Analysis of Cost Impacts of Integrating Advanced Onboard Storage Systems with Hydrogen Delivery

Amgad Elgowainy (Primary Contact), Ed Frank, Yusra Khalid, Krishna Reddi, and Jui-Kun Peng
Argonne National Laboratory
9700 South Cass Avenue
Lemont, IL 60439
Phone: (630) 252-3074
Email: aelgowainy@anl.gov

DOE Manager: Fred Joseck
Phone: (202) 586-7932
Email: Fred.Joseck@ee.doe.gov

Project Start Date: October 2017
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

Evaluate the impacts of onboard storage technologies for light-duty fuel cell electric vehicles (FCEVs) on the cost of hydrogen delivery and refueling.

Fiscal Year (FY) 2018 Objectives

- Determine the impact of dispensing pressure (P) and temperature (T) on the levelized cost of hydrogen delivery and refueling.
- Compare the levelized cost of hydrogen delivery and refueling of alternative onboard storage technologies to the delivery and refueling cost of baseline 700 bar onboard storage.

Technical Barriers

This project directly addresses Technical Barriers A, B, C, E, and I in the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.[1] These barriers are:

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

(B) Reliability and Costs of Gaseous Hydrogen Compression

(C) Reliability and Costs of Liquid Hydrogen Pumping

(E) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

(I) Other Fueling Site/Terminal Operations.

Contribution to Achievement of DOE Hydrogen Delivery Milestones

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

- Task 1.5: Coordinating with the Hydrogen Production and Storage subprograms, identify optimized delivery pathways that meet a hydrogen delivery and dispensing cost of <\$2/gge for use in consumer vehicles. (4Q, 2020)
- Task 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 2018 Accomplishments

- Developed a techno-economic model for evaluating hydrogen delivery and refueling cost for various onboard storage options.
- Studied the impact of various dispensing pressures and temperatures on the cost of hydrogen delivery and refueling of fuel cell light duty vehicles.

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

INTRODUCTION

The hydrogen refueling station cost is dominated by compressor, storage, and refrigeration costs, which accounted for approximately 50%, 15%, and 15% of total equipment cost, respectively. The refueling station costs contribute to approximately \$6–\$8/kg of the total dispensing cost to FCEV customers, which is currently at ~\$13–\$16/kg, including hydrogen production, delivery and dispensing costs [1, 2]. Thus, hydrogen refueling cost contributes approximately 50% of the total hydrogen dispensing cost to FCEV customers. This is mainly due to the need to compress hydrogen to very high pressures (~1,000 bar), and store hydrogen at such high pressure, in addition to precool hydrogen before dispensing into FCEV 700 bar tanks to enable fast dispensing (e.g., 5 kg in 3 minutes) without overheating the vehicle tank (i.e., to stay below 85°C).

This study evaluates the potential of reducing fueling-station costs by reducing compressor, storage, and/or refrigeration costs, assuming hypothetical vehicle onboard storage options that require a combination of dispensing pressure and temperature that satisfies the same onboard hydrogen storage capacity and fill rate. In particular, this study evaluated a dispensing pressure much lower than baseline 700 bar (e.g., 100 bar), and either cryogenic temperatures (e.g., liquid hydrogen [LH2] or liquid nitrogen [LN2] temperatures, such as these preferred by metal organic framework [MOF] onboard storage systems) or near ambient temperatures (300 K, e.g., temperatures preferred by metal hydride [MH] onboard storage systems). In addition, we examine physical storage systems that require dispensing at moderate pressures and cooling at cryogenic temperatures such as cryo-compressed hydrogen (CcH2) dispensing (350 bar and LH2 temperatures) and cold gas dispensing (400 bar and LN2 temperatures). We evaluate options where cooling takes place at the refueling station (e.g., -40°C for 700 bar dispensing and LN2 temperatures for dispensing into MOF) as well as options where cooling takes place at central facilities such as near or at LH2 and LN2 plants. Figure 1 shows a hydrogen refueling station configuration for a low pressure (100 bar) and near ambient temperature dispensing option. Figure 2 shows a cooling equipment configuration at a hydrogen refueling station that requires LN2 temperature cooling of both hydrogen gas and the onboard storage tank.

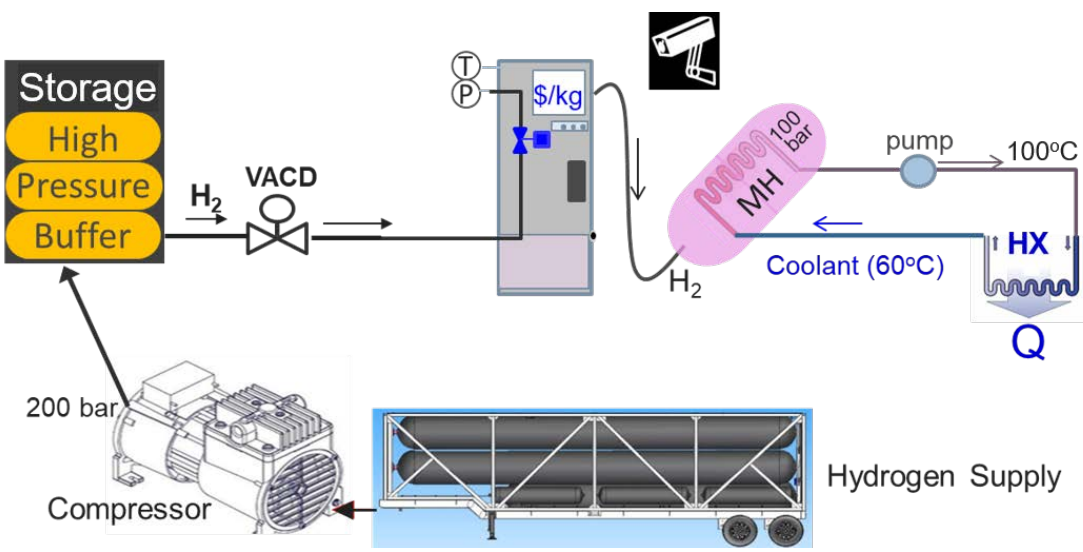

Figure 1. Hydrogen refueling station configuration for a low pressure (100 bar) and near ambient temperature dispensing

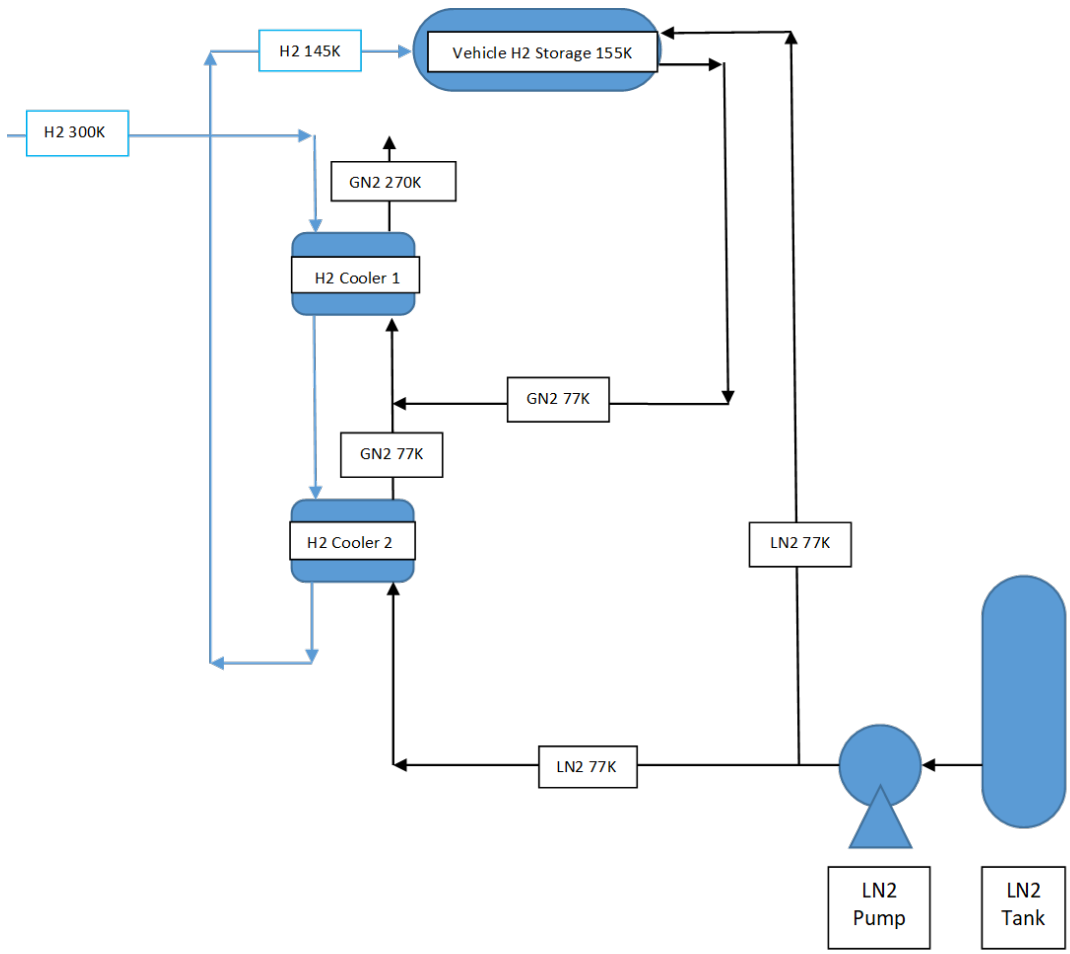

Figure 2. Cooling equipment configuration at hydrogen refueling station that requires LN2 temperature cooling of both hydrogen gas and onboard storage tank

For all evaluated dispensing options, we assume the following future scenario in an urban FCEV market:

- Market demand for 50,000 FCEVs (~30 metric tons per day)
- 37 hydrogen refueling stations (1,000 kg/day capacity, 80% capacity utilization)
- Cost reduction due to manufacturing volume/learning (20%–50% cost reduction depending on maturity of component technology)
- Truck delivery (500 bar tube trailers with 1 metric ton payload or LH2 tanker with 4 metric ton payload)
- Hydrogen production is located at 60 miles from city boundary.

APPROACH

- Define range of refueling conditions (e.g., P, T) for various onboard storage technologies
- Determine and size major items of refueling equipment (e.g., compressors, pumps, and heat exchangers)
- Acquire cost of delivery and refueling components for each onboard storage technology

- Implement refueling configuration and cost of components in the Hydrogen Delivery Scenario Analysis Model (HDSAM)
- Conduct techno-economic analysis and calculate the levelized refueling cost for baseline 700 bar onboard storage and the alternative storage options on a consistent basis (all costs are in 2016$).

RESULTS

Figure 3 shows the impacts of various FCEV onboard storage P and T requirements on the levelized cost of hydrogen refueling, assuming gaseous tube trailer delivery. The first bar on the left of Figure 3 represents the refueling station capital and operation costs, by component, for the baseline 700 bar, -40°C dispensing case (e.g., for refueling FCEV type III or type IV carbon fiber composite overwrapped pressure tanks). The second bar from the left shows a dramatic decrease in compression, and thus refueling cost, compared to the baseline 700 bar dispensing case, due to the reduction in dispensing pressure from 700 to 100 bar (see Figure 1). The precooling cost associated with -40°C in the baseline 700 bar dispensing case is matched by the heat exchanger cost in the near ambient temperature dispensing case, mainly due to its much higher heat rejection load (~1 MW) compared to the refrigeration load of ~20 kW associated with the -40°C precooling. The third bar from the left in Figure 3 represents a case where the precooling of hydrogen and onboard storage, using LN2, is performed at the refueling station (see Figure 2). In this case, despite the low compression cost, the capital cost of LN2 precooling equipment, and the cost of delivering LN2 to the refueling station dominate the refueling cost, which exceeds the refueling cost of the baseline 700 bar, -40°C case. The last bar from the left in Figure 3 represents a case where the precooling of hydrogen to LN2 temperature is performed at an upstream central facility, with subsequent delivery of the cryogenic hydrogen in insulated tube trailers to the refueling station, thus saving the precooling investment at refueling station and reducing the overall refueling station cost. However, in such case, the cost of delivering cryogenic hydrogen to the refueling station is significantly higher compared to the case where hydrogen is cooled at the station using LN2. Thus, adding hydrogen delivery cost to the refueling cost provides a consistent system boundary for comparing the cost of different dispensing options, which is presented in Figure 4.

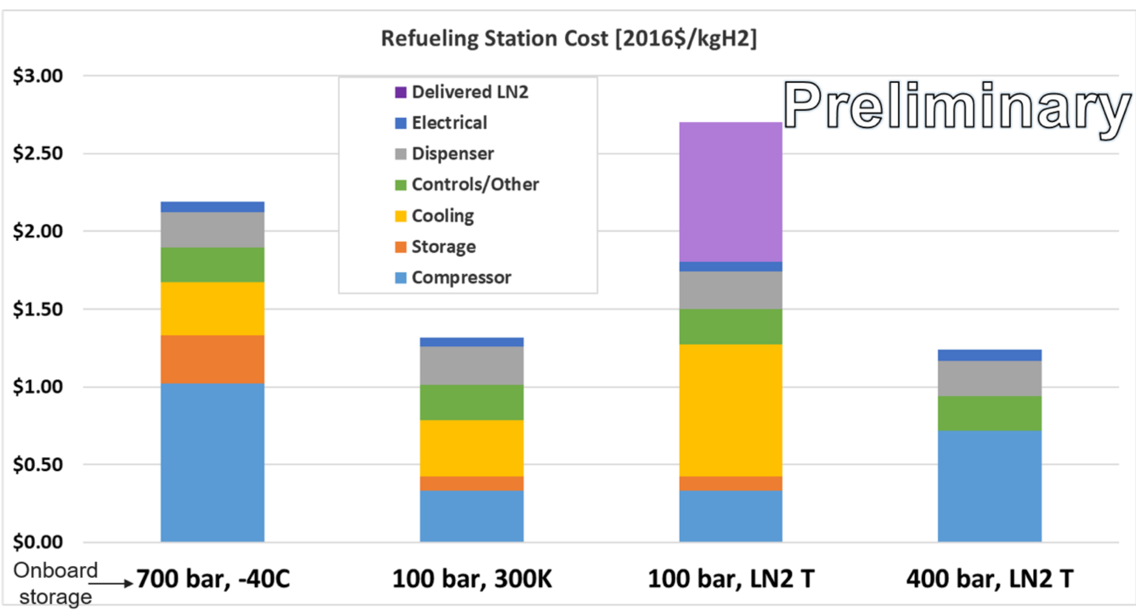

Figure 3. Impact of various FCEV onboard storage P and T requirements on the levelized cost of hydrogen refueling assuming gaseous tube trailer delivery

Figure 4 shows the impact of various FCEV onboard storage P and T requirements on the levelized cost of hydrogen delivery and refueling. For LH2 delivery in tankers, the delivery cost is more significant than refueling cost, mainly due to the liquefaction capital equipment and energy costs. For tube trailer deliveries, a trade-off between hydrogen delivery and refueling costs exists, depending on whether the precooling is achieved at a central facility before delivery to the refueling station, thus the precooling (or liquefaction) cost is implied in the delivery cost, or the precooling is performed at the refueling station, thus is explicit in the refueling cost. Figure 4 shows that FCEV onboard storage options requiring low pressure and near ambient temperature dispensing can significantly reduce the total hydrogen delivery and refueling cost. However, such onboard storage technology is yet to be discovered and requires significant research and development efforts before it can be realized.

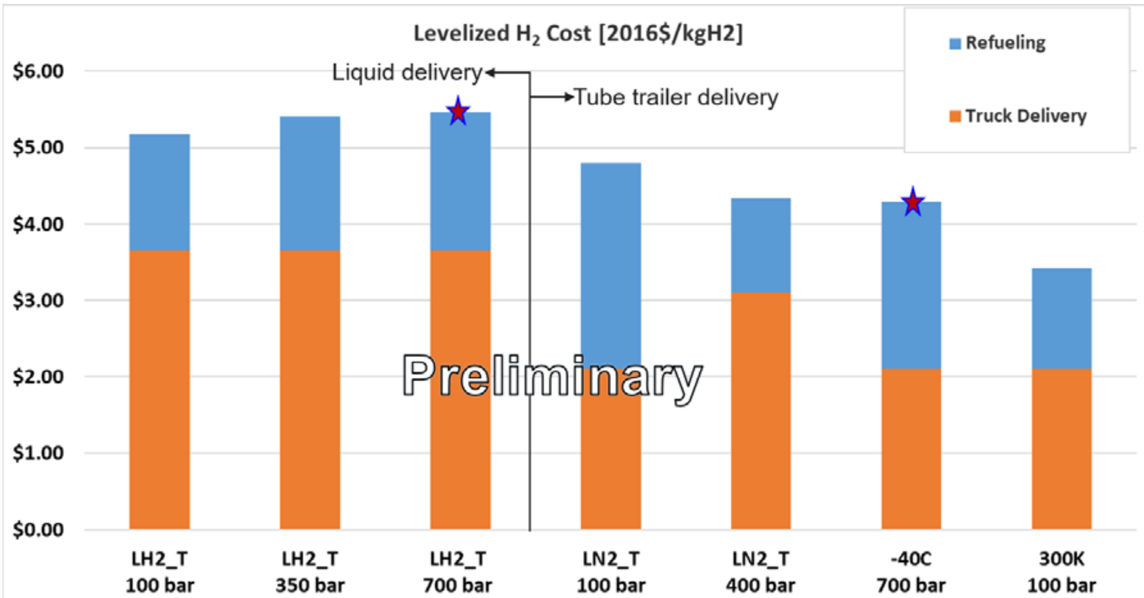

Figure 4. Impact of various FCEV onboard storage P and T requirements on the levelized cost of hydrogen delivery and refueling

CONCLUSIONS AND UPCOMING ACTIVITIES

The hydrogen delivery and refueling cost is strongly impacted by pressure and temperature requirements of FCEV onboard storage systems. Low pressure and near ambient temperature dispensing can significantly reduce hydrogen dispensing cost to FCEV customers. However, such an onboard storage system that can compete with the performance of the baseline 700 bar onboard storage system is yet to be developed. The conducted analysis can benefit from a detailed uncertainty analysis to capture the range of possible cost and performance of hydrogen delivery and refueling components.

REFERENCES

1. A. Elgowainy, K. Reddi, D.-Y. Lee, N. Rustagi and E. Gupta. “Techno-Economic and Thermodynamic Analysis of Pre-Cooling Systems at Gaseous Hydrogen Refueling Stations.” *International Journal of Hydrogen Energy* 42, no. 49 (2017): 29067-29079.
2. K. Reddi, A. Elgowainy, N. Rustagi, and E. Gupta. “Impact of Hydrogen Refueling Configurations and Market Parameters on the Refueling Cost of Hydrogen.” *International Journal of Hydrogen Energy* 42, no. 34 (2017): 21855-21865.