II.E.6 Hour-by-Hour Cost Modeling of Optimized Central Wind-Based Water Electrolysis Production

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Fiscal Year (FY) 2011 Objectives

- Corroborate recent wind electrolysis cost studies using a more detailed hour-by-hour analysis.
- Examine consequences of different system configuration and operation for four scenarios.
- Initiate understanding of sizing implications between electrolyzers and wind farms.
- Identify areas for further analysis and cost reduction.
- Determine the sensitivity of the cost of hydrogen to various inputs, such as turbine cost, electrolyzer efficiency, electrolyzer capital cost, capacity factors, and availability.

Technical Barriers

This project addresses the following technical barriers from the Production section (3.1) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program's Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency
(J) Renewable Electricity Generation Integration

Technical Targets

This analysis shows that using current prices for electricity from Class 4-6 wind resources, the hydrogen cost can approach the DOE 2012 cost per gallon of gasoline equivalent ($/gge) target. (See Table 1 for more details.) Using wind electricity prices collected in the 2000 to 2002 time frame, which are lower than now (2011), a Class 6 wind resource could produce hydrogen at the production plant gate for $3.06/gge. This analysis focused on the production components of hydrogen cost, including, electrolyzer capital, electricity cost, depreciation, and operation and maintenance. Table 1 includes an additional $1.88/kg for compression, storage, and dispensing, the value assumed by an independent review panel on low-temperature electrolysis from which the electrolyzer performance and costs were derived for this analysis [1].

TABLE 1. Progress towards Meeting Technical Targets for Distributed Water Electrolysis Production

Characteristics	Units	2012 Target[1]	2017 Target[1]	Status	Analysis
Hydrogen Cost at Production Gate	$/gge	3.70	<3.00	4.90-5.70[2]	5.70-7.49[3]

[1] 2012 and 2017 target for forecourt hydrogen station includes production and CSD (compression, storage, and delivery)
[2] The current (2009) state-of-the-art cost for delivered hydrogen from electrolysis for a forecourt refueling station ranges from $4.90/kg-H2 to $5.70/kg-H2 dispensed at the pump, with a base-case estimate of $5.20/kg-H2. This base-case estimate of $5.20/kg-H2 includes an electrolysis production cost of $3.32/kg-H2 and compression, storage and dispensing costs of $1.88/kg-H2. These costs are evaluated using Energy Information Administration Annual Energy Outlook (AEO) 2005 High A Case industrial electricity costs ($0.053/kWh on average)[1].
[3] The analysis found production gate values between $3.82-5.61/kg. Additional CSD of $1.88 CSD is included in agreement with the independent review panel [1].

FY 2011 Accomplishments

- Completed initial hourly analysis of central wind electrolysis production facility (50,000 kg/day).
- Determined that Class 4-6 wind sites can produce green hydrogen for between $3.82-$5.61/gge at the production plant gate without additional compression, storage, or dispensing.
- Presented results at the Fuel Cell Hydrogen Energy Association (FCHEA) conference, Feb. 14–16, 2011, Washington, D.C.
- Technical paper.
- Saur, G. and T. Ramsden, *Wind Electrolysis–Hydrogen Cost Optimization*. NREL/TP-5600-50408. Golden, CO: NREL 2011.

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Introduction

This project is a analytical component of the "Renewable Electrolysis Integrated System Development and Testing" and is aimed at understanding the barriers and costs associated with large-scale (50,000 kg/day) wind-based hydrogen generation plants. Such plants can take electrical energy from the wind or from the grid and use it to split water molecules into hydrogen and oxygen molecules. The hydrogen can then be used for a variety of purposes, including vehicle fuel, fertilizer feedstocks, petroleum upgrading, metal processing, and other industrial processes. The hydrogen can also be stored, converted back to electricity, and sold to an electric utility for the grid.

Approach

The approach used in this analysis was to review a range of wind sites from Class 1 to 6 for their ability to produce hydrogen economically by electrolysis. An hourly model was created by modifying the DOE H2A Production model version 2.1 to work in conjunction with an hourly analysis. The wind sites were modeled using 8,760 hr/yr data calculated from profiles in Western Wind Data Sets [2] and 3 MW turbine performance profiles adapted from the WindPACT Turbine Rotor Design Study [3]. Wind farms were created as a number of 3 MW wind turbines. Wind turbine costs came from the 2008 Wind Market Report [4]. The electrolyzer performance and cost was modeled consistently with an independent review panel on high volume production costs of the current state-of-the-art low-temperature electrolyzers [1]. Further, each site was analyzed under four different scenarios run hourly over a year.

A. Cost balanced: $ grid purchased electricity = $ wind electricity sold.
B. Power balanced: kilowatt-hour (kWh) grid purchased electricity = kWh wind electricity sold.
C. Same as A, but no purchase of summer peak electricity.
D. Same as B, but no purchase of summer peak electricity.

In addition to these scenarios, sensitivities to various inputs were analyzed, including wind turbine capital cost, wind electricity costs, electrolyzer efficiency, electrolyzer capital cost, capacity factor, and availability.

Results

This analysis found that in power balanced scenarios, the cost of hydrogen at the production plant gate can range from nearly $12/gge down to $3/gge, depending on the class of the wind site. It is only in wind sites of Class 4 or better that such a plant begins to approach DOE technical targets. This analysis looked at electricity prices in the California market. Electricity process will have an influence on the quality of the wind resource required.

An example of the range of costs for all the wind sites analyzed can be seen in Figure 1 which shows a power-balanced scenario where no summer peak electricity was bought from the grid. In this scenario the wind electricity sold to the grid was balanced with the grid electricity bought on a per megawatt basis per year. The electrolyzer was run at peak capacity except during summer peak hours in which it was run separate from any wind electricity

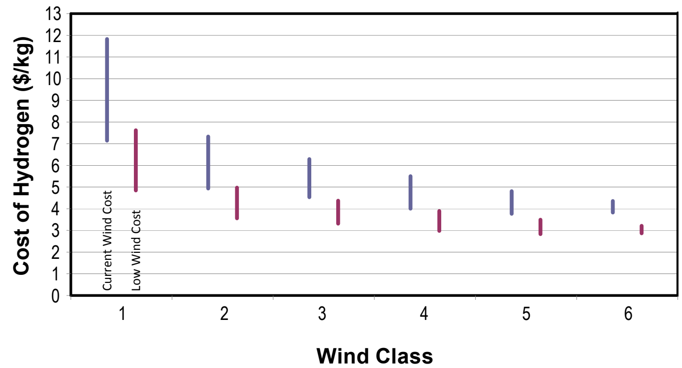

FIGURE 1. Power Balanced Scenario – Range of Costs at the Production Plant Gate

available. A ramification of this scenario was that slightly less than 50,000 kg/day of hydrogen was produced during the summer, but the cost of hydrogen at the production plant gate was also slightly less (~$0.10/kg) than it would be if expensive summer peak grid electricity was purchased. Figure 1 shows the range of costs for the power-balanced, no-summer-peak scenario across the different wind class sites analyzed.

In places with low-cost electricity (no production tax credit included), <$0.10/kWh, hydrogen can be produced for approximately $3.79-$5.90/gge at the production plant gate with no additional compression, storage, or dispensing. This was true of both power and cost-balanced scenarios. Scenarios with no-summer-peak electricity buy resulted in lower hydrogen costs but could also result in unmet hydrogen demand. The difference in the cost of hydrogen at the production plant gate between buying summer peak electricity and not buying was more pronounced in the cost-balanced scenarios, but resulted in <$0.10/kg for all of the power-balanced and between about $0.50-$0.10/kg for the cost-balanced scenarios depending on the quality of the wind profile. See Figure 2 for more details.

In order to produce 50,000 kg of hydrogen per day, the required installed wind capacity varies greatly with the wind class, and thus with the cost of wind electricity. It can be as low as 200 megawatt (MW) (Class 6), and as much as 850 MW (Class 1) (see Figure 3).

In the sensitivity analysis, the largest component changes in hydrogen cost were caused by wind turbine capital cost, followed by electrolyzer efficiency (see Figure 4).

In summary, at the production plant gate the largest hurdles to hydrogen cost from water electrolysis remain wind turbine capital cost and electrolyzer efficiency. Figure 4 shows the sensitivity of costs for a particular Class 5 wind site using the power-balanced, no-summer-peak scenario described previously. Table 2 shows the base case assumptions for the different variables with the high and low values used to calculate the cost of hydrogen at the production plant gate. As seen in Figure 4, a 20% reduction in wind turbine capital will reduce hydrogen costs by

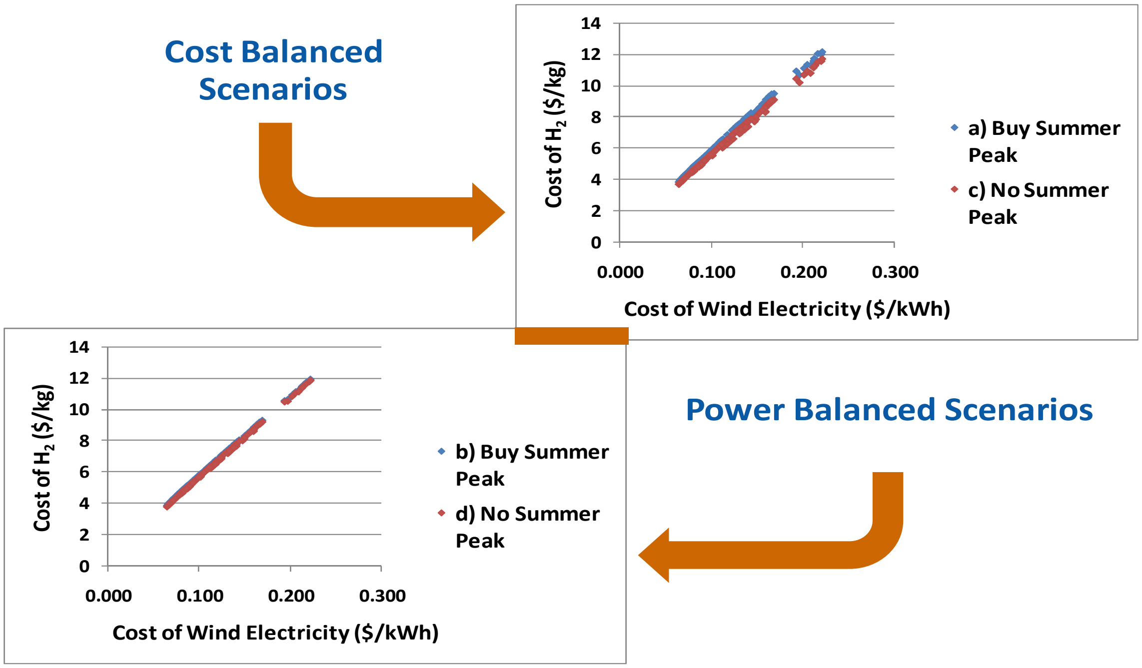

FIGURE 2. The Effect of Wind Electricity on the Cost of Hydrogen at the Production Plant Gate for Two Scenarios

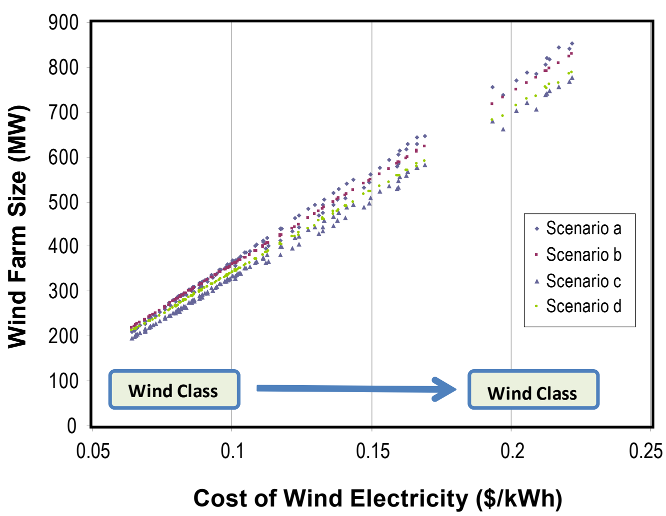

FIGURE 3. The Effect of Wind Electricity on the Installed Capacity of a Wind Farm Capable of Producing 50,000 kg/day of Hydrogen

$0.58/gge, or 15%. Similarly, dropping electrolyzer-specific energy use from 50 to 47.5 kWh/kg can remove another $0.13/gge from the hydrogen cost. Other sites and scenarios exhibited very similar ranges in the cost of hydrogen at the production plant gate for these sensitivity values.

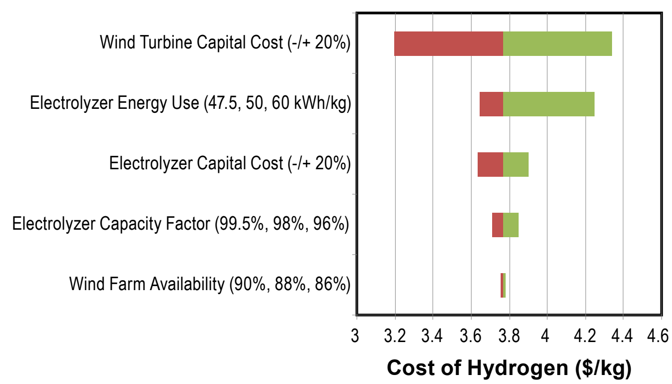

FIGURE 4. EHydrogen Cost at the Production Plant Gate - Example Sensitivity for a Power-Balanced Case, No-Summer-Peak Scenario, Wind Class 5

TABLE 2. Base Case and Sensitivities for a Power-Balanced, No-Summer-Peak Class 5 Wind Site, Cost of Hydrogen at the Production Plant Gate

Variable Name	Base Case Value	Low Value	High Value
Wind Turbine Capital Cost ($/kW)	1,964	1,571	2,356
Electrolyzer Energy Use (kWh/kg)	50	47.5	60
Electrolyzer Capital Cost ($/kW)	384	307	461
Wind Farm Availability (%)	88	90	86
Electrolyzer Capacity Factor (%)	98	99.5	96

Conclusions and Future Direction

Given the large influence of electricity pricing on this type of system, future work will analyze areas of the country with high electricity prices and good wind resources (Hawai'i and New England, for instance).

In addition to different geographical regions, the analysis will be deepened to look at solar integration and possibly smaller generation stations supporting the emerging vehicle and material handling fleet vehicle markets. Future analysis will include:

- More sensitivities to various inputs possibly including grid pricing, wind farm size, and production tax credit.
- Use of curtailed wind.
- Regionally expanded grid pricing structures.
- Examination of solar integration.
- Other optimal electricity/hydrogen production balance scenarios.

FY 2011 Publications/Presentations

1. Saur, G. and T. Ramsden, *Wind Electrolysis – Hydrogen Cost Optimization*, presented at FCHEA conference, Feb. 14–16, 2011, Washington, D.C.

2. Saur, G., Ramsden, T., Harrison, K., and Ainscough, C., *Hour-by-Hour Cost Modeling of Optimized Central Wind-Based Water Electrolysis Production*, presented at DOE Annual Merit Review, May 9–13, 2011, Washington, D.C.

3. Saur, G. and T. Ramsden, *Wind Electrolysis–Hydrogen Cost Optimization*. NREL/TP-5600-50408. Golden, CO: National Renewable Energy Laboratory, 2011.

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1. Genovese, J., et al. Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis: Independent Review. NREL/BK-6A1-46676. Golden, CO: NREL, 2009.

2. NREL: Wind Integration Datasets - Western Wind Dataset. [cited 2010 July 15]; Available from: http://www.nrel.gov/wind/integrationdatasets/western/methodology.html.

3. Malcolm, D.J.; Hansen, A.C. WindPACT Turbine Rotor Design Study, June 2000–June 2002 (Revised). NREL/SR-500-32495. Golden, CO: NREL, 2006.

4. Wiser, R.H., et al. 2008 Wind Technologies Report. LBNL-2261E. Berkeley, CA:LBNL, 2009.