

II.B.7 New Approaches to Improved PEM Electrolyzer Ion Exchange Membranes

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Proton OnSite, Wallingford, CT

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Project End Date: April 9, 2019

Overall Objectives

- Optimize electrolyzer membrane performance.
- Refine polymer and membrane and cell architecture to maximize durability.
- Down-select materials for optimization of membrane composite configuration.
- Scale-up and confirm cost estimates.
- Build the prototype.

Fiscal Year (FY) 2017 Objectives

- Optimize down-selected ionomers and membrane configurations for performance, durability, and hydrogen permeation.
- Investigate cell design modifications for a commercial prototype.
- Demonstrate material scale-up and reproducibility and assess production costs.

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

(K) Manufacturing

(L) Operations and Maintenance

Technical Targets

- Improved performance, reduced hydrogen permeation and lower costs compared with commercial perfluorosulfonic acid baseline.
- Membrane polarization loss after 500 h (200 mA/cm², 400 psi, 50°C) <10 mV.
- Reduction in crossover loss at 50°C and >200 psi.

FY 2017 Accomplishments

- Significant reduction in energy requirements for hydrogen production.
- 340–400 mV improvement in performance at 2 A/cm².
- Developed new techniques to reduce hydrogen crossover and demonstrated reduced loss at 50°C and >200 psi.
- Membrane polarization loss after 500 h (200 mA/cm², 400 psi, 50°C) <10 mV.
- Modified cell design for improved membrane compatibility.
- Down-selected two material configurations for further optimization.



INTRODUCTION

The potential to use ion exchange membrane-based electrolyzers at much higher differential pressures than fuel cells minimizes the need for additional costly mechanical compression of the hydrogen produced. This high pressure differential requires a robust membrane that is able to prohibit hazardous back diffusion of hydrogen to the oxygen source. A common solution to both enhance mechanical durability and reduce hydrogen diffusion is to simply increase the thickness of the membrane, however this increases ionic resistance and can significantly reduce the efficiency of the system. Increasing the operating temperature can improve efficiency but this usually accelerates physical and chemical membrane degradation, especially at higher pressures. Due to the limitations of current commercial membranes, new approaches are needed

to enable efficient, cost effective proton exchange membrane (PEM)-based hydrogen generation.

Previously we demonstrated excellent performance and low hydrogen permeation at less than half the thickness of current commercial perfluorosulfonic acid membranes. During 2017 we have developed our ionomer chemistry, and investigated a number of membrane configurations in order to improve performance and durability and further reduce hydrogen crossover.

APPROACH

During this project, more than 40 different membrane configurations were produced at Tetramer and supplied to Proton OnSite for performance evaluation. Variables investigated include backbone polymer architecture and molecular weight, ion exchange capacity, membrane thickness and configuration (including the incorporation of supports and additives), and membrane casting and post treatment techniques. Membranes were evaluated for physical integrity, electrochemical performance, water uptake and swell, hydrogen permeability (crossover) and durability. Cell design and membrane treatments were also investigated to enhance performance and material compatibility.

Various analytical techniques were employed at Tetramer to assess the efficiency of each of the synthetic steps and the purity of final ionomers and their precursors. Process development was carried out throughout this project to improve yields and reduce waste with a view to scale-up for commercial production. Key processes were carried out in duplicate in order to confirm reproducibility. In addition, cost evaluations were carried out in order to compare our production costs with current commercial membranes.

RESULTS

During this 2017 period, we down-selected our leading ionomer structures based on backbone molecular architecture and ion exchange capacity. This down-selection was carried out using a wide range of performance data including electrochemical performance, hydrogen permeation, water uptake and swell, and durability collected on more than 40 different membranes. Preliminary standard operating procedures have been developed for the complete synthesis, characterization, and quality control of down-selected materials. Membranes based on two of these down-selected structures outperform current commercial Nafion® (Figure 1).

Our custom batch membrane casting conditions have also been defined, based on our current down-selected membrane configuration, and standardized in order to allow direct comparison of test samples. We have previous experience working closely with commercial coaters and expect to translate our current developments into an effective continuous membrane production process that will provide

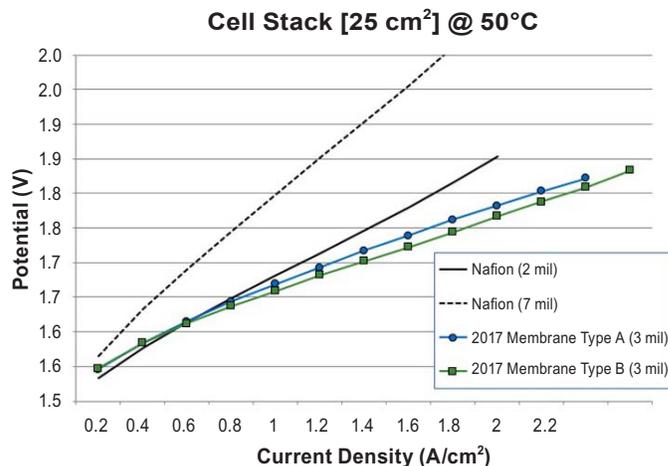


FIGURE 1. Electrochemical performance of our 2017 down-selected membranes compared with commercial perfluorosulfonic acid

membranes for an initial series of commercial electrolyzer prototypes.

The durability target of 500 h was exceeded, and stable performance and hydrogen crossover were observed for an initial down-selected membrane configuration at 50°C and 200 psi well beyond 1,000 h. We have continued efforts to further enhance durability of our down-selected materials with promising results. These durability improvements are important to allow the use of our membranes in larger capacity electrolyzer units, which operate at higher temperatures and pressures. We intend to develop these techniques to allow a further reduction in membrane thickness and thus minimize ionic resistance and reduce material costs.

A key advantage of our materials over many current commercial products is their inherently lower hydrogen permeation, which we have reduced by a factor of 2 based on our 2015 membranes (Figure 2). Additional crossover reducing techniques are under investigation to meet the requirements of larger capacity electrolyzers.

A number of cell design modifications were applied at Proton OnSite to increase the efficiency and compatibility of our membranes with their hardware. These adaptations will be continued towards prototype production in order to enhance the performance and durability of our down-selected membranes.

Initial scale-up and reproducibility studies have been successfully carried out, and standard operating procedures are in place for the individual production of our best performing membranes at a batch scale. In addition, a full production cost analysis was performed in order to assess current and future scale up production costs in comparison with current commercial membranes. Our analysis indicates that the cost of our down-selected membranes is significantly

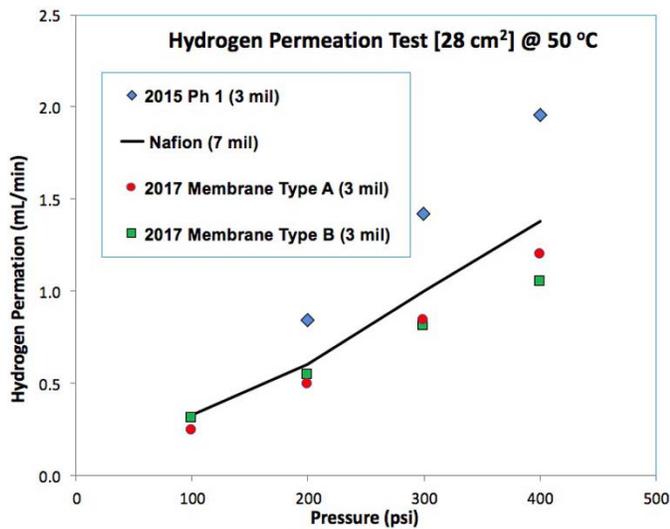


FIGURE 2. Hydrogen permeability of our 2017 down-selected membranes compared with our 2015 down-selected membrane and commercial perfluorosulfonic acid

lower than the reported cost of commercial perfluorosulfonic acid reference materials.

CONCLUSIONS AND UPCOMING ACTIVITIES

Our 2017 down-selected membranes demonstrate improved performance compared with the commercial perfluorosulfonic acid baseline (7-mil Nafion®) with lower hydrogen permeation and a potential cost reduction of >50%. The overall electrochemical performance advantages of this new lower cost technology project to a significant reduction in electricity costs.

We need additional process research for the further scale up, longer term durability and performance stability testing (beyond the 1,000 h already achieved), and further development of commercial cell prototypes, all of which will be the central focus for our ongoing commercialization efforts.