III.C.2 Hydrogen Delivery Infrastructure Options Analysis

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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 H_2 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 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 (3.2.4.2) 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

Since this project is conducting analysis, the Delivery technical targets do not apply. The results of this work will be used to develop a sound H_2 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

- Provided a critical review of formulas and databases used by the H2A delivery component and scenario models previously developed by the National Renewable Energy Laboratory (NREL) and Argonne National Laboratory (ANL), respectively.
- Surveyed the regional availability and potential of various energy resources (natural gas, coal, hydro, wind, solar, biomass, and nuclear) to produce and deliver hydrogen to the demand centers in the U.S.
- Surveyed current operation of gas stations in the U.S., including daily and seasonal fuel demand profiles, as the basis for the design and cost estimate of the hydrogen delivery to the forecourt and forecourt hydrogen storage and dispensing requirements.
- Surveyed current installations, operation, and costs of U.S. hydrogen delivery pipelines.
- Surveyed current operation and costs of gaseous hydrogen delivery by tube trailers and liquid hydrogen delivery by tank trucks in the U.S., including technology advances in liquefaction processes and tube trailers.
- Surveyed current installations and operation of natural gas transmission and distribution systems and oil pipelines to learn relevant construction and operation experience and cost data and to determine the suitability and capacity adjustment to convert these systems for hydrogen delivery and distribution.
- Provided an initial analysis of technical practicality and economics of four processes (pressure swing adsorption, membrane, hydrogen absorber, and methane hydrate) to separate hydrogen from natural gas at the city gate when hydrogen is delivered by blending with natural gas in existing natural gas transmission lines.
- Provided an initial analysis of the performance and economic effectiveness of five novel hydrogen carriers (alanates, chemical hydrides, liquid hydrocarbons, flowable powder, and bricks).
- Provided an initial analysis of the performance and economic effectiveness of three more conventional

hydrogen carriers (methanol, ethanol, and ammonia), which require on-site conversion into gaseous hydrogen at forecourt with subsequent compression and storage prior to dispensing into fuel cell vehicles (FCVs).

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 databases 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 potential to reduce the delivery cost to meet 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 or rail delivery of liquid hydrogen

Option 6: Use of novel solid or liquid H_2 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 the 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 the U.S. for hydrogen delivery

Task 4: Assess greenhouse gas (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 Task 1. The hydrogen pipeline experience collected is summarized in Figure 1.

The economics to convert natural gas pipelines to deliver hydrogen are shown in Figure 2. The cost of conversion is typically 5-50% of the cost of a new line based on actual field data from Air Liquide. As shown in Figure 2, the cost advantage of converting an existing oil or natural gas pipeline to transport hydrogen is very marginal because the only cost saving is on the transmission line cost, which is a very small cost component of the total delivery cost.

All the separation processes considered were found to be impractical. Nexant's team member, Air Liquide, came up with an innovative process to overcome this issue. Figure 3 shows the economics of this separation process. The blending of hydrogen into an existing natural gas line eliminates the transmission line cost but, on the other hand, this requires the separation facility at the city gate. Figure 3 shows that Air Liquide's process is economical only when the central production plant is more than 175 miles away from the city.

The current fueling profile at a typical gas station based on data provided by Chevron is shown in Figure 4. It shows:

- The daily fuel demand steadily increases from Monday to Friday. It reaches the peak on Friday as people fill up the fuel tank for the weekend. The demand on Saturday is the lowest. The demand then increases substantially on Sunday as people fill up the tank for work on weekdays.
- The hourly demands within a day can be divided into three patterns. The profile for days in the mid-

week (Tuesday, Wednesday, and Thursday) has two demand peaks at 8 am and 3 pm. The profile for the beginning and end of the weekdays (Monday and Friday) also has two demand peaks at 8 am and 3 pm, even though less pronounced. The profile for weekends (Saturday and Sunday), however, has only one demand peak, occurring about noontime.

- There are almost no cars coming to the gas station during midnight to refuel.
- There is also a seasonal demand variation. The winter demand is 70% and 90% of the summer demand in the North and South regions, respectively.

From Figure 4, it is seen that there is a very wide variation of fuel demand within a day and, to a much lesser extent, also within a week. It is expected that the demand for hydrogen in the fueling station will follow the same profiles. Figure 5 an shows oversized hydrogen pipeline is the most cost effective option to cope with this demand swing.

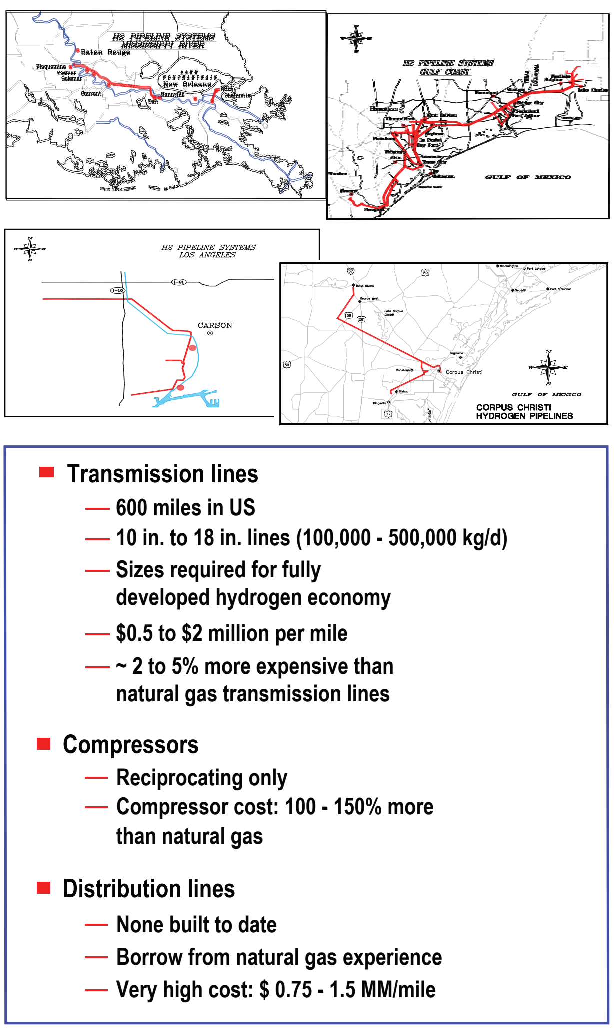

FIGURE 1. Hydrogen Pipeline Experience

Figure 6 shows a preliminary economic comparison of the five novel carriers considered.

Conclusions and Future Directions

The major conclusions from Task 1 are as follows:

- Forecourt H_2 demand profile is a critical factor to consider in selecting delivery options
- There is only marginal cost advantage to convert existing natural gas/oil pipeline for H_2 delivery if the transmission line is short

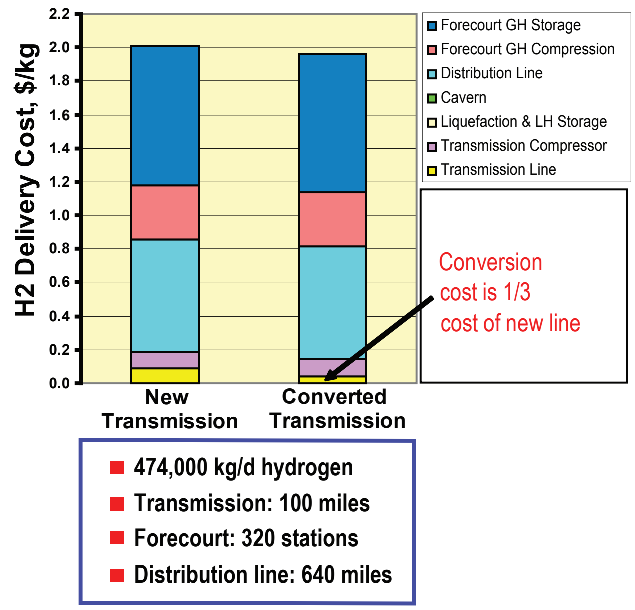

FIGURE 2. Economics for Converting Pipelines

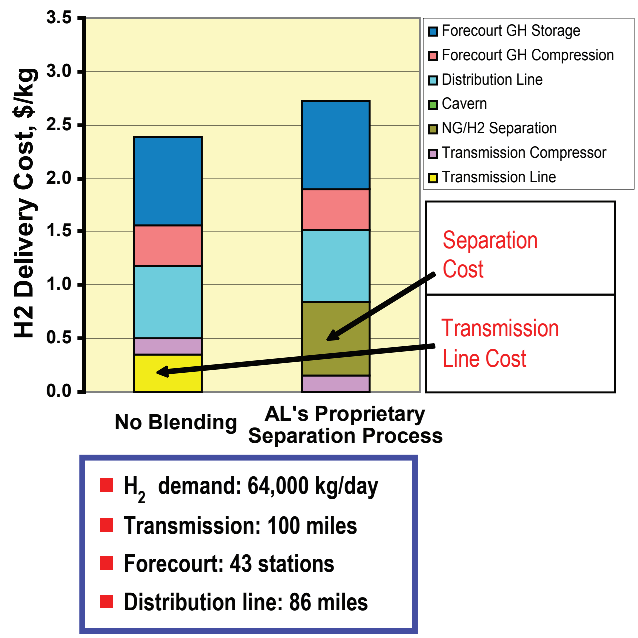

FIGURE 3. Economics of H_2 Separation from Natural Gas

- Blending H_2 into existing natural gas line does not pay if the gas transmission distance is short
- Liquid hydrocarbons, such as that being developed by Air Products, hold good promise to reduce the hydrogen delivery cost

With the knowledge bases established in Task 1, the Nexant team is developing a detailed design and cost estimate in Task 2 for each delivery option in order to refine and expand the H2A models.

FY 2006 Publications/Presentations

1. A presentation regarding the overall project status was given at the DOE Annual Merit Review Meeting (May 2006).

2. A presentation regarding the work accomplished in Task 1 was given at the NHA Conference (February 2006).

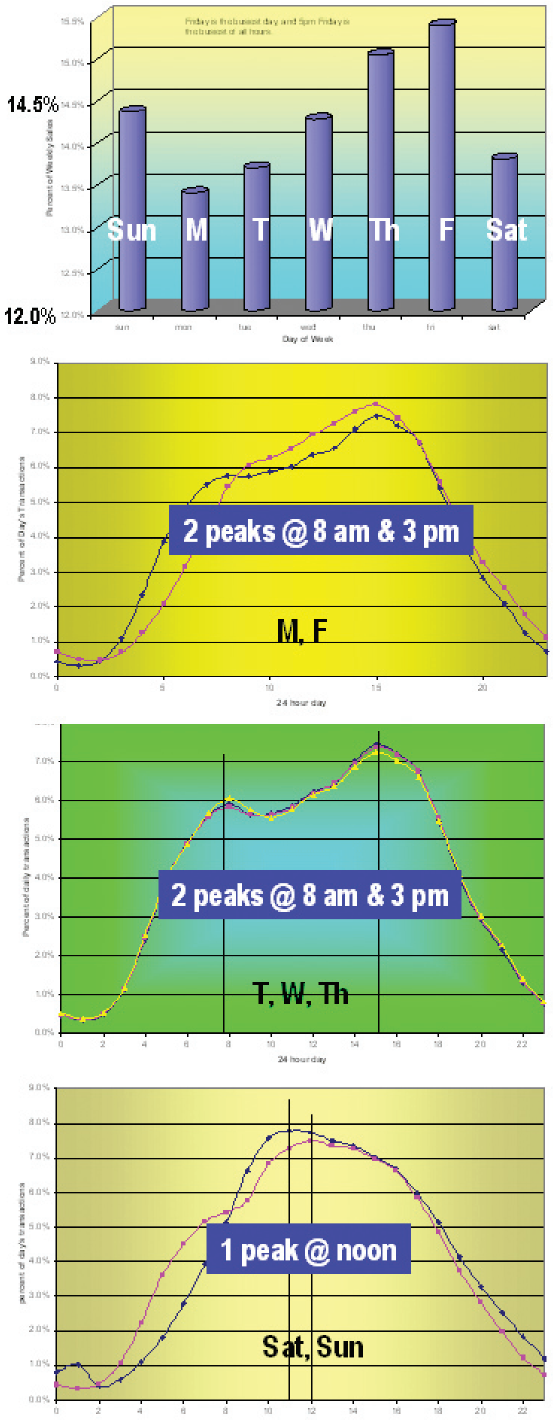

FIGURE 4. Gas Station Fueling Profile

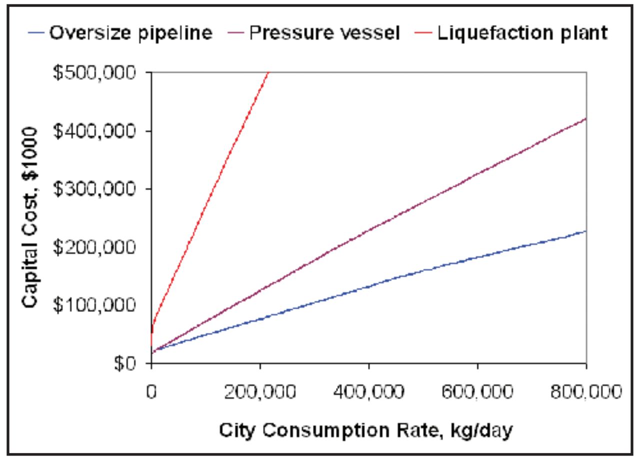

FIGURE 5. Options to Match Forecourt Demand

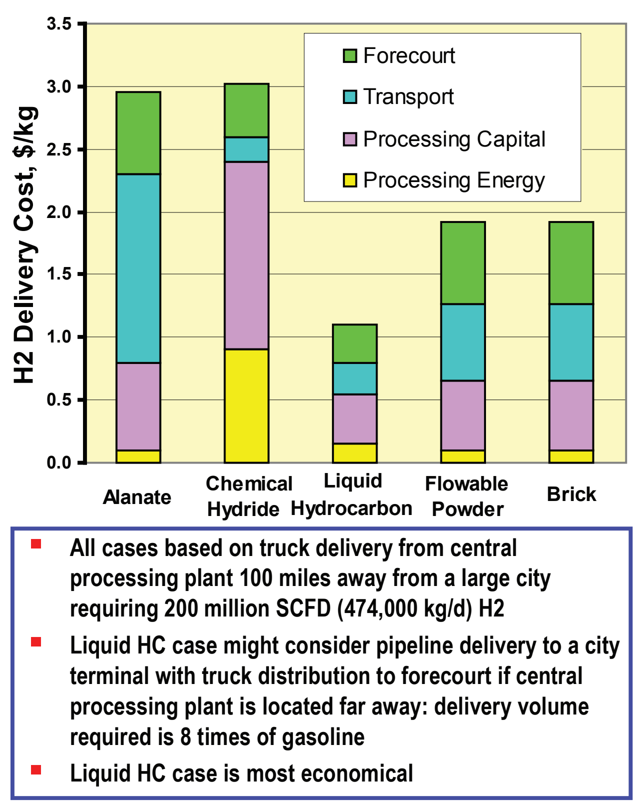

FIGURE 6. Comparison of Novel Carriers