VII.4 HyTrans Model: Analyzing the Potential for Stationary Fuel Cells to Augment Hydrogen Availability in the Transition to Hydrogen Vehicles

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- ICF, International, Washington, D.C.

Project Start Date: Fiscal Year 2004
Project End Date: Project continuation and direction determined annually by DOE.

Objectives

- Develop and maintain a computer model for simulation of the dynamic market transition from petroleum to hydrogen-powered motor vehicles and for combined heat and power (CHP).
- Identify and evaluate early market transition scenarios for the transition to hydrogen vehicles and analyze conditions that could lead to a sustainable long-term transition.
- Analyze the ultimate potential for hydrogen and fuel cell vehicles through 2050, addressing resources, hydrogen production, infrastructure, cost and benefits.
- Develop scenarios and analyze the potential for stationary combined heat-and-hydrogen power (CHHP) to increase the availability of hydrogen fuel during the early transition.

Technical Challenges

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

(A) Future Market Behavior
(B) Stove-piped/Siloed Analytical Capability
(D) Suite of Models and Tools
(E) Unplanned Studies and Analyses

Contribution to Achievement of DOE Systems Analysis Milestones

This project is contributing to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 5: Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- Milestone 7: Complete analysis of the hydrogen infrastructure and technical target progress for the hydrogen fuel and vehicles. (2Q, 2011)
- Milestone 26: Annual model update and validation. (4Q, 2010)

Accomplishments

- Developed the first integrated market scenarios of the transition to hydrogen vehicles, measuring vehicle manufacturers' "valley of death," excess costs of fuel infrastructure, and establishing the sustainability of the transition if DOE technology goals are met.
- Updated HyTrans model to latest H2A models, latest Annual Energy Outlook (AEO) projections and updated vehicle technology characterizations.
- Completed analysis of potential synergies between deployment of stationary CHHP fuel cells and fuel availability during the early stages of a transition to hydrogen vehicles.

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Introduction

Making a transition from petroleum-powered internal combustion engine vehicles to a hydrogen-powered system involves decisions by consumers, governments, and industry. HyTrans integrates all key components in a computer model that simulates market decision making from the present to 2050. Consumers choose among competing advanced technologies based on vehicle prices and energy costs, fuel availability and the diversity of makes and models offered. The cost and performance of advanced technology vehicles change over time affected by cumulative experience producing vehicles, economies of scale and research and development (R&D). Energy suppliers decide what resources and conversion processes to use to produce hydrogen. Key metrics include petroleum consumption and fuel cycle greenhouse gas emissions. HyTrans was used to produce DOE's first integrated scenarios of the transition to hydrogen vehicles [1].

In this study, the HyTrans model was used to analyze the potential for stationary fuel cells producing combined heat and electric power for buildings to serve as sources of hydrogen for motor vehicles during the early stages of a hydrogen transition. Stationary fuel cells convert a fuel such as natural gas to hydrogen, generating electricity and heat. Depending on the cycle of demand for heat and electricity, the ability to sell electricity to the grid and other factors, stationary fuel cells may also be able to produce hydrogen at relatively low cost for use by motor vehicles. Because stationary fuel cells will be co-located with large buildings and institutions, they could serve as small-scale distributed sources of hydrogen for motor vehicles thereby greatly increasing hydrogen availability in the critical stages of an early transition to hydrogen vehicles.

Approach

The analysis comprised three steps, defining scenarios of CHHP deployment, modifying and updating the HyTrans model to include hydrogen supply via CHHP, running the model and analyzing the results. The three hydrogen fuel cell vehicle market penetration scenarios of DOE's hydrogen transition analysis [1] were used to estimate the effects of greater hydrogen availability via CHHP.

Three national scenarios of CHHP deployment were created based on a study by the California Energy Commission and the Electric Power Research Institute [3]. The scenarios were intentionally designed to be optimistic about CHHP deployment to determine whether it could potentially affect hydrogen fuel availability and hydrogen vehicle market success. The California scenarios were extrapolated to the U.S. market by scaling the California CHP penetration estimates by residential and commercial energy demand by Census Region. The Base Case reflects expected future gas and electricity prices, existing and expected emissions standards, and existing CHP cost and performance with evolutionary improvement over time. The Base Case does not, however, include the existing California Self Generation Incentive Program (SGIP).

The High-R&D + Incentives Case accelerates progress on fuel cells by three years and adds the California SGIP nationwide. The SGIP incentive for fuel cells, $2,500/kW is much higher than for other technologies and is critical to the uptake of fuel cell CHP units. The High Deployment Case accelerates technological progress for fuel cells by another two years and assumes that a larger fraction of the market is willing to consider CHP and that they will accept a longer payback period. In the reference assumptions half of potential customers require a payback in two years or less. In the High Deployment Case half will accept a three-year payback period.

The HyTrans model was then recalibrated to the 2009 AEO American Recovery and Reinvestment Act Reference Case, updated with vehicle technology characterizations from DOE's Multi-Path Transportation Futures Study [3] as well as hydrogen production and distribution technologies from the H2A model and greenhouse gas emissions coefficients from the Greenhouse gases, Regulated Emissions and Energy use in Transportation model. Three sizes of CHHP units were represented: (1) 150 kW producing 56 kg/day, (2) 250 kW producing 93 kg/day, and (3) 1 MW producing 340 kg/day. The H2A model includes one representation of hydrogen delivery for CHHP: a short pipeline to a nearby refueling station. We added another option, collection of hydrogen from CHHP sites via tube trailer and trucking to a refueling within five miles of the CHHP site. The latter option was intended to allow greater flexibility in the quantities and timing of hydrogen production by CHHP units, as well as in the location and size of hydrogen refueling stations.

Results

The SGIP incentive has a large impact on the number of fuel cell CHP units projected for the year 2020. In the Base Case there are fewer than 2,000 fuel cell CHP units installed (Figure 1). With the SGIP nationwide almost 40,000 fuel cell CHP units are in service in 2020 in the High R&D Case, and over 60,000 in the High Deployment Case. All could potentially be CHHP units; however the actual number of CHHP units is determined by the demand for hydrogen in a given HyTrans model run. Substantial cumulative subsidies are required to achieve these levels of fuel cell deployment: $25 billion in the High R&D + Incentives Case and $43 billion in the High Deployment Case, compared with $0.3 billion in the Base Case.

Without any availability of hydrogen from CHHP, hydrogen is provided almost exclusively by distributed steam methane reforming (SMR) stations during the early transition. By 2020 there are less than 1,000 SMR stations nationwide (Figure 2). This compares with approximately 160,000 gasoline refueling stations.

In the High R&D and SGIP Case, the number of locations at which motorists can refuel with hydrogen exceeds 6,000 in 2020 and 14,000 by 2025, nearly 10% of all refueling outlets (Figure 3). The vast majority are supplied by midsize CHHP units. This reflects both the

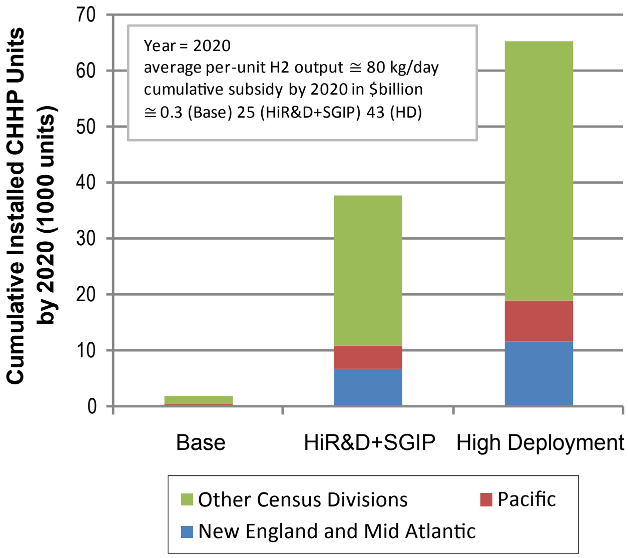

FIGURE 1. Projected Installed Fuel Cell CHP Units in 2020 in Three Scenarios.

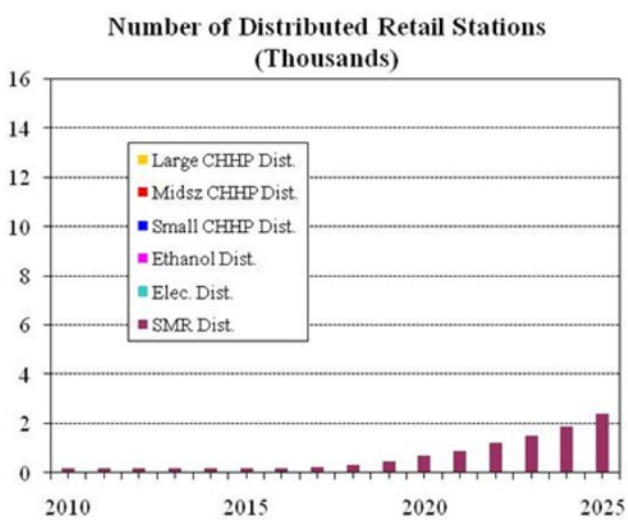

FIGURE 2. Numbers of Distributed Retail Hydrogen Refueling Stations Assuming no CHHP

numbers of CHHP units by size and the strong economies of scale in producing and delivering hydrogen from CHHP units. In general, hydrogen from the 250 kW units costs half as much as hydrogen from 150 kW units. Although it is still cheaper to produce hydrogen at the 1 MW units, there are far fewer of them. While the large majority of stations are supplied by CHHP in this Case, the majority of the hydrogen is supplied by larger (1,500 kg/day) distributed SMR stations.

Lack of hydrogen availability poses an extra cost for owners of fuel cell vehicles in terms of added time to access hydrogen fuel and concern about running

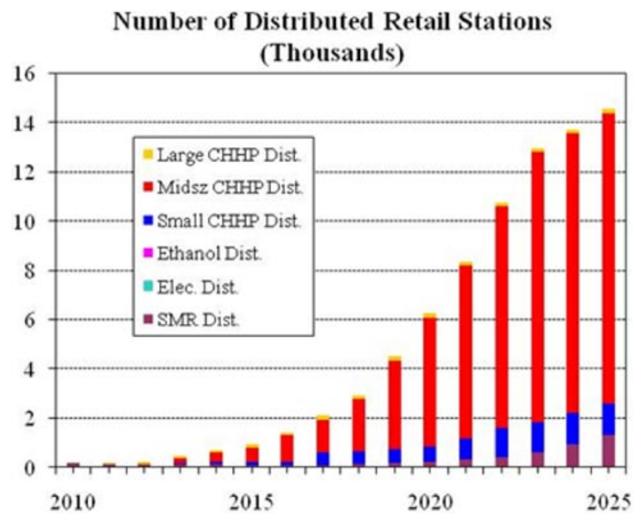

FIGURE 3. Number of Distributed Retail Hydrogen Refueling Stations in the High R&D and SGIP Scenario.

out. The HyTrans model attempts to measure the cost of lack of availability in $/kg of hydrogen. Without the added hydrogen availability due to CHHP stations, hydrogen availability costs outside of the core regions of Los Angeles and New York remain high ($1 to $4/kg) even in 2020; availability costs in the rest of the U.S. are far higher ($4 to $9/kg). With increased hydrogen fuel availability provided by dispersed CHHP units, the cost of availability falls below $1/kg, even in the medium and low density portions of the Pacific and Northeast Census Regions (Figure 4). After 2020 availability costs are below $2/kg in all regions of the country.

Conclusions and Future Directions

Like any analysis of this kind, the results are strongly dependent on premises and assumptions. Nonetheless, the following conclusions are likely to be robust to alternative assumptions.

- Distributed production and delivery of hydrogen from CHHP units of between 250 kW and 1 MW in size could greatly reduce the costs of hydrogen fuel availability during the early stages of a transition to hydrogen.
- The fuel availability benefits of CHHP units are especially strong in areas that are not centers of hydrogen vehicle penetration.
- Insuring a sufficient number of potential sources of CHHP hydrogen will require large subsidies to fuel cell CHP installations, on the order of $20 billion to $40 billion cumulative to 2025, nationwide.
- Even with large numbers of CHHP units providing hydrogen, the greatest quantities of hydrogen are likely to be produced by distributed SMR during the first two decades or so of the transition.

FIGURE 4. Cost of Delivered Hydrogen by Region: High R&D + SGIP Case.

The highest priority areas for further analysis are: (1) developing scenarios of national CHP penetration that better represent regional factors affecting the competitiveness of fuel cell CHP, and (2) developing alternative H2A models of hydrogen delivery from CHHP installations.

FY 2010 Publications/Presentations

1. "Towards a Policy Framework for Transportation's Energy Transition," presented at the *2010 Society of Automotive Engineers Government/Industry Meetings*, Washington, D.C., January 29, 2010.

2. "Hydrogen Policy and Analyzing the Transition," presented at the Workshop *Delivering Renewable Hydrogen*, National Renewable Energy Laboratory, Palm Springs, CA, November 16, 2009.

3. "Infrastructure for Transportation's Energy Transition," presented at the *Workshop on National Energy and Transportation Systems Investment Strategies, Engineering Policy and Leadership Institute*, Iowa State University, Ames, IA, November 30, 2009.

4. "HyTrans Model: Analyzing the Potential for Stationary Fuel Cells to Augment Hydrogen Availability in the Transition to Hydrogen Vehicles," U.S. Department of Energy 2010 Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation, Washington, D.C., June 8, 2010.

5. "A Policy Framework for Transportation's Energy Transition," 2010 STEPS Symposium, Institute for Transportation Studies, University of California at Davis, Davis, CA, June 14, 2010.

6. "Reducing Motor Vehicle Greenhouse Gas Emissions through Fuel-Efficient Vehicles and Low-Carbon Fuels," American Association of State Highway Transportation Officials/Federal Highway Administration joint Webinar, May 26, 2010.

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1. Greene, D.L., P.N. Leiby, B. James, J. Perez, M. Melendez, A. Milbrandt, S. Unnasch, M. Hooks, S. McQueen and S. Gronich, "Analysis of the Transition to Hydrogen Fuel Cell Vehicles & the Potential Hydrogen Energy Infrastructure Requirements," ORNL/TM-2008/30, Oak Ridge National Laboratory, Oak Ridge, TN, March 2008.

2. Darrow, K., S. McNulty and S. Price, "Assessment of California CHP Market and Assessment of Policy Options for Increased Penetration," report #1012075, Electric Power Research Institute, Palo Alto, California and California Energy Commission, Sacramento, California, final report, July, 2005.

3. Plotkin, S. and M. Singh, "Multi-Path Transportation Futures Study: Vehicle Characterization and Scenario Analyses," ANL/ESD/09-5, Argonne National Laboratory, Argonne, IL, July 22, 2009.