II.H.2 Hydrogen by Wire - Home Fueling System

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Fiscal Year (FY) 2012 Objectives

- Develop enabling technologies for 350-bar hydrogen home fueling
- Design key electrolysis cell stack and system components
- Fabricate, inspect and assemble prototype components
- Demonstrate prototype 350-bar hydrogen generation
- Demonstrate prototype 350-bar home fueling technologies

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

Technical Targets

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

Characteristics	Units	2012 Target	2012 Status
Hydrogen Cost	\$/gge[1]	3.70	5.99[2]
Electrolyzer Capital Cost	\$/gge	0.70	2.62[2]
Electrolyzer Energy Efficiency	% (LHV[3])	69	57[4]

[1] gge – gasoline gallon equivalent
[2] Based on H2A model modified for residential (non-commercial) application
[3] LHV – lower heating value
[4] Includes generation and compression to 350 bar with stack efficiency of 66% LHV

FY 2012 Accomplishments

- Completed prototype and final design of cell and stack components.
- Verified design of cell stack embodiment hardware.
- Completed full-scale stack pressure testing to 520 bar (7,500 psig).
- Verified gas diffusion at full differential pressure.
- Completed system component procurement and fabrication.
- Completed hydrogen phase separator fabrication and proof pressure testing.
- Completed system integration and system checkout.
- Demonstrated 350 bar (5,000 psig) differential pressure electrolysis.

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Introduction

Based upon the results of the Phase 1 study, the fundamental requirements for a hydrogen home fueling appliance have been defined. The conclusion of the Phase 1 study indicated that an overnight-fill proton exchange membrane (PEM) electrolysis device that fills the vehicle directly to a maximum of 350 bar with no mechanical compressor or secondary hydrogen storage can cost-effectively supply the daily hydrogen for a typical commuter operating a fuel cell vehicle. The case for including the hydrogen home fueling concept in the overall mix of fueling infrastructure is strong. The home fueler can grow in production volume and geographic distribution with individual vehicles as they are placed in the market with more flexibility than centralized fueling stations. Existing utility infrastructure (water, electricity) can be utilized within their existing capacities to cover the distribution aspect of the fueling infrastructure.

The goal of this Phase 2 project was to design and demonstrate the key hardware for 350-bar hydrogen home fueling based on PEM electrolysis. Proton Energy Systems has previously demonstrated durable PEM electrolysis equipment generating hydrogen at 165 bar. In addition, Proton has also demonstrated the ability of sub-scale prototypes to seal at the required proof pressure for 350-bar operation. Building upon this past work, designs have been developed utilizing Proton's reliable PEM electrolysis cell stack and system technologies for hydrogen generation and vehicle fueling at 350-bar.

Approach

The approach to the Phase 2 project was threefold. First, utilize the data and modeling results from the Phase 1 project to provide approximate sizing for the hydrogen generation rate. Second, build upon Proton's proven cell stack design and development experience to undertake the designs required for 350-bar operation. Third, utilize Proton's strong engineering processes that rely on a phased approach, with stage reviews, key written guidelines, and design output documentation to guide the successive levels of design refinement and demonstration. To that end, the project was organized into four main tasks: (1) Prototype System Design and Fabrication, (2) Prototype Stack Design, (3) Prototype Component Verification, and (4) Prototype System Testing.

Task 1 utilized engineering best practices to design and fabricate the prototype fueling system. This includes producing the plumbing and instrumentation diagram, electrical schematics, bill of materials, control schemes and component specifications for the prototype system. In addition, Task 1 included the procurement, fabrication, and acceptance testing of the prototype system. Task 2 included producing the component designs and assembly models for the cell stack in three-dimensional computer-aided design format. Moreover, it included completing design feasibility pressure testing using both sub-scale and full-scale active area components. Task 3 incorporated work on verifying the functionality of key components within the cell stack design and one or two custom components within the system design. Task 4 included assembling and checking the first electrolysis-ready version of the new prototype stack design. Furthermore, it includes integrating the prototype stack into the prototype system and operating in electrolysis to generate hydrogen at 350 bar.

Results

Now in the second year of this project, the team has made excellent progress toward the overall goals of the project. At the time of writing, the team has completed all of Tasks 1, 2 and 3. Task 4 is also 80% complete and the overall project is on schedule to meet the deliverables at the end of Year 2.

Within Task 1, Prototype System Design and Fabrication, activities in Year 2 first focused on completion of the system bill of materials which allowed ordering and subsequent receipt of all the major components for the prototype system. The prototype system design is based upon Proton's commercial HOGEN® HP high pressure hydrogen generator which delivers hydrogen at pressures of up to 2,400 psi. This high pressure system is also derivative of Proton's highly successful HOGEN S-series product with over 400 units now in operation. Based upon the completed prototype design review, the system was assembled and after completion fully checked out to verify operational status. The final programming of the system's programmable logic controller and data acquisition system was also completed and verified including identification and verification of all input/output communication channels. A picture of the completed system is shown in Figure 1. The plumbing and instrumentation diagram and electrical schematics were updated concurrently with assembly to reflect the final system configuration. A key development effort as part of the system design was the 350-bar hydrogen/water phase separator. The final phase separator configuration was fully fabricated and proof pressure tested (Figure 2). The phase separator was then integrated into the system and its testing completed during the full system checkout. System acceptance testing included leak checking, ground continuity testing, and hi-pot testing.

Within Task 2, Prototype Stack Design, the design of the 350-bar cell stack was completed during this past year. Based upon work completed in Year 1, cell frame and embodiment components were procured and full pressure testing of the stack design was achieved at proof pressures above the required 520 bar (7,500 psig). The design work then moved to cell active area design and was supported by component and full pressure testing during the verification work outlined in Task 3. The prototype and final design reviews were

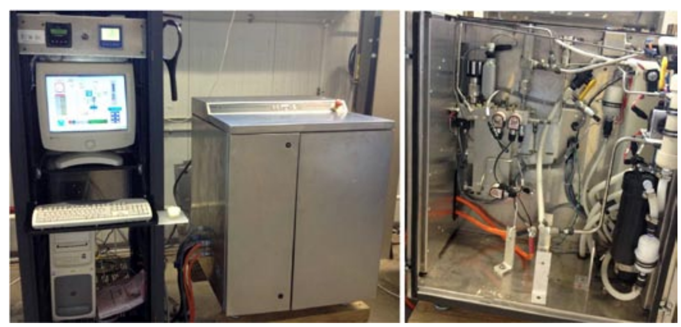

FIGURE 1. Prototype test system and data acquisition

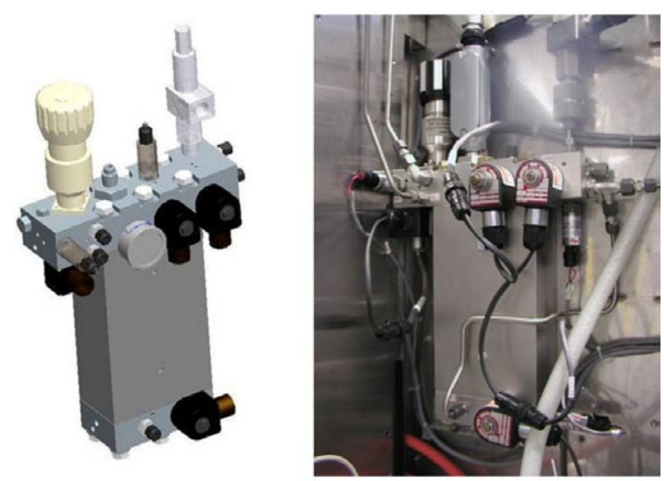

FIGURE 2. Phase separator design and fabricated unit

subsequently completed as the iterative design process honed and refined the final 350-bar cell stack design.

Activities in Task 3 involved the detailed design verification inspections and tests of the components. Non-operational stacks were built to verify sealing to proof pressure and proper distribution of load through the components. Pressure imaging in the sealing as well as the active area of the cell was used to verify uniform load within allowable margins of safety. Flow testing of single- and multiple-cell stacks was conducted and compared to similar lower pressure cell designs to confirm acceptable pressure drop. Proton exchange membrane materials suitable for use in the membrane electrode assembly component were also characterized at differential pressures up to 350 bar (Figure 3). Final activity during this task was the fabrication of an operational single-cell stack suitable for integration and testing in the prototype test bed.

The activities completed during Task 4 started with testing of the water circulation pump and system power supply. Final integration of the thermal management and data collection equipment was also completed. A key element of the system control is the management of the high pressure water collected from the production of 350-bar hydrogen. A hydrogen/water phase separator simulator was developed to mimic the operation of an actual phase separator in order to set the programmable logic control parameters without actually generating 350-bar hydrogen. This ultimately enabled rapid integration of the operating cell stack into the system with minimal premature shutdowns and adjustments. Finally, the single-cell 350-bar stack was installed, the system testing initiated and the milestone of hydrogen production at 350-bar pressure and full differential pressure was achieved during this period (Figure 4). This achievement sets the stage for additional testing and optimization of operational protocols during the remainder of the project.

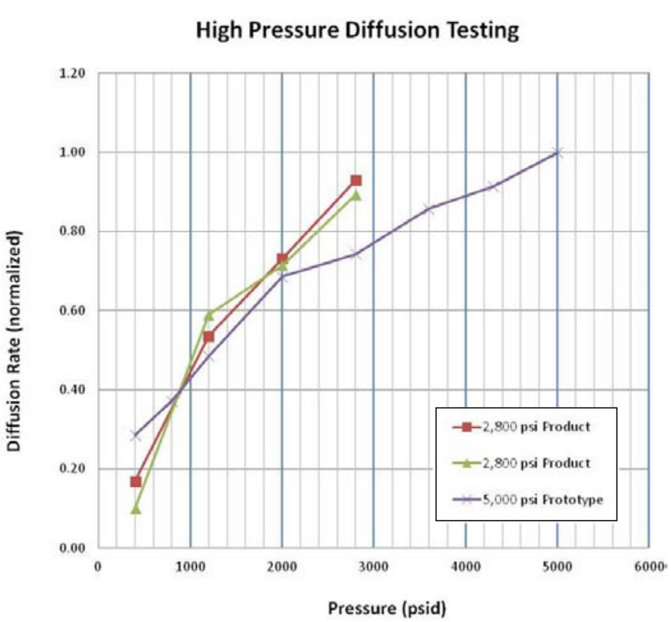

FIGURE 3. Cross-cell diffusion testing at up to 350-bar differential pressure

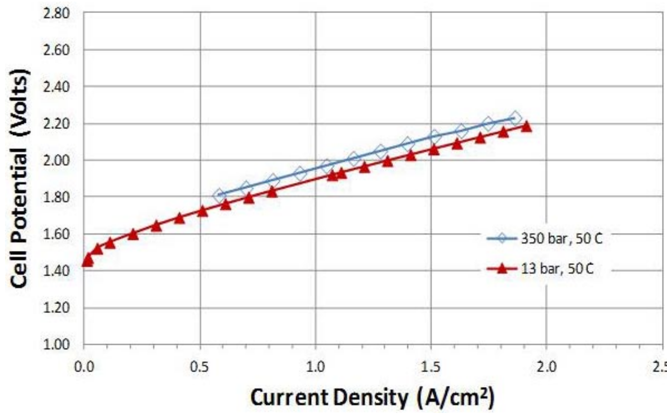

FIGURE 4. Polarization data during 350-bar (5,000 psig) hydrogen generation compared with 13-bar hydrogen generation

Conclusions and Future Directions

All of the diligent design and development work of the project team resulted in achievement of the initial demonstration of a 350-bar capable electrolysis stack and system. This accomplishment creates a foundation from which the hydrogen output and pressure can be scaled up and also design improvements can be made to improve the efficiency and economics of this small-scale high-pressure hydrogen generator system.

In summary, the following tasks have been completed for the 350-bar electrolysis fueling system development effort and the parallel 350-bar electrolysis cell stack development:

- All prototype system components have been ordered and procured.
- The prototype system is complete, including full system operational checkout.
- The high pressure cell stack design is finalized including overboard seal testing to proof pressures above 500 bar.
- All prototype cell and stack embodiment components have been ordered and procured.
- Design and verification of cell stack components is completed, including seal and active area full differential pressure testing.
- The operational prototype cell stack has been assembled and acceptance tested.
- The prototype system and operational stack have been integrated and operationally tested.
- 350-bar hydrogen generation from water electrolysis at full differential pressure has been achieved.

FY 2012 Publications/Presentations

1. Anderson, E., Dalton, L., Carter, B., and Ayers, K., "Elimination of mechanical compressors using PEM-based electrochemical technology," Paper ASR 14.5 presented at the World Hydrogen Energy Conference 2012, Toronto, CA, June 6, 2012.