XI.7 NEMS-H2: Hydrogen's Role in Climate Mitigation and Oil Dependence Reduction

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Fiscal Year (FY) 2011 Objectives

- Provide a comprehensive, market-based context for analyzing hydrogen scenarios.
- Use an economic framework with competition among vehicle and hydrogen production technologies.
- Analyze the impact of alternative technology outcomes (hydrogen production, fuel cell vehicles, etc.).
- Analyze the potential role and cost of policies to accelerate adoption of fuel cell electric vehicles (FCEVs).
- Demonstrate the potential contribution of FCEVs to meeting national goals of reducing greenhouse gas (GHG) emissions and oil imports.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior

(B) Stove-Piped, Siloed Analytical Capability

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the System Analysis and System Integration sections of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 8 (System Analysis) – Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for technology readiness (4Q, 2014).

FY 2011 Accomplishments

- Estimated the future responsiveness of market success with hydrogen FCEVs to various degrees of research and development (R&D) success.
- Estimated the rate of growth in adoption of hydrogen FCEVs in response to hydrogen retail station size and availability as well as responsiveness to station subsidies.
- Examined variations in future reliance on different production technologies in response to R&D and carbon policies, including allocation of biomass resources between electricity production (for the grid), biomass to liquids, cellulosic ethanol, and hydrogen production.
- Examined the effectiveness of a range of vehicle subsidy types, levels and FCEV prices.
- Developed 19 distinct scenarios (six reference cases, eight sensitivity cases and five policy cases) achieving a range of reductions in GHG emissions (up to 72%) and variations in oil imports (from a 12% increase to a 14% reduction) by 2050 compared to a 2005 base year for light-duty vehicles.

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Introduction

The National Energy Modeling System (NEMS) is used by the DOE and the Energy Information Administration (EIA) to provide an integrated economic analysis of the future U.S. energy system under a variety of scenarios [1]. We developed the NEMS-H2 model as a modification of the existing NEMS model specifically to better address the potential role of hydrogen within the context of the U.S. energy system. As an integrated energy model, NEMS-H2 can capture interactions among various fuels as hydrogen production creates demand for different feedstocks, such as natural gas or coal, and at the same time displaces traditional vehicle fuel use (primarily petroleum, but potentially biofuels as well). In this study we analyze a variety of scenarios to illustrate how hydrogen-powered FCEVs might provide oil and greenhouse gas emission reductions and identify other impacts on the energy system. These scenarios address the following questions:

1) What is the relative influence of different policy options in terms of penetration of hydrogen vehicles and associated benefits, and how does this depend on technological advances?
2) What are the carbon emissions and oil import reduction implications of reduced fuel demand and fuel switching as a result of technological advances in different types of hydrogen production and vehicle technologies?

Approach

The Office of Energy Efficiency and Renewable Energy (EERE) uses NEMS to estimate the benefits of its portfolio of R&D and deployment programs and to perform various types of policy analyses. Although well suited for representing most of the EERE programs, the original version of NEMS had limited hydrogen analysis capability. Hydrogen technologies were represented within NEMS on the demand side with natural gas fuel cells for stationary combined heat and power and with gasoline and hydrogen fuel cells in light-duty vehicles. The only representation of hydrogen supply is natural gas reforming used to meet the internal requirements of petroleum refineries and a simple assumption regarding natural gas consumption for hydrogen fuel cell light duty-vehicles. Therefore, one of the primary motivations for the original NEMS-H2 development was to add a representation of hydrogen pathways to NEMS to enhance its ability to estimate the benefits of the Fuel Cell Technologies Program.

The development of NEMS-H2 followed a multi-phased approach with additional features added incrementally. At this stage, the model contains the basic elements laid out in the design report, but not all of the features originally envisioned for the eventual production version have been implemented. The model has also been extended to 2050, which was essential for analysis in that the potential emergence of hydrogen as a significant source of energy supply is not anticipated until near the end of the standard NEMS time horizon of 2030 or 2035. For more detail on NEMS, see EIA's extensive NEMS documentation [1].

The major addition to the original NEMS model is a new conversion module called the Hydrogen Market Model (HMM), which takes as input from the other NEMS sub-models the prices for various fuels and the demand for hydrogen. The HMM then provides outputs of the delivered price of hydrogen for each region and market along with demand for feedstocks used in hydrogen production. Similar to the other conversion models within NEMS for the electricity and refinery sectors, HMM is formulated as a linear programming problem, although much smaller in size.

NEMS-H2 is also modified to include more detailed geographic representation of demand, with the following explicit market segmentations: large cities (population greater than 1 million), small cities (population between 50,000 and 1,000,000), and rural markets outside city areas (populations <50,000). With these market segments captured in each of the nine census regions used in NEMS, the NEMS-H2 model includes relatively detailed spatial representations of hydrogen pathways, including 12 production methods (eight central types, one city gate, and three distributed), multiple delivery pathways, and two retail station capacities (300 and 1,500 kg per day). Pathway costs are based upon H2A Production models from NREL, and delivery costs are based upon a set of iterative runs of Argonne National Laboratory's H2A Delivery Scenario Analysis Model (HDSAM). Though dynamic and more geographically explicit delivery costs have been developed using NREL's Scenario Evaluation and Regionalization Assessment model, the present version of NEMS-H2 relies upon delivery costs from HDSAM.

Results

Given that NEMS-H2 models the entire U.S. energy economy, a wide range of results have been collected through the development of 19 distinct scenarios. Some of the highlights are summarized in the following.

- In the carbon reference case, where significant carbon policies are adopted across the economy, FCEVs achieve 10 percent light-duty vehicle (LDV) market share by 2030 and approach 70 percent by 2050 if all R&D goals are met. In the 50% R&D success case, market share is very small before 2045 and just over 20 percent by 2050. Figure 1 indicates the on-road LDV stock associated with meeting R&D goals in the carbon reference case.

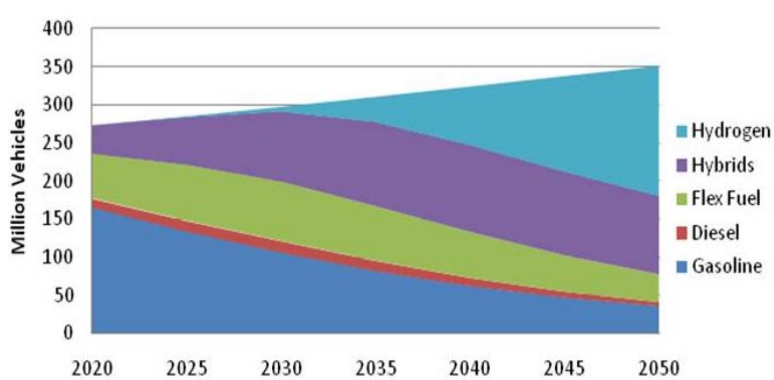

FIGURE 1. Light-Duty Vehicle Stock in the Carbon Policy Reference Case with FCEV R&D Success

- Introducing smaller stations results in greater station availability, accelerating consumer adoption (which is otherwise dampened by a lack of stations). Figure 2 indicates the influence of including small stations (300 kg/day) in NEMS-H2 in the carbon reference case, as opposed to only including large stations (1,500 kg/day).
- Sources of hydrogen are highly sensitive to carbon policy. With no carbon policy, onsite steam methane reforming and central coal gasification without sequestration are the dominant least-cost pathways, while strong carbon policy shifts production to central biomass with sequestration and coal with sequestration.

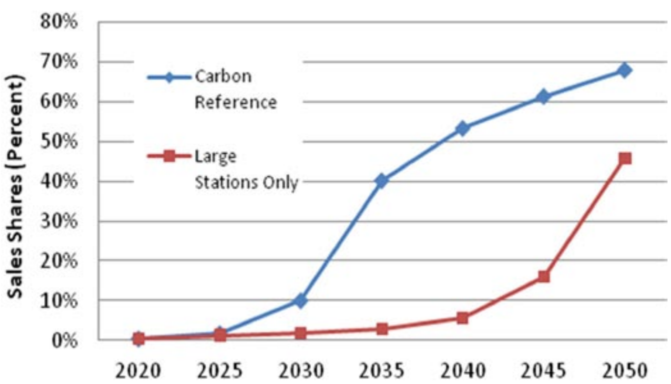

FIGURE 2. Influence of Including Smaller Stations in the Carbon Reference Case

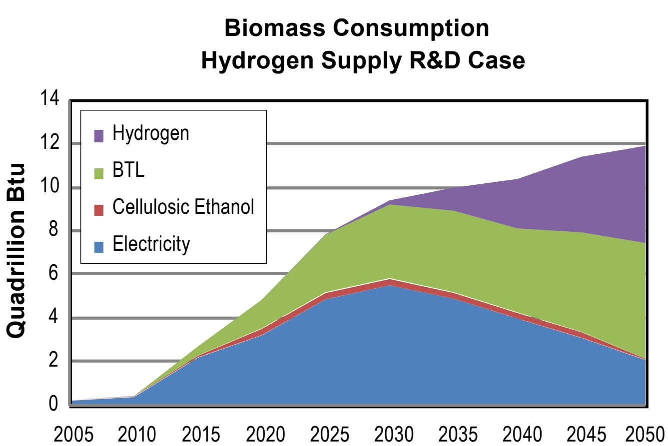

FIGURE 3. Biomass Supply and Products in the Production R&D Success Scenario

- Vehicle subsidies can be relatively effective (ranging from \$7–\$70/ton CO_2 reduced), but their effectiveness is highly dependent upon successful R&D.
- Significant use of biomass in hydrogen production could be realized if production and delivery R&D goals are met. Figure 3 shows the trend for growing biomass use in electricity, shifting toward liquid fuels around 2020, and then to hydrogen after 2030.

Conclusions and Future Directions

Our analysis has estimated the potential role of hydrogen FCEVs in the U.S. energy system using a modified version of the NEMS. The new model, NEMS-H2, estimates market share adoption and reductions in greenhouse gas emissions and petroleum consumption as a result of adopting FCEVs in the light-duty vehicle sector. We developed 19 distinct scenarios to examine important market dynamics, sector and technology interactions, R&D effects and policy strategies. Among these various scenarios, GHG emissions were reduced across a range of 16–72 percent by 2050 relative to 2005, while petroleum consumption increased in cases where FCEVs were not successful and was reduced by as much as 18 percent where they were successful. Other notable results include the importance of smaller stations in stimulating market growth, the sensitivity of hydrogen production sources to carbon policy, and the dependence of vehicle subsidy effectiveness on continued R&D progress.

FY 2011 Publications/Presentations

1. Hydrogen's Role in Climate Mitigation and Oil Dependence Reduction, 2011. F. Wood, N. Kydes, M. Melaina, T. Jenkin. National Renewable Energy Laboratory, technical report (forthcoming).

References

1. This version of NEMS-H2 is compatible with NEMS used for the Annual Energy Outlook 2008 (Energy Information Administration, "Annual Energy Outlook 2008 with Projections to 2030," DOE/EIA-0383(2008), June 2008). Documentation can be found on the EIA web site: http://tonto.eia.doe.gov/reports/filterD.cfm?other=Documentation