III.1 Hydrogen Delivery Infrastructure Analysis

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

Overall Objectives

Evaluate hydrogen delivery and refueling concepts that can reduce hydrogen delivery cost towards meeting the delivery cost targets.

Fiscal Year (FY) 2016 Objectives

- Update and publish Hydrogen Delivery Scenario Analysis Model (HDSAM) with station configurations, market data, and cost information of delivery components for near-term and long-term markets.
- Enable estimation of delivery cost for early markets with varying station utilization over the life of the project or analysis period.

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

Technical Targets

Update the HDSAM model with market data, component cost data for near-term and long-term markets (with varying market penetration), station configuration options, and utilization scenarios.

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 6.1: Define potential RD&D activities for other long-term market fueling/terminal needs. (4Q, 2015).
- 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

- Updated the HDSAM model and publicly released the updated Version 3.0.
- The new version includes updates of market data, cost indexes, alternate liquid delivery station configurations, and quantified the cost reduction potential with higher market penetrations.
- Studied the impact of various parameters including station design capacity, utilization rate, and station configuration on the hydrogen delivery cost.

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INTRODUCTION

HDSAM is an Excel-based tool that uses a design calculation approach to estimate the contribution of individual components of delivery infrastructure to hydrogen cost, energy use, and greenhouse gas emissions. The model links individual components in a systematic market setting to develop capacity and flow parameters for a complete hydrogen delivery infrastructure. Using that systems level perspective, HDSAM calculates the full, levelized cost (summed over all components) of hydrogen delivery, accounting for losses and tradeoffs among the various component costs. Users of HDSAM can specify their own inputs to the model or select default inputs, which are based on quotes from vendors of specific delivery components or from stakeholder inputs, data from the literature, or derived from basic engineering design calculations. The quality of the data and the direction of the analysis are vetted in formal interaction with partners from other national laboratories and independent consultants, and also via presentations to the Hydrogen Delivery Technical Team.

APPROACH

The HDSAM model has been updated with recent market data including key statistics of urban population, vehicle ownership rate, annual vehicle miles travelled, and average vehicle fuel economy for calculating market demand with vehicle penetration scenarios for all U.S. cities with population greater than 50,000. Cost formulas for all delivery components that are consistent with the latest cost data acquired for today's technologies, scale and production volumes have been updated. The model was also updated to include cost reduction factors for all delivery components for three hydrogen station market penetration scenarios to reflect the impact of learning, technology advancement and economies of scale, as shown in Table 1. The model was also updated to include an option to define a utilization scenario for hydrogen refueling stations over the station lifetime. The greenhouse gas (GHG) emissions data of all the delivery pathways have been updated consistent with the GREET® model 2015.

With increase in market penetration of the fuel cell vehicles, the number of hydrogen refueling stations are expected to increase. For this analysis we have considered three market scenarios: (i) "low," with 200 stations worldwide representing the current status of low volume production of refueling components; (ii) "high," with 10,000 stations worldwide representing a future mature market when refueling components are produced at high volume; and (iii) "mid," with about 5,000 station worldwide representing a midpoint between the first two.

In consultation with industry experts, all the delivery components have been divided into three technology baskets characterized by the current status of technology and scope for possible cost reduction through innovation and economies of scale. The three technology baskets and the cost reduction potential are summarized in Table 1.

RESULTS

Hydrogen Delivery Cost Reduction with Station Size and Production Economies of Scale

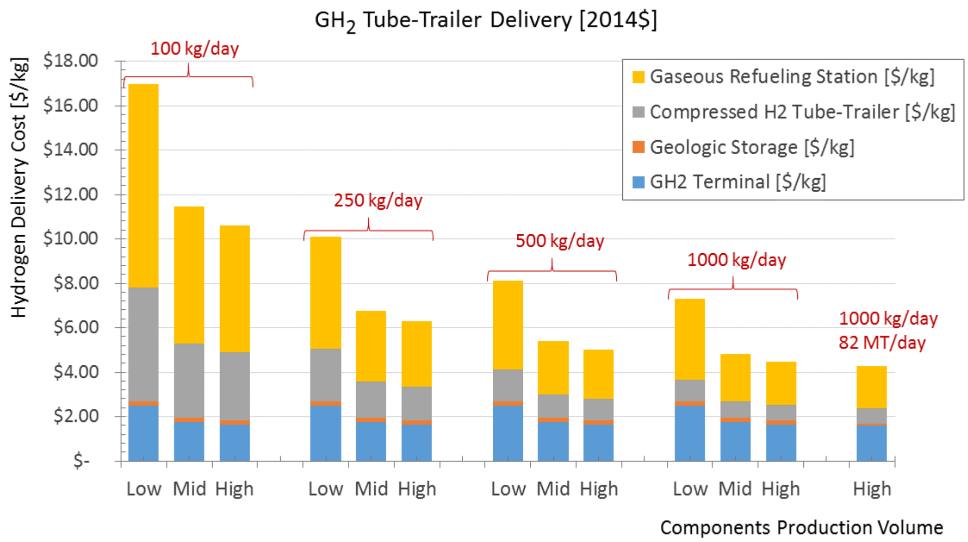
The Figures 1, 2 and 3 show the delivery cost contribution of each component of the tube-trailer, liquid tanker and pipeline delivery pathways respectively for a 16 metric ton (MT) per day market demand and 80% refueling station capacity utilization. All the three pathways enable a $4/kg delivery cost in a mature market (with 82 MT/d demand) taking advantage of the station economies of scale with large stations and cost reduction of components with increase in production volume.

For tube-trailer delivery pathways the hydrogen refueling station contributes (Figure 1) to about half the delivery cost for all market scenarios and that contribution decreases at larger station capacities. The contribution of the hydrogen refueling station and tube-trailer together is expected to reduce with market penetration of fuel cell vehicles from about $14/kg for 100 kg/d station at today's costs to about $2.5/kg for 1,000 kg/d station in a mature market. For the liquid delivery pathway the station contribution (Figure 2) is higher for smaller stations mainly due to the limitation

TABLE 1. Cost Reduction Factors for Different Technology Baskets for Different Market Penetrations

Cost Reduction Factors			
	Market (Production Volume)		
Technology baskets and definitions	**Near-Term (low volume)**	**Mid-Term**	**Long-Term (high volume)**
#1 Mature (low potential for cost reduction, 5% with each production volume doubling) Ex: *Low-Pressure Storage, Cryogenic Storage, H_2 Pipeline Cost Premium*	1	0.79	0.75
#2 Established (moderate potential for cost reduction, 10% with each production volume doubling) Ex: *Station Cascade Storage, Station Refrigeration, Tube-Trailer Vessel, LH_2 Truck Vessel*	1	0.61	0.55
#3 Developing (high potential for cost reduction, 15% with each production volume doubling) Ex: *Dispensers, Compressors, Cryogenic Pump, Station Controls/Safety Equip*	1	0.47	0.40

LH_2 - Liquid hydrogen



GH2 – Gaseous hydrogen

FIGURE 1. Delivery cost estimates for tube-trailer delivery pathway for different station capacities and production volumes

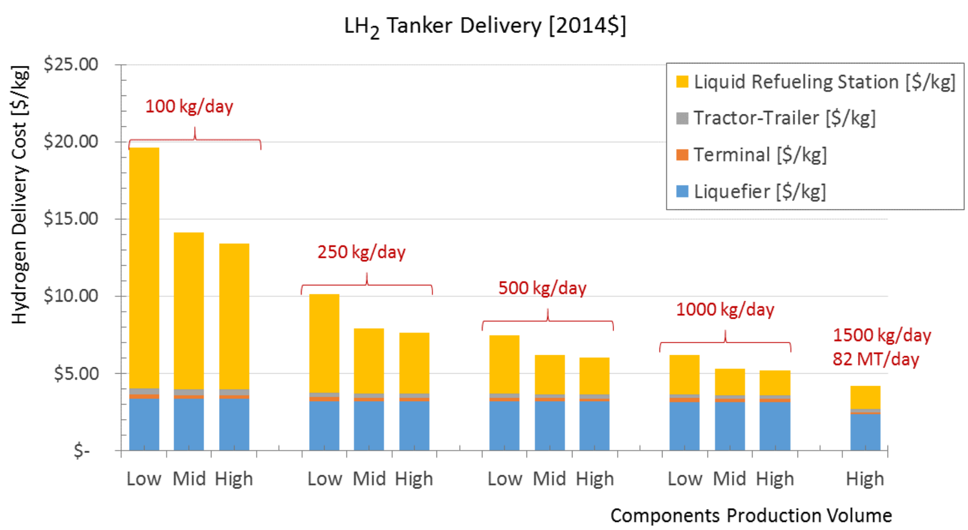


FIGURE 2. Delivery cost estimates for liquid tanker delivery pathway for different station capacities and production volumes

of available options for low boil-off pumps. In the current version of HDSAM a single version of low boil-off pumps have been incorporated, which has a capacity of about 120 kg/d costing about $700,000 (2014$). Due to the high capacity and cost of the pump, the liquid pumping option appears not suitable for stations with capacities lower than about 500 kg/d, making the liquid delivery pathway less attractive for smaller stations. The pipeline delivery pathway requires high capital investment and becomes economically viable at larger market demands with larger station capacities. For smaller markets and smaller stations, a larger distribution pipeline network is required, and contributes to about half (Figure 3) of the total delivery cost of hydrogen.

GHG Emissions Reduction with Cleaner U.S. Electric Grid

As shown in Figure 4, the GHG emissions are lower by about 40% when comparing the 2015 U.S. grid mix to the 2005 grid mix in previous version of HDSAM model. Updating the electricity supply to the 2015 U.S. grid mix resulted in lower GHG emissions for the liquid and tube-trailer delivery pathways compared to these estimated by the previous version of HDSAM.

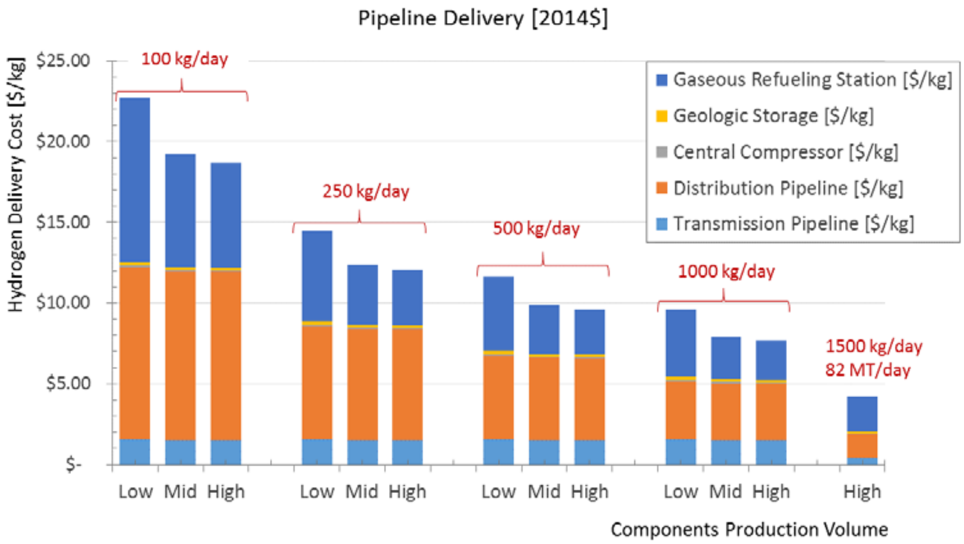


FIGURE 3. Delivery cost estimates for pipeline delivery pathway for different station capacities and production volumes

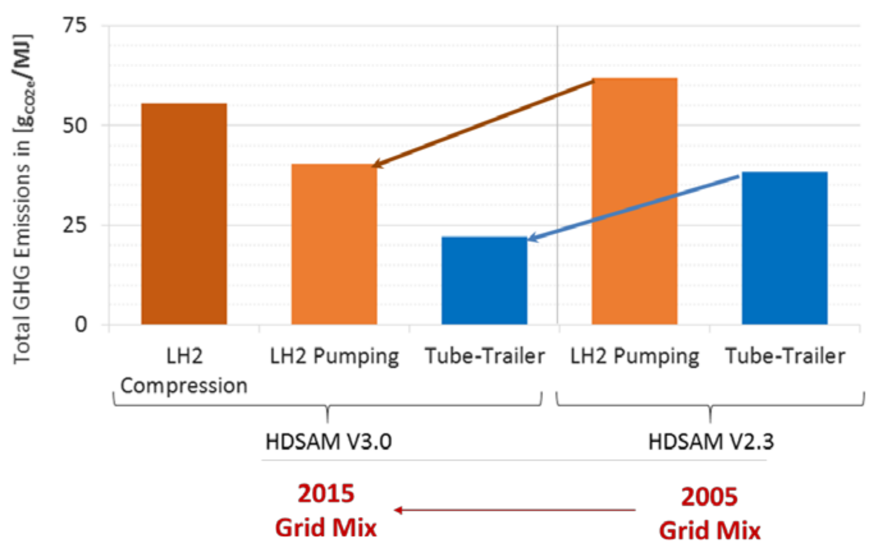


FIGURE 4. The GHG estimates from the current (V3.0) compared to the previous version (V2.3) of HDSAM model for liquid tanker and tube-trailer delivery pathways

CONCLUSIONS AND FUTURE DIRECTIONS

The tube-trailer delivery pathway appears as the most economical for early markets and smaller stations. The liquid delivery pathway is economical for moderate to large station sizes due to the limited options available for cryo-pumps in the current marketplace. The pipeline delivery pathway is economically viable only for supplying large stations in a mature market with large demands. Though each of the delivery pathways has its limitations, all the delivery pathways enable a delivery cost of $4/kg of hydrogen with larger station capacities and high market demand (i.e., high penetration of fuel cell vehicles). For the remainder of FY 2016, efforts will be directed toward updating, documenting, and publishing a newer version of HDSAM.

In the future, HDSAM will be updated with available cost data, emerging technologies and new pathways to evaluate new concepts and identify cost reduction potential towards meeting hydrogen delivery performance and cost targets.

PUBLICATIONS

1. Reddi, K., Elgowainy, A., Wang, M. 2016, "Special Section: Energy - Fuel Cells for Mobile Applications," July edition, CEP Magazine by AIChe.

2. Reddi, K., Mintz, M., Elgowainy, A., Sutherland, E. 2016, "Building a hydrogen infrastructure in the United States," in Compendium of Hydrogen Energy. Volume 4: Hydrogen Use, Safety and the Hydrogen Economy, eds. M. Ball, A. Basile, T. Nejat Veziroglu, Woodhead Publishing, pp. 293.