III.C.1 H2A Delivery Analysis

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Objectives

- Quantify the cost of delivering hydrogen by different modes and technologies under alternative types and levels of market demand by light-duty vehicles.
- Compare alternative delivery modes on a consistent, transparent basis.
- Identify delivery modes and infrastructures with potential to meet program delivery targets.
- Assist in developing program targets.

Technical Barriers

This project addresses the following technical barriers from 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

(F) Hydrogen Delivery Infrastructure Storage Costs

Technical Targets

Under this project, two models have been developed – the H2A Hydrogen Delivery Components Model and the H2A Hydrogen Delivery Scenario Analysis Model (HDSAM). The former estimates the costs associated with the various components required to deliver liquid or gaseous hydrogen from a central production plant to a forecourt station or another end-use site. The latter links these component costs in a systematic market setting to develop capacity/flow parameters for a hydrogen delivery infrastructure. Using that system-level perspective, HDSAM calculates the full cost (i.e., summed across all components) of hydrogen delivery, accounting for tradeoffs among the various component costs. As such, it is not a technical activity that can be measured against program targets but a tool that can be used to set such targets.

Accomplishments

- Added high-pressure (i.e., 7,000 psi) gaseous trucks, and two sizes of liquid and gaseous forecourts (i.e., refueling stations) to the Delivery Components Model and as user-selected options in HDSAM.
- Updated pipeline and storage portions of the two models.
- Added a “mixed” mode option to the beta version of HDSAM. This option permits the user to specify a “local distribution” mode (liquid or gaseous truck, pipeline) that is different from the “bulk delivery” or transmission mode.
- Expanded HDSAM’s graphical user interface (GUI) for user-specification of delivery scenarios to include mixed modes, additional pathways, and user-feedback if a selected pathway is “problematic” (e.g., low-pressure gas truck delivery to 1,500 kg/d stations in high demand scenarios).
- Participated in internal EERE modeling and analysis workshops, transferring beta versions of the models to teams working on system and transition models (e.g., HYTRANS, NEMS-H2, Macro System Model), assisting them in their use, and obtaining detailed reviews and other feedback .
- Worked with Nexant, Inc. and its team to obtain external review of model assumptions and industry input for ongoing model expansions.
- Incorporated review comments, updates and expansions from the above into Version 1.1 of the Hydrogen Delivery Components model and Version 1.0 of HDSAM, and posted the models on the EERE website.
- Developed Users’ Guides for the two models and posted them on the EERE website.
- Worked with staff responsible for the EERE help desk to establish a procedure for assisting users of the two models, to develop instructions for user access to the help desk, and to train help desk personnel who will be responding to user inquiries.
- Conducted sensitivity analyses of selected parameters.

Introduction

This work evolved from the H2A project which focused on developing consistent, transparent tools to model the three major sets of infrastructure (production, delivery and forecourt) that contribute to the cost of hydrogen fuel. Historically, considerable effort has been devoted to hydrogen production analysis. Process modeling tools and the knowledge base to apply them are readily available. This is not true for delivery analysis, a relatively recent addition to the DOE Hydrogen Program, where model development continues.

Delivery analysis seeks to characterize the cost of the various pieces or “components” of alternative pathways for the delivery of hydrogen fuel from a central production facility to the tank of a hydrogen-fueled vehicle. Coupled with scenario analysis, which is used to estimate the quantity of hydrogen needed to satisfy market demand, the cost of appropriately-sized components can be estimated and summed to calculate the cost of entire pathways for delivering hydrogen. This was accomplished in the past year by completing Version 1.0 of the Hydrogen Delivery Scenarios Analysis model (HDSAM) which estimates market demands and links components characterized in the Hydrogen Delivery Components model. Version 1.1 of the latter model was also produced this year. In addition to ongoing enhancements, the models are now being used to refine program targets, investigate tradeoffs and synergies among targets, and identify the impacts of technology improvements on cost targets.

Approach

As with other parts of the H2A program, this project is developing a set of tools to permit consistent, transparent analyses of hydrogen cost – in this case, for the chain of activities needed to deliver hydrogen from its production site to a vehicle. Both the Components Model and the Delivery Scenario model are based on Microsoft Excel.

Results

Initial versions of the Hydrogen Delivery Components and HDSAM models were completed in FY 2005. Version 1.0 of the Delivery Components Model was posted on the EERE website in July FY 2005. Posting of HDSAM was deferred pending additional review and enhancements. Following completion of those enhancements, HDSAM and an updated version of the Components Model were posted in April 2006, along with Users’ Guides and other information for assisting model users.

Enhancements completed in FY 2006 included the addition of high pressure (i.e., 7,000 psi) compressed gas tube trailers, “mixed” delivery modes (i.e., pipeline + liquid or gaseous truck), and two sizes of liquid and gaseous forecourts, revisions to pipeline and storage equations, and expansion of the GUI for user-specification of delivery scenarios. Figure 1 shows the GUI developed for HDSAM.

Figure 2 illustrates the effect of demand (in kg/day) on delivery cost for three potential delivery pathways to an urbanized area of 250,000 persons. Note how cost drops sharply for liquid truck or pipeline delivery, primarily due to scale economies for the liquefier and forecourt. Due to their much lower carrying capacity, this cannot occur with low-pressure (3,000 psi) hydrogen tube trailers.

Figure 3 shows comparable results for intercity/rural markets as a function of hydrogen demand. Note that delivery costs tend to be higher and pipelines tend to be less competitive in this market. Again, scale economies reduce LH2 truck and pipeline delivery cost.

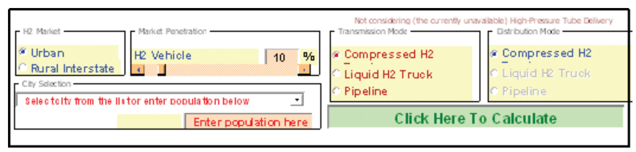

FIGURE 1. Screen-Capture of HDSAM GUI Illustrating User-Selection of Market Type and Size, Penetration and Delivery Mode

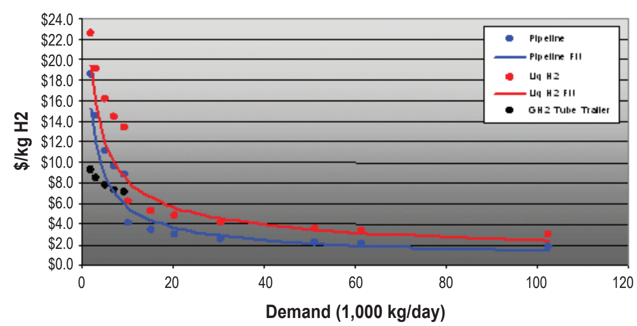

FIGURE 2. Cost of Delivering Hydrogen to an Urban Market Via Three Potential Pathways

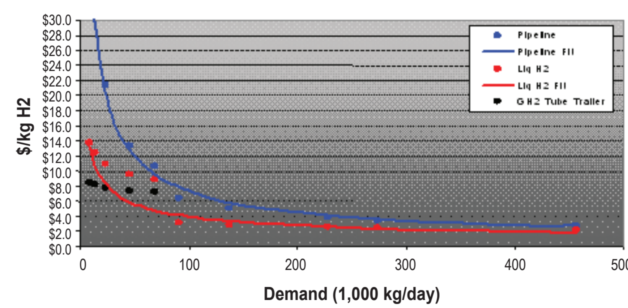

FIGURE 3. Cost of Delivering Hydrogen to a Rural/Interstate Market Via Three Potential Pathways

Conclusions and Future Directions

- Delivery costs are likely to be particularly high for rural/interstate delivery via conventional technologies. By increasing the scale of key components, "mixed" and/or multiple markets (consisting of several urban areas) may reduce rural delivery cost. These modeling options will be investigated in FY 2007.
- For pathways modeled, packaging (liquefiers, compressors), forecourts, and pipelines account for the largest shares of capital cost. In FY 2007, forecourt and pipeline design and operations will be investigated with an eye toward identifying opportunities for reducing system cost and improving model representations accordingly.
- Hydrogen carriers will also be examined to identify additional opportunities for reducing delivery costs. In FY 2007 this will be accomplished in collaboration with the Nexant Project Team.
- At low demand (<10% market penetration) compressed gas delivery to small stations may be most economic; at higher demand, larger stations (forecourts) are essential to reduce delivery cost. In FY 2007 the economics of a range of forecourt sizes will be modeled to test this observation.
- The cost of hydrogen delivery from a central hydrogen production plant to a city gate increases with distance for pipeline delivery but relatively little for liquid truck delivery. This initial observation from the "mixed mode", beta version of HDSAM will be investigated further in FY 2007.
- Additional model enhancements planned for FY 2007 include estimating energy efficiencies and CO_2 emissions associated with alternative pathways and improving reporting capabilities.

FY 2006 Publications/Presentations

1. Mintz, Marianne, Jerry Gillette, and Amgad Elgowainy, *Hydrogen Distribution Options Analysis Using a Generalized Model of Hydrogen Delivery*, Presented at the Windsor Workshop: Transportation Technologies & Fuels Forum, Toronto (June 6, 2006).

2. Ringer, Matt, *H2A Delivery Components Model Version 1.1: Users Guide* (April 2006).

3. Mintz, Marianne, Jerry Gillette and Amgad Elgowainy, *H2A Delivery Scenario Analysis Model Version 1.0 User's Manual* (April 2006).

4. Ringer, Matt, *H2A Hydrogen Delivery Components Model–Status Update*, Presented at the National Hydrogen Association Annual Meeting (March 15-16, 2006).

5. Mintz, Marianne, Jerry Gillette, and Amgad Elgowainy, *Hydrogen Distribution Options Analysis Using a Generalized Model of Hydrogen Delivery*, Presented at the National Hydrogen Association Annual Meeting (March 15, 2006).

6. Mintz, Marianne, Jerry Gillette, Amgad Elgowainy, Matt Ringer, Daryl Brown, Mark Paster and James Li, *HDSAM: A Hydrogen Delivery Scenario Analysis Model to Analyze Hydrogen Distribution Options*, Presented at the Transportation Research Board Annual Meeting, Washington, D.C. (January 23, 2006).

7. Marianne Mintz, Jerry Gillette, Amgad Elgowainy, Matt Ringer and Daryl Brown, *H2A Delivery Models and Results*, Presented at the DOE Analysis Workshop, Washington, D.C. (January 23, 2006).

8. Mintz, Marianne and Jerry Gillette, *H2A Delivery Modeling: Current Status and Approach to Incorporating Chemical H2 Carriers*, Presented at Chemical H2 Storage Systems Analysis Meeting, Argonne National Laboratory (October 12, 2005).

Special Recognitions & Awards/Patents Issued

1. 2006 DOE Hydrogen Program R&D Award "In Recognition of Outstanding Achievement in Delivery Analysis" presented to Daryl Brown (PNL), Amgad Elgowainy (ANL), Jerry Gillette (ANL), Marianne Mintz (ANL), Joan Ogden (UC Davis) and Matt Ringer (NREL).