VIII.8 HyTrans Model: Analyzing the Transition to Hydrogen-Powered Transportation

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Project End Date: September 30, 2010

Objectives

FY 2007

- Complete development of an integrated market model of the hydrogen transition.
  - Incorporate reduced form representations of the H2A production and delivery models.
  - Develop new fuel cell vehicle cost model in cooperation with industry partners.
  - Add regional detail sufficient for DOE early transition scenarios.
  - Additional enhancements.
  - Complete and publish model documentation.
- Use the HyTrans model to describe and analyze DOE's early transition scenarios (2012 to 2025) and publish a report on their:
  - Costs.
  - Benefits in greenhouse gas (GHG) and oil reduction.
  - Sustainability beyond 2015.

FY 2008

- Calibrate HyTrans to the 2007 Annual Energy Outlook (AEO) and to revisions to the H2A production and delivery models.
- Add segmentation of the motor vehicle market.
- Add useful representations of expectations and risk to HyTrans.
- Link HyTrans to international energy and vehicle markets, including markets for feedstocks for producing hydrogen, in collaboration with the International Energy Agency/International Partnership for a Hydrogen Economy (IEA/IPHE).
- Publish a thorough analysis of the potential costs and benefits of the transition to hydrogen-powered vehicles.

Technical Barriers

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

(A) Future Market Behavior
(D) Suite of Models and Tools
(E) Unplanned Studies and Analysis

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE systems analysis 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, 2007-2015)

Accomplishments

- The HyTrans integrated market simulation model was used to produce the first integrated scenarios of the transition to hydrogen powered transportation, in support of the DOE's *Analysis of the Transition to a Hydrogen Economy and the Potential Energy Infrastructure Requirements*. This report satisfies the Hydrogen, Fuel Cells and Infrastructure

Technologies Program Systems Analysis goal to, "by 2007, identify and evaluate transition scenarios consistent with developing infrastructure and hydrogen resources, including an assessment of timing and sequencing issues."

- For their contributions to the accomplishment of this goal, the team members, including ORNL researchers, received the DOE's 2007 Hydrogen R&D Award.
- Published ORNL report, *Integrated Analysis of Market Transformation Scenarios with HyTrans*, a key supporting document to the U.S. Department of Energy's Summary Report, "Analysis of the Transition to a Hydrogen Economy and the Potential Hydrogen Infrastructure Requirements" (USDOE, 2007).
- Enhanced HyTrans model by incorporating the latest versions of the H2A production and delivery models, and by developing a new representation of learning-by-doing and scale economies in fuel cell vehicle (FCV) production, in collaboration with original equipment manufacturers (OEMs).
- Recalibrated HyTrans model to AEO 2006 Reference and High World Oil Price Projections.
- Added regional detail to the national HyTrans model.

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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 to hydrogen, from the present until 2050. 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 endogenously determined within the HyTrans model.

The purposes of the HyTrans model are to assess the impacts of achieving R&D goals on the market success of hydrogen vehicles and hydrogen as an energy carrier, to aid in developing 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.

Approach

HyTrans integrates component models of the economic behavior of consumers, fuel suppliers and vehicle manufacturers using a dynamic, nonlinear optimization framework that simulates market outcomes. Consistency with other DOE models is insured by incorporating simplified yet accurate representations of them into HyTrans. The following models are included.

- H2A
  - Hydrogen Production
  - Hydrogen Delivery
- Powertrain Systems Analysis Toolkit (PSAT) and Automotive Systems Cost Model (ASCM)
  - Fuel economy and technology characterizations
  - 2010/2015 cost and performance goals
- ORNL Vehicle Choice Model
  - Fuel availability
  - Make and model diversity
  - Price, fuel economy, etc.
- Vehicle Manufacturing Cost Estimates (assisted by OEMs)
  - Scale Economies
  - Learning-by-doing
- Greenhouse gases, Regulated Emissions and Energy use in Transportation Model (GREET) GHG emissions
- Calibrated to National Energy Modeling System (NEMS) AEO 2006 through 2030, then extrapolated to 2050 and beyond.

Three scenarios were developed by the transition scenarios team representing different rates and geographical distributions of market penetration for hydrogen fuel cell vehicles from 2012 through 2025. Scenario 1 leads to 2 million vehicles on U.S. roads by 2025, while scenarios 2 and 3 result in 5 million and 10 million FCVs in use by 2025, respectively. The HyTrans model was used to "cost out" the transition scenarios and alternative policies for achieving them, and to test whether the scenarios, together with the achievement of the DOE's technology goals for fuel cell vehicles and hydrogen infrastructure technologies could lead to a sustainable transition to hydrogen powered transportation.

Results

Given the achievement of DOE's ambitious technology goals and the implementation of policies sufficient to insure that the early transition scenarios are achieved, all three scenarios appear to lead to a sustainable transition to hydrogen after 2025 without further policy intervention. The cumulative costs of the transition scenarios to the government range from $8 billion to $45 billion, depending on the policies adopted and the degree of cost-sharing with industry.

In the absence of such transition efforts, no transition to hydrogen vehicles is likely to begin before

2045. Instead, advanced technology hybrid vehicles come to dominate the light-duty vehicle fleet. The greater efficiency of the hybrids is able to hold light-duty vehicle petroleum use nearly constant through 2050. The success of hydrogen fuel cell vehicles, on the other hand, drives light-duty petroleum use towards zero (Figure 1).

Several pathways are able to supply hydrogen at competitive prices. In the near term, distributed steam methane reforming appears to be the most economical pathway. As hydrogen demand builds, centralized production from coal, biomass and natural gas delivered by pipeline or advanced truck become strong competitors (Figure 2). Small changes in feedstock cost assumptions, however, can tip the scales for or against a particular pathway.

In the absence of carbon constraining policies, the transition to hydrogen achieves about the same reduction in CO_2 emissions as a transition to advanced gasoline-electric hybrid vehicles (Figure 3). With significant carbon policy, equivalent to approximately $25/t$CO_2$, light-duty vehicle well-to-wheel CO_2 emissions could be driven towards zero. Both carbon policy and the transition to hydrogen fuel cell vehicles appear to be required.

Conclusions and Future Directions

The development of the integrated transition scenarios satisfies a key goal of the Hydrogen Systems Analysis program. The creation of the HyTrans model responds to a request from the National Academy of Sciences to develop systems analysis tools capable of representing the process of transition to a hydrogen economy. The scenarios create a shared vision of the hydrogen transition process for the Hydrogen R&D Program's stakeholders. The evaluation of the scenarios has produced important insights about the transition process, its costs and benefits, and the role of policy and planning in accomplishing the transition to hydrogen.

Special Recognitions & Awards/Patents Issued

1. Co-recipeint of 2007 DOE Hydrogen R&D Award.

FY 2007 Publications/Presentations

1. Leiby, P.N, D.L.Greene, D. Bowman and E. Tworek, "Systems Analysis of Hydrogen Transition with HyTrans", *Transportation Research Record No. 1983*, Transportation Research Board, National Research Council, 2006.

2. Greene, D.L, P.N. Leiby, D. Bowman, E. Tworek, "Integrated Analysis of Market Transformation Scenarios with HyTrans", forthcoming, ORNL/TM, Oak Ridge National Laboratory, Oak Ridge, TN, June 2007.

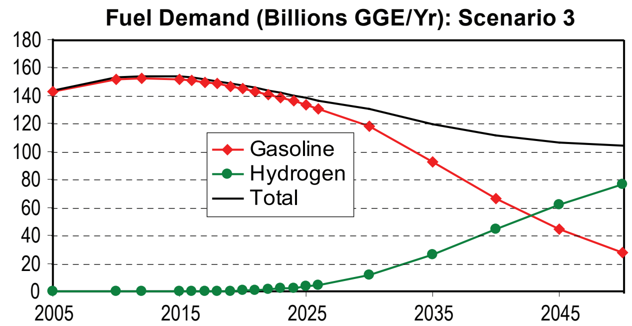

FIGURE 1. Light-Duty Vehicle Fuel Demand in Scenario 3

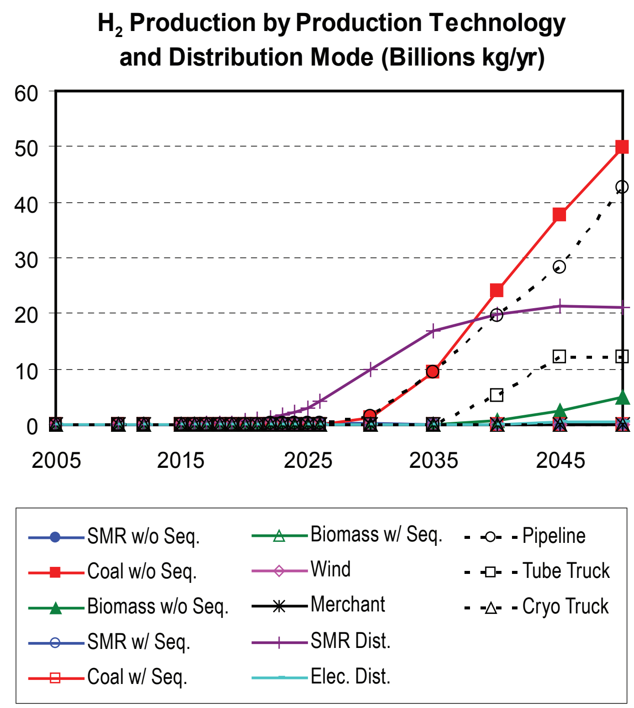

FIGURE 2. Hydrogen Production by Technology and Delivery Mode in One Scenario and Region

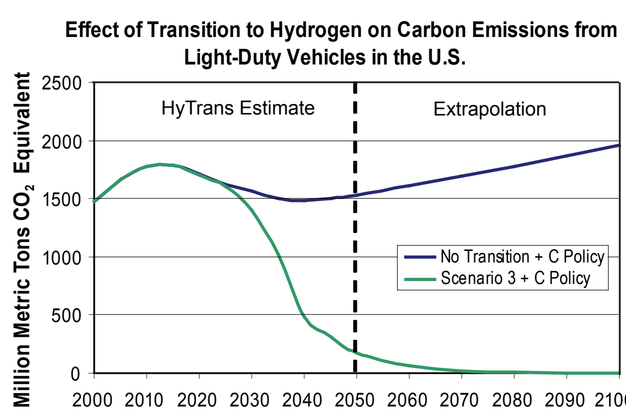

FIGURE 3. Effect of the Hydrogen Transition on Light-Duty Vehicle CO_2 Emissions

3. Gronich, S., et al., 2007. "Analysis of the Transition to a Hydrogen Economy and the Potential Hydrogen Energy Infrastructure Requirements", Summary Report, U.S. Department of Energy, Washington, D.C.