Hydrogen from Renewable Energy Sources: Pathway to 10 Quads For Transportation Uses in 2030 to 2050

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Objectives

- Identify a pathway for producing 10 quads of hydrogen per year for transportation uses from renewable sources in the years 2030 to 2050 (1 quad = 10^{15} Btu).

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- T. Renewable Integration
- AD.Market and Delivery

Approach

- Determine the total potential hydrogen generation from renewable resources in the U.S. in 2030-2050 to ensure that the production of 10 quads of hydrogen is possible.
- Only the resources that could make a contribution of at least 0.1 quads per year were included: biomass, solar, wind, and geothermal.
- The potential hydrogen generation from each of the four resources was determined on a state-by-state basis.
- The hydrogen demand for a given state in the year 2040 was estimated by assuming that the per capita demand for hydrogen would be proportional to the per capita gasoline usage in that state.
- The cost for hydrogen from each resource was calculated by applying discounted cash flow (DCF) analysis for each step along the hydrogen pathway from production to dispensing into vehicles.
- A simulation was created to generate a hydrogen production scenario for the continental U.S. based on resource availability, cost, and hydrogen demand.

Accomplishments

- Determined that the generation of 10 quads of H_2 from renewable sources is theoretically feasible in 2030-2050.
- Estimated the average cost of the 10 quads of hydrogen in the continental U.S.
- Issued Draft report for review (February 2003).

Future Directions

- Finalize report based on reviewer comments (expected July-August 2003).

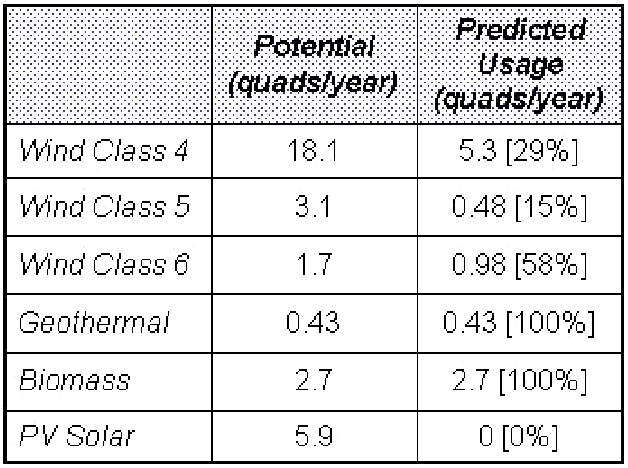
Introduction

This report is the final in a series of studies by Directed Technologies, Inc. of the cost and infrastructure requirements to supply hydrogen for fuel cell vehicles (FCVs). The previous studies have concentrated on the early development of the hydrogen infrastructure to supply a limited number of FCVs. In this study, the focus shifts to future years in which a significant fraction of passenger cars and trucks are FCVs. The goal of the current analysis was to develop a technically feasible pathway to supply 10 quads (one quad = 10^{15} Btu) per year of hydrogen fuel from renewable energy sources for transportation uses in the years 2030 to 2050. [In this report, the lower heating value (LHV) is used when referring to the energy content of a fuel.] The midpoint year 2040 was used for calculations of resource availability and demand that may change over the 20-year period. To put 10 quads of hydrogen energy in perspective, if the passenger vehicles currently on the road were converted to FCVs, 10 quads of hydrogen would be sufficient to fuel all of those vehicles (based on an average 2.2X efficiency gain for FCVs over conventional internal combustion engines).

Approach

We first determined the total potential hydrogen generation from renewable resources in the U.S. in 2030-2050 to ensure that the production of 10 quads of hydrogen is possible. All renewable resources were considered; however, only the resources that could make a contribution of at least 0.1 quads per year were included: biomass, solar, wind, and geothermal. Hydrogen from the biomass resources was assumed to be produced through gasification and steam reforming, and hydrogen from the electricity-generating resources by water electrolysis. (Alternate hydrogen production methods were considered, but the lowest-cost routes to hydrogen were gasification/reforming from biomass and electrolysis from wind, solar, and geothermal electricity.)

The potential hydrogen generation from each of the four resources was determined on a state-by-state basis. The U.S. totals for hydrogen potential in 2040 are listed in Figure 1. The hydrogen potential includes the effect of conversion efficiencies (gasifier or electrolyzer) and line losses in transmission.



	Potential (quads/year)	Predicted Usage (quads/year)
Wind Class 4	18.1	5.3 [29%]
Wind Class 5	3.1	0.48 [15%]
Wind Class 6	1.7	0.98 [58%]
Geothermal	0.43	0.43 [100%]
Biomass	2.7	2.7 [100%]
PV Solar	5.9	0 [0%]

Figure 1. Summary of Hydrogen Availability and Usage for each Resource Predicted by the Model

The hydrogen demand for a given state in the year 2040 was estimated by assuming that the per capita demand for hydrogen would be proportional to the per capita gasoline usage in that state (the per capita gasoline consumption varies considerably from state to state). To calculate the gasoline need for a state in 2040, we multiplied the predicted population by the current per capita gasoline usage, assuming that the relative gasoline use per capita remains the same for each state in the future. The 10 quads of hydrogen was then divided among the states in the same proportion as the projected gasoline consumption.

The cost for hydrogen from each resource was calculated by applying discounted cash flow (DCF) analysis for each step along the hydrogen pathway from production to dispensing into vehicles. The capital costs for equipment were taken from the literature or from projections for future costs for renewable technologies.

A simulation was created to generate a hydrogen production scenario for the continental U.S. based on resource availability and cost. The model strives to simulate an unregulated hydrogen market in which consumers in each state buy hydrogen generated from the least expensive available resource from any other state. In the simulation, hydrogen is purchased in small units (0.0001 quads), with each state purchasing the cheapest available hydrogen in each buying round until all of that state's hydrogen needs are met or the resources are consumed.

Results

The resulting costs of hydrogen at the dispensing site from the various pathways are shown in Figure 2. The hydrogen costs listed on Figure 2 include for comparison purposes the cost for 500 miles of transmission, although the distribution system described below accounts for actual transmission miles.

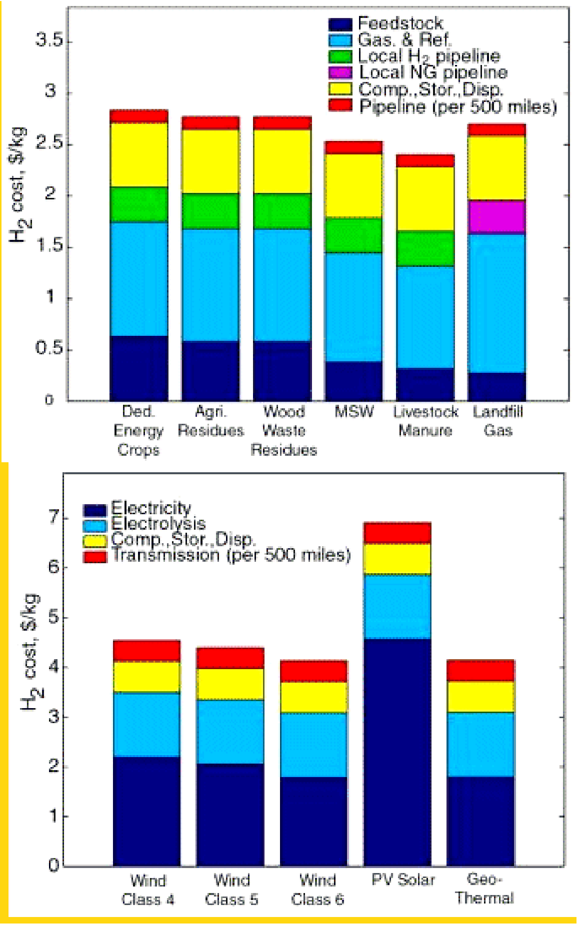


Figure 2. Cost of Hydrogen from Renewable Resources, Including 500 Miles Transmission from Source to Vehicle Dispensing for Reformation Production (top) and Electrolysis (bottom) Methods

Figure 1 shows the simulation results for the annual resource availability and consumption. Consumption of each resource depends both on its availability and on the cost of hydrogen from that resource relative to all other resources. While biomass and geothermal resources represent a small hydrogen potential relative to solar and wind energy, these resources make significant contributions to the national hydrogen demand due to their relatively low cost compared to other renewable resources. Solar energy, however, makes no contribution since it is considerably more costly than the abundant Class 4 wind energy with which it must compete. Of particular note is that 3.34 quads of the 4.8 quads of potential hydrogen from wind classes 5 and 6 goes untapped. Much of this unused wind potential is in the Midwest and Rocky Mountains, where the high transmission cost to the population centers on the coasts prohibits higher-class wind from being cost competitive with Class 4 wind resources at shorter transmission distances.

The distribution of cost of hydrogen in all states is shown in Figure 3, with an average cost of $3.98/kg. Generally, the least expensive hydrogen initially available to all states is from in-state biomass resources, followed by the biomass in neighboring states. Nearly half of all hydrogen from biomass is consumed in-state, with the amount transported out of state (via pipeline) decreasing with increasing inter-state distance. The average inter-state pipeline distance is 259 miles. As states consume their

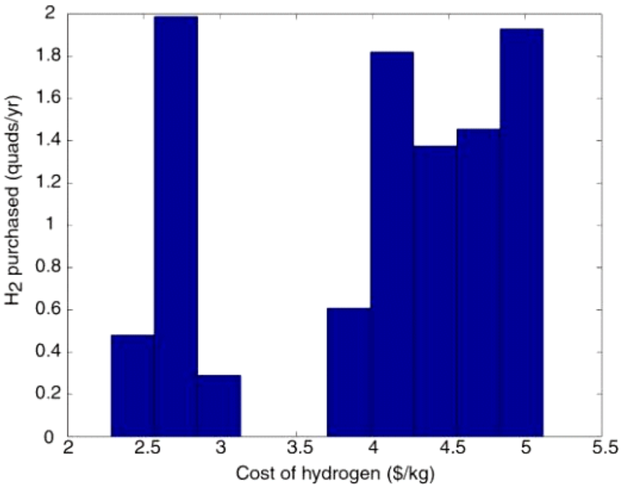


Figure 3. National Hydrogen Cost Histogram (Average is $3.98/kg)

surrounding biomass resources, they are forced to purchase electricity for hydrogen generation, which may be transmitted over longer distances. Only 24% of renewable electricity is used in-state for hydrogen production, and no obvious trend exists for quantity of hydrogen transmitted as a function of transmission distance. The mean distance for renewable electricity transmission is 540 miles. It is interesting to note that no resource is transmitted (via electrical lines or pipelines) more than 1,500 miles, indicating that coastal states reach no further than the middle of the country to meet their hydrogen demand. The resulting state-by-state cost of hydrogen is shown in Figure 4.

Conclusions

The annual generation of 10 quads of hydrogen in the years 2030-2050 from renewable sources for transportation uses in the U.S. is technically achievable and, according to our model, leads to a national average hydrogen cost of $3.98/kg ($33.24/GJ, LHV basis), excluding profits. Wind and biomass are the most significant resources (on an energy supplied basis) for hydrogen production, with geothermal playing a small role due to its limited potential.

Hydrogen from renewable electricity is expensive compared to that from the reformation of biomass for three important reasons. First, most renewable electricity, especially wind and solar, is expensive compared to electricity from fossil fuels due primarily to high capital costs for the wind and solar installations with relatively low capacity factors (all <50%). Secondly, electrolysis incurs large capital expenses and additional inefficiencies. Lastly, transmission of energy as electricity via transmission lines is more costly than hydrogen pipelines.

AL	$3.92	MA	$4.17	OH	$4.30
AR	$3.72	MD	$4.11	OK	$3.36
AZ	$3.49	ME	$2.73	OR	$3.33
CA	$4.09	MI	$4.17	PA	$4.39
CO	$3.51	MN	$3.60	RI	$2.62
CT	$3.25	MO	$3.84	SC	$3.98
DE	$2.60	MS	$3.48	SD	$2.56
FL	$4.72	MT	$2.60	TN	$4.11
GA	$4.49	NC	$4.50	TX	$4.03
IA	$3.11	ND	$2.54	UT	$3.13
ID	$2.73	NE	$2.62	VA	$4.34
IL	$4.16	NH	$2.72	VT	$2.57
IN	$4.01	NJ	$4.45	WA	$3.68
KS	$3.23	NM	$3.08	WI	$3.70
KY	$3.71	NV	$3.03	WV	$2.64
LA	$3.63	NY	$4.52	WY	$2.59

Figure 4. Average Delivered Cost of Hydrogen by State

FY 2003 Publications/Presentations

1. Duane B. Myers at the National Hydrogen Association annual U.S. Hydrogen Conference on March 5, 2003.
2. Duane B. Myers to the DOE H_2 Analysis Working Group on April 23, 2003.