

## II.E.2 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

(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 2011 Accomplishments

- Alternate electrode structures enabled 55% less precious metal on the anode (Proton process) and >90% less on the cathode (3M nano-structured thin-film [NSTF] structures).
- A new flow field design resulting in >20% part cost savings (12% stack cost savings) passed production validation and was commercially released.
- Composite bipolar plates from Entegris exhibited stability over >3,000 hours of operation.
- Alternative flow field manufacturing methods were surveyed and a path to additional 50% cost reduction in the subassembly was defined.
- Penn State comprehensive electrolyzer cell model was validated against physical test data and is being leveraged for cell characterization.
- Nitride coatings on flow fields and separators from Entegris, Proton, and Oak Ridge were characterized before and after cell operation and found to remain intact on surface after >500 hours.



### Introduction

This project addresses the DOE Hydrogen 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.

### Fiscal Year (FY) 2011 Project 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 through utilization of 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:

Currently, a significant portion of the electrolyzer system capital cost comes from the cell stack(s). When added together, the flow fields and membrane electrode assemblies (MEAs) constitute over half of the total cell stack cost (Figure 1). 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.

### 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, 3) computational performance modeling, and 4) flow field coating development. Higher efficiency oxygen evolution catalysts are of interest because the oxygen evolution reaction is inefficient and therefore requires high catalyst loadings to achieve reasonable operational voltages at the desired current densities. Improving catalyst utilization can substantially reduce the cost of the MEA by reducing the noble metal content in the catalyst layers. Novel electrode structures have been constructed using alternate synthesis and processing techniques and are being characterized for performance and durability.

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. A parallel path is being followed, utilizing the top candidate from each category. Material testing samples for the composite materials are under test for compatibility with the corrosive environment known to exist within operating electrolyzer cells. Prototype flow fields will be fabricated and tested to determine dimensional capability. 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 entirely. Validation of all of the previously mentioned design

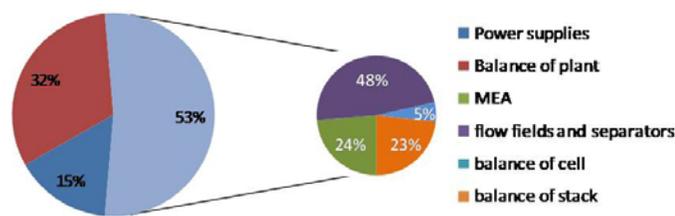


FIGURE 1. Relative Cost of Electrolyzer System Components

changes will be achieved through cost analysis based on the H2A model V2.1.

### Results

Significant advancements have been made in the development of an optimized catalyst formulation and application technique. This work has demonstrated a 55% reduction in the amount of precious metal used in the anode catalyst layers of the MEA vs. current commercial production. Durability testing showed no degradation over the duration of the test. The application technique represents an improvement over existing production techniques in that it allows for improved accuracy and uniformity while also enabling higher speed throughput. Work with 3M has also shown feasibility of greater than 90% reduction in catalyst loading vs. current commercial production on the cathode side of the cell utilizing 3M’s NSTF electrodes. Even with 15% higher membrane thickness, the reduced loading cathodes demonstrated roughly equivalent performance to a Proton baseline (Figure 2), and durability was demonstrated to over 3,500 hours. A non-proprietary test cell was also qualified and shared with collaborators for increased throughput and cost sharing.

Near-term electrolyzer stack cost reductions of 12% vs. Proton’s 2010 commercial product were identified through the testing and validation of non-metal cathode flow field components. The new part was implemented in Proton’s commercial product, with thousands of cells manufactured to date.

Composite bipolar plates which enable substantial further reduction in metal content were procured and have been on test for over 3,000 hours without significant voltage decay (Figure 3). Samples were nitrided to protect the part from oxidative corrosion and hydrogen embrittlement. Selected samples will be examined after longer operating times to predict overall life based on any signs of corrosion

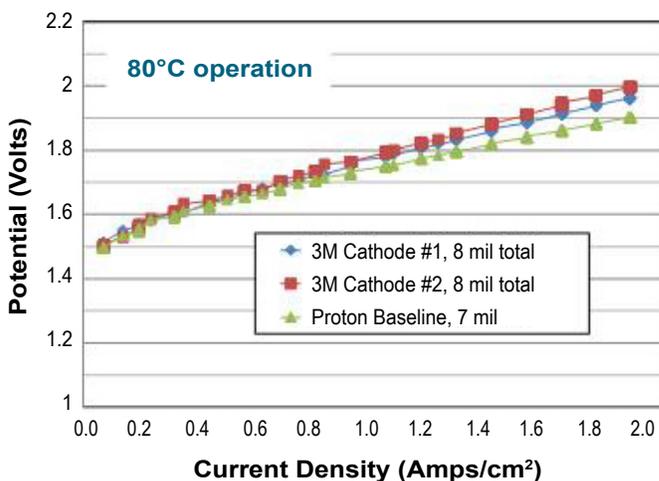


FIGURE 2. Performance of NSTF Electrodes as Electrolysis Cathodes

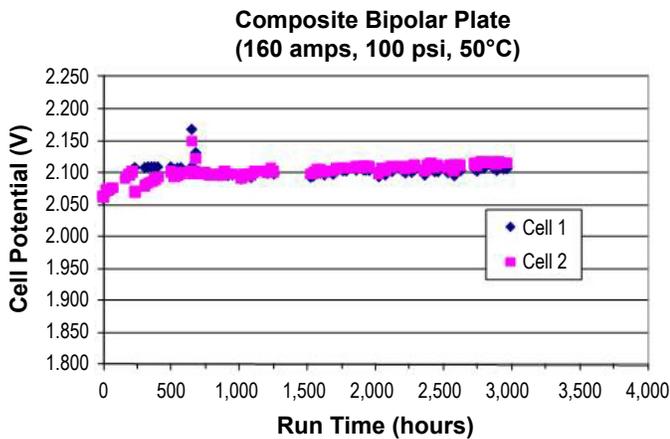


FIGURE 3. Voltage Trend for Composite Bipolar Assembly

or material degradation. A survey was also completed of over 30 bipolar assembly concepts, which showed opportunity for 50% cost savings in the subassembly over the production change already implemented. In addition to the composite plate, an alternate unitized part was selected for prototyping to verify cost and dimensional tolerancing.

The comprehensive computational model of an electrolyzer cell developed at Penn State was shown to be capable of predicting performance parameters based on the geometry of the flow fields and specified operating conditions. Calculated parameters included overall cell potential, distribution of potential and current density distribution, as well as volume fractions of water, oxygen and hydrogen in various regions of the cell. Predicted polarization curves were shown to be consistent with actual data. A parametric study was performed to flex the model variables. Learnings from this model will be used for refinement of cell component architecture for improved water distribution within the cell and better thermal management.

Nitriding was studied on both the composite parts as discussed above as well as metal parts. Characterization at Oak Ridge National Laboratory showed that both samples maintained similar thicknesses of the nitrided layer after electrolysis operation (Figure 4). Thermal nitriding was also explored at Oak Ridge 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.

### Conclusions and Future Directions

- Cost reductions can be made by controlling the catalyst formulation process and through advanced application techniques. Further work is needed to integrate the anode and cathode benefits realized in this project into a single MEA configuration.
- Initial cost reductions on the cathode flow field were successfully implemented in production.
- Tests have shown that alternative conductive materials can remain stable in the corrosive environment of operational electrolyzer cells for tests over 3,000 hours. Further analysis is required to determine durability projections and progress towards the 30,000 hour minimum operational life of Proton cell stacks, but no obvious degradation has been observed.
- A unitized flow field plus frame assembly has been selected as the parallel path to the composite bipolar plate, with initial predictions of over 50% part cost reduction.
- 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.

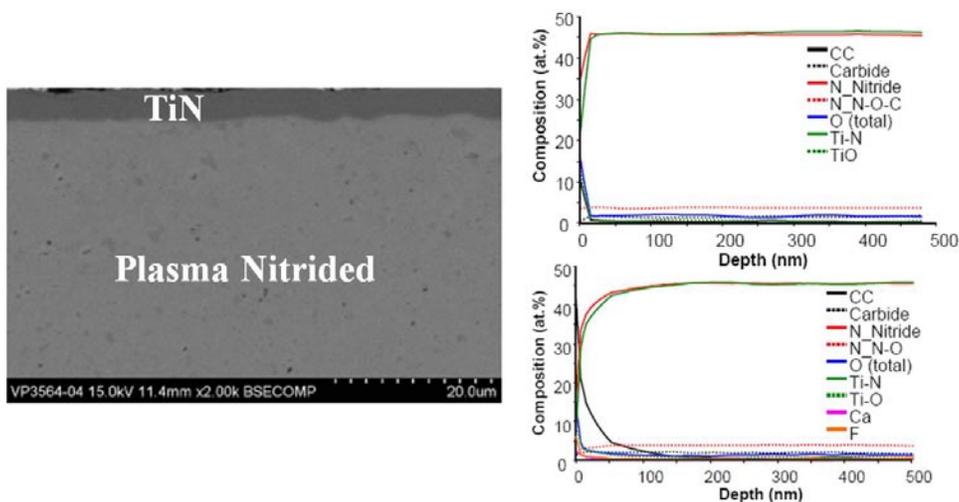


FIGURE 4. Image of Nitrided Part and Analysis of Composition vs. Layer Depth and Operation

- 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.