

VII.6 Cost and GHG Implications of Hydrogen for Energy Storage

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Objectives

- Evaluate the economic viability of hydrogen for utility-scale energy storage applications compared with other electrical energy storage technologies.
- Explore the cost and greenhouse gas (GHG) emissions impacts of the interaction between hydrogen energy storage and variable renewable electricity resources.

Technical Barriers

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

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

Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Program's Multi-Year Research, Development and Demonstration Plan:

- Milestone 26: Annual model update and validation. (4Q, 2010)
- Milestone 39: Annual update of analysis portfolio. (4Q, 2010)

Accomplishments

- Analyzed the levelized cost of energy (LCOE) for hydrogen energy storage versus competing technologies, finding that hydrogen is competitive with batteries and could be a cost-effective alternative to compressed air energy storage (CAES) and pumped hydro in locations that are not suitable for these technologies.
- Analyzed a hydrogen energy storage system with 1,400 kg/day excess hydrogen, finding an LCOE of \$4.69/kg, not including tanker truck transport and dispensing (which compares with about \$4/kg for the production portion of an electrolysis forecourt hydrogen station).
- Analyzed a hydrogen energy storage system with 12,000 kg/day excess hydrogen, finding an LCOE of \$3.33/kg, not including tanker truck transport and dispensing (which compares with about \$7/kg for electrolysis at a centralized hydrogen production facility of the same size).
- Analyzed energy storage system sensitivity to electricity price, finding that sensitivity to electricity price is roughly inversely proportional to energy storage system roundtrip efficiency and that efficiency improvements to a hydrogen energy storage system, especially the fuel cell, would have a larger positive impact on LCOE than similar improvements to competing technologies.
- Performed an initial study of the amount by which hydrogen energy storage reduces the amount of wind-generated electricity that must be curtailed and reduces the LCOE of the electricity delivered.
- Preliminarily analyzed the effect of obtaining financial credits for avoided carbon emissions on the LCOE of wind-generated electricity with and without hydrogen energy storage, finding that carbon credits can reduce the wind LCOE below the grid LCOE, with the addition of hydrogen energy storage providing lower LCOE than wind without storage.



Introduction

As renewable electricity becomes a larger portion of the electricity-generation mix, new strategies will be required to accommodate fluctuations in energy generation from these sources. Energy storage has been one of the primary strategies proposed for integrating large amounts of renewable energy onto the grid. Energy storage can absorb excess electricity-generating

capacity during times of low demand and/or high rates of generation and then reconvert the stored energy into electricity during periods of high demand and/or low renewable generation. The use of hydrogen for energy storage also creates a potential bridge between the electricity and transportation sectors: excess hydrogen generated by energy storage systems could be used to provide fuel for hydrogen-powered vehicles.

In Task 1, the LCOE of the most promising and/or mature energy storage technologies was compared with the LCOE of several hydrogen energy storage configurations. In addition, the cost of using the hydrogen energy storage system to produce excess hydrogen was evaluated. In Task 2, the use of hydrogen energy storage in conjunction with an isolated wind power plant—and its effect on electricity curtailment, credit for avoided GHG emissions, and LCOE—was explored.

Approach

For Task 1, a simple energy arbitrage scenario was developed for a hydrogen energy storage system consisting of a 300-MWh nominal storage capacity that is charged during off-peak hours (18 hours on weekdays and 24 hours on weekends) and discharged at a rate of 50 MW for 6 peak hours on weekdays. The system electrolyzes water to produce hydrogen, which is stored in compressed gas tanks or underground geologic formations and reconverted into electricity using a polymer electrolyte membrane fuel cell or hydrogen expansion combustion turbine. The lifecycle LCOE resulting from each hydrogen storage scenario was compared with the lifecycle LCOE resulting from use of several battery systems (nickel cadmium, sodium sulfur, and vanadium redox), pumped hydro, and CAES. The analyses were performed for the same energy arbitrage scenario, and with consistent financial and operational assumptions, using the National Renewable Energy Laboratory’s HOMER model (<https://analysis.nrel.gov/homer>). In addition, the cost of using the hydrogen energy storage system to produce 1,400 and 12,000 kg/day of excess hydrogen was analyzed.

For Task 2, three scenarios were modeled for an isolated wind power plant in North Dakota that transmits electricity to Chicago: 1) a base case in which electricity from a 1,000-MW wind plant with a capacity factor of about 50% is transmitted via a dedicated 750-MW capacity transmission line to the grid with no energy storage, 2) a storage-constrained case in which the wind plant is combined with a 400-MT hydrogen energy storage system at the wind plant location, and 3) a transmission-constrained case in which the wind capacity is combined with 2,600 MT of hydrogen energy storage but only 500 MW of transmission capacity is available. The LCOE and electricity curtailment resulting from these scenarios were evaluated.

Results

In Task 1, modeling suggested that the LCOE of hydrogen energy storage is competitive with batteries and could be a cost-effective alternative to CAES and pumped hydro in locations that are not suitable for these technologies (Figure 1). For each technology, high-cost, mid-range, and low-cost cases were analyzed, and sensitivity analyses were performed to generate a range of possible costs for each case. In Figure 1, the bottom of the bars represents the low end of the range for the low-cost cases, and the top of the bars represents the high end of the range for the high-cost cases. The numbers shown are the nominal values of the mid-range cases and can be considered an estimate for LCOE for a 3–5 year future time frame.

The range of costs for each system reflects the range found in the literature and estimates of potential cost reductions as technologies develop. The hydrogen fuel cell scenario cost range reflects the comparative immaturity of fuel cell technologies for this application. It is anticipated that costs for fuel cells will decrease as the technology matures. Cost considerations aside, hydrogen has some advantages over competing energy storage technologies. It has a very high energy density (170 kWh/m³ versus 2.4 kWh/m³ for CAES [1] and 0.7 kWh/m³ for pumped hydro [2]), which allows for the potential economic viability of aboveground storage. Also, hydrogen combustion turbines could prove to be viable for energy storage applications and could provide additional flexibility to utilities through co-firing of mixtures of natural gas and hydrogen.

The sensitivity analyses showed electricity price to be one of the most important factors influencing LCOE for each storage technology. Further analysis

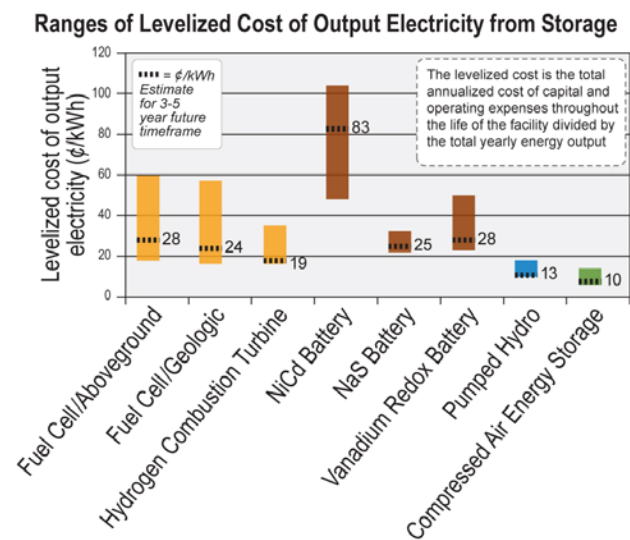


FIGURE 1. Ranges of Levelized Cost of Output Electricity for Electricity Storage Systems

showed that sensitivity to electricity price is roughly inversely proportional to the roundtrip efficiency of the energy storage technologies (Figure 2). Improvements in the efficiency of hydrogen storage system equipment, especially the fuel cell, would have a larger positive impact on LCOE than similar improvements for competing technologies.

Using the hydrogen energy storage system to produce 1,400 kg/day of excess hydrogen reduces the overall LCOE for this scenario by about 6% compared with the purely energy arbitrage scenario, and the excess hydrogen is produced for \$4.69/kg. Excess hydrogen produced in this way is still not competitive with hydrogen produced in a dedicated, distributed electrolysis process with the same daily output of hydrogen (\$4.00/kg). However, producing 12,000 kg/day of excess hydrogen to feed into a hydrogen pipeline results in a cost of \$3.33/kg, substantially less expensive than the \$6.86/kg for a dedicated, centralized 12,000-kg/day hydrogen electrolysis facility.

In Task 2, the preliminary analysis suggested that combining hydrogen energy storage with electricity from an isolated wind power plant reduces the amount of wind-generated electricity that must be curtailed and reduces the LCOE (Table 1). This preliminary analysis also suggested that combining wind power with hydrogen energy storage enhances the reduction in LCOE resulting from instituting a credit for avoided carbon emissions (Table 1).

Conclusions and Future Direction

The modeling analyses performed in Fiscal Year (FY) 2009 and FY 2010 suggested that hydrogen energy storage is economically competitive with batteries and could be a cost-effective alternative to CAES and pumped hydro in locations that are not suitable for these technologies. Excess hydrogen could be produced

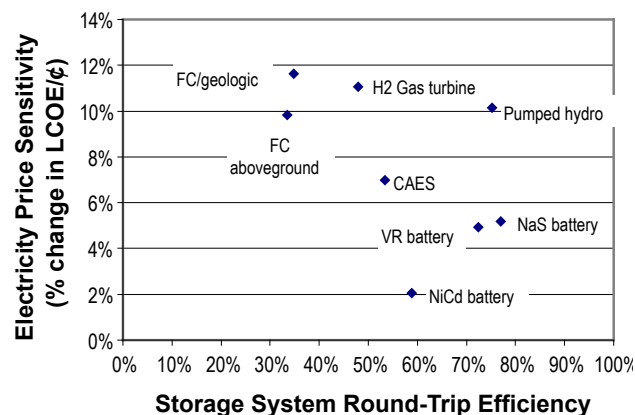


FIGURE 2. Electricity Price Sensitivity Vs. Energy Storage System Roundtrip Efficiency

TABLE 1. Effects of Hydrogen Energy Storage on Wind-Generated Electricity Transmission and Cost

	Base Case	Storage Constrained	Transmission Constrained
% of total wind power plant output			
Electricity direct from wind power plant to transmission line	82.7	82.7	60.8
Electricity from storage	N/A	4.5	7.4
Electricity curtailed	17.3	1.9	11.7
Net electricity to transmission line	82.7	87.2	68.2
% of total transmission line capacity			
Transmission line utilization	56.0	59.0	69.0
LCOE (¢/kWh)			
Without carbon credit	13	10	12
\$50/MT CO ₂ e credit	9	6	8
\$100/MT CO ₂ e credit	5	2	4

for the transportation market. In addition, preliminary analyses suggested that using hydrogen energy storage in conjunction with an isolated wind power plant could reduce electricity curtailment and LCOE for the wind plant. Additional work is needed to elucidate the impact of hydrogen storage on GHG emissions and credits for avoided emissions, especially in comparison to CAES. Future work may include the following:

- Further explore the costs and benefits of dual-use hydrogen energy storage systems in which hydrogen is used for electricity storage and fuel for vehicles.
- Develop a methodology for optimizing the size of the storage system components and transmission to minimize costs for an isolated wind or solar installation.
- Analyze an isolated solar installation with hydrogen energy storage.
- Compare GHG emissions/carbon tax implications for hydrogen energy storage and CAES.

FY 2010 Publications/Presentations

1. Steward, D., Saur, G., Penev, M., and Ramsden, T., *Lifecycle Cost Analysis of Hydrogen Versus Other Technologies for Electrical Energy Storage*, NREL/TP-560-46719, NREL Technical Report, November 2009, www.nrel.gov/docs/fy10osti/46719.pdf.
2. Steward, D. *Lifecycle Cost and GHG Implications of a Hydrogen Energy Storage Scenario*, NREL/PR-560-48198, National Hydrogen Association Conference and Expo, Long Beach, CA, May 3-6, 2010.

3. Steward, D., Ramsden, T., and Harrison, K., *Hydrogen for Energy Storage Analysis Overview*, NREL/PR-560-48360, National Hydrogen Association Conference and Expo, Long Beach, CA, May 3-6, 2010.
4. Steward, D., *Analysis of Hydrogen and Competing Technologies for Utility-Scale Energy Storage*, NREL/PR-560-47547, Hydrogen and Fuel Cell Technical Advisory Committee Meeting, Arlington, VA, February 11, 2010.

References

1. Crotogino, F., Huebner, S. (2008). "Energy Storage in Salt Caverns: Developments and Concrete Projects for Adiabatic Compressed Air and for Hydrogen Storage." Solution Mining Research Institute Spring 2008 Technical Conference, Porto, Portugal, April 28-29, 2008.
2. Schoenung, S.M.; Hassenzuhl, W.V. (2003). Long- vs. Short-Term Energy Storage Technologies Analysis: A Life-Cycle Cost Study. A Study For The DOE Energy Storage Systems Program. Livermore, CA: Sandia National Laboratories.