VIII.9 Impact of Renewables on Hydrogen Transition Analysis

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Contract Number: ACO-6-66414-01

Project Start Date: October 1, 2006
Project End Date: February 28, 2007

Objectives

- Project the most economically attractive renewable resources for producing hydrogen for future light-duty vehicles in the U.S.
- Optimize the allocation of renewably sourced hydrogen within the contiguous U.S. by minimizing the selling price of renewably sourced hydrogen.
- Understand how the cost structure of renewably sourced hydrogen varies throughout the country in terms of contributing factors (feedstock, production, transportation).

Technical Barriers

This project addresses the following technical barriers from the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

Hydrogen Production (3.1.4)

(D) Feedstock Issues

Systems Analysis (4.5)

(A) Future Market Behavior

Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes to achievement of the following DOE Systems Analysis milestone 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)**. Our Logistics Model enables a geographic analysis of renewably sourced hydrogen supply, demand, delivery and potential selling price.

Accomplishments

- Projected the most economically attractive renewable resources for producing hydrogen based on forecasts for the cost and performance of future technologies.
- Optimized the allocation of renewably sourced hydrogen using the TIAX Hydrogen Logistics Model for U.S. population centers greater than 300,000 people by minimizing the selling price of renewably sourced hydrogen.
- Determined the cost savings of delivering hydrogen via a networked pipeline system.
- Predicted the cost structure of renewably sourced hydrogen throughout the U.S. in terms of contributing factors (feedstock, production, transportation) for three projected demand levels.

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Introduction

Using domestic, renewable resources to produce hydrogen for future U.S. light-duty vehicles is considered the ideal pathway due to their low net greenhouse gas emissions and the potential stability of the supply[1]. Renewable resources such as wind and solar can be used to produce power which can, in turn, be used to produce hydrogen via water electrolysis. Biomass can be used directly as a feedstock to produce hydrogen via biomass gasification or other advanced routes. However,

[1] Note: This study does not investigate whether or not U.S. renewable resources are best utilized for hydrogen production versus other uses, such as for food, feed, or renewable-power for the electricity "grid."

understanding the economics of renewably sourced hydrogen is crucial to its efficient implementation and involves figuring out which renewable resources are the most attractive to develop based on their quality, proximity to demand and the demand level itself. Using cost and performance forecasts for technologies on the supply side, such as solar power towers, wind turbines, biomass gasifiers and hydrogen pipelines coupled with projections for regionally-specific demand enables calculation of the optimal allocation of renewable resources and the potential hydrogen selling price.

Approach

The potential for renewably sourced hydrogen production is investigated by modeling likely scenarios for future (2030-2050 timeframe) hydrogen supply and demand using the TIAX Hydrogen Logistics Model. Supply and demand variables, such as quality and availability of different renewable resources, as well as population and number of vehicles per capita, are inputs to the model. The model uses NASA's Earth Observing System (EOS) and the National Renewable Energy Laboratory's (NREL's) Geographic Information Systems (GIS) data for U.S. population and renewable resource quality and availability, combined with cost projections for U.S. renewable resources and hydrogen production and delivery, to determine the most economically attractive renewable resources and hydrogen infrastructure for the contiguous U.S.

The resource cost projections used in the model, which include wind and solar power cost of electricity and biomass feedstock costs, come from published studies assuming cost and performance improvements consistent with large-scale technologies that should be available in the year 2025 and beyond [1,2,3]. The hydrogen production costs and pipeline delivery costs are derived from H2A models using longer-term (i.e., 2030) technology assumptions[2]. Modifications to the H2A models were made to account for variation in the throughput and capacity factor of the plants since these are important variables when considering all potential renewable resources in the contiguous U.S. The calculational engine is MATLAB-based and employs the Simplex Method (a linear program) that carries out the resource optimization. A separate function of the model generates a pipeline network, which is a consolidation of the individual streams, from supply node to demand node, that result from the optimization. The networking program works by locating and joining individual streams that are nearby and traveling in a similar direction. The pipes join each other at a point which is optimized on a cost-basis.

[2] Production costs extracted from "h2a_central_wind_longer-term_final.xls" and "h2a_central_biomass_gasification_longer-term_final.xls" files.

For the analysis presented here, we limited the number of supply and demand variables to simplify the model inputs, calculations and results. First, we carried out an initial screening to identify the most promising and relevant renewable energy resources within the analysis timeframe. As a result, the analysis only considers large-scale wind and solar powered (both photovoltaic [PV] and concentrating solar power [CSP]) electrolysis plants and biomass gasification plants for the production of hydrogen. We did not consider smaller-scale, distributed production of hydrogen from renewables. In addition, only the top 240 most populous nodes[3] (i.e., those nodes with population greater than 300,000 people in 2040) are used in the analysis to simulate a likely future (2030-2050) scenario where high-demand urban areas are the most attractive hydrogen markets. As a consequence, the model includes about 42% of the contiguous U.S. population in these 240 nodes.

Results

Biomass and wind resources are predicted to be the lowest-cost options in the base case [4], where we assumed a hydrogen demand from renewables of 47,100 TPD H_2 (representing roughly 50% demand from vehicles in cities larger than 300,000 people for the year 2040). Map views, like the one presented in Figure 1, are generated by the Logistics Model to help make the results more comprehensible and illuminate trends that are difficult to see with numerical output. In the base case, biomass provides 20% and wind provides 80% of the assumed demand with a fair amount of overlap in the locations of biomass and wind plants except for the Rocky Mountain region and the Upper Midwest (both predominantly wind).

[3] In this analysis, the contiguous U.S. is subdivided into 13,521 nodes that measure 1/4° longitude by 1/4° latitude.

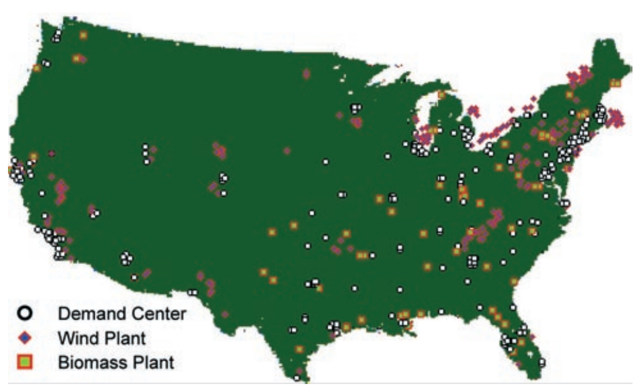

FIGURE 1. Locations of Renewable Plants and Population Centers in the Base Case

Employing the base case assumptions [4], the model predicts a mean hydrogen selling price of $4.40/kg, with most renewably sourced hydrogen predicted to have a selling price between $3.50 and $5.50/kg if all hydrogen is assumed to be delivered directly from the production plant to the "city gate". Figure 2 shows the distribution of hydrogen price within the base case for all 240 nodes evaluated and the separate distributions of hydrogen prices from the two employed renewable resources, biomass and wind. The bimodality of the wind-based price distribution is a result of the step change in wind-to-electricity cost in changing from Class 6 to Class 5 wind.

The Logistics Model calculates several other important statistics, including: the total quantity of each resource utilized; location, number, size and capacity factor of each renewable-based hydrogen plant; hydrogen delivery distances; and the breakout of hydrogen price between resource, production and delivery (including distribution). Costs associated with hydrogen delivery account for roughly half of the total price. Half of the delivery cost is associated with inter-city distribution, which includes local pipelines and forecourt hydrogen stations, and the other half is associated with transmission of the hydrogen from the plant to the "city gate" (see Figure 3). Altering the transmission delivery method from direct-route (i.e., "as the crow flies") to a networked pipeline system decreases the overall transmission distance. In the base case, the overall number of pipeline miles is halved when a networked approach is taken. An example of a network pipeline system for the base case is shown in Figure 4.

Conclusions and Future Directions

- There is good geographical distribution of U.S. wind and biomass resources that can be utilized to supply hydrogen to high-demand urban areas for future hydrogen light-duty vehicles. However, it should be noted that wind and biomass plants may not be acceptable in all the locations evaluated.
- There are no utility-scale solar resources utilized according to the current model assumptions and logic. Nonetheless, solar, in particular PV, will likely be an attractive technology option for distributed hydrogen production (not evaluated here).
- The vast majority of renewably sourced hydrogen will be more expensive than central natural gas-based hydrogen production and delivery based on current natural gas prices [5]. However, it should be noted that future natural gas prices will be much higher if a significant fraction is used to make hydrogen for light-duty vehicle use.
- A significant, but not overwhelming fraction of the hydrogen selling price from wind and biomass resources is projected to be due to transmission costs from the plant to the "city gate."
- The total miles of transmission pipeline required for the networked base case is half the direct-route approach since most U.S. cities are close together and the hydrogen piped to them can easily be

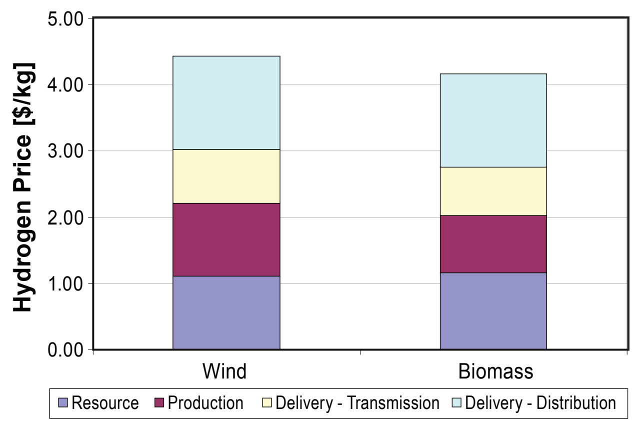

FIGURE 3. Breakout of the Hydrogen Selling Price in the Base Case

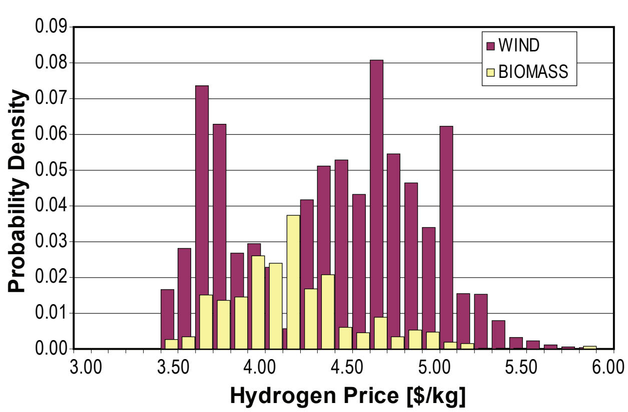

FIGURE 2. Average Hydrogen Selling Price Distribution in the Base Case

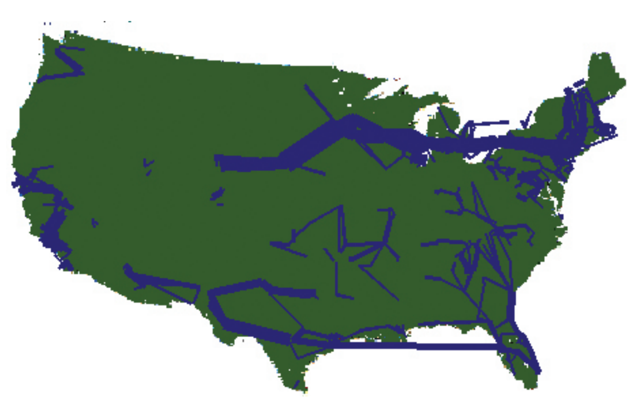

FIGURE 4. Pipeline Network in the Base Case (Maximum Segment Capacity is 3,500 TPD H_2)

consolidated into one pipeline for a large fraction of the transportation distance.

- The geographical distribution of hydrogen price shows a distinct trend for increasing from west to east (not shown here), suggesting that a renewably sourced hydrogen transition may also proceed in this direction.
- Modeling of three different renewable-based hydrogen demand levels representing 20%, 50% and 70% demand from vehicles in large cities shows very little change in the required hydrogen selling price (not shown here). This result suggests that the demand scale of this problem is not on a sensitive part of the renewable energy supply curve.

Given the limited scope of this study, we did not evaluate the following impacts, but recommend them for future work:

- Site-specific resource availability and utilization restrictions (e.g., siting wind turbines, water availability).
- Other uses for renewable resources (e.g., renewable “grid” power).
- Distributed (small-scale) hydrogen production using local renewable resources (e.g., PV).
- Non-hydrogen delivery options (e.g., high-power transmission lines, biofuels).
- Right-of-way limitations (including natural or man-made obstacles) for siting pipelines (and high-power transmission lines, if analyzed).
- Other domestic resource options (e.g., nuclear, “clean coal”, geothermal).
- Refinement of the cost of utility-scale PV technologies and evaluation of other advanced renewable-to-hydrogen technologies.

FY 2007 Publications/Presentations

1. Lasher, S., et al., “Impact of Renewables on Hydrogen Transition Analysis,” Presentation to the NHA Renewable Hydrogen Working Group, March 2007.

2. Lasher, S., et al., “Impact of Renewables on Hydrogen Transition Analysis,” Poster at the National Hydrogen Association Annual Meeting, March 2007.

References

1. EPRI/DOE, 1997, “Renewable Energy Technology Characterizations,” Prepared by the U.S. Department of Energy, Office of Utility Technologies, and the Electric Power Research Institute, TR-109496, December.

2. Sargent and Lundy, 2003, “Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts,” Sargent & Lundy LLC Consulting Group Report to the National Renewable Energy Laboratory, NREL/SR-550-34440, October.

3. Walsh, M., et al., 1998, “Economic Analysis of Energy Crop Production in the U.S. – Location, Quantities, Price and Impacts on Traditional Agricultural Crops,” October.

4. “Impact of Renewables on Hydrogen Transition Analysis,” TIAX LLC, Draft Final Report submitted to the National Renewable Energy Laboratory, March 23, 2007.

5. Gronich, S.; Scenario Analysis Meeting Presentation; January 31, 2007.