack. The stack passed all acceptance testing protocol and performance resulted in passing of the Go/No-Go review for the first phase of the project, kicking off the 0.6 ft^2 scale up design task and the build of a full-scale prototype production stack of the 0.1 ft^2 design. Previous work also demonstrated a 55% reduction in the amount of precious metal used in the anode catalyst layers of the MEA. The application technique represents an improvement over existing production techniques in that it allows for improved registration and uniformity while also enabling higher speed throughput. The 0.1 ft^2 prototype stack was fabricated utilizing the reduced anode catalyst fabrication method.

Nitriding was studied extensively during this period to protect the part from oxidative corrosion and hydrogen embrittlement. Performance of a variety of nitrided parts was evaluated for resistance to H_2 uptake, corrosion resistance, and performance under electrolysis conditions (Figure 2). Additionally, a comprehensive examination of Ti residual stress levels and the effect on H_2 uptake is in progress. Characterization at Oak Ridge National Laboratory (ORNL) showed that samples maintained similar thicknesses of the nitrided layer after electrolysis operation. Thermal nitriding

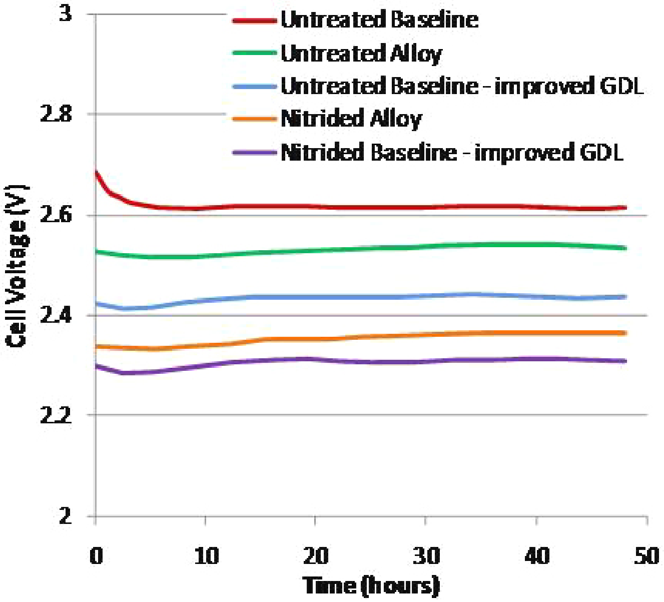

FIGURE 2. Performance of Surface Coatings vs. Untreated Flow Field Material

was also explored at ORNL and samples were tested for 500 hours in the electrolysis environment without evidence of corrosion. These results validate the potential for multiple options for plate fabrication and coating while eliminating noble metal coatings or plating. Commercial suppliers of thermal nitride coatings have been identified and evaluations were initiated. Sample thermally nitrided parts have been manufactured and initial prototype parts were analyzed at ORNL (Figure 3). Some discoloration has been observed on operated nitrided parts and this behavior has recently become a focus of investigation. ORNL is playing a key role in understanding and characterizing the nitride coatings. Selected samples have been examined after longer operating times to determine overall life based on any signs of corrosion or material degradation.

The overall reduction in cell stack cost was calculated from the bill of materials for the existing 0.6 ft^2 design, currently in pre-production, and quotations for the modified parts. Figure 4 shows the eliminated cost for the new design. The numbers are very consistent with the 0.1 ft^2 design, which showed an actual cost reduction of 44%. Using the H2A model, this capital cost savings translates to an overall cell stack capital cost of less than $0.50/kg for the new large format design. Combined with Proton's parallel efforts in efficiency improvements and system scale up, the cost status for hydrogen production based on the H2A model is $3.64/kg, at an electricity cost of $0.05/kWh.

Conclusions and Future Directions

- Initial cost reductions on the cathode flow field are successfully being produced and fielded in commercial cell stacks.
- Ongoing tests have shown that alternative conductive materials can remain stable in the corrosive environment of operational electrolyzer cells for tests over

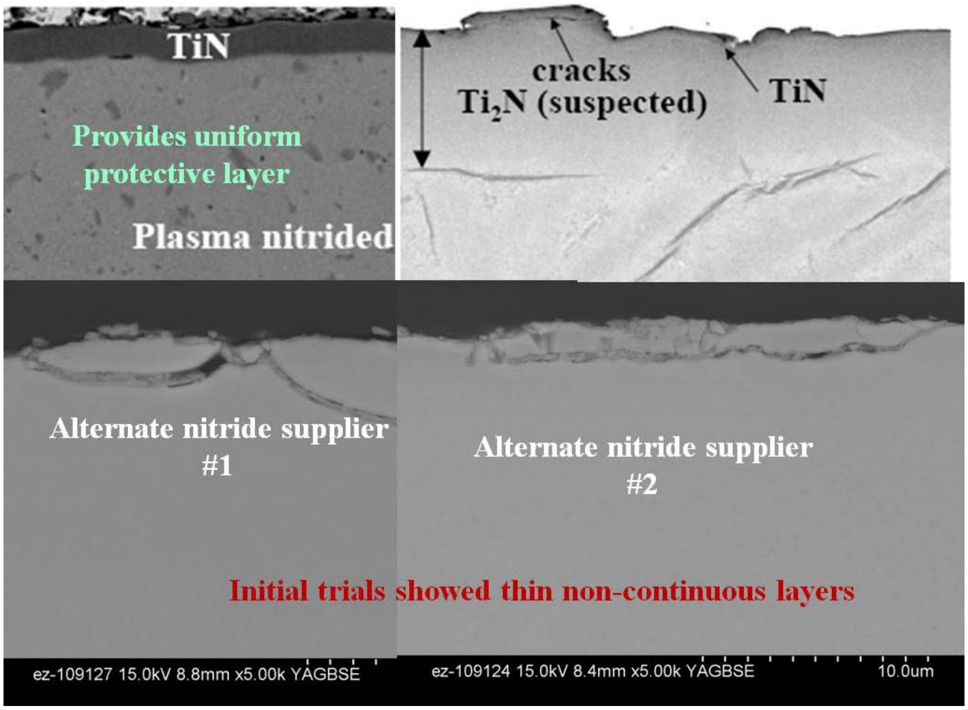

FIGURE 3. Image of Nitrided Part and Analysis of Composition vs. Layer Depth and Operation

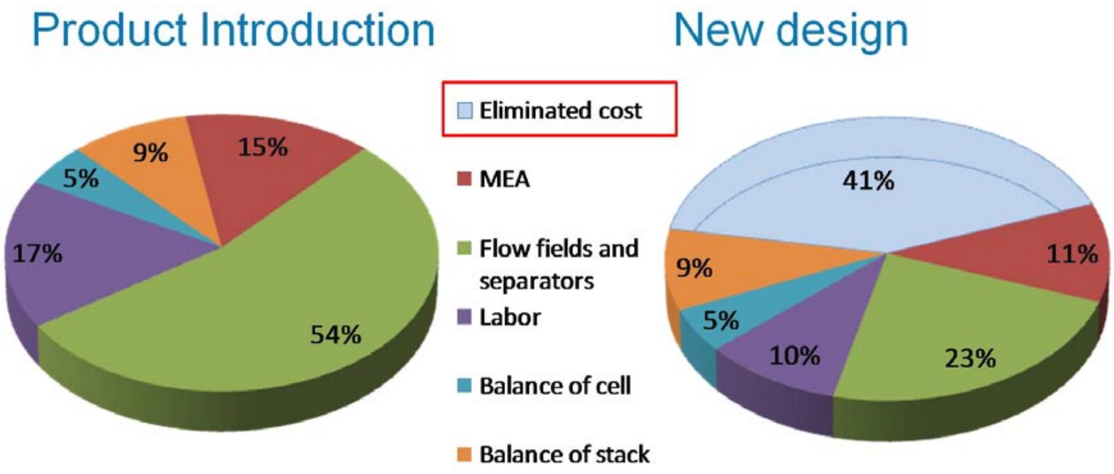

FIGURE 4. Large Format Cell Stack Cost Reduction Based on New Design

5,000 hours. Further analysis is required to determine durability projections and progress towards the 50,000 hour minimum operational life of Proton cell stacks, but no obvious degradation has been observed. A component manufactured from this alternate material was utilized in the 0.1 ft^2 prototype stack.

- A unitized flow field plus frame assembly was selected as the path to the consolidated bipolar plate assembly, with initial predictions of over 50% part cost reduction being attained. This unitized flow field will be implemented in the 0.6 ft^2 design.
- Electrolyzer cell performance can be predicted with the use of a comprehensive computational model and flow distribution across the bipolar assembly can be modeled to provide valuable insights on design and flow requirements. The Penn State model will be utilized to guide any changes to the flow field geometry of the 0.6 ft^2 scaled up design.
- Nitride coatings fabricated by different methods appear to be very stable in electrolysis conditions and may enable reduction in metal coatings. Further process development will be performed to determine the best approach for manufacturability. Qualification of an alternate lower cost nitriding process is currently in progress.

Special Recognitions

1. Hydrogen and Fuel Cells Program Sub-Program Award, for outstanding technical contributions in Hydrogen Production, presented at Annual Merit Review, May 14–18, 2012.