Report on Recommendations for Lab and Bench-Scale Tasks

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By

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Report on Recommendations for Lab and Bench-Scale Research Activities in Support of Accelerating Renewable Energy System Development for Hawai‘i

INTRODUCTION

As a result of the project efforts and on-going research activities within the Hawai‘i Natural Energy Institute (HNEI), it is now possible to bring forward some ideas for research initiatives that have emerged as a result of the progress of the project. Brief descriptions of these research initiatives are provided below. Any of these can be expanded based on interests within the Department of Energy (DOE) and the National Energy Technology Laboratory (NETL). In order to make this report more understandable in the context of research needs for the State of Hawai‘i, each research description is presented with the following sub-headings:

1. Relevance and importance to Hawai‘i;
2. Relevance to advancement of renewable energy and distributed energy resources (DER) technologies;
3. Current assessment of the state-of-the-art; and
4. Proposed technical and scientific approach.

While this paper fulfills a project requirement, this discussion also serves as a basis for considering one or more of these initiatives for additional laboratory-based tasks.

RESEARCH INITIATIVES

1.0 Renewable Distributed Power Generation Using a BioCarbon Fuel Cell – Dr. Michael J. Antal, Jr.

1.1: Relevance and Importance to Hawai‘i

Very large quantities of lignocellulosic residues (e.g., corncobs, coconut shells) accompany the production of bioethanol and biodiesel fuels. These residues can be efficiently and quickly converted into biocarbons (i.e., charcoal). In addition, in Hawai‘i large quantities of agricultural residues (e.g., macadamia nut shells, bagasse) and biomass from plantations (e.g., eucalyptus) are available for conversion into biocarbons. Carbon fuel cells can generate electricity from these biocarbons – as well as from coal and other fossil carbons – with a theoretical thermodynamic efficiency of 100%. A recent EPRI study indicates that carbon fuel cells have the potential to convert biocarbons into electrical power at a system level efficiency of about 60%, which is over 20% higher than the efficiencies realized by current state-of-the-art integrated gasification combined cycle (IGCC) or advanced pulverized coal power generation systems. With the cancellation last year of construction of nine coal fired power plants - representing 6,650 MW of capacity - because of concern for CO_2 emissions, both Hawai‘i and the nation must find alternatives to base load electric power generation by coal. One of the most promising alternatives is the biocarbon fuel cell.

HNEI’s interest in the aqueous-alkaline biocarbon fuel cell is further stimulated by the fact that aqueous-alkaline hydrogen fuel cells have been used to power an Austin car and a commercial London Black Cab. Thus, the development of a functional aqueous-alkaline carbon fuel cell may facilitate the replacement of non-renewable, liquid hydrocarbon transportation fuels with renewable, solid biocarbons.

1.2: Relevance to the Advancement of Renewable Energy and DER Technologies

Power generation by wind, solar thermal, and photovoltaic systems is promising but intermittent. Our country must develop technologies for the economic and effective use of renewable resources for base load power. EPRI research has identified carbon fuel cells (sometimes called "direct" carbon fuel cells) as one of the most promising technologies for the efficient generation of base load electric power. The laboratory that is led by Dr. Antal has been the principal supplier of biocarbons to Stanford Research Institute (SRI) for its Defense Advanced Research Projects Agency (DARPA) supported research on high-temperature carbon fuel cells. He has served as a consultant to SRI for the past 3 years on this research. Thus, Dr. Antal's laboratory is well positioned to develop this technology and bring it to Hawai'i.

1.3: Current Assessment of the State-of-the-Art

Nearly all carbon fuel cell researchers have emphasized consumable anodes made of fossil carbons with a variety of electrolytes as the charge carrier. Early work emphasized aqueous-alkaline, molten potassium hydroxide, solid zirconia stabilized with magnesia or yttria, and molten lead electrolytes. However, the focus of current work is the molten carbonate carbon fuel cell. For example, Cooper and his co-workers at the Lawrence Livermore National Laboratory (LLNL) have described the performance of a molten carbonate carbon fuel cell that employed nine different carbons and a porous nickel cathode. By operating at 800 °C, their cell delivered 50 – 125 mA/cm^2 at 0.8 V. Significantly, the LLNL researchers noted that their highest discharge rates (100 – 125 mA/cm^2 at 0.8 V) were obtained with biocarbon (peach pit and coconut shell activated carbon) anodes.

Previous work at the University of Hawai'i (UH) detailed the performance of a low-temperature aqueous-alkaline carbon fuel cell. Operating at 245 °C and 35.8 bar with 0.5 g of corncob charcoal, this cell realized an open circuit voltage (OCV) of 0.57 V and a short circuit current density of 43.6 mA/cm^2. A comparison of Temperature Programmed Desorption (TPD) data for the oxidized anode biocarbon with prior work indicated that the temperature of the anode was too low. Because of this fact, carbon oxides accumulated on the biocarbon without the steady release of CO_2 and active sites needed to sustain oxidation. Consequently, the OCV of the cell was less than the expected value. New thermogravimetric-mass-spectrometric studies by colleagues in the Hungarian Academy of Sciences substantiate the TPD findings, and show that oxygen chemisorption with an accumulation of carbon oxides on the biocarbon anode should give way to the steady release of CO_2 (i.e., steady oxidation) at temperatures approaching 300 °C. These new findings give credence to our expectation that our biocarbon fuel cell will perform according to expectations (i.e., at an efficiency approaching 100%) at temperatures near 300 °C.

1.4: Proposed Technical and Scientific Approach

The aim of this proposal is the development of an aqueous-alkaline/carbonate biocarbon fuel cell which performs well while realizing electrolyte invariance by exploiting electrochemical reactions that are favored at temperatures near 300 °C. This proposal is based on the following two hypotheses. 1) At temperatures approaching 300 °C the aqueous-alkaline/carbonate biocarbon fuel cell will offer an open circuit voltage (OCV) of about 1 V and a steady, maximum power density that exceeds $100 mW/cm^2$. 2) During operation, the composition of the electrolyte will evolve towards an equilibrium mixture of hydroxide and carbonate ions that afterwards will be invariant (i.e., stable).

The cathode of this cell resembles that of a Bacon fuel cell, where oxygen in the air is reduced to hydroxide ion over a silver catalyst. New thermodynamic analyses indicate that the cathode should perform well at temperatures approaching 300 °C. New thermodynamic analyses also indicate that at these temperatures both the hydroxide ion and the carbonate ion (formed by the reaction of CO_2 with hydroxide ion) should vigorously oxidize the carbon anode and release electrons, thereby generating power at high efficiency.

This proposal has three objectives: 1) to characterize the oxidation behavior of anodic charcoal in the aqueous-alkaline/carbonate environment of the fuel cell at temperatures near 300 °C; 2) to characterize the stability of the electrolyte, together with the catalytic effects of differing electrolytes on the anodic and cathodic reactions at temperatures near 300 °C; and 3) to characterize the performance of the biocarbon anode as a working electrode in a setup that includes a counter electrode and flow of the electrolyte through a heat exchanger bridge to a reference electrode maintained at system pressure but at a much lower temperature. As part of a potential collaborative activity, the first objective now enjoys partial sponsorship by the National Science Foundation (NSF).

Usually the practicality of an aqueous-alkaline carbon fuel cell is discounted because the carbon dioxide product of carbon oxidation reacts with and consumes hydroxyl ions in the aqueous-alkaline electrolyte, thereby forming carbonate ions. As a result of this reaction, the performance of an aqueous-alkaline carbon fuel cell is expected to deteriorate over time. Contrary to this expectation, we showed that the aqueous-carbonate ion can be as effective as the hydroxyl ion as a charge carrier when the temperature of the cell approaches 300 °C. Thermodynamic estimates of the Gibbs free energy of formation, $\Delta_f G°$ of the aqueous-carbonate ion, indicate that the change in Gibbs free energy of the relevant anodic carbon oxidation reaction by carbonate ion equals that of carbon oxidation by hydroxyl ion at temperatures approaching 300 °C. Also, consideration of the temperature dependence of the standard hydrogen electrode reveals that aqueous-hydroxyl ion production on the cathode should be favored at temperatures as high as 300 °C. These findings indicate that an aqueous-alkaline/carbonate biocarbon fuel cell operating at 300 °C should be able to generate power at efficiencies approaching 100%.

2.0: Electrical Energy Storage System and Infrastructure Development for Off-Grid Evaluations – Dr. Bor Yann Liaw

2.1 Importance and Relevance to Hawai‘i

As Hawai‘i seeks to increase use of its renewable energy resources for electricity generation, electric energy storage (EES) is an important part of this process. Hawai‘i’s grid connections are vulnerable to the intermittent nature of power generation from as-available renewable resources. Grid stability is a serious issue as the state’s utilities are required to meet aggressive Renewable Portfolio Standards (RPSs). However, limited experience with the use of EES to address this issue on a significant scale has made the introduction of renewable energy generation to Hawai‘i’s island grids challenging. Careful testing and evaluation of potential EES systems is important in meeting the goals of the state’s RPS. The proposed work addresses these needs by building off-grid infrastructure and testing protocols to evaluate emerging EES systems to characterize their performance, including strengths and weaknesses, for grid connection and management.

2.2: Relevance to the Advancement of Renewable Energy and DER Technologies

EES systems are crucial for renewable energy systems in terms of grid stability, energy and resource utilization efficiency, and the ability to provide ancillary power sources to serve as a reserve for peak demand. Currently, there is a lack of test facilities and protocols to evaluate emerging EES systems, to develop tools for control and integration of renewable energy systems, and to support timely implementation of these systems. The proposed work addresses these issues.

2.3: Current Assessment of the State-of-the-Art

In recent years a considerable number of emerging battery technologies have become more mature and competitive for EES applications. Besides traditional lead-acid batteries, several new systems such as Na-S and redox vanadium flow batteries have been introduced for field demonstrations, while Zn-Br, lithium metal, lithium ion, Ni-Zn and a few others are being seriously considered. Even within the same battery technology, various designs and chemistries are available. There is a strong need to evaluate these new EES systems for various types of storage applications. Some batteries are designed for high power applications while the others are for high energy storage. They have differing volumetric, power and energy capabilities to store electric energy with varying capacities, life spans, sizes and costs.

Electric utilities and battery manufacturers need to understand the performance characteristics of these emerging EES systems. Consistent test protocols are necessary for the collection of information to facilitate such understanding. It should be pointed out that typical test procedures used in the industry today cannot provide the needed information to manage complex duty cycles resulting from renewable energy systems in a grid operation. Capability in complex evaluation and analysis can be accomplished only with advanced test facilities and protocols to enable a proper evaluation of the EES systems under realistic operating conditions.

2.4: Proposed Scientific and Technical Approach

HNEI has recently developed a set of standardized test protocols for battery cells and modules for electric and hybrid vehicle applications. Work is proposed to expand this effort to include battery packs and EES systems. Such an expansion will allow cells with different sizes, capacities and chemistries, in pack or system configurations, to be realistically evaluated. Developing these test protocols will help both the energy storage industry and the utilities to meet the challenges of intermittent renewable energy generation. These protocols will facilitate collection of data to depict and to characterize battery degradation through its service life. Additionally, an investigation of the impacts of cell variations on EES system performance and life expectancy will be conducted.

It is important to point out that HNEI's modeling and simulation capability has been useful in providing accurate estimates of battery performance and life. HNEI's experience with laboratory test protocols for quick and precise parameterization has led to development of an enabling methodology for integration of single cell models with laboratory testing. HNEI also developed an effective approach to incorporation of cell-to-cell variations into a battery pack model to take into account extrinsic and intrinsic contributions that can lead to cell imbalance. Therefore, the degree of imbalance can be characterized and managed.

Our existing technology in battery modeling from cells to systems can be expanded to contribute to EES development, demonstration, and deployment. Our database with test data collected during the evaluations of various commonly-used batteries will be used in this effort. With both field testing and laboratory evaluation capability, our modeling and simulation tools can accelerate the integration of renewable energy systems with Hawai'i's utility grids.

3.0: Wind and Solar Power and Energy Capacity Forecasting – Dr. Bor Yann Liaw

3.1 Importance and Relevance to Hawai'i

The October 2008 energy agreement between the State of Hawai'i and the Hawaiian Electric Company calls for 70% of Hawai'i's energy to come from renewable resources and energy efficiency by 2030. It is anticipated that considerable additional capacity will be provided by large-scale wind and solar resources posing significant challenges to utility operation and grid stability. The addition of a considerable amount of energy storage to facilitate large-scale wind and solar power production will be required.

Wind and solar generation is dependent on geographic characteristics and weather patterns that impact both site planning and operational performance. The ability to forecast the amount of power generated at any point in time, as well as capacity, will be important to maintain grid stability. However, power and capacity forecasting is currently a challenging and complex task with factors that can make near-term predictions difficult despite the utilities' requirement for accurate forecast capabilities.

For instance, the topology of the landscape of the Hawaiʻian Islands can change wind patterns quite substantially, adding to the difficulty in predicting wind power output.

3.2: Relevance to the Advancement of Renewable and DER Technologies

The ability to predict potential wind and solar power, and capacity generation, at a given location can create substantial benefits for both capital investment and grid management. An accurate estimate of capacity will allow more appropriate sizing of generation and storage systems to meet grid demand. Such a capability will also allow the grid operator to anticipate the need for a reserve generator or energy storage unit to rapidly respond to loss of power.

3.3: Current Assessment of the State-of-the-Art

Several techniques have been proposed to analyze and perform short-term forecasting of wind speed and solar radiation intensity. These techniques are mainly based on statistical analyses or complex curve fitting using density functions. Although such approaches are commonly employed, as predictive tools, their capability and accuracy are limited. For instance, in predicting wind power, almost all these techniques lack the capability to combine both gust and duration (trend) information in the model to derive the wind speed data over a reasonable time frame to allow accurate prediction of spontaneous power and accumulative capacity. The state-of-the-art meteorological models are quite complex and can provide an overall forecast. However, they are not accurate enough to predict the wind speed at the temporal scale capable for grid management or at a spatial scale for a particular turbine. Some adaptive models have recently been developed for short-term forecasting, but their applicability remains to be validated. Currently, either these statistical analyses are too simple to allow adequate predictions, or the advanced modeling techniques are too complicated for a comprehensive application.

3.4: Proposed Scientific and Technical Approach

In recent years, HNEI has developed a comprehensive approach that employs fuzzy logic pattern recognition (FLPR) techniques to enable driving and duty cycle analyses for electric and hybrid vehicle field test data. This approach provides a comprehensive solution for the analysis of complex data structures for vehicle driving in real life situations that bear a sporadic and uncontrolled nature. Our comprehensive analysis allows us to associate driving and power usage patterns with temporal data, and therefore provides a method to classify “driving events” (Figure 1). This technique has been validated with a collection of two-year test data for over 18 electric vehicles driven in Honolulu. We were able to quantitatively analyze and classify driving cycles in the data collected according to driving conditions and drivers’ driving habits. By looking at the power consumption associated with each type of driving event, it is possible to predict the power consumption on any given trip if road and traffic conditions and the temperament of the driver are also considered. Most importantly, it can help us derive a representative usage pattern that can be used in the laboratory to assess its effect on performance of a storage system (see Figure 1).

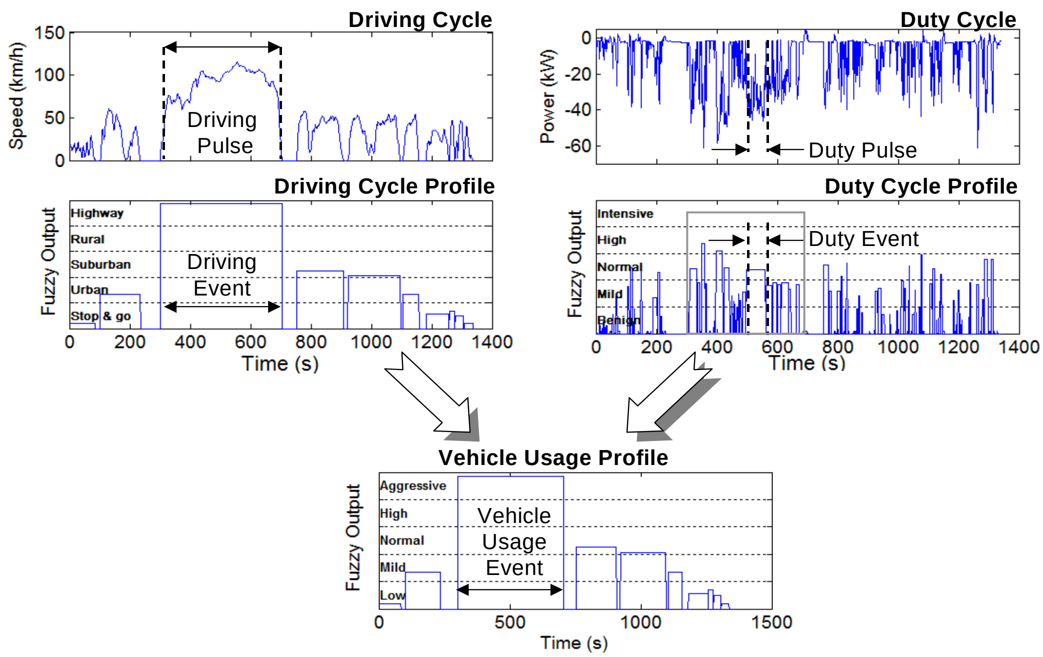

Figure 1: Schematic view of the driving and duty cycle analysis.

We believe that we can utilize a similar approach, based on experience with these driving and duty cycle analytical tools, to allow classifications of wind speed and solar radiation data. The ability to classify establishes the foundation for the forecast, the first step in understanding wind and solar radiation patterns in association with geographical and meteorological data. Regarding the wind speed and solar radiation intensity, time series data can be viewed as analogous to the vehicle speed time series data (as in the driving cycle), and power generation can be analyzed similarly to the vehicle power consumption time series data in a duty cycle. The similarity among these three types of data warrants a comprehensive approach as described in the driving and duty cycle analyses.

Figure 2 shows that by using a fuzzy logic pattern recognition technique, we are able to identify “wind events” (and, likely “solar events”) from a set of site-specific time series data. We can classify wind events based on information combining wind speed and gust variations in a simple and easy to understand density function presentation. This classification enables comparison of wind events with a database that collects data over a long period of time and uses intelligent algorithms to predict power and energy capacity. Preliminary work on a month of wind data from a single turbine located on the Big Island displays promising results, whereby “wind events” have been automatically identified and characterized according to their average wind speed and gust variations as shown in Figure 2.

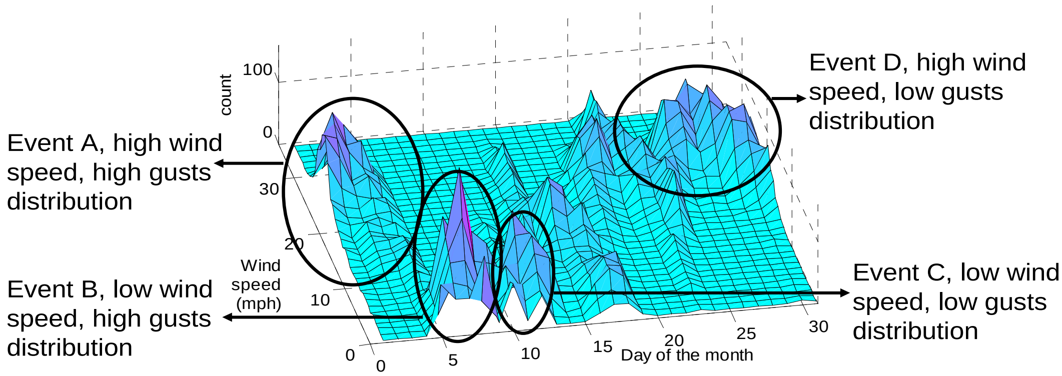

Figure 2: Example of "wind events" with different gust speed distribution.

Based on this preliminary effort, we propose to work with the Hydrogen Power Park team, Hawaiian Electric Company, and other generators (i.e., wind farms) in partnership to facilitate the establishment of a databank for wind and solar data from various sites in Hawai‘i. We will develop the wind and solar event classification techniques and apply them to an analysis of the databank to develop comprehensive algorithms for wind and solar power, and capacity prediction. Such a predictive capability will allow forecasts not only for short-term (e.g., 10 minutes to one hour) power generation, but also trend capacity estimates (seasonal or annual). We will also design a small bench-top or lab-scale experimental system with wind turbine, solar panel, and data acquisition capability combined with controlled operating conditions to permit early-stage algorithm development. This algorithm will then be applied to the analysis of real data from large commercial turbines and solar farms. The tools and pattern recognition techniques can be jointly developed in the laboratory in collaboration with the Green Holmes Hall Initiative (GHHI) that will be implemented on the roof of Holmes Hall on the University of Hawai‘i Manoa campus next year. In the GHHI effort, wind and solar radiation data will be acquired before and after installation of the wind and solar generation system.

In parallel, we will work with the UH Meteorology Department and International Pacific Research Center (IPRC) to access National Oceanic and Atmospheric Administration’s (NOAA’s) weather data, and use its specific forecasting models to generate meteorological data for a number of selected sites and for derivation of the correlation between weather forecast and site specific wind (and possibly solar) for capacity forecasting. If such correlation can be developed, it would provide us with additional information to forecast wind capacity based on the weather forecast information and wind power patterns developed from the databank. This potential capability will enable us to forecast wind and solar power generation and capacity for real-time prediction from the weather forecast models. We can later study the location-specific, seasonal, and size-dependent wind and solar power and capacity forecasts.

4.0: Extraction of Biofuels from Biomass – Dr. Michael Cooney

4.1: Importance and Relevance to Hawai‘i

The production of heavy carbon biofuels such as those made from bio-oils is of increasing importance to Hawai‘i for the displacement of imported petroleum fuels. These liquid-phase fuels of high carbon number (that is, heavy oils) are of particular importance to the local shipping and trucking industry. The extracted biomass also possesses potential as a feedstock for ethanol fermentation, assuming the cell wall material can be broken down into simple sugars. Because of their high productivity relative to plant biomass, microalgae are therefore considered a promising feedstock for the production of bio-oils. The issues of land use, water use, and labor supply, however, are concerns in the planning for use of local resources for development of a state-based industry in bio-energy.

4.2: Relevance to the Advancement of Renewable Energy and DER Technology

Microalgae are effectively grown using CO_2 and sunlight, a renewable process. The use of microalgae will be of particular importance in Hawai‘i where there are a number of potential projects utilizing systems that take advantage of local resources. These projects also recognize the lack of landmass available for larger traditional bio-energy farming activities.

4.3: Current Assessment of the State-of-the-Art

HNEI’s technology and research program uses novel “green” co-solvent mixtures to co-extract bio-oils and proteins from biomass sources such as jatropha, corn seed, microalgae, and yeast, from dry or wet biomass. There are several key advantages to the HNEI system. First, the extracted bio-oil is auto-partitioned to a separate immiscible phase which can be skimmed off the surface. Second, the protein is co-extracted into the co-solvent for further recovery. Third, the extracted biomass is treated such that it is far more permeable to enzymatic hydrolysis into simple sugars that can be used as feedstock for ethanol fermentation. This extraction, energy efficient, novel, and environmentally sound, is a new and emerging component area of the bio-oil process that merits additional research. A full patent on the basic concept has been submitted and HNEI is engaged with several companies in preliminary evaluation studies, including one interested in the bio-oil extraction as a pretreatment step prior to downstream protein extraction, and a second interested in bio-oil and protein extraction as pretreatment prior to enzymatic treatment of the extracted biomass into simple sugars. These applications are in contrast to current practices that apply energy-intensive cell-disruption techniques such as homogenization, sonication or microwave, as well as aggressive organic solvents such as hexane or dodecane which are problematic because they dissolve the bio-oils and therefore must be recovered through energy-intensive techniques such as distillation and condensation. Mechanical pressing, used with some oil seeds, can only extract with 60 to 70% efficiency.

4.4: Proposed Scientific and Technical Approach

There is a need for fundamental and applied research into solvent development that supports superior bio-oil auto-partitioning into separate immiscible phases, enables reduction of emulsions, enhances protein extraction and recovery, and prepares the biomass for further downstream processing (e.g., anaerobic digestion to gaseous fuels or enzymatic hydrolysis to simple sugars). In HNEI's extraction system, the bio-oil is extracted from the biomass into the co-solvent (a polar covalent molecule-salt system) where it auto-partitions to a separate immiscible phase. Polar covalent molecules are usually an alcohol (methanol, ethanol, iso-propanol), but can include other small polar molecules such as ketones, amides, amines, and aldehydes. The salt is a hydrophilic, room-temperature ionic liquid. While the partitioned bio-oil does auto-partition well, an emulsion that lies between the top bio-oil phase and the lower co-solvent can appear due to the presence of "bio-fines" or biomass material that is quite small and low in density – the degree to which varies with the biomass feedstock. The process can also be applied to microalgal culture that has been lightly centrifuged (~15% suspended solids or 85% water w/w) with good, but reduced, efficiencies.

Investigating the impact of water on the phase miscibility and extraction capacity of the co-solvent system would prove of great benefit towards the application of this system to wet biomass – progress that would significantly improve the potential for bio-fuels from microalgae. New knowledge gained regarding what biomass sources produce bio-fine emulsions and even which polar covalent molecules reduce this emulsion would provide great benefit. In addition, the mechanism by which this process extracts protein and how this impacts efficiency, stabilization, and recovery are all important questions (especially with regard to the choice of the polar covalent molecule and ionic liquid made to compose the co-solvent). Finally, there is the important issue of how best to recycle the co-solvent.

The status of this research is consistent with existing HNEI projects that have received small amounts of funding from different industrial companies. Our process is currently being evaluated by Energenetics International for its capacity to initially extract and separate the bio-oil so as to improve the downstream processing that extracts the protein. This would represent a positive improvement in the use of corn feedstock for the production of liquid bio-fuels and proteins.

5.0: Liquid Fuels from Macroalgae – Drs. Stephen Masutani and Brandon Yoza

5.1: Importance and Relevance to Hawai‘i

Biofuels are anticipated to represent a significant component of the future energy portfolio of the U.S. and the state of Hawai‘i. Although many biofuels enjoy a favorably low-carbon burden, use of terrestrial crop sources, such as corn, oil palm, and jatropha, has been the subject of increasing controversy arising from the food-or-fuel debate, water usage issues, and the expansion of monoculture plantations at the expense of naturally diverse environments. Microalgal sources have been proposed as an alternative, but there are significant technical and economic questions that must be addressed.

Macroalgae (seaweeds) have also been considered as possible feedstocks for biofuel production, but to date have not received the level of attention and investment enjoyed by terrestrial crops or microalgae, due to perceived difficulties in commercial scale cultivation and harvesting. Although ocean farming poses challenges, it appears inevitable that utilization of the 70% of the Earth's surface covered by water will expand in the future to sustain the growing human population. Moreover, seaweed cultivation (for food) has been successfully pursued for generations in many countries such as Japan. In consideration of this, it is worthwhile to assess the viability of energy production from seaweed, particularly for a state like Hawaiʻi with extensive ocean resources.

5.2: Relevance to the Advancement of DER and Renewable Technologies

Like terrestrial plants and microalgae, macroalgae produce carbohydrates via photosynthesis from carbon dissolved in seawater (e.g., anthropogenic CO_2 absorbed from the atmosphere). Conversion of these carbohydrates to combustible liquid fuels such as alcohols can be pursued using similar strategies and technologies developed for more conventional bio-feedstocks; significant cross-pollination and leveraging will be possible. As such, macroalgae should be taken to represent a renewable marine bioenergy resource that expands the scope of biofuel options for Hawaiʻi and the world.

5.3: Current Assessment of the State-of-the-Art

Macroalgae grow quickly, have a relatively high carbohydrate content and low lignin. These characteristics make macroalgae a good candidate for the production of alcohol biofuels. For the past year HNEI has been conducting small-scale exploratory research on this topic. Various species of invasive seaweeds were collected and analyzed. Invasive species were targeted, since they are the focus of an ongoing program to remove them from the reefs, where they frequently smother the coral. Biofuel production from these seaweeds could provide a desirable alternative to disposal or use as fertilizers. Preliminary results have been encouraging and proof of concept has been demonstrated through the production of ethanol from the macroalgae via a simple fermentation process.

Although it is unlikely that macroalgal-derived biofuel will constitute a major component of Hawaiʻi's renewable energy inventory due to limitations in feedstock, it extracts value from what otherwise would be an environmental nuisance (i.e., invasive seaweed) and provides incentive and economic offsets for the removal of this nuisance. Moreover, the technology developed from an R&D program could be marketed and applied in the future where marine cultivation of macroalgae feedstocks are pursued at a commercial scale. An additional benefit of the approach lies in the fact that macroalgae can also be employed for phytoremediation of contaminated bodies of water and remove dissolved CO_2 from seawater, which may help to moderate ocean acidification.

5.4: Proposed Technical Approach

Additional R&D is needed on a broad spectrum of topical areas related to the development of microalgal resources. This includes resource and economic assessments, cultivation and harvesting, and methods to process the feedstock and generate biofuels.

A macroalgal biofuels program would comprise the following components, which could be pursued in parallel or sequentially:

1. Assess the potential for sustainable liquid fuel production from macroalgae for Hawai‘i, the U.S., and the world. This would consider both near- and long-term scenarios based on existing macroalgal biomass resources, conversion technologies, future offshore cultivation, and reasonable technology advances. Compare macroalgae with terrestrial crops and microalgae as an energy resource.
2. Estimate the cost per unit energy of target macroalgal biofuels (e.g., ethanol) for various cultivation and production scenarios.
3. Expand preliminary chemical analyses of selected invasive reef seaweeds conducted at HNEI to other species such as kelp and seagrass to produce a database on carbohydrate content, lignin, and other properties that can be used to develop conversion technologies.
4. Conduct benchtop experiments of fermentation of macroalgae to generate alcohol utilizing different protocols.
5. Investigate the feasibility of other methods to produce liquid fuels from seaweed.
6. Initiate a preliminary evaluation of potential positive and negative environmental impacts of large-scale production of biofuels from macroalgae.

6.0: Production of Liquid Fuels and Chemicals from Biomass-Derived Syngas – Dr. Scott Turn

Fiber is a non-food, biomass resource that can be used to produce a wide variety of energy products including liquid transportation fuels and biobased chemicals. HNEI currently operates a fluidized bed gasifier facility that can produce syngas from fiber resources. This request seeks to extend HNEI's capabilities by developing a research facility for liquid fuel and bio-based chemical production from syngas. The facility would include reactors designed to operate at elevated pressure and temperature to react syngas over a catalyst, gas handling and delivery systems, safety systems, and analytical equipment to monitor the syngas quality, product quality, and evaluate system performance.

6.1: Importance and Relevance to Hawai‘i

Hawai‘i is the only state in the U.S. located in the tropics with access to the wide variety of biomass materials found in this region. These biomass feedstocks have varying properties that depend on the location where they are grown and the growing conditions. To study the use of these biomass crops for thermocatalytic production of bionenergy products requires that the facilities be located in Hawai‘i. Shipping biomass to facilities outside Hawai‘i is restricted by agricultural quarantine. An alternative would be to ship bottled syngas produced in Hawai‘i to mainland facilities. The duration of catalyst tests (on the order of weeks) would require large numbers of gas cylinders. Shipping them to the mainland is costly, creates time delays, and requires transport suitable for compressed gases.

6.2: Relevance to the Advancement of DER and Renewable Technology

Hawai‘i's current transportation and power generation systems are heavily dependent on liquid fuels derived from petroleum. Replacing petroleum products with renewable products that would not require major infrastructure changes along the supply chain could ease the transition. This lab facility will provide the capability to develop and test liquid fuel alternatives from local biomass resources.

6.3: Current Assessment of the State-of-the-Art

We currently have no research facilities of this type in the state. The U.S. Department of Energy has funded four projects that are focused on gasification followed by unit operations to obtain syngas followed by syngas conversion to liquid fuels. Conversion of natural gas and coal-derived gas-to-liquid fuels has been accomplished at commercial scales, most notably by Sasol in South Africa. The use of biomass as a feedstock to produce syngas will present challenges due to the reduced scale of operations compared to fossil-based plants and its unique slate of contaminants that may vary based on crop type and location.

6.4: Proposed Scientific and Technical Approach

This facility will provide catalyst testing capabilities for biomass-derived syngas generated from tropical feedstocks. The existing gasifier facility has the capabilities to generate syngas and explore clean up options. A bench-scale facility to produce liquid fuels and bio-based chemicals will complete the series of unit operations necessary to convert biomass to desired products. Work will focus on obtaining actual data on yields from biomass synthesis gas along with selectivity, productivity, efficiency, and lifetime of the catalysts.