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 organization, station developers, code officials, and equipment suppliers.
- Identify and provide designs for compact station concepts that enable siting of 3 times the number of stations in the dense urban example of San Francisco.

Fiscal Year (FY) 2019 Objectives

- Complete a revised draft report, based on workshop feedback, that includes assessment of layout suitability in at least three cities (e.g., San Francisco, New York, Boston).
- Provide designs for compact station concepts that enable siting of 3 times the number of hydrogen fueling stations identified as "Potential" in the Harris et al. report for the dense urban example of San Francisco, where one site out of seven was identified.

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 Milestones

This project contributes 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 1.4: 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/gge 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. The siting challenges related to separation distances are especially acute for delivered liquid hydrogen stations, and this project addresses this issue directly.

FY 2019 Accomplishments

- Revised station designs based on workshop feedback from FY 2018.
- Siting study assessed suitability of locations for refueling stations (hydrogen only and co-located with gasoline) in seven major U.S. cities.

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

- Economic comparison illustrated trade-offs for benefit of smaller lot size against cost of modifying design to obtain the smaller footprint.
- Completed the draft project report and sent it for feedback.

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 R&D 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 Reference Station Phase 2 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. We build on these tasks by considering larger stations suitable for urban areas.

APPROACH

This project continued previous Reference Station efforts by developing realistic potential layouts of gaseous and liquid hydrogen stations (both greenfield and co-located with gasoline) in compact footprints suitable for deployment in dense urban centers. In contrast to previous efforts, the Reference Stations for Urban Sites project considered stations that may not be attainable with today's technology or permissible with current prescriptive codes and standards. Results include an identification of 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 changes to National Fire Protection Association (NFPA) 2 prescribed setback distances, layouts with gaseous or liquid hydrogen storage underground, and rooftop installations.

We did not attempt to redesign existing hydrogen fueling station equipment in this project but focused on the application and layout of that equipment, using realistic sizing for components and tubing. The tools developed by the Fuel Cell Technologies Office safety, codes and standards effort at Sandia, as well as tools developed at Argonne National Laboratory, have been used in this project to engineer reference station designs. Base case stations for delivered gaseous hydrogen, delivered liquid hydrogen, and on-site gaseous hydrogen production via electrolysis were developed using a base set of assumptions resulting in estimates for the total area of a rectangular lot. Each of these three stations designs was then modified in five different ways to study the impacts of upcoming fire code changes, co-location with gasoline refueling, alternate delivery assumptions, underground storage of hydrogen, and rooftop storage of hydrogen, which resulted in a total of 32 different station designs. Once all the designs were complete and lot sizes estimated, these lot sizes were then compared to real-world refueling lot sizes in order to estimate how a smaller station could fit into more lots. Finally, an economic comparison estimated the cost of making a design change (such as burying the hydrogen storage underground) and compared this to the value of the reduced (or increased) land required due to the design change in order to compare the economic trade-offs that might arise from making these types of changes.

RESULTS

The base case designs for each of the three hydrogen sources (delivered gas, delivered liquid, and on-site electrolysis production) can be used as “reference” stations to inform different stakeholders around hydrogen refueling stations as well as provide a point of comparison for the other station designs considered. The footprint of these base case stations ranges from 13,221 to 21,250 ft^2, depending on the assumptions made regarding the delivery truck path and the source of hydrogen. The base case station design for delivered gaseous hydrogen is shown in Figure 1.

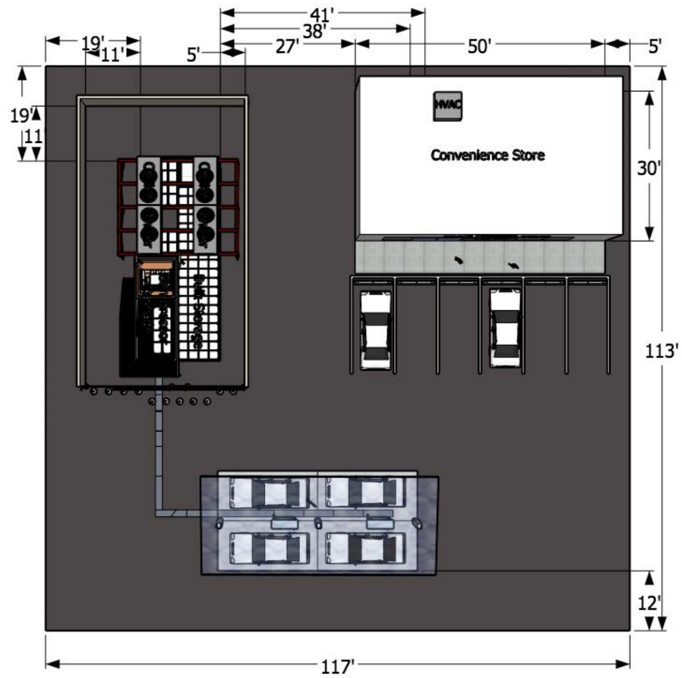

Figure 1. Top view of base case station design for delivered gaseous hydrogen showing NFPA 2 (2016 edition) setback distances, hydrogen system, convenience store, parking, and dispenser island.

Smaller delivery trucks lead to a 10.21% to 18.42% lot size area reduction relative to the respective base case designs. The elimination of the delivery truck path leads to smaller lot sizes and makes other factors (e.g., NFPA 2 separation distances) larger drivers of lot size. On-site production of hydrogen (i.e., the electrolysis cases in this study) does not need a hydrogen delivery truck to operate, which can lead to smaller lot sizes. However, if a station is unable to accept deliveries from a truck, the station could be without a source of hydrogen during downtime (scheduled or unscheduled) of the electrolyzer.

A significant focus of this study was the NFPA 2 requirements, especially the prescribed setback distances for bulk gaseous and liquid hydrogen storage. While some of the prescribed distances are large, these setback distances had a more nuanced impact on station lot size; for cases that assumed large delivery trucks, setback distances did not tend to drive lot size. New requirements in the new 2020 edition of the NFPA 2 code enable significant reductions in lot size for almost every case considered and cause non-hydrogen parts of the system (such as the convenience store, parking, and traffic flow) to become the main drivers of lot size. The most significant impacts are from the reduced setback distances for outdoor bulk gaseous storage and from a change in how setback distances should be applied to a system that has both bulk liquid and bulk gaseous hydrogen storage in the 2020 edition of NFPA 2. The change for bulk liquid systems enables the application of different setback requirements for the gaseous and liquid portions for a fueling station with bulk liquid storage—a change introduced directly due to work on this project.

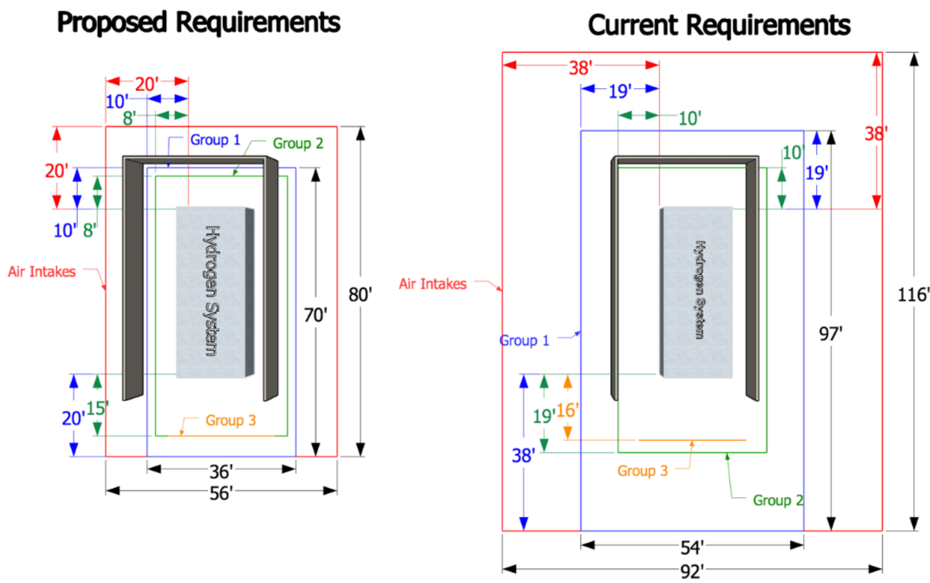

Figure 2. Top view of hydrogen system with prescribed setback distances for bulk gaseous outdoor hydrogen storage for 2016 edition (right) and 2020 edition (left) of NFPA 2 code.

Station designs with gasoline refueling co-located with hydrogen refueling result in 19.20% to 24.60% increases to lot sizes due to the four fueling positions for gasoline vehicles in addition to the four fueling positions for hydrogen vehicles. This type of design is most applicable to hydrogen add-ons to existing gasoline stations, though setbacks can be difficult for retrofits if existing utilities, buildings, air intakes, or other factors make placement of the hydrogen system difficult to comply with NFPA 2 requirements.

Station designs that utilize underground and rooftop storage can reduce footprint but may not be practical. Underground storage direct-bury requires that all lines also be buried to fully avoid setback distance requirements, and an underground vault for gaseous systems would need to be designed to prevent accumulation of hydrogen. Elevated hydrogen storage is highly visible, it does not eliminate setback distances (due to an unbroken line of sight), and the weight on the support structure is substantial. Both underground and rooftop storage may also be cost prohibitive, depending on the actual cost of burial or elevated structure and the market (cost of land) that the station would be in.

This study highlights how the current code could be applied to larger stations and can inform future code development. However, it must be stressed that these station designs have implicit assumptions and are simplified and idealized on rectangular lots, which often do not exist in the real world. Any specific actual refueling station location and design would need to consider many additional factors, such as utilities, the contents of neighboring lots, and the shape of the lot itself. However, station designs are useful for direct comparison to each other to quantify the effects of the various design changes made in this study.

The siting study compared lot sizes from existing gasoline stations as a proxy for future sites of hydrogen refueling stations. Smaller lot designs can be located in many more possible lots, making them much more flexible. A total of 227 existing gas station lot sizes were obtained from county property tax records from seven major U.S. cities in five states. Histograms showing the distribution of these lot sizes are shown in Figure 3.

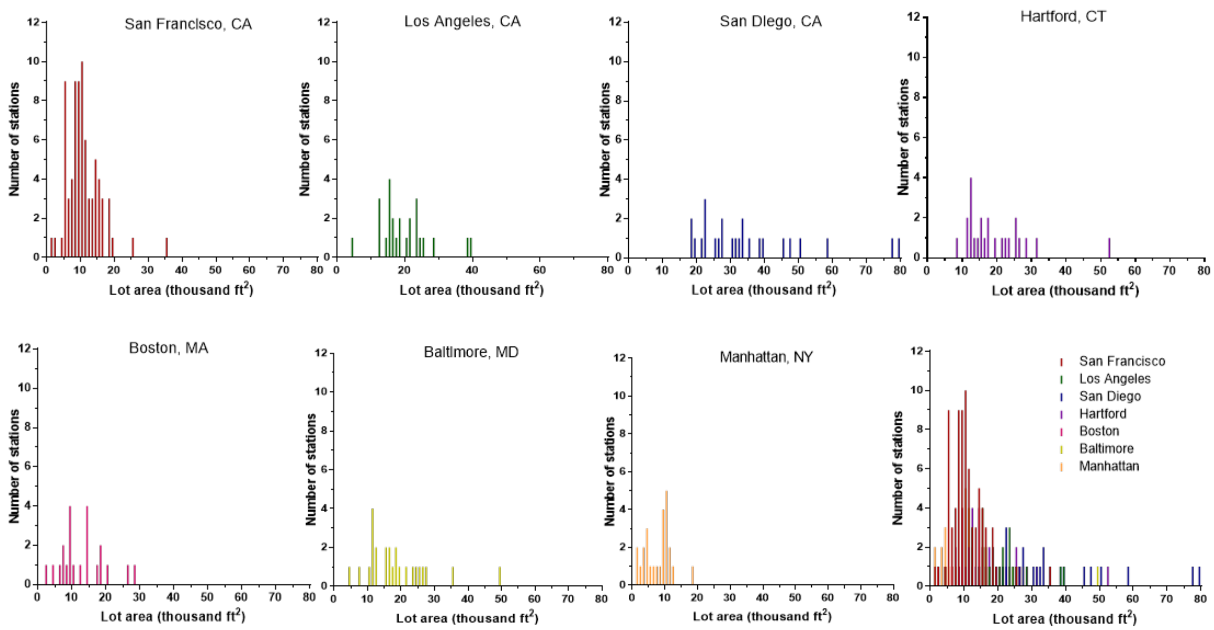

Figure 3. Lot size distribution of gasoline stations in selected cities in the five states

The economic comparisons showed that the cost of modifying a design (such as by burying the hydrogen storage) may or may not make direct financial sense in comparison to the land area reduced. Land values were obtained using county property tax records, and burial costs were estimated. An example economic comparison for underground storage is shown in Figure 4. Neither the siting study nor the economic comparisons are a complete examination of all possible configurations, but these analyses illustrate the benefit of smaller station footprints in the flexibility and cost savings they can provide.

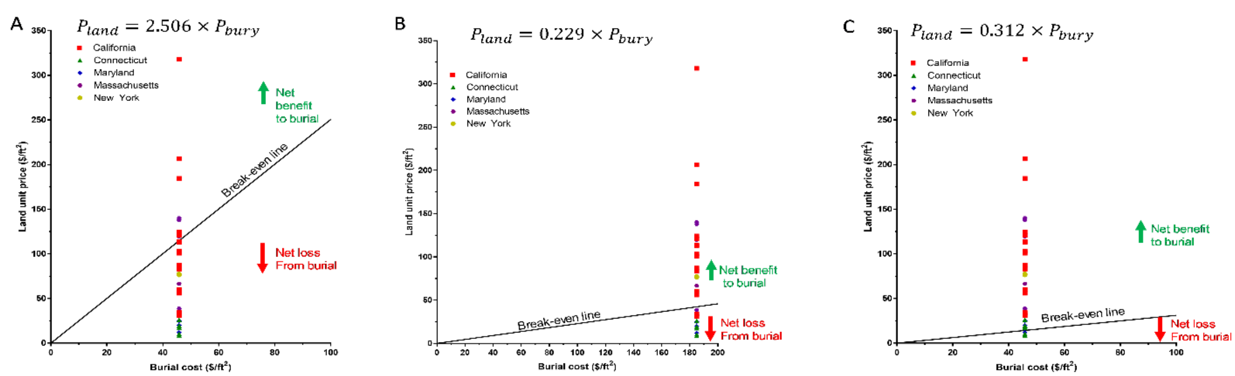

Figure 4. Comparison of burial cost and land unit price for (A) gaseous hydrogen underground direct-bury, with burial cost estimated at $45.8/ft²; (B) gaseous hydrogen underground vault design, with underground vault cost estimated at $185.0/ft²; and (C) liquid hydrogen underground direct-bury design, with burial cost estimated at $45.8/ft²

CONCLUSIONS AND UPCOMING ACTIVITIES

This study can be used as a reference for what different types of urban hydrogen refueling stations might look like, generic lot size requirements, and considerations for particular designs. The footprint of base case stations ranges from 13,221 to 21,250 ft^2, depending on the delivery truck assumptions made and the source of hydrogen. Smaller delivery trucks were considered, and these led to 10.21% to 18.42% reductions in lot size. Reduced setback distances for outdoor bulk gaseous storage, as changed in the 2020 edition of NFPA 2, lead to significant reductions, and a change in how setback distances apply to a system with both liquid and gaseous bulk hydrogen storage has an impact on liquid hydrogen station footprints. The prescribed setback distances for bulk liquid storage do not change in the upcoming 2020 edition of NFPA 2, and these distances can still be significant drivers of station layout. Hydrogen refueling stations co-located with gasoline refueling result in larger overall lot sizes but are the most applicable to hydrogen additions to existing gasoline stations; however, retrofits can be difficult if existing utilities, buildings, air intakes, or other factors make NFPA 2 compliance difficult. Station designs that utilize underground and rooftop storage can reduce footprint but may not be practical. Underground storage direct-bury requires that all lines also be buried to fully avoid setback distance requirements, and an underground vault for gaseous systems can lead to accumulation of hydrogen. Elevated hydrogen storage is highly visible, it does not eliminate setback distances (due to an unbroken line of sight), and the weight is huge. A siting study compared lot sizes from existing gasoline stations as a proxy for future sites of hydrogen refueling stations to illustrate the effect of differently sized lots; smaller lot designs are able to be located in many more possible sites, making them much more flexible. Economic comparisons were also performed to illustrate the impact of a smaller lot size by enabling a smaller lot to be purchased. The economic comparisons also showed that the cost of modifying a design (e.g., burying the hydrogen storage) may or may not make direct financial sense to offset the savings from land area reduction.

This project was completed in FY 2019; the final report will be published and publicly available soon, and no further work will be done on this effort. A valuable extension of this work could include significantly larger hydrogen systems of approximately 10 times the capacity that was examined here; these larger stations will become more important as more light-duty vehicles and heavy-duty trucks require hydrogen.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. Brian Ehrhart, Gabriela Bran-Anleu, Dongmei Ye, Ethan Hecht, Alice Muna, Ethan Sena, Chris LaFleur, and Carl Rivkin, "Reference Design of Hydrogen Stations for Urban Sites," Presentation at Joint Hydrogen Delivery, Codes & Standards, and Storage Tech Team Meeting, March 13, 2019. SAND2019-2734PE

2. Brian Ehrhart, Gabriela Bran-Anleu, Dongmei Ye, Ethan Hecht, Alice Muna, Ethan Sena, Chris LaFleur, and Carl Rivkin, "Hydrogen Stations for Urban Sites," Presentation at 2019 DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting, May 1, 2019. SAND2019-2422PE