VI.G.2 Power Parks System Simulation

Andrew Lutz
Sandia National Laboratories
P.O. Box 969, MS 9052
Livermore, CA 94551-0969
Phone: (925) 294-2761; E-mail: aelutz@sandia.gov

DOE Technology Development Managers:

Sigmund Gronich
Phone: (202) 586-1623; Fax: (202) 586-9811
E-mail: Sigmund.Gronich@ee.doe.gov

John Garbak
Phone: (202) 586-1723; Fax: (202) 586-9811
E-mail: John.Garbak@ee.doe.gov

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Objectives

- Develop a flexible system model of distributed generation in H_2 power parks.
- Analyze the efficiency and cost of producing H_2 and electricity at DOE facilities.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section (3.5.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(C) Hydrogen Refueling Infrastructure
(H) Hydrogen from Renewable Resources
(I) Hydrogen and Electricity Coproduction

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE technology validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

Milestone 11: Validate cost of producing hydrogen in quantity of $3.00/gge untaxed. The analysis uses data from the hydrogen power parks to compute the cost of hydrogen and extrapolate it to the production scale specified in the technical targets.

Milestone 15: Validate co-production system using 50 kW PEM fuel cell; hydrogen produced at $3.60/gge and electricity at 8 cents/kWh. The analysis performed simulations of hydrogen production and stationary fuel cells to produce electricity.

Milestone 20: Validate $2.85/gge hydrogen cost from biomass/wind (untaxed and unpressurized) at the plant gate. The analysis considers the projected cost of hydrogen through the use of a potential wind turbine.

Accomplishments

- H_2Lib contains models for reformers, fuel cells, compressors, pressurized storage, electrolyzers, photovoltaic (PV) collectors, chillers, heat exchangers, and wind turbines.
- Data from the DTE Energy (DTE), Arizona Public Service (APS), and Hawaii Natural Energy Institute (HNEI) facilities were used to calibrate the electrolyzer and fuel cell models. Economic analysis shows that electrolyzers can produce H_2 at a cost approaching the 2005 goal of $4.75/kg specified in the DOE Multi-Year Research, Development and Demonstration Plan (MYRDDP).
- Analysis of a potential wind turbine using data from a site on the Big Island of Hawaii shows that the projected cost of H_2 will be higher than the $2.85/kg target.

Introduction

The Hydrogen Program research plan [1] envisions the transition to widespread distribution of hydrogen refueling facilities will likely begin with distributed generation. Sites where power generation is co-located with businesses or industrial energy consumers are called power parks. Hydrogen power parks use combinations of technologies for the co-production of electricity and H_2, including renewable technologies such as PV and wind. The variety of technologies proposed suggests that each system will be different. A flexible simulation tool is useful in evaluating the various systems and optimizing their performance with respect to efficiency and cost.

Approach

This project has two primary deliverables: 1) technical/economic performance analysis of hydrogen validation projects worldwide and 2) H_2Lib, a flexible tool for simulation of H_2 systems, constructed in the language of the Simulink software [2]. Simulink provides a graphical workspace for block diagram construction and the flexibility to quickly assemble or reconfigure a system. We extended Simulink's existing library with a customized library of components for a H_2 system. The models are based on fundamental physics as much as possible, and can be adjusted to represent specialized components. Modules that handle gas/liquid mixtures use the Chemkin [3] package to provide thermodynamic properties.

Results

While we continued to survey operation data at three power parks (DTE, APS, and HNEI), this year's analysis focused on the DTE Hydrogen Technology Park. This report describes analysis of the electrolytic production of H_2 at the DTE park, with direct comparison to the data provided to Sandia by DTE [4], and analyzed in collaboration with Lawrence Technological University (LTU). In addition, this report describes analysis of a wind energy project that is being considered by HNEI for siting on the Big Island of Hawaii as part of their hydrogen project [5].

The DTE Hydrogen Technology Park contains a nominally 200 kW electrolyzer system, several high-pressure storage tanks, a vehicle refueling dispenser, a set of ten 5 kW fuel cell systems, and two photovoltaic arrays. Operational data from the system is provided via a secure web interface, and in collaboration with Elliott Schmitt (LTU), we have selected data for analysis and comparison with the model. An example of the data analysis is provided in Figure 1, which shows two representations of the electric-to-H_2 efficiency of the electrolyzer. The efficiency is defined as the H_2 flowrate times the lower heating value divided by the power supplied to the electrolyzer, including the stack and balance-of-plant, but excluding the compression work. The circles in the plot are the efficiency averaged over monthly periods, including times when the unit is on standby and consuming some power, but not producing any H_2. For comparison, the diamonds in the plot are efficiency averages taken over periods of at least 10 hours of steady operation, reflecting the best observed efficiency. The difference between these averages emphasizes the effect of duty cycle on the overall efficiency, much as the fuel economy that a vehicle experiences depends on the driving cycle.

Over the eight months of operation, the average electrolyzer efficiency was 48%, compared to a steady-operation average of 59%. This value is compared to the MYRDDP targets in Table 1. Including compression, the total system efficiency is 57% for steady-operation. The MYRDDP groups component efficiencies in two categories: (1) the cell stack and balance-of-plant and (2) the compression, storage and dispensing. The efficiency for the first component group and the total system are defined as ratios of the H_2 produced times a lower heating value to the sum of the electrical

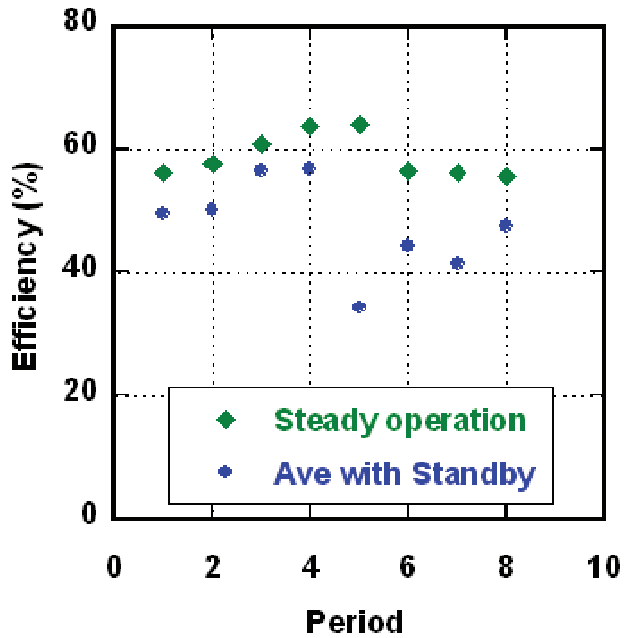

FIGURE 1. Efficiency (based on H_2 lower heating value) of the electrolyzer operated at the DTE Hydrogen Technology Park. Circles are monthly averaged performance, including stand-by operation; diamonds are the steady-state operation averaged over periods of at least 10 hours.

work input. However, the efficiency labeled for the compression group is a relative factor between the electrolyzer and the total system. Table 1 shows that operational data met the plan target for this relative factor. Using an absolute definition of compressor efficiency–the ratio of the isentropic work required by an idealized two-stage compressor to the actual work–shows that the average compressor efficiency was 67%.

TABLE 1. Electrolyzer System Data Compared to DOE MYRDDP Targets

	DTE Data	2005 Target	2010 Target
Cell & BOP	59%	68	76
Compression, Storage, Dispensing	95%	95	99
Total	57%	64	75

The economic analysis of the H_2 production used the steady-operation efficiency for the electrolyzer and assumed that the unit would operate using DTE Energy's off-peak energy rate of 2.5 cents/kWh. The MYRDDP cost targets are defined for a 70% capacity factor, which is nearly equal to the fraction of off-peak hours, but in practice, there would be higher demand charges for using some peak electricity. All other parameters in the economic analysis are taken from the defaults defined by the H2A project [6]. Since the DTE park is designed to produce roughly 50 kg/day, while the MYRDDP sets the target cost for a 1,500 kg/day facility, a significant task in the analysis is scaling the costs with facility size. The analysis scales the total capital cost of the electrolyzer system, including compression and dispensing, to the 0.6 power of H_2 production rate; the resulting curve is shown in Figure 2. This scale factor is based on literature estimates of electrolyzer unit costs (reported previously). The resulting projected cost of H_2 is shown in Figure 3. While the actual cost of H_2 for the existing facility is nearly $20/kg, the projected cost for a target facility approaches $5/kg. This suggests that it may be feasible to meet the near-term (2005) target of $4.75/kg; however, significant innovations to reduce the capital cost and improve efficiency will be necessary to reach the longer-term goal of $2.85/kg.

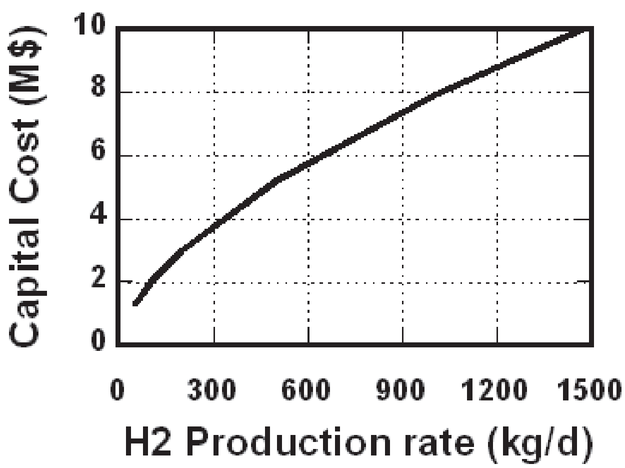

FIGURE 2. Power-law correlation between capital cost for the electrolyzer system and H_2 production rate used in economic analysis to scale the facility to the DOE target size.

Another significant modeling activity this year considered a wind turbine that the Hawaii Natural Energy Institute is proposing to locate at Kahua Ranch on the Big Island [5]. The turbine is rated at 500 kW, with a swept area of 866 m^2 and a hub height of 30 m.

We recently developed modules to describe the wind resource and turbine. The wind resource model accepts average air density and hourly average wind speed data, and characterizes wind shear using a power-law relationship. Wind data used for the analysis comes from a 1993 study [7] and is shown in Figure 4 in the form of the probability density function of the wind speed; the average wind speed is 7.3 m/s. The predicted capacity factor for this data is 24%. To consider a more optimistic wind resource, we factored in longer-term data [5] that had a higher average wind speed of 9.1 m/s, leading to a capacity factor of 37%. This scenario was simulated in the model by simply increasing the hourly dataset to obtain the higher average speed. The results of the two scenarios are presented in the economic analysis.

The wind turbine model uses a power map provided by the manufacturer to predict the electrical output versus wind speed. The model can evaluate the wind turbine output at various hub heights, based on the wind shear model. The electricity cost includes the capital cost of the turbine, including the tower and installation. Since constructing taller towers costs more, there is a trade-off between that cost and the increased power due to higher wind speed. We performed a parameter study to find that the optimal tower height is 40 m, although the difference between 40 m and 30 m is relatively slight–a few tenths of cents per kWh of the roughly 9 cents/kWh.

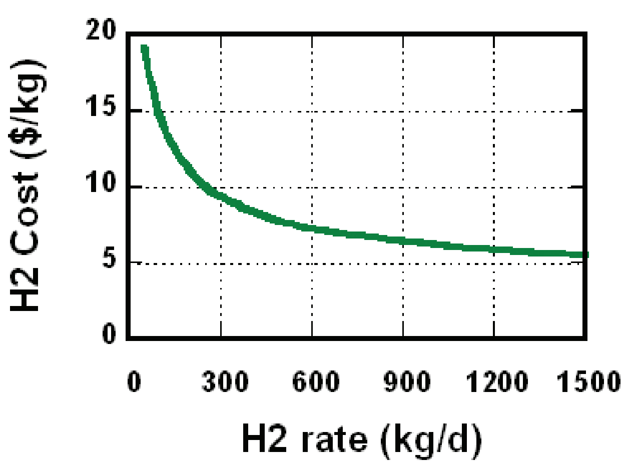

FIGURE 3. Levelized-cost of H_2 from electrolysis projected against production rate using the capital cost correlation in Figure 2.

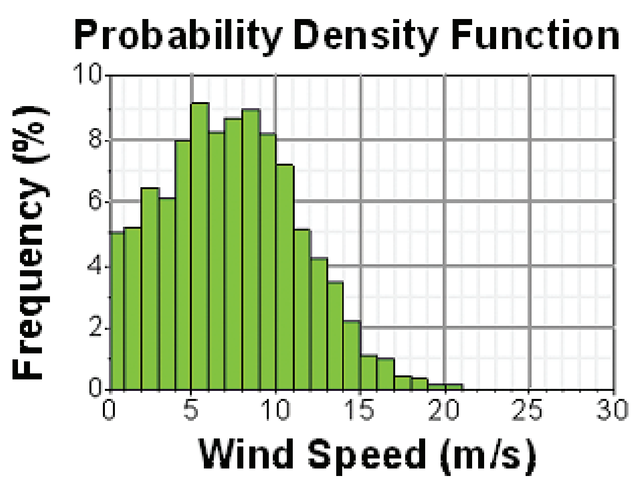

FIGURE 4. Probability density function of wind speed for the data at Kahua Ranch, Big Island, HI.

The objective of the demonstration is to couple the wind turbine to an electrolyzer to produce hydrogen for vehicles. To examine the cost of hydrogen that could be produced from this source, the model couples the wind turbine to an electrolyzer producing 50 kg/day at an expected electric-to-hydrogen efficiency of 60% (LHV), including compression. The proposed wind turbine will be connected to a DC-bus that will both feed the electrolyzer and the electric grid via an inverter. In this way the electrolyzer does not need to be sized to handle peak wind turbine output, reducing capital costs. Projected costs of the hydrogen are shown in Figure 5 in a parameter study on the electricity price and capital cost of the electrolyzer. The analysis uses the 30 m hub height for the turbine, with electricity costs of 6 and 9 cents/kWh, corresponding to the long-term or 1993 wind data. The resulting hydrogen cost varies between $5 and $11/kWh over the range of expected electrolyzer capital costs.

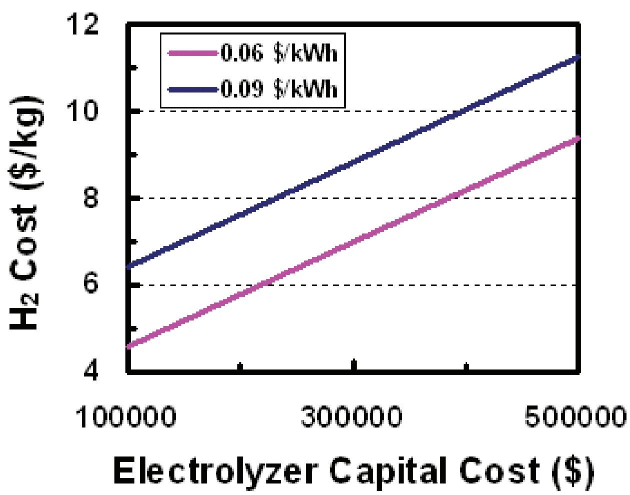

FIGURE 5. Projected cost of hydrogen produced by electrolysis using the power from the wind turbine at Kahua Ranch.

Conclusions and Future Directions

- Given demonstrated efficiency and projected capital cost scaling with production rate, distributed H_2 production by electrolysis may approach the 2005 goal of $4.75/kg for a 1,500 kg/d facility using off-peak electricity at 2.5¢/kWh. However, significant capital cost reductions and efficiency improvements are necessary to reach the 2010 goal of $2.85/kg.
- Distributed H_2 production by electrolysis at a proposed wind turbine facility on the Big Island of Hawaii is expected to be in the range of $5-$11/kg for a 50 kg/day system.
- Continue to compare the simulations with data collected from the APS, DTE, and HNEI sites to determine the economics and efficiencies required to meet Plan targets.
- Extend the H_2Lib tools to include availability analysis using the second-law of thermodynamics to identify where the efficiency of H_2 production pathways can be improved.

References

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