III.2 Hydrogen Delivery Infrastructure Analysis

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

Partners:
- Pacific Northwest National Laboratory, Richland, WA
- National Renewable Energy Laboratory, Golden, CO

Fiscal Year (FY) 2011 Objectives

- Refine technical and cost data in the Hydrogen Delivery Scenario Analysis Model (HDSAM) to incorporate additional industry input and evolving technology improvements.
- Expand the model to include advanced technologies and other pathway options leading to new versions of the models.
- Improve methodologies for estimating key aspects of delivery system operation and optimizing cost and performance parameters.
- Explore options to reduce hydrogen delivery cost, including higher pressure and/or lower temperature gases, and operating strategies.
- Provide analyses to support recommended hydrogen delivery strategies for initial and long term use of hydrogen as a major energy carrier.

Technical Barriers

This project directly addresses technical barrier A (which implicitly includes barriers B, C, D, F, H and J) in the Delivery Technical Plan, as well as barriers B, C and E in the Systems Analysis Plan of the Fuel Cell Technologies Multi-Year Research, Development and Demonstration Plan. These are:

(A) Lack of Hydrogen/Carrier and Infrastructure Options Analysis
(B) Stove-Piped/Siloed Analytical Capability
(C) Inconsistent Data, Assumptions and Guidelines
(E) Unplanned Studies and Analysis

Technical Targets

The project is developing and using a computer model to evaluate alternative delivery infrastructure systems and components. Insights from the model are being used to help identify elements of an optimized delivery system which could meet DOE's long-term delivery cost target.

FY 2011 Accomplishments

- Completed a review and update of pipeline cost functions. Changes include:
  - Steel transmission and distribution pipelines:
    - Updated material, labor, right-of-way and miscellaneous cost estimates.
    - Developed revised equations for nine U.S. regions and total U.S.
  - Fiber-reinforced piping:
    - Review of current applications and technologies.
    - Evaluation of material, labor and total cost estimates and trends especially as compared to steel pipe.
  - Incorporation of revised equations into HDSAM pipeline model.
- Updated cost/price indexes in HDSAM.
- Analyzed factors affecting HDSAM fuel station capital investment and levelized cost, including:
  - Scale: station size
  - Station utilization
  - Investment and rate of return
  - Fuel cell vehicle (FCV) onboard storage option
  - Station design configuration
- Conducted delivery cost target analyses to:
  - Investigate impact of delivery technology options and economies of scale on hydrogen delivery cost.
  - Identify components for which research and development (R&D) offers greatest potential cost reduction.

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Introduction

Initiated as part of the H2A project, the Hydrogen Delivery Scenario Analysis Model (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 the individual components in a systematic market setting to develop capacity/flow parameters for a complete hydrogen delivery infrastructure. Using that systems level perspective, HDSAM calculates the full, levelized cost (i.e., summed across all components) of hydrogen delivery, accounting for losses and tradeoffs among the various component costs. A graphical user interface (GUI) permits users to specify a scenario of interest. A detailed User's Guide and access to the DOE Energy Efficiency and Renewable Energy help desk also assist users in running HDSAM.

Results

Work continued on updating and expanding the HDSAM. Pipeline cost data were updated and equations were re-estimated. Factors affecting fuel station investment and levelized cost were examined. A delivery cost target analysis was conducted to investigate the impact of alternative technologies and scale on delivery cost and to identify those components for which R&D offers the greatest potential cost reduction.

Cost Updates

All cost estimates within HDSAM were updated to 2007 dollars using appropriate indices. Pipeline costs were re-estimated in a separate effort in which additional cost data were obtained, converted to 2007 dollars and analyzed. For transmission pipelines, a 30-yr time-series of steel pipeline cost data, compiled by the Oil and Gas Journal, was used to refine costs by element (material, labor, right-of-way, miscellaneous), diameter and census region (for the lower 48 states). A similar analysis of distribution pipelines was conducted using data compiled by the Pipeline and Gas Journal. Results of the two analyses were used to update transmission and distribution pipeline cost functions contained within HDSAM.

A separate analysis of fiber-reinforced piping was conducted to determine whether that technology might be cost competitive with steel piping. Although more costly than steel to purchase, reduced installation labor costs more than offset the difference. Fiber-reinforced pipe is commonly used in small-diameter natural gas gathering lines. Its inherent flexibility allows pipe diameters up to 6 inches to be wound onto a spool and then unwound during installation, significantly reducing pipe handling and joining costs. Because flexible fiber-reinforced pipe is relatively new, future cost reductions from installation learning and competition are expected. Such reductions could make multiple parallel fiber-reinforced pipes less costly than a single larger transmission line.

Refueling Station Analyses

Depending on delivery pathway, dispensing hydrogen at a refueling station can account for $800,000 to well over $2.5 million in capital investment and add $1-3/kg to the delivered cost of the fuel. In addition to station size or daily throughput (see Figure 1), a number of other factors – including learning, station utilization and the form in which hydrogen is used on board the vehicle – can affect both total investment and delivery cost.

Figure 2 shows the effect of station utilization on the station contribution to the levelized cost of hydrogen. For a 200 kg/day station, increased utilization brings hydrogen cost down from over $10/kg to under $4/kg at full utilization. Reductions occur proportionally in both installed capital and operations and maintenance (O&M).

Figure 3 shows how onboard storage affects station capital investment. For a 200 kg/day station with 700-bar onboard storage additional compression, storage and refrigeration equipment are needed at the station. Cryo-compressed (CcH2) onboard storage replaces some of the compression and refrigeration needs with cryo-pumping

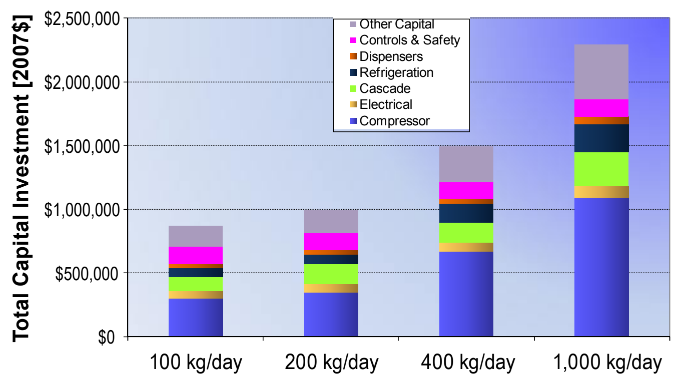

FIGURE 1. Effect of Size on Hydrogen Refueling Station Capital Investment

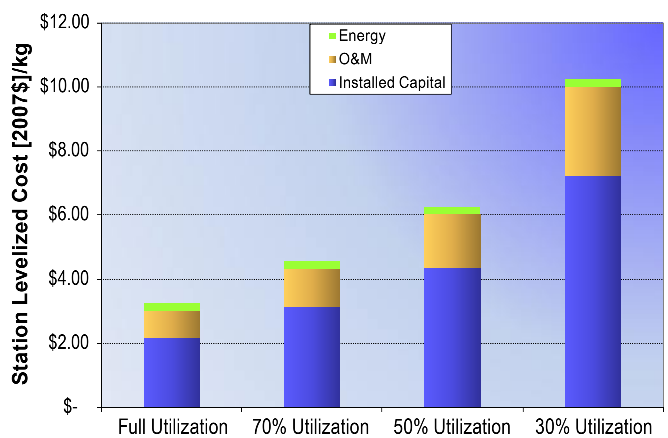

FIGURE 2. Effect of Station Utilization on Levelized Hydrogen Cost

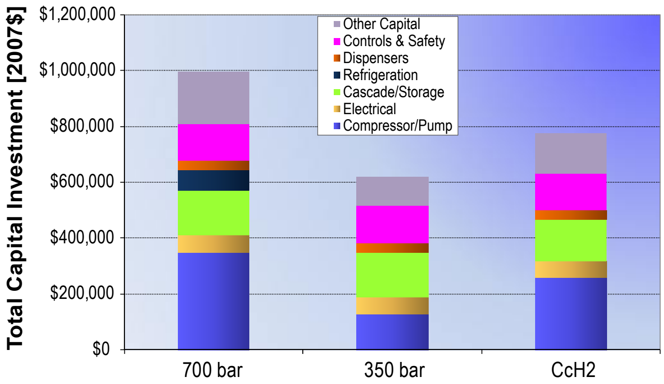

FIGURE 3. Effect of Onboard Storage Option on Station Capital Investment

which is less costly at the station (although some of the cost is shifted to the upstream component of liquefaction where it may be offset by economies of scale).

Delivery Cost Target Analyses

By combining delivery technologies into pathways and examining the cost of various combinations under different market assumptions, HDSAM permits the user to better understand the impact of a number of factors on hydrogen delivery cost. In addition to investigating the effect of delivery technology, scale, utilization, learning, and onboard storage, HDSAM provides insight into the individual components with the greatest impact on delivery cost. As shown in Figure 4, for pathways serving small, medium or large FCV markets with correspondingly small, medium or large fueling stations, preliminary analysis shows that hydrogen delivery costs drop from roughly $7 to $9/kg to below $3/kg. For liquid delivery pathways, liquefaction accounts for the largest share of delivery cost, followed closely by station costs; for gaseous pathways, the station represents the largest cost. Other costs (e.g., trucking or pipeline transportation, terminal and infrastructure storage) represent much smaller shares.

Conclusions and Future Directions

Hydrogen delivery infrastructure analysis seeks to identify aspects of hydrogen delivery that are likely to be especially costly (in capital and operating cost, energy and greenhouse gas emissions) and estimate the impact of alternative options on those costs. For the Fuel Cell Technologies Program this project has developed a model of hydrogen delivery systems to quantify those costs and permit analyses of alternative technologies and operating strategies. This work has been conducted collaboratively by staff of Argonne National Laboratory, Pacific Northwest National Laboratory and the National Renewable Energy Laboratory with the advice and assistance of several industrial partners. Regular interaction has also occurred with the Fuel Pathways and Delivery Tech Teams.

Through FY 2011, results affirm that hydrogen delivery could add $2.30 to over $9.00 to the levelized cost per kg of hydrogen "at the pump." The most promising options for reducing delivery cost tend to level demand (thereby reducing the need for hydrogen storage) or increase the energy density of the delivered fuel (by maintaining low temperature or high pressure in the delivery pathway).

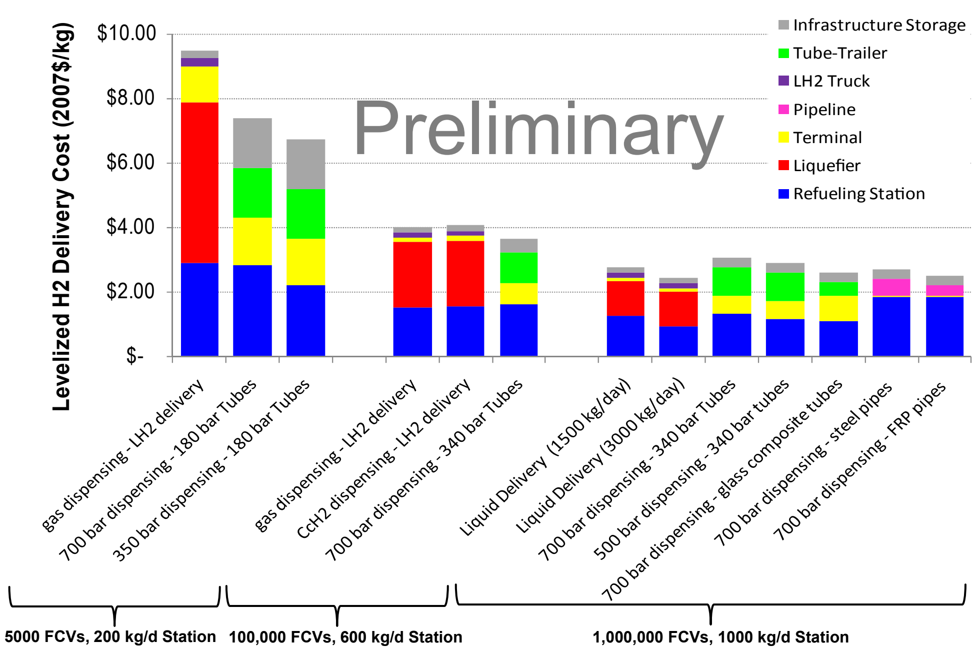

FIGURE 4. Levelized Hydrogen Delivery Cost for Select Pathways by Market Demand and Station Size

Improving the performance of individual, relatively costly delivery components is another promising option. Fueling station compressors are among the most costly of those components. In FY 2012 efforts will be directed to further study of advanced fueling compressor options, particularly as they relate to the HDSAM, and updating the model to reflect those options. In FY 2012, HDSAM will also be extended to model hydrogen delivery for early (non-automotive) fuel cell markets, especially forklift and cell tower backup power applications. Better understanding of delivery options for these early markets is critical to reducing hydrogen delivery cost for both automotive and non-automotive fuel cell applications.

Publications/Presentations

1. Elgowainy, A., M. Mintz, and D. Brown, *Hydrogen Delivery Modeling to Update Cost Targets and Identify Promising Deployment Options*, Fuel Cell and Hydrogen Energy Conference, Washington, DC, February 15, 2011.

2. Brown, D., J. Cabe, and T. Stout, *National Lab Uses OGJ Data to Develop Cost Equations*, Oil & Gas Journal, Jan. 3, 2011.

3. Elgowainy, A., M. Mintz, D. Steward, O. Sozinova, D. Brown and M. Gardiner, *Liquid Hydrogen Production and Delivery from a Dedicated Wind Power Plant*, draft report, Oct. 2010.

4. Elgowainy, A., M. Mintz and M. Gardiner, "Hydrogen Delivery Infrastructure: Analysis of Conventional Delivery Pathway Options" in *Handbook of Hydrogen Energy*, CRC Press, S.A. Sherif, D.Y. Goswami, E.K. Stefanakos and A. Steinfeld, eds., publication pending.

5. Gillette, J., M. Mintz and A. Elgowainy, *Land Requirements for Hydrogen Fuel Stations and Distribution Terminals*, draft report, May 2010.