Executive Summary: Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems

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1. Executive Summary

This report summarizes work conducted under Award Number DE-FC36-04GO14248, the Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems, funded through the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy to the Hawaii Natural Energy Institute (HNEI) of the University of Hawaii.

The HNEI Principal Investigator for this project was Richard E. Rocheleau. The project was carried forward with working partners and cost-sharing partners, as delineated below.

Working partners included the State of Hawaii Department of Business, Economic Development & Tourism; City and County of Honolulu; Hawaiian Electric Company; Hawaii Electric Light Company; The Gas Company; AirGas; Sandia National Laboratory; Hydrogenics/Stuart Energy; MVSystems, Inc.; ClearFuels Technology; New Mexico Institute of Mining and Technology; Hawaiian Commercial & Sugar Company; Center for a Sustainable Future; Pacific International Center for High Technology Research; Sentech; Kahua Ranch, and Benemann Associates.

Cost-sharing partners included the State of Hawaii Department of Business, Economic Development & Tourism; City and County of Honolulu; Hawaiian Electric Company; Hawaii Electric Light Company; The Gas Company; AirGas; MVSystems, Inc.; ClearFuels Technology; New Mexico Institute of Mining and Technology; Hawaiian Commercial & Sugar Company; Center for a Sustainable Future; and Pacific International Center for High Technology Research.

This overall project was divided into separate tasks and these included the following: Task 1 – Hawaii Hydrogen Power Park; Task 2 – Hydrogen Fuel Purity Assessment; Task 3 – Renewable Hydrogen Production; and Task 4 – Systems Integration.

Furthermore, Task 3 was subdivided into individual Subtasks: 3A – Electronic Materials for High-Efficiency Photoelectrochemical Hydrogen Production; 3B – Hydrogen Production from Biomass; and 3C – Biohydrogen Analysis.

Finally, Subtask 3B was further broken into these assignments: 3B-1 – Hydrogen via liquid biofuels; 3B-2 – Feedstock processing; and 3B-3 – Microbial biomass assessment.

Summaries for the various tasks of this project are presented in the paragraphs below. Following these summaries, this report continues with detailed sections for the individual tasks and subtasks of the overall project.

Task 1 – Hawaii Hydrogen Power Park

The studies realized during the hydrogen power park experiments in Hawaii produced real-world data on the performances of the commercialized electrochemical components and power systems integrating renewable and hydrogen technologies. By analyzing the different losses associated with the various equipment items involved, this work identifies the different improvements necessary to increase the viability of these technologies for commercial deployment. The stand-alone power system installed at Kahua Ranch on the Big Island of Hawaii required the development of the necessary tools to connect, manage and monitor such a system. It also helped the electrolyzer supplier to adapt its unit to the stand-alone power system application.

The Kahua Ranch installation is safe and capable of a stand-alone operation. It is also controllable remotely via the internet. This remote control system would allow the installation of a hydrogen storage system in remote locations and reduce the requirement and associated costs for human intervention on site.

By developing a remotely controllable installation having the capacity to be monitored remotely, thanks to an internet web site, the data is available to the public. It helps the general public to understand the present energy issues and offers a showroom for hydrogen storage technologies. The system could also be used for on-line education and science projects at the secondary school and college levels.

Task 2 – Hydrogen Fuel Purity Assessment

The efforts under this task yielded additional knowledge regarding fuel cell performance degradation due to exposure to several different fuel contaminants. In addition, a novel fitting strategy was developed to permit accurate separation of the degradation of fuel cell performance due to fuel impurities from other losses. A specific standard MEA and standard flow field were selected for use in future small-scale fuel cell experiments.

The fuel cell testing program carried out in this task gave reproducible results for tests up to 100 hours. Furthermore, the fitting strategy mentioned above was successfully used in data analysis of measurements taken during CO contamination testing of an MEA.

The test plan developed under this task will provide guidance for future testing efforts. HNEI worked closely with standards-developing organizations to develop impurity test protocols for use by various test laboratories, and help identify operating parameters, materials and hardware for continuing fuel quality work.

Task 3 – Renewable Hydrogen Production

3A – Electronic Materials for High-Efficiency Photoelectrochemical Hydrogen Production

The activities in this task have explored novel configurations of ‘traditional’ photovoltaic materials for application in high-efficiency photoelectrolysis for solar hydrogen production. The model systems investigated involved combinations of copper-indium-gallium-diselenide (CIGS) and hydrogenated amorphous silicon (a-Si:H). A key result of this work was the establishment of a robust "three-stage" fabrication process at HNEI for high-efficiency CIGS thin film solar cells. The other key accomplishment was the development of models, designs and prototypes of novel 'four-terminal' devices integrating high-efficiency CIGS and a-Si:H with operating features compatible with high-efficiency photoelectrochemical (PEC) water-splitting. In this study, it was found that the losses associated with device integration negated the expected benefits in performance. As a result, the targeted efficiencies were not met in the "four-terminal" prototypes, though avenues for further optimization in future work were identified. Additionally, alternative configurations for high-efficiency PEC hydrogen production based on modified CIGS materials were identified.

3B – Hydrogen Production from Biomass

3B-1 – Hydrogen via liquid biofuels

The objective of the first activity under Subtask 3B-1 was to conduct parametric testing of the Pearson gasifier and to determine the effects of gasifier operating conditions on the gas yields and quality. The hydrogen 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. 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 second activity in the ClearFuels Technology subcontract for the engineering design for a biomass gasifier research and development facility was completed. Details of this activity have been identified as proprietary by the subcontractor.

The objective of the third activity in Subtask 3B-1 was to develop hot gas clean-up capabilities for the HNEI gasifier test facility to support hydrogen-from-biomass research. The product gas stream at the outlet of the hot gas filter was characterized for concentrations of permanent gas species (CO, CO_2, H_2, CH_4, N_2) and contaminants including tar (principally benzene, naphthalene, and toluene) and sulfur (H_2S, COS, and C_4H_4S) species, ammonia, and NO_x. Total tar concentration in the dry product gas was ~10 g m^{-3}. Concentrations of H_2S, COS, and C_4H_4S were 56, 1, and 1.3 ppmv, respectively. NO and ammonia concentrations were determined to be 8.2 and 1,626 ppmv respectively.

A clean up strategy was developed to remove contaminant species or convert them to a benign form. Elements included sulfur removal using ZnO sorbent at 400 °C and a gas hourly space velocity of 8,000 hr^{-1}. Under these conditions, the primary sulfur component, H_2S, was reduced to 250 ppbv and COS was reduced by a factor of 4 to similar levels. Thiophene concentrations were not affected.

Tar and methane were successfully converted to permanent gas species using nickel catalysts. Temperatures of 850 °C and GHSV of ~1 m^3 kg^{-1} hr^{-1} effectively removed tar compounds below levels of 0.1 g total tar m^{-3} dry gas. Acenaphthalene and pyrene were two compounds identified in the gas stream exiting the reactor. The Ni catalyst also resulted in reductions of NH_3 from values of ~1500 ppmv to as low as 20 ppmv and complete conversion of methane and NO_x. Methane and tar conversion resulted in increased levels of H_2 and CO in the product gas exiting the tar cracking unit.

The fourth activity under Subtask 3B-1 was the development of advanced hydrogen purification systems by NMT that could potentially be used as auxiliary units for the HNEI bench-scale gasifier. Zeolite-based catalysts were prepared and tested for hydrogen production via reforming of hydrocarbons. These showed promise for alcohols but were inapplicable for glucose reforming. Zeolite membrane systems were tested and may have usefulness in driving CO_2 from a reforming system, with possible enhancement of H_2 production. Some success was observed with micro-reforming of ethylene glycol using a Pt catalyst, but such a catalyst is precluded from use with crop residue feedstocks having organic sulfur.

3B-2 – Feedstock processing

Subtask 3B-2 was a preliminary investigation into methods for processing sugar cane trash at the Puunene Sugar Factory on the island of Maui, Hawaii. The factory is owned and operated by Hawaiian Commercial and Sugar, a subsidiary of Alexander and Baldwin Incorporated. The objective of the investigation was to explore treatment methods that would enable the successful use of cane trash as fuel for the production of hydrogen via gasification. Note that the results are potentially applicable for other thermochemical energy devices as well. Cane trash consists of the leafy plant matter, both living and dead, that accumulates over the course of the growing period. Normally, this material is burned off before harvest in an open-field burn. An alternative is to harvest and process sugar cane trash into a viable fuel. Sugar cane trash is a poor fuel for thermochemical conversion due to its ash composition and the associated tendency to form slag and deposits that foul working surfaces.

Laboratory and pilot-scale tests were carried out using water as a leaching agent to investigate the removal of elements, K, Na, and Cl, known to be agents for slag and deposit formation. Leach-water temperature, leaching duration, and cane trash particle size were varied in the laboratory. Particle size was found to have a significant effect in the reduction of K, Na, and Cl concentrations, and an observed increase in ash fusion temperatures and a decrease in total alkali concentration per energy unit to a level below that empirically found to be the threshold for slagging and fouling. Similar pilot-scale tests were also performed, but particle size reduction was made impossible due to equipment failure. The pilot-scale samples were not reduced below the threshold for slagging and fouling in the leaching treatments.

3B-3 – Microbial biomass assessment

Analyses were completed for the technical and economic feasibility of producing biofuel from photosynthetic marine microbes on a commercial scale. Results included estimates for total costs, energy efficiency, and return on investment.

For the analyses completed early in 2005, the estimated production cost for this renewable fuel oil (without carbon credit) was about $42/bbl, and at that time, crude oil prices ranged from $42 to $57/bbl. The technology described is advanced enough to proliferate rapidly. Renewable biofuels could substantially reduce US dependence on foreign oil supplies.

3C – Biohydrogen Analysis.

The Biohydrogen team undertook a comprehensive review of the field and came to what we think is a realistic conclusion, with details provided in the journal quality paper we have prepared. To summarize, we recommend continued research in the fundamentals of the science related to genetic engineering and specific topics to cover knowledge gaps. In the meantime, we also advocate continued development of related processes which can be linked to pollution control and other real world applications. The extra revenues hydrogen can provide to these multi-product systems can improve profitability. The fact of the matter, though, is that the focused commercialization of hydrogen from biological processes awaits some necessary scientific breakthroughs and much higher conventional energy prices.

Task 4 – Systems Integration.

During the course of this task, HNEI assembled and organized a renewable hydrogen consortium for the purposes of: 1) conducting the necessary R&D for validating the technical and economic potential for renewable hydrogen, and 2) encouraging the development of renewable hydrogen and distributed energy resource options for the Big Island of Hawaii.

Efforts were begun towards the establishment of an energy roadmap for the future of the Big Island. These efforts included completion of modeling, calibrating and validation of the Big Island's electrical and transportation fuel infrastructures against current conditions, yielding an energy infrastructure baseline. This baseline is ideal for considering renewable energy technology scenarios and impacts on the Big Island.

These models together with the results of testing at the Power Park on the Big Island provide the necessary tools for development of cost-effective hydrogen pathways.