II.C.1 Renewable Electrolysis Integrated System Development and Testing

Kevin W. Harrison (Primary Contact),
Bill Kramer, Benjamin Kroposki,
Todd Ramsden, Johanna Levene and
Christopher Pink
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd.
Golden, CO 80401
Phone: (303) 384-7091; Fax: (303) 384-7055
E-mail: Kevin_Harrison@nrel.gov

DOE Technology Development Manager:
Roxanne Garland
Phone: (202) 586-7260; Fax: (202) 586-9811
E-mail: Roxanne.Garland@ee.doe.gov

Technical Advisor: Jamie Holladay
Phone: (202) 586-8804; Fax: (202) 586-9811
E-mail: Jamie.Holladay@pnl.gov

Project Start Date: September 2003
Project End Date: Project continuation and direction determined annually by DOE

Objectives

- Work closely with industry to provide independent testing, validation, and feedback about system performance, potential areas for improvement with regard to integrating renewable sources and advanced hardware, and control strategies to run the equipment.
- Identify opportunities for system cost reductions through breakthroughs and incremental improvements in component integration focused on commercialization and manufacturability.
- Quantify system-level efficiency improvements and cost reductions by designing, building, and integrating dedicated wind-to-electrolyzer stack power electronics to enable closer coupling of wind-generated electricity and electrolyzer stack requirements.
- Model, evaluate, test and optimize the renewable electrolysis system performance for dedicated hydrogen production and electricity/hydrogen cogeneration.
- Characterize and determine the system impacts and the ability of each electrolyzer technology to accommodate the varying energy input from wind turbines and photovoltaics coupled directly to the stack.
- Gain operational experience with a hydrogen production facility, including the compression of product gas and the use of a hydrogen-fueled internal combustion engine to generate electricity during peak demand hours.
- Evaluate safety systems and system controls for the safe operation of hydrogen production technologies.
- Explore operational challenges and opportunities related to energy storage systems and their potential for addressing electrical system integration issues inherent with variable wind-to-hydrogen energy systems.
- Explore system-level integration issues surrounding multiple electrolyzers of proton exchange membrane (PEM) and alkaline technologies that also produce hydrogen gas at different pressures to gauge their efficiencies, responsiveness, and performance to the variability of the wind.
- Create synergies from the coproduction of electricity and hydrogen by:
  - Storing hydrogen for later use. The project thus addresses the variable nature of wind power, creating a ready source of electricity for periods when the wind isn't blowing or the demand for electricity is high.
  - Providing consistent support of the electric grid via off-peak storage of hydrogen.
  - Producing hydrogen for vehicle use.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section (3.1.4) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency
(J) Renewable Electricity Generation Integration

Technical Targets

By addressing the technical barriers of capital costs, system efficiency, and integration with renewable energy sources, this project works to verify and achieve the DOE cost targets for distributed and central electrolytic hydrogen production.

- Distributed Electrolysis
  - By 2012, reduce the cost of distributed production of hydrogen from distributed electrolysis to \$3.70/gge of H_2 (delivered) at the pump.

- By 2017, reduce the cost of distributed production of hydrogen from distributed electrolysis to less than \$3.00/gge of H_2 (delivered) at the pump.

- Central Electrolysis
  - By 2012, reduce the cost of central production of hydrogen from wind electrolysis to \$3.10/gge of H_2 at the plant gate (\$4.80/gge delivered).
  - By 2017, reduce the cost of central production of hydrogen from wind electrolysis to less than \$2.00/gge of H_2 at the plant gate (less than \$3.00/gge delivered).

The detailed economic analyses of current day systems are based on cost data from literature searches, vendor quotes, and discussions with electrolyzer vendors. Three system sizes were considered that represent: (1) a small neighborhood (about 10 kg/day); (2) a small forecourt (about 100 kg/day); and (3) a large forecourt size (about 1,000 kg/day). In this analysis, the hydrogen selling prices were \$14.27/kg H_2 for the small neighborhood size, \$9.12/kg H_2 for the small forecourt size, and \$4.56/kg H_2 for the large forecourt size. (The analysis was performed with 2005 dollars.) For the forecourt case, electricity represents 62% of the cost of the hydrogen, and the capital costs represent only 30%. For the small forecourt case, the electricity contribution drops to 31% and the capital costs increase to 55%. In the neighborhood case, the capital costs continue to be the major cost factor at 64%, but electricity costs are still significant at 20%. This analysis demonstrates that for all systems, electricity price is a major contributor to hydrogen price, but for small-sized electrolyzers, capital costs are more significant.

Accomplishments

- Completed an update to the electrolysis milestone report, *Summary of Electrolytic Hydrogen Production*. The report provides a technical and economic overview of low-temperature electrolytic hydrogen production systems available as of January 2007.
- The electrolytic summary report included an initial cost boundary analysis, which was completed to determine the effects of electricity price on hydrogen costs. For the range of electrolyzers studied, the specific system energy requirement was used to determine how much electricity is needed to produce hydrogen; no capital, operating, or maintenance costs are included in the calculation.
- Developed a model to simulate a 10-kW wind turbine and 6-kW PEM electrolyzer stack. The model enabled the control algorithm to be designed and verified in software and downloaded directly to the controller to improve energy capture over the first generation power electronics system.
- Developed, tested, and demonstrated improved energy capture and hydrogen production of the second-generation power electronics interface between the 10-kW wind turbine and the electrolyzer.

✧ ✧ ✧ ✧ ✧

Introduction

One issue that limits greater penetration of renewable energy sources (e.g. wind and solar) is their variable and seasonal energy production. One solution may be to produce hydrogen through water electrolysis and use that hydrogen in a fuel cell, either to fuel vehicles or to produce electricity during times of low power production or peak demand. Most electrolyzers commercially available today are designed for grid-connected operation; therefore, they incorporate power electronics to convert AC from the grid to DC power required by the cell stack. These power converters can represent 25% to 30% of the total cost of the electrolyzer. Power converters are also required for the renewable energy source. For example, when variable-speed wind turbines use wind energy, they rely on power electronics to convert the variable frequency, variable voltage that is produced at the generator to DC; when connected to the grid, this voltage must be converted back to AC at grid frequency (60 Hz).

Approach

This project examines the design and optimization of electrolyzers, power electronics, and system components to integrate renewables and electrolyzers to improve the efficiency, cost, and robustness of these systems. Hydrogen production via electrolysis is heavily dependent on the cost of electricity. System integration research aims to reduce the costs of hydrogen production by:

- Optimizing and developing new controls, subsystems, and power electronics to improve system efficiency.
- Reducing the capital costs of electrolysis system through new designs with lower cost materials.

Results

In 2006, final construction, shakedown, and programming of the Win2H2 system was completed. The system Hazops team completed the single-mode failure analysis of the system. The work reduced all risk/consequence levels to low with proper engineering controls, safe work practices, and administrative controls. Components were tested individually to debug the system and hydrogen production and compression were started. The second generation power electronics system was further designed and tested to show improved power capture from the 10-kW wind turbine to the 6-kW electrolyzer stack.

One goal of this work is to characterize system performance and develop power electronics and control algorithms to optimize the production of hydrogen from wind power. Baseline testing of the Xcel/NREL wind to hydrogen (Wind2H2) project was started to provide data about system performance under steady power provided from the utility (Figure 1). NREL used the simulation and test results completed last quarter to continue developing a second generation power electronics interface and control strategy. Adjustments were made to the thyristor bridge to maximize its effectiveness throughout the expected operating frequency and voltage range of the 10-kW wind turbine. The software was completed to protect the system during high-current, high-voltage, and low-frequency operation. The second generation AC/DC power electronics were designed and tested on the Wind2H2 system (Figure 2).

The second power electronics design demonstrated improved energy capture from the 10-kW wind turbine over the first generation model tested last year (Figure 3).

Conclusions and Future Directions

In 2006, the Wind2H2 construction project neared operational readiness. Individual devices were tested while full-system operation remains to be completed in 2007. A second generation AC to DC power converter was designed, modeled, built and tested. Improved control of the power electronics demonstrated improved energy capture from a 10 kW variable-speed wind turbine.

Future work will include sensor calibrations and hardware installation to allow direct communications with the PEM electrolyzer for automated unattended operation. The 800-VDC to 150-VDC power converter will be designed and tested during the coming wind season to power the 30-kW alkaline electrolyzer stack.

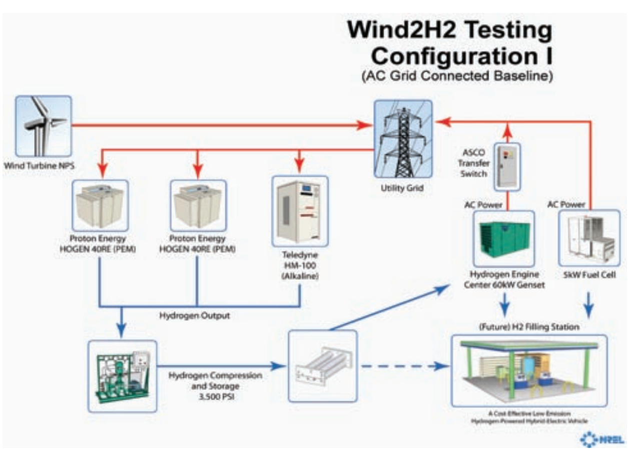

FIGURE 1. FY 2007 System Configuration for Baseline Testing

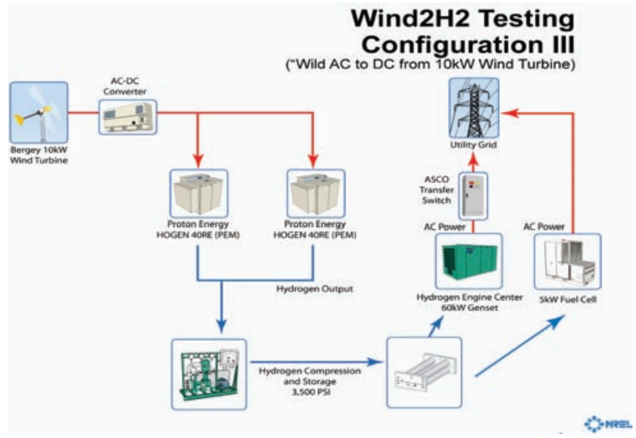

FIGURE 2. FY 2007 System Configuration for 10-kW Wind Turbine to 6-kW Electrolyzer Stack Testing

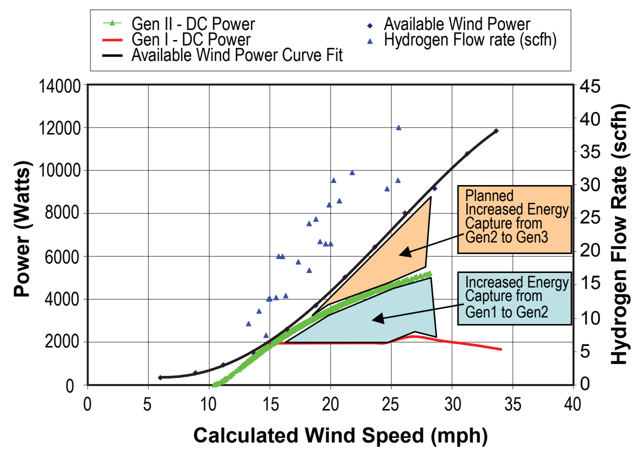

FIGURE 3. Composite Graph of Improved Power Capture of Second Generation Power Electronics Design

FY 2007 Publications/Presentations

1. Harrison, K., Kramer, W., Kroposki, B. (2006). Interim Status Report on Xcel/NREL Wind to Hydrogen Demonstration Project - Renewable Electrolysis Milestone Report 3.7.5.

2. Harrison, K., Kroposki, B., Pink, C. (2006). Characterizing Electrolyzer Performance for Use with Wind Turbines, AWEA Conference, June 4–7, Pittsburg, PA.

3. Levene, J.; Kroposki, B.; Sverdrup, G. (2006). Wind Energy and Production of Hydrogen and Electricity – Opportunities for Renewable Hydrogen: Preprint. 18 pp.; NREL Report No. CP-560-39534.

4. Kroposki, B. (2006). Renewable Electrolysis Integrated System Development and Testing (Presentation). 27 pp.; NREL Report No. PR-560-39803.

5. Kroposki, B.; Levene, J.; Harrison, K.; Sen, P.K.; Novachek, F. (2006). *Electrolysis: Information and Opportunities for Electric Power Utilities*. 33 pp.; NREL Report No. TP-581-40605.

6. Levene, J. I.; Kroposki, B.; Sverdrup, G. (2006). Wind Energy and Production of Hydrogen and Electricity -- Opportunities for Renewable Hydrogen (Presentation). 7 pp.; NREL Report No. PR-560-39767.

7. Harrison, K. W.; Kroposki, B.; Pink, C. (2006). Wind Energy and Production of Hydrogen and Electricity – Opportunities for Renewable Hydrogen (Presentation). 28 pp.; NREL Report No. PR-560-40100.