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
Argonne, IL 60439
Phone: 630-252-3074
E-mail: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) 2019 Objectives

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

Technical Barriers

This project directly 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
- (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 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 2019 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 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 account for approximately 50%, 15%, and 15% of total equipment cost, respectively. The refueling station costs contribute approximately \$6–\$8/kg of the total hydrogen dispensing cost, which is currently at ~\$13–\$16/kg, including hydrogen production, delivery, and dispensing costs. Thus, the hydrogen fueling cost contributes approximately 50% of the total hydrogen dispensing cost to FCEV customers. This is mainly due to the need to compress and store hydrogen at very high pressures (>900 bar) and to precool hydrogen to -40°C before dispensing into the 700-bar tank to enable fast dispensing (e.g., 5 kg in 3 minutes) without overheating the vehicle's tank (i.e., to stay below 85°C).

This study evaluates the impact of theoretical hydrogen fuel cell vehicle onboard storage options on fueling-station costs by examining their requirement for compression, storage, and precooling or heat exchanger costs, for a combination of dispensing pressures and temperatures that satisfy a specific onboard hydrogen storage capacity and fill rate. In particular, this study evaluated a dispensing pressure much lower than baseline 700 bar (e.g., near 100 bar), and either cryogenic temperatures (e.g., liquid hydrogen (LH_2) or liquid nitrogen (LN_2) temperatures) for sorbent materials, such as metal organic framework (MOF) onboard storage systems, or above-ambient temperatures (>300 K, e.g., temperatures preferred by metal hydride [MH] onboard storage systems). In addition, we examined physical storage systems that require dispensing at moderate pressures and cooling at cryogenic temperatures such as the cryo-compressed hydrogen (CcH_2) dispensing (350 bar and LH_2 temperatures). We evaluate cryo-temperature options where cooling takes place at the refueling station (e.g., -40°C for 700 bar dispensing, and LN_2 temperatures for dispensing into MOF), as well as options where cooling takes place at central facilities, such as LH_2 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 on-site LN_2 temperature cooling of both hydrogen gas and the onboard storage tank. This study conducted analysis for high-temperature MH with maximum ΔH = 44 kJ/mol and hydrogen charged at 140 bar, low-temperature MH with ΔH = 28 kJ/mol and hydrogen charged at 100 bar, and cryogenic sorbent (MOF) with ΔH = 7 kJ/mol and hydrogen charged at 100 bar.

For all 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 LH_2 tanker with 4 metric ton payload).

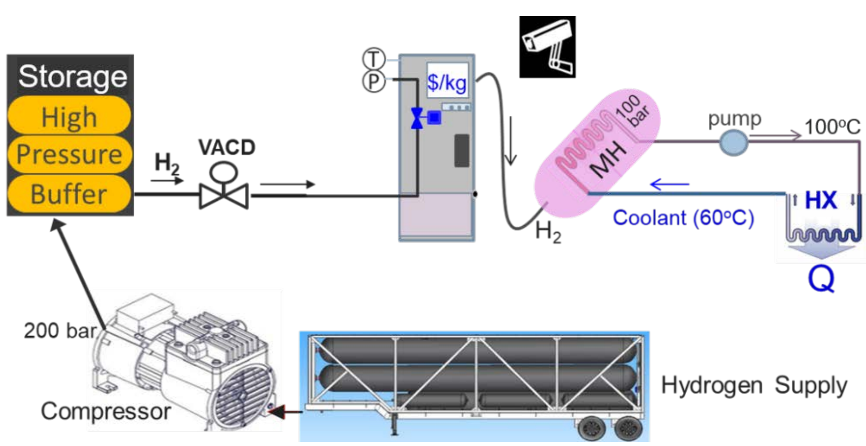

Figure 1. Hydrogen refueling station configuration for low-pressure (100 bar) and near-ambient-temperature dispensing

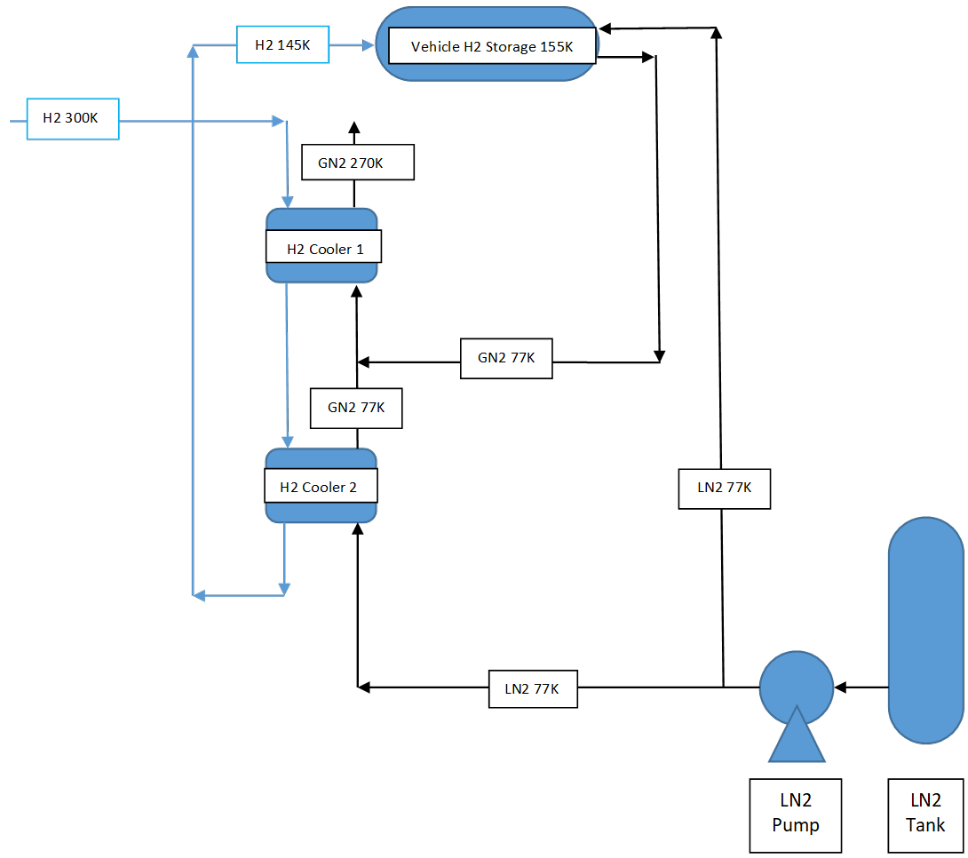

Figure 2. Cooling equipment configuration at a hydrogen refueling station that requires LN_2 temperature cooling of both hydrogen gas and onboard storage tank

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.
- 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 or liquid hydrogen tanker delivery. The first bar on the left of Figure 3 represents the levelized fueling station capital and operation costs, with hydrogen delivered via tube trailer, 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 also represents the levelized fueling station costs for 700-bar tanks, but with liquid hydrogen delivered via cryogenic tankers. The third and fourth bars from the left show a dramatic decrease in compression, and thus fueling cost, compared to the baseline 700-bar dispensing case, due to the reduction in onboard storage pressure from 700 to 100 bar, while operating above ambient temperature. The precooling cost associated with -40°C in the baseline 700-bar dispensing case is almost matched by the heat exchanger cost in the above-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.

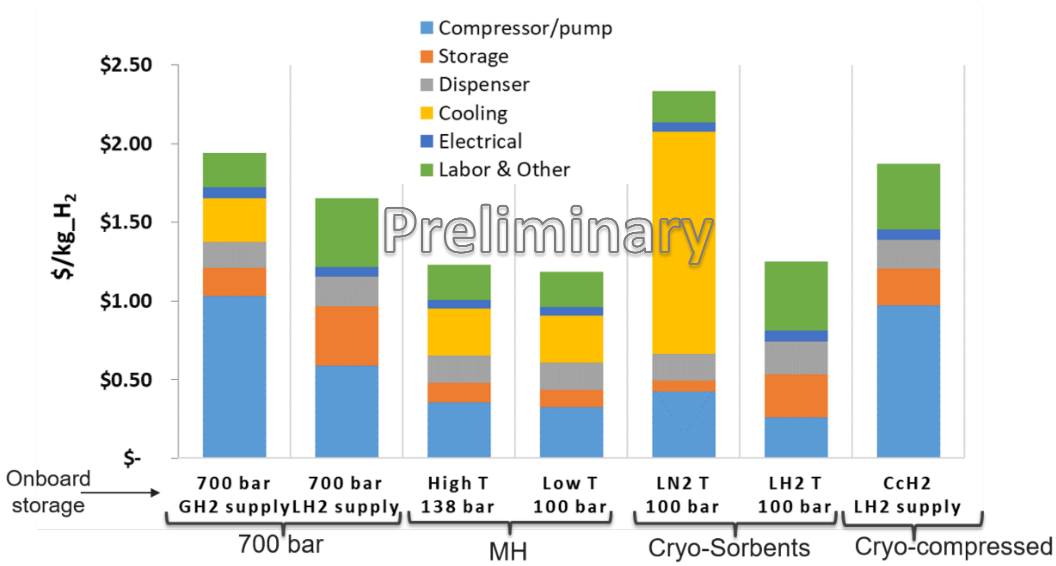

Figure 3. Impact of various FCEV onboard storage P and T requirements on the levelized cost of hydrogen fueling assuming gaseous tube trailer or liquid tanker delivery

The fifth bar from the left in Figure 3 represents a case where the precooling of hydrogen and the onboard storage, using LN_2, is performed at the fueling station. In this case, despite the low compression cost, the capital cost of LN_2 precooling equipment and the cost of delivering LN_2 to the refueling station significantly increase the fueling cost, which exceeds that of the baseline 700-bar, -40°C case. The sixth bar from the left represents a case where the LH_2 charge is assumed to be capable of not only absorbing the heat of adsorption associated with MOF charging but also cooling the sorbent bed and tank walls. The last bar on the right represents the corresponding cost of fueling a CcH_2 hydrogen tank. In this case, a high-pressure cryo-pump is employed to increase the hydrogen pressure to 450 bar.

Figure 3 shows that FCEV onboard storage options requiring low-pressure and above-ambient-temperature dispensing can significantly reduce the hydrogen fueling cost. However, such onboard storage technology is yet to be developed and requires significant research and development efforts before it can be realized.

CONCLUSIONS AND UPCOMING ACTIVITIES

The hydrogen fueling cost is strongly impacted by pressure and temperature requirements of the FCEV onboard storage system. Low-pressure and above-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 baseline 700-bar onboard storage systems is yet to be developed. The uncertainty analysis shows that changing key parameters of low-pressure, above-ambient-temperature systems does not significantly impact their low fueling cost results.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. E.D. Frank, A. Elgowainy, Y.S. Khalid, J.K. Peng, and K. Reddi, "Refueling-Station Costs for Metal Hydride Storage Tanks On Board Hydrogen Fuel Cell Vehicles," *International Journal of Hydrogen Energy* 44 (2019): 29849–29861. https://doi.org/10.1016/j.ijhydene.2019.09.206.