

VII.B.3 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, Inc. (APCI), Allentown, PA

Project Start Date: December 1, 2012

Project End Date: June 30, 2017

Overall Objectives

- Validate energy savings of up to 11 kWh/kg H₂ 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) 2016 Objectives

- 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 Program 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 isn't a 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 2016 Accomplishments

- Installed Sun Hydro 2 compact station at a National Park Service (NPS) maintenance facility in Washington, D.C.
- Validated compact station installation footprint and code-directed clearances.
- Reported SunHydro 1 hydrogen energy usage data to fuel cell electric vehicle (FCEV) Infrastructure Composite Data Product (CDP) database.



INTRODUCTION

This multi-year, two-phase 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 in Washington, D.C., 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 ft × 8 ft 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, and 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 have been accomplished based on the following approaches. For



FIGURE 1. SunHydro 1 and SunHydro 2 stations

higher pressure, higher efficiency PEM cell stacks, Proton has qualified a 30% reduction in PEM thickness for 15 bar 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 was built using the thinner material and advanced catalyst deposition to show the performance improvement at full-scale compared to previous technology stacks. We upgraded 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 results in better combined compression energy and higher throughput capability.

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

RESULTS

Task 1.0: Validate full-scale 57 bar higher efficiency PEM cell stack. Work on this task was concluded during the last reporting period. 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 H₂ over the 30 bar commercial version. 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 h through the second and third quarter of 2014. This stack continues to operate stably at 30 bar and remains capable of 55 bar operating pressures through the current reporting period. Most recent demonstrated operating voltages of 2.03 VDC/cell, a performance improvement of 120 mV over baseline, is routinely achieved on Proton's 0.73 ft² active area commercial cell stacks. Based on this 120 mV per cell improvement, we have demonstrated energy savings of 3.2 kWh/kg H₂.

Task 2.0: Validate full-scale 57 bar, 65 kg/d hydrogen generator. Work on this task was concluded during the last

reporting period. 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. Specific energy data from the upgraded 55 bar C Series electrolyzer and the fueling station compressor were gathered in kWh/kg H₂ 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 H₂ and a compressor energy reduction of 0.3 kWh/kg H₂ for a total savings of 1.8 kWh/kg H₂, halfway toward the statement of project objectives goal of 3.6 kWh/kg H₂.

Task 3.0: Validate higher addressable capacity composite hydrogen storage tubes. Storage tube validation continues as the SunHydro 1 station continues to service vehicles and as SunHydro 2 comes on line in 2016. The newer Type II SunHydro 1 tubes serve as the primary bank as they are used first to fill; the other three banks of previous generation Type II tubes serve to top up. On average the new tubes are pressure cycled three days per week from 89 MPa to less than 46 MPa based on the demands of an average fleet size of 10 fuel cell vehicles. A second set of storage tubes has entered into validation testing with the deployment of SunHydro 2 station in 2016.

Task 4.0: Validate compressor increased throughput capacity with 57 bar input. Work on this task was concluded during the last reporting period. With the successful completion of Task 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 1.5 kWh/kg H₂ and a compressor energy reduction of 0.3 kWh/kg H₂ for a total savings of 1.8 kWh/kg H₂, halfway toward the statement of project objectives goal of 3.6 kWh/kg H₂.

Task 5.0: Hydrogen station safety operation procedure and EX (potential hazardous area) zone review. In prior reporting periods, results of Chapters 6, 7, and 13 of the National Fire Protection Agency (NFPA) 2 “Hydrogen Technologies Code” [1] 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 non-classified areas. As previously reported, this compact hydrogen station arrangement and a corresponding site general arrangement permitted was granted by Braintree, Massachusetts, authorities in October 2014.

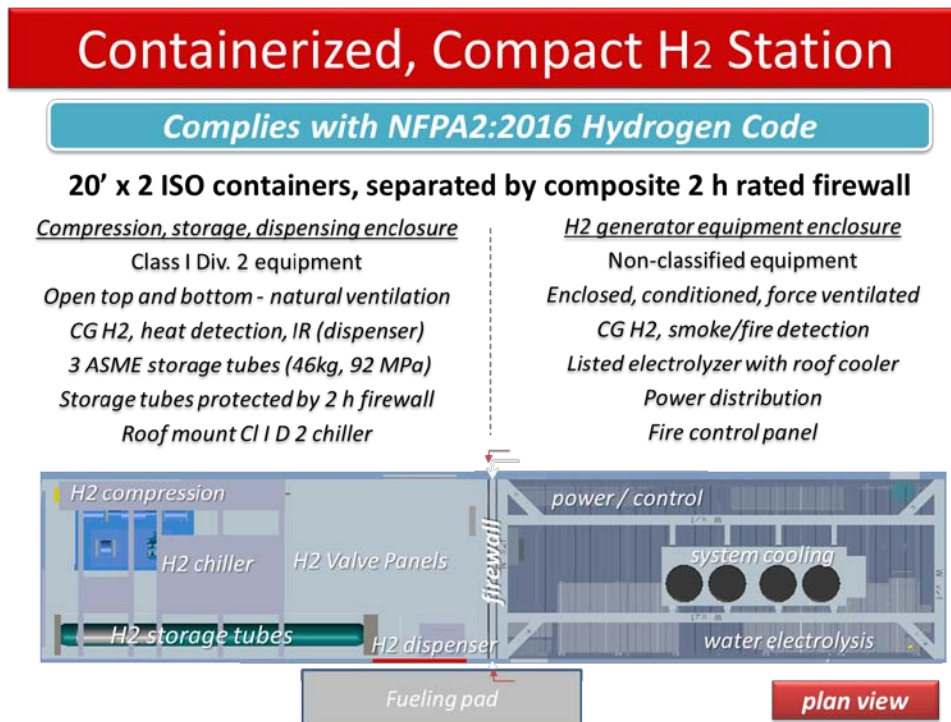
The station hardware was subsequently redirected to provide demonstration of a compact hydrogen station infrastructure in Washington, D.C. In this reporting period,

this compact hydrogen station was successfully installed at the NPS Brentwood Maintenance Facility in Washington, D.C., after a siting review that addressed tight clearance requirements of the NPS installation site. A safety operating and emergency response procedure was approved, then used to train more than 200 Washington, D.C., firefighters and first responders.

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 now preparing the 2018 update to the original 2016 edition of NFPA 2. Improvements to Chapter 7 concerning hydrogen equipment in enclosures, specific code that addresses hydrogen processing equipment and storage in prefabricated intermodal enclosures, will help code officials with permitting compact containerized hydrogen fueling stations.

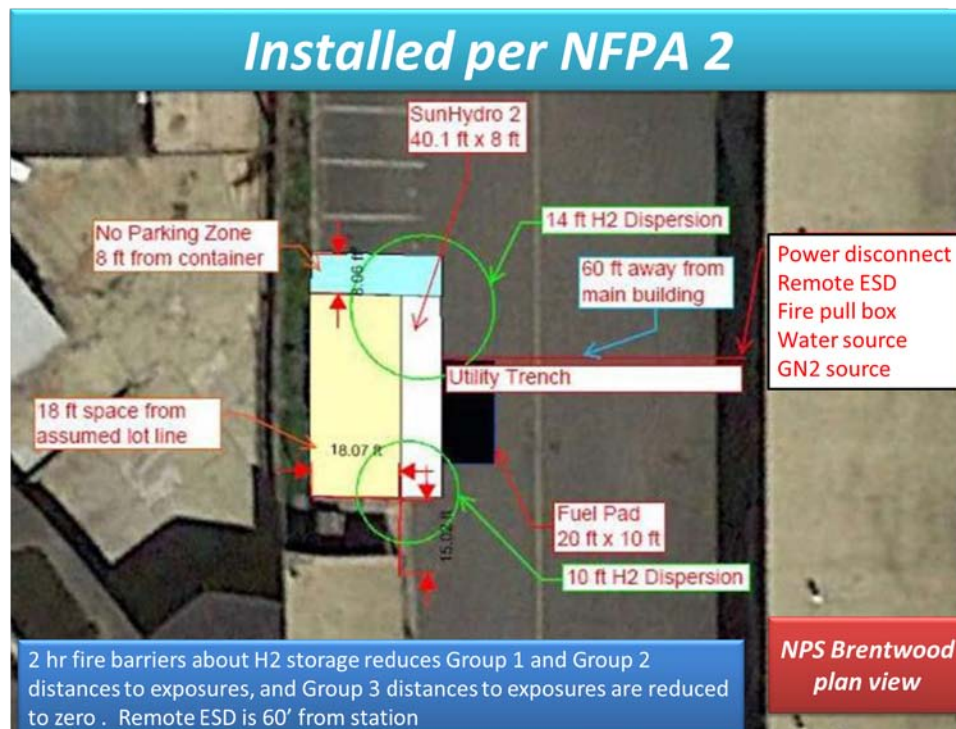
Task 6.0: Validate novel compact and non-EX rated component arrangements. The compact SunHydro hydrogen fueling station was formally opened in July 2016 at the NPS Brentwood Maintenance Facility in Washington, D.C., a validation of the 8 ft × 40 ft compact station footprint goal. Component general arrangement is shown in Figure 2, and separation distances to site exposures are shown in Figure 3. 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. Installation effort is confined to pouring three concrete footings, construction of a concrete vehicle fueling pad, and supply of electrical and water utilities. NFPA 2 hydrogen code permits reduction of separation distances to near-zero values when a 2-h 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 enabled SunHydro 2 station installation within the tight confines of the NPS Brentwood site.

Task 7.0: Hydrogen station data acquisition system & 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 CDP. Identical data acquisition equipment is installed in SunHydro 2 and is now active ready to acquire data as the station starts to be used. Four reports of SunHydro 1 station data were prepared for the FCEV Infrastructure CDP during the previous fiscal year, 11 in total since the start of our contract.



CG – Combustible gas sensor

Figure 2. Arrangement, hydrogen generator container, SunHydro concept, combined containers



ESD – Emergency shutdown device; GN₂ – Nitrogen, gaseous

FIGURE 3. General arrangement and distances to exposures, SunHydro 2 station

CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions

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

Future Directions

- Initiate SunHydro 2 data acquisition CDP operational data reporting.
- Continue reporting SunHydro 1 CDP operational data reporting.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. AMR 2016 moulthrop TV-012.

REFERENCES

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