Hydrogen Stations for Urban Sites

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Project Start Date: March 2017
Project End Date: July 2019

Overall Objectives

- Create compact gaseous and delivered liquid hydrogen reference station designs appropriate for urban locations, enabled by hazard/harm mitigations, near-term technology improvements, and layouts informed by risk (performance-based design).
- Disseminate results and obtain feedback through reports and a workshop with stakeholders representing code/standard development organizations, station developers, code officials, and equipment suppliers.
- Identify and provide designs for compact station concepts that enable siting of three times the number of stations in the dense urban example of San Francisco.

Fiscal Year (FY) 2018 Objectives

- Produce layouts for base case stations, modified delivery stations, stations adhering to new National Fire Protection Association (NFPA) 2 requirements, risk-informed stations, and underground storage and provide to NFPA 2 collaborators for review and feedback.
- Disseminate draft results including base case designs, modified delivery stations, stations adhering to new NFPA 2 requirements, designs informed by risk, stations with underground storage, and rooftop storage at a workshop. Include at least three designs with equivalent risk to the baseline designs and obtain feedback at the workshop with at least 10 stakeholders representing code/standard development organizations, station developers, code officials, authorities having jurisdiction, and equipment suppliers.

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[1]:

A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis

I. Other Fueling Site/Terminal Operations

K. Safety, Codes and Standards, Permitting.

Contribution to Achievement of DOE Delivery Milestones

This project will contribute to the 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 1.4: Go/no-go on the use of liquid hydrogen carriers as an effective means of hydrogen delivery. (4Q, 2019)
- 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/gallon gas equivalent of hydrogen for the gaseous delivery pathway. (4Q, 2020)

This project will help to inform and enable siting of hydrogen fueling stations into dense urban areas, which will greatly improve the station economics. These siting challenges are especially

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

acute for delivered liquid hydrogen stations, and this project addresses this issue directly.

FY 2018 Accomplishments

- Completed preliminary designs for delivered gas, delivered liquid, and on-site electrolysis production stations for base case, alternate delivery, new NFPA 2, underground storage, rooftop storage, gasoline colocation, and risk-informed stations.
- Performed risk-informed hazard analysis for base case stations and for alternate methods, indoor location, and alternate pipe size designs.
- Presented preliminary results and obtained feedback at workshop in Livermore, California.

INTRODUCTION

Additional fueling stations need to be constructed in the United States to enable the widespread adoption of fuel cell electric vehicles. A wide variety of private and public stakeholders are involved in the development of this hydrogen fueling infrastructure. Each stakeholder has particular needs in the station planning, development, and operation process that may include evaluation of potential sites and requirements, understanding the components in a typical system, and/or improving public acceptance of this technology. Publicly available templates of representative station designs can be used to meet many of these stakeholder needs. 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, enabling quick assessment of the suitability of a particular site for a hydrogen station, and identifying contributors to poor economics and research and development areas for certain station designs.

This project builds on past and current reference station design tasks. The Reference Station Phase 1 design task identified desirable fueling station parameters (e.g., capacity, consecutive fills) and down-selected many permutations to five economically favorable layouts, two of which stored hydrogen as a liquid. These layouts and stations would meet projected near-term market needs using current or near-term technology. One of the recommendations from this work was the need for science-based methods to reduce the setback requirements for liquid stations if they are to achieve market penetration in urban areas. The Phase 2 Reference Station design task considered hydrogen production (and delivery) costs, and modular station design layouts, but not for stations that store hydrogen as a liquid, and only using current technology and fire code separation distances.

APPROACH

In this project, we are continuing the previous reference station efforts by developing realistic potential layouts of gaseous and liquid hydrogen stations (both greenfield and colocated with gasoline) in compact footprints suitable for deployment in dense urban centers. In contrast to previous efforts, the Reference Stations for Urban Sites project considers stations that may not be attainable with today's technology or permissible with current prescriptive codes and standards. These reference stations include justification of their safety (e.g., through a risk assessment) and/or identify high-priority development needs (e.g., revision of the fire codes) to enable these designs to be approved by local authorities having jurisdiction now or in the near future. In particular, this project includes footprint reduction by considering alternative gaseous and liquid hydrogen delivery vehicle designs, the impact of proposed changes to NFPA 2-prescribed setback distances (which are currently under review), station layouts informed by risk assessment rather than prescriptive setback distances, layouts with gaseous or liquid hydrogen storage underground, and rooftop installations.

We do not attempt to redesign existing hydrogen fueling station equipment in this project but rather focus on the application and layout of that equipment. The tools developed by the Fuel Cells Technology Office Safety Codes and Standards effort at Sandia National Laboratories are used in this project to engineer reference station designs. Whereas the Sandia National Laboratories safety codes and standards efforts are focused on development of models and tools for assessing risk, this Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project effort is focused on application of these tools to real-world designs. As with other reference station projects, cost models will also be developed for these designs. Because the reference stations in this project may include the use of equipment that has not yet been developed, some cost determinations will be estimates based on component-level modifications of previous reference station projects.

RESULTS

Initially, the work focused on creating and refining designs and assessing the associated safety of three base stations with delivered gas, delivered liquid, and on-site production via electrolysis. This involved sizing the stations to accommodate 600 kg of hydrogen dispensed per day, including sizing of storage tanks, pipe sizes, and equipment. Additionally, the fueling stations incorporate a number of design choices not related to the hydrogen system itself: traffic flow, parking, the delivery truck path, and a convenience store. Any changes to design choices or assumptions required an update to all aspects of the designs (including the calculation of setback distances and footprint) as well as the risk hazard scenario calculations. The base case for a delivered gas station design is shown in Figure 1.

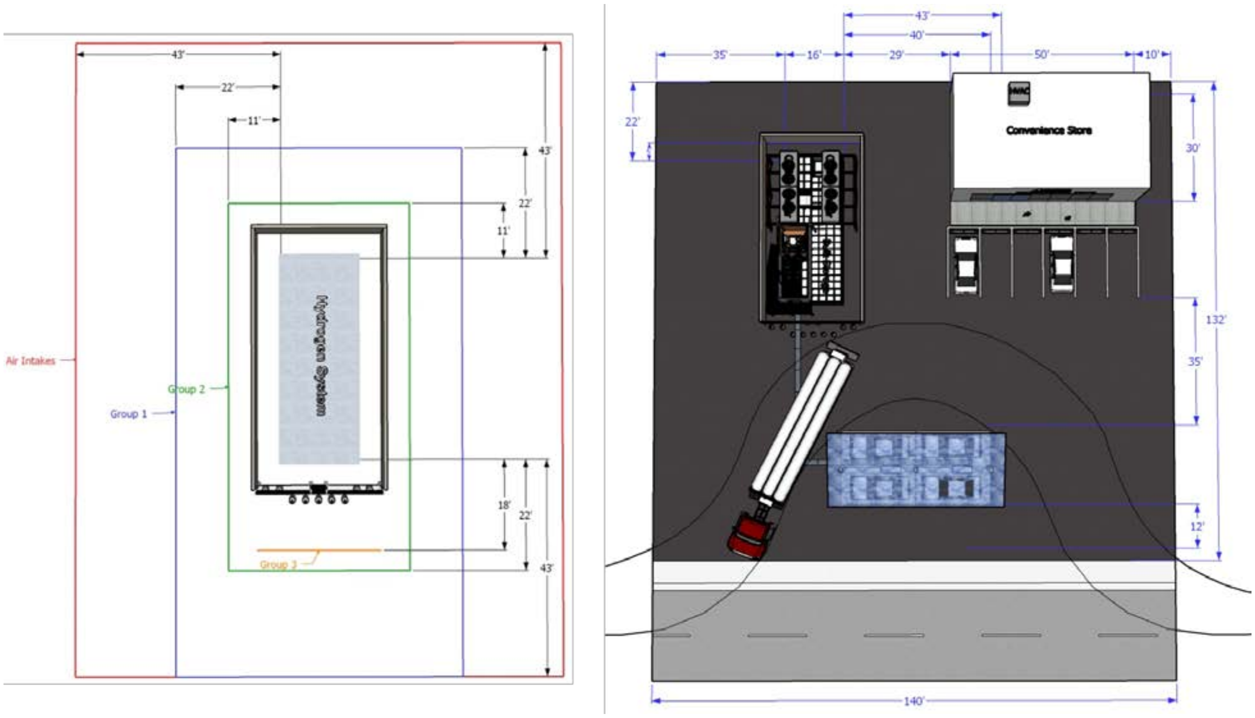

Figure 1. Delivered gas base case footprint, showing NFPA 2 setback distances on the left and full station footprint on the right

Subsequent designs deviated from these base cases for comparison purposes. A review of NFPA 2 requirements cited in the base cases was used to look for proposals to NFPA 2 that may affect these requirements in the next edition of the code. These proposals are currently under review and subject to change, so these analyses may or may not be valid when the next NFPA 2 edition is released. However, it is still useful to consider changes in the next version of the code in order to see how this would affect the reference station designs. Many requirements appear to be unchanged in the next (draft) edition of the code (at least as of this writing), but bulk gaseous setback distances have been reduced significantly, especially Group 1 exposures (which include air intakes and lot lines). Additionally, bulk liquid storage systems that also have bulk compressed hydrogen gas are currently treated as liquid-only (a peculiarity pointed out by this project team); this has been changed in the next (draft) edition. Both of these changes affect the setback distances that the hydrogen system uses and have an impact on station footprint. The effects of these changes are shown in Figure 2.

Although the overall project considers only over-the-road (not pipeline) hydrogen delivery to refueling stations, the assumptions made in the delivery pressure, delivery capacity, and physical dimensions of the delivery truck can have a significant impact on the reference station design and footprint. Low-pressure (and low-capacity) gaseous delivery means that the delivered gaseous reference station would need an unrealistically high number of deliveries to operate near capacity. High-pressure (and higher capacity gaseous) deliveries would alleviate this. Additionally, the higher pressure allows for a smaller physical footprint of the delivery truck, meaning it could be much more maneuverable within the station area. Conversations with experts indicated that, especially for urban sites, the truck should be able to maneuver within the station footprint, rather than assuming the truck can pull directly in or out of the station. Current delivery trucks for liquid hydrogen tend to be very large, with more than enough capacity for multiple stations. Therefore, considering a smaller truck (with still more than enough capacity for an individual station) will similarly increase maneuverability within the station footprint. The largest reduction in delivery truck size considered was for liquid hydrogen delivery; the effect of this modified truck path on station footprint is illustrated in Figure 3.

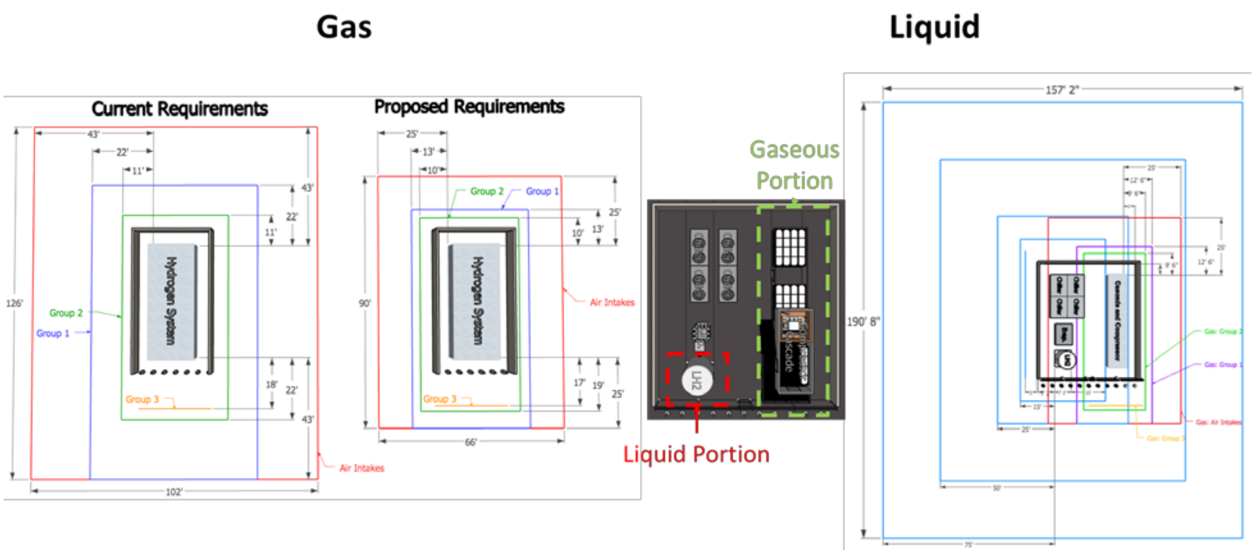

Figure 2. Proposed changes to NFPA 2 setback distances for bulk gaseous hydrogen storage on the left and bulk liquid hydrogen storage on the right

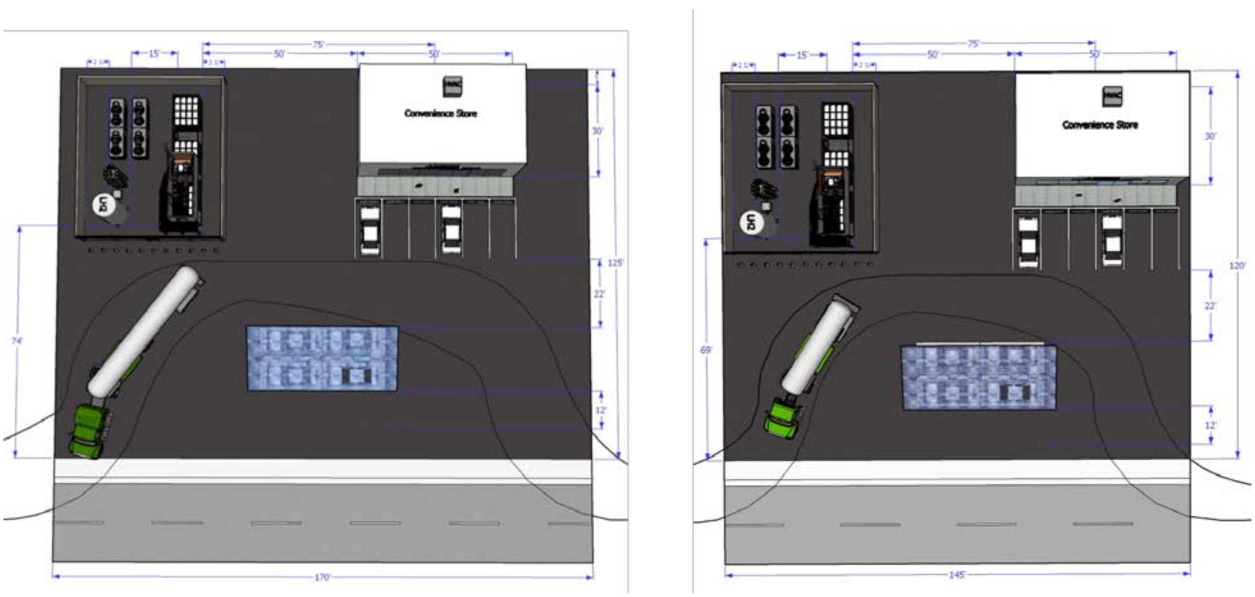

Figure 3. Effect of smaller delivery truck path on full station layout for delivered liquid base case on the left and alternate delivery truck size on right

Another set of designs focused on storing the hydrogen either below ground (direct buried or in a vault) or above ground on an elevated platform. It is expected that both methods would increase the capital cost of the station, although this has not been specifically evaluated yet. Both methods achieved reductions in the refueling station lot size, but the way NFPA 2 is currently written, both of these station designs would need to locate equipment in nonintuitive ways. For example, the underground direct-bury system designs had a very large layout of underground pressure vessels, each of which needed to be connected to the central at-grade equipment enclosure via welded pipes that are also underground. By contrast, the elevated designs required a huge amount of very heavy equipment be located a significant distance off the ground; it is not clear if any advantage to reducing setback distances can be gained from such a design.

Another set of designs considered the colocation of hydrogen refueling systems on the same lot as gasoline vehicle refueling. This led to larger lot sizes due to the additional fueling capacity, but the gas and liquid hydrogen systems that had delivery did not have a significant increase due to the fact that the gasoline delivery truck could use the same truck path as the hydrogen. By contrast, the electrolysis system with no hydrogen delivery had a large increase in lot size because the gasoline delivery truck needed a large path to be incorporated. The full layouts for delivered gas and electrolysis hydrogen refueling stations colocated with conventional fueling stations are shown in Figure 4.

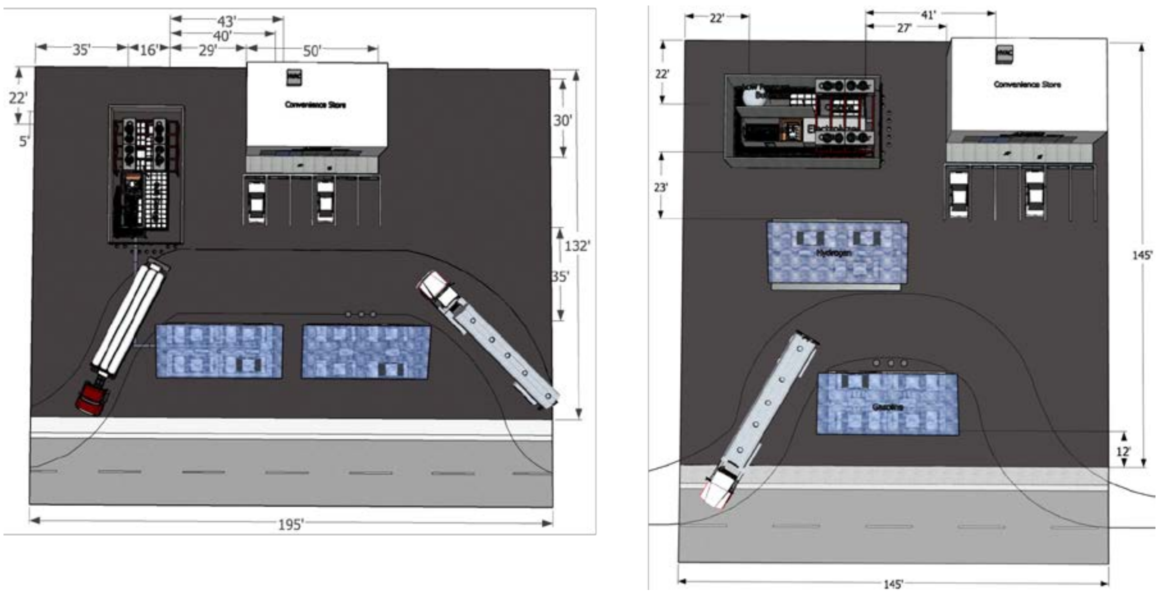

Figure 4. Colocation of hydrogen and conventional refueling stations for delivered gas on the left and electrolysis on the right

A final set of designs focused on other designs that use a performance-based design framework to justify alternate means for not meeting particular setback distances. This was applied to a bulk delivered liquid system that did not meet some of the longest setback distances, but still needed to achieve equivalent levels of safety risk. This analysis led to the identification of some specific issues with the current methodology (as outlined in NFPA 2), which will be addressed next FY. Other designs considered in this category actually met code requirements but seemed to be nonstandard in other ways, such as locating the bulk hydrogen system indoors or changing pipe sizes to reduce the pipe diameter (and associated setback distance). All of these designs achieved refueling station footprint reductions, but it is not clear if they would be technically realistic or economically viable.

Preliminary results for all of these designs and analyses were presented at a workshop in Livermore, California, to various industry experts and stakeholders. This workshop helped identify issues in the analysis that will be addressed next FY but also helped to give confidence to other designs that did not seem to have any significant issues. The preliminary station footprint area values are shown in Table 1, along with how those areas compare to the base case. These values will change as the designs are updated and modified in the next FY.

Table 1. Summary of Preliminary Hydrogen Refueling Station Lot Sizes and Comparison to Base Case Designs

Scenario	Total Lot Area (ft^2)	Reduction from Base Case
Base Case Gas	**18,480**	–
New NFPA Separation Distances	16,240	12.1%
New Delivery Single Truck	16,500	10.7%
New Delivery Double Truck	16,500	10.7%
Gasoline Colocation	25,740	39.2% (Increase)
Underground Direct-Bury	15,400	16.7%
Underground Vault	13,720	25.8%
Rooftop Storage	16,000	13.4 %
Non-Prescriptive Gas	14,950	19.1%
Base Case Liquid	**21,250**	–
New NFPA Separation Distances	18,252	14.1%
New Liquid Delivery	17,400	18.1%
Gasoline Colocation	22,040	3.7% (Increase)
Underground Direct-Bury	15,515	27.0%
Rooftop Storage	19,840	6.63 %
Non-Prescriptive Liquid	12,992	38.9%
Base Case	**12,051**	–
New NFPA Separation Distances	9,180	23.8%
Gasoline Colocation	21,145	75.5% (Increase)
Rooftop	11,020	8.5%

CONCLUSIONS AND UPCOMING ACTIVITIES

On-site production, smaller delivery truck paths, upcoming NFPA 2 requirements, and underground storage can all achieve significant station footprint reduction to varying extents. The economic trade-offs to these design choices have not yet been evaluated.

In the next FY, feedback from the workshop will be incorporated into the station designs. This will also include modifications to the performance-based framework used to justify alternate risk-informed methods for meeting NFPA 2 requirements. An economic evaluation will be performed on the station designs to illustrate trade-offs for various designs that can reduce station footprint. This will also help to show the economic value of reducing the footprint in addition to the ability to site stations in more locations. Similarly, a national siting study will be performed to identify how different amounts of footprint reductions can increase the number of potential sites available for hydrogen fueling stations. The improvements to the risk assessment, economic evaluation, and national siting study will help to identify and inform future needs to further efforts to expand hydrogen fueling infrastructure.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. B.D. Ehrhart, G. Bran-Anleu, E.S. Hecht, C. Rivkin, A. Muna, E. Sena, "Reference Stations for Urban Sites Workshop," Presented preliminary results and obtained feedback from stakeholders in Livermore, CA, September 6, 2018. SAND2018-9895 PE.