III.4 Hydrogen Delivery Analysis

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Project Start Date: Fiscal Year (FY) 2004
Project End Date: Project continuation and direction determined annually by DOE

FY 2011 Objectives

- Provide hydrogen delivery cost analysis
- Update and maintain the H2A Delivery Components Model
- Design new delivery components and scenarios
- Support the other hydrogen models with delivery data

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies (FCT) Program Multi-Year Research, Development and Demonstration Plan:

(A) Lack of Hydrogen/Carrier and Infrastructure Option Analysis

(F) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

Technical Targets

This project aims to improve the efficiency of the hydrogen delivery process through analyzing various delivery pathways to understand the behavior and drivers of the fuel and vehicle markets and to meet Milestone 12 from the FCT Multi-Year Research, Development and Demonstration Plan: “By 2017, reduce the cost of hydrogen delivery from the point of production to the point of use at refueling sites to less than $1 per kg.”

FY 2011 Accomplishments

- Completed analysis of hydrogen delivery by rail in comparison with the other delivery options and reviewed the congestion of U.S. railroad network.
- Introduced a pipeline branching algorithm and tested the delivery components for the multi-node delivery scenario model.
- Analyzed hydrogen delivery by composite tube-trailers with capacity of 550 kg of hydrogen, and reviewed highway regulations.
- Analyzed hydrogen delivery via existing natural gas pipelines, and reviewed U.S. natural gas networks.

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Introduction

At NREL, for hydrogen delivery analysis, we use multiple models, such as the H2A Delivery Components Model, Scenario Evaluation, Regionalization and Analysis (SERA) Model, Fuel Cell Power Model and others. The H2A Delivery Components Model is an Excel-based, fully transparent model for the user, and publicly available. It can be used to calculate the cost of delivering hydrogen through multiple delivery pathways. SERA is an NREL dynamic optimization model. It is geographic information system (GIS)-based, java-coded software that determines the optimal production and delivery infrastructure build-outs and traces its evolution. The H2A Delivery Components Model also serves as a delivery cost data source for the NREL H2A Production Model, DTI HyPro Model, SERA Model, as well as for the NREL Biogas Model, Macro-System Model (through interconnection with HyPro), and HyDRA (through interconnection with SERA).

Approach

Since its start in 2004, the project has followed the general H2A approach and guidelines: closely collaborating with industry to update cost data and technical specifications, keeping consistency of the cost inputs across all H2A models, employing H2A standard assumptions, and maintaining publicly available models.

Results

Addressing barrier (A) - Lack of Hydrogen/Carrier and Infrastructure Option Analysis, we completed analysis of hydrogen delivery by rail in comparison with the other delivery options and performed a review on the U.S. railroad network congestion. Liquid hydrogen delivery by rail is the least expensive option for the large range of distances and demands (Figure 1). Therefore, it is well suited for delivering hydrogen produced from renewable sources for both early and mature markets. Analysis of the U.S. railroad networks [1] showed that 88% of the railroads are below capacity and could be potentially used to transport hydrogen.

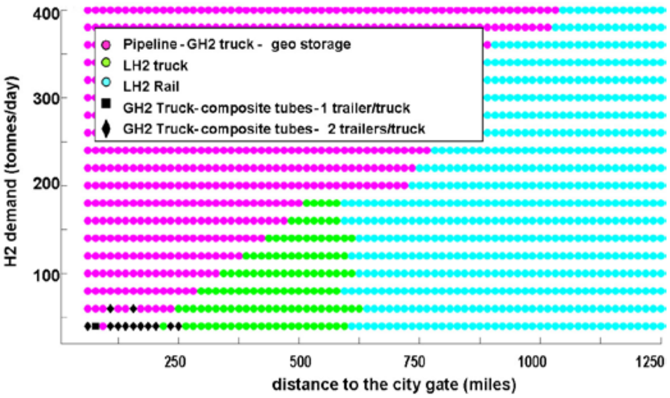

FIGURE 1. Lowest Delivery Cost Pathways

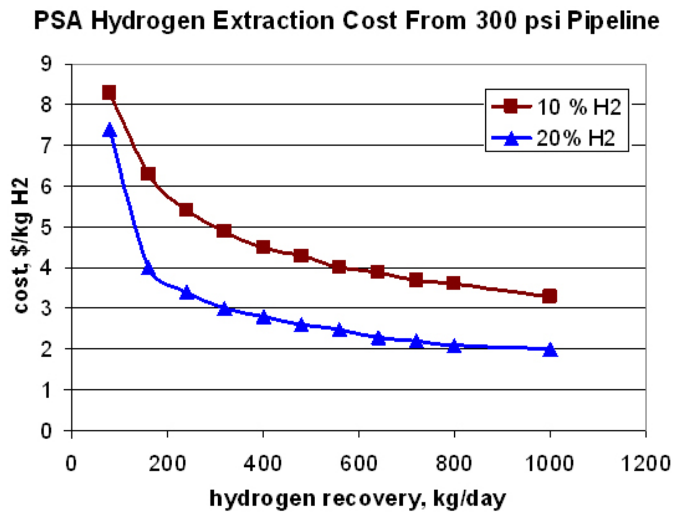

FIGURE 2. Estimated Cost of Hydrogen Extraction by PSA unit from 300 psi Distribution Pipeline (Assumed hydrogen recovery factor is 80%.)

Barrier (A) was also addressed though analyzing the delivery of hydrogen via existing natural gas infrastructure. This assessment [2] revealed that up to 20% hydrogen can be safely injected into the natural gas pipeline with no major concern for hydrogen induced failures and aging. Hydrogen addition to the distribution mains involves some modification for integrity management. Among the available gas separation technologies (membranes, electrochemical separation, and pressure-swing adsorption [PSA]), the PSA is the most commercially ready technology for today. We assessed the cost of hydrogen extraction by a PSA unit, assuming mass production and mature PSA technology. For 10% hydrogen concentration and 20% hydrogen recovery factor, the estimated cost of hydrogen extraction by PSA from a 300 psi distribution pipeline ranges from $3.3 to $8.3/kg of hydrogen extracted, depending on recovery rate. For 20% hydrogen concentration and 20% hydrogen recovery factor, the extraction cost ranges from $2.0 to $7.4/kg (see Figure 2). If hydrogen extraction can take place at a pressure reduction facility, (so the high recompression cost of natural gas can be avoided), the extraction cost would range from $0.3 to $1.3/kg of hydrogen extracted, depending on recovery rate.

We also addressed barrier (A) by assessing scenarios where hydrogen can play a role as an energy carrier. We designed and evaluated two wind-to-liquid hydrogen scenarios: grid-independent with seasonal storage, and grid-connected. Both scenarios assume hydrogen production in the amount of 40 tonnes daily near Albuquerque, New Mexico, and delivery by rail to Long Beach, California. We used NREL Wind Resource data [3], modified NREL's Fuel Cell Power Model [4] for wind farm optimization, and the H2A Delivery Components model for delivery cost. Also, we used NREL GIS data [5] for location and capacity of geologic storage, and for the nearest transmission line location and capacity. The cost of dispensed hydrogen in grid-independent case is $11.3/per kg, and $10.6 per kg in grid-connected case. As sensitivity analysis showed, there is a cost reduction possibility. Production cost is highly sensitive to the wind turbine cost. Recently, wind turbine market showed extensive volatility [6]. If wind turbines can be installed for $1,000/kW (instead of $1,500/kW – the number we used in the analysis), production cost can be dropped more than three times (to $2/kg instead of $6.6/kg) (see Figure 3). The grid-independent case is an attractive scenario in terms of energy sustainability. Nevertheless, it requires a significant amount of storage to accommodate seasonal wind variations. With the storage in geologic formation being the least expensive option for large hydrogen amounts, it is not currently feasible country-wide. Additional research and analysis has to be done to assess hydrogen storage in geologic formations.

Addressing barrier (F) - Gaseous Hydrogen Storage and Tube Trailer Delivery Costs, we analyzed the possibility of delivering gaseous hydrogen in a composite tube-trailer with a tube pressure of 250 bar and 550 kg of hydrogen capacity. Also, we reviewed Federal Highway Administration

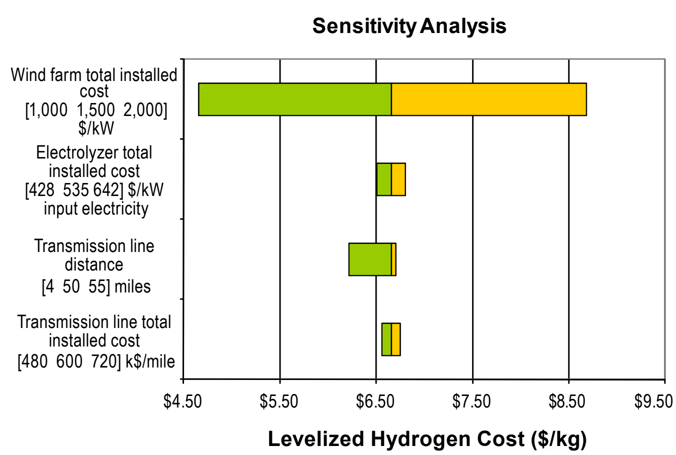

FIGURE 3. Sensitivity of Levelized Hydrogen Production Cost to Select Input Parameters

(FHWA) regulations regarding size and weight limitations on commercial motor vehicles [7]. For renewable (long-distance) hydrogen delivery, composite tube-trailers can compete with rail delivery only if a second trailer for a single truck can be allowed (Figure 4). As FHWA weight and size regulation review showed, this possibility potentially exists in the states of AK, AR, CO, ID, IN, IA, KS, MO, MT, NV, ND, OH, SD, UT, NM, NY, WY, and OR. Composite truck delivery also shows a potential for intra-city delivery, when a hydrogen production plant can be placed at the city border. The transportation cost in this case can be decreased twice with allowing for a second trailer, or increasing tube pressure up to 550 bar.

Barrier (F) was also addressed through developing a novel method of hydrogen delivery when a hydrogen plant not necessarily serves only one city, but can accommodate demand from multiple cities. By introducing these multi-node delivery scenarios, we can model pipeline and hydrogen storage systems shared between multiple cities that potentially can decrease the cost of storage designed for plant outage and demand surge. For designing multi-node delivery networks, we used the SERA Model. Considering that the SERA Model is not completely ready for multi-node delivery task, we enhanced the SERA delivery data block with coding delivery components directly into the SERA Model. The second phase of this process was completed this year. Fourteen delivery components were coded, and 10 of them were successfully tested against the H2A Delivery Components data.

Conclusions and Future Direction

In FY 2011, analyzing multiple delivery options, we reached the following conclusions:

- Hydrogen delivery by rail is the least expensive option for a large range of distances and volumes. Therefore, it is well suited for delivering renewable hydrogen; as in most cases, significant renewable sources are located far away from large demand centers.
- Delivering hydrogen in existing natural gas pipelines can be a safe and feasible option for up to 20% of hydrogen concentration. Although, the cost of this option seems to be prohibitively high except for limited cases when hydrogen extraction can be arranged at the pressure reduction facilities.
- Producing hydrogen from wind at the wind-abundant and low-electricity cost locations and delivering it to the centers of high energy demand over long distances can be a viable option to provide energy shortcomings for these areas. Such options can provide hydrogen (produced and dispensed) at the cost as low as $6/kg.
- Delivering hydrogen in composite tube-trailers has a potential of decreasing transportation cost by allowing for a second trailer per truck, or increasing tube pressure up to 550 bar.

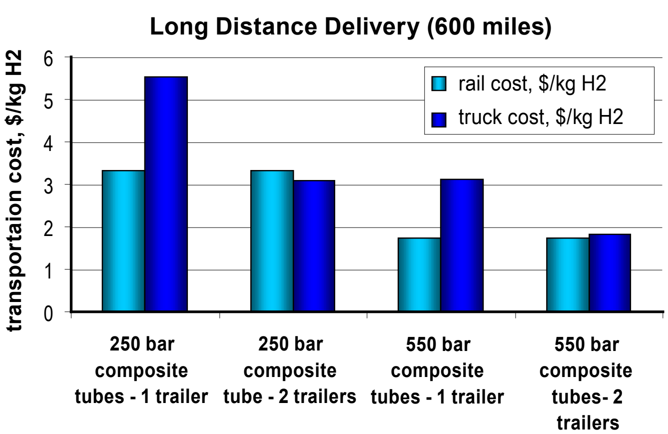

FIGURE 4. Total Cost of Gaseous Hydrogen Delivery by Rail or Truck over 600 Miles Distance

In the upcoming year, the major effort for the H2A Delivery Analysis and H2A Delivery Components Model will focus on:

- Maintaining and updating the H2A Delivery Components Model.
- Analyzing early- and mid-term delivery scenarios.

FY 2011 Publications/Presentations

1. Sozinova, O., "Hydrogen Delivery Analysis at NREL," Delivery Analysis Team Meeting, DOE Headquarters, Washington, DC, August 11, 2010.

2. Sozinova, O., "H2A Delivery Analysis at NREL," Delivery Analysis Team Meeting, DOE Headquarters, Washington, DC, February 18, 2011.

3. Bush, B.; Melaina, M.; Sozinova, O.; Steward, D. "Optimal Production, Transport, and Delivery Infrastructure for Hydrogen Production from Renewable Sources," Fuel Cell and Hydrogen Energy Conference and Expo, February 14, 2011.

4. Elgowainy, A; Mintz, M.; Steward, D.; Sozinova, O.; Brown, D.; Gardiner, M. "Liquid Hydrogen Production and Delivery From a Dedicated Wind Power Plant," October 2010 (in review).

5. Sozinova, O.; Melaina, M.; Penev, M. "Hydrogen Delivery in Natural Gas Networks," NREL Report (in review).

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1. "Association of American Railroads, National Rail Infrastructure Capacity and Investment Study," prepared by Cambridge Systematics, Inc. (Washington, DC, September 2007).

2. Sozinova, O.; Melaina, M.; Penev, M. "Hydrogen Delivery in Natural Gas Networks," NREL Report (in review).

3. NREL Western Wind Resource Data: http://www.nrel.gov/wind/integrationdatasets/western/methodology.html.

4. NREL Fuel Cell and Power Model: http://www.hydrogen.energy.gov/fc_power_analysis.html.

5. NREL GIS: http://www.nrel.gov/gis/about.html.

6. Wiser, R. and Bolinger, M., "2009 Wind Technologies Market Report," Report No. LBNL-3716E. Berkeley, CA: Lawrence Berkeley National Laboratory. http://eetd.lbl.gov/ea/emp/re-pubs.html.

7. "Federal Size Regulations for Commercial Motor Vehicles," U.S. Department of Transportation Federal Highway Administration: http://ops.fhwa.dot.gov/freight/publications/size_regs_final_rpt/size_regs_final_rpt.pdf.