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Economic Analysis of Hydrogen Production from Wind

Preprint

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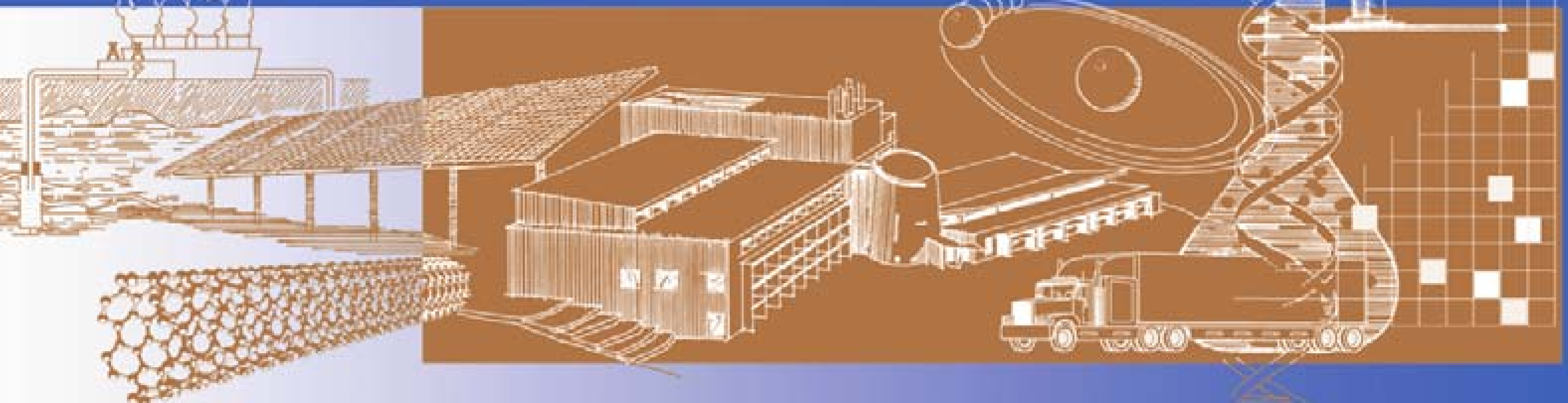
To be presented at WindPower 2005 Conference
Denver, Colorado
May 15–18, 2005

Conference Paper
NREL/CP-560-38210
May 2005

NREL is operated by Midwest Research Institute ● Battelle   Contract No. DE-AC36-99-GO10337



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Executive Summary

Wind energy can be harnessed to provide electricity at some of the lowest costs available for new generation. Coupling wind turbines with hydrogen-generating electrolyzers has the potential to provide low-cost, environmentally friendly electricity and hydrogen. In this way, hydrogen generation can be a pathway for using wind energy to contribute directly to reducing the Nation's reliance on imported fuels.

But what is the cost of hydrogen from such a pathway, and what are the potential technical and economic barriers of this technology? The price of hydrogen production from wind was calculated using the Department of Energy's (DOE) Hydrogen Analysis model (H2A) – a discounted cash flow analysis tool that uses standard DOE analysis methodologies and parameters to provide consistent analysis results across technologies. The analysis was conducted to determine the cost of hydrogen produced from wind energy via electrolysis, and to identify which technical areas are key cost drivers in the near, mid, and long term. The study focused on large-scale wind farms of 300-500 MW connected to a co-located electrolysis plant that produces 50,000 kg of hydrogen per day. Different scenarios were studied, from standalone wind hydrogen systems that produce only hydrogen to grid connected systems which can co-produce electricity. Results from this study will help researchers and analysts determine where efforts should be focused if wind is to play a major role in the future hydrogen economy.

The results from this analysis show that the price of hydrogen from a 50,000 kg/day wind-hydrogen system can range from $5.69 per kilogram of hydrogen in the near term to $2.12 per kilogram of hydrogen in the long term. Slightly higher prices are seen without the co-production of electricity. Sensitivity analyses indicate that research should focus on reducing the capital costs of the wind/hydrogen system, while analysis should focus on electricity pricing scenarios, and validate depreciation assumptions.

1.0 Introduction

The purpose of this analysis is to determine the cost of using wind energy to produce hydrogen for use as a transportation fuel. This analysis assumes that a market exists for 50,000 kg of hydrogen per day produced from wind at the wind site; only production costs to the front gate are included, no delivery or dispensing costs are included. Three different scenarios are examined: near term, which represents 2005 currently available technology; mid term, which represents technological improvements and price reductions in the next 5-10 years; and long term, which is representative of the best technology gains and price reductions surmised by industry at this point, and represents the next 10-25 years.

For purposes of clarity a few conceptual explanations are needed. First, hydrogen can be produced from wind power by a process called electrolysis, which splits the water molecule into hydrogen gas and oxygen gas. This is accomplished when electricity is passed through two electrodes in water. The water molecule bonds are broken and oxygen gas is produced at the anode and hydrogen gas is produced at the cathode via the following reaction: $H2O \rightarrow ½ O2 + H2$. In an ideal system, with no losses, the thermodynamic amount of energy needed to produce 1 kg of hydrogen from liquid water is approximately 39 kWh. Note that the amount of energy needed in actual electrolysis systems is larger than this due to system losses and peripheral equipment demands, such as pumps and dryers.

In the previous explanation, the amount of energy needed to produce one kilogram of hydrogen was presented for a reason. Typically, when discussing hydrogen for transportation fueling needs, a kilogram of hydrogen is the unit used. This is because a kilogram of hydrogen is roughly equivalent in energy to a gallon of gasoline. A gallon of gasoline has roughly 108,000 – 123,500 British Thermal Units (BTU) per gallon, while hydrogen falls between those two values at 116,000 BTU per kilogram. Often, a kilogram of hydrogen is referred to as a gallon of gasoline equivalent or (GGE) when comparing hydrogen to gasoline. Therefore, if a gasoline engine and a hydrogen engine had the same miles per GGE efficiency, a kilogram of hydrogen and a gallon of gasoline would result in the same number of miles traveled when used in said engine. The caveat to this rule is that if you compare a traditional internal combustion gasoline engine to a hydrogen fuel cell engine, and fuel cells are twice as efficient, than only half the amount of hydrogen would be needed to travel the same distance. In other words, if the fuel cell were twice as efficient, twice the mileage with a GGE of hydrogen would result compared to a gallon of gasoline in a traditional internal combustion engine.

2.0 H2A Model

The DOE Hydrogen Fuel Cell and Infrastructure Technologies (HFC&IT) program developed the H2A model used for this analysis. The H2A model was developed to provide the levelized selling price of hydrogen required to attain a specified internal rate of return using a discounted cash flow rate of return analysis; or in other words, to determine a minimum hydrogen selling price. The reason for the H2A model's development was to provide a framework where hydrogen analysis could be performed on a consistent and transparent basis. When comparing hydrogen technologies, analysts found that too often differences in analyses were the result of differing assumptions, such as internal rate of return (IRR) or feedstock costs, and not actual system differences. Models that examined the same hydrogen production system, such as wind electrolysis, might yield completely different results due to the assumptions used. The goal of the H2A model is to provide a common framework to improve the understanding of the differences among analyses.

To date two H2A modeling frameworks have been developed: a hydrogen production cash flow model and hydrogen delivery model. For this analysis, the hydrogen central production model was used, which is intended for hydrogen production facilities that produce at least 50,000kg/day of hydrogen. When using this model, hydrogen purity must be suitable for Proton Exchange Membrane (PEM) fuel cells, and minimal storage is provided for operational support purposes only.

The H2A effort was unique as many different national labs, universities, and agencies contributed to its development. In addition, industrial collaborators were used to validate the model's structure and assumptions. These key industrial collaborators (KIC) were also used to validate results produced once analyses were completed.

H2A Analysis Process

A chevron showing the basic flow of the H2A model is presented in Figure 1. If a model were being built using H2A, the analysis would start at the left side of the diagram and move towards the right. Beginning on the far left side, the model provides standard feedstock and utility prices along with physical property data. The analyst then must provide some basic information about the hydrogen production system in the description and the title. Then, the analyst is responsible for providing data about the cost and technical analysis. The model is not a process simulation tool, so the analyst must gather this information before entering it into the model. The cost analysis includes financial inputs, cost inputs, and replacement costs of the system. Financial inputs include parameters such as tax rate, depreciation type and period, internal rate of return, and construction data. Cost inputs include capital, operating, utility, and byproduct costs. The technical analysis includes the performance assumptions, process flowsheet, and stream summary of the system. The performance assumptions include the efficiencies of the different aspects of the system, along with purity data. The stream summary includes a mass and energy balance of the system, provided to the same level of detail as shown in the process flowsheet. Once the cost and technical analysis sections are completed, the model can produce information such as minimum selling price, and the data shown in the results chevron: cash flow, cost contribution, and sensitivity analyses. Examples of the types of results that can be obtained from H2A can be seen in the results section of this paper.

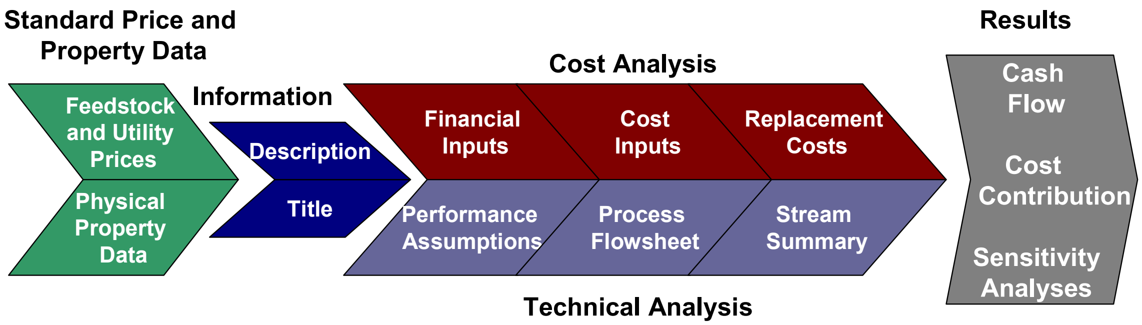

Figure 1: H2A Chevron

3.0 Systems Analyzed

The purpose of the H2A wind electrolysis study was to analyze the technical and economic aspects of hydrogen production from wind. Two scenarios were run. The first, seen in Figure 2 is a standalone wind hydrogen system not connected to the grid, so no byproduct electricity was sold. This scenario may make sense in a good wind location where there are grid constraints, or where there is no grid available.

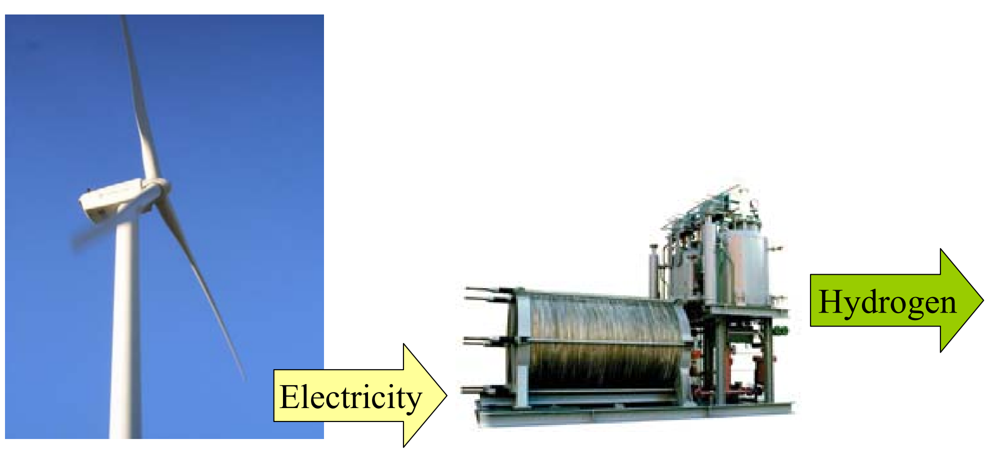

Figure 2: Standalone Wind/Hydrogen Plant

The second system, seen in Figure 3, is grid connected, but only excess electricity is sold as a byproduct of the system; the system does not purchase power from the grid. In both cases, hydrogen is only produced with renewable power.

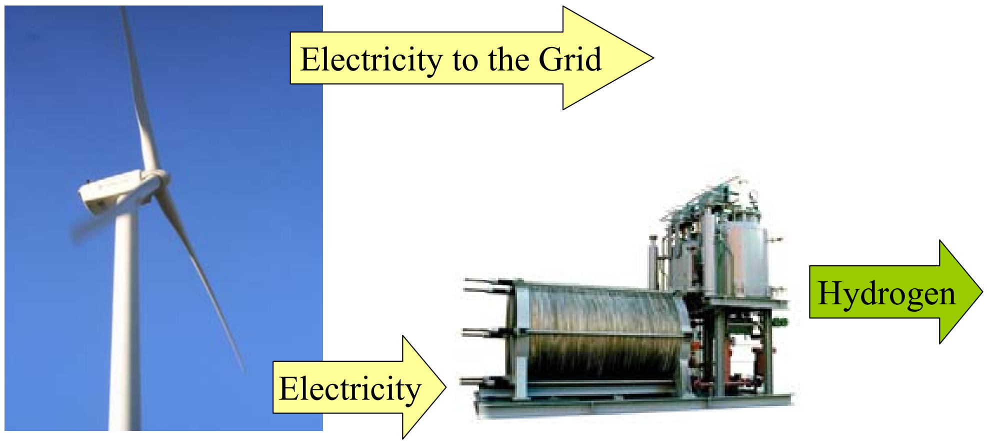

Figure 3: Grid Connected Wind/Hydrogen Plant

4.0 System Assumptions

As stated before, one of the main goals of the H2A development was to provide a modeling framework where consistent assumptions would be used. A sampling of the financial assumptions used in this model is seen in Table 1.

Table 1: Financial Assumptions

After-Tax Real IRR (%)	10%
Depreciation Type (MACRS, Straight Line)	MACRS
Depreciation Schedule Length (No. of Years)	15
Analysis Period (years)	40
Plant Life (years)	40
Effective Tax Rate (%)	38.9%
% Equity Financing	100%
Length of Construction Period (years)	2

Capital costs and capacity factors are critical assumptions for this analysis. Wind farm capital costs and capacity factors were modeled as following: near term, $873/kW capital cost and 0.4 capacity factor; mid term $754/kW capital cost and 0.5 capacity factor; long term, $706/kW capital cost and 0.54 capacity factor. Near term electrolyzer costs came from a quote provided by electrolyzer manufacturer Norsk Hydro, and mid and long term costs were estimated using input from the H2A and H2A KIC teams. The values of $800/kW (near term), $480/kW (mid term), and $360/kW (long term) were used for electrolyzer installed capital costs. The replacement costs of both the electrolyzer and the wind turbines were included. The electrolyzer cell stack was refurbished every 10 years at a cost of 30% of the initial electrolyzer investment. The turbine rotors were replaced at 20 years at a cost of 20% of the initial turbine investment.

In addition, several system assumptions were made. The system was assumed to be sited at a class-6 wind location. The wind farm is co-located with an electrolysis plant that produces 50,000 kg of hydrogen per day. The maximum size for wind farms was assumed to be approximately 300 MW in 2005 and 2015, and 500 MW in 2030. From the specifications provided by Norsk Hydro on their electrolyzer, it was assumed that the hydrogen was produced from the hydrogen generation unit without external compression at a pressure of 440 psig and 99.8% pure hydrogen. In the grid-connected systems, any electricity produced as a by-product would be sold at a price of $0.03/kWh. Finally, for the base case, the Production Tax Credit (PTC) was not used except for in the case where electricity was sold to the grid in the near term, as it is known that the scenario does currently exist. However, the effect of the PTC for all electricity produced was run for all cases, and can be seen in the sensitivity analysis section.

Next, assumptions specific to each scenario (stand-alone and grid connected), and each timeframe (near, mid and long term) were made. The system assumptions specific to the standalone scenario without electricity co-production for all three timeframes can be seen in Table 2.

Table 2: H2A Assumptions - Without Electricity Co Production

Scenario	**Without Electricity Co Production**		
Time Period	*Near Term*	*Mid Term*	*Long Term*
Number of Electrolyzers	119	97	89
$/kW for electrolyzer (installed)	800	480	360
Electrolyzer Energy Requirement (kWh/kg)	53.4	47.9	44.7
Electrolyzer Efficiency (HHV)	64%	71%	76%
Electrolyzer Capacity Factor	41%	50%	54%
Number of Turbines (1.5 MW Current, 3 MW Near and Long Term)	185	68	58
Total kW capacity	277,500	204,000	174,000
Wind Farm Capacity Factor	41%	50%	54%
Total annual GWh Produced	997	886	829
Electrolyzer kW	113,340	100,187	94,188
Co Product kW	580	981	561
$/kW for turbine (installed)	873	754	706

The system assumptions specific to the grid-connected scenario with electricity co-production for all three timeframes can be seen in Table 3.

Table 3: H2A Assumptions - With Electricity Co Production

Scenario	**With Electricity Co Production**		
Time Period	*Near Term*	*Mid Term*	*Long Term*
Number of Electrolyzers	110	82	63
$/kW for electrolyzer (installed)	800	480	360
Electrolyzer Energy Requirement (kWh/kg)	53.4	47.9	44.7
Electrolyzer Efficiency (HHV)	64%	71%	76%
Electrolyzer Capacity Factor	44%	58%	77%
Number of Turbines (1.5 MW Current, 3 MW Near and Long Term)	202	92	141
Total kW capacity	303,000	276,000	423,000
Wind Farm Capacity Factor	40%	50%	54%
Total annual GWh Produced	1,089	1,199	2,017
Electrolyzer kW	111,400	99,876	94,139
Co Product kW	12,988	36,998	136,197
$/kW for turbine (installed)	873	754	706

5.0 System Optimization

In the previous tables, note that for all timeframes the turbine and electrolyzer capital costs decrease over time. Note also, that the wind and electrolyzer capacity factors increase over time. However, in the standalone systems, the wind farm capacity factor and electrolyzer capacity factor are the same, while in the grid connected system the electrolyzer capacity factor is higher than the wind farm capacity factor. This is due to a system optimization that was run for both scenarios and all timeframes.

For all systems, the ratio of electricity produced from the turbine and electricity sent to the electrolyzer was varied, and the resultant hydrogen price of the system was calculated. The minimum ratio for all systems was one, meaning that all electricity produced by the turbine was sent to the electrolyzer for hydrogen production; the wind farm size exactly matched the hydrogen plant size, so a 100 MW wind farm would have 100 MW of available electrolyzer plant. As the ratio increased from one, the wind farm size increased, and the electrolyzer plant decreased so that approximately 50,000 kilograms per day of hydrogen was produced. When the new plant size was determined, the resulting hydrogen price was calculated. This process was repeated, and the results were graphed. An example of the graph resulting from the mid term co-production case can be seen in Figure 4. In the standalone plant, the increase in wind farm size and decrease in hydrogen plant size meant that during peak periods, electricity was thrown away, and in the co-production scenario, these excess electrons were sold to the grid at a price of $0.03/kWh.

The optimization found that for the standalone wind/hydrogen plants the hydrogen plant and the wind farm are most economical for hydrogen production when the hydrogen plant is sized the same as the wind farm, so both operate at the same capacity factor. However, the scenario was different for grid-connected plants. In this scenario, a minimum was found where the wind farm was oversized to a certain amount, and thus the hydrogen plant could be downsized, and as a result, operate at a higher capacity factor. An example of this optimization for the mid term co-production plant can be seen in Figure 4.

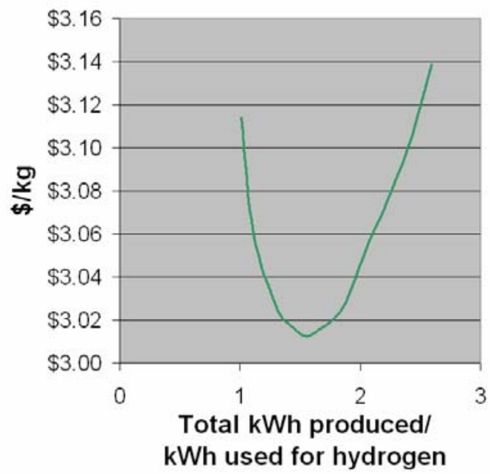

Figure 4: Mid Term Plant with Co-Product Optimization

Figure 4 shows that there is a point where the mid term plant with electricity co-product is optimized for the lowest price for hydrogen production. Once the system is constrained not to allow fractional wind turbines and fractional electrolyzers, the system is optimized when 324 GWh/year sold as electricity and 875 GWh/year used for hydrogen production, for a total electricity production of 1199 GWh/year, which yields a ratio of 1199/875 or 1.4. All three of the timeframes for the co-production scenario yielded curves with minimum selling prices of hydrogen when the wind farm was oversized, and the results of those optimizations yielded the number of electrolyzers and turbines for the co-production scenarios.

The optimized systems found are a result of the assumptions and constraints of the system. For example, if the hydrogen system were allowed to fall below 50,000kg/hydrogen per day, a lower hydrogen cost could be achieved. As a result, the system sizes presented are optimized according to the constraints of this study and will not be indicative of other systems where other assumptions are used.

6.0 Results

The results from this analysis show that the price of hydrogen from a 50,000 kg/day wind-hydrogen system can range from $5.69 per kilogram of hydrogen in the near term to $2.12 per kilogram of hydrogen in the long term. Slightly higher prices are seen without the co-production of electricity. Figure 5 displays the price of hydrogen produced from all three time frames in both scenarios.

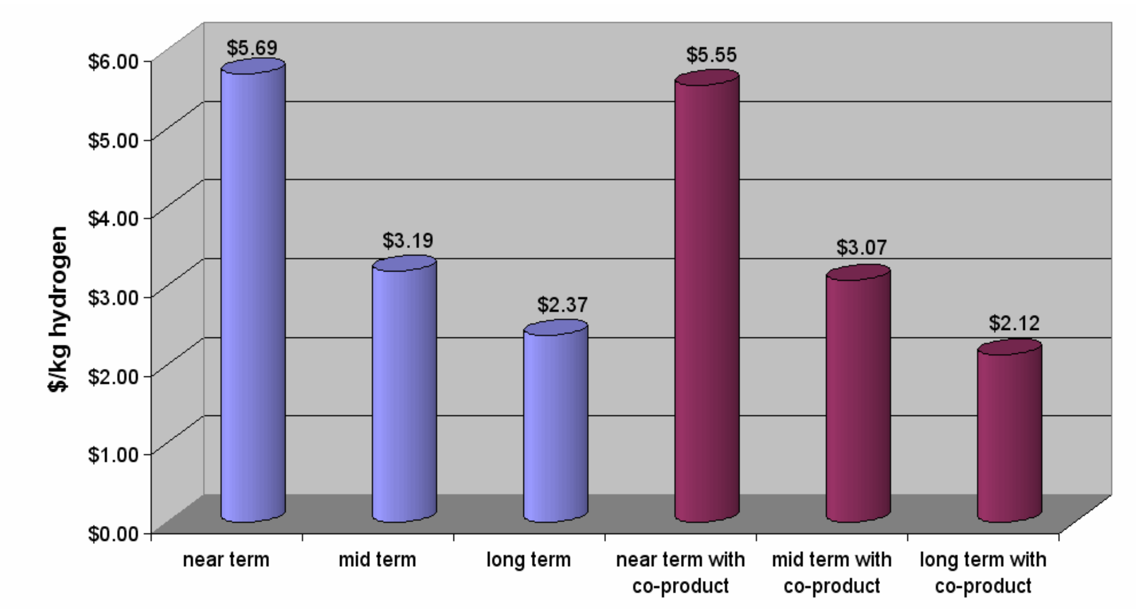

Figure 5 - Graph of Hydrogen Wind Generation Cost Over Time

The overall cost reductions from time period to time period result from the decrease in capital costs and increased efficiency of the electrolyzer and wind turbines. The ability to use electricity as a co-product decreases the cost of hydrogen from $5.69 to $5.55 in the near term, from $3.19 to $3.07 in the mid term, and from $2.37 to $2.21 in the long term.

The DOE HFC&IT program goal for wind produced hydrogen in 2015 is $2.75/kg. This timeframe falls towards the end of the mid term timeframe and towards the beginning of the long term timeframe. In order to better understand why the cost target is not met in the mid term and is met in the long term, the cost contributions for each timeframe need to be analyzed, and sensitivity analyses are required.

Cost Contribution

The H2A analysis model provides a breakdown of cost contributors to the price of hydrogen. The price is broken down into capital cost, decommissioning, fixed operation and maintenance (O&M), feedstock, other raw materials, byproduct, and other variable costs. The cost contributors for this process can be seen in Figure 6. The most significant contributors for all scenarios and timeframes are the capital costs of the wind farm and the electrolysis unit, followed by the fixed O&M costs of the system, which include costs such as labor, property taxes, and materials for maintenance and repairs. All cost contributors other than capital cost, fixed O&M, and by-product credit for this system are small enough to be insignificant.

When comparing the co-product scenario timeframes, note that the capital costs for the co-product scenario fluctuate as the wind farm size in the mid term is actually smaller than the short term. However in the long term, the wind farm is significantly larger, and thus the capital cost increases significantly. The higher capital costs in the long term are offset because of the positive cost contribution from the electricity co-product, which can be seen below the $0/kg x-axis. This co-product credit needs to be subtracted from the positive cost contributors of the system to yield the final hydrogen selling price.

When comparing the standalone systems to the co-product scenarios, note that in all three timeframes the co-product cases have a higher cost (above the $0/kg x-axis) than their corresponding standalone systems in the same timeframe, but those additional costs are offset by the by-product credit. Even though the co-product systems have a larger overall cost, their ability to sell byproduct electricity makes the final hydrogen selling price lower.

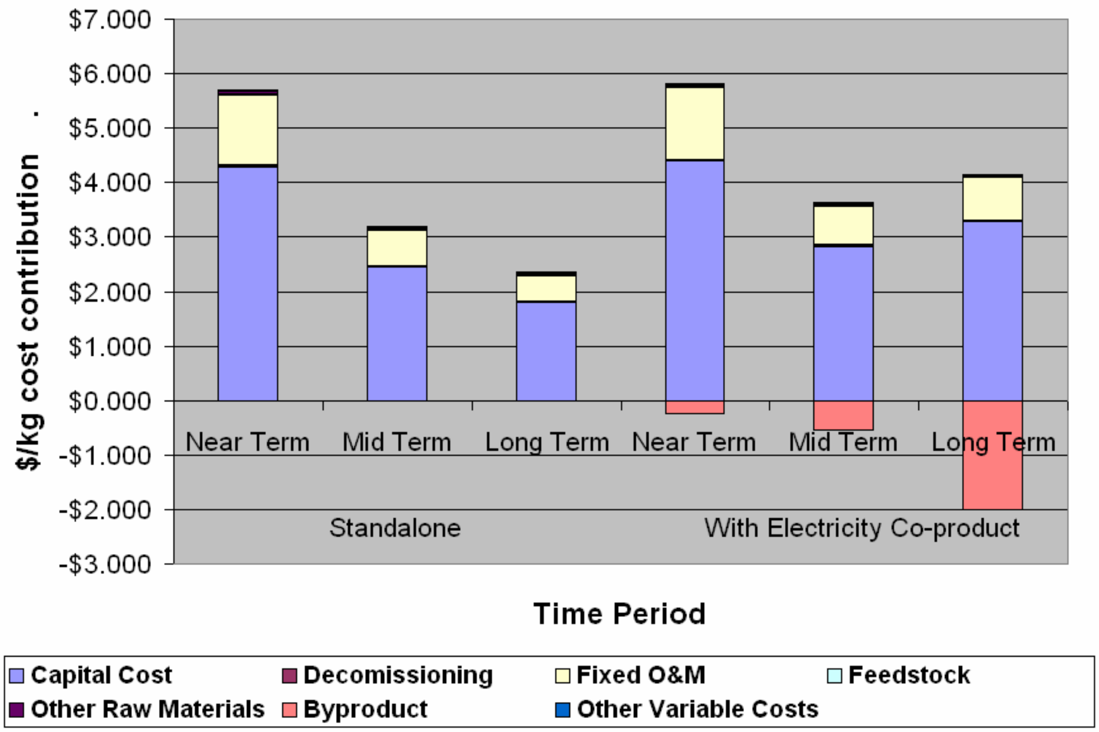

Figure 6 - Graph of Hydrogen Cost Contribution Over Time

Sensitivity Analyses

Once the base case hydrogen price is determined for each scenario in each time frame, a sensitivity analysis is run on each case to determine to which parameters the price of hydrogen is most sensitive. For this analysis, six parameters were analyzed for the standalone case, and seven were analyzed for the co-production cases. The parameters were varied one at a time, while all other parameters were held constant, so the effect of each parameter could be determined independently. A list of the parameters varied is in Table 4.

Table 4 – Sensitivity Parameters

Scenario 1 = Standalone system
Scenario 2 = System with electricity co-product

Parameter varied	1	2	Sensitivity Range
MACRS depreciation period	X	X	Renewable energy systems, such as wind farms are allowed a 5-year MACRS depreciation period. However, this may not be applicable to the hydrogen system. Standard MACRS depreciation period is 20 years, so the parameter was varied from 5-20 years.

Wind farm capital cost	X	X	Capital costs were varied from +20% of the base case to –20% of the base case.
Electrolyzer capital cost	X	X	Electrolyzer capital costs were varied from 600-730/kW in the near term, 300-600/kW in the mid term, and 250-500/kW in the long term.
Electrolyzer energy requirement	X	X	Electrolyzer energy requirements varied from 56.7-52.3 kWh/kg in the near term, 53.1-45.9 kWh/kg in the mid term, and 53.1-43 kWh/kg in the long term.
By-product electricity value		X	The value of the byproduct electricity was only used in cases where electricity could be sold to the grid, and was varied from \$0.02/kWh - \$0.06/kWh
Production Tax Credit	X	X	In all cases except the near term co-product case, the PTC was not applied to any energy produced. For the near term co-product case the PTC was only applied to the electricity sold to the grid in the base case, as it was unknown if electricity used to make hydrogen was eligible for the PTC. A sensitivity analysis was run for all cases from no electricity produced being allowed the PTC to all electricity produced, even that used to make hydrogen, being allowed the PTC.
Oxygen by-product	X	X	This parameter was varied from 0% of the oxygen produced to 100% of the oxygen produced being sold at \$0.02/kg.

Once each of the above parameters were varied for each case, and the resultant hydrogen price found, the results were ordered from the parameter that had the highest effect on the hydrogen price when varied, to the parameter that had the lowest effect. These parameters were then graphed on a tornado plot, and an example of the two mid term plots can be seen in Figures 7 and 8 below.

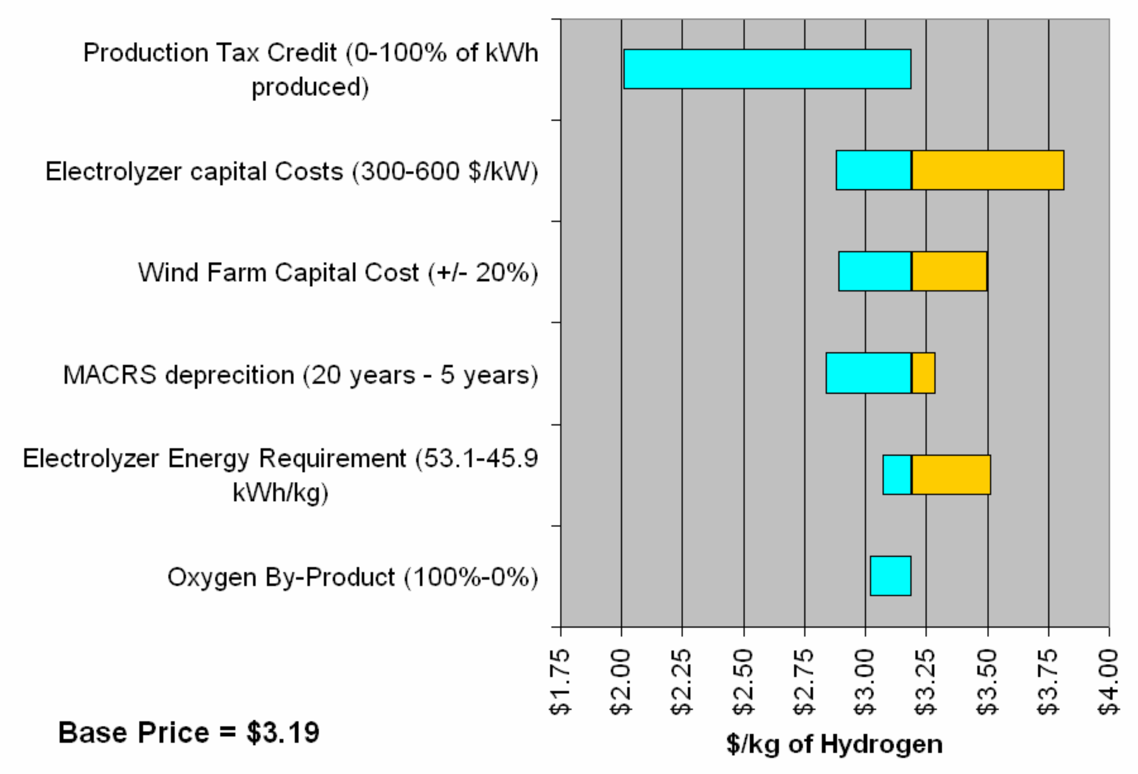

Figure 7 - Mid Term Central Wind Tornado Plot

Figure 7 shows that even with no electricity co-product, the ability to take the PTC for electricity produced to make hydrogen would allow the mid term process to make hydrogen for below the DOE cost target of $2.75. This is not a parameter research can effect, but it is worth noting as it is the only parameter when varied alone can make the standalone technology in this timeframe meet the $2.75 cost targets. The next two most significant parameters, electrolyzer cost and wind farm capital costs are areas where research can help reduce costs. For example, work is being done at NREL currently to optimize a wind/hydrogen system to help combine components common to both the wind turbine and the electrolyzer, thus reducing the cost. The fourth most important parameter, Modified Accelerated Cost Recovery System (MACRS) depreciation is a financial parameter that again, cannot be helped with research. However, like the PTC, it is worth noting so future analyses can be sure to verify the correct depreciation period to use for hydrogen systems. The fifth most important parameter, electrolyzer efficiency could be improved with additional research. Note that the oxygen by-product credit is minimal given that the additional capital costs of oxygen purification, compression, and storage were not included when the credit was taken.

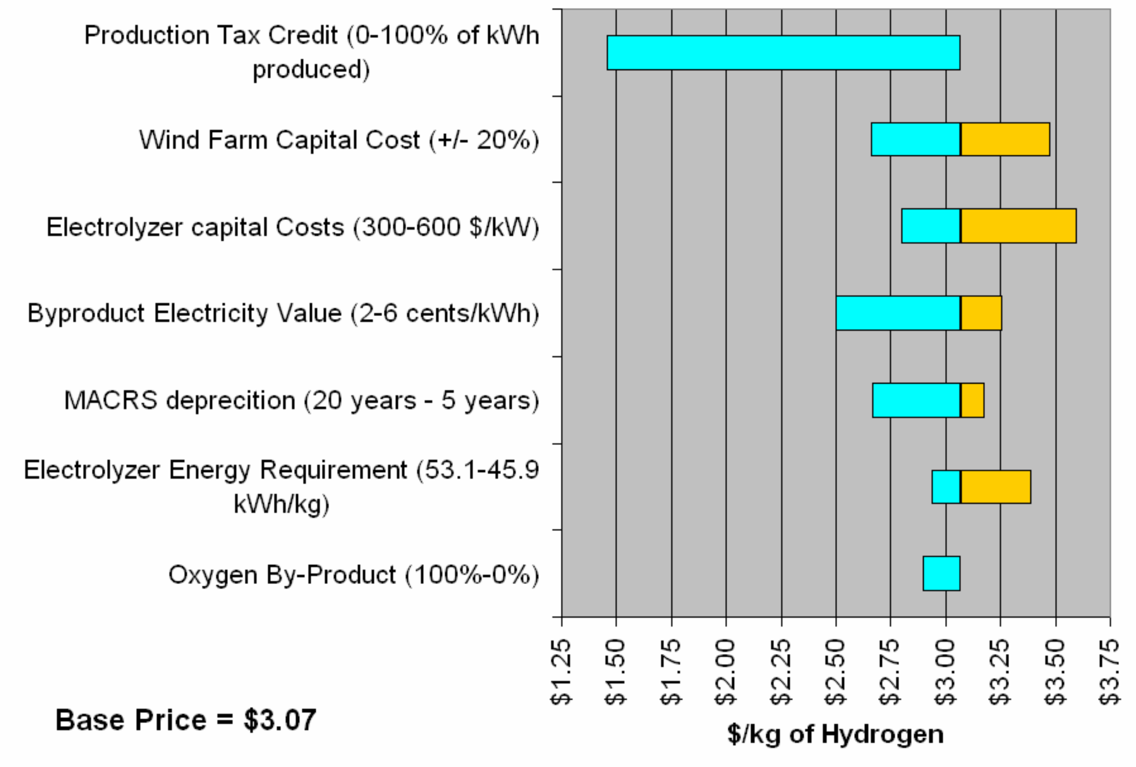

Figure 8 - Mid Term Central Wind with Electricity Co-Product Tornado Plot

Figure 8 shows that even with electricity co-product, the top three most sensitive parameters are the same as the system without co-product electricity. However, the PTC has a much larger effect on this system, as it produces more electricity than the standalone system. With the PTC, the mid term process easily achieves the DOE cost target of $2.75. In this case, the fourth most important parameter is the byproduct electricity value, because this system produces 324 GWh/year of byproduct electricity. Future analyses need to better establish the worth of co-product electricity. The final three parameters are of the same importance in this system as in the standalone system. This scenario differs from the standalone scenario in that four parameters, when varied independently, can reach the DOE cost target: PTC, wind farm capital cost, byproduct electricity value, and MACRS depreciation. The ability to produce co-product electricity makes the electricity price parameters more important; makes the wind farm larger, which increases the wind farm capital cost; and makes the overall capital cost larger, which increases the importance of the depreciation period.

The top three most sensitive parameters for each scenario and timeframe are shown in Table 5 below, so the variations over time and between scenarios can be understood.

Table 5 – Hydrogen Cost Sensitivity Ranking

Technology	Hydrogen Cost Sensitivity Ranking		
	1	2	3
Near Term no co-production	Production Tax Credit (0-100% of kWh produced)	MACRS depreciation length (20-5 years)	Wind farm capital costs (+/- 20%)
Near Term with co-production	Production Tax Credit (0-100% of kWh produced)	Wind farm capital costs (+/- 20%)	MACRS depreciation length (20-5 years)
Mid Term no co-production	Production Tax Credit (0-100% of kWh produced)	Electrolyzer capital Costs (300-600 $/kW)	Wind farm capital costs (+/- 20%)
Mid Term with co-production	Production Tax Credit (0-100% of kWh produced)	Wind farm capital costs (+/- 20%)	Electrolyzer capital Costs (300-600 $/kW)
Long Term no co-production	Production Tax Credit (0-100% of kWh produced)	Electrolyzer capital Costs (250-500 $/kW)	Wind farm capital costs (+/- 20%)
Long Term with co-production	Byproduct Electricity Value (2-6 cents/kWh)	Production Tax Credit (0-100% of kWh produced)	Wind farm capital costs (+/- 20%)

In all cases, the production tax credit and wind farm capital costs are in the top three most sensitive parameters. Electrolyzer capital costs are in the top three in half of the cases, and the MACRS depreciation length is in the top three for the near term cases. The depreciation effect is understandable as the individual component capital costs for these systems are higher in the near term. Electrolyzer efficiencies are not to be ignored, as the effect this parameter has on hydrogen price ranged from \$0.44 - \$0.49/kg, which by itself is not enough to make the hydrogen cost target, but when combined with other parameters may be significant.

Based on the sensitivity analyses, wind/hydrogen research should focus on the following: 1.) reduce wind farm capital cost; 2.) reduce electrolyzer capital cost; 3.) improve electrolyzer efficiency. Other critical parameters were the production tax credit, the byproduct electricity value, and the MACRS depreciation period, which are policy and electricity related parameters, and are outside the scope of wind/hydrogen research and development, but which should be better understood via analysis.

Future studies should determine the effect on hydrogen price if several of the above parameters were decreased simultaneously. It may be that the cost target could be reached with smaller changes to some or all of these parameters, if implemented simultaneously.

7.0 Conclusions

The results of this analysis demonstrate that wind has the potential to generate hydrogen via electrolysis for prices ranging from \$5.69 per kilogram of hydrogen in the near term, and as low as \$2.12 per kilogram in the next 10-25 years, if capital costs and process efficiency improvements are fully recognized as assumed. Furthermore, the mid term scenario shows that this process can produce hydrogen for \$3.19/kg in a standalone wind hydrogen plan and \$3.07/kg in a plant that can co-produce electricity. These values are \$0.44/kg and \$0.32/kg respectively above the DOE cost target of \$2.75/kg for hydrogen production from wind electrolysis by 2015. However, the sensitivity analyses show that including the production tax credit, lowering wind turbine costs, receiving an increased byproduct electricity value, or using an accelerated depreciation period can all help to make the cost target achievable by 2015 independently. Similarly, if process improvements occur quicker than the timeline assumes, the long term scenarios may be valid by 2015, in which case both the standalone and co-product cases can meet the DOE 2015 cost target.

Research efforts need to focus on reducing wind farm capital costs, reducing electrolyzer capital cost, and improving electrolyzer efficiency. Individual components need to be considered, along with optimizing the system as a whole by eliminating redundancies in the system. Analysis should be used to better understand the effects of the production tax credit, the byproduct electricity value and valid depreciation periods for hydrogen systems.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
May 2005

2. REPORT TYPE
Conference Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Economic Analysis of Hydrogen Production from Wind: Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
NREL/CP-560-38210

5e. TASK NUMBER
HY513771

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-560-38210

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

The purpose of this analysis is to determine the cost of using wind energy to produce hydrogen for use as a transportation fuel. This analysis assumes that a market exists for 50,000 kg of hydrogen per day produced from wind at the wind site; only production costs to the front gate are included, no delivery or dispensing costs are included. Three different scenarios are examined: near term, which represents 2005 currently available technology; mid term, which represents technological improvements and price reductions in the next 5-10 years; and long term, which is representative of the best technology gains and price reductions surmised by industry at this point, and represents the next 10-25 years.

15. SUBJECT TERMS
Wind energy; hydrogen production; cost analysis

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPONE NUMBER (*Include area code*)