VIII.F.2 Power Parks System Simulation

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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 Technology Validation projects/facilities.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section 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 Co-Production

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 and other technology validation projects 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 50kW PEM fuel cell; hydrogen produced at $3.60/gge and electricity at 8 cents/kWh.* The analysis performs simulations of hydrogen production for vehicle fueling and stationary fuel cells to produce electricity.

Approach

- Use a library of modules (H_2Lib) developed for the various components to assemble system models of power parks.
- Compare simulations to the operational data from demonstration sites.

Accomplishments

- H_2Lib contains models for reformers, fuel cells, compressors, pressurized storage, electrolyzers, photovoltaic (PV) collectors, chillers, and heat exchangers.
- A detailed engineering model for a polymer electrolyte membrane (PEM) fuel cell stack was developed that simulates performance using a polarization curve calibrated to data.
- Data from the 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 near the 2005 goal specified in the DOE Multi-Year Research, Development and Demonstration Plan (MYRDDP).
- Economic analysis of the steam reformer at the City of Las Vegas (CLV) facility showed that distributed H_2 production costs are close to the 2005 target of the MYRDDP.

Future Directions

- Continue to develop additional modules in the Simulink library, including a wind turbine and a H_2-fueled reciprocating internal combustion engine generator.
- Compare the simulations with data collected from the APS, DTE, and HNEI sites to determine the economics and efficiencies required to meet Plan targets.

Introduction

The Hydrogen Program MYRDDP [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) the creation of 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, and can be adjusted to represent specialized components. Modules that handle gas/liquid mixtures use the Chemkin [3] package to provide thermodynamic properties.

Results

This year's analysis focused on the electrolysis systems at the APS and HNEI power parks. The detailed electrolyzer model developed last year was calibrated using site-specific performance data for electrolyzer power and H_2 production. An example of the model calibration is shown in Figure 1 for the HNEI electrolyzer data [4]. HNEI operated the electrolyzer at five different load points between half and full power. The electrolyzer model uses a polarization curve represented by the green line in Figure 1, which is adjusted to match the linear region where the data is available. The resulting electrolyzer efficiency for this unit varies from 57% at half-power to 51% at full load.

Using the calibrated electrolyzer model, the simulation projects the cost of distributed H_2 production using a levelized cost approach consistent with the analysis embodied in the H_2A spreadsheet [5]. The total H_2 cost includes the capital cost (spread over a 20-year life), the feedstock (electricity) cost, and the O&M costs, which are scaled to 2% of the capital cost for the calculations in this report. A parameter study of the projected H_2

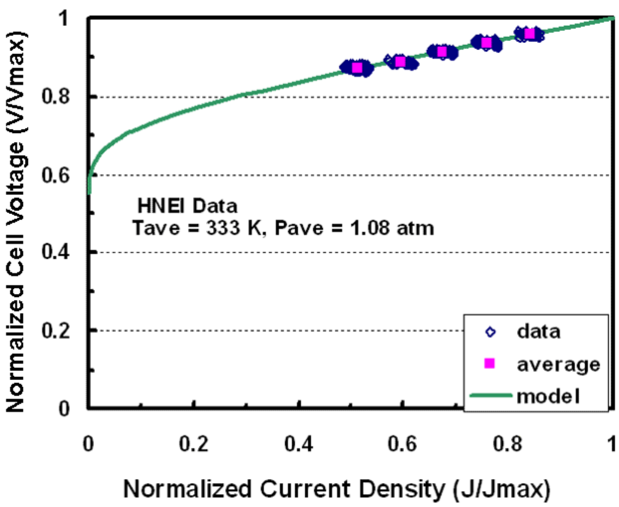

Figure 1. Normalized Voltage-Current Curve fit to the HNEI Electrolyzer Data

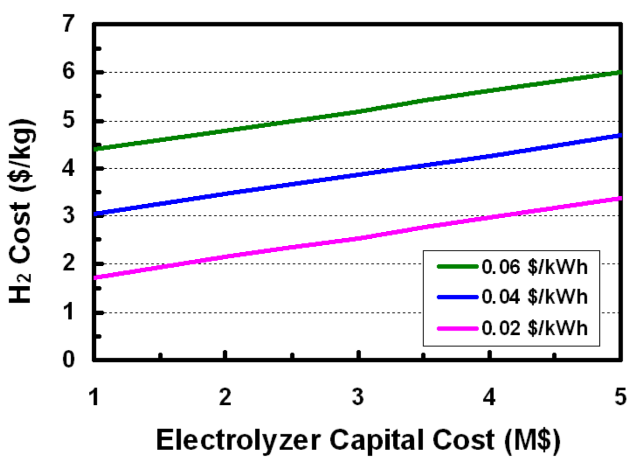

Figure 2. Parameter Study for H_2 Cost Versus Electrolyzer Capital and Electricity Price

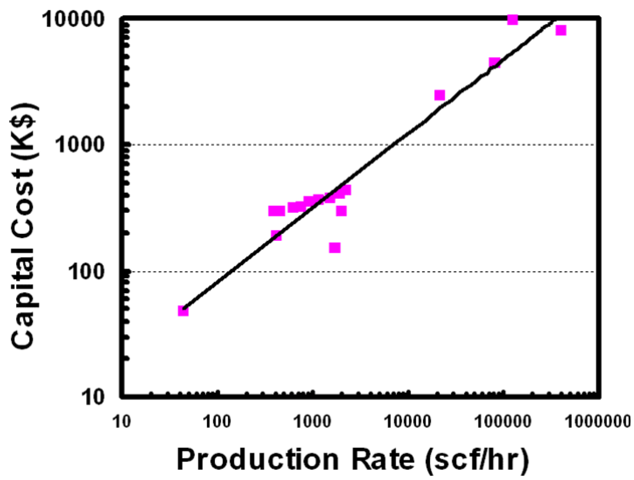

Figure 3. Trend for Electrolyzer Capital Cost versus H_2 Production Rate

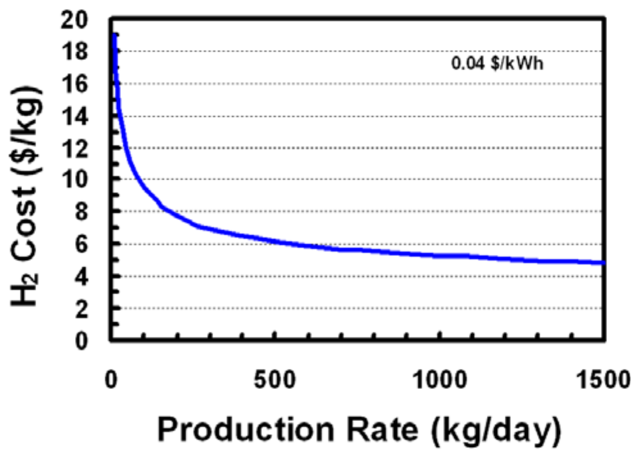

Figure 4. H_2 Cost Projected for Electrolysis versus Production Rate, Scaled to the Plan Target of 1500 kg/day

costs is shown in Figure 2, where the electrolyzer capital cost and the cost of the electricity are varied; the projected H_2 cost varies between 2 and 6 $/kg. The electrolyzer is operated at full load at the target facility scale of 1500 kg/day, which is significantly larger than the actual HNEI facility.

In order to extrapolate the electrolyzer to the Plan's target size, the capital cost and production rate are simultaneously varied, using a fit to literature cost values shown in Figure 3. The electrolyzer at HNEI produces 12 kg/day (200 scf/hr), compared to the target of 1500 kg/day (25,000 scf/hr). The simultaneous variation of capital cost and size produces the nonlinear economy-of-scale in the H_2 cost shown in Figure 4. While the projected H_2 cost for the small-scale electrolyzer is nearly $20/kg (using 4¢/kWh for electricity), the projected cost at 1500 kg/day is $4.86/kg, which is close to the $4.75/kg target. The parameter studies suggest that the electrolyzer capital cost must be reduced drastically to reach the 2010 target of $2.85/kg.

Similar results were obtained for analysis of the electrolyzer operation at the APS facility. While the PEM electrolyzer operated at APS is a different technology from the alkaline unit at HNEI, the projected cost of H_2 follows similar trends. Data collected on the PEM electrolyzer at APS showed that it operated at 35% overall efficiency at peak load. This rather low efficiency leads to projected H_2

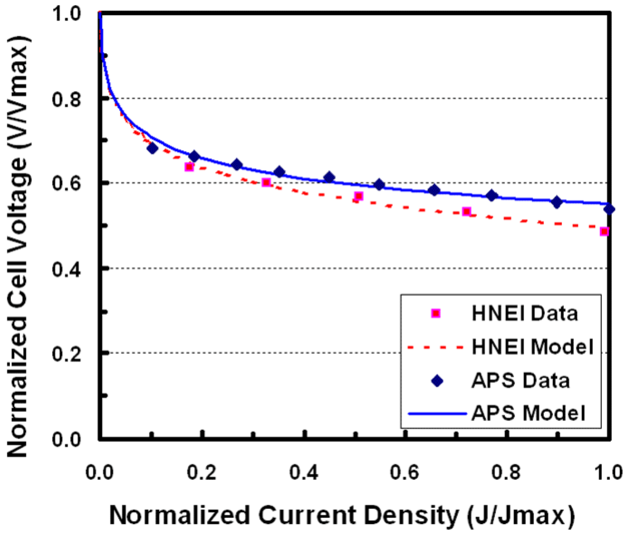

Figure 5. Normalized Polarization Curves for Fuel Cell Data Collected at HNEI and APS

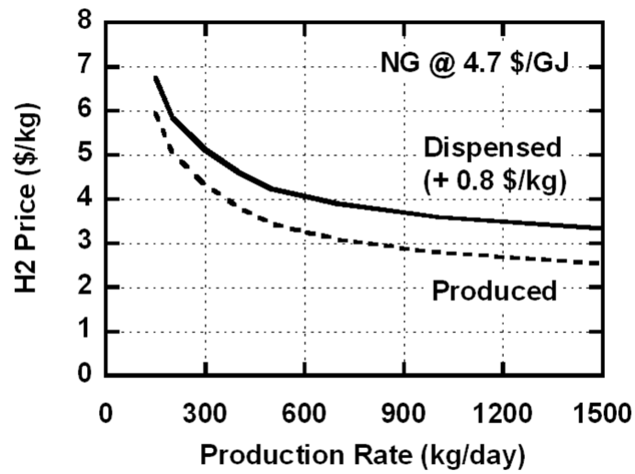

Figure 6. H_2 Cost Projected for Steam Reforming versus Production Rate, Scaled to the Plan Target of 1500 kg/day

costs of $5.50/kg when extrapolated to the target size. However, if the efficiency could be improved to the Plan's target of 68%, then the H_2 cost would be reduced to $3.70/kg—below the 2005 target.

In addition to vehicle refueling, both the HNEI and APS facilities include 5kW stationary fuel cell stacks for electricity generation to provide power at peak loads. The model calibration to the site data is shown by the polarization curves in Figure 5; the diamonds and solid curve represent the APS data and fit, while the squares and dotted curve represent HNEI results. While still under investigation, the significant variation between these similar Plug Power units may represent degradation with different amounts of operating time or variation between units. A parameter study for a range of capital cost for the fuel cell stack between 1000 and $5000 /kW, the resulting electricity price is in the range of 0.35 to $0.50/kWh, using H_2 at $4.86/kg from the HNEI electrolyzer. This electricity price is nearly an order of magnitude higher than the co-production target of 8¢/kWh, suggesting that both the H_2 cost and the fuel cell capital cost will have to be reduced.

The model was also applied to H_2 production by steam reforming as demonstrated at the CLV refueling station. The model predicts that the reformer can run at 68% thermal efficiency. Using a capital cost versus production rate correlation, the projected economy-of-scale for H_2 price is shown in Figure 6. The dashed curve is cost for H_2 produced and compressed to 5000 psi; the solid curve adds $0.80/kg for the cost of dispensing. The results suggest that distributed reforming can produce H_2 near the 2005 target of $3/kg.

Conclusions

- Given demonstrated efficiency and literature-based capital cost scaling with production rate, distributed H_2 production by electrolysis can potentially reach the 2005 goal of $4.75/kg using electricity at 4¢/kWh. Capital cost reductions and efficiency improvements are necessary to reach the 2010 goal of $2.85/kg.
- Distributed H_2 production by steam reforming can also reach the 2005 goal of $3/kg, using natural gas at $4.70/GJ.

FY 2005 Publications/Presentations

1. DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program Systems Analysis Workshop, Washington, D.C., July 28-29, 2004.

References

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2. Simulink. The MathWorks, Inc, MA, 2002.

3. The CHEMKIN program and subroutine library are part of the Chemkin Collection, Release 3.7, Reaction Design, Inc., San Diego, CA (1999).
4. Ewan, M., HNEI, private communication (2005).
5. Mann, M., NREL, private communication (2005).
6. Hobbs, R., "Technology Validation: Hydrogen Power Park Business Opportunities Concept Project", APS Quarterly Report, December (2004).