XI.5 Infrastructure Costs Associated with Central Hydrogen Production from Biomass and Coal

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Project Start Date: Fiscal Year (FY) 2010
Project End Date: Project continuation and direction determined annually by DOE

FY 2012 Objectives

- Elucidate the location-dependent variability of infrastructure costs for biomass- and coal-based central hydrogen production and delivery and the tradeoffs inherent in plant-location choices
- Provide modeling output and correlations for use in other integrated analyses and tools
- Publish results so they are available to relevant decision makers and analysts

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:

(B) Stove-piped/Siloed Analytical Capability
(D) Insufficient 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 milestones from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1.9: Complete analysis and studies of resource/feedstock, production/delivery, and existing infrastructure for technology readiness. (4Q, 2014)

FY 2012 Accomplishments

- Calculated costs of pipeline-based delivery of hydrogen from hypothetical hydrogen-production plant locations throughout the entire United States to nearest demand centers, ranging from about $0.20 to $2.70 per kilogram of hydrogen.
- Identified viable biomass-based hydrogen-production plant locations based on adequacy of woody biomass resources within a 100-mile radius for enabling full-capacity plant operation (about 730,000 dry metric tons per year required for 155,200 kg H_2/year plant), concluding that biomass resource availability determines where plants can be built.
- Calculated costs of truck-based delivery of biomass to the viable plant locations, ranging from $0.11 to $0.26 per kilogram of hydrogen.
- Calculated total biomass-based hydrogen infrastructure costs for plants located near select cities, ranging from $0.35 per kilogram (for a plant 25 miles from Houston) to $0.58 per kilogram (for a plant 50 miles from Detroit).
- Identified carbon-sequestration sites with storage potential equivalent to 40 years of carbon storage from coal-based hydrogen-production plants.
- Calculated costs of transporting carbon dioxide (CO_2) from potential coal-based hydrogen-production plant locations to carbon-sequestration sites. Pipeline and well infrastructure needed to transport and sequester CO_2 adds approximately $0.20 to $0.70 per kilogram to the cost of hydrogen.
- Calculated costs of building railroad spurs for coal delivery from primary rail lines to potential hydrogen-production plant locations, ranging from $0.01 to approximately $0.40 per kilogram of hydrogen.
- Concluded that distance from adequate carbon-sequestration sites limits coal-based hydrogen-production plant locations or increases infrastructure costs (for pipeline delivery of CO_2 to sequestration sites) substantially.
- Calculated total coal-based hydrogen infrastructure costs for plants located near select cities, ranging from $0.42 per kilogram (for a plant 25 miles from Detroit) to $0.96 per kilogram (for a plant 25 miles from Boston).

- Produced geographic information system (GIS) maps illustrating infrastructure costs for biomass- and coal-based hydrogen production.

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Introduction

The United States has abundant biomass and coal resources, which could be used to produce substantial amounts of hydrogen in support of a national hydrogen economy. Further, the environmental impact of producing hydrogen from both types of resources could be manageable. Biomass captures CO_2 as part of its natural growth, so biomass-based hydrogen could produce near-zero net greenhouse gas emissions. The CO_2 emitted during coal-based hydrogen production could be sequestered, thus reducing the associated environmental impact.

As with all hydrogen technologies, reducing cost is a key challenge related to biomass- and coal-based hydrogen production. Cost-reduction opportunities exist for growing biomass feedstocks and for producing hydrogen from coal and biomass. However, few studies have addressed the location-dependent cost of the distribution infrastructure required to transport biomass and coal to centralized hydrogen-production plants, transport hydrogen from the plants to demand centers, and transport CO_2 (from coal-based plants) to carbon-sequestration sites. This project takes a first step toward filling this gap by quantifying national infrastructure requirements and costs related to centralized hydrogen production plants based on woody biomass resources (this project focuses on forest residues and primary mill residues) and coal. Project partners include the U.S. DRIVE Fuel Pathways Integrated Tech Team, DOE Biomass Program researchers, Pacific Northwest National Laboratory, and the National Energy Technology Laboratory (NETL).

Approach

The project's approach combines GIS data and tools with DOE's Hydrogen Analysis (H2A) models—the H2A Production and Delivery Components models—following three general steps: 1) Map resources, existing infrastructure, land features that impact infrastructure construction, and demand centers; 2) Construct infrastructure cost correlations in H2A models based on distance, terrain, and land use; and 3) Determine infrastructure costs for hypothetical plants in each square kilometer across the United States.

Hypothetical plant configurations were selected, including characteristics such as hydrogen-production capacity and flow of biomass or coal required to operate at full capacity. For biomass-based plants, a maximum distance of 100 miles from the plants to biomass-collection areas was defined by assuming that 100 miles is the maximum distance that could be served economically via truck transport of biomass to plants. National woody biomass resources were quantified, and potential plant locations were identified wherever a plant could obtain enough biomass within a 100-mile radius to operate at full capacity (approximately 155,200 kg of hydrogen per year). The cost of trucking biomass (including harvest, pre-processing, grower payments, and trucking of biomass on existing roads) to the potential plant locations was calculated and mapped. Next, the pipelines required to transport hydrogen from potential plant locations to the nearest hydrogen-demand centers were identified and their costs calculated and mapped. Finally, the biomass trucking costs and hydrogen pipeline costs were combined and mapped to show the total infrastructure costs of potential biomass-based hydrogen-production plants.

For coal-based plants, similar assumptions about piping hydrogen to nearest demand centers were used. However, instead of truck delivery of biomass, rail delivery of coal to hydrogen-production plants was assumed, and the cost of building spurs from existing rail lines to plants was calculated and mapped (accounting for distance, land use, and terrain). In addition, carbon-sequestration sites with storage potential equivalent to 40 years of carbon storage from coal-based plants were identified—using NETL's National Carbon Sequestration Database and Geographic Information System—and the cost of piping CO_2 from the plants to the sites was calculated and mapped. Finally, the rail, hydrogen-pipeline, and carbon-sequestration costs were combined and mapped to show the total infrastructure costs of potential coal-based plants.

Results

Figure 1 shows the map of viable biomass-based plant locations based on the adequacy of woody biomass resources within a 100-mile radius for enabling full-capacity plant operation. Based on this analysis, the cost of truck-based delivery of biomass to the viable plant locations ranges from \$0.11 to \$0.26 per kilogram of hydrogen. Figure 2 maps costs for delivering hydrogen via pipeline from hypothetical hydrogen-production plant locations (all potential U.S. locations, not just viable biomass-based plant locations) to nearest demand centers, ranging from about \$0.20 to \$2.70 per kilogram of hydrogen; note that terrain and federally protected land restrictions impact costs in the western United States. For biomass-based plants, hydrogen pipeline cost dominates the total cost, and biomass resource availability determines where plants can be built. Table 1 shows the infrastructure-cost variations for biomass-based hydrogen-production plants near select cities. Note that Boston's low hydrogen-delivery cost gives the city the lowest overall infrastructure cost even though its biomass-delivery cost is higher than for Houston or Seattle.

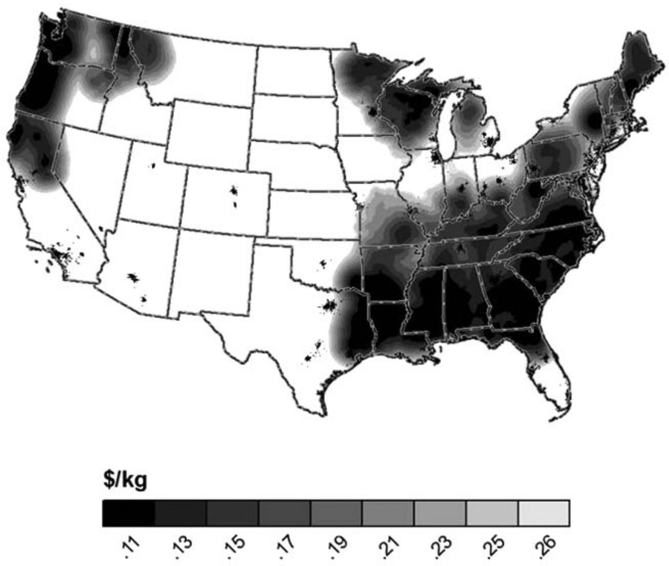

FIGURE 1. Total estimated cost of delivering woody biomass to hydrogen plants via truck (100-mile maximum transport distance). White denotes areas in which the hypothetical biomass plants are not viable because full-capacity operation cannot be supported with the woody biomass resources available within the 100-mile transport distance. Billy Roberts, NREL, July 2012.

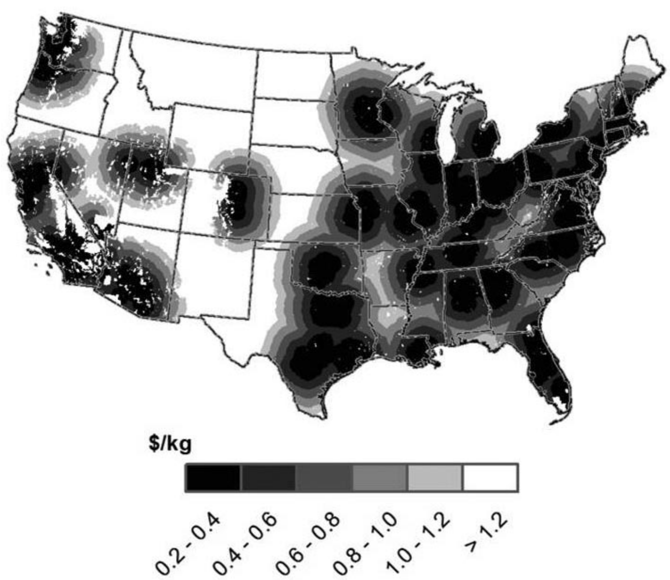

FIGURE 2. Total estimated cost of delivering hydrogen to demand centers via pipeline. Billy Roberts, NREL, July 2012.

TABLE 1. Biomass-based hydrogen infrastructure costs for plants near select cities

City (plant distance to city outskirts - miles)	Biomass Truck Delivery (¢/kg)	H_2 Pipeline Delivery (¢/kg)	Total Infrastructure Cost (¢/kg)
Boston (25, W)	19	21	40
Boston (50, W)	17	24	40
Houston (25, N)	11	25	35
Houston (50, N)	11	37	48
Seattle (25, S)	11	32	43
Seattle (50, S)	10	34	44
San Francisco (25, N)	23	26	48
San Francisco (50, N)	21	35	55
Detroit (25, W)	24	22	46
Detroit (50, W)	23	35	58

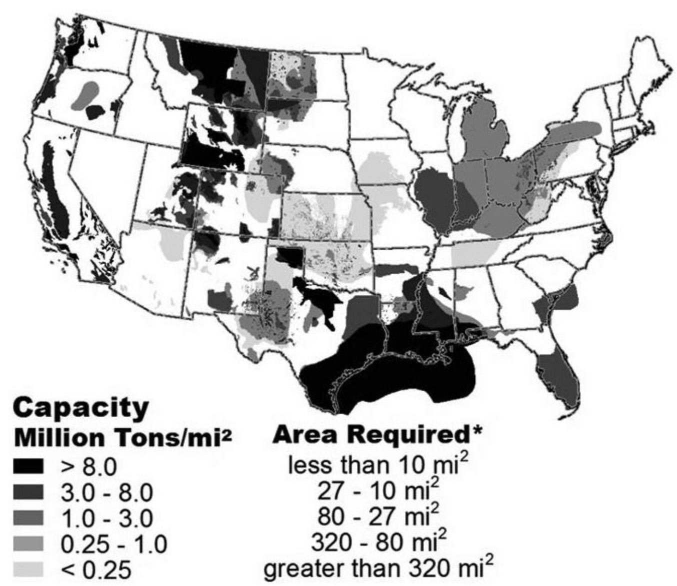

FIGURE 3. Total estimated U.S. CO_2 sequestration capacity from un-mineable coal seams, saline formations, and depleted oil and gas reservoirs with adequate storage for 40 years. Reservoir data: National Energy Technology Laboratory (www.natcarb.org). Billy Roberts, NREL, July 2012. *Approximate surface area of reservoir required for 40 years of CO2 storage from a single hydrogen-production plant.

Figure 3 shows carbon-sequestration sites with storage potential equivalent to 40 years of carbon storage from coal-based hydrogen-production plants. Costs of CO_2 pipelines account for restrictions on sequestration site access based on proximity, pipeline route availability (e.g., avoiding restricted areas such as national parks), and the impact of terrain characteristics on installation cost. Total infrastructure costs were calculated based on CO_2 pipeline/well costs (about $0.20 to $0.70 per kilogram of hydrogen) the cost of building railroad spurs for coal delivery from primary rail lines to potential hydrogen-production plant locations (about $0.01 to $0.40 per kilogram of hydrogen), and the cost of piping hydrogen to demand centers (about $0.20 to $2.70 per kilogram of hydrogen, Figure 2). The distance from adequate carbon-sequestration sites limits hydrogen-production plant locations or increases infrastructure costs substantially. Table 2 shows the infrastructure-cost variations for coal-based plants near select cities. Boston has high infrastructure costs because suitable carbon sequestration sites are far from the city.

TABLE 2. Coal-based hydrogen infrastructure costs for plants near select cities

City (plant distance to city outskirts - miles)	CO_2 Pipeline (¢/kg)	Rail Spur (¢/kg)	H_2 Pipeline Delivery (¢/kg)	Total Infrastructure Cost (¢/kg)
Boston (25, W)	72	3	21	96
Boston (50, W)	60	0	24	84
Houston (25, N)	17	5	25	47
Houston (50, N)	17	2	37	56
Seattle (25, S)	17	3	32	52
Seattle (50, S)	17	14	34	65
San Francisco (25, N)	24	0	26	50
San Francisco (50, N)	23	11	35	69
Detroit (25, W)	17	3	22	42
Detroit (50, W)	17	1	35	53

Figure 4 compares total infrastructure costs for biomass-based (top) and coal-based (bottom) hydrogen-production plants, with plant locations limited to those with infrastructure costs of $1 per kilogram of hydrogen or less. As the figure shows, infrastructure for coal-based hydrogen plants is usually more expensive than infrastructure for biomass-based hydrogen plants. However, coal-based plants are viable in some metropolitan areas where biomass-based plants are not because of inadequate biomass resources within the assumed 100-mile truck-delivery radius.

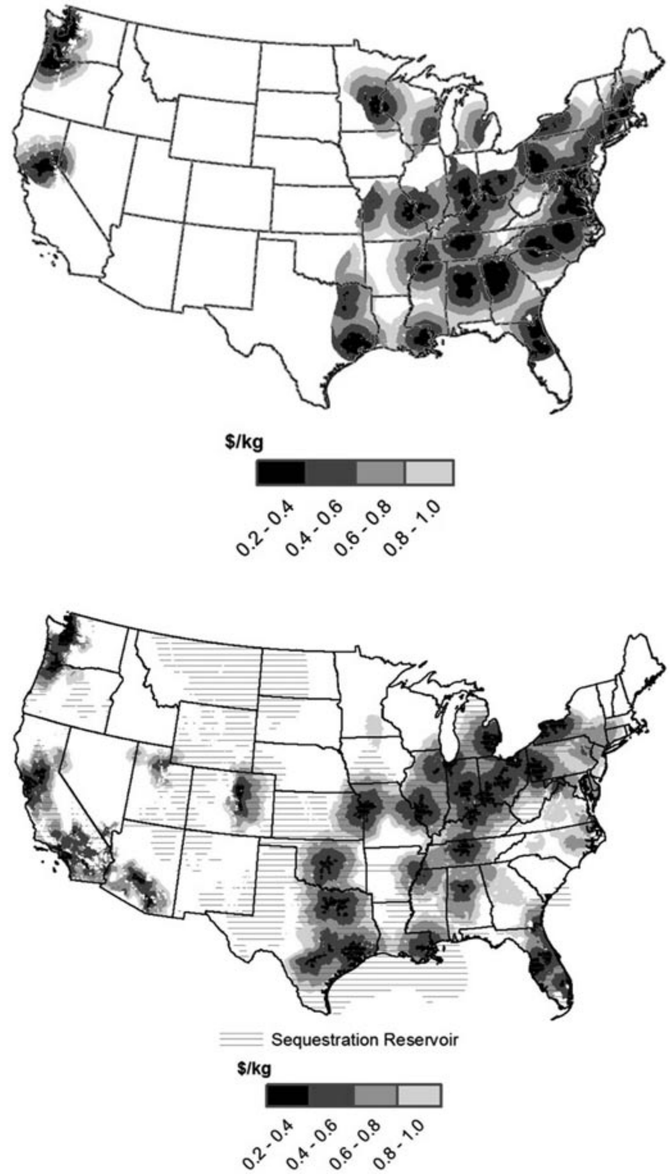

FIGURE 4. Total estimated infrastructure cost of producing and delivering hydrogen from woody biomass-based (top) and coal-based (bottom) plants. Billy Roberts, NREL, July 2012.

Conclusions and Future Directions

This analysis shows the benefit of using GIS data and tools in conjunction with established DOE models to explore the location-dependent variability of infrastructure costs for hydrogen production and delivery from various feedstocks as well as the tradeoffs inherent in plant-location choices. The modeling output and correlations will be made available for other integrated analyses and tools, and the results will be published so they are available to relevant decision makers and analysts.

Although work in the remainder of FY 2012 will focus on publishing results of the work done to date, various strategies could refine and/or reduce hydrogen infrastructure costs. For example, performing the analysis assuming rail delivery of biomass, smaller biomass-based hydrogen plants, or both could show increased geographic availability of this technology. For coal-based hydrogen plants, CO_2 sequestration costs could be refined by accounting for differences in carbon reservoir permeability and size. For both hydrogen-production technologies, infrastructure cost/supply curves could be developed. Finally, the National Renewable Energy Laboratory's Scenario Evaluation, Regionalization & Analysis model could be used to optimize hydrogen infrastructure locations.