VIII.2 Impact of Hydrogen Production on U.S. Energy Markets

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Subcontractors:
- Brookhaven National Laboratory (BNL), Upton, NY
- Power & Energy Analytic Resources (PEAR), Atlanta, GA

Start Date: April 2005
Projected End Date: September 2008

Objectives

- Develop a consistent, integrated framework for evaluation of impacts of hydrogen production within U.S. energy markets.
- Evaluate costs and timeliness of various scenarios for developing hydrogen supply infrastructure.
- Evaluate impacts on U.S. energy markets including price and consumption changes for coal, natural gas, renewables and electricity.
- Identify most economic routes and financial risks of hydrogen production infrastructure.

Technical Barriers

This project addresses the following technical barriers for Systems Analysis from the April 27, 2007 HFCIT Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior
(B) Stove-piped/Siloed Analytical Capability
(C) Inconsistent Data, Assumptions and Guidelines
(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) A key feature of MARKAL is the simulation of all energy markets so that impacts of hydrogen use on other energy markets can be analyzed through scenarios for policy options, oil resource endowment and prices, technology advances, etc.
- **Milestone 22:** Complete the modification of the MARKAL model to include hydrogen analysis. (4Q, 2007) The regional MARKAL model to be developed under this work will include a full complement of hydrogen production technology options and end-use technology options for hydrogen as a transportation fuel and for stationary uses.

Accomplishments

In the two years of this project (May 2005 – June 2007) the following items have been accomplished:

- Created initial scenarios for metropolitan market area hydrogen demand through 2060 to develop infrastructure design and cost algorithms.
- Researched regional coal resource base descriptions, size estimates and cost distributions.
- Researched historical coal transportation costs and developed modeling algorithms.
- Created more consistent performance and cost inputs for coal-to-hydrogen and other coal conversion technologies in MARKAL.
- Researched geologic sequestration cost and maximum storage capacities by region.
- Developed algorithms for carbon dioxide transportation.
- Researched biomass resource base descriptions, regional availability estimates and cost distributions.
- Developed suite of distance-based costing algorithms for hydrogen and its feedstocks to allow specification of cost trade-offs of infrastructure location and size.
- Performed an analysis of natural gas infrastructure adequacy for transition period by major metropolitan area.

- Used original version of MARKAL model and initial regional model to investigate integrated hydrogen scenarios.

Introduction

The objectives of this project are 1) to develop a consistent, integrated framework for the evaluation of the impacts of hydrogen production within U.S. energy markets and 2) to use that framework to evaluate how various scenarios for developing a hydrogen supply infrastructure will impact U.S. energy markets including price and consumption changes for coal, gas, renewables, and electricity. Through scenario analysis, the project seeks to identify the routes to hydrogen production with the lowest economic costs and financial risks.

Approach

The EEA, together with BNL and PEAR, will create a new regionalized version of the MARKAL model to conduct an analysis of options and trade-offs involved in the establishment of a hydrogen production infrastructure. MARKAL is an integrated, inter-temporal analytical tool capable of evaluating changes in energy markets over the long-term (2005 - 2050). For this project MARKAL will be modified to incorporate the latest and most consistent cost and performance data for alternative hydrogen production technologies and will be built-out to represent separate regions of the U.S. A key focus of the work will be to evaluate impacts of an evolving hydrogen economy on U.S. energy markets including price and consumption changes for coal, natural gas, renewables, nuclear and electricity.

Results

Underground Carbon Sequestration Cost Curves

EEA prepared a revised assessment of the U.S. underground carbon sequestration capacity based on reports from the DOE-sponsored NATCARB program completed in 2006. EEA prepared cost curves showing for each state or for the nation the cumulative quantities of carbon dioxide that can be sequestered at various cost points (see Figure 1). These curves are created as a function of crude oil, natural gas and electricity prices. The oil and gas prices are used to estimate the by-product revenues for enhanced oil recovery (EOR) and for enhanced gas recovery of coalbed methane and shales. Electricity is a cost for pumping carbon dioxide. This information is to be used to produce sequestration cost curves for each MARKAL region. These cost curves are estimated in a spreadsheet program that will be updated as additional NATCARB information is developed

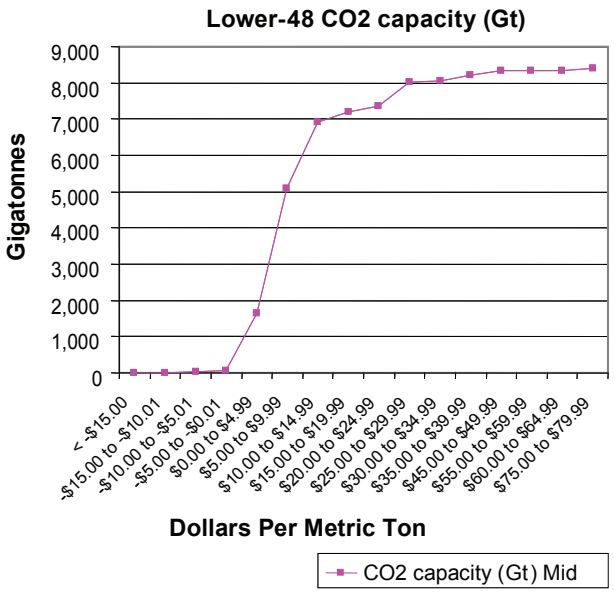

FIGURE 1. Sequestration Economics for U.S. Storage Capacity (Middle Estimate)

Regional Shipping Cost Algorithms

EEA developed cost algorithms that are used to assess how infrastructure could be built in each region to supply the market with hydrogen. The algorithms are all distance-based and include additional factors accounting for fuel cost such as diesel fuel (for trains and trucks) and electricity (for hydrogen storage and pipeline transportation). These algorithms also were developed for coal transportation to central hydrogen production facilities and for carbon dioxide transport for sequestration. These algorithms will be used to geographically place centralized hydrogen production, carbon sequestration, hydrogen storage and hydrogen distribution systems. The objective is to locate infrastructure within each region so as to reduce the cost of providing feedstocks, distributing hydrogen, storing hydrogen and disposing of carbon dioxide created in manufacturing the hydrogen for any given technology.

Metropolitan Area Natural Gas Supplies

The first part of this task was to estimate the quantities of natural gas that could be demanded as hydrogen feedstock in 26 major metropolitan areas during the transition period to hydrogen fuels (see Figure 2). The second part was to determine what additional natural gas infrastructure would be needed assuming that all or much of hydrogen supply came from onsite reformers at refueling stations. EEA created maps, tables and presentations for this task and provided

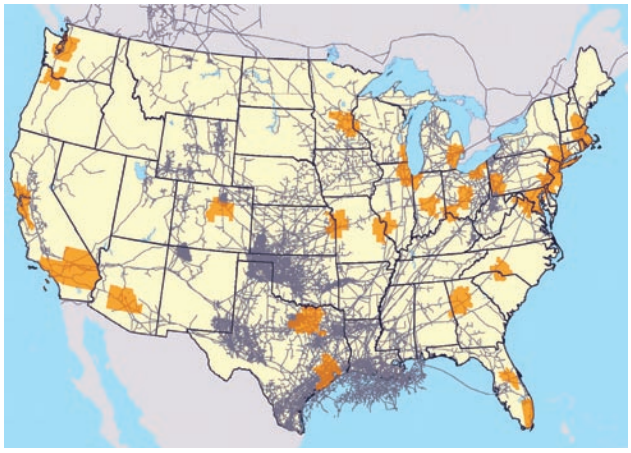

FIGURE 2. Gas Pipeline Infrastructure and Expected Metropolitan Areas for Initial Hydrogen Penetration

DOE with supplemental information related to gas transmission pipeline and local distribution company line costs. The conclusions for this task were also presented to the Fuels Pathway Integration Technical Team in November 2006.

Underground Coal Gasification

EEA conducted research and prepared cost estimates for underground coal gasification as a technology option for hydrogen manufacturing and for power generation to be represented in the MARKAL model. This technology could reduce the costs relative to conventional underground mining and could make deep coals which are now uneconomic to mine, viable as a hydrogen feedstock or primary fuel source for power.

Policy Analysis

EEA analyzed future policies that the Federal government could pursue to accelerate the transition to a hydrogen economy. EEA activities included:

- Worked with Oak Ridge National Laboratory (ORNL) to summarize and present information obtained in meetings with three of the Japanese auto manufactures on fuel cell vehicle costs, technology and introduction strategies. This included presentations to DOE and outside reviewers.
- Coordinated with National Renewable Energy Laboratory (NREL)/ORNL on scenario timing, vehicle sale targets and infrastructure development.
- Conducted a trip to Germany to discuss fuel cell vehicle costs, technology and introduction strategies with two auto manufactures, Linde (industrial gases) and Bosch (automotive components).

EEA worked with ORNL to summarize information from the trips and to present it to DOE.

Biomass Resource Base and Costs

BNL researched biomass resource base descriptions, regional availability estimates and cost distributions to develop regional cost curves in MARKAL. The economic analysis work was conducted with the help of Marie Walsh using the POLYSYS model. POLYSIS is a dynamic model of the U.S. agricultural sector. It represents 305 supply region models for the land allocation decision with relatively homogeneous production characteristics (Agricultural Statistical Districts). The model simulates impact of changes in policy, economic, or resource conditions to the U.S. agricultural sector. POLYSIS can analyze many variables including: planted and harvested acres, yields, production, exports, variable costs, market demand by use, farm price, cash receipts, government payments, and net realized income. The objective is to determine the quantity of each biomass resource type of interest at a range of selected production costs, in at least two population density areas. The POLYSIS supply curves contain roughly twice the amount of resource as the 2007 DOE Annual Energy Outlook (AEO) supply curves, but less than the ultimate resources shown in DOE's Billion Ton Study (see Figure 3). Transportation costs are factored in to the final cost of each feedstock type in MARKAL.

MARKAL Analysis

BNL used a new regional version of the MARKAL model to investigate integrated hydrogen scenarios based on the 2007 AEO assumptions through 2030 and extrapolated values to 2050. An example of results is shown in Figure 4 for alternative scenarios. The cases examined include:

- Base case
- HFCIT technology goals model optimized path
- National Academy of Sciences recommended penetration rate (10 million vehicles by 2025), model optimizes path after 2025

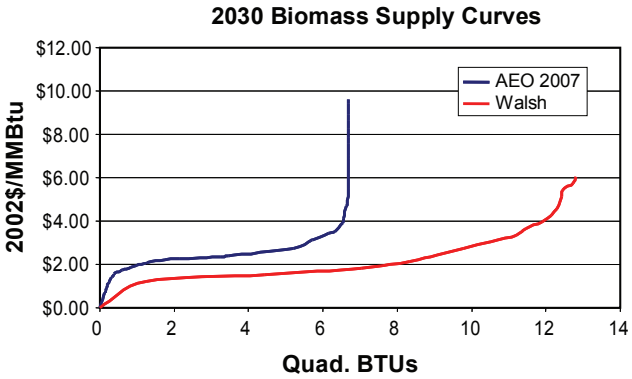

FIGURE 3. Biomass Supply Curves for 2030

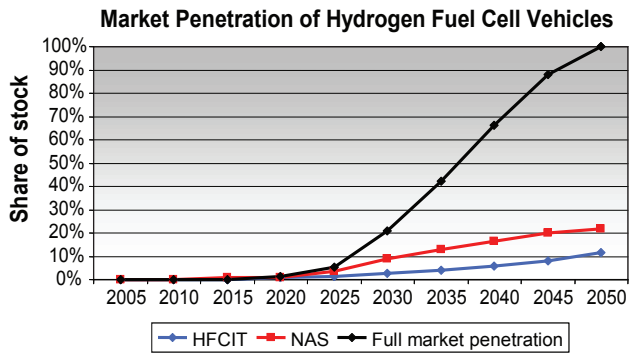

FIGURE 4. Market Penetration for Hydrogen Fuel Cell Vehicles

- Fixed penetration path with 100% market share by 2050

All the scenarios presented are based on the AEO 2007 Reference Case economic activity, vehicle fleet and fuel prices. The cases show a significant impact from hydrogen on liquid fuel markets is possible as petroleum refiners need to adapt to changes in fuel demand that has a much higher distillate to gasoline ratio. There is limited ability to fuel switch away from other liquid fuels (or to gasoline) in the rest of the economy. If the hydrogen transitions are taking place in the rest of the world there is also a limit to the amount of excess gasoline that can be exported from the U.S. The cases also show that even though natural gas plays an important role in the transition period, there is only a small overall impact on natural gas prices from hydrogen production because the natural gas market is large in comparison to the extra demand as hydrogen feedstock. Another conclusion from the MARKAL cases is that there is significant pressure on biomass resources from both the transportation and power generation sectors. Hydrogen production in combination with the demand for biofuels under the Renewable Fuel Standard, may require a large share of the available biomass resources go to transportation when economic technologies to convert biomass to hydrogen are assumed.

Conclusions and Future Directions

During the next year, EEA and BNL will finalize data inputs for MARKAL, perform analyses of alternative integrated scenarios and examine various sensitivities. EEA and BNL also will produce report on methodology, data, assumptions and conclusions. Some of the key issues to be examined include:

- Performance of fuel cell vehicles (FCVs) is critical to their market penetration: MARKAL sensitivity cases will include assumption of DOE performance goals as well as more conservative performance projections.
- Competitors of hydrogen FCVs will also be advancing in terms of costs and performance and may prove to be better options in many instances: MARKAL cases will include alternative competitive cases and the report will discuss conditions for market success in transportation market.
- Nature and timing of any greenhouse gas (GHG) limits will affect relative energy prices and market for low-GHG technologies in all sectors: alternative cases to be examined in MARKAL will include severe limits now being discussed (80% reduction by 2050).
- Costs and volume limitations of biomass and other renewables is critical to their ultimate role in power and transportation fuels energy markets. Detailed biomass curves developed for this project will be tested against alternative assumptions within MARKAL.
- Feedback of GHG limits on additional oil supplies (through EOR with carbon sequestration) combined with lower oil demand (fuel substitution, higher efficiency) could have major effects on oil markets and refining. This will be one of the major energy market interactions to be addressed in model runs and our final report.

Publications/Presentations

1. Presentation on project progress entitled “Impact of Hydrogen Production on U.S. Energy Markets”, H. Vidas, P. Friley, DOE Annual Merit Review Meeting, Arlington, VA, May 2007.