III.1 Hydrogen Delivery Infrastructure Options Analysis

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- Air Liquide, Houston, TX
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- Chevron Technology Venture, Houston, TX
- Gas Technology Institute, Chicago, IL
- National Renewable Energy Laboratory (NREL), Golden, CO
- TIAX, Cambridge, MA

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Objectives

- Refine technical and cost data in the H2A models developed previously based on industrial experience.
- Explore new options to reduce hydrogen delivery cost.
- Expand H2A component and scenario models to include new options.
- Recommend hydrogen delivery strategy to DOE in terms of a pathway to build a cost-effective and energy efficient infrastructure for both the transition and long-term hydrogen deliveries.
- Assist DOE to plan required research and development (R&D) efforts to achieve the performance and cost goals for hydrogen delivery.

Technical Barriers

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

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

Technical Targets

Sound and good hydrogen delivery strategy for DOE to plan for the Hydrogen Program and fund required R&D to achieve the targets for various hydrogen delivery technologies.

Accomplishments

- Refine and update the formula and database used by the H2A delivery component and scenario models previously developed by NREL and ANL, respectively, by collecting more data from the suppliers for each delivery component.
- Take into account in the refinement and updating also the hydrogen station fueling profile, seasonal variation of hydrogen demand, outage of central hydrogen production plant, larger power demand of hydrogen stations than gas stations, and hydrogen station plot area requirements.
- Program the refinement and updating into the H2A component and scenario models.
- Add the life cycle greenhouse gas (GHG) emission estimate into the H2A component and scenario models.
- Develop formula for the various components involved in hydrogen delivery by several novel carriers (alanates, chemical hydrides, and liquid hydrocarbons).

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Introduction

NREL and ANL have developed the H2A delivery component and scenario models as tools for DOE to analyze the costs of various delivery options and to plan for the hydrogen delivery strategy and R&D program. But these models have included only three options: gaseous hydrogen delivery by pipelines, gaseous hydrogen delivery in tube trailers, and liquid hydrogen delivery by tank trucks. The current study will refine many of the assumptions and database used in these previous efforts by reviewing more thoroughly the industrial practices and examining more closely the various system components involved in each delivery option. It will also expand the number of delivery options to explore whether the new options added can be more economical and have the potential to reduce the delivery cost within the DOE targets and whether some of them can be good transition solutions.

Approach

The project will evaluate and analyze the following seven options for delivering hydrogen from central, semi-central, and distributed production plants to the points of use:

Option 1: Dedicated pipelines for gaseous hydrogen delivery.

Option 2: Use of existing natural gas or oil pipelines for gaseous hydrogen delivery.

Option 3: Use of existing natural gas pipelines by blending in gaseous hydrogen with the separation of hydrogen from natural gas at the point of use.

Option 4: Truck or rail delivery of gaseous hydrogen.

Option 5: Truck, rail, or pipeline transport of liquid hydrogen.

Option 6: Use of novel solid or liquid hydrogen carriers in slurry/solvent form transported by pipeline/rail/trucks.

Option 7: Transport methanol or ethanol by truck, rail, or pipeline and reform it into hydrogen at point of use.

The analysis will be conducted under the following six technical tasks:

Task 1: Collect and compile data and knowledge for the seven delivery options and relevant information on the regional energy resources and hydrogen demand centers in U.S.

Task 2: Evaluate current efficiencies and costs of the seven delivery options considered and their potential performance and cost improvements.

Task 3: Evaluate existing infrastructure capability in U.S. for hydrogen delivery.

Task 4: Assess GHG and pollutant emissions of the seven delivery options considered.

Task 5: Compare and rank the seven delivery options, including the construction and use of a performance/cost model for these options.

Task 6: Recommend transition and long-term hydrogen delivery strategies for both urban and rural areas, including required R&D and also the proper split of central and distributed production in conjunction with the production infrastructure analysis.

Results

The Nexant team has completed Tasks 1 and 3 in the last year. The effort of this year focused on Tasks 2 and 4.

Task 2 did not analyze Delivery Options 1, 3, and 7 in depths because a preliminary analysis has shown that they are not economical or practical. Delivery Options 2, 4, and 5 are already included in the H2A model. The major efforts of Task 2 for these options are to refine and update the formula and database used by collecting more data from the suppliers for each delivery component. The refinement and updating also took into account the hydrogen station fueling profile, seasonal variation of hydrogen demand, outage of central hydrogen production plant, larger power demand of hydrogen stations than gas stations, and hydrogen station plot area requirements. The H2A model, HDSAM 1.0, is revised accordingly and the revised version, HDSAM 2.0, has been issued and available on Energy Efficiency and Renewable Energy's Web site.

The enhancements of HDSAM 2.0 over HDSAM 1.0 are:

- The delivery components are sized to meet the real hydrogen demand profiles in refueling stations.
- Necessary storages are provided to cover the outages of central hydrogen production plants, summer peak demand of fuel for driving, and hourly peak demand of hydrogen at refueling stations.
- The station size can vary from 50 to 6,000 kg/d hydrogen.
- Additional hydrogen delivery pathways, such as mixed-mode deliveries and combined markets, are included.
- Refined design for the various components in a refueling station.
- A system optimization was conducted and included for refueling stations to minimize their costs.
- Practical limits on the size of the delivery components are considered: liquefier, compressors, storage, etc.
- Land area is taken in account in the design for the refueling station and hydrogen distribution terminals.
- Refined capital and operations and maintenance cost estimates for the liquefier, pipeline, compressor, storage, indirect costs, labor, and land.
- The market profiles for hydrogen, such as population, vehicle ownership, fuel economy, and mileage driven per year, are updated.
- The properties and prices of fuels used are updated.
- The life-cycle GHG emission and criteria pollutant emissions associated with each delivery option are calculated; the GHG emission estimate was built on

the work already done by the DOE's GREET model. The estimate included fulfills the work requirements for Task 4.

- Additional user options are provided: modification of the hydrogen demand profile at the refueling station, underutilization of the refueling station, and plant outage rates.

Task 2 has evaluated Delivery Option 6: novel hydrogen carriers. Efforts were concentrated on three carriers: alanates, chemical hydride, and liquid hydrocarbon. Correlations were developed for the performance and costs of the various components required for hydrogen delivery based on use of these carriers. The H2A model is currently being expanded to include Delivery Option 6 based on the correlations developed.

Shown in Figures 1, 2, and 3 are sample output from HDSAM 2.0 in comparison with that from HDSAM 1.0, for Delivery Options 1, 4, and 5, respectively. It is seen that the delivery costs increase from HDSAM 1.0 to HDSAM 2.0 for all the options. For higher market penetration, which also justifies large refueling station (the sample run chooses 1,050 kg/d), gaseous hydrogen pipeline delivery is more cost-effective than liquefied hydrogen tank truck delivery. For low market penetration, which usually can justify very small refueling station, the delivery cost by gaseous hydrogen tube trailer is very expensive.

Conclusions and Future Directions

The sample runs from HDSAM 2.0 show the results, which are expected. But they do provide a quantitative analysis of the delivery cost. More runs will be made on this refined and updated H2A delivery model model.

The future work in this project will be to conduct Tasks 5 and 6. The novel carriers in Option 6 are still under development and have high levels of uncertainties in their performance and costs. So, the carriers will not be considered in constructing the hydrogen delivery roadmap.

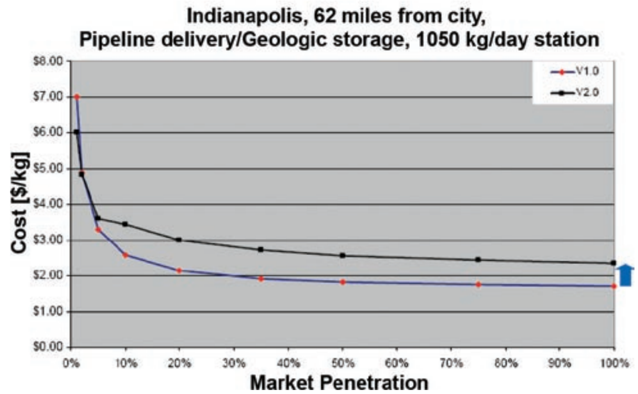

FIGURE 1. Hydrogen Delivery Cost for Option 1: Gaseous Hydrogen by Pipeline

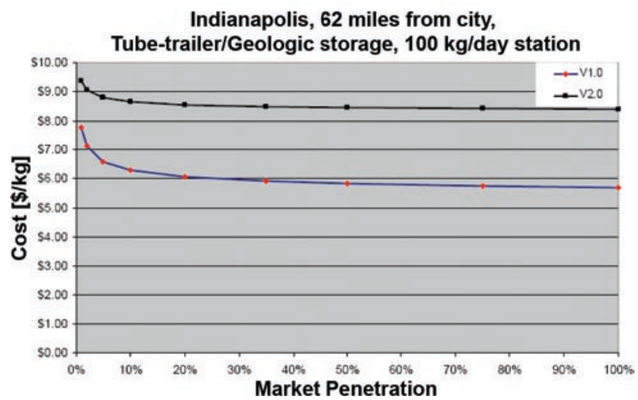

FIGURE 2. Hydrogen Delivery Cost for Option 4: Gaseous Hydrogen by Tube Trailer

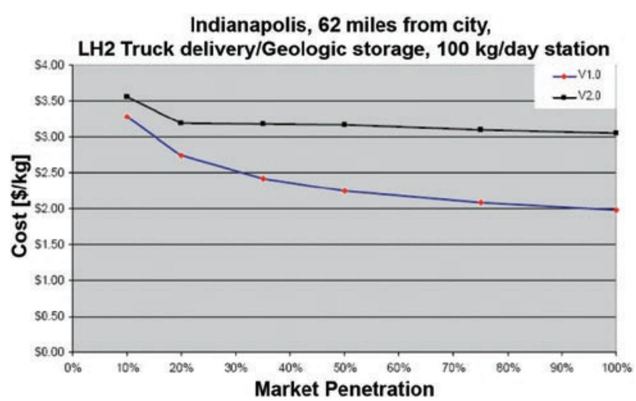

FIGURE 3. Hydrogen Delivery Cost for Option 5: Liquefied Hydrogen by Tank Truck