

II.B.2 Economical Production of Hydrogen through Development of Novel, High-Efficiency Electrocatalysts for Alkaline Membrane Electrolysis

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Subcontractor

Illinois Institute of Technology (IIT), Chicago, IL

Project Start Date: February 20, 2012 (Phase 1)

Project End Date: April 21, 2015 (with Phase 2 continuation)

- Develop a prototype system package with the option of incorporating carbonate in the electrolyte fluid stream and perform testing of up to 500 hours
- Provide a product cost analysis demonstrating the cost saving for the lab-scale generator and H₂A modeling for a large scale AEM electrolysis system

Fiscal Year (FY) 2014 Objectives

- Complete material assessment of alkaline compatible system/stack materials (cost and strength)
- Determine optimal electrode composition for increased durability
- Evaluate alternative cathode catalyst for AEM
- Complete cell stack fluid calculations to quantify maximum cell capacity of 28-cm² design
- Create computer-aided design models and assemble cost-reduced prototype AEM lab-scale electrolyzer
- Report elucidating fundamental degradation pathways in AEM as ascertained using two-dimensional nuclear magnetic resonance

Overall Objectives

- Determine how the composition (choice of A, B and A/B ratio) influences pyrochlore microstructure and physical properties
- Understand how the intrinsic activity of pyrochlore catalysts for the oxygen reduction/evolution reaction changes with composition and processing induced changes in microstructure
- Determine the impact of key anion exchange membrane (AEM) properties (conductivity, water uptake, gas crossover) on AEM performance
- Derivatize hydrocarbon or fluorocarbon backbones with basic cations to form new AEMs and characterize said AEMs for mechanical and electrochemical properties
- Select the electrolyte (deionized water or carbonate) based on understanding of the influence on ion conductivity and stability of the AEM in electrolysis conditions
- Process promising membrane and catalyst materials into membrane electrode assemblies/gas diffusion electrodes (MEAs/GDEs) and test in operational cells
- Down-select a final electrode configuration for the cell stack for durability testing

Technical Barriers

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

(G) Capital Cost

(H) System Efficiency

Technical Targets

TABLE 1. Proton OnSite Progress towards Meeting Technical Targets for Distributed Water Electrolysis Hydrogen Production

Characteristics	Units	2011 Status	2015 Target	2020 Target	Proton Status
Hydrogen Levelized Cost	\$/kg	4.2	3.9	2.3	3.46
Electrolyzer System Capital Cost	\$/kg	0.70	0.50	0.50	0.64
	\$/kW	430	300	300	
Stack Energy Efficiency	% (LHV)	74	76	77	67
	kWh/kg	45	44	43	

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 2014 Accomplishments

- System components procured, assembled, and functionally verified
- Prototype unit operational testing initiated
- Demonstrated improved operational stability through the introduction of carbonate into AEM system
- Completed cost and strength analysis of materials for cost reduction of alkaline system/stack
- Stack maximum cell count calculations completed



INTRODUCTION

The project aims to address some of the barriers associated with the strategic development of a hydrogen infrastructure. This is viewed as a major impediment to the wide spread deployment of hydrogen-fueled vehicles. All of the world's major automotive companies have hydrogen vehicle programs and are poised to roll out the next generation of vehicles, with plans that number in the thousands of units by 2015. Hydrogen is also an ideal storage medium for renewable energy and stationary power applications. However, economical and environmentally benign production and storage of hydrogen for energy markets remains a challenge. The project leverages anion exchange membranes, enabling elimination of the highest expense materials in the cell stack, while the new catalyst formulations provide higher efficiencies than existing state of the art. The project would culminate in a commercial fidelity prototype to demonstrate the cost improvements.

APPROACH

The project addresses both of the following issues by replacing the proton exchange membrane with an AEM and exploring new pyrochlore-based catalysts for oxygen evolution.

- The high capital expense associated with expensive catalysts and flow field materials of construction, required for the acidic environment associated with proton exchange membrane electrolyzers
- Improving operational efficiency, to reduce the \$/kg H₂

Moving to an anion exchange membrane platform enables flow fields made of lower cost nickel or stainless steel. In addition, the classes of catalyst materials which are stable in the alkaline membrane environment are expanded vs. the acid environment. This project will thus advance development of higher efficiency hydrogen and oxygen production at lower cost than existing electrolysis methods.

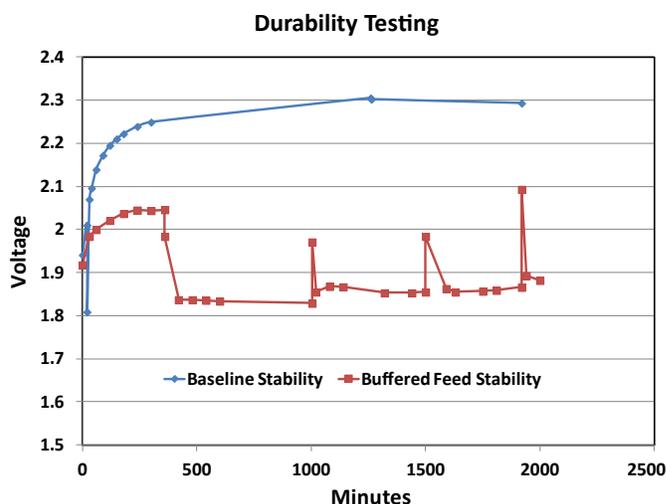


FIGURE 1. Improved Performance with the Introduction of Carbonate to the AEM System

The Phase 2 project has continued material exploration initiated in Phase 1, furthering the development of an optimized catalyst formulation based on the theory developed in Phase 1. The ionomer is also being tailored for stability in the electrolysis environment, leveraging added carbonate if necessary. Gas diffusion electrode configurations and manufacturing approaches have been explored, as a means to improve operational durability. A prototype system concept is being developed with manufacture pending as an initial step to commercialization, as well as cost validation and durability testing.

RESULTS

Building from initial Phase I studies, progress has been made towards scale up production of the non-noble metal catalyst being explored. This scale up in synthesis is critical in producing quantities large enough for full-scale cell stack testing from a single batch. Additionally, improvements in electrode performance were realized through the introduction of carbonate to the electrolyzer feed water. Cell potential was reduced through the use of carbonate, as shown in Figure 1. This is thought to improve durability as well.

Non-noble metal catalysts synthesized at IIT were operated in an electrochemical cell at Proton and demonstrated significantly improved efficiency over the baseline configuration. With the optimized composition, an ~8% gain in efficiency was calculated at 500 mA/cm² when using the LHV of hydrogen. This result is shown in Figure 2. Durability testing is being pursued through the incorporation of these catalyst powders with a variety of binders known to work well in proton exchange membrane systems, and through the pursuit of alternative deposition techniques, focused on creating both GDEs and catalyst-

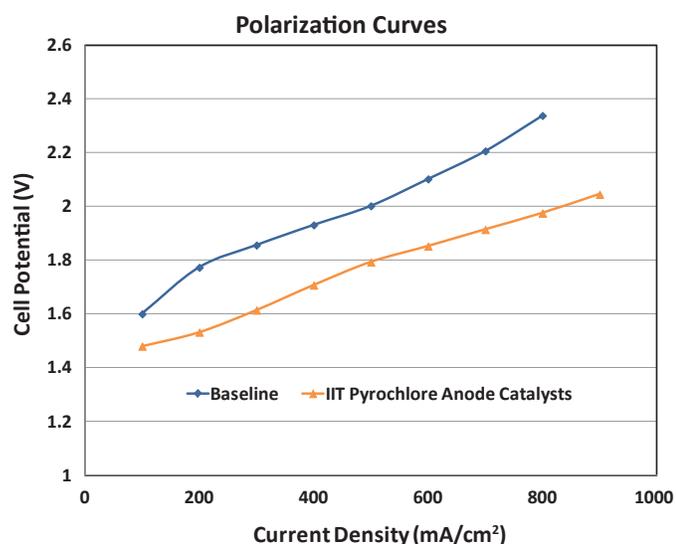


FIGURE 2. Performance of the IIT Pyrochlore Catalyst vs. Baseline

coated membranes. In addition to the development of a robust electrode, work at Proton has also been conducted on in-house synthesis of non-precious metal oxygen evolution catalysts. Work to date has not produced materials exceeding the performance of the IIT synthesized powders, but is being reviewed for possible iteration on the compositions to improve the activity.

System development has been initiated, with operational verification completed for the unit. Additional control capability is expected by August 2014, which will allow unattended durability testing of multi-cell configurations at various current densities. The electrochemical module is designed to be removable, so testing of specific configurations and materials can be switched without risk of cross-contamination of materials. The design of this system will also enable the generation of electrochemically pressurized hydrogen, up to 8 bar. This system prototype is

shown in Figure 3 during verification testing. Cell hardware has been manufactured at this scale, including the AEM MEA for planned durability testing.

CONCLUSIONS AND FUTURE DIRECTIONS

- Scale up to production type quantities demonstrated for non-noble metal catalysts:
 - Performance improvement shown with durability and repeatability tests on-going
- Operational testing of catalyst powders with alternative binder formulations in process:
 - Compositional testing of Proton synthesized powders in progress at MEA level
 - IIT catalysts evaluated and undergoing compositional optimization
- Electrode and stack scale up initiated:
 - Parts manufactured and assembled into Proton commercial cell stack
 - Bench testing initiated to verify stack integrity
- Initial prototype system assembled:
 - Removable electrolysis module tested
 - Additional balance of plant being integrated to add operational parameter control and gas drying
 - Conduct material analysis
 - Update with MEA electrical efficiencies and operational data as testing progresses, with capital and operating cost impacts reported.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. 2014 DOE AMR presentation: pd094_ayers_2014.

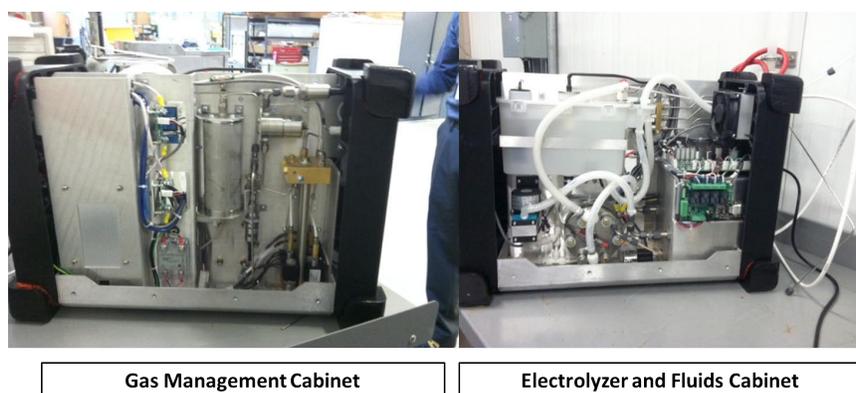


FIGURE 3. Full System being Evaluated for Durability Testing