X.1 Development of HyTrans Model and Integrated Scenario Analysis

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Objectives

The HyTrans model is a dynamic, non-linear market simulation model in which all the key components of a transition to hydrogen vehicles are represented: hydrogen supply, vehicle manufacturing and consumer purchase and use. Its objectives are to:

- Simulate market behavior in the transition to hydrogen-powered vehicles.
- Analyze the impacts of technological goals on the transition.
- Measure the economic costs and benefits.
- Estimate the impacts on greenhouse gas emissions and oil dependence.
- Create and analyze credible scenarios of the transition to hydrogen vehicles.
- Evaluate the impacts of alternative policies on the transition to hydrogen.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis, Technical Barriers section (4.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior
(B) Stove-piped/Siloed Analytical Capability
(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the HFCIT 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 8:** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for technology readiness. (4Q, 2014)
- **Milestone 26:** Annual model update and validation. (4Q, annually)

Accomplishments

- Published peer-reviewed report of the first integrated analysis of the transition to hydrogen fuel cell vehicles.
- Produced estimates of the greenhouse gas mitigation and oil dependence reduction potential of the transition to hydrogen vehicles that showed a greater than 80% reduction in light-duty vehicle CO_2 emissions by 2050 and a reduction in oil use of 4-6 mmbd.
- Working with the International Partnership for the Hydrogen Economy (IPHE)/International Energy Agency (IEA) Hydrogen Transition Scenarios group, completed DOE's contribution to the group's final report.
- Completed an unplanned analysis showing the potential of a government acquisition program for proton exchange membrane (PEM) fuel cells in non-automotive applications to establish a sustainable private market for PEM fuel cells in the U.S. of approximately 5,000 units per year in 2014 and 35,000 by 2020.
- Updated HyTrans to incorporate the 2008 Annual Energy Outlook Reference, High Oil Price and Low Oil Price Scenarios, as well as the updated versions of the H2A Production and Delivery Models.

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Introduction

The HyTrans model simulates a market transition of U.S. light-duty vehicles from conventional petroleum-powered internal combustion engines to hydrogen, from the present until 2050. The purposes of the HyTrans model are to assess the impacts of achieving research and development (R&D) goals on the market success of hydrogen vehicles and hydrogen as an energy carrier, to develop credible visions of the transition to hydrogen-powered transportation, to estimate the potential benefits and costs of the transition, and eventually to understand the role of policy as well as technology in achieving the transition. The market success of hydrogen and hydrogen-powered vehicles, including the decisions of energy suppliers to produce and deliver hydrogen, the decisions of manufacturers to build and sell hydrogen-powered vehicles and the decisions of consumers to buy and use the vehicles, are all determined within the HyTrans model. An important contribution of HyTrans is the explicit representation of technological progress and cost reductions over time. These features make HyTrans unique among existing models of the evolution of hydrogen-powered transportation.

The modeling capabilities acquired in developing the HyTrans model were applied to analyzing the potential to create a sustainable domestic PEM fuel cell industry by means of a government acquisition program for non-automotive PEM fuel cells. Relying on existing market research and in-depth interviews with original equipment manufacturers (OEMs) a simulation model was developed to estimate the impacts of government PEM fuel cell purchases on learning-by-doing and scale economies in the non-automotive PEM fuel cell industry.

Approach

Hydrogen and fuel cell vehicles will compete with other alternative energy sources and advanced automotive technologies in the marketplace. Our approach is to combine representations of the best available models of hydrogen production, delivery, manufacturing, and consumer demand into an integrated representation of the U.S. market for vehicles and fuels. This model can be calibrated to national or international energy market scenarios, such as the Energy Information Administration's Annual Energy Outlook. Using competitive economic theory, the HyTrans model then calculates how advanced technologies and supporting policies could change the future evolution of vehicles and their energy use. The key feature of the integrated market modeling method is that the decisions of the participants in the market, hydrogen suppliers, vehicle manufacturers and consumers, are fully interdependent. That is, the model simulates the market solution to the "chicken or egg" problem faced by alternative energy systems by explicitly representing the roles of barriers such as learning-by-doing, economies of scale, limited fuel availability and limited make and model choice.

HyTrans is a tool for integrated analysis; it depends on other models and assessments for key inputs. HyTrans relies on the H2A Production models to represent the cost of hydrogen supply, the H2A Delivery model to estimate the costs of delivery and retailing, the GREET model for the energy and emissions of alternative production and use pathways and the PSAT model for vehicle technology characterizations. This year, HyTrans will be used as one tool among many in two major analyses:

1. Development of early transition scenarios incorporating stationary fuel cells as sources of hydrogen supply.
2. Assessment of the impacts of alternative hydrogen storage technologies and pathways on the transition to hydrogen fuel cell vehicles.

In addition, methods developed and lessons learned in through integrated market modeling will be applied in unanticipated analyses, such as the assessment of a government PEM fuel cell acquisition program completed in Fiscal Year 2008.

Results

The major achievement of FY 2008 was the publication of the first integrated scenarios of the transition to hydrogen fuel cell vehicles in the United States. This report documented the scenario analysis produced by a team of researchers from the DOE, the national laboratories, private firms and universities, and advised by dozens of experts representing key stakeholders. This analytical effort received the 2007 DOE Hydrogen Program R&D Award for its accomplishments. Publication of the report makes the integrated scenario analysis available to hydrogen research community as a credible vision of how the transition to a transportation system powered by hydrogen might be accomplished. Three alternative scenarios that placed 2 to 10 million fuel cell vehicles on U.S. roads by 2025 all led to sustainable transitions, assuming DOE HFCIT program goals were met. Figure 1 shows the shares of new light-duty vehicle sales achieved by advanced gasoline vehicles, advanced hybrid gasoline-electric vehicles and fuel cell hybrid vehicles in Scenario 3 of the study. Scenario 3 assumes industry and government efforts that place 10 million fuel cell vehicles on the road by 2025. After 2025, no special programs to promote or subsidize fuel cell vehicles or hydrogen infrastructure are assumed yet the market completes the transition on its own due to the superiority of fuel cell vehicles that meet the DOE technology goals.

A transition to hydrogen fuel cell vehicles such as illustrated in Figure 1, combined with strong policies to curb greenhouse gas emissions (such as

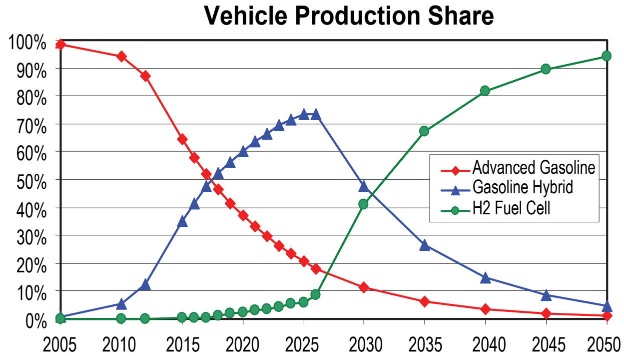

FIGURE 1. New Vehicle Sales Shares of Advanced Technologies: Transition Scenario 3

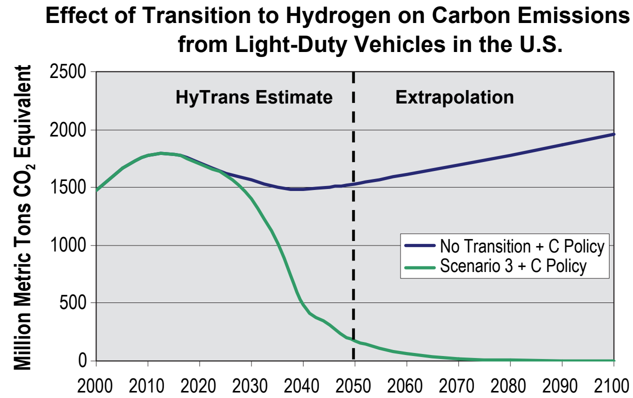

FIGURE 2. Effect of Transition to Hydrogen on Light-duty Vehicle CO_2 Emissions

a carbon price in the vicinity of \$25 to \$50 per ton of CO_2) could nearly eliminate CO_2 emissions from light-duty vehicles. A transition to super-efficient gasoline-electric hybrid vehicles could only hold CO_2 emissions constant through 2050 (blue line in Figure 2), according to HyTrans model computations based on well-to-wheel emissions take from the GREET model (Figure 2). Although HyTrans forecasts only to 2050, a simple extrapolation to 2100 illustrates the importance of a transition to carbon-free hydrogen vehicles to greenhouse gas mitigation. One of the innovations incorporated in the 2008 version of the HyTrans model allows it to predict the impacts of carbon prices on the carbon intensity of electricity generation based on studies done by the Energy Information Administration. In a scenario including strong climate policy, the U.S. electricity sector becomes decarbonized over time, so that electricity used in hydrogen compression or liquefaction contributes little to hydrogen's well-to-wheel emissions.

A transition to hydrogen will also drastically reduce U.S. petroleum use. The transition scenarios published in 2008 all begin in 2012. In these scenarios, hydrogen fuel cell vehicles save approximately 6 million barrels per day of petroleum by 2050. But even if the mass-market introduction of fuel cell vehicles was delayed until 2020 they would still reduce 2050 petroleum consumption by 4 million barrels per day (Figure 3).

The North American PEM fuel cell industry may be at a critical juncture. A large-scale market for automotive fuel cells appears to be several years away and in any case will require a long-term, coordinated commitment by government and industry to insure the co-evolution of hydrogen infrastructure and fuel cell vehicles. The market for non-automotive PEM fuel cells, on the other hand, may be much closer to commercial viability. Cost targets are less demanding and manufacturers appear to be close, perhaps within a factor of two, of meeting them.

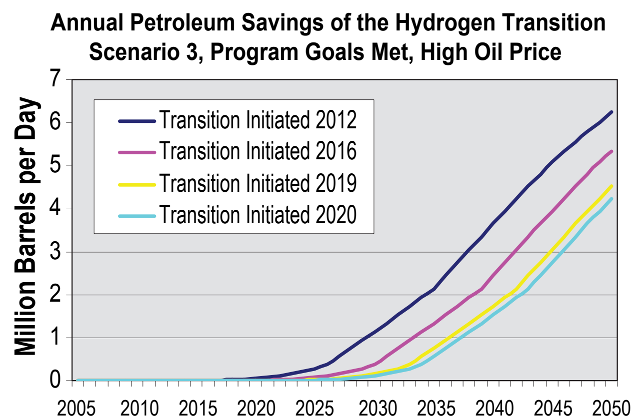

FIGURE 3. Estimated Petroleum Savings by Hydrogen Fuel Cell Vehicles by Introduction Date

PEM fuel cells appear to be potentially competitive in two markets: (1) backup power supply, and (2) electrically-powered material handling equipment. There are several OEMs of PEM fuel cell systems for these applications but production levels have been quite low (on the order of 100-200 per year) and cumulative production experience is also limited (on the order of 1,000 units to date). As a consequence, costs remain above target levels and PEM fuel cell OEMs are not yet competitive in these markets. If cost targets can be reached and acceptable solutions to hydrogen supply found, a sustainable North American PEM fuel cell industry could be established. If not, the industry and its North American supply chain could disappear within a year or two.

The HFCIT program of the U.S. Department of Energy (DOE) requested a rapid assessment of the potential for a government acquisition program to bootstrap the market for non-automotive PEM fuel cells by driving down costs via economies of scale and learning-by-doing. The study included in-depth interviews of three manufacturers, visits to two production facilities, review of the literature on potential markets in North America and potential federal government procurements, development of a cost model reflecting economies of scale and learning-by-doing, and estimation of the impact of federal PEM fuel cell procurements on fuel cell system costs. The evolution of private market demand was estimated under four scenarios: (1) Base Case with no government procurement program, (2) Scenario 1, an aggressive program beginning with less than 200 units procured in 2008 ramping up to more than 2,000 units in 2012, (3) Scenario 2 which is identical to Scenario 1 except that the private market is assumed to be twice as sensitive to price, and (4) Scenario 3, a delayed, smaller federal procurement program beginning in 2011 increasing to a maximum of just over 1,000 units per year in 2012.

The analysis suggests that the aggressive program of Scenario 1 would likely stimulate a sustainable, competitive North American non-automotive PEM fuel cell industry. Given plausible assumptions about learning rates and scale economies, the procurements assumed in Scenario 1 appear to be sufficient to drive down costs to target levels and create a small but viable market on the order of 30-35,000 units per year by 2020 (Figure 4). These findings are conditional on the evolution of acceptable hydrogen supply strategies, which were not explicitly analyzed in the study. Success is less certain under Scenarios 2 and 3, and there appears to be a strong probability that existing OEMs would not survive until 2011. In the Base Case, no program, a viable North American industry does not emerge before 2020 (Figure 4).

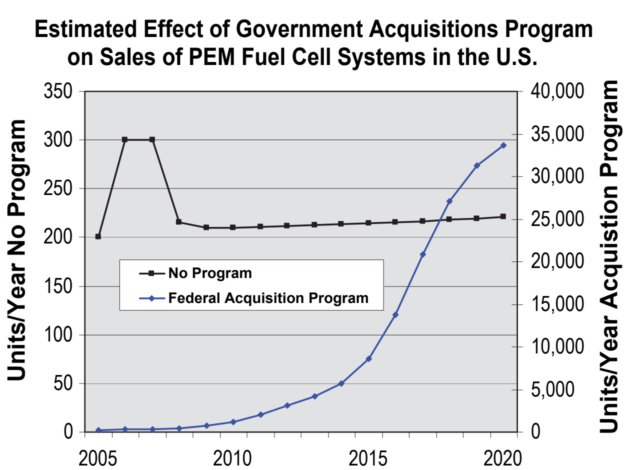

FIGURE 4. Estimated Effect of Government Acquisitions of PEM Fuel Cells on Sales

Conclusions and Future Directions

The report "Transition to Hydrogen Fuel Cell Vehicles" presented the first integrated market scenarios illustrating how a sustainable market for hydrogen-powered transportation could be established in the United States, provided that DOE's technology goals for hydrogen and fuel cells are met. Future analyses will 1) analyze the implications of alternative technological outcomes for the viability of the transition to hydrogen and in particular quantify the impacts of alternative hydrogen storage outcomes, and 2) develop and analyze scenarios of the transition to hydrogen than are initiated by stationary applications that can serve as initial sources of hydrogen supply.

The assessment of the potential carbon emissions mitigation and petroleum avoidance potential of hydrogen fuel cell vehicles provided useful quantitative estimates demonstrating the value of hydrogen fuel cell vehicles to achieving these national goals. Similar benefit analysis will be carried out for the scenarios to be developed in FY 2009.

Coordination with the IPHE/IEA hydrogen scenarios development process benefits DOE's systems analysis efforts through the exchange of information between European Union and U.S. modelers, and the development of global scenarios for the hydrogen transition. In a global marketplace, even an economy the size of the United States cannot be considered in isolation. Future work will develop methods for embedding HyTrans' market analyses in a global context.

The assessment of the potential for a government acquisition program to create a viable market for non-automotive PEM fuel cells in the U.S. indicated that an aggressive but feasible government program could establish a small but sustainable domestic fuel cell industry. It is likely that additional unanticipated systems analyses will be required in FY 2009.

The experience gained in developing the first integrated hydrogen transition scenarios has helped to identify key areas for improving and enhancing the HyTrans market simulation tool. Key developments planned for FY 2009 are:

- Calibrate to AEO 2008.
- Incorporate new vehicle technology data including plug-in hybrid electric vehicles.
- Incorporate explicit representation of uncertainty.
- Facilitate alternative assumptions and sensitivity analysis.
- Update to new versions of H2A, and GREET.

Special Recognitions & Awards/Patents Issued

1. With other team members, 2007 DOE Hydrogen Program R&D Award.

FY 2008 Publications/Presentations

1. Leiby, P.N, D.L. Greene, "Integrated Market Analysis of the Impacts of Hydrogen Storage Costs on the Transition to Fuel Cell Vehicles", a presentation to the H2 Storage Tech Team, USCAR Headquarters, Dearborn, Michigan, July 17, 2008.

2. Greene, D.L, P.N. Leiby, "Analysis of the Transition to Hydrogen Fuel Cell Vehicles & the Potential Hydrogen Infrastructure Requirements", Plenary Session presentation at the 2008 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Arlington, Virginia, June 9, 2008.

3. Greene, D.L., P.N. Leiby, "Modeling the Transition to Hydrogen", presentation at the 2008 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Arlington, Virginia, June 10, 2008.

4. Greene, D.L., et al., "Analysis of the Transition to a Hydrogen Economy and the Potential Hydrogen Energy Infrastructure Requirements", ORNL/TM-2008/30, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 2008.

5. Greene, D.L. and K.G. Duleep, "Estimating the impacts of a government acquisition program for PEM fuel cells", presentation to the Hydrogen and Fuel Cell Interagency Task Force, April 15, 2008, Arlington, Virginia.

6. Greene, D.L. and K.G. Duleep, "Bootstrapping a Sustainable North American PEM Fuel Cell Industry: Could a Federal Acquisition Program Make a Difference?", report to the Hydrogen Fuel Cells and Infrastructure Technology Program, U.S. Department of Energy by Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 18, 2008.

7. Greene, D.L., "Bringing Down Hydrogen Fuel Cell Vehicle Costs: Observations on Scale, Learning and Cost-Sharing From an Analysis for the US DOE", presentation to the California Air Resources Board, March 27, 2008, Sacramento, California.

8. Leiby, P.N. and P. Seydel, "Infrastructure Transition Analysis", presentation to the IPHE/IEA Working Group on Transition Scenario Analysis, March 18, 2008, Munich, Germany.