VIII.B Power Parks

VIII.B.1 Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems*

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Subcontractors:
Clearfuels Technology, HI
MVSystems, CO
New Mexico Institute of Mining and Technology, NM
Pacific International Center for High Technology Research, Honolulu, HI
Pearson Technologies, Aberdeen, MS
Sentech Inc., Washington, DC

Partners:
Airgas, Honolulu, HI
Center for a Sustainable Future, Honolulu, HI
City & County of Honolulu, Honolulu, HI
Hawaii Department of Business, Economic Development & Tourism, Honolulu, HI
HELCO/HECO, Honolulu, HI
Hawaiian Commercial & Sugar Co., Honolulu, HI
National Renewable Energy Laboratory (NREL), Golden, CO
Sandia National Laboratory Livermore (SNLL), Livermore, CA
The Gas Company, Honolulu, HI

Start Date: October 1, 2004
Projected End Date: June 30, 2006

**Congressionally directed project*

Objectives

- Hawaii Hydrogen Power Park – Develop and operate a test bed for validation and characterization of hydrogen technologies in a real world setting which will:

  - Integrate a renewable energy source with an electrolyzer, fuel cell, and hydrogen-fueled internal combustion engine to power a building.
  - Collect real world cost and engineering data.
  - Outreach to local authorities and the general public.
- Hydrogen Fuel Quality Assessment – Characterize the effect of trace level contaminants on the performance and durability of proton exchange membrane (PEM) fuel cells:
  - Collect data suitable for use in development of fuel quality guidelines.
  - Develop and validate test plans and test protocols.
- Renewable Photoelectrochemical (PEC) Hydrogen Production – Develop novel multi-terminal device configurations which offer potential for higher efficiency photoelectrodes for solar hydrogen production than achievable with current thin film approaches:
  - Develop high efficiency copper-indium-gallium-diselenide (CIGS) solar cells compatible with 4-terminal devices.
  - Demonstrate high efficiency 4-terminal photoelectrodes.
- Renewable Hydrogen Production Using Biomass – Investigate critical steps for hydrogen production from biomass, including biomass and syngas conditioning/cleanup, optimal pathway assessment, and characterization of selected biomass gasification technology:
  - Evaluate hydrogen production potential of the Pearson Technologies' gasification process.
  - Develop processes for tar reforming and hydrogen purification processes at the *Hawaii Natural Energy Institute* (HNEI) gasifier facility.
  - Analyze hydrogen yield potential of commercial gasifier facilities under development in Hawaii.

Technical Barriers

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

Hawaii Hydrogen Power Park.

- B, C, E, H, I. Hydrogen Infrastructure - Technology Validation
- G, H. Hydrogen Safety

Hydrogen Fuel Quality Assessment

- A, C. MEA Materials and Components – durability and performance – Fuel Cells

Renewable Photoelectrochemical Hydrogen Production

- AP, AQ. Materials efficiency and durability – Hydrogen Production
- AS. Device configuration design – Hydrogen Production

Renewable Hydrogen Production Using Biomass

- W. Capital Cost and Efficiency of Biomass Gasification/Pyrolysis Technology – Hydrogen Production

Approach

Hawaii Hydrogen Power Park

- Leverage Phase 1 State Energy Program Power Park experience at Hawaii Fuel Cell Test Facility which includes a Stuart electrolyzer, high pressure hydrogen storage system, and 5kW Plug Power fuel cell.
- Work closely with Sandia National Laboratory Livermore (SNLL) modeling group to identify appropriate data base insuring broadest applicability of results.

- Select a show-case site which contributes to outreach objectives – Hawaii Gateway Energy Center on the Big Island.

Hydrogen Fuel Quality Assessment

- Leverage Department of Defense (DOD) investment in Hawaii Fuel Cell Test facility.
- Work in close collaboration with industry, Society of Automotive Engineers (SAE), United States Fuel Cell Council (USFCC), and United States Department of Energy (DOE) working groups to develop detailed test plans and test protocols.
- Use 3rd party, non-proprietary membrane electrode assemblies (MEAs) to allow post-test analysis.

Renewable Photoelectrochemical Hydrogen Production

- Integrate existing high-efficiency CIGS (HNEI) and amorphous silicon (a-Si) (MVSystems) technologies to demonstrate high efficiency concepts.
- Utilize modeling to identify highest performance device configurations.
- Utilize detailed optoelectronic characterization of materials and devices for component optimization and model input parameters.

Renewable Hydrogen Production: Biomass

- Conduct parametric gasification tests on Pearson Technologies' pilot plant (4.5 Mg per day) in Aberdeen, Mississippi.
- Develop skid-mounted, producer-gas clean-up test bed to include tar reforming and hydrogen purification unit operations. Test bed may be used at other biomass facilities in Hawaii to evaluate hydrogen yield potential and cost projections.

Accomplishments

Hawaii Hydrogen Power Park

- Electrolyzer fully operational.
- Fuel cell commissioned.
- Data acquisition system designed and installed.
  - Instrumentation plan developed with SNLL.
  - Full characterization of electrolyzer at various power levels.
- Data being acquired and analyzed by HNEI and SNLL.

Hydrogen Fuel Quality Assessment

- Participating in SAE, USFCC and DOE working groups for development of test protocols and work plans.
- Fuel cell hardware from General Motors (GM), Ballard Power Systems (BPS), and UTC Fuel Cells on site – reference and test cells provided.
- Protocols for MEA assembly, cell build, cell conditioning and operation, and manufacturer specific test diagnostics transferred to HNEI.
- Additional test stand capacity specified and orders placed.

Renewable Photoelectrochemical Hydrogen Production

- >15% photovoltaic (PV) efficiency possible using currently available materials in 4-terminal configuration.
- Reduction of reflection losses at interfaces critical for high efficiency.
- Process modifications to improve the robustness of HNEI's high efficiency fabrication process have been implemented.

- CIGS Process Endpoint Detection – pyrometer for substrate temperature monitoring is being installed.
- CIGS Evaporation Source Stability – Cu source fill level optimized for more stable deposition rate.

Renewable Hydrogen Production Using Biomass

- Five short-duration preliminary parametric studies have been conducted at Pearson Technologies 4.5 Mg per day (5 tons per day) pilot plant in Mississippi.
  - Atmospheric pressure entrained-flow reactor utilizing steam as the oxidizer.
  - Reactor exit temperature 925°C.
  - Average inert-free gas composition of 51% H_2, 31% CO, 6% CH_4, 12% CO_2.
  - Gas yield of 1.3 m^3 gas per kg biomass (at STP).

Future Directions

Hawaii Hydrogen Power Park

- Relocate Power Park to the Hawaii Gateway Energy Center.
- Investigate opportunities to use Big Island geothermal, wind, and biomass renewable resources for H_2 production.
- Continue data acquisition task and work with SNLL.
- Identify additional partners/technologies for incorporation into Power Park:
  - HELCO: grid reliability issues.
  - GasCo: clean energy fuel station.
  - Collier Technologies: hydrogen IC engine.

Hydrogen Fuel Quality Assessment

- Install additional test stands.
- Complete characterization of CO and H_2S contaminant effects.
- Initiate testing using other contaminants identified by USFCC and DOE working group.

Renewable Photoelectrochemical Hydrogen Production

- Continue development of high-efficiency CIGS solar cells compatible with PEC device integration.
- Design, model and fabricate 4-terminal device compatible with hydrogen production requirements using best available materials.

Renewable Hydrogen Production Using Biomass

- Complete longer-term testing at Pearson Technologies' pilot plant.
- Complete design, fabricate and operate skid-mounted, producer-gas clean-up unit at the HNEI gasifier facility.
- Transport skid-mounted unit to Kauai for evaluation of 45 Mg per day gasifier under development at the Gay & Robinson Sugar factory.

Introduction

The Hawaii Hydrogen Center for the Development and Deployment of Distributed Energy Systems was initiated in September 2004 with funding from the Consolidated Appropriations Act, 2004 and the FY 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 & Infrastructure Technologies Program*. The tasks were selected to leverage HNEI's unique expertise and facilities; past and ongoing investments from

DOE, DOD and industrial partners; and the unique aspects and needs of Hawaii's energy system. The FY 2004 agreement included four primary focus areas: 1) research, testing and validation of hydrogen technologies through the Hawaii Hydrogen Power Park, 2) assessment of hydrogen fuels purity requirements for fuel cell applications, 3) research and development of cost-effective renewable hydrogen production, and 4) analysis of potential hydrogen and distributed energy systems for the Big Island grid system.

Approach

A significant emphasis was placed on analysis to ensure that critical technological needs were addressed in the detailed research plans. HNEI also forged a strong public/private team comprised of industrial partners, national labs and other universities such as New Mexico Institute of Mining and Technology. Under the Phase I agreement, Task One, Hawaii Hydrogen Power Park, was focused on procuring significant quantities of hydrogen from the local refinery, transporting this hydrogen to a distributed energy site run by the City and County of Honolulu (C&C) and using the hydrogen in an advanced alternative fuel combined heat and power (CHP) engine. Infrastructure for this project was put in place at significant expense to C&C. Unfortunately, as a result of the mayoral election and changing priorities, the C&C plans to put the CHP engine into place were dropped. HNEI now plans to establish the power park related activities on the Big Island. 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 both wind-electrolysis and hydrogen derived from biofuels will be supported.

The second activity, Assessment of Hydrogen Fuel Purity Requirements, results from our ongoing participation with the DOE Codes and Standards Working group addressing this issue, and participation in the SAE Hydrogen Fuel Purity Workshop. This activity will continue critical testing services to these industry and government working groups and contribute to the advancement of fuel cell technology. This activity leverages a multimillion dollar investment by the Office of Naval Research in Hawaii for fuel cell testing.

In the third focus area, Renewable Hydrogen Production, specific subtasks include the development of advanced electronic materials for high efficiency photoelectrochemical hydrogen production, the production of hydrogen from biomass and experiments to validate our cost analysis for the direct production of biodiesel using high lipid content algae.

The fourth activity, analysis of potential hydrogen and distributed energy systems for the Big Island grid system, will be closely integrated with the revised Task 1 which we also now propose to site on the Big Island.

Results

Hawaii Hydrogen Power Park

Phase 1 of the Power Park activity has focused on the design and installation of hydrogen infrastructure to fuel a 5 kW PEM fuel cell. During 2003, the hydrogen infrastructure was developed and incorporated into the Hawaii Fuel Cell Test Facility (HFCTF). A Stuart electrolyzer was acquired and commissioned in May 2003. The electrolyzer was integrated with the HFCTF hydrogen storage system allowing transport of the hydrogen into fuel cell test stands or on-site storage cylinders. System controls, safety systems, and data acquisition were implemented into this fully permitted facility. The permitting process provided valuable experience in working with city officials and educating them on hydrogen technologies. Considerable operational experience and valuable insight has been gained from operating the unit. Operation of an electrolyzer has not been straightforward, requiring substantially more research effort than anticipated. The 5 kW Plug Power fuel cell was installed in a test rig in the Hawaii Fuel Cell Test facility and commissioned in May 2005 (Figure 1). Initial data has been acquired and analyzed by SNLL and HNEI (Figure 2).

Hydrogen Fuel Quality Assessment

A test plan that meets the requirements of the SAE and industrial partners is strategic to the success of this project. Therefore, considerable consultation

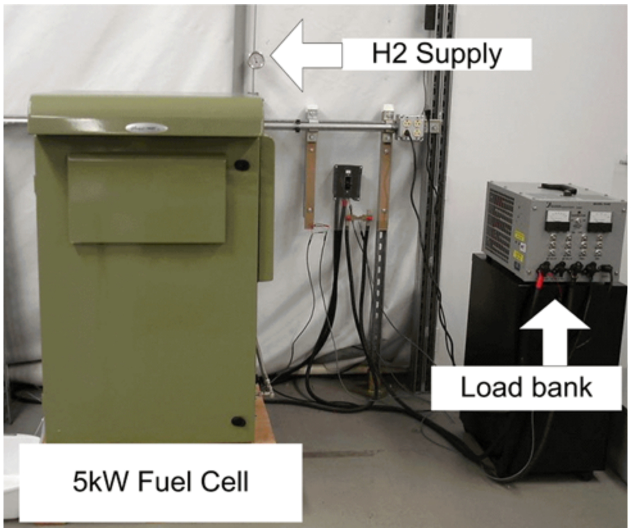

Figure 1. Fuel Cell Test Rig at the HFCTF

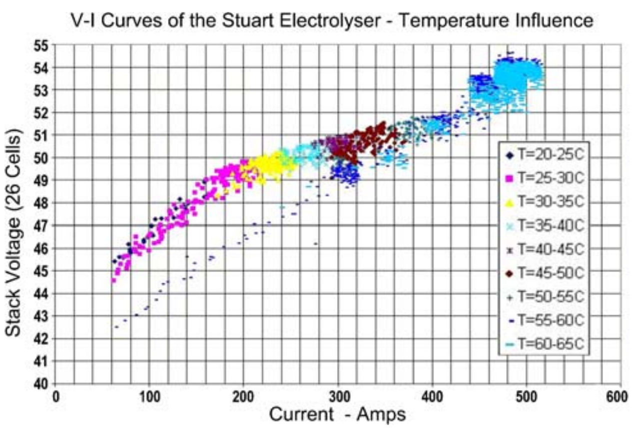

Figure 2. Example of Data Analysis – Effect of Temperature on the V-I Curves for a Stuart Electrolyzer

has taken place and significant progress has been made on the development of the test plan. Other preparatory activities included the transfer of technology from Ballard Power Systems (BPS) for assembly and testing of fuel cells and the validation of HNEI equipment and testing procedures by ensuring test results obtained at HNEI were representative of BPS results. Discussions were conducted with GM concerning further tests to validate HNEI's equipment and testing protocols with GM fuel cells. Improvements were made to HNEI's gas analysis technology; however, the equipment is still short of what is required. In limited testing, HNEI obtained initial CO

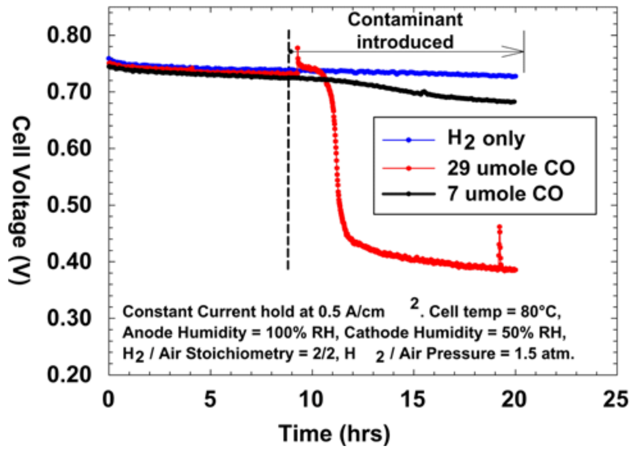

Figure 3. Effect of CO Contamination on Fuel Cell Performance

Table 1. Improvement of HNEI 4-Terminal Device (15.6%) Compared to CIGS (14.0%)

4-Terminal Device	V_{OC} (mV)	J_{SC} (mA/cm^2)	FF	PV Efficiency
Top: thin a-Si	933	7.09	0.75	5.0%
Bottom: CIGS (filtered light)	604	24.77	0.71	10.6%
CIGS stand-alone (unfiltered)	604	32.73	0.71	14.0%
Top+Bottom total				**15.6%**

contamination results that were similar to results in published literature (Figure 3).

Renewable Photoelectrochemical Hydrogen Production

A 4-terminal device concept was developed which, using our currently available CIGS and a-Si materials, has a projected PV efficiency exceeding 15%, as seen in Table 1. This represents an improvement over either the CIGS or a-Si used alone. Further progress was made in the development of a more robust CIGS deposition process. Specific emphasis was put on the improvement of the copper effusion rate stability. The Radak II furnace had in the past been operated near its temperature limit with a full charge of Cu, and the Cu rate had often diminished over the duration of the deposition process. In experiments with different Cu charges, it was found that more stable rates could be obtained at 10%-30% fill levels. Additional emphasis was on improvement of the CIGS process end point detection (EPD). A decision was made to evaluate the use of a pyrometer instead of a thermocouple for the EPD, based on the reported potential for enhanced EPD signal resolution in pyrometers. An Omega OS37-10-K was selected and purchased, and necessary mounting hardware was fabricated. Progress was made in the acquisition of a large-area sputtering system that will allow more uniform depositions of Mo, ZnO, and indium-tin-oxide (ITO) for improved CIGS solar cell fabrication. Research tasks to develop specific fabrication processes for the 4-terminal device were initiated.

Renewable Hydrogen Production Using Biomass

A report for the subcontract established with ClearFuels Technology in the fourth quarter of 2004 was received. The report detailed the design of experiments for parametric testing of the Pearson Technologies Inc. gasification system. Preliminary tests were conducted in the Pearson Technologies' five ton per day gasification pilot plant in Aberdeen, Mississippi using bagasse from a Louisiana sugar factory as fuel. The bagasse was found to be partially decomposed, resulting in a high ash content and reduced concentrations of carbon, hydrogen and oxygen. This was found to affect system performance and the test project has been suspended until fresh bagasse is obtained from a Florida sugar factory.

A meeting was held at the Hawaiian Commercial & Sugar Co. (HC&S) Puunene sugar factory to discuss the project and plan activities. HC&S agreed to provide access to cane bagasse from commercial fields and to coordinate collection with aid from their cane ripening crew. HC&S also agreed to provide access to a Cuba mill facility for the processing experiments.

A preliminary design of a skid-mounted, producer-gas clean-up test bed to include tar reforming and hydrogen purification unit operations was developed (Figure 4). The test bed may be used at other biomass facilities in Hawaii to evaluate hydrogen yield potential and cost projections.

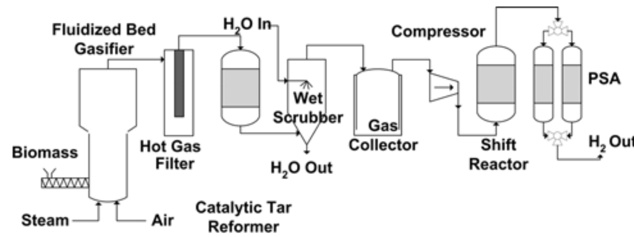

Figure 4. Preliminary Design of Skid-Mounted, Producer-Gas Clean-Up Test Bed

Conclusions

Hawaii Hydrogen Power Park

- Electrolyzer and 5kW fuel cell were fully commissioned.
- A data acquisition system was designed, installed and operated.
- Additional instrumentation was added to the electrolyzer and fuel cell.
- The electrolyzer was fully characterized at various power levels.
- Data was shared with SNLL and initial data analyses performed by HNEI and SNLL.

Hydrogen Fuel Quality Assessment

Significant progress was made in preparing for the commencement of fuel cell testing including:

- A test protocol was developed by HNEI with input from SAE, USFCC, and DOE.
- Reference and test fuel cell hardware was provided by General Motors, Ballard Power Systems and UTC Fuel Cells.
- Protocols for MEA assembly, cell build, cell conditioning and operation, and manufacturer specific test diagnostics were transferred to HNEI.
- The performance of HNEI's test stations was verified.

Renewable Photoelectrochemical Hydrogen Production

- A 4-terminal device concept was developed which, using currently available CIGS and a-Si materials, has a projected photovoltaic efficiency exceeding 15%; development of the fabrication processes necessary for the realization of this concept, both in high-efficiency photovoltaic and photoelectrochemical conversion configurations, is currently underway.

Renewable Hydrogen Production: Biomass

- Significant progress was made in running parametric testing with Pearson Technologies' gasifier and in designing a skid-mounted, producer-gas clean-up test bed.

FY 2005 Presentations

Hawaii Hydrogen Power Park

1. R. Rocheleau, J. Ewan – "Power Park", US DOE Workshop on Distributed Energy Resources, Honolulu, HI, 24 August 04
2. R. Rocheleau, E. Miller, J. Ewan, C. Jensen, M. Kaya, J. Hurwitch, T. Quinn, "Hydrogen Programs in Hawaii", 2004 NHA Conference
3. T. Gillen, Documentary Video "Sustainable Hawaii" featuring Power Park, August 2004

Fuel Purity Assessment

1. T. Thampan, Keith Bethune, R. Rocheleau, "Impact of Hydrogen Quality on PEM Performance", submitted for 2005 Fuel Cell Seminar
2. R. Rocheleau, E. Miller, K. Bethune, D. Wheeler, "Full Scale PEM Testing at the Hawaii Fuel Cell Test Facility: Recent Progress", Electrochemical Society Meeting, October 2004
3. R. Rocheleau, Hydrogen Fuel Contaminant Tests: Status Report. Presented to the DOE Hydrogen Fuel Quality Working Group, March 2005, Washington, DC

Renewable Hydrogen Production – Photoelectrochemical

1. B. Marsen, A. Madan, S. Dorn, S. Marsillac, F. Matsunaga, R. Rocheleau, and E. Miller, "Four-Terminal Solar Cell Based on High-Efficiency Cu(In,Ga)Se_2 Device on Metal Foil", 206th ECS Meeting, Honolulu, 2004.
2. B. Marsen, S. Marsillac, S. Dorn, R. Rocheleau, "Effect of Selenium Effusion Rate on CIGS Thin Films Deposited at Low Substrate Temperature", 31st IEEE PVSC, Orlando, 2005
3. 2004 NHA Conference – 26-30 April 2004