VII.11 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 Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior: especially the interdependencies and linkages of hydrogen supply, vehicle supply and the demand for vehicles and hydrogen.

(B) Stove-piped/Siloed Analytical Capability: coordinating and integrating analysis resources across all facets of the analytical domain.

(D) Suite of Models and Tools: improving HyTrans as a component model of the suite to make it more usable and consistent.

(E) Unplanned Studies and Analysis: such as analysis of potential delays in meeting technical program objectives and potential impacts of falling short of initial on-board hydrogen storage goals.

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 Hydrogen, Fuel Cells and Infrastructure 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 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

- Completed updating of the HyTrans model and calibration to the 2009 Annual Energy Outlook projections, including High and Low Oil Price Scenarios.
- Completed revision of HyTrans' representation of fuel cycle greenhouse gas emissions to accurately represent the latest version of the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model, and to incorporate emissions representations for new vehicle technology characterizations.
- Completed updated characterization of advanced vehicle technologies, including plug-in hybrid vehicles (PHEVs) based on multiple sources: Argonne National Laboratory (ANL) Powertrain Systems Analysis Toolkit (PSAT) runs, Multipath Study Scenarios, Massachusetts Institute of Technology (MIT) and European Union (EU) Conservation of Clean Air and Water in Europe

(CONCAWE) scenarios. Integrated new technology representations into HyTrans, adding PHEVs for both conventional internal combustion engine (ICE) and fuel cell vehicles (FCVs) as technology options.

- In collaboration with ANL PSAT modelers, developed a new method for determining the optimal range and therefore optimal storage capacity of hydrogen-powered vehicles, for use in assessing the impacts of storage technology on hydrogen vehicle market success.
- Updated HyTrans to include the latest version of the Hydrogen Delivery Scenario Analysis Model (HDSAM) model (Version 2.0 downloaded 12/10/2008), adding a new representation of delivery options that distinguish between urban and rural environments, and include additional modal choices, such as cryo-compressed trucks. Delivery is now separately determined for transmission and local distribution allowing a greater diversity of solutions.
- Updated HyTrans to include the latest version of the updated versions of the H2A Production model (H2A Production Case Studies, downloaded 12/10/2008).
- Published Edition 28 of the Transportation Energy Data Book: posted on its Web site on June 29, 2009, available in hardcopy on July 13, 2009.
- Analysis of the impacts of alternative technical achievements for on-board hydrogen storage on the potential market for hydrogen vehicles (to be completed in Fiscal Year 2009).
- Analysis of the effects of delays in achieving DOE Hydrogen FCV Program goals on market success and reductions in U.S. oil dependence and greenhouse gas (GHG) emissions (to be completed in FY 2009).

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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 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 proton exchange membrane (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 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. Building on this research, analysis of stationary fuel cell applications will be significantly expanded in FY 2010.

Approach

Hydrogen and FCVs 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, in addition to updating and expanding its capabilities, HyTrans has been used in two analyses:

1. Assessment of the impacts of delays in achieving technical targets on the timing and ultimate success of hydrogen vehicles and their ability to reduce oil dependence and GHG emissions.
2. Assessment of the impacts of alternative hydrogen storage technologies and pathways on the transition to hydrogen FCVs.

Results

The major focus of FY 2009 has been updating and enhancing the HyTrans model to reflect significant improvements in related models, new oil price scenarios, and a more complete and up-to-date representation of advanced vehicle technologies. Most of the major submodels received a complete updating:

- HyTrans production submodel was updated to represent in reduced form the revised H2A model (downloaded 12/10/2008).
- HyTrans delivery model was restructured and updated to reflect HDSAM Version 2.0 (downloaded 12/10/2008).
- HyTrans scenarios to 2050 were recalibrated to conform to the 2009 Annual Energy Outlook Reference, Low Oil Price and High Oil Price Projections.
- Updated HyTrans to reflect latest version of GREET model and enhance representation of fuel cycle GHG emissions. Lifecycle emissions estimates for nine hydrogen production pathways were updated using GREET_1.8b.xls. Wind energy was added as one of the hydrogen production pathways.
- Modified HyTrans' vehicle technology choice structure to include PHEV versions of conventional ICE vehicles and PHEV versions of hydrogen FCVs. Analysis of the impacts of this change will be completed in FY 2009.
- Conducted an analysis of the impacts of a ten-year delay in achieving DOE program goals for hydrogen FCV technology on the timing and degree of market success of FCVs and their impacts on U.S. oil dependence and GHG emissions. The results will be documented in a memorandum to be completed in FY 2009.
- Conducted an analysis of the potential effects of alternative on-board hydrogen storage goals on the timing and degree of market success of FCVs. Four alternative energy densities and storage costs were considered. The results will be documented in a memorandum to be completed in FY 2009.
- Published Edition 28 of the Transportation Energy Data Book: posted on its Web site on June 29, 2009, available in hardcopy on July 13, 2009. Copies have been distributed to over 1,000 researchers in 31 countries.
- Updated the ORNL Oil Security Metrics Model and calibrated it to the Annual Energy Outlook 2009 Reference, Low Oil Price and High Oil Price Projections. The model was used to estimate the impacts of DOE's Vehicle Technologies Program on U.S. Oil Dependence through 2050. A paper making use of the Oil Security Metrics Model, proposing a measurable definition of oil independence and assessing what would be require to achieve it was peer-reviewed and published in the journal *Energy Policy*.
- Developed a methodology, in collaboration with ANL, for defining the optimal on-board storage for hydrogen vehicles as a function of vehicle technical performance and storage cost. The method trades off the marginal value of range to car owners versus its marginal cost, as a function of fuel availability, of achieving that range in a hydrogen FCV (Figure 1). The pattern of results is intuitive: as the cost of on-board storage increases, less on-board storage is preferred; as fuel availability increases, less on-board storage is optimal. This suggests that the earliest FCVs should be designed with greater amounts of on-board storage than will be required in later years when hydrogen fuel is more widely available. Though not surprising, these results represent the first quantification of these relationships for advanced technology, alternative fuel vehicles.

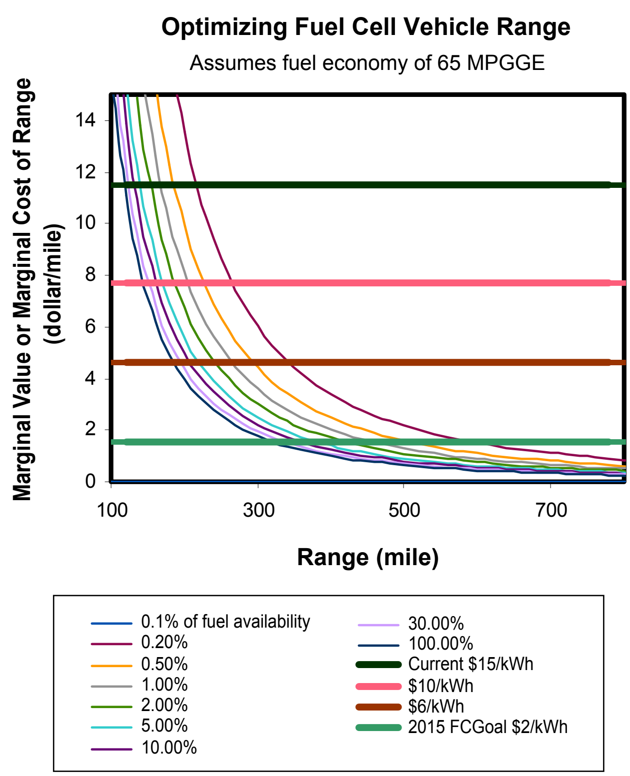

FIGURE 1. Optimizing Fuel Cell Vehicle Range

- Vehicle technology characterizations were updated based on PSAT and MultiPath Study data. Four major sources of advanced vehicle cost projections were identified and detailed results (including assumptions) were summarized. Two of the sources were based on the latest DOE studies using the PSAT model. Based on this analysis, two alternative cost scenarios have been developed and will be documented in a technical memorandum in FY 2009. The cost scenario reflecting full accomplishment of DOE's program goals is illustrated for passenger cars in Figure 2. A key performance attribute, fuel economy, is likewise shown for the two scenarios in Figures 3 and 4.

Conclusions and Future Directions

The comprehensive updating and enhancement of the HyTrans model accomplished in FY 2009 positioned the model for new analyses of a variety of significant questions. Analysis of the potential impacts of alternative on-board storage technology was initiated prior to the writing of this report and will be completed by the end of FY 2009. Likewise, model runs analyzing the effects of delays in reaching program goals on the impacts of hydrogen vehicles has been completed and will be documented in a memorandum this fiscal year. Finally, an analysis of the effects of PHEV technology on the success of FCVs will be initiated in FY 2009 with the intent of completing it during the fiscal year. Innovations developed during the creation of a PHEV model for Vehicle Technologies will be incorporated in HyTrans, as well.

The experience gained in building an integrated market model integrating supply of hydrogen, supply of vehicles, and demand for and use of vehicles will be useful in the coming fiscal year in transitioning to a greater emphasis on stationary fuel cell deployment and its role in the transition to hydrogen. The HyTrans team members will be joined by a new post-doctoral staff member with experience in modeling and optimization applied to automotive technology policy analysis.

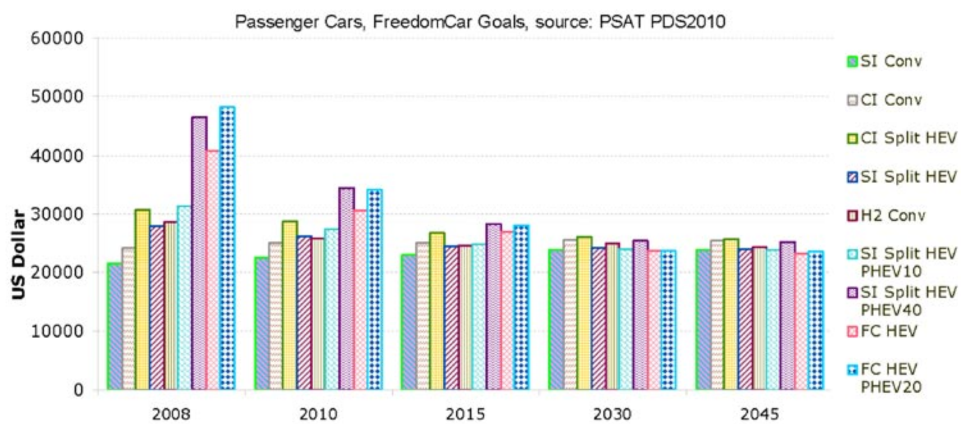

FIGURE 2. Long-Run Retail Prices of Advanced Technology Passenger Cars: Program Goals Met

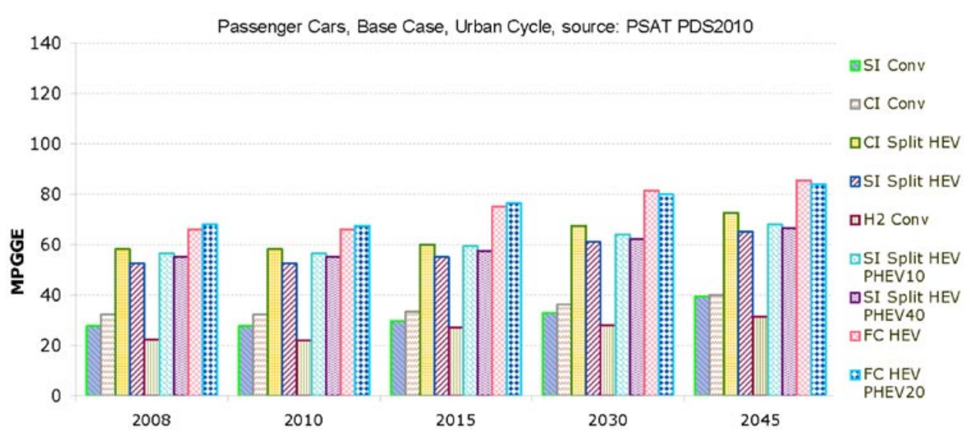

FIGURE 3. Fuel Economies of Advanced Technology Passenger Cars: Program Goals Met

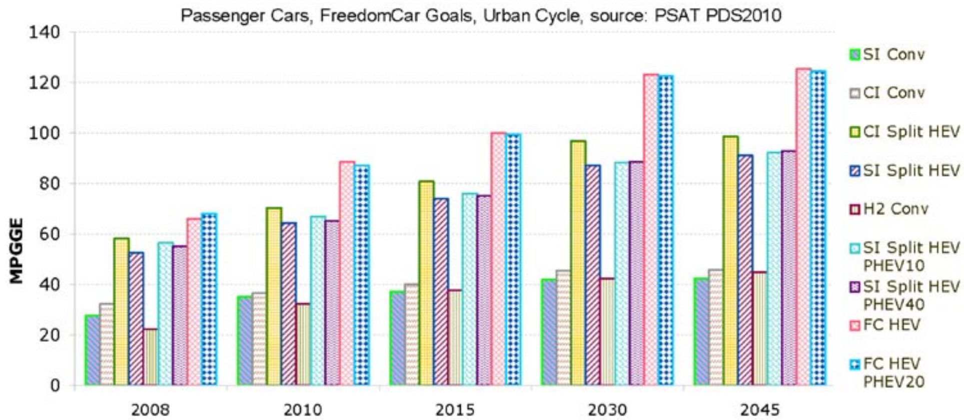

FIGURE 4. Fuel Economies of Advanced Technology Passenger Cars: Alternative Case

Special Recognitions & Awards/Patents Issued

1. Dr. David L. Greene was selected to the Energy Efficiency Hall of Fame by the Alliance to Save Energy in FY 2009.

2. Dr. David L. Greene received the Science Communicator of the Year Award from UT-Battelle in November, 2008.

FY 2009 Publications/Presentations

1. Greene, D.L., "Measuring Energy Security: Can the US Achieve Oil Independence?", published online, *Energy Policy*, May 2009.

2. Leiby, P.N, D.L. Greene, Z. Lin, D. Bowman, S. Das, "Modeling the Transition to Advanced Vehicles and Fuels", a presentation to the MIT-Ford-Shell Workshop: "Strategies for Market Transitions to Alternative Energy Transportation Systems", June 9, 2008.

3. Davis, S.C., S.W. Diegel, R.G. Boundy, *Transportation Energy Data Book: Edition 28*, ORNL-6984, June 2009.