III.16 Reference Station Design, Phase II

Ethan S. Hecht (Primary Contact), Joseph Pratt
Sandia National Laboratories
P.O. Box 969, MS 9052
Livermore, CA 94550
Phone: (925) 294-3741
Email: ehecht@sandia.gov

DOE Manager: Neha Rustagi
Phone: (202) 586-8424
Email: Neha.Rustagi@ee.doe.gov

Project Start Date: February 2016
Project End Date: March 2017

Overall Objectives

- Provide publicly available templates and information on representative hydrogen fueling station designs to enable quick assessment of the suitability of a particular site for a hydrogen station.
- Identify contributors to poor economics and areas of research needed for certain station designs.

Fiscal Year (FY) 2017 Objectives

- Provide near-term economic assessment of the cost of hydrogen for stations supplied by centrally produced, delivered hydrogen and those with hydrogen produced on-site.
- Illustrate the economic drivers for hydrogen delivery costs.
- Show how to reduce capital and operating costs through design decisions and operating methods.
- Demonstrate footprint reduction methods while maintaining compliance with current codes.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(A) Lack of Hydrogen/Carrier and Infrastructure Options Analysis

(E) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

(I) Other Fueling Site/Terminal Operations

(K) Safety, Codes and Standards, Permitting

Contribution to Achievement of DOE Hydrogen Delivery Milestones

This project will contribute to achievement of the following DOE milestones from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 1.5: Coordinating with the H_2 Production and Storage sub-programs, identify optimized delivery pathways that meet a H_2 delivery and dispensing cost of <$2/gge for use in consumer vehicles. (4Q, 2020)
- Milestone 6.3: By 2020, reduce the cost of hydrogen delivery from the point of production to the point of use in consumer vehicles to <$2/gge of hydrogen for the gaseous delivery pathway. (4Q, 2020)

FY 2017 Accomplishments

- Demonstrated that for current stations, those served by centrally produced, delivered gaseous hydrogen are more economical compared to those which generate hydrogen on-site via steam methane reforming or electrolysis, and the economic drivers for this finding.
- Depicted and described how modular stations and stations with on-site production have a substantially decreased lot size requirement due to reduced equipment size, reduced truck access requirements, and reduced setback distances.
- Evaluated the economics of different station concepts and determined the lowest current hydrogen cost of $12.65/kg for a 300 kg/d modular station with delivered hydrogen at an installed cost of $1,360,000.

INTRODUCTION

For the wide-spread adoption of fuel cell electric vehicles, additional fueling stations need to be constructed in the United States. A wide variety of private and public stakeholders are involved in the development of this hydrogen fueling infrastructure. Each stakeholder has particular needs to be met in the station planning, development, and operation process. A sample of stakeholders and needs is given here.

- Station developers and operators: quick evaluation of potential sites and needs, lower investment risk, general cost and return estimates.
- Local authorities: understand devices, components in a typical station.

- Code developers: understand near-term needs for code refinement.
- Other analysis groups: tools and baseline for economic studies.
- Businesses, entrepreneurs, and research and development organizations: identification of near-term business solution and technology needs.
- Local municipalities and the general public: high-level understanding of typical stations lowering acceptance risk.
- Funding and financing organizations: understanding of current technological capabilities, costs, and market needs.

Hydrogen fueling station equipment, designs, and costs vary between developers and are often treated as proprietary information. While necessary from a business standpoint, this can hinder the ability to discuss station design details in a collaborative way. Publicly available templates of representative station designs can be used to meet many of the stakeholder needs outlined above. These reference stations help reduce the cost and speed the deployment of hydrogen stations by providing a common baseline with which to start a design, enable quick assessment of the suitability of a particular site for a hydrogen station, and identify contributors to poor economics and areas of research needed for certain station designs.

APPROACH

This work presents five new reference station designs for use by the hydrogen infrastructure community. The Phase 1 Reference Station Design Task [1] examined four build-on-site stations which obtained hydrogen from compressed gas or liquid delivery trucks. The current work builds on the Phase 1 work by producing designs and economic analyses of factory built modular stations and stations utilizing on-site generation, and also brings the cost of supplied hydrogen into the analysis. It includes one traditional design from the Phase 1 work to enable equal comparisons between all station types in the two works. For all station types, three capacities were examined: 100 kg/d, 200 kg/d, and 300 kg/d. The five station types developed in this work are:

- Conventional (assemble on-site) stations with hydrogen:
  - Delivered as compressed gas from a centralized, already operational production facility (baseline).
  - Produced on-site through steam methane reforming.
  - Produced on-site through electrolysis.
- Modular fueling stations with hydrogen:
  - Delivered as compressed gas from a centralized production facility.
  - Produced on-site through electrolysis.

RESULTS

The cost components of hydrogen fueling stations consist of capital cost of equipment, installation, site acquisition and development, and operating expenses. For conventional stations, capital costs of the equipment were estimated based on updated bills of material from the Phase 1 [1] work. Capital costs for modular stations and modular hydrogen production units were based on discussions with several manufacturers. Operation costs, such as the cost of electricity and other utilities, if necessary, were estimated using data from several sources.

Revenue was assumed to be solely from the sale of hydrogen. Operating expenses and revenue calculations depend on the assumed throughput of hydrogen. The same utilization profile used in the Phase 1 work [1] was used in this project to calculate throughput, although it was delayed in the onset year. This utilization model estimates that starting in 2017, 5% of station capacity will be utilized. As the number of fuel cell vehicles on the roads continues to increase, the utilization of stations is projected to increase, up to a maximum of 80% in 2026. All costs were combined with revenue to determine the overall cost of hydrogen to the station developer/operator such that the station would break even on investments in 7 years. Station developer/operator margin and retail fuel taxes will be added to the calculated hydrogen cost to determine the final price to the consumer, but both of these aspects were outside the scope of this project.

Because the costs in this project were estimated (typically averages of costs from various situations and/or a range of manufacturers), they will likely be different than that of an actual station. To correct for differences in up-front capital or installation costs of a real-world station, a graphical tool was developed to estimate the resulting change in hydrogen cost for a given change in investment cost. This is shown in Figure 1, for a 300 kg/d station. For example, the tool can be used to show that a decrease of $300,000 in (depreciable) up-front costs from that estimated herein for a 300 kg/d station would result in a corresponding $1.00/kg decrease in hydrogen cost. When trying to meet a <$2/gge (1 gge is 1 kg of hydrogen) cost target, the capital costs must be kept low and/or the economic assumptions (such as the utilization profile or the specification of breaking even in seven years) must be changed.

Economic results of the five different station concepts showed that stations served by centrally produced, delivered gaseous hydrogen are more economical compared to those which generate hydrogen on-site via steam methane

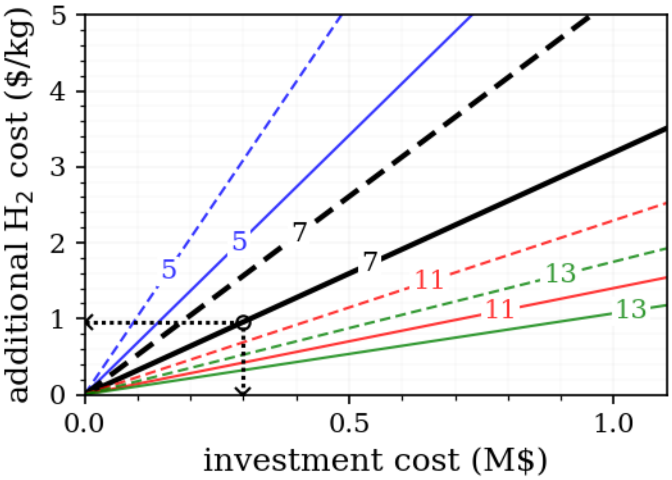

FIGURE 1. Additional cost of hydrogen as a function of the initial construction/capital investment for a 300 kg/d station. Numbers on the graph lines are the years required to break even on the investment (seven years was the baseline assumption for this project), solid lines are for a depreciable asset (on a 7-yr Modified Accelerated Cost Recovery System schedule, and dashed lines are for a non-depreciable asset).

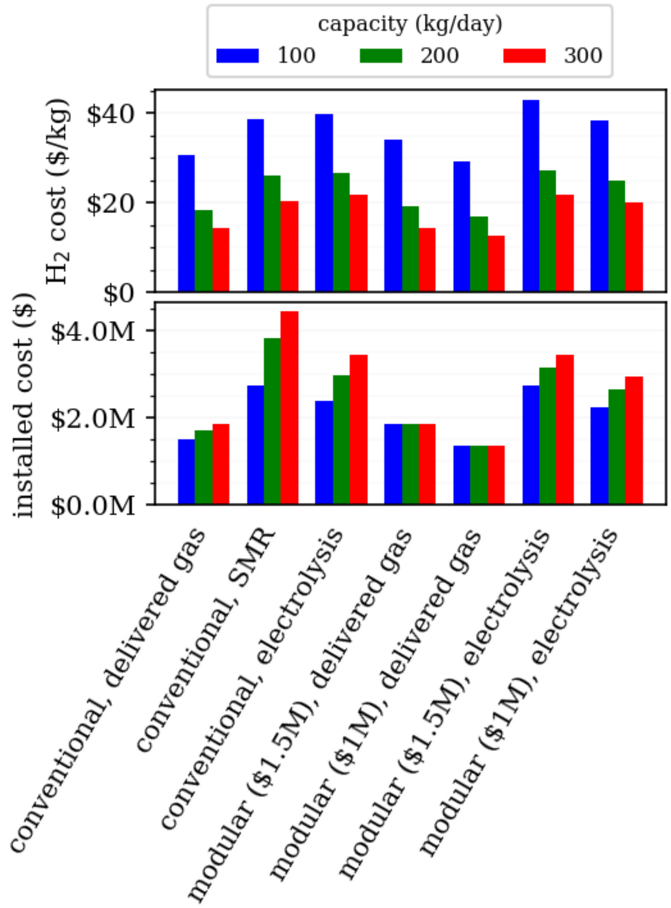

FIGURE 2. Hydrogen cost to break even at Year 7 (top), and installed cost (which includes site preparation, engineering and design, permitting, and component capital and installation costs) in 2016$ (bottom), for the stations analyzed in this work

reforming or electrolysis. Higher capacity stations were found to have a lower cost for hydrogen to break even at the same point in time compared to lower capacity stations. Use of the economic model specifying that a station would break even in Year 7 demonstrated that both 300 kg/d modular stations (at $1,500,000 for the uninstalled modular unit) and conventional stations with central hydrogen production and delivery in tube trailers, would have a hydrogen cost of $14.25/kg (a lower uninstalled modular unit price of $1,000,000 resulted in a hydrogen cost of $12.66/kg). On-site production stations, either through steam methane reforming or electrolysis, were shown to have significantly higher capital costs than delivered, centrally produced hydrogen. This increase in capital resulted in a hydrogen cost increase of $6–$10/kg, depending on the station capacity. While steam methane reforming capital costs were shown to be higher than electrolyzer costs, the electricity cost ended up making electrolyzer-supplied stations the most expensive option in terms of resulting cost per kilogram of dispensed hydrogen under the assumptions of this work. Full cost results are shown in Figure 2.

In addition to the economics, the station equipment was laid-out in typical land use arrangements, with the example of a modular station supplied by electrolysis shown in Figure 3. Modular stations and stations with on-site production were shown to substantially decrease the overall required lot size due to reduced equipment size, reduced truck access requirements, and reduced setback distances. The project report also includes piping and instrumentation diagrams of these station concepts, with system level requirements for components and instruments and an estimate of utility requirements which are intended to be useful for site screening.

CONCLUSIONS AND UPCOMING ACTIVITIES

The final report for Reference Station Design, Phase II details the economics of current hydrogen refueling stations, and includes some sketches of what these fueling stations might look like. It visually depicts the contributions to capital and operational costs of hydrogen for different station concepts, making it easy to find the largest contributors to a high cost of hydrogen to the consumer. This information can be used to devote research and development towards these high contributors. At the station, the dispenser, compressors, and chillers are expensive pieces where additional development, or higher volume production could reduce station costs. For electrolysis, the purchase of low-priced electricity could serve to make on-site production cost competitive with central production and delivery. The report

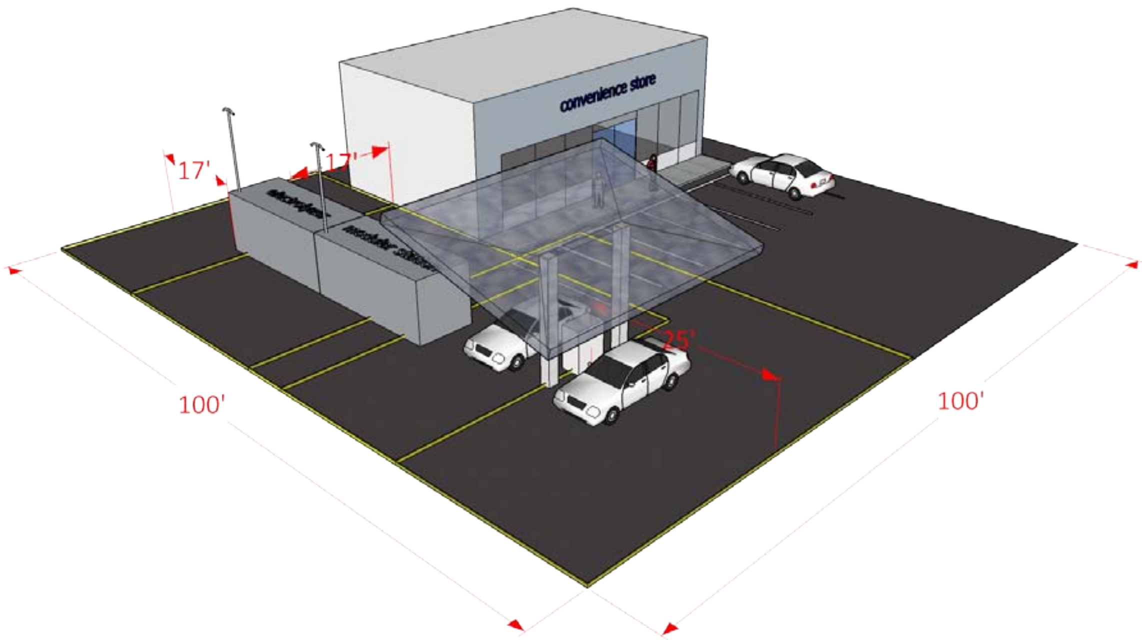

FIGURE 3. Renderings of a modular station layout with an electrolyzer for on-site production, with a small, reduced footprint

enables the comparison of different station concepts that could be implemented in various market scenarios.

As more fuel cell electric vehicles hit the roads, even larger capacity fueling stations will be needed in urban areas. Ongoing work under H2FIRST is addressing this challenge by considering unique strategies for footprint reduction of hydrogen fueling stations that could be suitable for construction in urban areas (e.g., San Francisco, Boston, New York). The work is considering new delivery concepts, potential changes to the fire code, and underground and rooftop storage concepts.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. E.S. Hecht, J. Pratt. "Comparison of conventional vs. modular hydrogen refueling stations, and on-site production vs. delivery," Technical Report SAND2017-2832, Sandia National Laboratories, March 2017. (available at https://energy.gov/eere/fuelcells/h2first)

1. E.S. Hecht, J. Pratt, "Reference Station Design, Phase II: Comparison of conventional vs. modular hydrogen refueling stations, and on-site production vs. delivery," presented at the 2017 DOE Hydrogen and Fuel Cells Program Annual Merit Review, Washington D.C., June 9, 2017. (SAND2017-4928 C).

REFERENCES

1. J. Pratt, D. Terlip, C. Ainscough, J. Kurtz, and A. Elgowainy. H2FIRST reference station design task. Technical Report SAND2015-2660R, Sandia National Laboratories, April 2015. (available at http://energy.gov/eere/fuelcells/h2first)