III.9 Hydrogen Refueling Analysis of Heavy-Duty Fuel Cell Vehicle Fleet

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Project Start Date: October 2007
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

Evaluate impacts of key market, technical, and economic parameters on refueling cost of heavy-duty fuel cell vehicles.

Fiscal Year (FY) 2017 Objectives

- Evaluate the precooling requirements for various heavy-duty fuel cell vehicle (HDFCV) tank systems, characterized by the tank type and configuration, fill pressure, and fill rate.
- Develop and publish a techno-economic model to estimate the hydrogen station cost contribution for refueling HDFCV fleets.
- Evaluate the impact of market and technical parameters on the hydrogen station levelized cost (\$/kg H_2).

Technical Barriers

This project directly addresses Technical Barriers A, B, C, and E in the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. 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 milestone from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Task 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)
- 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).

Accomplishments

- Developed a techno-economic model for HDFCV fleet refueling to estimate the hydrogen refueling cost.
- Studied the impact of market parameters, including fleet size, hydrogen supply state (i.e., gaseous or liquid), station utilization and market penetration, etc., as well as technical parameters, including refueling pressure, tank type, dispensed amount and fill rate, etc., on cost of hydrogen refueling of HDFCV fleets.

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INTRODUCTION

Medium- and heavy-duty vehicles (MHDV) constitute the second largest and fastest growing energy consumer in transportation. In the past few years, fuel cells have made significant strides in this space, with deployments in buses, drayage trucks, and military vehicles. Techno-economic models such as Argonne's Hydrogen Delivery Scenario Analysis Model and Hydrogen Refueling Station Analysis Model, which are developed to calculate the light-duty vehicle (LDV) hydrogen refueling station levelized cost, are not appropriate for the evaluation of fuel cell MHDV refueling stations due to differences in the key parameters such as fill rate, fueling pressure, fueling amount, fueling strategy, and precooling requirement. In order to inform DOE and industry stakeholders of the key parameters that impact cost of hydrogen refueling for HDFCV, we have developed a new tool that estimates the station cost for various market and technical parameters specific to HDFCV fleet fueling.

APPROACH

The Hydrogen Station Cost Optimization and Performance Evaluation Model (H2SCOPE), developed by Argonne National Laboratory, was used to examine the effect of vehicle tank configuration or properties and fueling rates (7.2 kg/min, 3.6 kg/min, and 1.8 kg/min, provided in the SAE technical information report) on the precooling requirement for fueling HDFCV. The precooling requirements for 350 bar and 700 bar, Type III and Type IV tanks have been estimated at 25°C ambient and 40°C pre-soak using the H2SCOPE model so that the tank temperature does not exceed 85°C at end of fill (Table 1).

TABLE 1. HDFCV Onboard Tank Configurations Evaluated by H2SCOPE

Bus Onboard Storage System		
	350 bar	700 bar
Storage System Capacity	40	40
Number of Tanks	8	16
Individual Tank Capacity [kg]	5	2.5

The developed model for HDFCV refueling is an Excel-based tool that uses a design calculation approach to estimate the contribution of individual components of refueling to levelized hydrogen cost. The tool sizes refueling components given a set of design specifications and boundary conditions, and calculates the levelized cost of hydrogen, accounting for tradeoffs among the various refueling components using basic engineering design formulas. Component cost information is obtained from vendor quotes, industry inputs, or open literature. The quality of the data and the direction of the analysis are guided and vetted through formal interaction with partners from other national laboratories and independent consultants, and via presentations to the Hydrogen Delivery Technical Team. The HDFCV refueling model is in compliance with the SAE technical information report on hydrogen fueling of HDFCVs to satisfy the fueling performance requirements (including fill rates and fill amounts, etc.). The fuel cell bus fueling has been used as a surrogate for HDFCV fleet fueling.

RESULTS

The impact of each fueling parameter has been studied by varying one parameter at a time, while keeping all other variables constant. The baseline (or default) values of fuel cell MHDV fueling variables are provided in Table 2. The precooling temperature requirements to avoid tank overheating are shown in Table 3. Type III tank system requires no precooling, while Type IV tank system requires nominal precooling for 350 bar fueling, especially at higher fill rates. For 700 bar refueling, a moderate precooling of -10°C is required at 7.2 kg/min fueling rate into Type IV tank system, as shown in Table 3.

TABLE 2. HDFCV Fleet Fueling Parameters (Baseline Values)

Market Parameters	
Fleet Size	30
Hydrogen Supply	20 bar gaseous
Market Penetration (Production Volume)	Low
Technical Parameters	
Refueling Pressure	350 bar
Tank Type	III
Dispensed Amount [kg]	35
Fill Rate [kg/min]	3.6
Fill Strategy	Back to Back (constrained by fill rate)

TABLE 3. Precooling Requirement for Fueling of HDFCV

		Precooling Temperature [°C]	
Tank Type	Fueling Rate [kg/min]	350 bar	700 bar
III	1.8	Not Required	N/A
	3.6	Not Required	N/A
	7.2	Not Required	N/A
IV	1.8	Not Required	15°C
	3.6	18°C	0°C
	7.2	5°C	-10°C

N/A – not applicable

Figure 1 shows the impact of fueling rate on the levelized refueling cost of hydrogen. For low fueling rates, the refueling cost is low, and is comparable for gaseous and liquid stations. Liquid stations can handle faster fills with less cost increase, primarily because the cryopumps at liquid stations have a relatively high throughput of 120 kg/h. High fueling rates increase the allowed number of back-to-back fills, which in turn increases the amount of hydrogen dispensed during each hour, thus requiring larger refueling equipment and increasing the refueling cost. With 1.8 kg/min fueling rate, the number of back-to-back fills are limited to two, requiring more dispensers due to limitation of the total hours allowed for the fleet refueling. Adding a dispenser is more favorable than doubling the fill rate for gaseous stations, while doubling the fill rate is more favorable for liquid stations than adding a dispenser. Figure 2 shows the levelized cost of hydrogen refueling for different hydrogen supply sources. The tube-trailer hydrogen supply minimizes station cost for moderate fleet sizes, but partially shifts the cost burden upstream of the station, while also suffering limited payload. For liquid station, pumping provides a lower cost option compared to compression. Figure 3 shows the impact of fleet size on the levelized cost of hydrogen

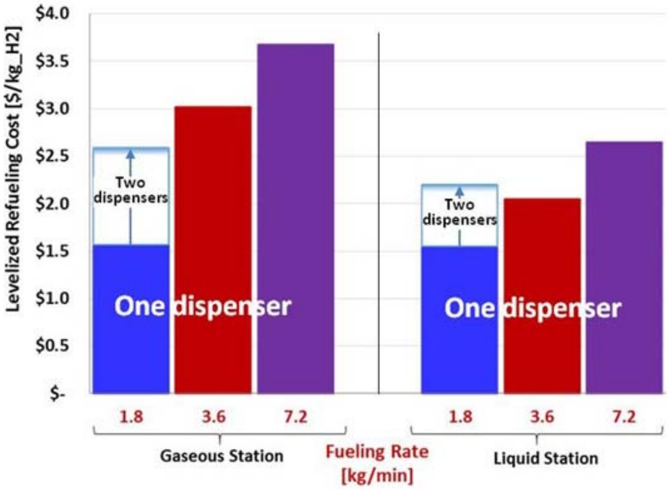

FIGURE 1. Impact of fueling rate on the levelized refueling cost of hydrogen refueling

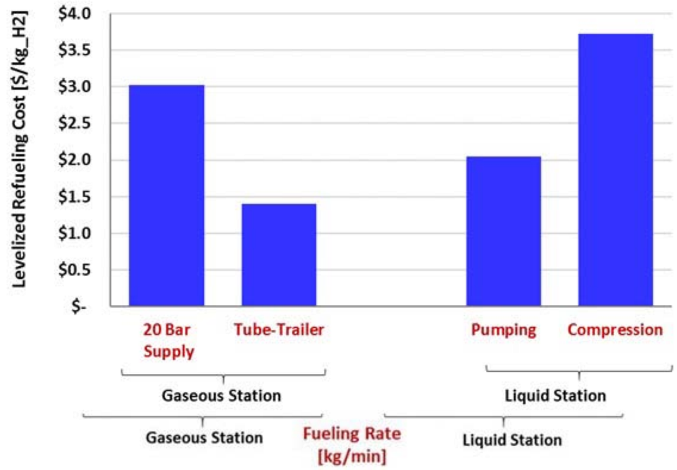

FIGURE 2. Impact of the hydrogen supply source/state on the levelized cost of hydrogen refueling

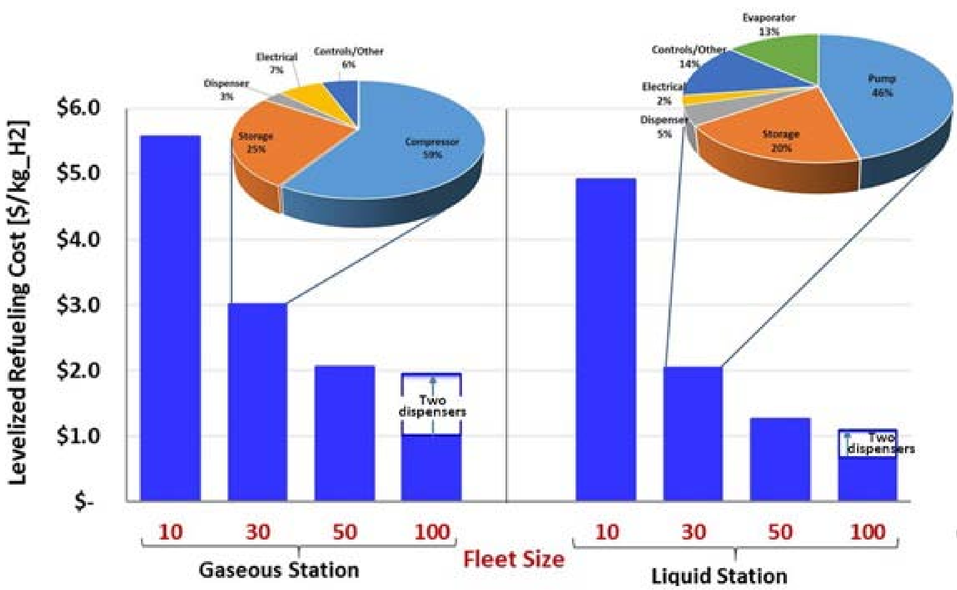

FIGURE 3. Impact of fleet size on the levelized cost of hydrogen refueling

refueling. Refueling cost can be as low as $1/kg H_2 for large fleet sizes due to the strong economies of scale. Compression and pumping dominate the refueling cost for gaseous and liquid refueling stations, respectively, as shown in the Figure 3. However, liquid stations, in general, provide lower refueling cost option compared to gaseous stations.

CONCLUSIONS AND UPCOMING ACTIVITIES

Hydrogen refueling cost for HDFCV fleet is lower when compared to LDV refueling. Strong economies of scale can be realized with fleet size and fill amount, which define the station demand or capacity. Faster fill rates require higher capacity equipment, resulting in higher refueling cost. The impact of higher fueling rate on refueling cost is lower for liquid hydrogen stations compared to gaseous stations. Compression and pumping dominate fueling cost for gaseous and liquid stations, respectively. Liquid stations provide lower refueling cost option for HDFCV fleet refueling compared to gaseous stations. Tube-trailer supply partially shifts the cost upstream and reduces the cost for small fleets in early markets, but the limited payload is not likely viable for large fleets. Refueling cost can be reduced to $1–$1.5/kg H_2 for large fleets when refueling equipment are produced at high volume. Future work may consider evaluating typical bus service schedules and refueling profiles for commercial (non-fleet) heavy duty vehicles. The HDFCV refueling model will be peer-reviewed and posted in public domain.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. Elgowainy, A., and Reddi, K., ENHANCED METHODS FOR OPERATING REFUELING STATION TUBETRAILERS TO REDUCE REFUELING COST, Docket No.: ANL-IN-13-058, submitted to United States Patent and Trademark Office on September 27, 2013 (Received Notice of Allowance on May 22, 2017).

FY 2017 PUBLICATIONS

1. Reddi, K., Elgowainy, A., & Rustagi, N., & Gupta, E., 2017, Impact of hydrogen refueling configurations and market parameters on the refueling cost of hydrogen, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2017.05.122

1. Reddi, K., Elgowainy, A., & Rustagi, N., & Gupta, E., 2017, Impact of hydrogen SAE J2601 fueling methods on fueling time of light-duty fuel cell electric vehicles, International Journal of Hydrogen Energy, 42(26), 16675-16685.