XI.5 Cost and GHG Implications of Hydrogen for Energy Storage

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Objective

Use analysis of scenarios for renewable electricity generation coupled with hydrogen systems to find opportunities for cost savings and other benefits of hydrogen energy storage and renewable hydrogen for vehicles.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(B) Stove-Piped/Siloed Analytical Capability
(D) Suite of Models and Tools
(E) Unplanned Studies and Analysis

Technical Targets

The update of the H2A models directly supports the following milestones from the Systems Analysis function from FY 2004 through FY 2016.

Milestone 26	Annual model update and validation. (4Q, 2008; 4Q, 2009; 4Q, 2010; 4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014; 4Q, 2015)
Milestone 39	Annual update of Analysis Portfolio. (4Q, 2007; 4Q, 2008; 4Q, 2009; 4Q, 2010; 4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014; 4Q, 2015

FY 2011 Accomplishments

- Four case study (theoretical) wind farms were identified using the NREL Western Wind Dataset (http://www.nrel.gov/wind/integrationdatasets/western/methodology.html).
- Cost estimates were developed for wind turbines, transmission lines, storage cavern development, electrolyzers, fuel cells and auxiliary equipment based on literature values.
- Two primary scenarios were developed and analyzed for the four wind farms.
  - Load leveling of the wind farm electrical output using hydrogen for electricity storage.
  - Hydrogen production via electrolysis used as dispatchable load for times of high wind output.
- The NREL Fuel Cell Power Model (http://www.hydrogen.energy.gov/ fc_power_analysis.html), which combines hourly energy analysis of various generators and loads with the H2A discounted cash flow analysis tool, was used to calculate the levelized cost of all output energy (electricity and/or hydrogen) from the wind farms and storage systems.

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Introduction

In FY 2008, NREL began investigating the use of hydrogen as an energy storage mechanism for electric utilities. In this application, various system configurations were modeled for producing hydrogen from renewable energy via electrolysis and storing it. The stored hydrogen can later be converted back to electricity using fuel cells to meet peak electricity demand. In subsequent analyses, NREL evaluated the costs of competing energy storage technologies (batteries, compressed air energy storage, and pumped hydro), additional fuel cell types, and investigated the potential dual benefit of producing excess hydrogen for the vehicle market (see reference [1]). This work builds on previous studies and incorporates more realistic analysis of the impacts of variable wind farm output. Four theoretical wind farms of various sizes and proximity to demand centers are analyzed for two primary scenarios: (1) hydrogen for energy storage; and (2) hydrogen production for transportation using otherwise curtailed wind-generated electricity.

Approach

Four theoretical wind farms were identified using the Western Wind Dataset. Groups of 10, 3-MW turbines were aggregated to the desired total wind farm size and the 10-minute power output data from the dataset was averaged to 1-hour data to create one hourly dataset for each wind farm (see Table 1 and Figure 1).

TABLE 1. Four Theoretical Wind Farms Used in the Energy Analysis

Location	Size (Nameplate Capacity MW)	Capacity Factor	Dedicated Transmission Line Distance (miles)
North Portal, ND	1050	42%	1,000
Wyoming	1620	41%	300
Oklahoma	330	37%	300
Palmdale, CA	450	39%	50

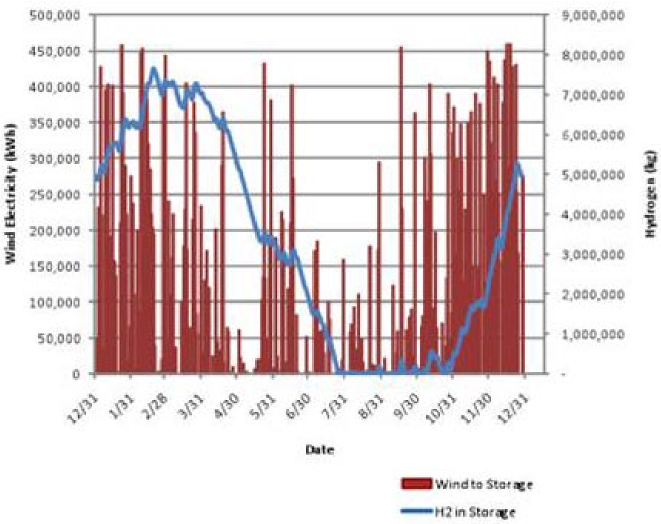

FIGURE 1. Curtailed Electricity and Hydrogen Storage use for the North Dakota Wind Farm

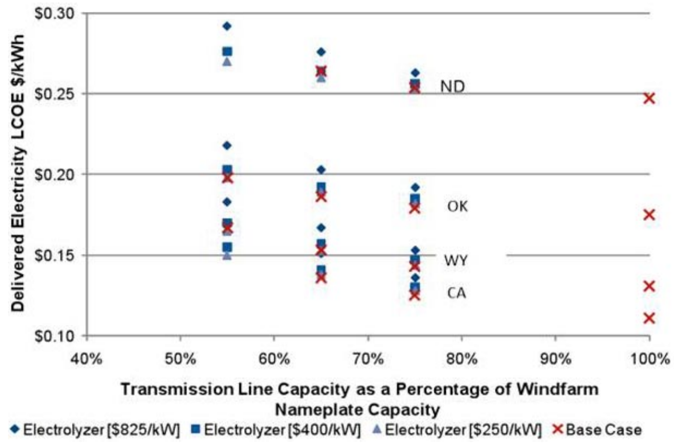

FIGURE 2. Levelized Cost of Delivered Electricity for the Four Wind Farms at Various Transmission Line Capacities

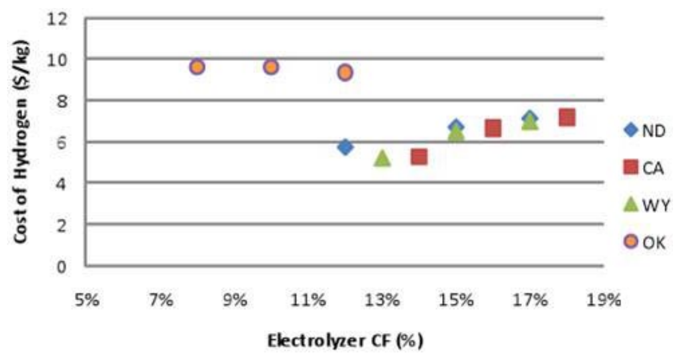

FIGURE 3. Economic Analysis for use of Otherwise Curtailed Wind for Hydrogen Production

The Fuel Cell Power model calculates the levelized, profited cost of energy output from the system being analyzed. A "base case," in which there is no storage system or hydrogen production, was analyzed for each wind farm. The amount of electricity curtailed is determined by the capacity of the dedicated transmission line for the wind farm. In this analysis the transmission line capacity was varied from 100% to 55% of the nameplate capacity rating of the wind farm, resulting in curtailment of 0% to ~25%. The amount curtailed at each transmission line size varied depending on the specific wind profile for that site. The base case provided a baseline cost of delivered electricity for the wind farm, taking into account the unrealized value of the curtailed electricity. Additional costs to install the storage system or electrolyzer are offset by the additional revenue from capturing some value of the curtailed wind. Thus, the primary cost metric for the analyses answers the question of whether the revenue from the storage system or hydrogen fully offsets the cost of installing additional equipment.

Results

Figure 2 presents the results of adding a hydrogen energy storage system to each wind farm. The base case for each wind farm, in which some electricity is curtailed, is indicated by the red "X"s. The blue symbols show the delivered cost of electricity for the same wind farms where hydrogen energy storage has been added. In all cases, the electrolyzer has been sized to capture all the wind-generated electricity that would otherwise have been curtailed. The results indicate that the electrolyzer cost must be less than $400/kW in most cases to make the energy storage system pay for itself.

Results of the analysis using electrolysis as a dispatchable load to produce hydrogen for the transportation sector are shown in Figure 3. The electrolyzer use was increased by diverting more of the wind farm output to the electrolyzer. Electricity in excess of what would have been curtailed must be "purchased" for electrolysis. The analysis results indicate that diverting more electricity to the electrolyzer increases the electrolyzer capacity factor and increases the cost of the hydrogen produced for all but the Oklahoma wind farm. At the Oklahoma wind farm, the very low equipment use causes the capital cost of the electrolyzer to be the primary cost driver. In this case, increasing use, even with higher input electricity cost, reduces the resulting hydrogen cost. In all other cases, increasing the cost of electricity increases the hydrogen cost, even with better equipment use.

Conclusions and Future Directions

Increasing power generation from intermittent renewable resources will require new strategies for balancing generation and demand, including energy storage and dispatchable demand, both of which are addressed by the two hydrogen systems studied in this work. If hydrogen can play a role in addressing these needs, hydrogen will be more likely to gain a foothold as a viable alternative vehicle fuel. Two potential benefits are:

- The availability of renewable resources dedicated to hydrogen production will be limited in the near term, as these resources are being developed for electricity generation. Therefore, hydrogen must be integrated into the electricity system in such a way that it provides a service or use for excess power in addition to its value as a vehicle fuel. The strategies being analyzed in this work accomplish that objective.
- The high cost of alkaline electrolysis is primarily due to labor-intensive manufacturing methods and low production volumes. Using electrolysis to produce hydrogen, either for electricity storage or for vehicles, could increase demand to the point that more automated manufacturing methods could be used and costs would be dramatically decreased.

The analyses indicate that equipment costs, including electrolyzer costs analyzed here, must be reduced for hydrogen to be an economical alternative for energy storage or production of vehicle fuel from otherwise curtailed wind-generated electricity. However, no additional credit was taken for the various potential services that could be provided by hydrogen production, nor was any attempt made to take advantage of arbitrage opportunities.

Future work will focus on developing similar analyses for solar installations and quantifying greenhouse gas emissions and carbon tax implications, especially in comparison to compressed air energy storage.

References

1. Steward, D.; Saur, G.; Penev, M.; Ramsden, T. Lifecycle Cost Analysis of Hydrogen Versus Other Technologies for Electrical Energy Storage, NREL TP-560-46719, 2009. http://www.nrel.gov/docs/fy10osti/46719.pdf.