VII.9 Validation of an Advanced High Pressure PEM Electrolyzer and Composite Hydrogen Storage, with Data Reporting, for SunHydro Stations

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Contract Number: DE-EE0005887

Subcontractors
- SunHydro LLC, Wallingford, CT
- Air Products and Chemicals, Incorporated (APCI), Allentown, PA

Project Start Date: December 1, 2012
Project End Date: June 30, 2015 (go/no go decision for next phase)

Overall Objectives

- Validate energy savings of up to 11 kWh/kg H_2 through system and stack advancements
- Double usable hydrogen storage per unit volume by increasing pressure cycling range
- Provide advanced packaging design to reduce station footprint
- Collect and report station performance for up to 24 months

Fiscal Year (FY) 2015 Objectives

- Quantify full scale advanced cell stack energy savings and performance
- Quantify system portion of energy savings for 55 bar operation of hydrogen dryer and compressor
- Demonstrate higher addressable capacity hydrogen storage tubes
- Validate advanced packaging arrangement
- Conduct reporting of station performance

Technical Barriers

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

(C) Hydrogen Storage

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

(E) Codes and Standards

Technical Targets

Advanced Electrolysis-Based Fueling Systems:

There is not a target table in the Technology Validation section of the (MYRDD) Plan specific to hydrogen refueling infrastructure. This project is conducting technology validation of improved cell stack, system, and storage components for an electrolysis-based hydrogen refueling station. These improvements will support the following targets.

- Reduce station energy use by up to 11 kWh/kg
- Reduce the storage volume by 50% per kilogram of hydrogen dispensed
- Package a station based on polymer electrolyte membrane (PEM) electrolysis within a 12 m International Organization for Standardization (ISO) container

FY 2015 Accomplishments

- Operated full scale cell stack utilizing advanced manufacturing process
- Demonstrated SunHydro 1 operation at 55 bar hydrogen generation, drying, and compression
- Quantified performance enhancement of 55 bar operation
- Validated five back to back fills with composite hydrogen storage tubes
- Received SunHydro 2 components
- Validated Sun Hydro 2 compact station code approach with Massachusetts install permit
- Acquired hydrogen station data acquisition system at SunHydro 1

- Reported SunHydro 1 hydrogen energy usage data to the fuel cell electric vehicle (FCEV) infrastructure composite data product (CDP) database

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INTRODUCTION

This project primarily leverages Proton's SunHydro 1 station in Wallingford, Connecticut, with access to over 100 kg/d in generation capacity, and a new containerized SunHydro 2 station for field deployment, for technology validation of improved components for hydrogen fueling stations (Figure 1). Our compact, containerized SunHydro™ station design (Figure 2) embodied by SunHydro 2 can address initial demand for small, manufactured hydrogen fueling infrastructure in a manner that affords rapid, scalable deployment. The SunHydro station product "skid," integrating hydrogen generation, compression, storage, and dispensing in an intermodal transport ISO container, mitigates significant site permitting issues by virtue of its small 40 ft x 8 ft footprint and an innovative application of hydrogen code that drastically reduces required clearances.

Proton and SunHydro are continuing down this pathway to demonstrate advanced generation/compression/storage component technologies, including (1) higher pressure hydrogen generation with electrochemical compression; (2) higher efficiency generation with lower resistance electrolyte and advanced catalyst; (3) higher addressable capacity composite storage, and (4) advanced packaging concepts for reduced footprint.

APPROACH

For higher pressure/higher efficiency PEM cell stacks, Proton has qualified a 30% reduction in PEM membrane thickness for 15 bar and 30 bar hydrogen generator product lines. Furthermore, Proton has been developing advanced

FIGURE 1. SunHydro 1 and SunHydro 2 stations

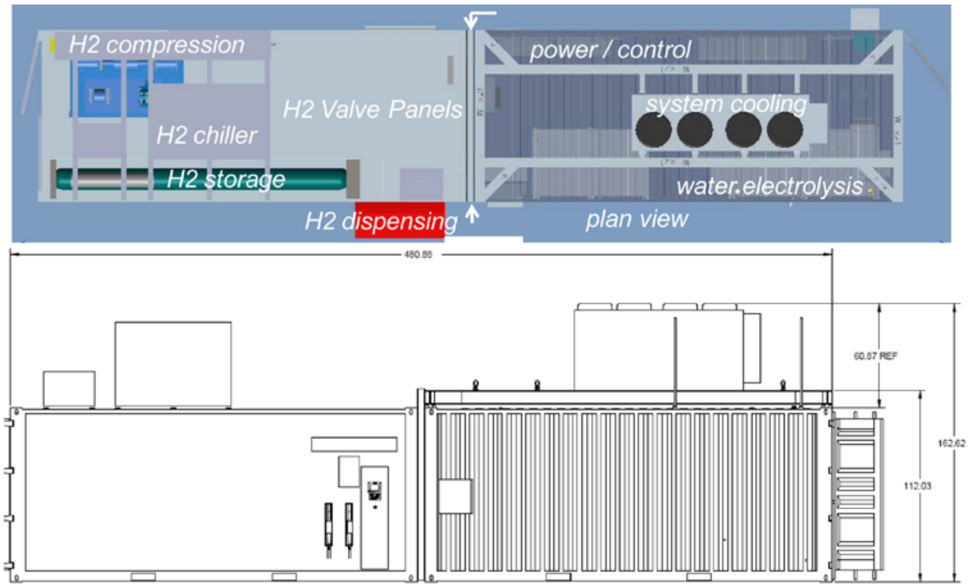

FIGURE 2. Arrangement, H_2 generator container, SunHydro concept, combined containers

catalyst materials and processes that simultaneously reduce the cost of the product and improve the electrochemical performance. A 55 bar militarized cell stack design will be built using the thinner material and advanced catalyst deposition to show the performance improvement at full scale compared to previous technology stacks. We will upgrade a commercial 30 bar C series electrolyzer to operate at 55 bar by strengthening the gas drying components. An increase in hydrogen generation pressure from 30 bar to 55 bar can improve hydrogen fueling system efficiency in two areas – hydrogen gas drying and dried hydrogen compression into station storage. The dryer purge losses can be expected to decrease substantially since the water vapor concentration at 55 bar will be about 55% of the concentration at 30 bar. Higher dry hydrogen pressure into the station mechanical compressor will result in better combined compression energy and higher throughput capability.

For higher addressable capacity storage and reduced station footprint, Proton will install and validate new compact Type II composite storage tubes and apply fresh interpretations of hydrogen safety code to design a complete fueling station within the compact footprint of an ISO container. Proton will apply these new rules to the design of the SunHydro 2 station. The impact of all performance improvements will be reported through instrumentation of the station before and after the design changes. The impact of new compact station arrangements will be reported in site approval time and in station operability data.

RESULTS

Task 1.0 Validate Full Scale 57 bar Higher Efficiency PEM Cell Stack

The project goal was to implement advanced membranes and electrodes in a full scale 57-bar PEM electrolyzer stack to show energy savings approaching 8 kWh/kg H_2 over the 30 bar commercial version. The required improved voltage performance had been previously demonstrated with smaller active area short-stack test articles. Therefore, the challenge was to take the process developed and apply it at a larger scale to the largest stack size currently in production at Proton in the 2013–2014 performance period, the 0.23 ft^2 active area C series cell stack. The expected energy savings based on subscale testing is described by the polarization curves shown in Figure 3. A reduction in voltage from 2.15 VDC/cell to 1.85 VDC/cell at the same current density would yield the estimated 8 kWh/kg H_2 that was targeted.

Achieving the target performance required implementing both thinner membrane as well as advanced catalyst application techniques. As the advanced catalyst application techniques were scaled to support a full production run for the advanced C series cell stack used in Proton's fueling station, some challenges were observed. The larger batch sizes were not as stable during the fabrication process and were more susceptible to variations in ambient environmental conditions. During operation of the stack using the advanced membrane electrode assemblies (MEAs), the performance was approximately equal to the baseline stack. After reviewing the manufacturing process and operating conditions, it was determined that the actual catalyst loading

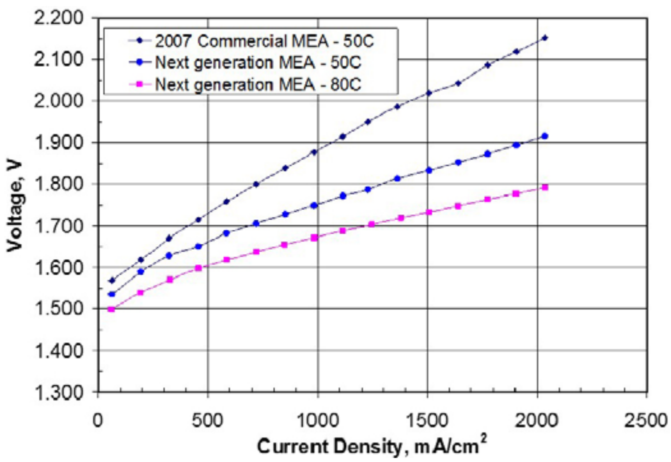

FIGURE 3. Circa 2007 commercial PEM MEA technology is contrasted with next generation MEAs qualified in smaller-scale product lines (performance shown)

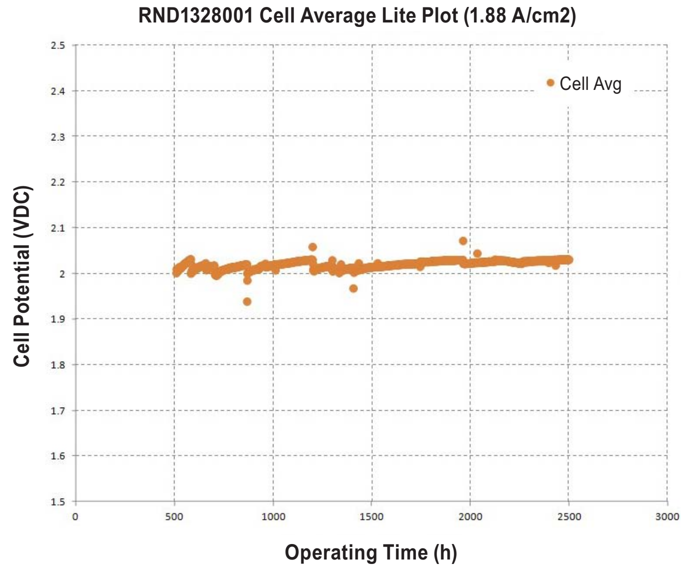

FIGURE 4. With further advances in the fabrication process, demonstrated large-scale active area performance has improved

applied fell below the target level. The performance of the stack was stable over time, indicating that there was not a continuing degradation mechanism. The full scale 55-bar PEM cell stack was successfully installed into the 57-bar capable C series and was operated at 55 bar over 900 hours through the second and third quarter of 2014. The stack has continued to operate stably at both 30 bar and 55 bar operating pressures.

Discussion: As development and demonstration of this advanced MEA with improved efficiency is important to Proton, we made process refinements and continued to demonstrate progress with large active area electrodes. Proton has subsequently introduced to the market a 0.73 ft^2 active area commercial PEM electrolysis cell stack and system, the M series, targeted at power to gas energy storage, fueling, and industrial applications. An example of the further progress we have made is described in Figure 4. With this larger active area electrode, a multi-cell electrolysis stack capable of 10 kg/d H_2 output was produced with the advanced catalyst application technique. This more recent attempt demonstrated an operating voltage of 2.03 VDC/cell, a performance improvement of 120 mV over baseline. Based on this 120 mV/cell improvement, we have demonstrated energy savings of 3.2 kWh/kg H_2. This value represents the current progress toward the 8 kWh/kg target established at the program start.

Task 2.0 Validate Full Scale 57-bar, 65-kg/d Hydrogen Generator

The build of the Proton C Series hydrogen generator that is the test bed for the advanced cell stack was completed in late 2012 and supplies the hydrogen used by the SunHydro 1 station at Proton. The hydrogen gas management portion of Proton's commercial C series 30 bar pressure hydrogen generator is comprised primarily of proprietary design hydrogen–water phase separator and a pressure–swing absorber (PSA). Proton engineering completed a mechanical design analysis of these components in FY 2013 to learn that only minor changes to valve seats, retaining bolts, orifices, and pressure sensors were needed to operate at 55 bar. These modifications were designed to easily revert back to 30 bar operation in the event that Proton product factory support testing was required. Upon a successful system Acceptance Test Plan, work culminated with tuning the PSA regeneration steps to maximize the efficiency gains allowed by higher operating pressures.

Method: The upgraded C series electrolyzer was operated at the elevated pressure for dryer tuning and compressor efficiency testing. The pressure-swing dryer purge stream was tuned to reduce the regenerative hydrogen purge stream volume as guided by calculations and verified by stable dry hydrogen product production at less than 1 ppmv moisture, same as the baseline 30-bar dryer.

Specific energy data from the upgraded 55-bar C series electrolyzer and the fueling station compressor were gathered in kWh/kg H_2 over a period of approximately 30 days in the second and third quarter of 2014. The resulting values were compared to the specific energy data produced under 30 bar operation within a similar time frame. By increasing the PEM water electrolyzer generation pressure from 30 bar to 55 bar, Proton achieved an electrolyzer energy reduction of 1.5 kWh/kg H_2 and a compressor energy reduction of 0.3 kWh/kg H_2 for a total savings of 1.8 kWh/kg H_2, halfway toward the statement of project objectives (SOPO) goal of 3.6 kWh/kg H_2.

Discussion: The specific energy consumed by the C series electrolyzer operating at 55 bar operation decreased

2.6% due to a 45% reduction in the hydrogen dryer purge losses over the 30 bar baseline. The specific energy consumed by the hydrogen compressor decreased more than 13% over the 30 bar baseline. Based on these results, it is evident that operating a C series hydrogen generator at 55 bar produces a noticeable decrease in the specific energy consumed over the 30 bar baseline.

Task 3.0 Validate Higher Addressable Capacity Composite Hydrogen Storage Tubes

Late in FY 2014, the storage tubes were delivered and promptly installed at the SunHydro 1 station. These tubes allow for deeper pressure cycling providing a higher addressable storage capacity. This capability was demonstrated during commissioning with the entire station managing the sequential filling of five vehicles, an increase over the previous filling capability of the SunHydro 1 station of only slightly more than two vehicles back to back.

Storage tube validation continues as the SunHydro 1 station continues to service vehicles. The new tubes serve as the primary bank as they are used first to fill, the other three banks serving to top up. On average the new tubes are pressure cycled three days per week from 870 bar to less than 500 bar based on the demands of an average fleet size of 10 fuel cell vehicles. A second set of storage tubes will enter into validation testing with the deployment of SunHydro 2 station in 2016.

Task 4.0 Validate Compressor Increased Throughput Capacity with 57 bar Input

With the successful completion of Tasks 2 and 3, validation of the anticipated increased throughput capacity of the compressor is completed. By increasing the PEM water electrolyzer generation pressure from 30 bar to 55 bar, Proton achieved an electrolyzer energy reduction of 1.5kWh/kg H_2 and a compressor energy reduction of 0.3 kWh/kg H_2 for a total savings of 1.8 kWh/kg H_2, halfway toward the SOPO goal of 3.6 kWh/kg H_2.

Task 5.0 Hydrogen Station Safety Operation Procedure and EX Zone Review

Results of Chapters 7 and 13 of the National Fire Protection Association (NFPA) 2 “Hydrogen Technologies Code” were used to determine hazardous equipment zones and methods to mitigate code-directed separation distances to develop the novel compact component layout and model in Task 6 with respect to classified and nonclassified areas. Following procedure and zone review, Proton’s efforts shifted to actively working the site permitting for SunHydro 2 based on our compact arrangement and addressing several Massachusetts specific issues. An installation plan set was generated to address these issues and a permit application for the 46 kg of hydrogen to be stored in the SunHydro 2 high pressure composite storage tubes was granted by Braintree, Massachusetts authorities in October 2014.

Proton is an industry member of the NFPA 2 Hydrogen Technologies Code technical committee, and has a representative on the Hydrogen Safety Panel (HSP). The technical committee has prepared the 2016 edition of NFPA 2. The HSP, with Proton support, has contributed to a draft public comment concerning hydrogen equipment in enclosures that was reviewed at the second draft meeting for the NFPA 2 committee and subsequently accepted during formal balloting. Creating specific code to address hydrogen processing equipment and storage in prefabricated intermodal enclosures will help code officials with permitting compact containerized hydrogen fueling stations.

Task 6.0 Validate Novel Compact and Non-EX Rated Component Arrangements

An installation permit application for SunHydro 2 was granted by Braintree, Massachusetts, authorities in October 2014. Proton’s analysis of compact hydrogen station component arrangements under this work shows an advantage to using the nonclassified area immediately around our PEM hydrogen generator to house almost all electrical power and control equipment. Further, NFPA 2 hydrogen code permits reduction of separation distances to near zero when a 2-h rated firewall is interposed. Our arrangement shows significant space saving advantages in placing this firewall in between the nonclassified electrolyzer generator container space and the classified container space that houses compression, storage, and a built-in dispenser. This approach will be further validated to meet the 8 ft x 40 ft goal in the SunHydro 2 station when installed in the next fiscal year.

Task 7.0 Hydrogen Station Data Acquisition System and Task 8.0 Quarterly Operation Data Reporting

The data acquisition system is installed in SunHydro 1 and has provided operating data for quarterly reports to the FCEV infrastructure CDPs. Identical data acquisition equipment awaits installation in SunHydro 2. Four reports of SunHydro 1 station data were prepared for the FCEV infrastructure CDP during the previous fiscal year, seven in total since the start of our contract.

CONCLUSIONS AND FUTURE DIRECTIONS

<u>Conclusions</u>

- 55 bar generation and compression yields efficiency gains over the 30 bar baseline.
- Compact station arrangements using non-EX rated components can be approved by authorities having jurisdiction (AHJs) for installation using NFPA 2 code.

Future Directions

- Install and validate novel compact and non-EX rated component arrangement of SunHydro 2 with AHJ permit for Washington, DC, site
- Initiate SunHydro 2 data acquisition CDP operational data reporting
- Continue reporting SunHydro 1 CDP operational data reporting

FY 2015 PUBLICATIONS/PRESENTATIONS

1. AMR 2015 moulthrop TV-012.

REFERENCES

1. NFPA 2 Hydrogen Technologies Code, NFPA, 1 Batterymarch, Quincy, MA.