VII.11 Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems*

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Partners:

- State of Hawaii Department of Business, Economic Development & Tourism, Honolulu, HI
- City and County of Honolulu, Honolulu, HI
- Hawaiian Electric Company, Honolulu, HI
- Hawaii Electric Light Company, Hilo, HI
- The Gas Company, Honolulu, HI
- Airgas Gaspro, Honolulu, HI
- Sandia National Laboratories (SNL), Albuquerque, NM
- Hydrogenics/Stuart Energy, Mississauga, ON, Canada
- Electric Hydrogen, Toronto, ON, Canada
- MVSystems, Inc., Golden, CO
- ClearFuels Technology, Aiea, HI
- New Mexico Institute of Mining and Technology, Socorro, NM
- General Electric Global Research Center, Niskayuna, NY
- Hawaiian Commercial & Sugar Company, Puunene, HI
- Center for a Sustainable Future, Honolulu, HI
- Pacific International Center for High Technology Research, Honolulu, HI
- Sentech, Inc., Bethesda, MD
- Kahua Ranch, Kahua Ranch, HI
- Benemann Associates, Walnut Creek, CA

Project Start Date: March 15, 2004
Project End Date: June 30, 2008

*Congressionally directed project

Objectives

- Develop/operate a test bed to validate/characterize hydrogen technologies in a real-world setting.
- Integrate a renewable energy source with an electrolyzer, hydrogen storage, and fuel cell.
- Collect real-world cost and engineering data for the hydrogen infrastructure elements.
- Conduct outreach to local authorities and the general public regarding hydrogen infrastructure.
- Evaluate hydrogen yield potential of Pearson Technologies' biomass gasification process.
- Develop a skid-mounted bench-scale test system for tar reforming/hydrogen purification.

Technical Barriers

This project addresses these technical barriers from the indicated sections of the October 2007 edition of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

Hydrogen Production section 3.1.4 Technical Challenges, subsection on Barriers

Biomass Gasifiction/Pyrolysis Hydrogen Production

(S) Feedstock Cost and Availability
(T) Capital Cost and Efficiency of Biomass Gasification

Technology Validation section 3.6.4 Technical Challenges, sub-section on Barriers

(B) Hydrogen Storage
(E) Codes and Standards
(H) Hydrogen from Renewable Resources
(I) Hydrogen and Electricity Co-Production

Hydrogen Safety section 3.8.4 Technical Challenges, sub-section on Barriers

(G) Expense of Data Collection and Maintenance
(H) Lack of Hydrogen Knowledge by Authorities Having Jurisdiction

Contribution to Achievement of DOE Milestones

This project contributes to these DOE milestones from sections of the Multi-Year Research, Development and Demonstration Plan:

- Hydrogen Production section 3.1.6 Milestones, Biomass Gasification
  - **Milestone 19:** Verify 2012 cost and efficiency targets through the operation of an integrated biomass gasification development unit.

- **Milestone 20:** Laboratory research results project to achieving 2017 cost and energy efficiency targets.

- Technology Validation section 3.6.6 Milestones
  - **Milestone 33:** Validate an electrolyzer that is powered by a wind turbine at a capital cost of $665/kWe and 62% efficiency including compression to 5,000 psi with quantities of 1,000. Our Kahua Ranch system generates hydrogen utilizing a pressurized proton exchange membrane (PEM) electrolyzer powered by both wind and photovoltaic (PV) primary energy sources. Data has been collected to evaluate cost and technical performance.
  - **Milestone 34:** Complete power park demonstrations and make recommendations for business case economics. Our Kahua Ranch Power Park will be completed by June 30, 2008, providing data collection opportunities.

Accomplishments

Renewable hydrogen production, biomass:

- Conducted bench-scale gasifier tests of catalytic filter units with process intensification potential.
- Conducted bench-scale gasifier tests for the quantification and control of sulfur species in the product gas.
- Conducted bench-scale gasifier tests for the quantification and control of nitrogen species in the product gas.
- Conducted bench-scale gasifier tests for the quantification and control of tar (C_6+) species in the product gas.
- Collected samples for analysis of the fate of biomass impurities under gasification conditions.
- Completed parametric testing and evaluation of Pearson Technologies' process development unit potential for hydrogen production.
- Completed design of downstream process elements required for hydrogen production from the Pearson Technologies' gasifier unit.

Evaluation of power park elements at the Hawaii Fuel Cell Test Facility (HFCTF):

- All system components received, assembled and tested as a complete system.
- LabVIEW interface for remote operation developed and tested.
- Load-following, pressurized PEM electrolyzer (175 psi maximum) received from Electric Hydrogen (EH) Inc. and tested. Worked with EH to upgrade.

Kahua Ranch: PV-Wind-Hydrogen-Fuel Cell Test Bed:

- Infrastructure installed – concrete slabs, firewalls, wiring and conduit.
- 8 kW Bergey wind turbine modified to produce 48 volts direct current (VDC) output.
- 10 kW PV array reconfigured to produce 48 VDC output.
- 48 VDC industrial lead acid battery system reconditioned as PV-Wind energy absorber.
- System installed and commissioned.
- Remote internet Data Acquisition and Control System commissioned.
- Data collection and analysis completed.
- Scientific papers published and presented at technical conferences.

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Introduction

The *Hawaii Hydrogen Center for the Development and Deployment of Distributed Energy Systems* was initiated in 2004 with funding from the Consolidated Appropriations Act, 2004 and the Fiscal Year 2004 Conference Report. The work being conducted under this project supports a number of program elements specified in the U.S. DOE Multi-Year Research, Development and Demonstration Plan for Hydrogen, Fuel Cells and Infrastructure Technologies Program. The tasks were selected to leverage HNEI's unique expertise and facilities, as well as past and ongoing investments from DOE, the Department of Defense and industrial partners; and to address the unique aspects and needs of Hawaii's energy system. Work done in this project is concentrated on two primary focus areas: 1) research, testing and validation of hydrogen technologies through the Hawaii Hydrogen Power Park, and 2) research and development of cost-effective renewable hydrogen production, with emphasis on biomass gasification.

Approach

The HNEI of the University of Hawaii at Manoa forged a strong public/private team comprised of industrial partners, national labs and other universities such as New Mexico Institute of Mining and Technology. The first important activity area, the Hawaii Hydrogen Power Park, evaluated major system components such as an industrial-sized Stuart electrolyzer, and a 5 kW fuel cell at HNEI's HFCTF on Oahu. After several changes due to changes in funding and site availability, the project focused on developing and installing a remotely-operated PV-Wind-Hydrogen system at Kahua Ranch on the Big Island. This site provides the opportunity to utilize its excellent solar and wind resources to generate hydrogen. With the move to the Big Island and consistent with other priorities of this project and DOE objectives, the development and validation of technologies for renewable hydrogen production including PV and wind were supported.

The second activity, Renewable Hydrogen Production, was focused on the production of hydrogen from biomass. The HNEI bench-scale gasifier facility was used for evaluation of catalytic filter elements and identification of components in the gasifier product stream. Additional HNEI work was aimed at 1) gaining information useful in gas clean up system design, and 2) fuel processing of sugar cane trash before use as a fuel in a gasifier. Collaborative work was carried on with ClearFuels Technology and Pearson Technologies, involving evaluation of the Pearson Technologies' gasification pilot plant using bagasse.

Results

Hawaii Hydrogen Power Park

The primary technical activity has been assembling and testing the components of the Kahua Ranch PV-Wind-Hydrogen-Fuel Cell system (Figure 1), and developing the LabVIEW data acquisition and control system (DACS) (Figures 2 and 3). In parallel, the supporting site improvements at the ranch were accomplished, including rehabilitating an old storage shed to house the system, pouring concrete slabs, and erecting a concrete block firewall for the hydrogen storage system (Figure 4). Also at the ranch, an existing 10 kW PV array was rewired to produce 48 VDC power, and an existing Bergey wind turbine was modified to produce 48 VDC. Finally an existing set of Trojan fork-lift batteries was reconditioned and reconfigured into a 48 VDC battery system. The hydrogen production system was successfully assembled and tested at the HFCTF, disassembled, shipped by inter-island barge to the Big Island, and installed at the ranch. The electrolyzer was returned to the supplier to be modified.

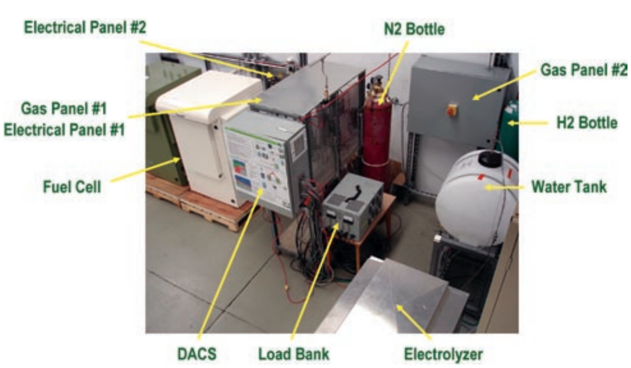

FIGURE 1. Component Testing at the HFCTF

The modified unit was received and has undergone testing. The electrolyzer is a rapid load-following PEM pressurized (175 psi) electrolyzer specifically designed for intermittent renewable energy sources such as wind and PV. The design has the potential of significantly reducing electrolyzer capital costs. The DACS has been successfully tested and allows the system to be remotely operated and monitored over the internet. This includes starting and stopping the electrolyzer, disconnecting wind and PV, and monitoring distilled feed water and hydrogen storage levels.

Throughout the period, we have leveraged a volunteer organization called the "Friends of NELHA" to provide public outreach to K-12 students, residents, and tourists from around the globe. This has been accomplished by providing: 1) training workshops on hydrogen and the Power Park to the volunteers, and 2) briefing materials that they include in their presentations. Hydrogen is an important component of their presentations to these groups.

Renewable Hydrogen Production: Biomass

ClearFuels Technology Subcontracts

All deliverable reports for the subcontract with ClearFuels Technology have been received and accepted. These included: 1) evaluation of the Pearson Technologies' five ton per day gasification pilot plant in Aberdeen, Mississippi using bagasse from a Louisiana

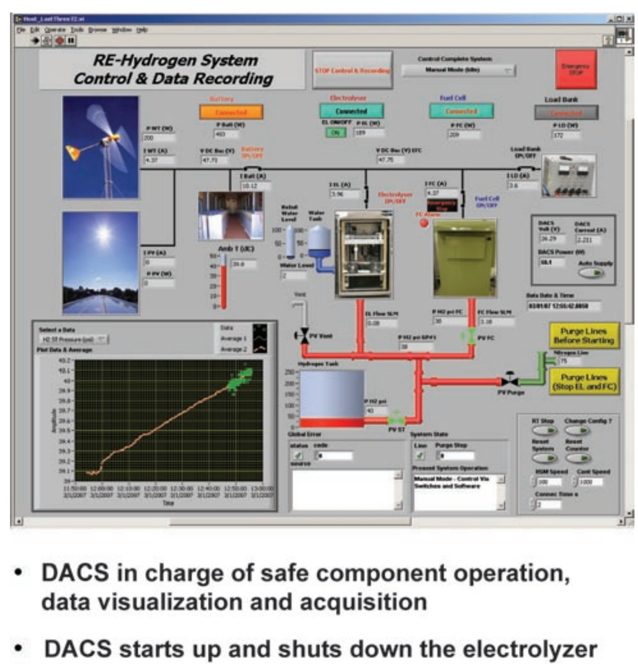

FIGURE 2. LabVIEW Interface for Control of the PV-Wind-Hydrogen System

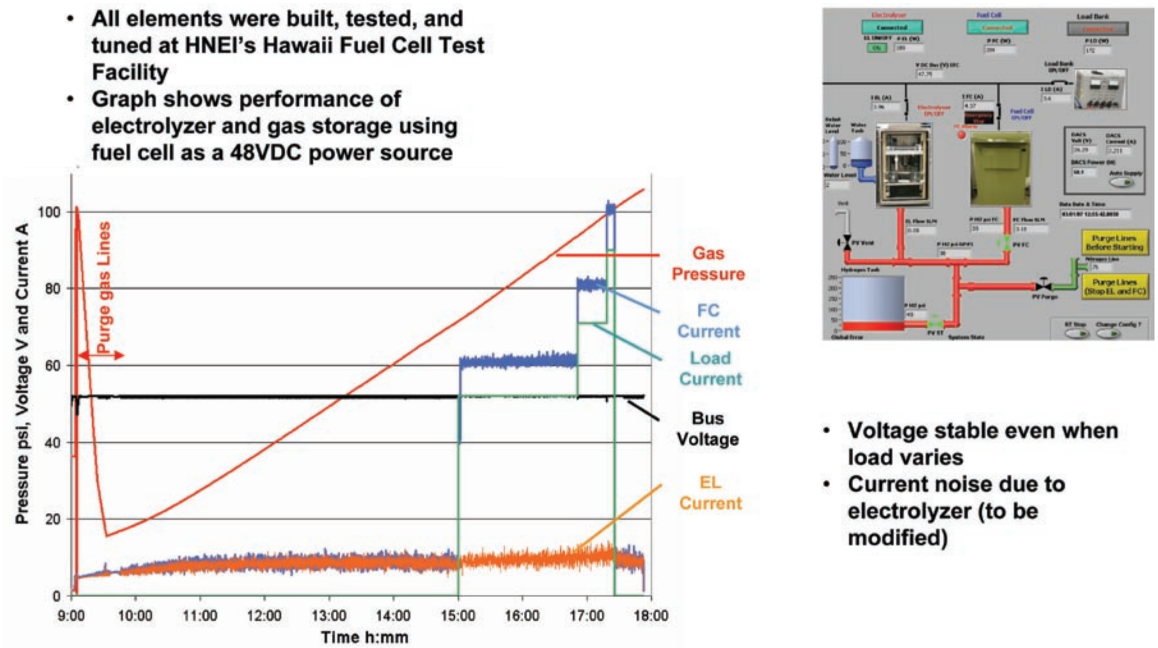

FIGURE 3. Validation of Components and Control System

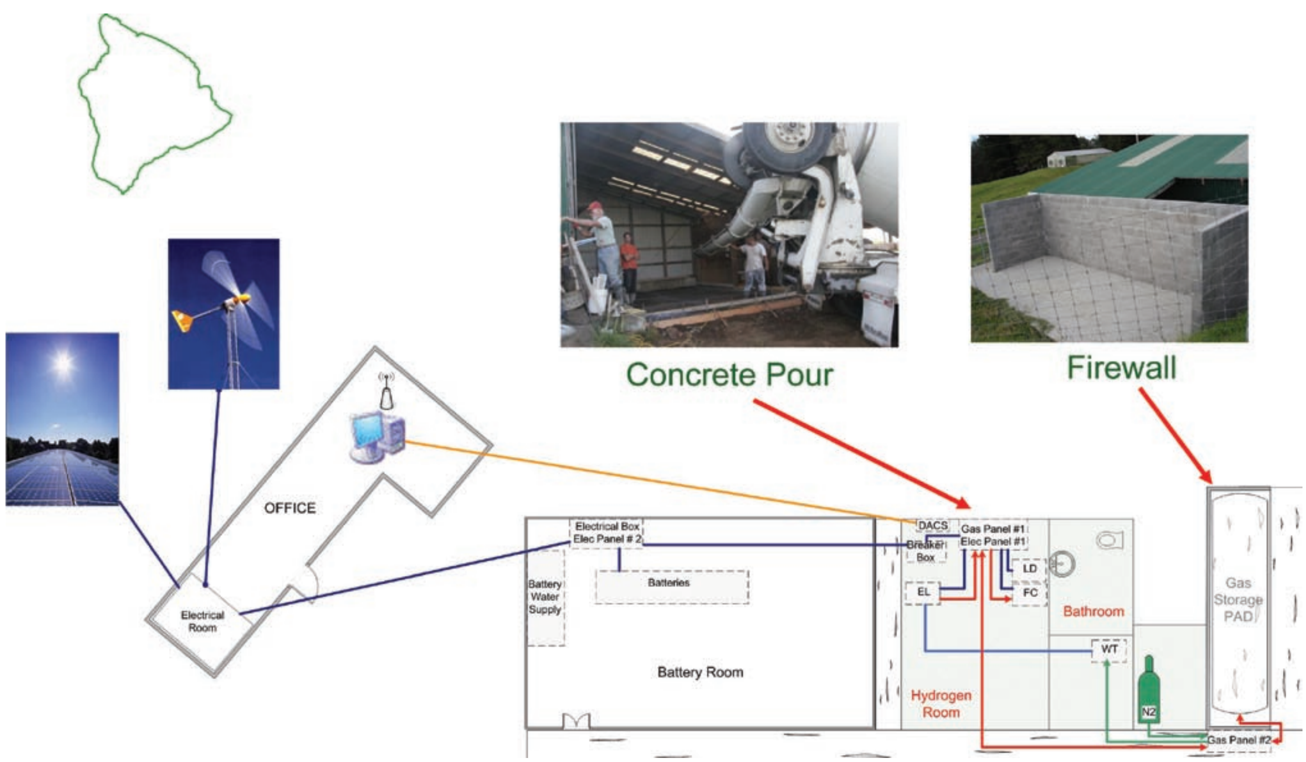

FIGURE 4. Kahua Ranch Infrastructure

sugar factory as fuel, and 2) design of downstream process elements required for hydrogen production.

The H_2 yield from the Pearson gasifier was evaluated in a parametric test series over a range of residence times from 0.8 to 2.2 seconds as shown in Figure 5. H_2 concentrations as high as 55% (volume) were measured in the product gas at the longer residence times and this corresponds to a hydrogen yield of 90 kg per tonne of bagasse without gas upgrading. The

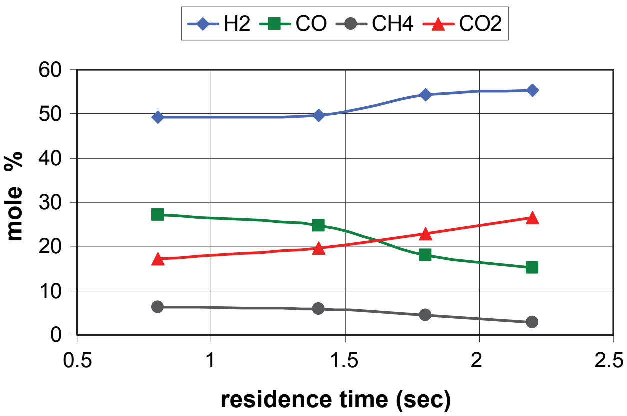

FIGURE 5. Hydrogen Concentration in the Product Gas as a Function of Residence Time for the Pearson Gasifier

CO and CH_4 in the product gas have the potential to yield additional H_2 through the use of reforming and water-gas shift reactors. Increasing residence time from 0.8 to 1.4 seconds and 1.8 to 2.2 seconds increased H_2 concentration by less than 1% (absolute) in the product gas. Lengthening residence time from 1.4 to 1.8 seconds produced the greatest single increase from 49.8 to 54.4% (absolute). Although more extensive testing should be performed to further validate these results, these preliminary findings indicate that the greatest gains in hydrogen concentration can be realized by maintaining residence time above 1.8 seconds. This information is useful in designing biomass reforming systems as it allows the increased capital costs associated with longer residence times to be weighed against increases in hydrogen content of the product gas. This information may also impact downstream systems where greater concentration of hydrogen in the product gas could lead to decreased purification requirements and costs. Note that extended details of the final report have been identified as proprietary by the subcontractor.

Task 2 in the ClearFuels Technology subcontract for the design of downstream process elements required for H_2 production was completed in the past year. Details of this report have been identified as proprietary by the subcontractor.

Hawaii Natural Energy Institute Activities

Tests on catalytic filter elements for conversion of tar and heavy hydrocarbon species have been conducted in the HNEI bench-scale gasifier. Release of test results as they relate to catalytic filter performance is pending. Tests of non-catalytic filter elements to characterize the gasifier product stream for tar species are completed and the results are shown in Figure 6. Benzene, napthalene, and toluene are the three largest tar components and the sum of the tar compounds totaled 8.1 and 7.6 g per Nm^3 for the two tests shown in the figure. Unidentified

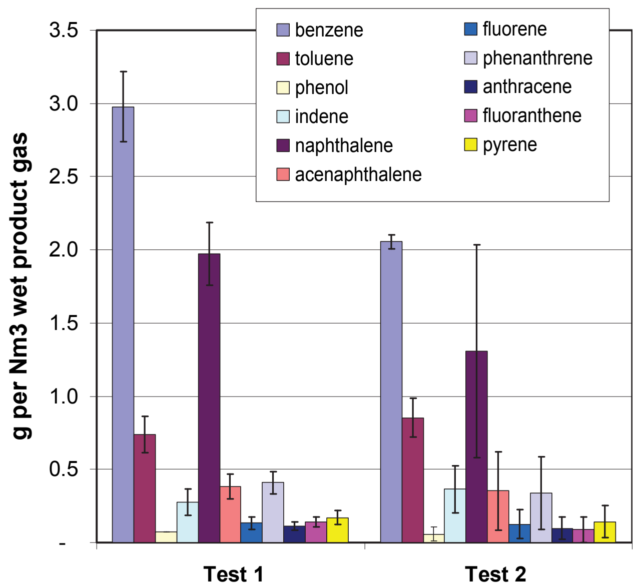

FIGURE 6. Results of analysis of tar species in the product gas from the HNEI bench-scale gasifier at an equivalence ratio of 0.26, steam-to-biomass ratio of 0.3, and gasifier reactor temperature of 800°C.

compounds for the two tests were 10 and 14%, respectively.

Identification of contaminant species present in biomass producer gas has been an additional emphasis of HNEI activities. The HNEI fluidized-bed gasifier facility was operated using *Leucaena* as fuel at a nominal feed rate of 1 kg hr^{-1} and a steam-to-biomass ratio of 2. Nitrogen was added to the reactor to control fluidization. Sulfur and nitrogenous species were of particular interest. Sulfur work was geared toward identifying sulfur species and their concentrations, and testing zinc oxide (ZnO) sorbent for sulfur control. Levels of H_2S, COS, and C_4H_4S were quantified in the product gas from the HNEI bench-scale gasifier unit at ~50 ppmv, 1 ppmv, and 1.5 ppmv, respectively. Figures 7 and 8 show the effects of operating temperature and space velocity on the ZnO sorbent efficacy in removal of the three compounds. Both of these activities will produce results that will provide information needed in the design of gas clean-up systems and the environmentally acceptable disposal of potential waste effluent streams. Hydrogen cyanide (HCN) and ammonia (NH_3) concentrations of 12 ppmv and 1,500 to 2,000 ppmv, respectively, were also measured in the product gas streams.

Fuel processing of sugar cane trash prior to use as a gasifier fuel in order to improve gasification characteristics was included in the HNEI activities. The focus was on the removal of contaminant species (particularly alkali and chlorine) prior to entry of gases to the gasifier as a method of improving gas quality. Treatments of the cane trash using leaching techniques

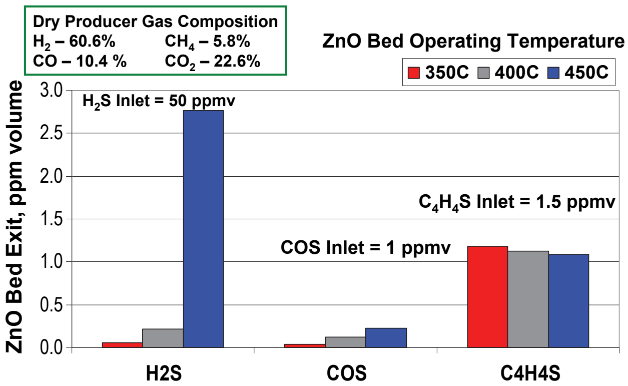

FIGURE 7. Sulfur contaminant speciation and removal from biomass producer gas using ZnO sorbent as a function of temperature.

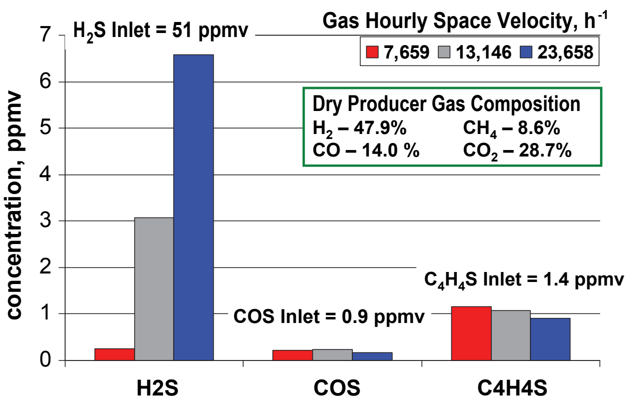

FIGURE 8. Sulfur contaminant speciation and removal from biomass producer gas using a ZnO sorbent bed as a function of gas hourly space velocity (hr^{-1}).

were conducted using experimental variables of leach water temperature, treatment time, and particle size. The use of hot water as a leaching fluid has not been reported in the fuel processing literature, and the recovery and use of hot water effluent from evaporator equipment in sugar factories holds promise for the use of low-grade heat streams to improve fuel characteristics. Figure 9 shows the improvements in fuel properties attained in an experimental investigation of the effects of leaching water temperature, fuel particle size, and leaching time.

Conclusions and Future Directions

Conclusions – Hawaii Hydrogen Power Park

- A highly flexible PV-Wind-Hydrogen-Fuel Cell test bed system capable of collecting data on the economics of producing hydrogen utilizing wind and solar intermittent primary renewable energy sources has been established at Kahua Ranch on the Big Island of Hawaii and data has been collected in support of DOE technology validation objectives.

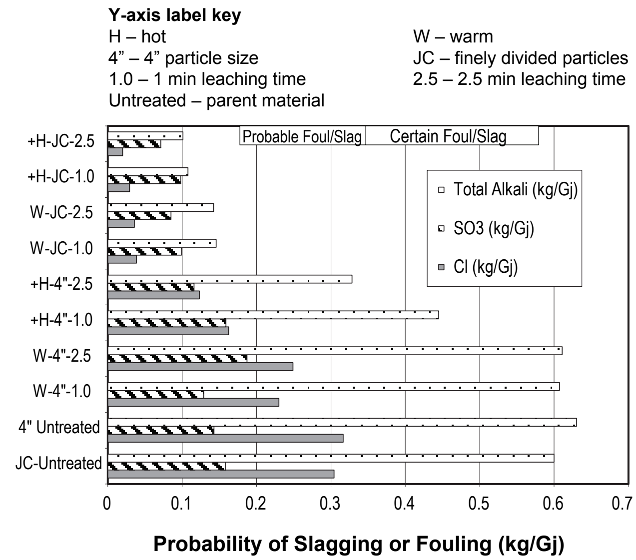

FIGURE 9. Reductions in total alkali, Cl, and SO_3 in sugar cane trash by hot water leaching treatments.

Conclusions – Hydrogen Production: Biomass

- The Pearson Technologies gasifier unit can yield 90 kg of hydrogen per tonne of sugar cane bagasse when residence times are above 1.8 seconds.
- Increased hydrogen yield and a purified gas stream are possible from the Pearson Technologies gasifier, based on installation of process units for which engineering design has been completed.
- Tar species, primarily benzene and naphthalene, H_2S, COS, C_4H_4S, HCN, and NH_3 concentrations in the product gas from the HNEI gasifier have been quantified. Methods to either remove them from the gas stream or convert them to benign species have been explored.
- Methods to remove Cl and alkali species from sugar cane trash using hot water leaching techniques have been developed and improvements in fuel characteristics of the treated material have been quantitatively assessed.

Future Directions – Hawaii Hydrogen Power Park

The Kahua Ranch PV-Wind-Hydrogen-Fuel Cell system was operated until the completion of the project in June 2008. The data was shared with SNL and we conducted economic and engineering analysis of the system. A final report will be prepared describing the results. We intend to seek new project opportunities that can leverage this test bed using larger components (electrolyzer, wind turbine, PV array, etc.).

The Hawaii Hydrogen Power Park has received funding (under a different project) to install a hydrogen refueling station on the Big Island. It is planned to leverage the Power Park hydrogen fueling facility by sharing the fueling infrastructure in support of a National Park Service (NPS) research project that calls for the technical validation of two (2) hydrogen fuel cell plug-in hybrid shuttle buses at the Hawaii Volcanoes National Park (HAVO). HAVO's vision for this project is to position the park as a NPS system-wide resource to demonstrate and validate new zero-emission transportation solutions for the NPS as a whole (392 national parks). It is also planned to leverage the NPS shuttle bus project and the Power Park project as the first step in establishing a Hawaii Hydrogen Highway on the Big Island.

Future Directions – Hydrogen Production: Biomass

Although the ClearFuels Technologies subcontracts related to the evaluation of the Pearson Technologies gasifier unit for hydrogen production have been completed, the results indicate that this pathway for hydrogen production shows great promise. Further testing with more complete characterization of product gas to include contaminant species should be conducted.

Evaluation work at the HNEI bench-scale gasifier of catalytic filter performance and potential for process intensification will continue. Design and fabrication of a producer-gas clean-up unit at the HNEI gasifier will be completed.

The evaluation of hot water treatment as a method for improving gasification characteristics of sugar cane trash will be continued.

FY 2008 Publications/Presentations

Hawaii Hydrogen Power Park

1. S. Busquet, C.J, Mas, "Experimental Results and Analysis of an Alkaline Electrolyzer and Fuel Cell System," in preparation for the Journal of Power Sources.

2. R. Rocheleau, M. Ewan, S.Q. Turn,"Renewable Hydrogen: The Hawaii Hydrogen Power Park," 235th American Chemical Society National Meeting & Exposition, New Orleans, LA, April 6-10, 2008.

3. S. Busquet, M. Ewan, "Description and First Results of a Wind-PV Hydrogen System at Kahua Ranch on the Big Island of Hawaii," National Hydrogen Association Annual Conference, Sacramento, CA, March 30 – April 3, 2008.

4. M. Ewan, R. Rocheleau, "Hawaii Hydrogen Power Park – Keystone to Developing a Hydrogen Economy in Hawaii," National Hydrogen Association Annual Conference, Sacramento, CA, March 30 – April 3, 2008.

Renewable Hydrogen Production: Biomass

1. A. Douette, S.Q. Turn, W. Wang, V. Keffer, An Experimental Investigation of Hydrogen Production from Glycerin Reforming, *Energy & Fuels*, in press, 2007.