DOE Hydrogen and Fuel Cells Program Record	
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Title: Hydrogen Delivery and Dispensing Cost	
Originator: Mariya Koleva, Neha Rustagi	
Peer Reviewed by: Marc Melaina (DOE), Amgad Elgowainy (Argonne National Laboratory), Ghassan Sleiman (FirstElement Fuel), Andrew Martinez (California Air Resources Board), Matthew Blieske (Shell)	
Approved by: Ned Stetson (DOE), Sunita Satyapal (DOE)	**Date:** 10/2/2020

Item

This record establishes the levelized unit cost of hydrogen delivery and dispensing[1] at fueling stations in 2020. For liquid tanker-based stations, delivery costs are calculated to be approximately $11/kg at 450 kg/day and projected to be roughly $8/kg at 1,000 kg/day stations. For tube-trailer gaseous stations, delivery costs are projected to be $9.50/kg and $8/kg at 450 kg/day and 1,000 kg/day stations, respectively (2016$). The cost range has been derived using the Hydrogen Delivery Scenario Analysis Model (HDSAM) [1] under specific assumptions consistent with operation data from today's stations operating in California.

Background

This record estimates the early market, i.e., low volume production, levelized cost of hydrogen delivery from centralized production, including transmission and distribution to stations that retail hydrogen fuel to customers with fuel cell electric vehicles (FCEVs). The DOE target for the cost of hydrogen fuel at the dispenser for light-duty vehicles in early markets was previously set at $7/kg, including production, delivery, and dispensing [2].

Hydrogen is currently distributed from centralized production facilities to retail fueling stations primarily through gaseous tube trailers, and increasingly through liquid tankers (only very limited sites use hydrogen pipelines). Bulk storage at terminals and in underground reservoirs is used to buffer fluctuations in market supply and demand. After fueling stations receive hydrogen in gaseous or liquid form for bulk on-site storage, the hydrogen is then dispensed as a pressurized, chilled gas into an FCEV's onboard storage system during fueling.

In this record, the cost of hydrogen delivery and dispensing has been estimated assuming that the hydrogen is delivered via tube trailers or liquid tankers and is dispensed to a 700 bar onboard storage system following SAE J2601 fueling protocol for T40 stations. The cost of delivery and dispensing into FCEVs is estimated using version 3.1 of the HDSAM model [1]. HDSAM is a bottom-up techno-economic model that calculates the levelized cost of hydrogen delivery to fueling stations and dispensing into vehicles. Users can define options such as market type (urban, rural interstate), FCEV market penetration, station capacity, hydrogen supply method, economic and financial assumptions, etc. The major assumptions are discussed in the following section.

[1] The reported costs are for hydrogen delivery and dispensing, excluding hydrogen production.

Table 1 below summarizes the hydrogen delivery and dispensing costs for gaseous tube trailers and liquid tankers for two different station capacities. These costs do not include amortization of capital costs for equipment, production of hydrogen, maintenance costs, land lease agreements, and other operational costs.

Table 1. Levelized hydrogen cost estimates for delivery and dispensing at fueling stations considering various scenarios [2]

	Gaseous tube trailers		Liquid tankers	
Capacity	450 kg/day	1,000 kg/day	450 kg/day	1,000 kg/day
Hydrogen delivery and dispensing cost	$9.46/kg	$8.17/kg	$11.35/kg	$8.31/kg

Scenarios and Assumptions

The California Air Resource Board (CARB) previously developed recommendations for minimum hydrogen station capacity for use in California's hydrogen station grant funding programs. Per these recommendations, a station capacity of at least 450 kg/day is suggested for most early market areas [3]. CARB defined this daily capacity with additional constraints: (1) the station only receives a hydrogen delivery at the beginning of the day, and (2) all fills are completed with an ending state of charge of 95%. This record adopts 450 kg/day as a low station capacity assumption. The number of FCEV full fills per station during peak hours is 7 fills per hour, assuming a 4 kg dispensed amount per vehicle, so that approximately 112 vehicles per day can be served.

For a large station capacity, this record assumes 1,000 kg/day. Each of the station capacities has been considered for two hydrogen transmission and distribution modes in the evaluated scenarios, i.e., via tube trailer and liquid tanker.[3] It must be noted that liquid tankers are considered to be the most viable option for supplying 1,000 kg/day of hydrogen as they are able to carry more than 4 times payload compared to gaseous tube trailers without exceeding the U.S. Department of Transportation regulations for gross vehicle weight [4, 5]. In order to provide a level comparison, this record assesses delivery by both high-capacity gaseous tube trailer and liquid tanker deliveries, for capacities as high as 1,000 kg/day.

CARB developed a generalized fueling station utilization progression curve [3] based on analysis by Joint Agency Staff Reports [6]. According to the publication, stations are assumed to reach their cap utilization at 75% for high utilization scenarios and 85% for full utilization scenarios within a maximum of 10 years, depending on the maturity level of the market. In the current record, a utilization progression curve for less than 10 and more than 3 stations within a 15-minute drive from each other has been adopted. In such a scenario, a maximum utilization rate of 85% is achieved in the 9th year of operation.

[2] The cost estimates reported in the table are direct outputs from HDSAM under the assumptions listed in Table 2.

[3] The current record assumes that high pressure gaseous hydrogen tube trailers are filled at terminals where hydrogen is produced and subsequently stored in bulk in gaseous form or injected into a pipeline. However, it is important to note that, in the current market, when the end user of hydrogen is distant from such gaseous terminals, tube trailers are instead filled at terminals with liquid hydrogen storage that are close to the use point. At these terminals, liquid hydrogen is pumped and then vaporized at high pressure to fill the tube trailers. This pathway takes advantage of existing liquid hydrogen infrastructure in the early market. As demand grows, installation of gaseous hydrogen production near the point(s) of use will likely become the more economically attractive solution.

For all station capacities and delivery methods, an urban hydrogen market is assumed. A city with population of approximately 1.5 million people, representing the median of the populations of the 30 largest cities in the United States, has been selected for the simulations. Further, within HDSAM, the early market scenario is based on a market penetration of 1% and low-volume manufacturing of fueling components, representing current equipment cost.

The key numerical assumptions for the calculations in this report are listed in Table 2. One of the major assumptions in the analysis, which translates to a higher hydrogen delivery and dispensing cost, is station underutilization in early years.

Table 2. Early market assumptions for hydrogen delivery and dispensing cost method

Hydrogen delivery method		Gaseous tube trailers (at 547 bar pressure and 88% usable capacity)	Liquid tankers
Hydrogen fueling station capacity		450 kg/day and 1,000 kg/day	
Dispensing option to vehicle tank		700 bar gas via compressor and cascade storage	700 bar gas via high-pressure pump/evaporator and cascade storage
Annual station utilization rate	Year 1	8%	
	Year 2	23%	
	Year 3	41%	
	Year 4	52%	
	Year 5	61%	
	Year 6	68%	
	Year 7	74%	
	Year 8	80%	
	≥ Year 9	85%	
Station analysis period		10 years	
Delivery components analysis period		30 years	
Station discount rate		8% [7]	
Fuel cell vehicle market penetration		1% in a city with population of approximately 1.5 million people—the median of the 30 largest cities in the U.S.	
Dollar year of estimate		2016$	

References

[1] Argonne National Laboratory (2016), *Hydrogen Delivery Scenario Analysis Model*, https://hdsam.es.anl.gov/index.php?content=hdsam.

[2] N. Rustagi, A. Elgowainy, and J. Vickers (2018), *Current Status of Hydrogen Delivery and Dispensing Costs and Pathways to Future Cost Reductions*, https://www.hydrogen.energy.gov/pdfs/18003_current_status_hydrogen_delivery_dispensing_costs.pdf.

[3] California Air Resource Board (2019), *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development*, https://ww2.arb.ca.gov/sites/default/files/2019-07/AB8_report_2019_Final.pdf.

[4] Worthington Industries (2018), "Cryogenic Transport Trailers," https://worthingtonindustries.com/getmedia/87bfa6a3-2205-45c9-98ff-25f0b89fc2ac/TransportTrailer_CombinedSpecSheets.pdf?ext=.pdf.

[5] Air Products (2014), "Liquid hydrogen," https://www.airproducts.com/-/media/airproducts/files/en/900/900-13-082-us-liquid-hydrogen-safetygram-9.pdf?la=en&hash=26801E3C3BB42612F9C62D84860D739C.

[6] California Energy Commission and California Air Resources Board (2019*), Joint Agency Staff report on Assembly Bill 8: 2019 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*, Report No CEC-600-2019-039, https://ww2.energy.ca.gov/2019publications/CEC-600-2019-039/CEC-600-2019-039.pdf.

[7] F. Joseck, E. Miller, N. Stetson, D. Papageorgopoulos (2018), *FCTO FY18 Inputs and Assumptions for Program Analysis*, https://www.hydrogen.energy.gov/pdfs/18001_fcto_fy18_inputs_assumptions.pdf.