VIII.3 Hydrogen Transition Modeling and Analysis: HYTRANS

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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 Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) and FreedomCAR program goals.
- 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 (4.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(B) Lack of Consistent Data, Assumptions and Guidelines

(C) Lack of a Macro-System Model

(E) Lack of Understanding of the Transition of a Hydrocarbon-Based Economy to a Hydrogen-Based Economy

Technical Targets

As an integrated market model of the transition to hydrogen, HyTrans incorporates simplified representations of the key infrastructure systems analysis models, as well as the outputs of related models such as Greenhouse Gas Energy and Emissions in Transportation (GREET), Powertrain Systems Analysis Toolkit (PSAT) and Automotive Systems Cost Model (ASCM). Because the representations of these models are considerably simplified, HyTrans does not replace the function of the Macro-Systems model. On the other hand, as a market simulation model, HyTrans adds a representation of the demand side of the hydrogen market. HyTrans is the only model currently capable of simulating the market transition to hydrogen and is being used to produce realistic scenarios of the early transition (2010 to 2025), as well as the long-term consequences of the early transition for the full market transition. HyTrans is a critical component of meeting DOE's systems analysis milestones for early transition analysis, as shown in Table 1 below.

TABLE 1. Progress Toward Meeting DOE Systems Analysis Milestones

Activity	Current Status	Future Activity
Begin coordinated study of transition analysis with H2A and Delivery Models	Functioning version of HyTrans incorporating H2A and Delivery models was completed and test runs were executed by the end of second quarter 2006.	Documentation of the HyTrans model integrating the H2A and Delivery models will be completed by end of FY 2006.
Complete study for transitioning scenarios for a hydrogen economy	Adaptations of HyTrans were made to enable it to model the early transition scenarios.	Draft report on early transition scenarios will be completed by 9/30/06.

Accomplishments

- Broke out Region 9 (Pacific) and Region 2 (Northeast) from the rest of the U.S. so that there are now three regions in HyTrans rather than one.
- Implemented a more precise representation of the density of motor fuel demand within regions.
- Added a representation of existing hydrogen supplies in Regions 9 and 2 and rest of U.S.
- Modified HyTrans' code to allow year-by-year solution through 2025 and 5-year intervals afterwards instead of 5-year intervals throughout.

- Improved representation of manufacturers' behavior based on in-depth discussions with vehicle manufacturers. Also, recalibrated learning curves and scale economy functions based on information gained in these discussions.
- Revised the representation of consumer demand for hydrogen fuel cell vehicles based on information gained in discussions with manufacturers.
- Developed methods for and added a reduced form representation of the H2A Delivery model.
- Updated the existing representation of the H2A production model.
- Updated greenhouse gas emission coefficients based on the 2006 release of the GREET model.
- Updated the reference scenario by calibrating to the DOE Annual Energy Outlook (AEO) 2006 Reference Case Projection.
- Revised the representation of DOE hydrogen technology goals to insure consistency with the multi-year program plans.
- In collaboration with K.G. Duleep of Energy and Environmental Analysis, Inc., developed policy scenarios consistent with the DOE early transition scenarios.
- Developed early transition scenarios in collaboration with NREL, and documented the public and private costs of the early transition, as well as its impacts on the later success of hydrogen-powered vehicles.
- Completed documentation of the HyTrans model used to develop the initial early transition scenarios.

Introduction

The HyTrans Model simulates a market-based transition of U.S. light-duty vehicles from conventional petroleum-powered internal combustion engines 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 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 vintaged 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). HyTrans depends on representations of present and future hydrogen production and delivery systems derived from other HFCIT and FreedomCar models such as the H2A Production and Delivery Models, the PSAT and ASCM models and the GREET model. World energy market scenarios are obtained from AEO projections to 2030 and Market Allocation Model (MARKAL) extensions to 2050.

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 insures 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 complete knowledge. Future development will implement alternative models of expectations under uncertainty.

Results

Key results in FY 2006 include incorporating accurate representations of H2A production and delivery models into HyTrans, disaggregation to achieve greater regional detail, addition of the ability to solve year-by-

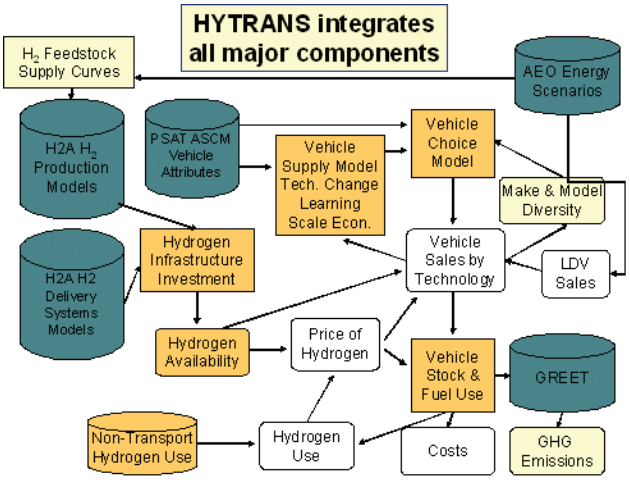

FIGURE 1. Schematic Diagram of HyTrans Model Showing Inputs from other HFCIT Systems Analysis Models

year in early periods for greater resolution in the early transition period, and simulation of the first realistic scenarios of the early (to 2025) transition to hydrogen fuel cell vehicles and their impact on the ultimate conversion of light-duty vehicles to hydrogen.

The transition to hydrogen fuel cell vehicles is expected to begin in California, extending next to the northeast states that have "opted into" the California zero emission vehicle (ZEV) mandate. The Department of Energy and its partners are developing plans to nurture this early transition by developing strategic niche markets, first in Los Angeles and then extending to other major metropolitan areas. These "lighthouse" metropolitan areas will build up the first integrated fuel delivery systems and will benefit from federal cost sharing of demonstration vehicles and refueling infrastructure. In order to more accurately simulate the market response to these early transitional efforts and to coordinate with geographically detailed scenarios developed by NREL, the U.S. was disaggregated into three geographic regions based on Census regions: Region 9 (Pacific), Region 2 (Northeast) and rest of U.S. Within Region 9, Los Angeles is broken out separately from the rest of the high-fuel-demand-density counties in the region (Figure 2). Adding regions multiplies the number of decision variables for which HyTrans must solve, but we have found that even with three geographic regions instead of one, as well as year-by-year resolution in the early years, HyTrans still converges and in a reasonable amount of time.

Adding the H2A Delivery Model (released in February 2006 and revised in April, 2006) to HyTrans and updating to the latest version of the H2A production model gave HyTrans full compatibility with the H2A modeling system. This achievement is extremely important for developing realistic transition scenarios. Highly accurate reduced form representations of the H2A Delivery Model were created by running the model hundreds of times for each delivery mode and statistically estimating unit delivery costs, chiefly as a function of total hydrogen demand and city area. The functional form employed allows each component of the delivery process to reflect scale economies and delivery distance effects. Delivery modes differ substantially with respect to costs, scale effects and delivery distance. For example, delivery in liquid form by crogenic trucks is very sensitive to scale economies but relatively insensitive to delivery distance (Figure 3). Delivery in compressed gaseous form by truck is relatively sensitive to delivery distance but has only modest scale economies (Figure 4).

Greater temporal and numerical resolution is required to model the early transition to hydrogen in specific metropolitan areas. Originally, HyTrans was designed to solve every five years to 2050 and beyond. In addition, when solving for a national, long-run transition, it is not necessary to have accuracy at very small levels of vehicle sales and energy use. However, finer resolution is essential for simulating the early stages of transition in a single metropolitan area (Figure 5). HyTrans' code was modified to allow solution year-by-year through 2025, connecting with five-year intervals thereafter. This required flexibly defined stock and flow variables, as well as logic for reconciling them. HyTrans is now capable of accurately simulating early transitions involving thousands of vehicles within a single metropolitan region.

FIGURE 2. High (dark), Medium (light) and Low (white) Fuel Demand Density Regions in California

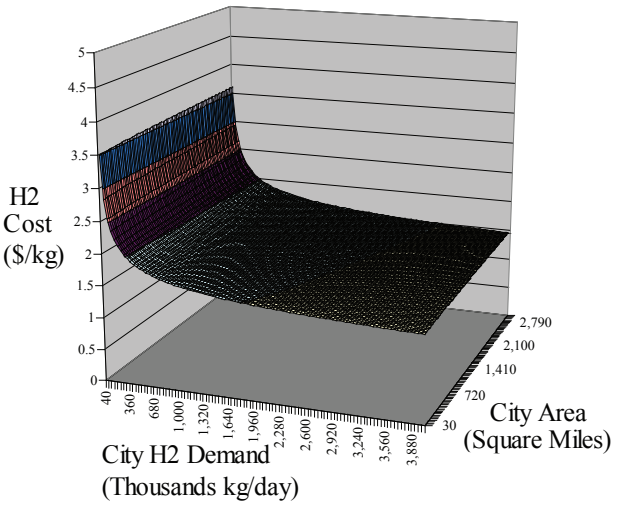

FIGURE 3. Costs of Hydrogen Delivery by Cryogenic Truck to 1,500 kg/day Forecourts

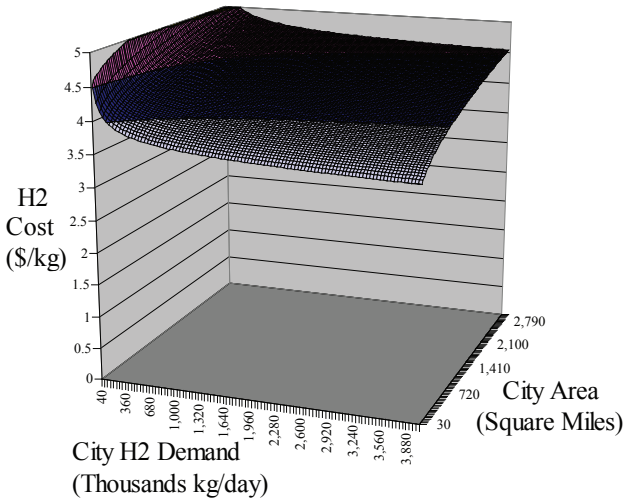

FIGURE 4. Cost of Hydrogen Delivery by Compressed Gas (3,000 psi) Truck to 100 kg/day Forecourts

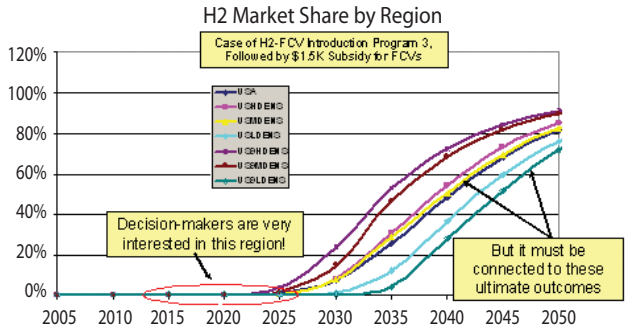

FIGURE 5. Original Level of Resolution of HyTrans Model Geared to Long-Run, National Transition

Finally, the HyTrans model was used to simulate the early transition to hydrogen and the policies necessary to achieve it. The results, which will be documented in a draft report in FY 2006 were not available at the time of writing this annual report.

Conclusions and Future Directions

In FY 2006, HyTrans was enhanced to be capable of producing realistic scenarios of early, as well as the long-run transition to hydrogen fuel cell vehicles. The inclusion of the H2A production and delivery models in HyTrans established critical linkages to HFCIT's Hydrogen Systems Analysis models, thus enabling HyTrans to serve as an integrating market model. HyTrans' new capabilities were demonstrated by producing a set of realistic scenarios of the early transition to hydrogen and connecting these scenarios to long-run, nationwide transitions to hydrogen. Still, significant developments must be made in FY 2007 to complete the development of the HyTrans model as a market simulation tool capable of integrated analysis of the transition to hydrogen and fulfilling its goals for creating credible transitions scenarios, estimating costs and benefits of achieving program goals, and policy analysis.

Publish Transition Scenarios

In FY 2006 the first work on detailed modeling and analysis of early transitions scenarios was carried out. The team of analysts from NREL, ORNL, DTI and EEA worked together to develop credible scenarios of the early transition to hydrogen and produced an initial set of scenarios. HyTrans will be used to estimate the costs, benefits and investment requirements of these early transition scenarios and will link them to credible longer-term scenarios in which the transition to hydrogen-powered vehicles is successfully completed. These scenarios will be vetted with DOE's technical advisory teams, with industry and the public. Final revised scenarios will be completed and documented in technical reports by December 17, 2006.

Update HyTrans with latest versions of Hydrogen Systems Analysis Models

HyTrans depends on and integrates the results of several key modeling efforts, including the H2A Production and Delivery Models, the GREET Model, Energy Information Administration (EIA) Annual Energy Outlook forecasts and National Energy Modeling System (NEMS) component models, as well as results of PSAT and ASCM model estimates of the performance and costs of technologies under development by the FreedomCar program. These models are continually being improved and updated as new information and new technologies are added. It is critically important that HyTrans be periodically updated to keep up with the latest developments in the other key Hydrogen Systems Analysis models. This will enable the inclusion of additional candidate technologies, such as promising fuel production methods or innovative delivery systems.

Test Sensitivity of Results to Expectations and Risk

Decision-making under uncertainty and the risks it entails are not currently included in the barriers to the hydrogen transition that are explicitly represented in the HyTrans model. Firm and consumer perceptions about the risk associated with some long-lived capital investments may significantly affect the rate at which hydrogen is introduced, and the selection of one technology pathway over another. In FY 2006, the HyTrans team developed a new method for representing year by year decisions for the early part of a forecast period and transitioning to 5-year forecast intervals in the out-years. This method lends itself to various methods of representing limited foresight within a

moving window of year-by-year decision-making. At least two formulations of limited foresight will be formulated and implemented in the HyTrans model. The limited foresight models will be tested on a set of scenarios, most likely the early transition scenarios described above. Differences between complete information and limited foresight results will be described and analyzed, and policies that may be helpful in overcoming the additional barrier posed by limited foresight will be identified.

International linkages

Other developed economies from Japan and Korea to the European Union are conducting research, development and demonstration to develop commercially viable hydrogen vehicles and hydrogen production, delivery and storage technologies. The U.S. cooperates with other nations seeking a transition to hydrogen via the International Partnership for the Hydrogen Economy (IPHE). At present the HyTrans model does not explicitly consider how progress in other countries may affect the U.S. Both energy and automotive markets are global. This task will develop methods for linking transition scenarios for other key countries to the HyTrans model so that international impacts can be taken into account. Possible implications of these linkages for the nature and timing of the transition and its costs and benefits to the U.S. will be assessed.

FY 2006 Publications/Presentations

1. Leiby, P. N., D.L. Greene, D. Bowman, and E. Tworek, 2006. "Systems Analysis of the Hydrogen Transition with HyTrans", forthcoming, *Transportation Research Record*, National Research Council, Washington, DC.

2. "Toward Realistic Scenarios of a Hydrogen Fuel Cell Vehicle Transition" a presentation by David Greene and Paul Leiby to Ben Knight, V.P. Honda R&D Americas, Inc., Torrance, California, May 30, 2006, also presented to Bill Reinert, National Manager, Advanced Technologies Group, Toyota Motor Sales and his staff, Torrance, California, May 31, 2006.

3. "Strategies and Policies for a Hydrogen Fuel Cell Vehicle Transition", a presentation by David L. Greene and K.G. Duleep to Mr. Eji Makino, Director, Technology Planning, and staff of Nissan Motor Co., Ltd, Oppama, Japan, also to Taiyo Kawai, General Manager, Fuel Cell System Engineering Div. and other staff of Toyota Motor Coporation, Aichi, Japan, also to Mr. Shoji Tange, Technical Adviser and Mr. Izuho Hirano, Deputy Director, FC-EV Center, Japan Automobile Research Institute, Tokyo, Japan.

4. "Using HyTrans to Study H2 Transition Scenarios", a presentation to the DOE FreedomCar and Fuels Partnership Analysis Workshop, January 26, 2006, Washington, D.C.

5. "Hydrogen Transition Modeling and Analysis: HyTrans v. 1.5", a presentation to the 2006 DOE Hydrogen Program Review, May 18, 2006, Washington, D.C.