III.3 HyTrans Model Development

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Objectives

- Develop, document and demonstrate a market-based model of the transition to hydrogen-powered highway transportation.
- Create plausible scenarios of the transition to hydrogen-powered transportation vehicles.
- Estimate the public and private benefits and costs of achieving the program goals set by the DOE Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program and FreedomCAR.
- Validate HyTrans as a tool for hydrogen transition modeling, technology assessment, policy analysis and program evaluation.

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:

- E. "Lack of Understanding of the Transition of a Hydrocarbon-Based Economy to a Hydrogen-Based economy." The HyTrans model simulates market-based transitions from the conventional petroleum-based light-duty vehicle transportation system to a hydrogen-based system. It will make an important contribution to understanding the economics of the transition and the roles that technological advances and policies can play in enabling and facilitating the transition.
- C. "Lack of a Macro-System Model." HyTrans will be linked to the Macro-Systems Model currently being designed. HyTrans will be one component of this larger, more complex model.
- D. "Stove-Piped/Siloed Analytical Capabilities." HyTrans already links to several key models (e.g., GREET, H2A hydrogen production models, NEMS) and is in the process of establishing other linkages (e.g., PSAT, ASCM, H2A Delivery Systems and Components, EERE MARKAL). These linkages to models and the working relationships with analysts that we are creating along with the linkages will contribute to the integration of analytical resources across different facets of the infrastructure and help to integrate infrastructure analysis with hydrogen demand analysis.

Approach

- Design a market-based model capable of endogenously solving for the decisions of hydrogen producers and retailers, vehicle manufacturers and consumers.
- Implement the model as a dynamic, multi-period optimization model.
- Link the HyTrans model to other key HFCIT Systems Analysis models, including H2A Production, H2A Delivery, GREET, and to related models including PSAT, ASCM and the EERE MARKAL model, and ultimately to the Macro Systems Model.
- Document and test the model to establish its validity for analysis.
- Use the model to create scenarios of the transition to hydrogen based on achievement of DOE's Hydrogen Program goals versus alternative paths of technology evolution.
- Use the model to estimate the public and private benefits and costs of achieving a transition to a hydrogen-powered transportation system.

Accomplishments

- Implemented and tested version 1 of HyTrans using the GAMS computer language.
- Produced draft report describing preliminary hydrogen transition scenarios developed using HyTrans.
- Incorporated representations of all H2A production technologies in HyTrans, in addition to all National Academy of Sciences (NAS) production technologies.
- Produced report documenting sensitivity analyses of the HyTrans model.
- Modified the HyTrans model to create symmetry in treatment of conventional and alternative technologies with respect to learning, scale economies, diversity of choice and fuel availability.

Future Directions

With support from HFCIT, the following key tasks will be accomplished.

- Linkage to Macro Systems Model and other hydrogen systems models
- Regional feedstock supply and transportation demand analyses
- Improved representations of uncertainty and imperfect foresight in technological progress and decision-making
- Validation of HyTrans

With support from the Program, Budget and Analysis office of DOE, the following enhancements to HyTrans will be made:

- Incorporate alternatives to perfect foresight in market decision-making
- Estimate impacts of the transition to hydrogen on U.S. oil dependence
- Estimate the economic and societal benefits of the transition to hydrogen
- Improve representations of vehicle and production pathway choices

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Introduction

The HyTrans model simulates a market-based transition of U.S. light-duty vehicles from conventional petroleum-powered internal combustion engines (ICEs) to hydrogen over the time frame of 2000 to 2050. HyTrans' objective is to predict a competitive market outcome over time, with and without new policy initiatives and utilizing different assumptions about technological progress.

The HyTrans model has been developed to provide plausible scenarios of the transition to a hydrogen-powered transportation system, produce insights about the roles of advanced technologies in achieving a transition to hydrogen, predict public and

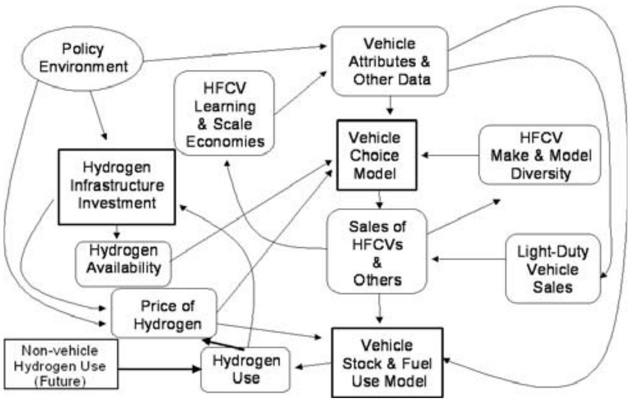

Figure 1. Schematic Representation of the Components of HyTrans

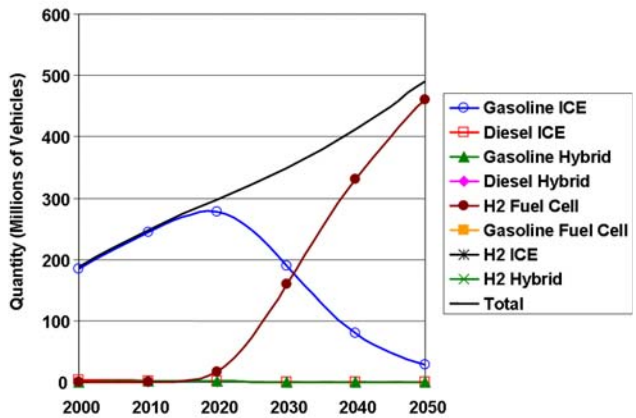

Figure 2. Timing and Rate of a Successful Transition to Hydrogen Vehicles

private benefits and costs of transitioning to hydrogen-powered vehicles, and analyze policies for facilitating the hydrogen transition.

Approach

The HyTrans model represents market interactions among fuel providers, vehicle producers, fuel retailers, private vehicle purchasers and fleet vehicle programs. New vehicles and vintage on-road vehicle stocks are tracked. Also tracked are vehicle production capacities and utilization, fuel production and capital, and fuel retail production and capacity (Figure 1).

The model finds a market-based solution to the choices available to hydrogen producers, vehicle manufacturers and consumers by maximizing the benefits to these decision-makers over the time period from 2005 to 2050. The formulation as an optimization model ensures that theoretical competitive market conditions with respect to pricing and the simultaneous determination of supply and demand are met. The current version of HyTrans assumes all actors have perfect foresight. Future development will implement alternative models of expectations under uncertainty.

Results

HyTrans has been able to generate scenarios of stable market-based transitions to hydrogen, given a combination of advanced technology and policies to stimulate the demand for hydrogen vehicles. To date, hydrogen production and delivery technologies consistent with the DOE's program goals have not been incorporated in HyTrans. However, by combining the FreedomCAR vehicle technology goals with a temporary vehicle subsidy of $1,500, HyTrans was able to predict a stable transition to hydrogen (Figure 2). While this scenario must be considered preliminary and by no means definitive, it does represent the first successful estimation of a market-based transition to hydrogen vehicles in which decisions about infrastructure, vehicle manufacture, purchase and use are all determined endogenously. A key feature of the scenario is that it is stable. Policies that induce the transition can be terminated and the hydrogen system does not revert to a petroleum-based system but remains in place. This achievement demonstrates that HyTrans is capable of simulating the "knock-out" of conventional technology as well as the "lock-out" of novel technologies and fuels. The scenario illustrated in Figure 2 and numerous others have been documented in the progress reports cited in the publications section.

A transition to hydrogen-powered passenger cars and light trucks would have an enormous impact on U.S. petroleum demand, as well as transportation energy use, according to HyTrans' predictions. Not only does the model predict that hydrogen can replace virtually all light-duty vehicle petroleum use in a successful transition scenario, but the growth of overall energy use would be reversed by the greater efficiency of hydrogen fuel cell vehicles (Figure 3).

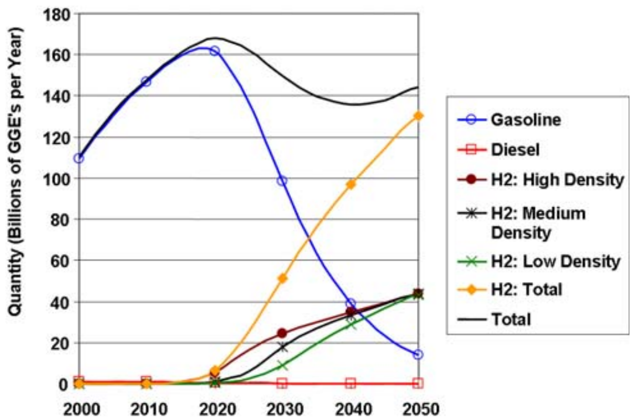

Figure 3. Impact of a Transition to Hydrogen on Light-Duty Vehicle Energy Use

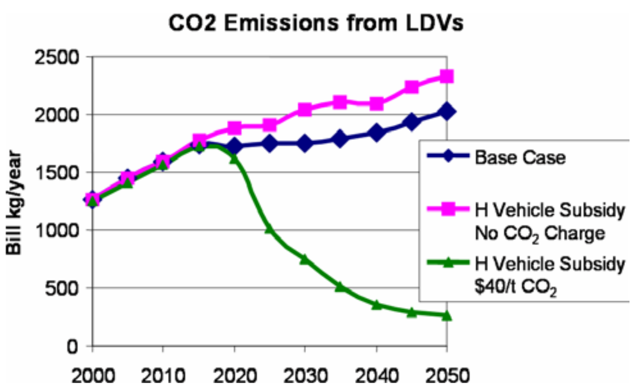

Figure 4. Potential Impact of Hydrogen-Powered Light-Duty Vehicles (LDVs) on CO_2 Emissions

A linkage to the Greenhouse gases, Regulated Emissions and Energy use in Transportation (GREET) model enables HyTrans to estimate the potentially enormous impact of a hydrogen transition on carbon dioxide emissions given strong policies to discourage greenhouse gas (GHG) emissions (Figure 4). At present, only carbon dioxide emissions rather than total GHG emissions are estimated due to the lack of a full set of hydrogen production pathways in the GREET model (expansion of GREET to include all pathways is underway).

Conclusions

Over the past year, the HyTrans model has progressed to be able to consistently produce plausible projections of the transition to hydrogen, and it is beginning to generate insights about how a transition to hydrogen-powered motor vehicles might evolve. The successes of HyTrans in FY 2005 have established that useful market-based modeling of the transition to hydrogen is possible.

The costs and performance of advanced drive train technologies are critically important factors in the cost, timing and sustainability of a transition to hydrogen-powered vehicles. While both the FreedomCAR program goals and alternative views of technological progress anticipate enormous progress for advanced technologies, the FreedomCAR goals lead to a decidedly earlier and less costly transition. Getting the technology characterization right is key to producing useful projections. Major improvements are expected in this area as we link to the Power-train System Analysis Toolkit (PSAT) and Automotive System Cost (ASCM) models. Still, important unexplored issues remain, for example, how to characterize the likelihood that all technologies will succeed simultaneously versus more plausible alternatives.

The characterization of hydrogen production technology is also crucial. Sensitivity tests did not reveal strong differences between the NAS and H2A hydrogen production models. However, the incorporation of the DOE HFCIT Multi-Year Research, Development and Demonstration Plan goals is likely to produce significantly different results in terms of market shares for alternative hydrogen production technologies. In addition, truly satisfactory estimation of the market shares of production pathways will not be achieved until the HyTrans model adequately represents the factors that would cause the desirability of these technologies to vary across regions or to different decision makers.

Assuming economic agents act with perfect foresight produces useful results in that it generates the best possible outcome, is consistent with the theoretical operation of competitive markets, and provides a unique solution. However, it is the most difficult solution for optimization software to find and does not reflect the uncertainty inherent in real-world decision-making. While we should continue to use perfect foresight as a default assumption, alternative limited foresight formulations should be developed and implemented, as well, to produce additional insights into how the transition to hydrogen may proceed.

FY 2005 Publications/Presentations

1. Bowman, D., D.L. Greene, P.N. Leiby, E. Tworek, 2005. "HyTrans Sensitivity Analysis", National Center for Transportation Research, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 30, 2005.
2. Greene, D.L., P.N. Leiby, D. Bowman, E. Tworek, 2005. "Initial Hydrogen Transition Scenarios Developed Using the HyTrans Model", draft report, National Center for Transportation Research, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 29, 2005.
3. Greene, D.L., P.N. Leiby and E. Tworek, 2005. "Incorporating H2A Production, Delivery and Forecourt Models into HyTrans", draft report, National Center for Transportation Research, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 28, 2004.
4. Leiby, P.N., D.L. Greene, D. Bowman, E. Tworek, 2005. "Analyzing Transitions to Hydrogen Powered Vehicles with HyTrans", presentation to the National Hydrogen Association Conference 2005, March 30, 2005, Washington, D.C.
5. Leiby, P.N., D.L. Greene, D. Bowman, E. Tworek, 2005. "Analyzing Transitions to Hydrogen Powered Vehicles with HyTrans", presentation to the EIA Midterm Energy Outlook and Modeling Conference, April 12, 2005, Washington, D.C.
6. Greene, D.L. and P.N. Leiby, "Expert Review of the ORNL Hydrogen Transition HyTrans Model", a presentation at the Institute for Transportation Studies, University of California at Davis, June 28, 2005, Davis, California.
7. Greene, D.L. and P.N. Leiby, "HyTrans", a presentation to the National Research Council Hydrogen Committee, January 24, 2005, Washington, D.C.