VIII.1 Using HyPro to Evaluate Competing Hydrogen Pathways

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- H_2Gen Innovations, Inc., Alexandria, VA
- Chevron Technology Ventures, Houston, TX
- Teledyne Energy Services, Hunt Valley, MD

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Objectives

- Develop understanding of how a hydrogen production infrastructure for H_2 fuel cell (FC)/internal combustion engine (ICE) vehicles might develop in the U.S.
- Quantify production methods under consistent cost and state-of-technology assumptions.
- Analyze infrastructure development under dynamic conditions over time.
- Determine factors that will drive infrastructure development.
- Define role of externalities such as policy and technology advancement.
- Develop a computational model to aid in the analysis.

Technical Barriers

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

(B) Stove-Piped/Siloed Analytical Capability
(C) Inconsistent Data, Assumptions and Guidelines
(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE systems analysis milestones from the Systems Analysis section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 3:** Begin a coordinated study of market transformation analysis with H2A and Delivery models. (1Q, 2006)
- **Milestone 5:** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- **Milestone 21:** Complete the Production Infrastructure Options model. (4Q, 2007)
- **Milestone 30:** Survey hydrogen community for assumptions, data sets, targets, and constraints for input to the database. (2Q, 2005)

Accomplishments

- Improved production database with more accurate carbon sequestration system costs, bulk hydrogen storage, and production options from nuclear and distributed ethanol.
- Reconfigured hydrogen pathways to include terminals as separate components and allow for mixed-mode delivery methods.
- Modified the dispensing and delivery databases to reflect H2A Components model and modified HyPro model to compute terminal, dispensing and delivery costs with net present value (NPV) calculations.
- Upgraded model to include infrastructure capital costs, learning, and component stranding. Modified pipeline algorithm to an approximation of the minimum spanning tree algorithm rather than the ring and trunk system used in the Hydrogen Delivery Scenario Analysis Model (HDSAM).
- Evaluated the impact of carbon sequestration and greenhouse gas emissions policies on the overall capital costs of the hydrogen infrastructure.
- Compared model results with other models in the hydrogen community.

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Introduction

Historically, getting society to transition to a new technology is a lengthy process. The conversion of gasoline light-duty vehicles to hydrogen fueled vehicles is no exception. Consequently, the challenge is to determine what incentives are necessary to minimize the transition time and cost while maximizing market penetration. This project's goal is to develop a better understanding of how the H_2 production infrastructure to support fuel cell automobiles might develop in the continental U.S. taking into account the dynamic conditions under which it will evolve. The project provides analysis of the options and trade-offs associated with establishing the required hydrogen production infrastructure to provide hydrogen to fuel cell vehicles in the 2020 timeframe and beyond.

The results from this analysis effort will inform the DOE of the expected cost of delivered hydrogen from a wide range of production and delivery options absent externalities and the impact of policies, credits and taxes that the government could implement to promote the transition to hydrogen fuel for light duty vehicles. DOE will develop a better understanding of the transition from these results and be better able to allocate future resources to the most promising policy and hydrogen production alternatives.

Approach

The primary approach to achieve this goal is through the development and use of a computational model simulating industry's decision making process regarding construction of new H_2 production facilities. In Task 1, a database of key information describing current, emerging, and proposed hydrogen production, terminal, delivery, and dispensing technologies is created. All data are based on a consistent set of economic and performance criteria. The production methods are characterized by feedstock, product form, size and location. Feedstocks and their method of conversion to hydrogen explored include coal (gasification), natural gas (steam methane reforming [SMR]), water (electrolysis), and biomass (gasification). Product forms are gaseous and liquid outputs. The sizes are small (100 kgH_2/day) and large (1.5 tons per day [TPD]) forecourts as well as city-gate (15 TPD) and central sizes (100's of TPD). Central plants were also distinguished by locations such as inner city, city limits, central, and regional. Within the baseline database there are approximately 40 production alternatives considered. In Task 2, a computer model is developed. Using the Task 1 database as input, the computer model performs economic optimization calculations for each of the production/terminal/delivery/dispensing infrastructure options, simulating which option is constructed in a given year based on the pathway with the lowest total profited cost per kilogram of hydrogen dispensed. When viewed over multiple years, a clear picture of the transition to the hydrogen economy is presented. The model identifies quantity, type and scale of the hydrogen facilities built in each year, the expected cost of hydrogen at the pump (profited cost), and any stranded assets resulting from lower cost options entering the market in later years. The model is exercised on a Los Angeles transition scenario that serves as a baseline case.

Sensitivity analyses and case studies are part of Task 3. By varying model parameters such as hydrogen demand, facility costs, and technological developments, and applying policy drivers (carbon taxes, preferential tax treatment, and H_2 subsidies), one arrives at the key parameters that influence the infrastructure development. The results report is essentially Task 4. Recommendations will be provided to the DOE regarding how to facilitate the development of the production infrastructure for widespread hydrogen fuel cell vehicle usage.

Results

The model was run with a simulated hydrogen demand curve for Los Angeles which assumed 15% H_2 vehicle penetration in the first 10 years of the transition and approached full transition in 38 years. The demand profile and expected resulting hydrogen infrastructure build out are shown in Figure 1. As seen in the figure, hydrogen is initially supplied from merchant hydrogen production sources in the LA area that have surplus capacity. (The surplus gaseous hydrogen from multiple plants is collected by a pipeline network, liquefied at a newly constructed facility, and sent to forecourt 1,500 kgH_2/day dispensing stations via truck.) After H_2 demand exceeds the surplus hydrogen availability, new production facilities need to be fabricated. The 1,500 kgH_2/day forecourt distributed SMR production option is selected as the pathway supplying the lowest delivered

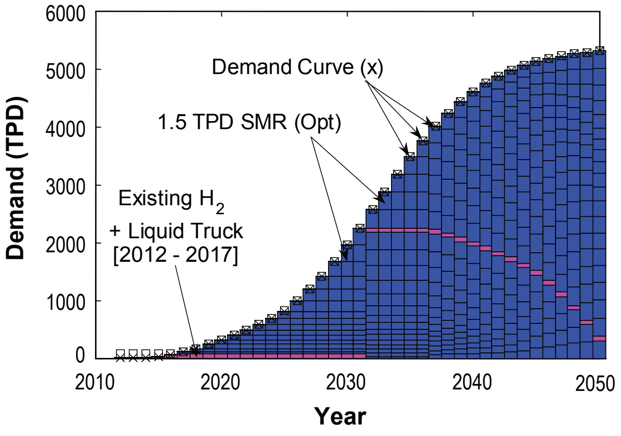

FIGURE 1. Hydrogen Build Out for Los Angeles (Baseline)

cost of H_2 for every additional year in the analysis. Each production option is shown as a separate color, thus the prevalence of blue indicates the dominance of the forecourt SMR option.

In Figure 2 the profited costs of several options are plotted against the analysis year and provide insight into the relative cost differences between the options rather than just noting the lowest cost option. For clarity, this plot is not inclusive of all the pathways considered but rather is a subset of the infrastructure pathways of interest. From this plot it is evident that the baseline forecourt SMR has the lowest projected delivered cost of hydrogen in every year of the analysis period. We call this option the Optimistic 1.5 TPD SMR because the costs associated with this option are at the low end of the capital cost estimates to reflect modular factory construction at high volume. In contrast, we also evaluated a Pessimistic 1.5 TPD SMR option with approximately double the total installed capital cost. While a 2x factor on capital cost may seem extreme, estimates from experts in the community span that range. Figure 2 shows the profited cost of this option is much greater and thus other options become more competitive if the Pessimistic is indeed the more accurate estimate for forecourt production.

However, depending on forecourt SMR plants for all future hydrogen production has drawbacks that are not captured in a purely economic analysis. The premise of the conversion of light-duty vehicles to hydrogen fuel has two goals: first, to nationally reduce greenhouse gas emissions and second, to reduce our dependence on foreign energy sources. Widespread use of forecourt SMRs helps but is not ideal for either goal. Since currently there is not an identified means of forecourt CO_2 sequestration, non-renewable forecourt options primarily shift greenhouse gas emissions from the tailpipes of cars to the production site rather than eliminating them. (Although significant reduction does result due to the higher efficiency of fuel cell vehicles compared to ICE vehicles.) Additionally, forecourt SMRs use natural gas (NG) as the primary feedstock. Increased use of natural gas would reduce foreign oil importation but would increase foreign natural gas importation. This is arguably a favorable tradeoff but a reduction/elimination of imports is much preferred. Thus even though forecourt SMRs are the lowest cost option and may play a key role in the transition, in the long run they do not satisfy the objectives of the DOE. Other alternatives should be considered.

To look at alternatives, we used the model to evaluate how two policies could modify the infrastructure build out. First we looked at requiring carbon sequestration for all new production plants built after 2020. The resulting expected build out is shown in Figure 3. The build out results are the same as in Figure 1 up through 2020, but once the policy is in effect production is switched to central plants which can sequester carbon. The expected central plants are NG SMR and coal gasification plants. This is because once the carbon sequestration costs are factored in, both plants deliver hydrogen at the same profited cost. Although this build meets our emissions goal, natural gas is still the primary feedstock in several of the production plants. To address this we evaluated the impact of a renewable mandate where all new plants built after 2020 would have to use renewable feedstocks. The resulting build out is shown in Figure 4. Again there are no changes to the build out prior to the mandate. However in this case, since biomass and nuclear production methods are still costly and demand is still low in 2020, forecourt ethanol plants with a feedstock cost of $1.07 per gallon ethanol are the lowest cost production option. Similar to the baseline case, the ethanol plants are built year after year picking up the incremental hydrogen demand. Forecourt ethanol production, previously too costly, is thus the preferred option under these transition conditions. Once there is sufficient increase in hydrogen demand, the central biomass plants become more cost effective than the forecourt ethanol stations followed

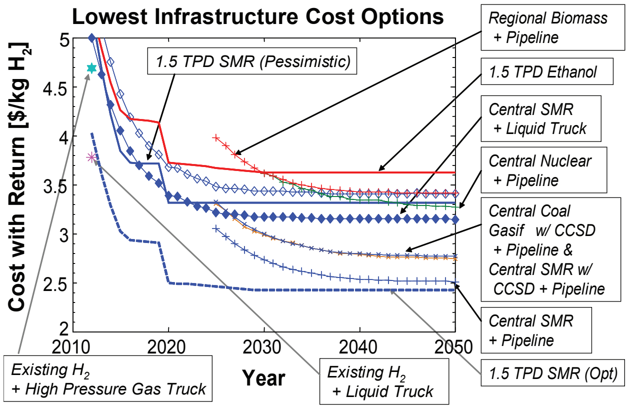

FIGURE 2. Profited Cost Comparison for a Subset of Options

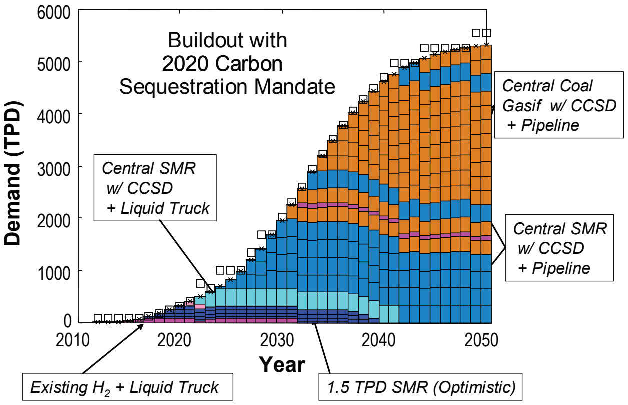

FIGURE 3. Los Angeles H_2 Build Out with a Carbon Sequestration Mandate in 2020

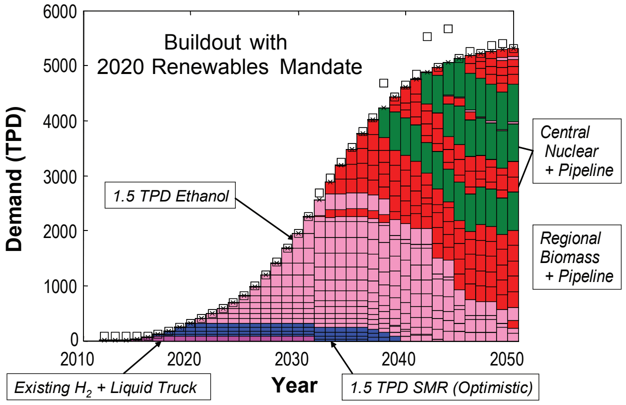

FIGURE 4. Los Angeles H_2 Build Out with a Renewable Mandate in 2020

by the nuclear plants. The capital investment required to complete the infrastructures in Figures 3 and 4 is much higher than the baseline solution because carbon sequestration equipment and disposal is costly and the technology to produce hydrogen from renewable resources is still immature.

Conclusions and Future Directions

- The HyPro computational model provides a transparent, easy to use mechanism to quantitatively assess the cost of hydrogen production-delivery-dispensing costs and to determine the key cost drivers.
- Based on economics alone, forecourt natural gas plants would most likely be selected by industry to provide cost effective hydrogen for light-duty vehicles.
- While potentially playing a key role in the transition, natural gas plants do not satisfy DOE's long term goals of major reduction/elimination of greenhouse gases and foreign energy dependence.
- The HyPro computational model allows an exploration of various policies, taxes, feedstock pricing within the analysis space.
- Within the time remaining additional cities will be explored to assess the impact of regional differences such as feedstock pricing and availability.
- Findings from the many analysis conditions will be documented along with a manual describing the model and its operation.

Special Recognitions & Awards/Patents Issued

1. DOE Hydrogen Program R&D Award. May 2007.

FY 2007 Publications/Presentations

1. "Hydrogen Transition Sensitivity Studies using HyPro", Aug. 9, 2006. DOE Transition Team.
2. "Evaluating the Hydrogen Infrastructure using HyPro", Nov. 13, 2006. Fuel Cell Seminar.
3. "Hydrogen Production Infrastructure Analysis using HyPro", Mar. 19, 2007. National Hydrogen Association Annual Conference.
4. "HyPro Analysis Tool Demonstration", Mar. 22, 2007. Fuel Pathways Integration Tech Team (FPITT).
5. "HyPro's Hydrogen Buildout for Los Angeles", Apr. 18, 2007. National Academy of Sciences.
6. "Hydrogen Pathway Analysis using HyPro", May 17, 2007. DOE Annual Merit Review.
7. "Hydrogen Infrastructure Pathways Analysis Using HYPRO", Transition Report, Apr. 2, 2007. National Academy of Sciences.