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

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Contract Number: DE-SC0001149

Project Start Date: August 15, 2010
Project End Date: August 14, 2012

Fiscal Year (FY) 2011 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	2011 Status
Hydrogen Cost	$/gge	3.70	5.99*
Electrolyzer Capital Cost	$/gge	0.70	2.62*
Electrolyzer Energy Efficiency	% (LHV)	69	57**

*Based on H2A model modified for residential (non-commercial) application
**Includes generation and compression to 350 bar with stack efficiency of 66% lower heating value (LHV)

FY 2011 Accomplishments

- Defined requirements for cell stack size.
- Completed cell stack concept designs.
- Initiated cell prototype component orders.
- Completed system plumbing and instrumentation diagram (P&ID).
- Drafted system electrical schematic and safety analysis.
- Specified and selected key system components (valves, etc.).
- Designed upgrades to pressure test apparatus.

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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 is 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 initiated to utilize 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 is 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 utilizes engineering best practices to design and fabricate the prototype fueling system. This includes producing the P&ID, electrical schematics, bills of materials, control schemes and component specifications for the prototype system. In addition, Task 1 includes the procurement, fabrication, and acceptance testing of the prototype system. Task 2 includes producing the component designs and assembly models for the cell stack in three-dimensional (3-D) computer-aided design (CAD) format. Moreover, it includes completing design feasibility pressure testing using both sub-scale and full-scale active area components. Task 3 incorporates 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 includes 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

During this first year, the team has made excellent progress toward the overall goals of the project. At the time of writing, the team has completed more than 40% of Task 1 and more than 70% of Task 2. At the end of year 1, we expect to be 50% complete with Task 1 and 100% complete with Task 2, which is on schedule to meet the deliverables at the end of Year 2.

Within Task 1, Prototype System Design and Fabrication, the initial conceptual designs of the major system components and system architecture were completed. This concept design effort culminated in an internal concept design review in December 2010. The design team then refined the concept design further through a prototype design stage. In this stage, the P&ID was modified to include more detail and finalize the piping architecture. The electrical schematic was completed, including the electrical safety circuit devices. The packaging of the mechanical components was completed in a 3-D CAD model (Figure 1). The actuated valves, piping, and fittings available for operation at 350 bar were evaluated and selections were made. The primary cell stack power supply was selected and a quote was requested. One key component, the hydrogen-water phase separator, required a higher level of detailed analysis because of the increases in system pressure, since the original phase separator had been designed for 165 bar operation. This part was re-designed and analyzed using finite element analysis (FEA) techniques to ensure that the stresses in the part would be acceptable at the 350 bar operating pressures (Figure 2). The approach for controlling the system as a laboratory prototype was selected to utilize the flexible programmable logic controller (PLC) type of hardware. The key inputs to and outputs from the PLC were identified and listed to facilitate the selection of the PLC in-out cards. Finally, the system-level hazard analysis was initiated by defining the subsystem nodes within the overall system, identifying the hazards, and identifying hazard mitigation strategies. This prototype design stage culminated in a second internal design review. At the time of writing, the specification of the remaining components necessary to have a complete bill of materials (BOM) is underway. The system BOM will be completed allowing orders for all the major components to be placed by the conclusion of year 1.

Within Task 2, Prototype Stack Design, the design process started with a continuation of the feasibility testing previously started by Proton under internal research and development funding to demonstrate overboard sealing of a sub-scale test article. The previous testing was extended by doing short duration elevated temperature soaks to more closely simulate the operating temperature of a cell stack. Finally, an optimization of the sealing features

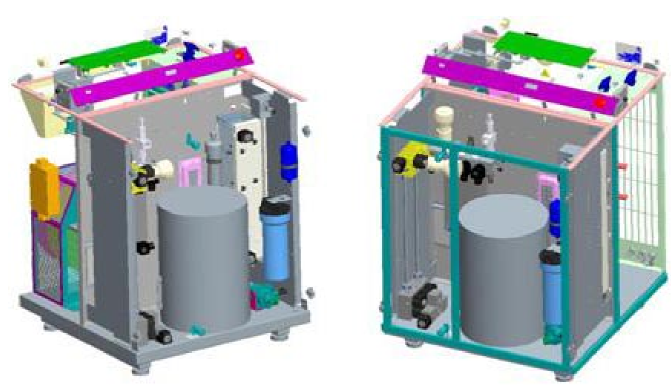

FIGURE 1. Prototype Test System 3-D Package Design

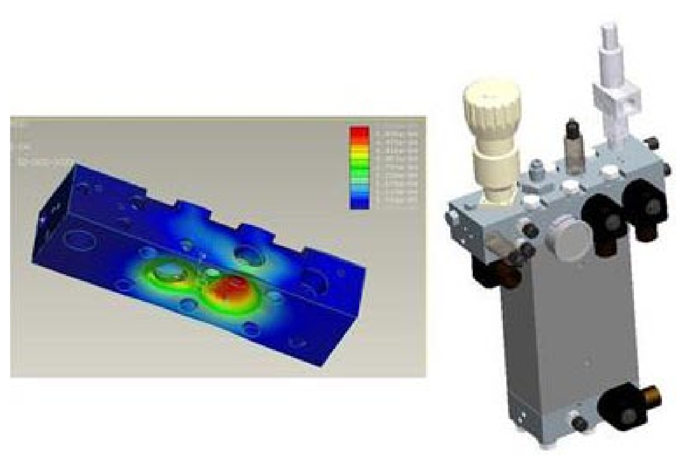

FIGURE 2. Phase Separator Design and Finite Element Analysis

was undertaken to permit more efficient sealing to the same proof pressure. The design of the full-scale stack started with rough sizing of the endplates and bolts for the required strength and stiffness of a 350-bar electrolysis cell stack (Figure 3). The design process continued with conceptual designs of the cell frames and the internal flow field components. As the design of the cell components firmed up, the initial rough designs of the endplate, fluid manifold, electrical bus plates, and tie rods were revised and refined (Figure 4). This iterative design effort included two intermediate design reviews and culminated with a concept stage design review. Based upon the approved designs, quotes were requested on the key components necessary for the first rounds of Task 3, Prototype Component Verification. Orders were placed for the key components to permit full-scale active area pressure testing. At this time, we anticipate that Task 2 will be 100% complete at the end of year 1.

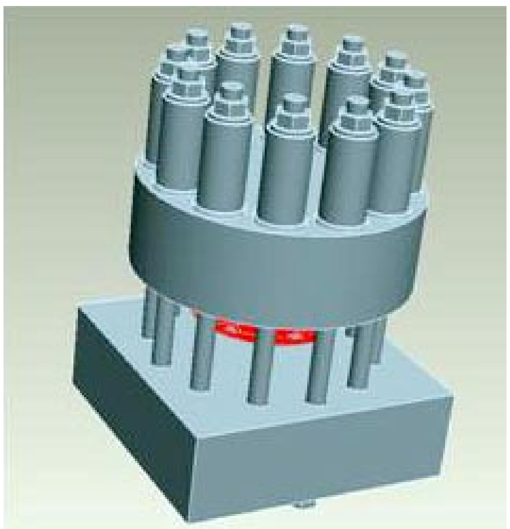

FIGURE 3. Initial Endplate and Tie Rod Sizing

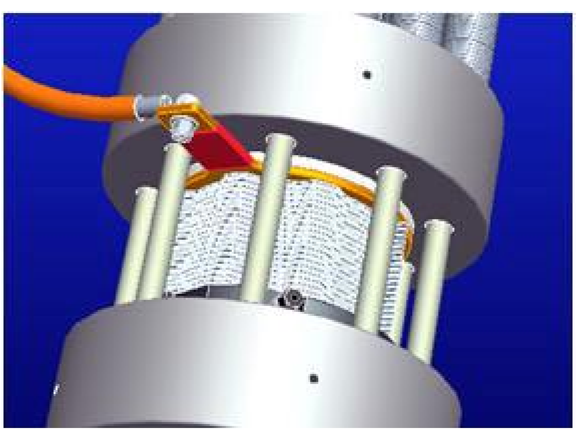

FIGURE 4. Initial Cell Component Design

Conclusions and Future Directions

The project team is making excellent progress toward the culminating demonstration of 350-bar capable electrolysis technology. Moving into year 2 of the project, Task 1 will heavily involve the fabrication and assembly of the prototype system. This task will culminate with the basic sensor calibrations and acceptance tests including leak, ground continuity, and hi-pot testing. As Task 2 reaches completion, Task 3 will pick up with the detailed design verification inspections and tests of the components. Non-operational stacks will be built to verify sealing to proof pressure and proper distribution of load through the components. Flow tests will be conducted on single- and multiple-cell stacks. All of the tasks will culminate in the Prototype System Testing (Task 4). In this task, an operational electrolysis cell stack will be fabricated, assembled, and checked through standard acceptance criteria. The stack will then be integrated with the system and operated for a significant demonstration of 350-bar electrolysis technology.

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

- The prototype system design is complete, including P&ID, electrical schematic, and 3-D CAD layout.
- The component BOM list is complete with all components quoted for prototype purchase.
- Key prototype system components have been ordered.
- Feasibility cell sealing tests were completed favorably, demonstrating overboard sealing at full proof pressure.
- Differential pressure cross-cell capability feasibility tests were completed at greater than operating pressure.
- Preliminary design calculations have been completed for a full-size cell stack.
- All cell components have been modeled in 3-D CAD and detailed engineering drawings have been drafted for the preliminary design.
- Key prototype cell stack components have been ordered.
- Initial rounds of component verification testing will begin at the end of year 1 and the start of year 2.

FY 2011 Publications/Presentations

1. E. Anderson, L. Dalton, and K. Ayers, “Small-Scale, High Pressure PEM Electrolysis for 350 and 700 bar Residential Fueling Applications,” Fuel Cell & Hydrogen Energy, Washington, D.C., 15 February 2011.