VII.5 Validation of an Advanced High-Pressure PEM Electrolyzer and Composite Hydrogen Storage, With Data Reporting, for SunHydro Stations

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

Project Start Date: December 1, 2012
Project End Date: December 31, 2014 (Go/No-Go decision for next phase)

Overall Objectives

- Validate energy savings of up to 11 kWh/kg hydrogen 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) 2014 Objectives

- Build full-scale advanced cell stack for stack portion of energy savings
- Install system upgrades for reduced dryer losses for system portion of energy savings
- Install and commission higher addressable capacity hydrogen storage tubes
- Complete analysis of codes and standards for advanced packaging arrangement
- Complete instrumentation of station and initiate 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 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 specific target table in the Technology Validation section of the Multi-Year Research, Development, and Demonstration 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 kg of hydrogen dispensed
- Package a station based on proton exchange membrane (PEM) electrolysis within a 12-m International Organization for Standardization (ISO) container

FY 2014 Accomplishments

- Built and operated full-scale cell stack utilizing advanced manufacturing process
- Upgraded SunHydro#1 to 55-bar operation at generator and compressor
- Commissioned higher addressable capacity composite hydrogen storage tubes
- Acquired compression, storage and dispensing section of SunHydro#2
- Installed and utilized hydrogen station data acquisition system at SunHydro#1
- Reported hydrogen energy usage data to the Fuel Cell Electric Vehicle Infrastructure Composite Data Product database

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INTRODUCTION

This project primarily leverages Proton's SunHydro#1 station in Wallingford, CT, with access to over 100 kg/day in generation capacity, and a new containerized SunHydro#2 station deploying to Braintree, MA, for technology validation of improved components for hydrogen fueling stations (Figure 1). Our compact, containerized SunHydro™ station design 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' x 8' footprint and an innovative application of hydrogen code that drastically reduces required clearances.

Proton and SunHydro LLC 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

These hydrogen fueling improvements will be accomplished based on the following approaches. For higher pressure/higher efficiency PEM cell stacks, Proton has recently qualified a 30% reduction in PEM membrane thickness for 15- and 30-bar hydrogen generator product lines. Furthermore, Proton has been developing advanced 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.

FIGURE 1. SunHydro#1 and SunHydro#2 Stations

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 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

During the previous FY, work on the full-scale 57-bar higher efficiency PEM cell stack progressed from build planning to successful system level testing. Multiple iterations of platform specific tooling to interface with the electrode fabrication equipment to hone the process was procured. Separator plates with advanced coating for durability at high-pressure operation and the balance-of-stack embodiment hardware culminated in a completely assembled stack that passed acceptance test procedure midway through the FY. During green-run testing, cell voltage was higher than expected when compared to previous sub-scale testing. As this was the first manufacturing run at this scale with the advanced fabrication process, a review of manufacturing steps of both full- and sub-scale cells was initiated to discern any differences that may exist. It was determined that the desired catalyst loading point was not achieved during membrane electrode assembly fabrication. Efficiency gains from this first scale up fabrication run of the advanced cell stack manufacturing techniques were not yet realized on this full-scale sample. However, even with this reduced loading, cell stack performance to date has matched the existing production cell stack and efficiency gains may still be achieved in future iterations of the manufacturing scale up.

Task 2.0 Validate Full-Scale 57-bar, 65-kg/day 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 to assist with any factory testing as required. Upon a successful system acceptance test procedure, work culminated with tuning the PSA regeneration steps to maximize the efficiency gains allowed by higher operating pressures. Initial work cut the waste purge gas usage by 40%, however future tuning of the overall PSA cycle will be performed and validated during the next FY.

Task 3.0 Validate Higher Addressable Capacity Composite Hydrogen Storage Tubes

Within FY 2014, there were numerous delays on the delivery of the advanced storage tubes due to manufacturing difficulties and extended qualification processes. During this time, Proton engaged third party professional engineers to perform an assessment of the existing concrete pad in preparation for the addition of the new storage tubes. The assessment determined no modifications would be needed. A similar assessment of stability and seismic requirements found that both the site and tube stacking arrangement were adequate as well. Late in the FY, 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 sequential filling of five vehicles, an increase over the previous capability of the SunHydro#1 station of only slightly more than two. Validation of the increase will be performed in the next FY.

Task 4.0 Validate Compressor Increased Throughput Capacity With 57-bar Input

During early work on this validation, Proton began drafting the techniques and computer models to calculate the anticipated increased throughput capacity of the compressor. With the successful completion of Task 2.0 and 3.0, validation of the anticipated increased throughput capacity of the compressor is anticipated to be completed early in the next FY.

Task 5.0 Hydrogen Station Safety Operation Procedure and EX Zone Review

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 6.0 with respect to classified and non-classified areas [1]. 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. A plan set is being generated to address these issues and a permit application for the 46 kilograms of hydrogen to be stored in the SunHydro#2 high-pressure

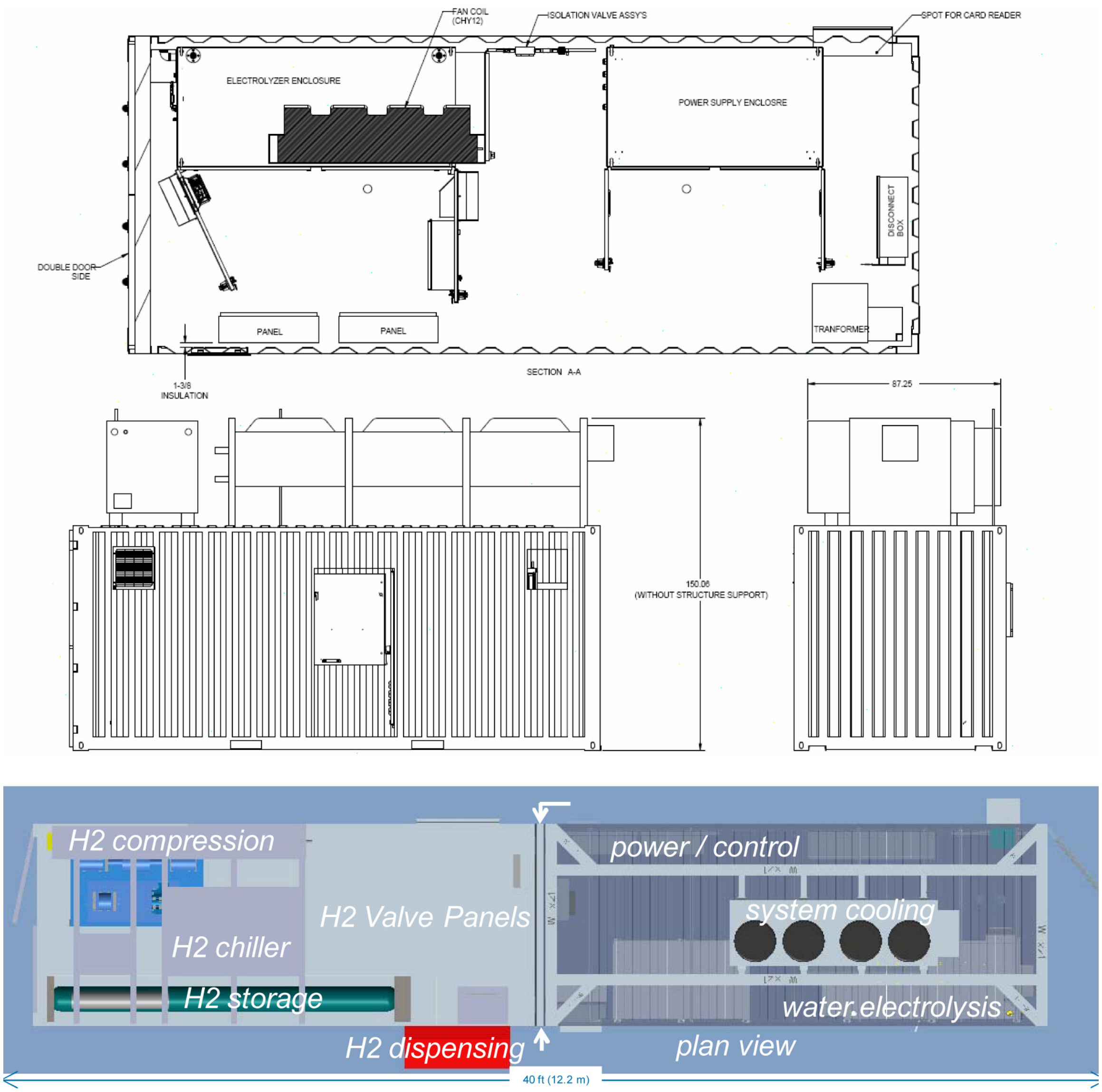

FIGURE 2. Arrangement, Hydrogen Generator Container Section and SunHydro Concept

composite storage tubes has been prepared for review by the appropriate authorities during the next FY.

Proton is an industry member of the NFPA 2 Hydrogen Technologies Code technical committee, and has a representative on the Hydrogen Safety Panel. The technical committee is preparing the 2016 edition of NFPA 2. The Hydrogen Safety Panel, 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. Creating specific code to address hydrogen processing equipment and storage in pre-fabricated 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

Work on a compact fueling station arrangement for the SunHydro#2 station progressed through all design phases during the previous FY (Figure 2). Procurement of a completely fabricated compression, storage, and dispensing container and all major components of the generation container then followed. Proton's analysis of compact hydrogen station component arrangements under this work shows an advantage to using the non-classified 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-hour rated firewall is interposed. Our arrangement shows significant space saving advantages in placing this firewall in between the non-classified electrolyzer generator container space and the classified container space that houses compression, storage, and a built-in dispenser. This approach will be validated to meet the 8' x 40' goal in the SunHydro#2 station when installed in the next FY.

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

Before reporting any data to the DOE for Task 8.0, a comprehensive data acquisition system needed to be specified and installed. This included the specification and selection of the power meter sensing equipment and associated signal conditioning equipment. Furthermore, detailed design effort was needed to define the component architecture to acquire, buffer, and transfer the power data to a file type accessible for data manipulation. The selected architecture utilizes a programmable logic controller to totalize the data from the power meters. These signals are also connected to the SunHydro programmable logic controller to provide a single collection point for energy usage and vehicle fill data. The SunHydro#1 data acquisition system generated data for two reports to the Fuel Cell Electric Vehicle Infrastructure Composite Data Product during the previous FY.

CONCLUSIONS AND FUTURE DIRECTIONS

Future Directions

- Show measurable reduction in dryer purge loss of SunHydro#1 with 57 bar hydrogen generation
- Validate SunHydro#1 dispensing capacity increase
- Validate compressor improvement or increased throughput capacity with 57-bar inlet pressure
- Install and validate novel compact and non-EX rated component arrangement of SunHydro#2
- Install data acquisition for SunHydro#2
- Continue reporting operational data to Fuel Cell Electric Vehicle Infrastructure Composite Data Product database

FY 2014 PUBLICATIONS/PRESENTATIONS

1. AMR 2014 Moulthrop TV-012

REFERENCES

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