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Wind Energy and Production of Hydrogen and Electricity — Opportunities for Renewable Hydrogen

Preprint

J. Levene, B. Kroposki, and G. Sverdrup

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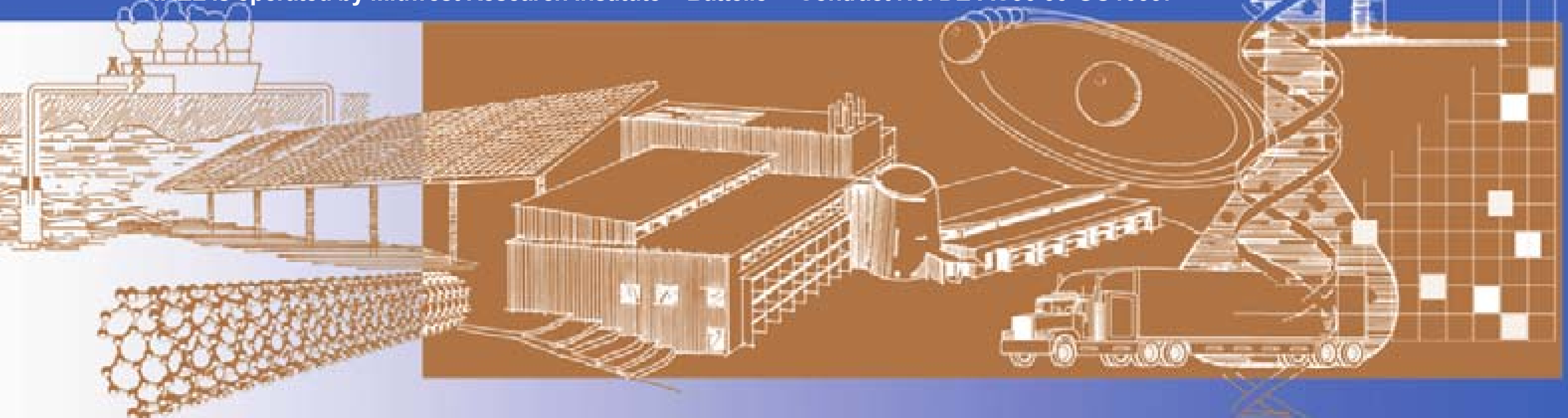

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Executive Summary

Hydrogen can be produced from a variety of domestic, renewable sources of energy. An assessment of options for wind/hydrogen/electricity systems at both central and distributed scales provides insight into opportunities for renewable hydrogen as well as research priorities for this hydrogen production pathway.

The analysis of the central production of hydrogen from wind was conducted. This technology involves hydrogen production at the wind site with hydrogen delivered to the point of use. The results of this study are that hydrogen can be produced at the wind site for prices ranging from $5.55/kg in the near term to $2.27/kg in the long term. A research opportunity in this scenario is the elimination of redundant controls and power electronics in a combined turbine/electrolysis system.

A second analysis was completed in which wind power was used in a distributed fashion for hydrogen production. The wind farm provides a signal to a remotely located electrolyzer, which allows the electrolyzer to run only when the wind is blowing. An advantage of this scenario is that signals from many different wind farms could be used, which would increase the capacity factor and thus decrease the cost of the hydrogen production system. The results of this second study are that hydrogen can be produced at the point of use for prices ranging from $4.03/kg in the near term to $2.33/kg in the long term. This novel approach results in low production costs and could minimize delivery costs if the electrolyzer was located at the filling station.

Both analyses reveal that in order to optimize the production of hydrogen from wind, the electricity and hydrogen production needs to be examined as an integrated system. Researchers at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) are working to build renewable hydrogen from wind into a viable production method for transportation fuel in the future.

Background and Purpose of the Study

In early 2005, Xcel Energy approached NREL to conduct a study to determine if hydrogen could be economically produced via wind power for transportation fuel use. NREL had done such studies in the past, but the ability to partner with a utility and to use Xcel Energy's expertise of the electricity sector provided a unique opportunity for analysis. Two cases were studied; one where hydrogen was produced at the wind site, and delivered to the point of use, and a second novel approach where hydrogen was produced at the point of use using wind energy transported through the electric grid from several wind farms. In both studies low temperature electrolysis units were used to convert the wind energy to hydrogen.

Electrolysis is the production of hydrogen from water. An electric current is passed through an anode and a cathode in contact with water. The net reaction which occurs is:

$$2H_2O_{\text{liquid}} + \text{electricity} \rightarrow 2H_2 + O_2$$

This reaction requires 39 kWh of electricity to produce 1 kilogram of hydrogen at 25 degrees C, and 1 atmosphere. When efficiencies of electrolysis systems are stated in this study they are calculated by dividing the energy used by the system into 39 kWh/kg.

All hydrogen cost results in this report are shown in terms of dollars per kilogram ($/kg) of hydrogen. A kilogram of hydrogen is used as the base unit because a kilogram of hydrogen has roughly the same energy content as a gallon of gasoline. On a lower heating value basis, hydrogen contains approximately 116 MMBTU/kg, while gasoline contains 108 to 124 MMBTU/gallon. Therefore, if used in engines with the same efficiency, a kilogram of hydrogen would allow a vehicle to travel the same distance as a gallon of gasoline.

HOMER® Model

For this study the HOMER® model (hereinafter "Model") was used for the system optimization and hydrogen price calculation. The Model was developed at NREL to allow users to optimize electric systems and ease the evaluation of the many possible configurations that exist with such systems.[1] For example, when designing an electric system to meet a 30 kW load for an hour every day, the Model can answer questions such as: should the system have enough turbines so that hour always has 30 kW, or should battery storage be added, or a diesel engine, and which option costs less? The ability to model hydrogen was added to the Model in 2004, and further enhanced in 2005 for use in this study.

One of the advantages of using the HOMER® model is its ability to conduct analysis on an hourly basis. For this study, system components, available energy resources, and loads are modeled hour by hour for a single year. Energy flows and costs are constant over a given hour. This type of model is ideal for showing intermittent renewable electricity producing hydrogen for fluctuating hydrogen demands.

The Model requires inputs such as technology options, component costs, and resource availability. The Model uses these inputs to simulate different system configurations, and generates a list of feasible configurations sorted by net present cost (NPC). NPC can also be referred to as lifecycle cost and is the present cost of installing and operating the system over the lifetime of the project. Model results include a COE (cost of energy) or COH (cost of hydrogen) for each feasible configuration. [2] The configuration with the lowest COE or COH is determined to be the most economic solution.

The Model calculates the levelized COH with the following equation

$$COH = \frac{C_{ann,tot} - v_{elec}\left(E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}\right)}{M_{hydrogen}}$$

- $\mathbf{C_{ann,tot}}$ is the total annualized cost [$/yr],
- $\mathbf{M_{hydrogen}}$ is the annual hydrogen production [kg/yr]

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[1] HOMER® model, www.nrel.gov/homer/, National Renewable Energy Laboratory.
[2] Lambert, Tom. *Levelized Cost of Energy,* HOMER® help file. www.nrel.gov/homer/, National Renewable Energy Laboratory. October 27, 2004.

- v_{elec} is the value of electricity [$/kWh]
- The E values in parentheses are the total annual useful electrical production [kWh/yr]

The Model calculates the annual electricity value by multiplying the value of the electricity produced by the annual electrical production. The final COH is calculated by dividing the difference of the total annualized cost and the annual electricity value by the annual hydrogen production, resulting in the $/kg of hydrogen produced during the year. If no electricity is produced by the system, the E terms in the parentheses will be zero, and the cost of hydrogen is simply the annualized cost divided by the annual hydrogen production.

Cases

For this study, two cases were considered. The first has been previously studied by NREL[3] and considers the production of hydrogen at the wind farm. However, new assumptions were made and more specific data were used in this study as a result of the Xcel Energy/NREL partnership. This scenario is of interest to NREL and Xcel Energy because of the research and potential cost savings opportunities. For example, cost savings could be realized by combining power electronics of wind and electrolysis systems or by including storage of hydrogen in the wind turbine towers.[4] Both activities are being investigated at NREL.

In Case 1, two sites were considered. One site was near the University of Minnesota West Central Research and Outreach Center (WCROC) Site in Morris, MN. The WCROC site was chosen as the university is in the process of beginning wind hydrogen research and is partnering with NREL and Xcel Energy. This site has an average wind speed of 7.41 m/s. The second site was located in Gobbler's Knob, near Lamar, Colorado. The Gobbler's Knob site was chosen because there is currently a wind farm located there from which Xcel Energy buys wind energy. This site has an average wind speed of 8.50 m/s. A diagram of Case 1 is shown in Figure 1.

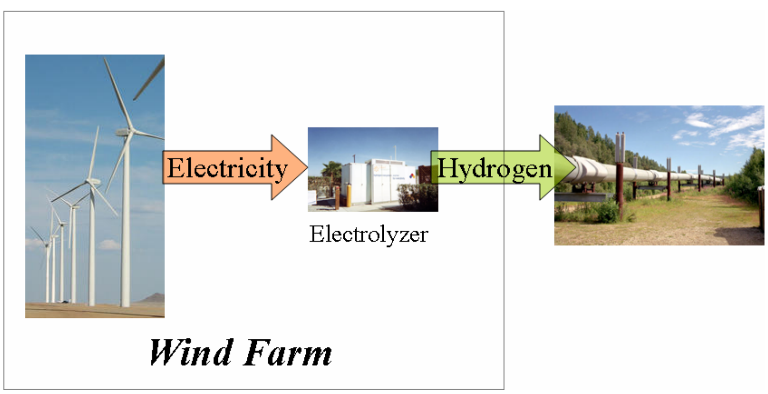

Figure 1: Case 1 – Hydrogen Produced at a Wind Farm

The second case studied was the production of hydrogen at the point of use using wind generated electricity from three large Colorado wind farms from which Xcel Energy buys wind energy:

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[3] *Production Case Studies.* www.hydrogen.energy.gov/h2a_prod_studies.html and Levene, J. *An Economic Analysis of Hydrogen Production from Wind*. WINDPOWER 2005, American Wind Energy Association, 2005.

[4] Kottenstette, R and Cotrell, J. *Hydrogen Storage in Wind Turbine Towers: Cost Analysis and Conceptual Design*. NREL/CP-500-34851. September 2003. Golden, CO: National Renewable Energy Laboratory; 10 pp.

Lamar, Peetz Table, and Ponnequin. A diagram of Case 2 is shown in Figure 2. In Case 2 it was assumed that a signal could be sent from all three wind farms to remote electrolysis sites. This signal would indicate to the electrolyzer when wind energy was being produced by any of the three wind farms. If wind energy was being produced, the electrolyzer would be allowed to produce hydrogen, with certain constraints. If wind energy wasn't being produced at any of the three wind sites, hydrogen wouldn't be produced. If only a small amount of wind energy were produced, then only a small amount of hydrogen would be produced. This novel approach to analyzing a wind hydrogen system was only possible due to the partnership with Xcel Energy as detailed data were needed with regards to the wind energy production and electricity demand on their system.

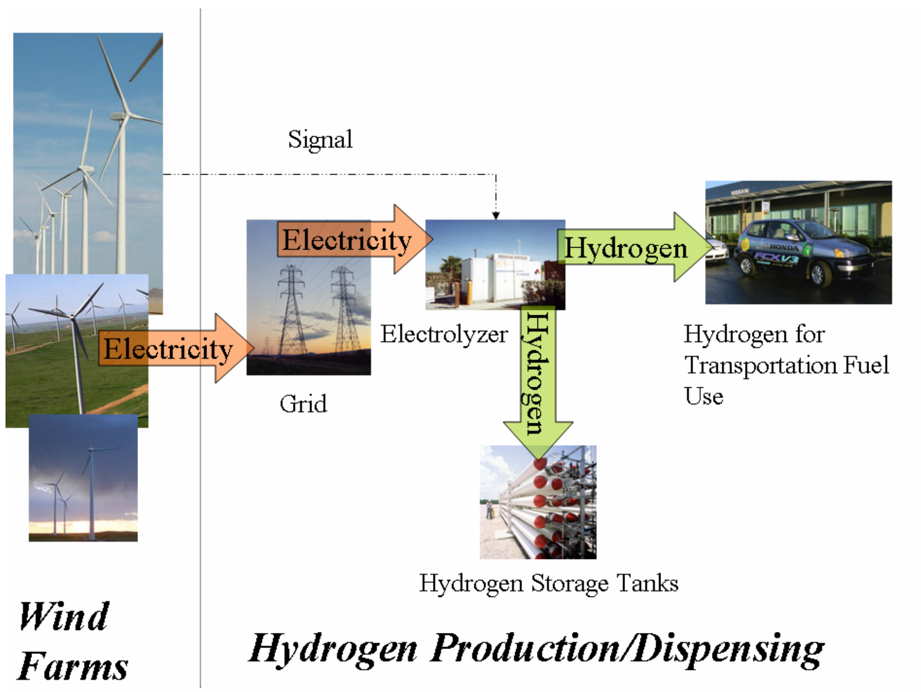

Figure 2: Case 2 – Aggregate Wind Producing Hydrogen at Point of Use

For both Cases the costs of the system were analyzed in the near term, mid term, and long term. The costs and efficiencies of the equipment change over the timeframes, and are detailed in the assumptions sections. The timeframes used are defined as follows:

- Near term = today until 2010
- Mid term = 2010 – 2020
- Long term = 2020 – 2030 or best scenario in the future

Assumptions

For this study, Xcel Energy and NREL worked closely to ensure that the values used in the study were consistent with Xcel Energy's method of doing business. As a result, some key common assumptions were used for both cases. Detailed assumptions for both cases can be seen in Appendix A.

Key Common Assumptions

Parameter	Assumption
Peak electricity	• Peak electricity usage is from 4-7 p.m. on weekdays, so no hydrogen can be produced during those three hours • There are no peak hours during the weekend, so electrolyzer can run 24 hours a day.
System pressure	• Hydrogen is compressed after production to 6500 psi • Storage is provided at 6500 psi
Wind turbine capital and operating costs	• Turbine costs are not specifically used in analyses, rather the cost of wind generated electricity is used – Assumes this cost includes capital, replacement and operating costs of the wind turbines • Xcel Energy purchases wind generated electricity at a rate of $0.038/kWh
Electrolyzer	• Costs are assumed to be $740/kW, $400/kW, and $300/kW in near, mid, and long term • Uses AC power
Compressor costs	• $600,000, $300,000 and $100,000 for a 1500 kg compressor in near, mid, and long term
Annual Real Interest Rate	• Discount rate used to convert between one-time costs and annualized costs[5] • Study uses 10%
Hydrogen dispensing	• No hydrogen dispensing costs included

In addition to the common assumptions, each case has some unique aspects. The key assumptions for Case 1 are:

Case 1 Key Assumptions

- The model used a hydrogen load of 1000 kg/day, but allowed for 100% of that load to not be met. The result of this assumption in the model is that the amount of hydrogen produced is fluctuated until the minimum COH for the system is found. A minimum electrolyzer size of 100kW was included to ensure that the system would not eliminate the hydrogen production unit all together.
- No hydrogen delivery costs are included, because the hydrogen is produced at the wind site, and the Model does not have the ability to include hydrogen delivery at this time.

For Case 1, the system components included in the Model can be seen in Figure 3, and includes a Vestas V82 turbine, the WCROC or Gobbler's Knob wind resource, an electrolyzer, hydrogen storage, a variable hydrogen load, and the grid. The Vestas V82 turbine was selected as it is the turbine currently located at the WCROC site. The grid is

[5] Lambert, Tom. *Interest Rate,* HOMER® help file. www.nrel.gov/homer/, National Renewable Energy Laboratory. May 6, 2004.

included so electricity produced during the peak hours of 4-7 p.m. can be sold at a rate of $0.066/kWh, which is consistent with Xcel Energy's peak rates for selling electricity.

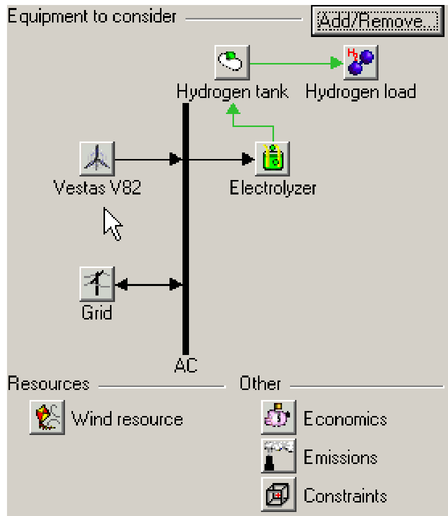

Figure 3: System Components for Case 1 in the Model

While Case 1 optimizes a single wind resource and allows hydrogen production to fluctuate to minimize hydrogen cost, Case 2 has some different constraints due to the aggregate wind source and the point of use hydrogen production unit.

Case 2 Key Assumptions

- This Case assumes all energy from Lamar, Peetz, and Ponnequin wind farms in Colorado is available for hydrogen production.
- The hydrogen production system is located at the demand site, rather than at the wind site, so hydrogen prices calculated include delivery, but not dispensing.
- The hydrogen demand is that of a 1500 kg/day filling station, and no unmet hydrogen load is allowed. The profile of this hydrogen demand can be seen in Figure 4.

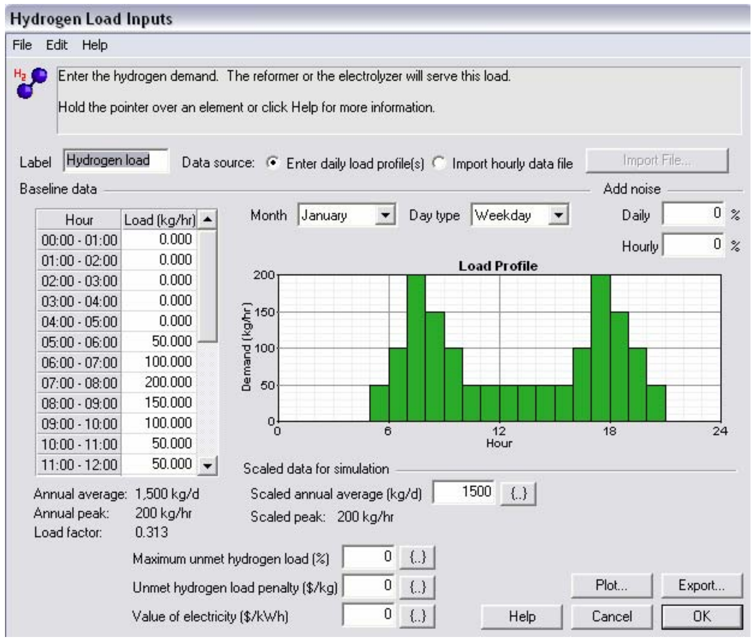

Figure 4: Case 2 hydrogen demand profile

The load profile shows that hydrogen demand at a filling station is assumed to be highest during normal commute hours, from 8 and 9 a.m. and from 5 to 6 p.m. Hydrogen demand is assumed to be negligible late at night and in the early hours of the morning. Note that the "maximum unmet hydrogen load (%)" value for this case is 0%, meaning that fueling stations must meet the demand every hour out of the year, either through hydrogen production or hydrogen storage.

For Case 2, the system components include an aggregate wind resource, an electrolyzer, hydrogen storage, a fixed 1500 kg/day hydrogen load, and the grid so electricity can be obtained from the wind farms. See Figure 5 for the system component diagram from the Model.

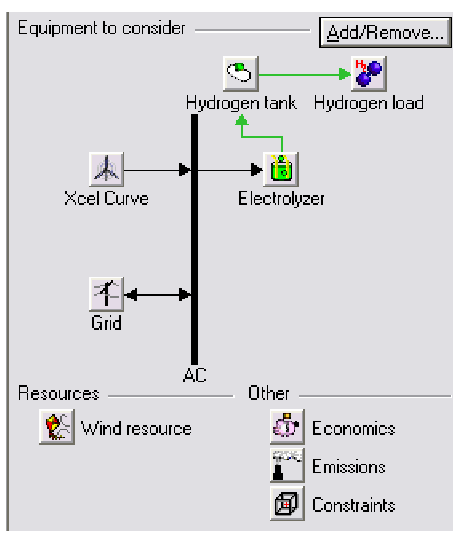

Figure 5: System Components for Case 2 in the Model

Results

The purpose of this study was to determine if hydrogen can be produced economically from wind generated electricity. The Department of Energy Hydrogen, Fuel Cells and Infrastructure Technologies (DOE HFC&IT) program goal for delivered hydrogen in 2015 at the filling station is $2-3/kg,[6] and the program goal for delivery and dispensing is $1/kg for delivery.[7] This means that for Case 1, hydrogen needs to be produced for $1-$2/kg as the delivery cost is not included in this study. For Case 2, the hydrogen can be produced for roughly $2-3/kg, as the hydrogen can be produced at the point of use, eliminating the need for delivery.

The results from Case 1 demonstrate that hydrogen can be produced at the wind site for prices ranging from $5.55/kg in the near term to $2.27/kg in the long term. Figure 6 shows the hydrogen prices for the WCROC and Gobbler's Knob sites in the near, mid, and long term.

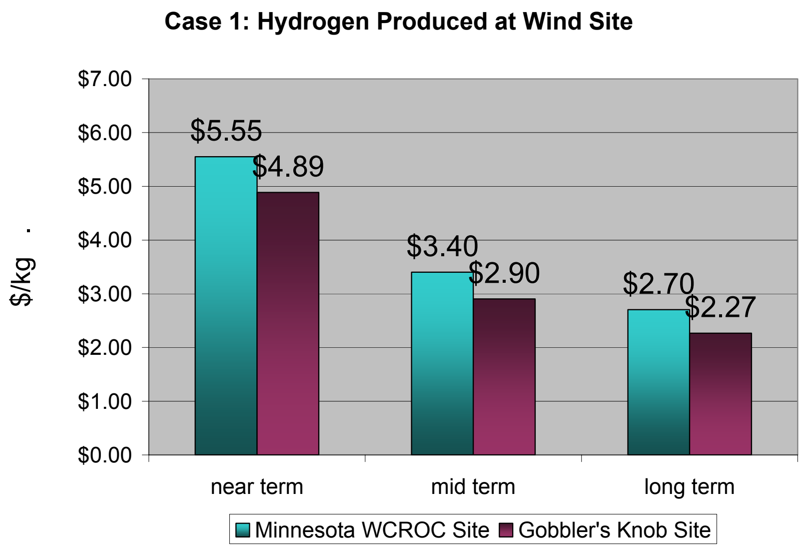

Figure 6: Case 1 Results

These results illustrate that using wind to produce hydrogen from Gobbler's Knob results in a 12 – 16% hydrogen price reduction over hydrogen produced at the WCROC site. This is partially because the average annual wind speed at the WCROC site is 7.41 m/s, while the average annual wind speed at the Gobbler's Knob site is 8.50 m/s. The study shows that higher average annual wind speeds can lead to lower hydrogen prices.

The results also illustrate that as the long term prices for wind-produced hydrogen are $2.70 - $2.27/kg, so the resulting lowest delivered hydrogen prices from these systems are $3.70 - $3.27/kg including the $1/kg delivery goal. These costs are slightly higher then the overall DOE cost targets. As a result, this Case appears to only be economic for a small scale niche market with good wind or subsidies that help to drive the cost below $3/kg. However, because Case 1 does not take into account any potential cost savings of an optimized wind/hydrogen/electricity

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[6] *DOE Announces New Hydrogen Cost Goal*, July 14, 2005, www.eere.energy.gov/hydrogenandfuelcells/news_cost_goal.html.
[7] *Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan*, February 2005, www.eere.energy.gov/hydrogenandfuelcells/mypp, p. 3-45.

system, NREL and Xcel Energy see this as a potential research area. If costs of the system can be reduced \$0.27 - \$0.70/kg wind hydrogen may be produced and delivered for less than the DOE cost target.

The results from Case 2 in Figure 7 show hydrogen can be produced using aggregate wind at the point of use for prices ranging from \$4.03/kg in the near term to \$2.33/kg in the long term, assuming wind energy is available at the point of use for \$0.038/kWh. These prices include delivery, as the hydrogen is produced at the demand center, but do not include dispensing. Assuming dispensing is a small portion of the DOE delivery target, it is likely that hydrogen can be produced for the DOE HFC&IT cost target of \$2 - \$3/kg delivered.

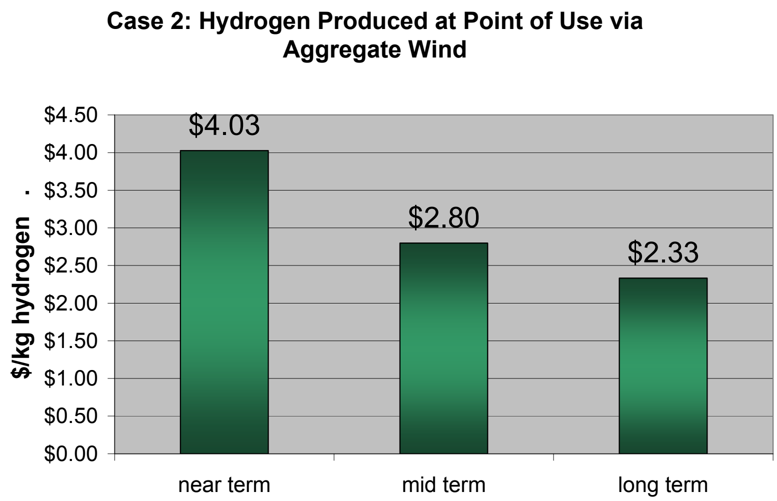

Figure 7: Case 2 Results

Comparing Case 2 to Case 1 results for Gobbler's Knob, Figure 8, shows that in the near and mid term, hydrogen can be produced at the point of use for less then the cost of producing hydrogen at the wind farm. One reason for this is that the capacity factors of the electrolyzers are higher in Case 2 then in Case 1 because the aggregate wind signal helps even out the peaks and valleys of the intermittent wind energy. For example, in the near term, the capacity factor for the electrolyzer is 81% in Case 1 and 90% in Case 2. This increased capacity factor has a higher effect on hydrogen price in the near and mid term, as the capital costs are higher. In the long term, the production cost of hydrogen from Case 2 is slightly higher than at the Gobbler's Knob site. However, as stated earlier, the hydrogen prices from Case 2 include the delivery of hydrogen, and the hydrogen prices from Case 1 do not, so the Case 2 results actually result in a lower delivered price of hydrogen.

These results appear to show that producing hydrogen from aggregate wind at the point of use appears to be the most economic option. However, if research of the system in Case 1 can lead to cost reductions that offset the delivery costs, this study shows that hydrogen production at the wind site can makes fiscal sense.

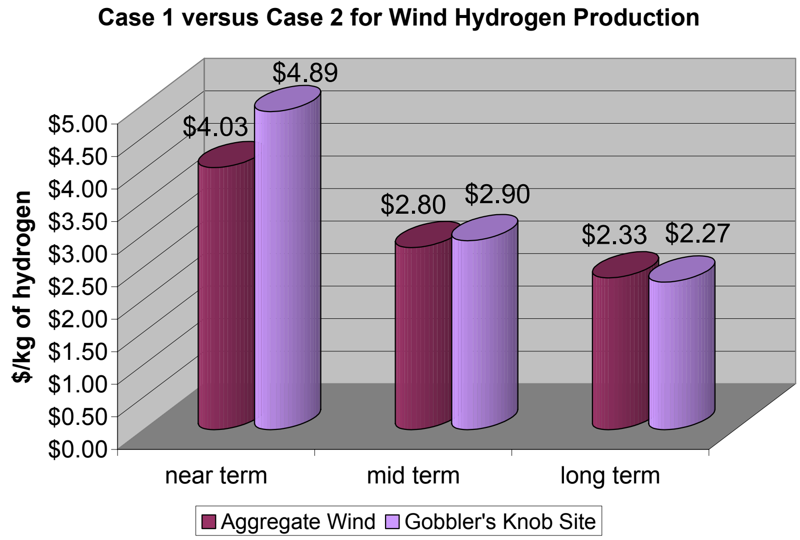

Figure 8: Comparison of Case 1 and 2

Research at NREL

NREL is investigating opportunities for reducing hydrogen costs through component optimization for integrated hydrogen-electricity production applications. Most electrolyzers commercially available today are designed for grid-connected operation and, therefore, incorporate power electronics to convert alternating current (AC) from the grid to direct current (DC) power required by the cell stack. These power converters can represent 25%-30% of the total cost of the electrolyzer. Power converters are also required for renewable energy sources. For example, when using wind energy, variable speed wind turbines rely on power electronics to convert the variable frequency, variable voltage AC power produced at the generator to DC. This is then converted back to AC at grid frequency and voltage to connect to the grid. Photovoltaic (PV) systems also have DC-DC converters and DC-AC inverters. These wind and solar power converters can be a significant percentage of the renewable energy system cost. Designing integrated power electronics packages and optimizing the sizing and integration of components are opportunities for improving the efficiency, cost, and robustness of these systems.

As part of this work, NREL is developing standardized test protocols that can be used to evaluate electrolyzer performance when connected to renewable energy systems. The protocols will be based on actual testing with renewable energy systems. Specific performance measures may include short and long-term effects of intermittent operation on the efficiency and purity of hydrogen, and how the electrolyzers perform at low input power levels. NREL is working with electrolyzer manufacturers to test the performance of their systems under these protocols. The long-term goal of this activity is to develop a consensus-based testing protocol with industry on electrolyzer performance.

NREL currently has the ability to test electrolyzers connected to either PV systems or wind turbines up to 75kW. This year, NREL is expanding its testing capability and infrastructure is being added that will allow testing of electrolyzers up to 1MW in size. With both renewable energy systems and electrolyzers, there is an economy of scale in terms of cost; larger systems as less expensive on a $/kW basis. As these types of systems are deployed, the larger MW class systems will be most cost effective. Being able to test these size systems is extremely important to the hydrogen economy.

NREL is also working through a cost-shared cooperative research and development agreement with Xcel Energy. In the Wind2H2 Project, NREL and Xcel Energy are examining the system integration issues with wind-hydrogen production, compression, storage, and use. The project will integrate wind turbines directly to electrolyzers testing both AC and DC connections. The hydrogen will then be compressed and stored for use in a hydrogen internal combustion engine.

Conclusion

Hydrogen produced from wind electricity appears to have potential to meet the DOE HFC&IT program goals. If aggregate wind electricity is available at the filling station for \$0.038/kWh, it is possible for production, compression, and storage to cost below the target of \$2-3/kg delivered hydrogen. Hydrogen production at the wind site makes fiscal sense if cost reductions offset delivery cost, and cost reductions need to be between \$0.27 and \$0.70/kilogram to meet the DOE HFC&IT cost targets. Researchers at NREL are working to determine if optimized hydrogen/electricity production applications can help improve the efficiency and costs of renewable hydrogen productions systems.

Acknowledgements

The authors would like to thank Frank Novachek and Vicki McCarl of Xcel Energy for their invaluable assistance and support during this analysis effort.

Appendix A – Detailed Assumptions

Common Assumptions

Common Assumptions	Parameter	Near Term Assumption	Mid Term Assumption	Long Term Assumption	Notes
Wind Turbine	Capital Cost	$0	$0	$0	Not included in analysis. Assume cost is included in purchased electricity rate from turbine at $38/MWh
	Replacement Cost	$0	$0	$0	Not included in analysis. Assume cost is included in electricity rate.
	O&M	$0	$0	$0	Not included in analysis. Assume cost is included in electricity rate.
	Lifetime	Rotor will need to be replaced after 20 years at 15-20% of initial investment	Rotor will need to be replaced after 20 years at 15-20% of initial investment	Rotor will need to be replaced after 20 years at 15-20% of initial investment	Not included in analysis. Assume cost is included in electricity rate.
Electrolyzer	Size	1000 kg/day	1000 kg/day	1000 kg/day	
	Capital Cost, electrolyzer	$2,302,000	$1,220,000	$790,000	includes electrolyzer at $740/kW, $400/kW, and $300/kW [8]
	Replacement Cost	$1,110,600	$576,000	$307,000	Every 10 years replace the cell stack on electrolyzer at 30% of cost from H2A[9] and 100% of the compressor.
	O&M	$115,100	$61,000	$39,500	5% of capital investment, does not include electricity
	Sizes to consider	100 kW - 6900 kW	100 kW - 6900 kW	100 kW - 6900 kW	A wide range of sizes is considered, so the Model simulation can optimize the electrolyzer size
	Lifetime	10 years	10 years	10 years	

[8] *Production Case Studies.* www.hydrogen.energy.gov/h2a_prod_studies.html
[9] Ibid.

Electrolyzer (cont.)	Efficiency	70%	78%	83%	53.4, 47.9, and 44.7 kWh/kg for electrolyzer. Includes 2.09 kWh/kg for compression.[10] Efficiencies based on HHV of hydrogen of 39 kWh/kg
	Compressor Cost	$600,000	$300,000	$100,000	Cost for a 1500 kg/day compressor from DOE delivery contacts
	Compressor Energy Requirement	2.09 kWh/kg	2.09 kWh/kg	2.09 kWh/kg	From H2A forecourt scenarios[11]
Hydrogen Tank	Size	85 kg	85 kg	85 kg	
	Capital Cost	$93,000	$40,000	$26,000	From EPC quote and H2A forecourt assumptions[12]
	Replacement Cost	$93,000	$40,000	$26,000	Assume entire tank needs replacement
	O&M	$4,650	$2,000	$1,300	5% of capital investment, does not include electricity
	Lifetime	20 years	20 years	20 years	Based on "Compressed Gas H2 Storage Tubes" from H2A Delivery.[13]
Other Costs	Electricity Cost (purchase)	$38/MWh	$38/MWh	$38/MWh	Electricity is only purchased for hydrogen being produced. Purchasing power from a wind farm.
	Electricity Cost (sell)	$66/MWh	$66/MWh	$66/MWh	
	Annual Real Interest Rate	10%	10%	10%	Discount rate used to convert between one-time costs and annualized costs.

[10] *Production Case Studies.* www.hydrogen.energy.gov/h2a_prod_studies.html
[11] Ibid.
[12] Ibid.
[13] *Production Case Studies.* www.hydrogen.energy.gov/h2a_delivery.html

Case 1 Assumptions

Case 1	Parameter	Near Term Assumption	Mid Term Assumption	Long Term Assumption	Notes
Wind Turbine	Power Curve				Using University of Minnesota Vestas V82 1.65MW Turbine. Purchase electricity used from turbine at $38/MWh
	Hub Height	70	70	70	From University of Minnesota
Wind Resource	Resource	University of Minnesota	University of Minnesota	University of Minnesota	University of Minnesota monthly average wind speeds. Sensitivity was run using Gobbler's Knob data.
	Altitude	1090	1090	1090	1090 feet from NREL GIS group
	Surface Roughness	0.01	0.01	0.01	
Hydrogen Load	Hourly load profile	42 kg/hour	42 kg/hour	42 kg/hour	Use max hydrogen load from a 1000 kg/day system. No hydrogen load from 4-7 p.m. on weekdays
	Unmet Hydrogen Load	100%	100%	100%	Allow up to 100% of load to not be met
Other Costs	Fixed Capital Investment	35% of electrolyzer, compressor and storage capital investment	35% of electrolyzer, compressor and storage capital investment	35% of electrolyzer, compressor and storage capital investment	

Case 2 Assumptions

Case 2	Parameter	Near Term Assumption	Mid Term Assumption	Long Term Assumption	Notes
Wind Turbine	Power Curve	Aggregate Xcel Energy Wind	Aggregate Xcel Energy Wind	Aggregate Xcel Energy Wind	Data from 3 Xcel Energy wind farms was aggregated, and it is assumed that power is available at a remotely located site, but the electrolyzer will only run when wind power is available
Wind Resource	Resource	Aggregate Xcel Energy Wind	Aggregate Xcel Energy Wind	Aggregate Xcel Energy Wind	
Hydrogen Load	Hourly load profile	variable	variable	variable	Must match filling station demand chart
	Unmet Hydrogen Load	0%	0%	0%	Hydrogen load must be met every hour of the day
Other Costs	Fixed Capital Investment	20% of electrolyzer, compressor, and storage capital investment	20% of electrolyzer, compressor, and storage capital investment	20% of electrolyzer, compressor, and storage capital investment	

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13. **SUPPLEMENTARY NOTES**

14. **ABSTRACT** *(Maximum 200 Words)*
An assessment of options for wind/hydrogen/electricity systems at both central and distributed scales provides insight into opportunities for renewable hydrogen.

15. **SUBJECT TERMS**
renewable hydrogen; hydrogen production; wind hydrogen electricity; central production; distributed production

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