VI.B.2 Power Parks System Simulation

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Project Start Date: FY 2002
Project End Date: FY 2008

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 demonstration 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) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
(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 24: 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 for comparison to the technical targets.
- **Milestone 35: Validate \$1.60/gge hydrogen cost from biomass and \$3.10/kg for renewable/electrolysis (untaxed and unpressurized) at the plant gate.** The analysis considers the projected cost of hydrogen from wind turbines and biomass gasification.
- **Milestone 36: 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.

Approach

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

Accomplishments

- H_2Lib provides a set of engineering models for the components of H_2 power systems.
- Data from the DTE Energy (DTE), Arizona Public Service (APS), and Hawaii Natural Energy Institute (HNEI) facilities were used to calibrate the models.
- Developed a model for the Italian “Hydrogen from the Sun” house (International Energy Agency [IEA] Task 18).
- Exergy computations now allow for second-law availability analysis of H_2 production.

Future Directions

- Compare simulations with new data collected from the DTE and HNEI sites to determine the economics and efficiencies required to meet the Plan targets.
- Support IEA Task 18 working group by providing analysis of H_2 demonstration projects.

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Introduction

The Hydrogen Program research plan [1] envisions the transition to widespread distribution of hydrogen refueling facilities will likely begin with distributed generation at sites called power parks. Hydrogen power parks use combinations of renewable technologies for the co-production of electricity and H_2. A flexible simulation tool is useful in evaluating the variety of systems and technologies.

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 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, based on fundamental physics. Modules that handle gas/liquid mixtures use the Chemkin [3] package to provide thermodynamic properties. Control systems are modeled within Simulink to provide guidance on system operation and economics [4].

Results

While we continued to survey and analyze operation data at DOE demonstrations (APS, DTE, HNEI), we added a new focus this year on the "Hydrogen from the Sun" project located in Brescia, Italy, in support of the International Energy Agency Hydrogen Implementing Agreement Task 18: Integrated Systems.

Analysis of Italian Hydrogen Demonstration

The "Hydrogen from the Sun" project, developed in conjunction with the European Union (EU) and a private investor, is modeled to provide an economic, thermodynamic, electrical and control system analysis. This project is important to the DOE in supporting IEA Task 18 commitments and meeting Plan targets with further technical data.

The H_2 house is intended to operate independent from the electrical grid during times of emergency. Power for the private residence is managed by the load management system and supplied by a 5 kW polymer electrolyte membrane fuel cell (PEMFC), a 3,000 A-h battery and the photovoltaic (PV) panels. The PV panels supply 11 kW at peak solar incidence; this is connected through a DC-to-DC converter and bus bar system to the 6.7 kW alkaline very high pressure electrolyzer, which produces 1 Nm^3/hr of hydrogen at 200 bar. The electrolyzer can only operate when the solar power is greater than 6.7 kW. The load management system controls the flow of the PV power such that when the electrolyzer is not in operation, the PV can power the load directly. A schematic of the "Hydrogen from the Sun" project is shown in Figure 1.

The stochastic nature of the solar energy collection is handled by a fuzzy logic control system that provides continuous control conditions, instead of direct digital control, where boundaries are rigidly fixed. For example, if the PV supplied is just above 6.7 kW for 10 s, it is not practical to pulse the electrolyzer system. Using fuzzy logic, the control system will continue to charge the battery until the PV output is sufficient for electrolyzer operation. The smoother system response is defined through a control surface, as shown in Figure 2 and the system response output from Simulink is shown in Figure 3. A similar control system strategy is applied to the grid connection and the hydrogen flow between tank and metal hydride storage. The control strategy uses the metal hydride storage as the primary storage, and the pressurized tanks as secondary storage [5].

The site does not contain a hydrogen refueling station, and therefore the electrolyzer and hydrogen storage were sized to supply the fuel cell load only.

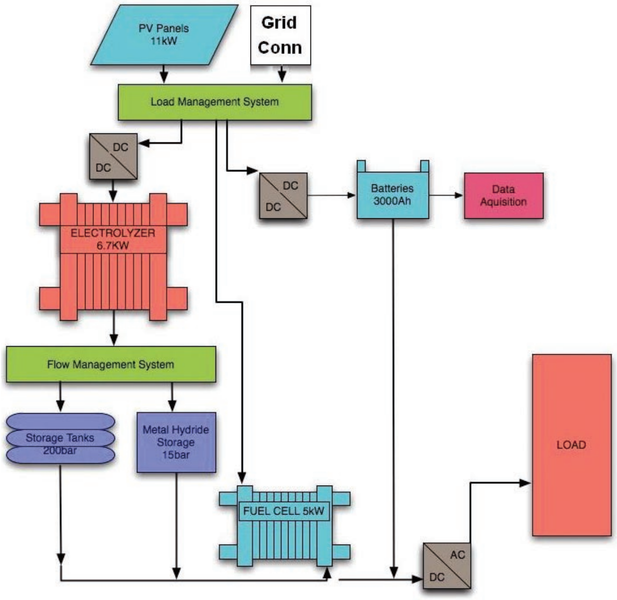

FIGURE 1. Schematic of the Italian "Hydrogen from the Sun" Project, Including PV Panels, Electrolyzer, Fuel Cell, Batteries, Storage and the Control and Management Systems

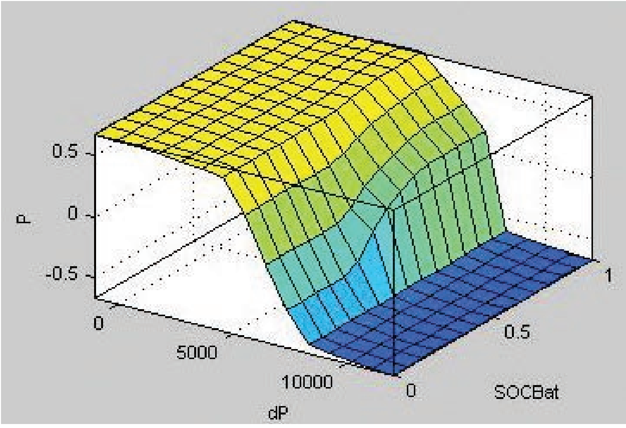

FIGURE 2. Fuzzy Logic Surface Map of the Power Control Signal (P) versus the PV Input (dP) and the Battery State-of-Charge (SOC)

This results in a higher cost overall for the hydrogen of $23/kg (Table 1). The economic analysis of the H_2 production used the steady-operation efficiency for the electrolyzer and assumed that the unit would operate using the off-peak energy rate of 2.5 cents/kWh. All other parameters in the economic analysis are taken from the defaults defined by the H_2A project [6].

TABLE 1. Hydrogen Costs from the Italian "Hydrogen from the Sun" Project by Components, Illustrating the High Percentage Capital Cost Comprises

Contribution	$/Kg-H2
Capital	15.67
Feedstock	5.00
Operations & Maintenance	2.27
TOTAL	22.94

The electrolyzer system efficiency is predicted to be 54%, where 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.

Analysis of Biomass Gasification

Analysis of hydrogen production by a biomass gasification process being pursued at HNEI is in progress, starting with establishing the validity of an equilibrium model. The gas composition measured in experiments by Turns et al [7] is compared to the model in Figure 4. The experiments included trials with individual parameter variations that examine the effects of temperature, steam, and oxygen. The equivalence ratio is defined as the actual oxygen-to-fuel ratio divided by the stoichiometric oxygen-to-fuel ratio, such that equivalence ratios from 0 to 0.4 are fuel rich. The compositions in Figure 4 represent the gas mixture after gasification and removal of water and nitrogen. For the variation in equivalence ratio, the trends of hydrogen, carbon dioxide, and carbon monoxide are captured with reasonable agreement. However, chemical equilibrium does not predict any methane formation, whereas the experiments found up to 10%, suggesting that there are kinetic limitations on the conversion of methane. The experiments noted some char/tar formation, without quantitative measurements; in contrast, the equilibrium composition does not contain any solid carbon (representing char) at these conditions.

Exergy Analysis of Steam Methane Reforming

The evaluation of available energy (exergy) now exists as a module in the H_2Lib palette of Simulink tools. As a demonstration of the utility of exergy analysis, Figure 5 shows a pie chart of the unused exergy–exhaust plus destroyed–in steam-methane reforming (SMR). The majority of the exergy destruction occurs in the reformer, due to irreversibilities inherent in the reaction, heat transfer, and mixing. Heat transfer in other components in the SMR system accounts for significant exergy destruction. Analysis of first-law energy conservation alone would suggest the exhaust is the main cause of inefficiency. Second-law exergy analysis shows that exergy is left unused in the exhaust, but it is not the major cause for the loss of useful energy.

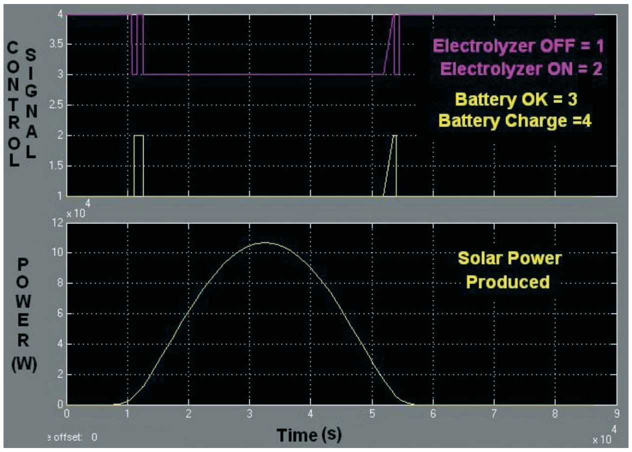

FIGURE 3. Response of Italian "Hydrogen from the Sun" Model to Control Inputs for the Electrolyzer Only Being Active at Optimal Power Points Supplied from the PV

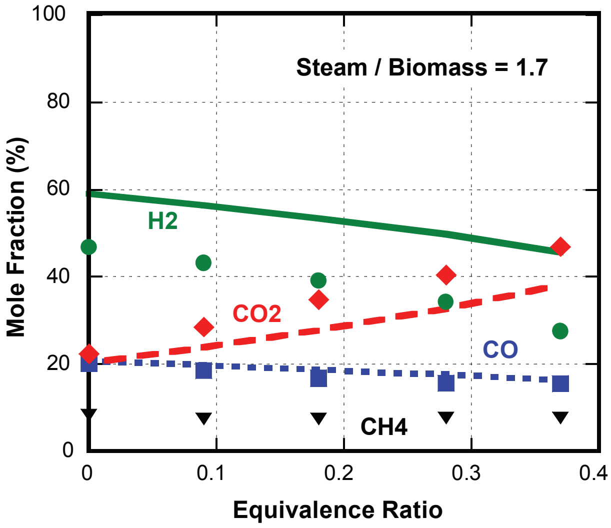

FIGURE 4. Species mole fraction from the gasification of biomass at 850°C, steam-to-biomass ratio of 1.7 (by mass), and varying equivalence ratio. Curves are chemical equilibrium; symbols are experimental data from Turns et al [4].

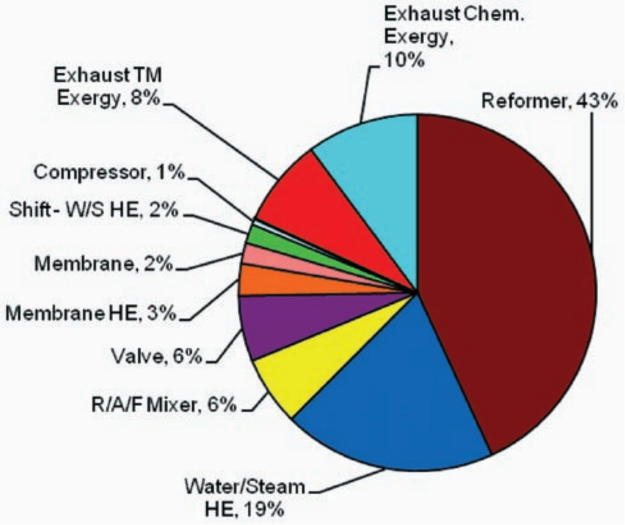

FIGURE 5. Breakdown of Unused Exergy (Exhaust Plus Destroyed) in a Steam-Methane Reformer

Conclusions and Future Directions

- Italian H_2 Demonstration
  - Analysis of the Italian H_2 demonstration predicts that hydrogen will be produced at an efficiency of 54% and a cost of \$23/kg. The high cost is due to the small electrolyzer being sized for the residential load.
  - The model demonstrates a control system that will be used to compare strategies for optimal economic and thermal efficiency.
  - Validation will use operation data from the facility as it becomes available.
- HNEI H_2 Demonstration
  - Future analysis of the gasification process will include kinetic parameters and include a complete system model of the gasification process.

FY 2007 Publications/Presentations

1. NHA 2007 paper presented "Analysis of the Italian Hydrogen House" Emma M. Stewart, A.E. Lutz, S. Schoenung, M. Chiesa.

References

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7. Turns, S., Kinoshita, C., Zhang, Z., Ishimura, D., and Zhou, J., "An Experimental Investigation of Hydrogen Production from Biomass Gasification", *Int J Hydrogen Energy*, Vol. 23, No. 8, pp. 641-648, 1998.