X.2 Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications

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Contract Number: SNL 1024882

Project Start Date: May 2010
Project End Date: November 2011

Fiscal Year (FY) 2011 Objectives

- Model bulk hydrogen storage integrated with intermittent renewable energy production of hydrogen via electrolysis for utility applications.
- Determine cost-effective scale and design characteristics.
- Explore potential attractive business models.

Barriers

This project addresses the following barriers assigned to this project:

- Non-technical barriers to commercialization of hydrogen and fuel cells.
- Ensure continued technology utilization growth for domestically produced hydrogen and fuel cell systems.
- Enable greater penetration of clean renewable energy production while addressing the market for large-scale storage of hydrogen and hydrogen technologies.

FY 2011 Accomplishments

- Updated utility energy storage model to include purchase of curtailed wind energy.
- Updated costs for fuel cell and hydrogen systems and other storage technologies and compared. Other technologies are pumped hydro storage, compressed air energy storage, advanced lead-acid batteries, sodium sulfur batteries and flow batteries.
- Performed sensitivity analyses, primarily around the operating times and economic factors.
- Established a utility with renewables business case, in which excess, or "spilled" wind power is used to produce hydrogen via electrolysis. Large-scale storage stores the hydrogen for later use in fuel cell power generation. The excess power is used at no cost. In discussions with a number of utilities and grid operators, the case of excess wind for a period up to six hours was established for analysis.
- Made benefit/cost estimates based on the present value of costs and benefits, where benefit values are recently published in the utility energy storage literature.

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Introduction

Previous work by this author [1,2] and others [3] has explored the potential use by the electric utility industry of hydrogen produced and stored in bulk. These studies show promise in some applications, especially where large scale is demanded and particularly in conjunction with intermittent energy resources such as wind.

The use of hydrogen will compete with other energy storage technologies, including modular systems, such as batteries, and other large-scale systems such as compressed air energy storage and pumped hydro storage. The major weakness in the hydrogen system is the relative inefficiency of energy conversion through the electrolysis and fuel cell subsystems. The major advantage is low storage cost and high volumetric energy density. The use of "spilled wind" presents an opportunity to install large scale hydrogen storage.

Approach

The approach to this work proceeds along the following steps:

- Assume a design concept in which energy storage is connected to an electric grid that includes power generation from wind. The storage system is charged from the grid and discharged back to the grid.
- Calculate the capital cost of the energy storage systems, dependent on the size of the storage system, i.e., the number of hours of stored energy for full power discharge. Cost assumptions for the hydrogen system components and other storage technologies are shown in Tables 1 and 2 [4,5].

TABLE 1. Cost and Efficiencies of Hydrogen Technologies in this Study

	Current Efficiency	Target Efficiency	Current Cost - Mid	Target Cost - Low
Electrolyzer	73.5%	75%	340 $/kW	125 $/kW
Gas Storage	Not Applicable	Not Applicable	15 $/kWh	2.5 $/kWh
Underground Storage	Not Applicable	Not Applicable	0.3 $/kWh	0.3 $/kWh
Fuel Cell	55%	58%	500 $/kW	100 $/kW

TABLE 2. Cost and Performance Assumptions for Energy Storage Technologies

Technology	Power Subsystem Cost $/kW	Energy Storage Subsystem Cost $/kWh	Round-Trip Efficiency %	Cycles
Advanced Lead-Acid Batteries (2,000 cycle life)	400	330	80	2,000
Sodium/Sulfur Batteries	350	350	75	3,000
Flow Batteries	400	400	70	3,000
Compressed Air Energy Storage	700	5	N/A (70)	25,000
Pumped Hydro	1,200	75	85	25,000

- Calculate the annual life cycle cost, including the costs of operations and maintenance, charging electricity, replacement costs, and capital charge.
- Convert to present value for comparison with benefits estimates from published literature.

Results

Results include comparison of annualized costs for energy storage technologies in "load-leveling" mode. This required an update of the energy storage cost model and the cost estimates for hydrogen systems and other technologies. The economic model was then modified for the "spilled wind" application. Figure 1 shows the comparison of hydrogen at medium and low hydrogen cost estimates with other technologies for the spilled wind case. If spilled wind is available free of charge for six hours each day (or night), the hydrogen approach is competitive with other technologies, even compressed air energy storage (CAES).

The present value of costs is compared with the present value of benefits estimated for electric utility value propositions. Figure 2 shows the present value (PV) of costs for load-leveling and spilled wind cases for medium and low-cost hydrogen systems on a $/kW basis, compared with the present value of benefits based on a study published by Sandia National Laboratories (SNL) for the DOE Energy Storage Systems program [5]. These results show a positive benefit/cost ratio if capacity credits are added to time-shift benefits.

Figure 3 shows the same comparison on a $/kWh basis, where benefits have been estimated by the Electric Power

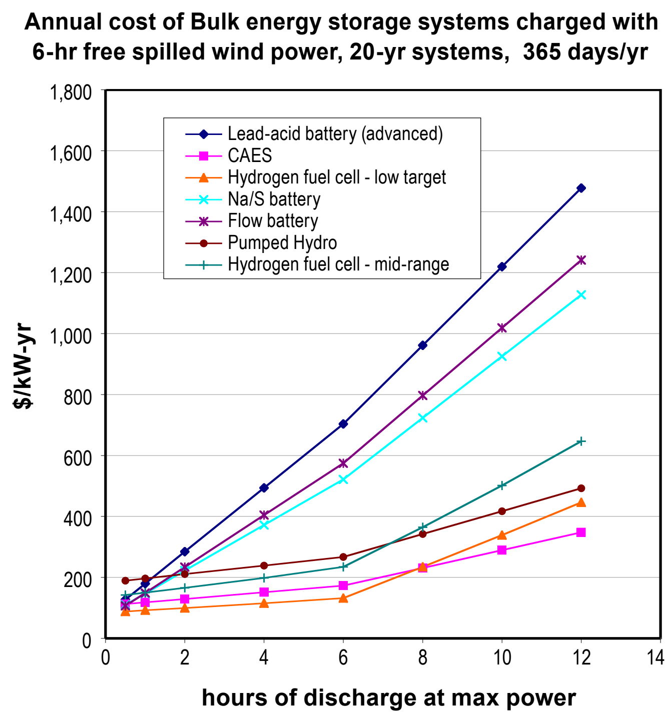

FIGURE 1. Annualized Cost of Energy Storage Systems for Spilled Wind Case

Research Institute (EPRI) [6]. In this case, the energy capacity credit is very large, so that even the medium cost system has a positive benefit/cost ratio. This represents an attractive opportunity for bulk hydrogen storage with wind.

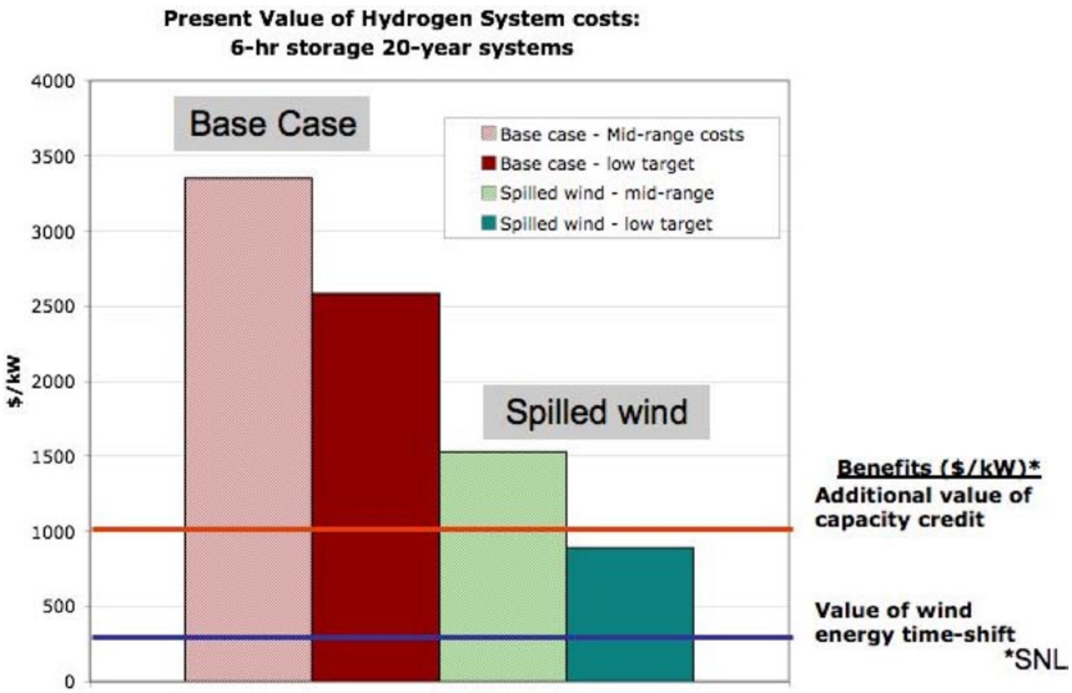

FIGURE 2. Present Value of Costs and Benefits on a $/kW Basis

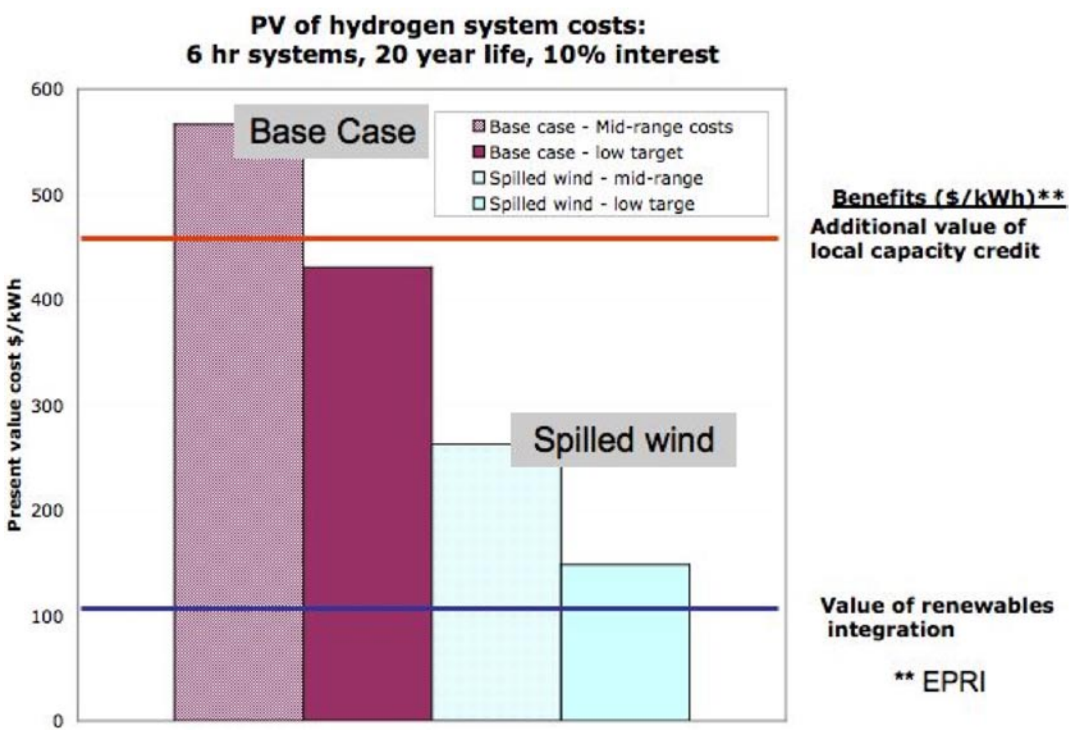

FIGURE 3. Present Value of Costs and Benefits on a $/kWh Basis

Conclusions and Future Directions

Some conclusions from this study include the following:

- Hydrogen energy storage is an ideal match for renewables of all scales, especially large-scale wind, and particularly when excess wind is available off-peak.
- Hydrogen with renewables is effective for reducing greenhouse gases from power generation.
- Underground storage offers opportunities to store hydrogen because it can provide high capacity at cost competitive rates.
- Market opportunities for bulk hydrogen storage need development.

Recommendations for further work include:

- Add scaling considerations to utility business model, considering the spectrum of value propositions, both at much large scale of storage, and smaller scale of storage.
- Add location considerations to cost and benefit analysis.
- Build third-party (non-utility) opportunities into business model.
- Continue discussions and deliberations with commercial interests, market potential.

FY 2011 Publications/Presentations

1. Eyer, Jim and Schoenung, Susan, "A comprehensive survey of utility-related storage: value propositions and technology," Electric Utility Consultants, Inc., *Electricity Storage: Business and Policy Drivers Conference*, 24–25 January 2011, Houston, TX.

2. Schoenung, Susan, "Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications," *International Colloquium on Environmentally Preferred Advanced Generation*, sponsored by the National Fuel Cell Research Center, 8–10 February, 2011, Costa Mesa, CA.

3. Schoenung, Susan, "Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications," *International Conference on Sustainable Energy Storage*, 22–24 February, 2011, Belfast, UK.

4. Schoenung, Susan, "Energy Storage – Emerging technology for climate change mitigation," a lecture at Stanford University, Department of Mechanical Engineering, March 2011.

5. Schoenung, S.M. *Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications*. SAND2011-4845.

References

1. Schoenung, S.M. and Hassenzahl, W.V. *Long- vs. Short-term Energy Storage Technologies Analysis: A Life-Cycle Cost Study*. SAND2003-2783. 2003.

2. Schoenung, Susan and Eyer, James. *Benefit/Cost Framework for Evaluating Modular Energy Storage*. SAND2008-0978. 2008.

3. Steward, D. et al, *Lifecycle cost analysis of hydrogen versus other technologies for electrical energy storage*. NREL/TP-560-46719. 2009.

4. Schoenung, S.M., Energy Storage Systems Cost Update, SAND2011-2730, 2011.

5. Schoenung, S.M., *Economic Analysis of Large-Scale Hydrogen Storage for Renewable Utility Applications*. SAND2011-4845.

6. Eyer, J. and Cory, G., *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide.*" SAND2010-0815. 2010.

7. *Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs and Benefits.* EPRI. 12-23-2010.