FINAL TECHNICAL REPORT

Hawai‘i Distributed Energy Resource Technologies for Energy Security

Prepared for the

U.S. Department of Energy

Office of Electricity Delivery and Energy Reliability

Under Cooperative Agreement No. DE-FC26-06NT42847

Hawai‘i Distributed Energy Resource Technologies for Energy Security

By the

Hawai‘i Natural Energy Institute
School of Ocean and Earth Science and Technology
University of Hawai‘i

December 2012

Acknowledgement: This material is based upon work supported by the United States Department of Energy under Cooperative Agreement Number DE-FC-06NT42847.

Table of Contents

Executive Summary

This report summarizes work conducted under Cooperative Agreement Number DE-FC26-06NT42847, Hawai‘i Distributed Energy Resource Technologies for Energy Security. This effort was funded by the U.S. Department of Energy (DOE), Office of Electricity Delivery and Energy Reliability (OE), and the Office of Energy Efficiency and Renewable Energy (EERE), with administration by the National Energy Technology Laboratory (NETL), to the Hawai‘i Natural Energy Institute (HNEI), School of Ocean and Earth Science and Technology, University of Hawai‘i.

HNEI has conducted research to address a number of issues important to move Hawai‘i to greater use of intermittent renewable and distributed energy resource (DER) technologies in order to facilitate greater use of Hawai‘i's indigenous renewable energy resources. Efforts have been concentrated on the Islands of Hawai‘i, Maui, and O‘ahu, focusing in three areas of endeavor: 1) Energy Modeling and Scenario Analysis (previously called Energy Road mapping); 2) Research, Development, and Validation of Renewable DER and Microgrid Technologies; and 3) Analysis and Policy. These efforts focused on analysis of the island energy systems and development of specific candidate technologies for future insertion into an integrated energy system, which would lead to a more robust transmission and distribution system in the state of Hawai‘i and eventually elsewhere in the nation. The overall work was divided into twelve tasks, summarized in the following paragraphs.

Task 1: Hawai‘i Analysis – Assessment of Electricity Infrastructure and Microgrid Applications

Under a previous award (DE-FC36-04GO14248), GE Global Research Center, under contract to HNEI, assessed the electric and transportation infrastructure for the Island of Hawai‘i. Building on those results, additional analyses were conducted under this award to address target objectives of petroleum reduction, grid stability, and economic viability related to specific changes to grid operation and infrastructure. These analyses were performed so as to be consistent with the local utilities' Integrated Resources Plan, and were initially developed to modify the Island of Hawai‘i's energy infrastructure to best meet the target objectives, while satisfying technical, social, and economic constraints identified by stakeholders.

Potential options were developed to address issues such as transmission congestion, management of high saturations of distributed energy resources, matching energy resources with grid loading dynamics, and the intermittency of renewables.

Task elements included:

- Development and validation of GE’s electric grid models (MAPS™ and PSLF™) and transportation models.
- Stakeholder interviews and a follow-on stakeholder summit to work through the preferred metrics for addressing grid issues and for determining specific electricity scenarios to be modeled.

- Conceptual designs for the installation of new technology, such as energy storage including identification of site-specific barriers that could inhibit the successful deployment of the proposed energy solution were described.
- Development of scenarios of enhanced penetration of renewable resources on the utility grid.

Task 2: Research, Development and Testing of Distributed Energy Resource and Microgrid Technologies

Under this task, HNEI developed, tested, and validated emerging bulk energy storage and distributed energy technologies that afford opportunities for improved grid performance and facilitate more effective utilization of Hawai‘i 's indigenous resources. This task included the following subtasks:

2.1 Identify and Evaluate Emerging Distributed Energy Resource and Bulk Storage Technologies: Technologies considered included:

- Grid energy storage such as batteries and pumped hydroelectric storage systems.
- Hydrogen technologies as possible components of future DER and micro-grid systems. This effort leveraged investment in hydrogen infrastructure by the State of Hawai‘i through the Department of Business, Economic Development and Tourism (DBEDT).
- Biomass technologies were identified and evaluated for potential contribution to Hawaii’s energy mix including consideration of both crop production and conversion technologies.

2.2 Develop, Test, and Validate Distributed Energy Resource and Microgrid Technologies
This subtask examined a range of DER technologies for eventual use in operational utility grids and micro-grids including:

- Hydrogen - Work in this technology area focused on the off-peak production and storage of hydrogen. The efficacy of new systems for energy storage and peak demand utilization were tested and evaluated.
- Biomass - HNEI conducted R&D to advance biomass-to-energy distributed energy resource technologies. Specifically, HNEI examined use of biomass feedstock for fermentation, pyrolysis, gasification, biodiesel production, and related combined heat and power applications.
- Photovoltaics - HNEI conducted evaluations of the performance of various module designs, including total energy output and suitability for use in large-scale distributed energy systems.

Task 3: Develop Public Policy/Outreach to Accelerate Acceptance of Distributed Energy Resource and Micro-grid Applications
HNEI partnered with the University of Hawai‘i’s Hawai‘i Energy Policy Forum (HEPF) to explore and develop protocols for linking technology demonstration and deployment activities with state and national policy and regulatory initiatives. By linking technology to policy, the potential for successful long-term commercialization will be enhanced. In order to implement effective program strategies for deploying successful technologies, HNEI

provided technical information, where possible, and explanations of its significance to policy decision makers. To this end, HNEI worked closely with state and federal stakeholders in ensuring that technology advances are adequately described in terms of their application and significance to the community and nation. HNEI provided information to decision makers on the results of these analyses, all of which have been completed.

Task 4: The Hawai'i Energy Road-mapping Study - Project Implementation Plan
The Hawai'i Energy Road-mapping project goals included the development of a strategic energy roadmap for the Island of Hawai'i (discussed in Task 1). By analyzing and quantifying numerous technical, regulatory, and policy issues associated with the electricity and transportation infrastructures on the Island of Hawai'i, this study provided a significant contribution to meeting the Nation's energy objectives, where the tools, procedures, and conclusions developed and technologies deployed will address similar energy issues throughout the rest of the country.

As part of activities described in Task 1, models of electricity and transportation infrastructures were developed, calibrated, and validated against the conditions on the Island of Hawai'i, and stakeholders were engaged to establish target goals, key metrics, and potential technology responses to meet the State's energy goals. As a result of model development efforts, additional interaction between the local utility and system modelers became necessary to ensure that the correct information had been captured for this system. Based on this stakeholder input and the exhaustive information from the electricity utility, various integrated energy scenarios were developed and analyzed using electricity and transportation models that were developed and refined in earlier parts of the project. Each scenario was evaluated against the stakeholders' target objectives, while satisfying technical, social and economic constraints.

Due to the unique nature of the early findings (and their direct implications to larger mainland systems) obtained in these programmatic activities, this task ensured that the true nature and explicit aspects of the Island of Hawai'i's energy infrastructure were properly characterized. This was a key overall project requirement, since the grid issues being evaluated and analyzed on a relatively small grid on the Island of Hawai'i have direct and considerable implications on the future of mainland grid systems. These issues have been discussed with DOE program managers in Washington and at NETL. This task follows on from earlier results to properly capture all aspects of these important issues. The "lessons learned" report resulting from this task will be used to set the stage for future demonstrations of technologies that will enhance the performance and ameliorate current problems with the grid system on the Island of Hawai'i.

Task 5: Development of information, Models, and Analyses for Characterizing the Future Electricity Grid on Maui
The Maui Electric Company (MECO), a wholly owned subsidiary of the Hawaiian Electric Company (HECO), generates and distributes electrical power on the island of Maui. The generation mix currently includes some renewable energy resources, primarily associated with a 51 megawatt (MW) wind farm in Kaheawa. High cost of electricity, coupled with aggressive renewable energy targets for the state of Hawai'i, make expansion of renewable

energy resources likely. Examples of this potential expansion include Shell's desire to add 40 MW of wind power with pumped hydro firming at the remote corner of 'Ulupalakua Ranch on Haleakala. Additionally, significant solar power generation projects have been discussed among the larger end-use customers on Maui. Under this task HNEI developed and validated MAPSTM and PSLFTM models of the MECO grid system.

Subtasks completed for this task include: 1) data consolidation and preliminary model feasibility analysis for the Island of Maui, 2) data evaluation, completion and manipulation, and 3) system model development and baseline model validation. Following completion of the model validation effort, a negotiated agreement by the State of Hawaiʻi Public Utilities Commission required that the model be utilized in conjunction with independent power producers as part of a complaint resolution. Thus, no scenarios were run using federal funding following the completion of the subtask.

Task 6: Coordination and Support of DOE/OE R&D Initiatives
HNEI supported the DOE's OE in developing new and appropriate systems for evaluating new research, development and deployment initiatives. Existing approaches that focus on the exclusive use of the NEMS model, while required, need to be supported by additional planning tools that can address the unique nature of the DOE/OE technology portfolio and goals. To this end, HNEI staff participated with other organizations selected by DOE/OE to address this issue and recommend other planning tools to incorporate into the decision-making process.

HNEI also worked closely with DOE management to help implement new technology deployment programs for Hawaiʻi. This new initiative requires close coordination between energy end-users, the state utilities, state agencies, DOE consultants, members of the national laboratory system, and DOE management.

HNEI also worked with NMT to coordinate overall programmatic activities. These efforts included the sharing of significant results and breakthroughs, as well as coordinating interactions with key utility partners, prime subcontractors and DOE program management.

Task 7: Energy Modeling and Scenario Analysis
Task 7 continued the efforts initiated under tasks 1, 4 and 5, for which detailed assessments of the grid systems of the Island of Hawaiʻi and Maui were developed as well as a transportation model for the Island of Hawaiʻi and Maui. In addition, various scenarios for evolution of the electricity system of the Island of Hawaiʻi have been evaluated and reported.

Under Task 7, HNEI specifically conducted additional scenario studies for the islands of Oʻahu and Maui grid systems with emphasis on the detailed evaluations needed to plan for implementation of projects. In addition, plans were made for evaluation of the impact of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) on the Maui grid.

Task 8: Continued Research, Development and Validation of Critical Renewable Distributed Energy Resource, Microgrid and End-Use Energy-Efficient Technologies

This task, following on the efforts completed under Task 2, was structured to address both original plans as well as lessons learned during the earlier parts of the project. Work under Task 8 is structured around several potential renewable, DER, and micro-grid technology initiatives. Specific technologies examined included: 1) PHEVs, 2) use of hydrogen for energy storage, 3) photovoltaic system demonstration, and 4) technologies for energy-efficient buildings.

Task 9: Public Policy Analysis and Assessment
This particular task followed on the work of Task 3. It continued the effort to link technology with policy and economics. Specific subtasks are described below.

Subtask 9.1: Hawai‘i Bioenergy Master Plan
As part of this task, HNEI (in consultation with relevant stakeholders), worked with the State's Department of Business, Economic Development, and Tourism in developing a state biomass energy strategic plan. The primary objective of the master plan was to develop a Hawai‘i renewable biofuels program to manage the State's transition to energy self-sufficiency based in part on biofuels for power generation and transportation. The bioenergy master plan addressed outcomes such as: strategic partnerships, evaluation of biofuel potential, biofuels demonstration projects, promotion of biofuels to potential partners and investors, and a plan to implement commercial biofuels development.

The bioenergy master plan also addressed: objectives and timelines; water resources; land resources; marine and land distribution infrastructure; labor resources/issues; technology to develop bioenergy feedstock and biofuels; permitting; financial incentives/barriers and other funding; business partnering; policy requirements for implementing the master plan; and identification/analysis of the impacts of transitioning to a bioenergy economy while considering applicable environmental concerns.

Subtask 9.2: Economic and Environmental Modeling of Island Energy Systems
HNEI worked with the University of Hawai‘i Economic Research Organization to develop these models, which were used to better determine the impacts of potential legislation related to greenhouse gases on the economy of Hawai‘i. As the need arises, these analyses can be related to other activities in the United States, Europe, and Asia in evaluating the consequences of climate change, new regulatory requirements and the attendant economic impacts associated with these activities. As part of this effort, HNEI has developed a flexible, spreadsheet-based model to analyze the different scenarios for the Hawai‘i utilities meeting the State's Renewable Portfolio Standards requirements (see the Subtask 9.2 Deliverable report referenced under Subtask 9.2 in the main body text of this report). By implementing the model within a spreadsheet, the various stakeholders can assign their own assumptions about the future and assess the outcomes. HNEI anticipates following a similar approach in developing future models for policy analysis.

Subtask 9.3: Analysis of Integrated Tropical Biorefineries
HNEI has been involved in biomass energy research and development for many years. As a result of new interest in tropical agricultural and aquacultural feedstocks, HNEI worked with private sector entities to evaluate and plan for potential development of future commercial biorefineries in Hawai‘i based on these feedstocks. Analysis included (1)

establishing baseline material and energy balances for well-defined feedstock production and/or conversion modules, (2) integrating the modules to investigate their use as components of tropical biorefineries, and (3) preliminary estimation of production costs for the primary product of each module.

Task 10: Energy Modeling and Scenario Analysis
Subtasks completed under this task have included: 1) O‘ahu Scenario Analysis -- the O‘ahu Wind Integration Study report, and 2) System Simulation using High-Performance Computing -- reports that: a) describe numerical tools for simulating/analyzing the state of the grid and estimating stability indices for the grid, and b) describe model abstraction techniques for power systems with a large penetration of renewable energy.

Task 11: Research and Development on Distributed Energy Resource and Renewable Energy Systems
This task continued to focus on the utilization of DER and renewable energy systems in Hawai‘i. All efforts were predicated on the concomitant focus of utilizing what is developed in the State for related purposes on the mainland. This task builds from the related Task 8 subtasks.

Subtasks for this task addressed the issues of: 1) photovoltaic systems, 2) energy storage systems, and 3) end-use energy efficiency and demand response.

Task 12: Policy Analyses and Assessments
This activity continued efforts commenced under Task 9 in a previous amendment to this cooperative agreement. The new and expanded subtasks include the following elements: 1) bioenergy analyses covering a variety of issues, 2) energy and economic model development, 3) use of geographic information system (GIS) resources to aid in the State of Hawai‘i biomass/bioenergy/biofuel future, and 4) life cycle analyses of bioenergy production systems.

Information on Obtaining Special Status Reports (Deliverables) Submitted during the Course of This Cooperative Agreement
In the main body of this report, each of the award tasks will be discussed in separate sections. For each task, an overview of accomplishments is presented and summaries are provided for the large number of deliverable reports that were submitted over the six years of this Cooperative Agreement. The last section of each task is one entitled Topical Report(s) Submitted Under This Task. The reports are presented there in chronological order for the date the report was submitted. Each report has reference to the deliverable number for that report and the title for the report.

For readers who are interested in examining any of those reports, it is possible to download any of them from the HNEI website (http://www.hnei.hawaii.edu/). In the green navigation band at the top of our homepage is an item entitled PUBLICATIONS. Clicking on that item will reveal a list of publication sections, the top one of which is entitled DOE PROJECT REPORTS. By clicking on that item you will be led to a page showing several HNEI DOE projects. Clicking on the item entitled Hawai‘i Distributed Energy Resource

Technologies for Energy Security: DE-FC26-06NT42847 will lead to a listing of the deliverables submitted for all tasks of this report. They are arranged in chronological order, showing the dates submitted for all of the reports plus references to the deliverable numbers and title for each report. Clicking on any of these items will bring up the PDF document for the deliverable report of interest.

Introduction

The Hawai‘i Distributed Energy Resource Technologies for Energy Security program, funded by the U.S. Department of Energy (DOE), was initiated in July of 2006 under Cooperative Agreement Number DE-FC-06NT42847. The program goal was to demonstrate, test, and evaluate distributed energy resource (DER) technologies to facilitate greater penetration of Hawai‘i’s indigenous renewable energy sources and reduce Hawai‘i’s predominant (>90%) dependence on imported fossil fuels. Specific activities included energy modeling and scenario analysis; development, and validation of renewable DER and microgrid technologies; and analysis to support policy decisions.

The following sections of this report present details of accomplishments for each of the tasks delineated in the Executive Summary. Where appropriate, specific deliverable items previously submitted under this Cooperative Agreement are referenced and made available on the HNEI website.

Task 1: Hawai‘i Analysis – Assessment of Electricity Infrastructure and Microgrid Applications

The electric and transportation infrastructure for the Island of Hawai‘i had been assessed by HNEI and the GE Global Research Center (GE -- subcontractor to HNEI) under a previous DOE award (DE-FC36-04GO14248). Building from those efforts under this Cooperative Agreement, the energy situation on the Island of Hawai‘i was described to energy stakeholders to obtain their views on how priorities to balance costs, environment (local and global), economic development, reliability and energy security, and cultural sensitivities. The information obtained was utilized in developing scenarios for enhanced penetration of renewable resources on the utility grid for the Island of Hawai‘i – operated by the Hawai‘i Electric Light Company (HELCO).

Subsequently, the scenarios or specific cases chosen were examined within GE’s modeling software programs. These modeling efforts were carried out in cooperation with HELCO and with the use of HELCO utility data.

1.1 Scenario Development and Selection

Using the results of the stakeholder interview process, a number of specific themes relating to electricity generation were identified. Combining these themes with the applicable stakeholder inputs, scenario development efforts were completed. In this process, the following list of potential scenarios was considered:

Scenario 1: Higher wind penetration

Scenario 2: Enhanced Energy Management

Scenario 3: Increasing Energy Security

Scenario 4: Reducing Cost of Electricity

Details for the higher wind penetration scenario can be seen in Figure 1.

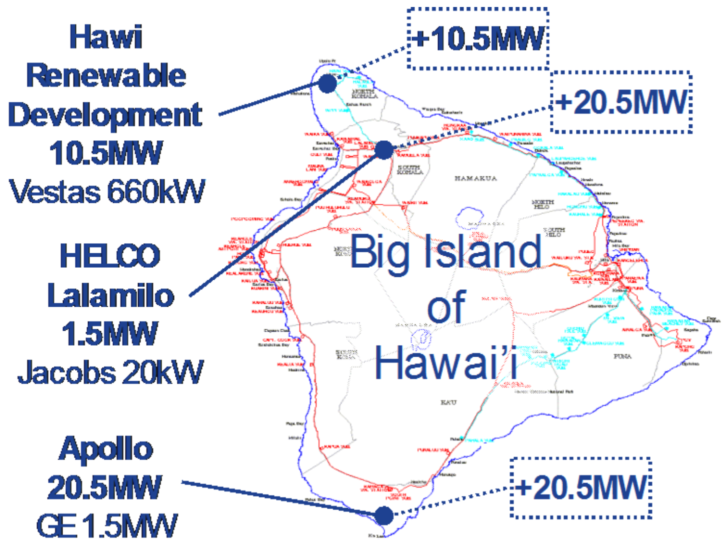


Figure 1: Higher wind penetration scenario for the Island of Hawai'i

The options selected were aimed at addressing issues such as transmission congestion, management of high saturations of distributed energy resources, matching energy resources with grid loading dynamics, and the intermittency of renewables.

The overall scenario selection process is illustrated in Figure 2. This figure shows the method used for integrating the various program features.

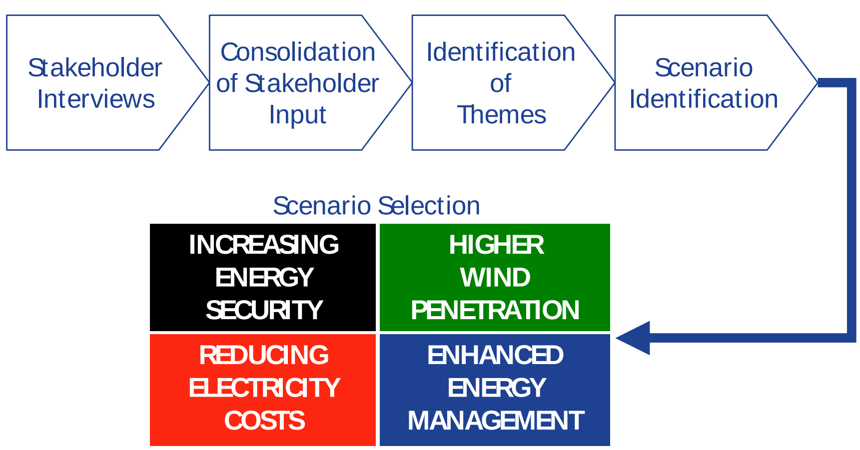


Figure 2: Scenario selection process diagram

In the ultimate analysis, a total of four scenarios or specific cases were evaluated in the modeling efforts using GE’s modeling software programs. Figure 3 shows the scenarios used within this evaluation. The specific scenarios included a baseline (or business-as-usual) condition, higher wind penetration, higher geothermal penetration, and enhanced energy management.

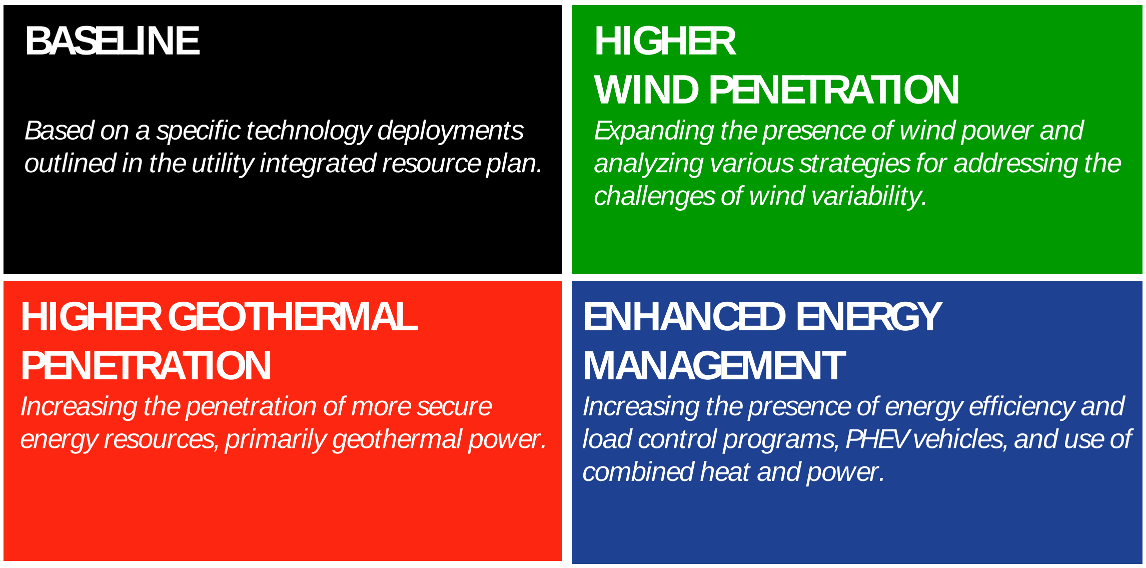


Figure 3: Scenarios used in the Island of Hawai‘i analysis

The higher wind penetration scenario included a production cost model as well as dynamic modeling. The higher geothermal scenario included the possible geothermal plant deployments on the Island of Hawai‘i as shown in Figure 4. Under the enhanced energy management scenario, considerations were given to the utility’s Integrated Resource Plan as well as features of energy efficiency, combined heat and power operation, and EV and PHEV charging.

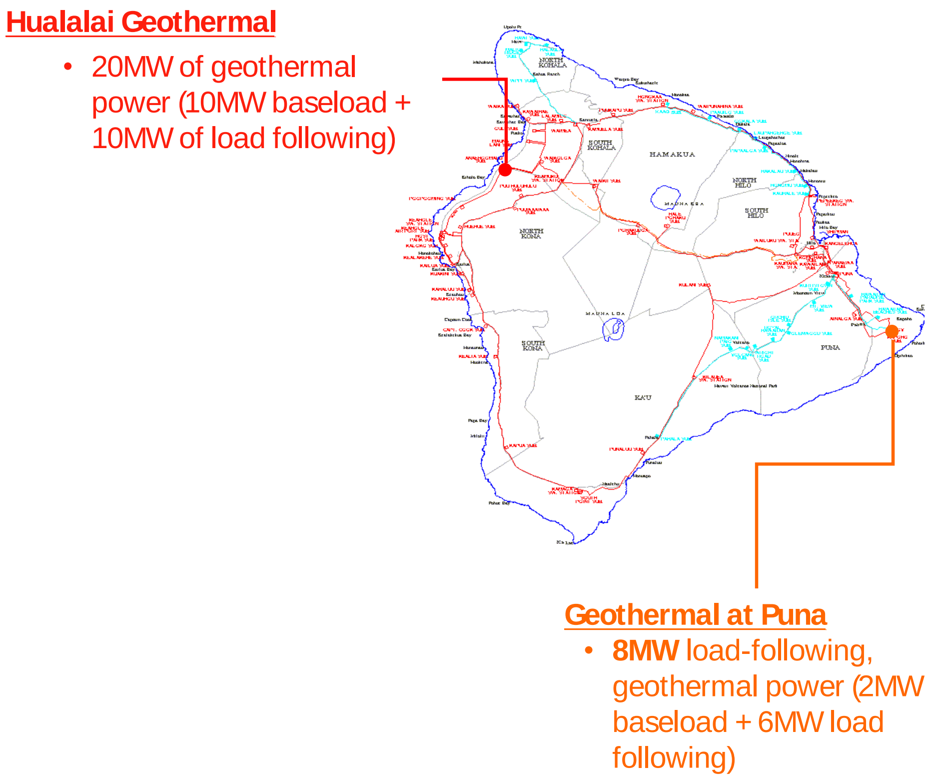


Figure 4: Geothermal plant deployments considered

1.2 Modeling Validation and Scenario Analysis

The modeling approach was focused on providing a foundation from which simulations can be used to provide quantitative information necessary for evaluating the electric infrastructure. The model aimed at capturing technical aspects of challenges related to regulation, frequency control, load following and unit commitment within the transmission system capabilities associated with the present infrastructure, including intermittent resources such as wind generation. The quantitative analysis covered a broad range of timeframes, including:

- Seconds to minutes (regulation and frequency control) – Dynamic simulation
- Minutes to hours (load following, balancing) – Dynamic simulation
- Hours to days (unit commitment, day-ahead forecasting and schedules) – Production cost simulation

Under long-term dynamic simulations performed for HELCO's grid, GE used its *Positive-Sequence Load Flow (PSLF™)* software. Production cost simulation was performed with GE's *Multi Area Production Simulation (MAPS™)* software program. The programs were used for analysis of the baseline "business-as-usual", higher penetration wind, higher geothermal penetration, and enhanced energy management scenarios.

Topical Reports Submitted Under Task 1

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of key reports submitted under this agreement. Specific reports for this task include:

- Task 1 Deliverable #1 (Stakeholder Interview Report), 10/18/2007
- Task 1 Deliverable #2 (Summary Report on Stakeholder Workshop), 11/20/2007
- Task 1 Deliverable #3 (Report on Scenario Development and Analysis), 11/26/2007
- Task 1 Deliverable #4 (Utilization of a Validated Power System Model on Two Scenarios: Base Case and High Wind Penetration), 07/31/2008

Task 2: Research, Development and Testing of Distributed Energy Resource and Microgrid Technologies

This task was dedicated to development, testing, and validation of emerging bulk energy storage and distributed energy technologies that afford opportunities for improved grid and microgrid performance, and facilitate more effective utilization of Hawai‘i 's indigenous resources. This task included two subtasks, as described in the following subsections.

2.1 Identify and Evaluate Emerging Distributed Energy Resource and Bulk Storage Technologies

As part of the system evaluation conducted by GE Global Research, the impact of various emerging DER resources and storage technologies were evaluated. Systems that were given consideration included energy storage technologies including pumped hydroelectric storage, PHEV, enhanced energy management, hydrogen, and integrated combined heat and power technologies. Details of this analysis are included in the Subtask 2.1 Report, “Evaluation of Future Energy Technology Deployment Scenarios for the Big Island” available on the HNEI website.

Biomass technologies were identified and evaluated for potential incorporation into micro-grids. These considerations included crop production, biomass combined heat and power, fermentation, pyrolysis, gasification, reforming, and gas stream scrubbing technologies. The analysis developed a summary of biofuels technology readiness and described a biomass gasification gas analysis project. These initial studies clearly demonstrate potential for utilizing indigenous biomass resources for replacing of fossil resources. Biomass results are included in the Task 2.2 reports.

2.2 Develop, Test, and Validate Distributed Energy Resource and Microgrid Technologies

Under this subtask, a broader range of critical DER technologies was considered and methods for improving microgrid performance were explored. HNEI evaluated technologies which can be utilized to take advantage of under-utilized renewable energy resources for alleviating transmission congestion, providing peak power, and addressing renewable technology intermittency issues. Specific technologies studied included hydrogen, biomass, and photovoltaic (PV) systems.

Hydrogen Systems

HNEI installed, tested, evaluated, and demonstrated integrated systems for the production of hydrogen from renewable energy resources. This effort was originally planned for implementation at the Hawai‘i Gateway Energy Center (HGEC), located at the Natural Energy Laboratory of Hawai‘i Authority (NELHA) on the Island of Hawai‘i; however, Kahua Ranch, also located on the Island of Hawai‘i, was selected to host this effort. There were a number of reasons for doing this -- Kahua Ranch owners have worked for several years with the Pacific International Center for High Technology Research (PICHTR) to obtain funding from the Japanese government’s Ministry of Foreign Affairs to test, demonstrate, and deploy renewable energy systems to Pacific Island Nations. As a result of these efforts (which included cost share from PICHTR and Japan), considerable infrastructure already existed at Kahua, comprised of PV, wind turbine (WT), battery, and electrical distribution infrastructure systems, which are not available at HGEC. This effort also leveraged major system components moved to Kahua, such as the fuel cell, electrolyzer, and data acquisition systems, which were purchased and tested under a previous program.

The layout of the Kahua Ranch system can be seen in Figure 5, including the electrochemical components (electrolyzer and fuel cell) of the hydrogen storage system. The PEM electrolyzer system was provided by Electric Hydrogen. The 5 kW fuel cell system was provided by Plug Power. The Kahua Ranch Power System was designed as a stand-alone power system including: 1) renewable energy resource generators comprised of a WT generator and a PV array, 2) a lead-acid battery as short-term electricity storage, and 3) a hydrogen storage system for long-term energy storage, consisting of an electrolyzer, a low-pressure (175 psi) hydrogen gas storage system, and a fuel cell. Within this system, hydrogen was supplied to the 5 kW fuel cell power system that then provided 48 VDC power to the 48 VDC main electrical bus bar.

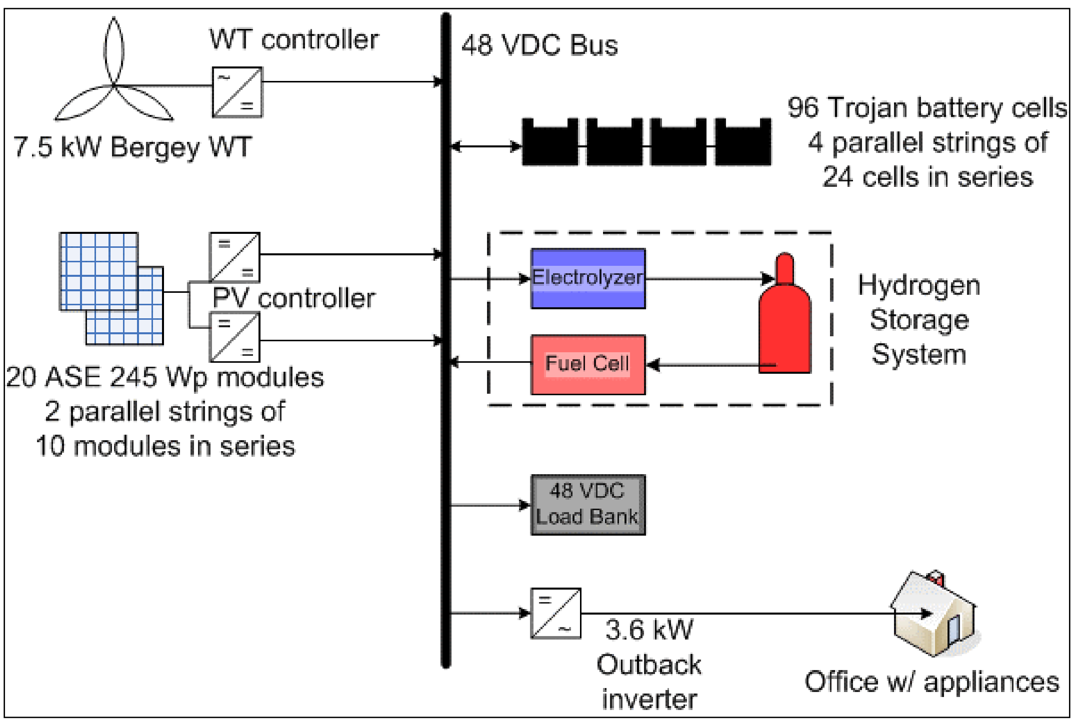


Figure 5: Kahua Ranch system layout

Details of this analysis are included in the Subtask 2.1 Report, “Development and Testing of Hydrogen Storage Systems(s) for Capturing Intermittent Renewable Energy Sources for Peak Demand Utilization on the Grid” available on the HNEI website.

Biomass Systems

Under this activity HNEI addressed technology issues related to bioenergy development in Hawai‘i within the framework of crops and conversion technologies presented in Figure 9 on the following page. The plants listed on the left hand side of the figure are not all inclusive but represent a selection of the broad spectrum that are being considered as potential bioenergy species in Hawaii. These plants were selected based on their capacity to generate the intermediate products depicted in the figure; sugar, starch, fiber, and oil.

As shown in Figure 9, the intermediate products are transformed into bioenergy products using conversion technologies. Starch is hydrolyzed into sugars which can then be fermented to produce ethanol or butanol. The hydrolysis step is not required for sugar bearing crops. Fiber can also be used to produce ethanol or butanol by hydrolyzing its cellulose and hemicellulose portions to simple sugars that can be fermented. Fiber can also be converted into a number of bioenergy products including electricity, heat, synthetic diesel, charcoal, etc. The primary conversion technologies required to realize these transformations include gasification, pyrolysis, and combustion. Finally, oils from oil seed, tree nuts, or algae can be directly combusted to produce heat and power or converted to biodiesel for use as a transportation fuel or in stationary power applications.

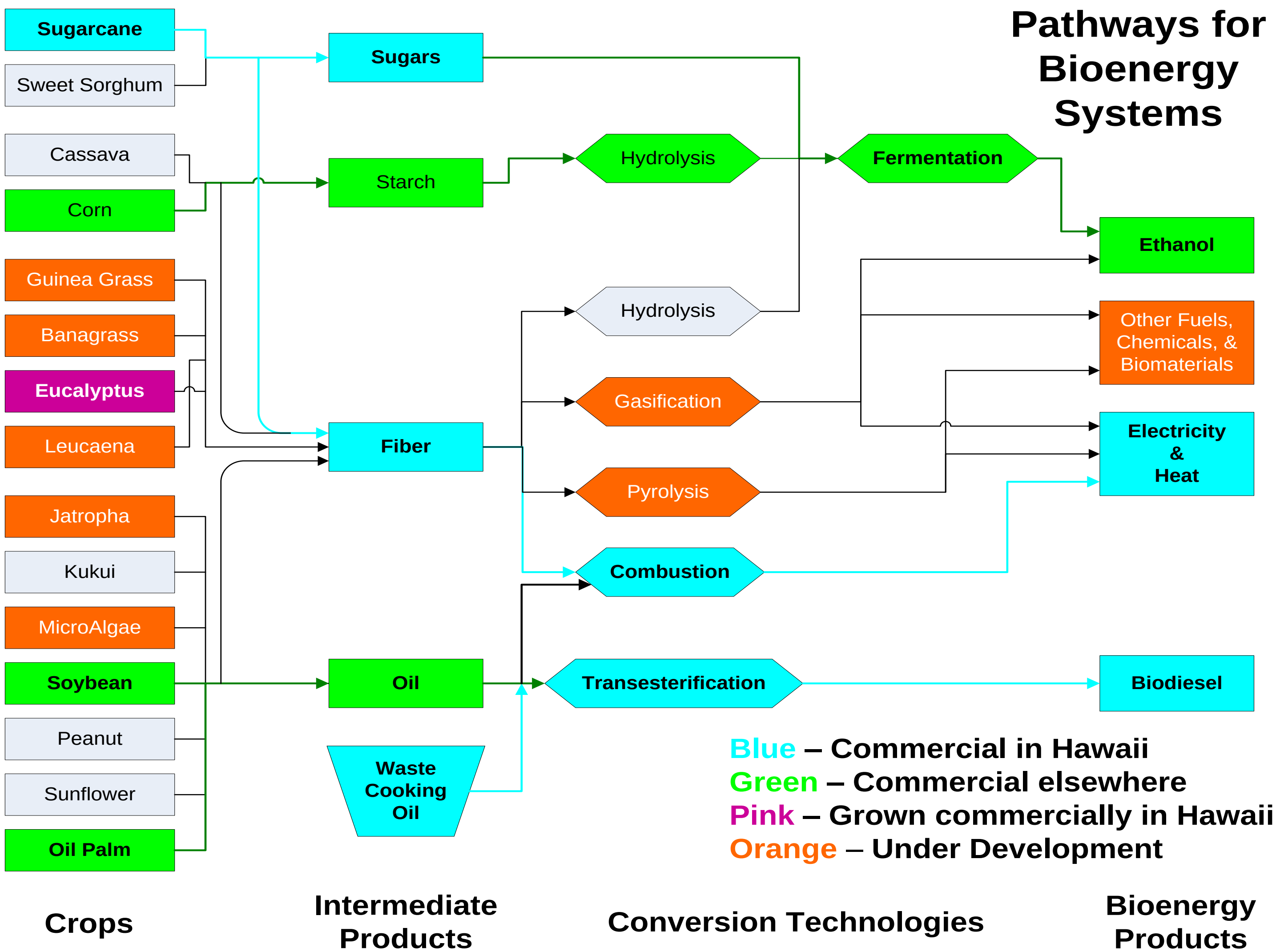


Figure 6: Pathways for bioenergy systems

Figure 9 illustrates that multiple pathways exist between plant/crop options on the left of the diagram and bioenergy products on the right. A number of technology components may be required for any given pathway. Agricultural producers in Hawai‘i have grown a variety of crops and the basic cultural practices of land preparation, seed production, planting, fertilization, and weed control are well understood and are not viewed as primary technology challenges. Crop harvesting and the transportation of the material from field to conversion facility are two remaining unit operations. Many of the crops proposed for bioenergy development have not previously been grown commercially in the state and cost effective harvesting techniques will be important. For sugar cane, harvesting accounts for ~30% of total production costs, thus harvesting costs play a large role in determining economic viability. Due to Hawai‘i's agricultural worker wage rate (>$10 per hour) and anticipated prices for bioenergy products, hand harvesting techniques are not considered to be viable and mechanized harvesting techniques will be required.

All of the bioenergy technologies reviewed in this section have potential application in Hawai‘i but all are not expected to be commercial. The utility of the technologies will depend on completion of technology development for those that are not yet fully commercial and the availability of suitable, cost competitive, sugar, starch, fiber, and oil feedstock resources. Details of this analysis are included in the Subtask 2.2 Report, "Integrated Renewable Energy and Energy Storage Systems" available on the HNEI website.

Photovoltaic Systems

The use of photovoltaics is on the rise in Hawai‘i. The Hawaiian Islands' abundant sunshine in conjunction with heavy reliance on imported fuels for energy and high electricity cost (relative to the US mean) are providing strong incentives for accelerated investment in PV. The average solar resource in Hawai‘i is among the highest in the United States, and considerably higher than in most of the populated world. On average, about 5.7 kWh/m^2/day of solar energy can be available in Hawai‘i for flat panel PV-conversion, while approximately 7 kWh/m^2 can be converted with tracking PV systems.

Hawai‘i's favorable environmental and political climate has led to a rapid rise in PV installations across the state in recent years. The state is among the leaders in the nation in grid-tied PV installations. To accommodate this, dozens of Hawai‘i-based PV-installation companies are currently licensed. In the past few years, a number of commercial-scale PV installations have also been successfully completed, or are near completion.

Under this task, and the follow on activities under Tasks 8 and 11, HNEI has developed PV test beds to assess the performance and lifetime of various commercially available PV technologies under different environmental conditions. Details of the planning for the test beds is included in the Subtask 2.2 Report, "Integrated Renewable Energy and Energy Storage Systems" available on the HNEI website. Details of the test beds and data collected under this program are available in the reports under subtask 11.1.

Distributed Energy Resource Technologies within Microgrids

In 2004, studies conducted for the U.S. Department of Energy by the Hawai‘i Department of Business, Economic Development and Tourism (DBEDT), with Sentech, Inc., Hawai‘i Electric Light Company (HELCO), and Hawaiian Electric Company (HECO) looked at the potential benefits of microgrids and energy storage on the Big Island of Hawai‘i. The studies employed production cost and distribution load flow models, together with examination of feeder loads and customer mix, to perform screening evaluations of different grid reinforcement options for HELCO to meet anticipated high load growth, especially on the west side of the island.

A subsequent and recently concluded study, “Evaluation of Future Energy Technology Deployment Scenarios for the Island of Hawai‘i,” was conducted by the Hawai‘i Natural Energy Institute (HNEI), General Electric Company (GE), HECO, HELCO, and Sentech. This study used comprehensive, detailed power system modeling (production cost and system dynamics) to evaluate the effects of the Big Island’s anticipated increased penetration of electricity generation using as-available renewable energy, primarily wind and solar, in addition to existing or increased geothermal.

Based on the more detailed power system analysis of the second study, this report provides an evaluation of whether evolving technologies and load growth patterns offer new options for microgrids on the Big Island. This evaluation applies the original findings and technical assessments of the microgrid study with the more detailed electric system modeling and updated conclusions of the HNEI Big Island energy study. The HNEI study, however, did not look at the distribution system and potential contributions to the bulk power system of distributed technologies (e.g., microgrid-sited distributed generation and storage) dispatched as a microgrid. The original microgrid study can help fill this gap.

The objective of this analysis was to identify the characteristics and capabilities of microgrid-sited technologies that could have significant benefits in grid stability, production economics, reliability, and/or power and voltage quality for the Big Island. The analysis is based on the Big Island energy studies, and includes three task areas:

- Summarize findings of the previous studies.
- Update the list of candidate microgrid technologies based on: 1) technical and cost improvements since 2004; and 2) recent changes in load growth, generation, transmission, and energy policy on the Big Island.
- Provide recommendations for microgrid technologies and locations to be considered in HELCO system plans.

See the report referenced below, “Recommendations for Technologies for Microgrids on the Big Island”, for more information.

Topical Reports Submitted Under Task 2

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Subtask 2.1 Deliverable (Evaluation of Future Energy Technology Deployment Scenarios for the Big Island), 08/12/2009
- Subtask 2.2 Deliverable #1 (Development and Testing of Hydrogen Storage System(s) for Capturing Intermittent Renewable Energy Sources for Peak Demand Utilization on the Grid), 06/02/2008
- Subtask 2.2 Deliverable #2 (Integrated Renewable Energy and Energy Storage Systems),09/30/2009
- Subtask 2.2 Deliverable #3 (Compilation of Expenditures for the Hawai‘i Gateway Energy Center), 03/11/2009
- Subtask 2.2 Deliverable #4 (Recommendations for Technologies for Microgrids on the Big Island), 08/12/2009
- Subtask 2.2 Deliverable #5 (Report on Recommendations for Lab and Bench-Scale Tasks), 08/12/2009

Task 3: Develop Public Policy/Outreach to Accelerate Acceptance of Distributed Energy Resource and Micro-grid Applications

Efforts under this task were directed towards two specific goals. The first was an evaluation of the economic impacts due to changes in petroleum prices and utilization. The second was an identification of obstacles in Hawai‘i laws to implementation of energy efficiency and renewable resources. Each of these areas is described in the following subsections.

3.1 Economic Impacts of Changes in Petroleum Prices and Utilization

The integrated summary report covering this subject included considerations of the current energy situation in Hawai‘i, an analysis of petroleum price impacts on the State economy, and scenario analyses, as well as conclusions and comments. .

Features of the energy situation in Hawai‘i that were explored included imports of petroleum, petroleum use by sector, electricity use, transportation (gasoline usage and other petroleum products for transportation), petroleum product usage in buildings, and other energy-related activities and products from state-based refineries. In Figure 16, Hawai‘i’s heavy dependence on petroleum (all imported) is easily seen.

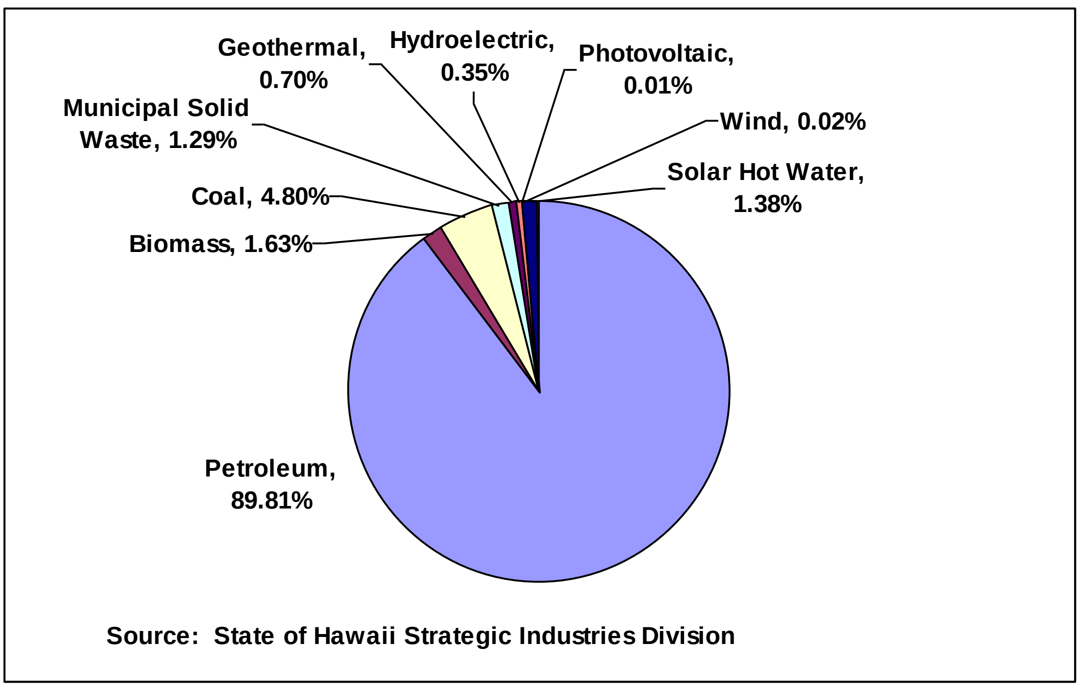


Figure 7: State of Hawai‘i primary energy sources 2005

The State of Hawai‘i Congressional delegation requested DOE to fund a study which would examine the impacts on the state’s economy that would arise from the possible implementation of the three scenarios specified within Section 355 of the Energy Policy

Act of 2005. The first two scenarios are based on an evaluation of accelerated use of renewable resources for a) transportation fuels, and b) electricity generation. The third scenario required an evaluation of liquefied natural gas (LNG) being added to the energy resource mix in Hawai‘i.

Given the details of the study scope and design highlighted in the original Scope of Work, the conclusions of this subtask have been written in three parts. The first part is one in which the analysis and data contained therein were sufficiently robust to warrant rather firm conclusions. The second area is one in which some conclusions can be made, with additional commentary on the need for future technical evaluation and analysis. The third area outlines those topics that are important to the study, but for which no conclusions can be made due to the lack of data or inability to obtain information for the analyses.

While there are some very useful analyses contained in the results of this subtask, it did not allow quantitative assessment of the full impact of these system changes. The primary reason for this is that the key point – the economic impact to the state due to changes in oil resource requirements – was not examined. Specifically, there can be no true analysis of the impact to the state's economy based on any one of the three scenarios contained in Section 355 without being able to examine the impact on refinery operations. Thus, any analysis, other than hypothesis and conjecture, would need to be based on a set of assumptions that have yet to be validated. Thus, a qualitative evaluation of the impact to the state's economy is lacking and this is a serious drawback to the overall study.

It is the bottom-line recommendation of the study that this work be continued to closure with the current study team. Lacking sufficient key information, there is a clear need to continue these efforts. The overall effort allowed for the development of a strong project team that included two University of Hawai‘i organizations, the National Renewable Energy Laboratory, and FACTS Global Research. The result of a continued study including the key information will be what was originally intended in the Energy Policy Act of 2005 Section 355 legislation: specifically, to develop a set of recommendations to be used by public policy decision-makers for new approaches for reducing the dependence of the state on petroleum.

For details included in the report, see the first deliverable, indicated in the Topical Reports Submitted section below.

3.2 Obstacles to Implementation of Energy Efficiency and Renewable Resources

The goal of this subtask was to determine what existing laws, policies, and regulations in Hawai`i present obstacles to the implementation of energy efficiency and renewable energy resources. The resultant report was a preliminary effort to ensure that Hawai`i's laws promote sound energy policies. The report sought to find opportunities to improve Hawai`i's laws and practices by identifying barriers that could ultimately be removed.

The synopsis of findings for the subject report included consideration of the following elements:

- The government as a consumer of energy,
- The government as a source of funding,
- Government regulation,
- Taxation, and
- Transportation.

Summarized very briefly, the general findings of the report were:

- Hawai`i's laws and rules pose few outright, unwarranted obstacles that are fixed in law,
- Hawai`i's laws could go further to promote or require implementation of energy efficiency and renewable energy resources,
- In order to be effective, laws must provide specific requirements and/or incentives, and
- In order to be effective, laws must be supported by sufficient resources and programs to provide for implementation and enforcement.

For details included in the report, see the second deliverable, indicated in the Topical Reports Submitted section at the end of the write-ups for this task.

Topical Reports Submitted Under This Task

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai'i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Task 3 Deliverable #1 (Integrated Summary Report: Evaluation of Economic Impacts Due to Changes in Petroleum Prices and Utilization), 10/24/2007
- Task 3 Deliverable #2 (Obstacles in Hawai'i Laws to Implementation of Energy Efficiency and Renewable Resources), 01/14/2008

Task 4: The Hawai'i Energy Road-mapping Study - Project Implementation Plan

The Hawaiian Electric Company's utilities have experience with large amounts of renewable energy; HECO, serving O'ahu, MECO, serving Maui, and HELCO, serving the Island of Hawai'i. In addition to operating experience, they have conducted planning studies and simulations. Their experiences are also relevant to microgrid operations.

Since these experiences and lessons learned may provide guidance to other U.S. utility systems, regulatory agencies, and DOE, this task involved describing the utilities' experiences and observations on operating their systems with large amounts of variable renewable energy sources. The lessons learned and shared in the report prepared for this task (see the reference in the Topical Report Submitted section below) are focused on the HELCO and MECO utilities. The report was not meant to be prescriptive, but simply to add to the industry's body of knowledge.

4.1 Renewable Energy Issues

Most of the renewable energy resources are characterized by the term "as available," meaning they cannot be dispatched and controlled to the extent as combustion turbines, diesels or steam generators. The geothermal units on the Island of Hawai'i can be backed down to some extent (3 MW of the 30 MW capacity). The bio-fueled units on Maui and the Island of Hawai'i are owned by independent power producers. While their output can be regulated, the utility is obligated to purchase as much or their energy as it can, and there may also be constraints based on thermal needs of the facilities.

MECO and HELCO are small systems (about 200 MW peak each), and do not carry traditional spinning reserve. They maintain operating reserves adequate to manage fluctuations due to the as-available nature of the renewable energy resources and variance in loads, as well as to prepare for failure contingencies (forced outage of a generator or trip/outage of a transmission line) to the extent possible. It is true, however, that system simulation studies have shown that it would be prohibitively expensive – in production cost and fossil fuel consumption – to maintain enough operating reserve to rigorously guard against the most serious single or double generation and transmission contingencies.

The addition of large amounts of as-available generation present significant challenges to the system operators:

- System minimum loads (nighttime) are often not large enough to accept all available renewable generation after the minimum dispatchable generation necessary for system regulation and must-run units are committed.
- Sudden large fluctuations in wind farm output have resulted in large drops in system frequency. (time scale of seconds to minutes).
- Slower but sustained changes in windfarm output (time scale of 10 seconds to an hour) present a dilemma to the system dispatcher: will the wind farm output continue to drop, necessitating start-up of a fossil-fueled generator (or de-committed if windfarm output increases enough)? The system operator wants to

wait as long as possible to make this decision, but continuing or more rapid decline in wind farm output may require a diesel be fast-started, with a penalty in fuel efficiency. There is no suitable accurate wind forecasting procedure to remedy this.

- These variations in output of as-available generation require the utility to carry more fossil-fueled operating reserves, eroding the fossil fuel savings potential of renewable energy technologies.
- While windfarms are large and their output is monitored through the utility SCADA system, the actual electrical production of small residential PV installations is unknown. Since the utility does not know the exact amount of as-available PV, it also does not know how much it must increase its regulating reserves to compensate for the PV's variability.
- The IEEE 1547 standard for distributed generation has anti-islanding requirements for safety issues; however, Hawai‘i's grids routinely experience larger frequency deviations than do large mainland utilities. When the frequency drops because of an instability problem (or a sudden drop in wind farm output), not due to a fault, inverters on PV systems, complying with IEEE 1547, drop out. Unfortunately, in a non-fault disturbance, this exacerbates the problem, as the grid loses additional generation just when it needs as much generation as possible to stabilize the grid.
- While not a system operations problem per se, another issue in Hawai‘i is that despite their high reliance on renewable energy, HELCO and MECO customers have seen their electricity prices spike as petroleum prices have increased. This is because legislatively-mandated (PURPA) provisions of the power purchase agreements with independent power producers (IPPS) require the utility to pay according to its marginal generation cost. As oil prices rise (e.g., after Katrina), HELCO's and MECO's marginal generation production costs rose. The IPPs were paid more for their power generation, and these costs were passed along to the consumers through the energy cost Adjustment Clause (ECAC).

4.2 Examples of As-Available Generation Issues

Two specific examples were explored in this subtask. The following paragraphs discuss each of these.

Curtailment of Wind Generation during Low Loads

This situation was explored on the HELCO system. It is HELCO's practice to accept as much energy from as-available wind and hydro units as operationally possible (there may be 14 MW of run-of-river hydro on line). At times some of the as-available units are curtailed because there is more on-line generation than what is needed to meet the system load. Future contracts may be subject to curtailment during the off-peak periods.

The analysis included the example of a typical day to further explain the impacts to the HELCO system. The total online capacity is always slightly higher than the system load, but there is usually not enough reserve to cover a large loss of generation, so such an event usually results in low frequency. HELCO's current system may lead to problems controlling frequency since wind causes higher MW fluctuations on the system. The addition of greater quantities of as-available units like wind will force HELCO to carry larger amounts of regulating reserve.

Impacts of Windfarm Output on System Frequency

A severe, sudden drop in the wind can cause a significant reduction in the on-line frequency for a generating system. Figure 17 shows the result of a wind-speed drop-off in the MECO system.

HELCO has experienced similar frequency excursions. An example of such an excursion under low-load conditions in provided in Figure 18 on the next page. Excursions have also been noted under high-load conditions.

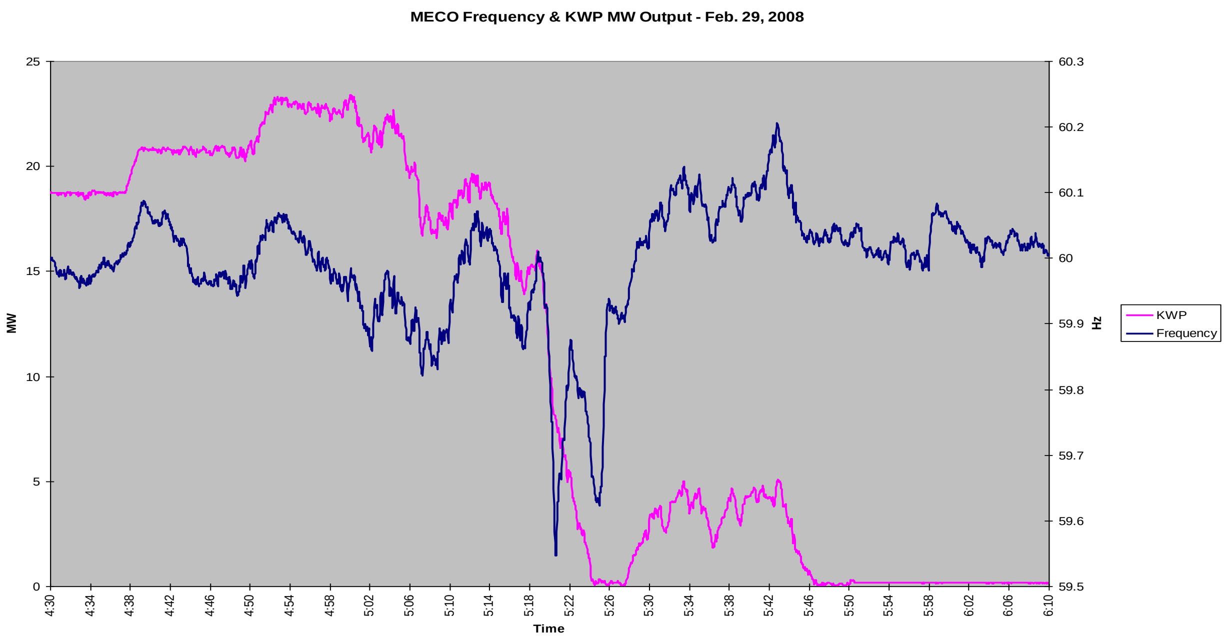
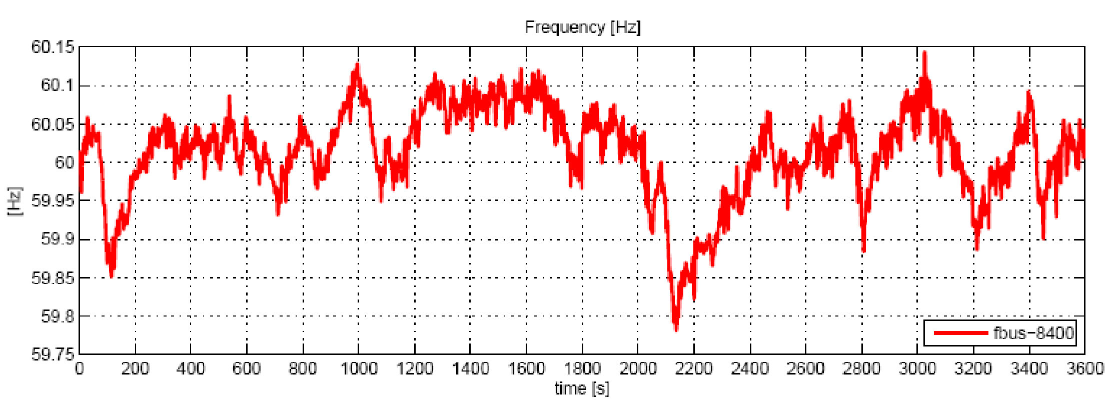


Figure 8: Wind power variability on the MECO generating system



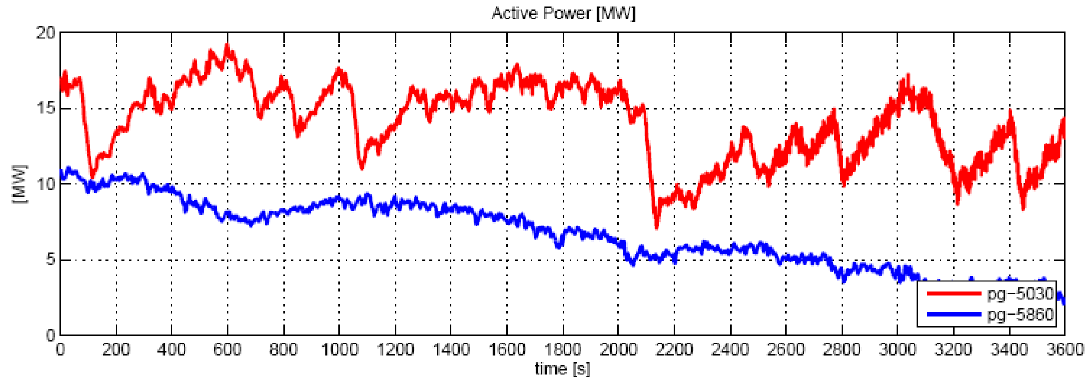


Figure 9: Frequency response to wind power variations during a low-load condition on the HELCO generating system

4.3 Lessons Learned

As HELCO, MECO and HECO continue to gain more experience with ever larger amounts of as-available renewable energy sources, they will continue to adapt their planning and operating practices. Already, these utilities have been able to better accommodate as-available resources. Shortly after the 30 MW Kaheawa windfarm was commissioned on Maui, MECO experienced several severe system disturbances as a result of its output fluctuations. By applying what HELCO had learned operating its system with large penetrations of renewable energy sources and by gaining its own operating experience, MECO system operators were able to reduce the additional operating reserve requirements needed to manage that windfarm from 12 MW to 6 MW within a year. Further improvements are expected, and this will be necessary, as MECO expects about 90 MW of additional renewables on its system.

The following "lessons" are not rules and are not applicable to all utility situations, but they represent observations that may help other utilities deal with the large amounts of as-available and non-dispatchable power generation technologies expected to be connected to the grid. The items listed are merely summaries of specific issues. Detailed descriptions of all items are given in the Task 4 Deliverable report, indicated in the Topical Report Submitted section below.

1. De-tuning of AGC to prevent "hunting."
2. Energy storage to mitigate output fluctuations.
3. Demand response to support frequency or avoid fast-starting units.
4. Structure of Power Purchase Agreements.
5. Setting firm ramp rate limits.
6. Reviewing utility system performance metrics.
7. Using forecasts of as-available renewable energy when committing fossil units.
8. Managing numerous small distributed PV installations.

Topical Report Submitted Under Task 4

More extensive details for the element completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai'i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. The specific report for this task is found by reference to the item shown below:

- Task 4 Deliverable (Lessons Learned: Planning and Operating Power Systems with Large Amounts of Renewable Energy-Based Generation), 08/29/2012

Task 5: Development of Information, Models, and Analyses for Characterizing the Future Electricity Grid on Maui

In carrying out this task which aimed at adequate modeling of the Maui Electric Company (MECO) grid, HNEI made extensive use of the services of GE Global Research (GE). The following paragraphs outline the various subtasks involved. The Hawaiian Electric Company (HECO) of O‘ahu was also involved in issues of data collection.

5.1 Data Consolidation and Model Feasibility Analysis

Modeling of the MECO grid was an essential first step of the work needed to investigate grid operation with a high content of as-available energy. The work of this subtask outlined the data requested by GE and data submitted by MECO to develop transient performance and production cost models of the MECO system.

GE confirmed the feasibility of developing system models that can be used for future state analysis. The GE team began analyzing the data and submitted a subsequent data request to MECO based on the data already received. The objective of this subtask was to identify missing data and evaluate the adequacy of the available data for the modeling activity. Based on the data delivered by MECO to GE, GE was comfortable with the data and proceeded with the next subtask.

5.2 Data Evaluation, Completion and Manipulation

A series of weekly meetings was held with HNEI, GE, MECO and HECO to review data requirements, highlight any concerns and redirect the modeling effort early in the development of the GE MAPS™ (production cost) and GE PSLF™ (transient dynamic system) models, as well as establish reasonable expectations regarding the level of modeling fidelity. The meetings also served to identify the assumptions and preview the evaluation of the data received.

The GE team completed evaluation of the initial set of delivered data. This data was fully analyzed and documented. The result indicated the need for submittal of another data request. This request was fulfilled by MECO and HECO. GE was then able to proceed with development of the transient performance and production cost models based on the data received.

5.3 MECO System Model Development

Based on the data supplied by MECO and HECO, the GE team developed the databases of the GE MAPS™ and GE PSLF™ models for the MECO system. The economic data and assumptions for the GE MAPS™ analysis included issues such as thermal plants, independent power producers, and load demand. For the dynamics features under the GE PSLF™ analysis, attention was given to matters of load flow, basic stability model data, the long-term dynamics model, performance criteria, and limiting stability events.

Following population of the models with the appropriate data and assumptions, both of the models were calibrated and validated. Conclusions regarding validation of each model are given in the following paragraphs.

The project team agreed that the production cost model of the MECO system accurately captured the energy production, by unit type, within 1% and the system heat rate within 5%. The GE team is satisfied with the level of fidelity of the production cost model and recognizes that some of the discrepancy between actual historical production and simulate production can be attributed to factors as described in the last Deliverable listed in the Topical Reports Submitted section below. The project team believes that the use of this tool to analyze system scenarios on the MECO system is appropriate for future phases of effort.

For the dynamic model, steady-state simulation results were confirmed by HECO/MECO as similar challenges in the actual system operation. Transient simulation models of fast system events (faults and generation trips) were also setup. The resulting system model (AGC, governors, generators, network, etc.) captures the relevant dynamics of the actual system in the recorded data. The project team believes that the fidelity of these dynamic models is of sufficient quality to be used in subsequent efforts.

Topical Reports Submitted Under This Task

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai'i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list*:

- Task 5.1, 5.2 Deliverable (Data Consolidation and Model Feasibility Analysis on the Island of Maui), 07/01/2008
- Task 5.3 Deliverable (Data Evaluation, Completion and Manipulation), 07/01/2008
- Task 5.4 Deliverable (Maui Electrical System Model Development: Data and Assumptions), 08/06/2008
- Task 5.5 Deliverable (Maui Electrical System Simulation Model Validation), 11/17/2008

---

*These items were labeled differently at time of submission to DOE. The task numbers above align with the final SOPO, May 2011. .

Task 6: Coordination and Support of DOE/OE R&D Initiatives

As a result of the incremental funding received from DOE/NETL in September 2007, this task was added to the project. HNEI management followed up on this activity by meeting with New Mexico Tech (NMT) program management in November 2007 to ensure that our activities were being coordinated wherever possible.

In a Washington meeting in December 2007, it was agreed that HNEI would support and participate in the DOE Office of Electricity Reliability and Energy Security (OE) activities examining the calculation of benefits accrued to the nation as a result of OE R&D funding initiatives. The first meeting to discuss this was on January 16th, 2008. Following additional conference calls, it was agreed that Navigant Consulting and Energetics, Inc. would do future work. A letter report describing HNEI efforts for both Hawai‘i Clean Energy Initiative and the related benefits assessment was delivered to DOE/NETL on December 23, 2008, completing this task.

As indicated in the letter report, OE was supported in two areas. The first focused on developing a new set of metrics to use as part of OE’s strategic planning activities. The second area involved the provision of input to the planning process as part of the integration working group in the Hawai‘i Clean Energy Initiative.

Topical Report Submitted Under This Task

More extensive details for the element completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. The specific report for this task is indicated below:

- Task 6 Deliverable (Coordination and Support of DOE/OE R&D Initiatives), 11/23/2008

Task 7: Energy Modeling and Scenario Analysis

Work under this task involved a continuation of efforts begun under previous tasks (prior years). Specifically, this task addressed study of additional scenarios for the electrical grid systems on Maui and O'ahu. The Maui efforts were concerned with PV scenarios and the O'ahu work focused on dynamic and production cost models for the O'ahu grid.

7.1 Maui PV Scenarios

The effort under this subtask was kicked off in March 2011, following a rescoping of the Statement of Program Objectives (SOPO), reflecting the increased interest in high penetration PV. The objective was to assess the challenges to operate the Maui grids under high penetration of Wind and PV. The study team included General Electric Company (GE), HECO, MECO, HNEI, National Renewable Energy Laboratory, and AWS Truepower (AWST).

AWST kicked off the study by developing and validating PV data for individual central and distributed PV plants on the Maui grids. To do so was a significant challenge, as actual PV data (from central and distributed plants) does not exist on the Maui grids. AWST successfully completed this task by using irradiance data available from local schools and an airport, and incorporating data from other mainland resources.

Technical grid analysis started in August 2011 and concluded in September 2012. Studies of the Oahu and Maui grids were conducted in parallel with similar objectives. The Oahu work was funded by HECO and the National Renewable Energy Laboratory, without funds from this award. The Maui analysis was funded by this award, HECO and NREL. As the two grids have different generation resource mixes and different operating practices, each has unique challenges for integration of large penetration of renewables, however, the models and analysis procedures were shared between the two projects. The results were presented as separate reports for each grid. This subtask focused only on the analysis and implications for the Maui grid.

The Study team planned to analyze the following scenarios of high penetration of Solar PV on the Maui grid:

1. Baseline scenario – 72MW of Wind, 15MW of Distributed Solar.
2. Scenario 1 – Same as Baseline.
3. Scenario 2 – Baseline + 15 MW Distributed Solar.
4. Scenario 3 – Baseline + 15 MW Distributed Solar +15 Centralized Solar.

After performing the Baseline Scenario, the study team analyzed the highest Solar PV penetration scenario (Scenario 3). Modeling of Scenario 3 indicated that with this distribution, the Maui grid curtailed much of the additional solar generation in addition to the large amount of curtailment that already exist in the Baseline. Based on this finding, the study team agreed to concentrate on Curtailment Mitigation measures for Scenario 3.

Since a majority of the additional renewable energy added in Scenario 3 was curtailed, the study focused on mitigations to reduce that curtailment. The mitigations that where analyzed included: 1) economic commitment of Maalaea combined-cycle units in single or dual train, 2)

removal of the Kahului 1-4 must-run requirements, and 3) increasing the thermal unit commitment priority on spinning reserves.
Additional energy storage (a battery energy storage system (BESS) rated at 10 MW for 2 hours) was also evaluated as a curtailment mitigation alternative for Scenario 3. Two BESS operating strategies were considered:

Reserves: The BESS provides 10 MW of operating reserves, similar to the existing KWP2 BESS.

Time-Shifting Energy: The BESS stores energy that would otherwise be curtailed and delivers it back to the grid at the first opportunity when the system can absorb it.

When providing reserves, the BESS reduces curtailment by 21 GWh/yr and operating costs by \$5M/yr. Use of the BESS reduces the amount of spinning reserves required from thermal resources, thereby reducing commitment of thermal generation, which lowers the Pmin of the generation fleet. When the strategy of time-shifting energy is employed, the BESS reduces curtailment by 12 GWh/yr and operating costs by \$1.8M/yr. Details of this analysis is included in the Subtask 7.1 Report, "Hawai‘i Solar Integration Study: Final Technical Report for Maui" available on the HNEI website.

7.2 O‘ahu Grid Model

Prior to the high penetration solar studies, referenced above, the baseline model for the Oahu grid system was developed under substask 7.2 of this award. The O‘ahu Grid Study was a joint effort by Hawaiian Electric Company (HECO), the Hawai‘i Natural Energy Institute (HNEI) and GE. The primary objective of the study was to develop and calibrate dynamic and production cost models for the O‘ahu Grid. This was the first step in an activity designed to help HECO identify technologies or operating strategies that will enable the system to manage higher amounts of as-available renewable energy. These models were validated against a base year and can be used to model and evaluate power system expansion scenarios for the island of O‘ahu. The program began with the data acquisition and model development. This subtask highlights the validation of the power systems models for the island of O‘ahu.

In order to ensure that the model accurately captured HECO's present system operation, the model was calibrated and validated against historical data. Significant iterations with the HECO team were needed to ensure the model accurately captured HECO system operation to a level of fidelity that is sufficient for future study. Meetings of a Technical Review Committee were organized by David Corbus of the National Renewable Energy Laboratory as part of the Hawai‘i Clean Energy Initiative in which the GE team presented results of the model development and validation. Based on the responses to the questions and the inputs and directions from HECO and the Technical Review Committee, the GE team implemented the necessary changes to revise and update the model. The project team became comfortable with the level of accuracy of both the GE PSLF^{TM} and GE MAPS^{TM} models of the HECO system for the application of these tools to system scenario analysis.

The project team agreed that the production cost model of the HECO system accurately captured the total energy production within a margin of 1.6%, total fuel consumption by HECO within a margin of 2.8%, and the system heat-rate within a margin of 1.25%. The project team was satisfied with the level of fidelity of the production cost model.

Various aspects of understanding the system behavior for change in system settings were addressed with dynamic modeling. The load flow database was successfully created from the data provided for the event considered in the study. Transient simulation models of the considered fault-induced load rejection event were setup and the event was simulated for comparison with the same event in the KEMA study. The differences of the dynamic simulations with KEMA study are understood and mostly associated to governor responses. The GE model incorporates the planned improvements in governor responses at HECO units. The use of the more aggressive ramp rates indicated as "Once in a while" ramp rates in AGC may also be a difference with the KEMA report. As requested by HECO Power Supply, the "Once in a while" ramp rates will initially not be used as the emergency AGC ratings in the GE model for future work. The resulting system model (AGC, governors, generators, network, etc.) captures the relevant dynamics of the actual system in the recorded data. The project team is comfortable with the fidelity of the dynamic models and is prepared to use these models in future efforts.

Details of this baseline analysis for the Oahu grid is included in the Subtask 7.2 Report, "O'ahu Grid Study: Validation of Grid Models" available on the HNEI website.

Subsequently, under Task 10.1, HNEI collaborated with HECO and GE Energy to develop and validate detailed models for the O'ahu Wind Integration Study (OWIS). Details of this effort are described under Task 10.1.

As part of the rescoping, the OWIS models from Subtask 10.1 were also used as the basis for an additional task under 7.2 which focused on evaluating how enabling technologies can facilitate the delivery and utilization of renewable energy on the O'ahu power grid. Specifically, the integration of significant penetration of EVs and the appurtenant charging infrastructure, was explored in detail to determine the impact that various energy delivery and utilization strategies might have on minimizing the curtailed renewable energy that results from: a)the variability of renewable energy, b) the lack of perfect alignment between renewable energy supply and system loads in Hawai'i , and c) the existence of minimum operating rules under which the utility must operate to maintain system stability.

GE Energy modified the OWIS models which previously had evaluated the impact of 600 MW of renewable energy on operating characteristics of the O'ahu grid to assess the delivery of 800 MW and 1,000 MW of nameplate intermittent renewable generation and varied modeling scenarios to test assumptions regarding system load profiles, vehicle charging strategies, EV adoption rates, and storage support. The results of the simulations show comparative impacts on curtailed renewable energy, power plant generation, emissions and fuel consumption.

The report generated by this work, indicated as an Interim Report, highlights the key findings of the analysis to date, notably the maximum achievable levels of curtailed energy reduction the system can be expected to see. Other findings include the impact of varying the time of day vehicles are charged, the expected benefit of smart grid technologies, the impact of increasing or decreasing the number of EVs on the grid, the impact of storage, and the effect of modifying the utilities available reserves. The mix of renewables comprising the 1,000 MW is also explored, changing the mix of wind, central plant solar and distributed solar resources. This Interim Report will be followed up by a full report in the spring of 2013, resulting from a continuation of this effort under the Hawai‘i Energy Sustainability Program, DOE Cooperative Agreement No. DE-EE-0003507. The full report will have a comprehensive discussion of the modeling, assumptions, variables and results. Details of this preliminary analysis is included in the Subtask 7.2 Report, “Electric Vehicle Charging as an Enabling Technology” available on the HNEI website.

7.3 Kaua‘i Grid Model

Work was originally intended to cover analysis for the electric utility on Kaua‘i. Subsequent to Amendment 9 to this Cooperative Agreement, resources previously allocated to this effort were used in a similar manner to expand attention to the Maui electric grid.

Topical Reports Submitted Under Task 7

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Subtask 7.1 Deliverables 1 and 2 (Hawai‘i Solar Integration Study: Final Technical Report for Maui), 12/19/2012
- Subtask 7.2 Deliverable 3 (O‘ahu Grid Study: Validation of Grid Models), 09/29/2009
- 12/04/2012 Subtask 7.2 Deliverables 1 and 2 (Electric Vehicle Charging as an Enabling Technology)

Task 8: Continued Research, Development and Validation of Critical Renewable DER, Microgrid and End-Use Energy-Efficient Technologies

See Task 11 for results on the deployment and testing of PV and energy storage technologies. Certain of the energy efficiency efforts conducted are reported below.

8.1 Plug-in-Hybrid Electric Vehicles

Two Prius Hybrid vehicles from the Hawai'i State Motor Pool became available to HNEI for this subtask. These vehicles were converted to obtain information on plug-in hybrid electric vehicle (PHEV) operation. They were subsequently included in a PHEV demonstration program run by Idaho National Laboratories, with assessment available at: http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/phev/hymotion_prius_wrapup_inl-ext-11-23746.pdf.

8.2 Hydrogen for Energy Storage

Under this subtask, HNEI evaluated the use of hydrogen as part of an integrated storage system, with emphasis on the use of hydrogen production to provide ancillary services support to a grid system with a high penetration of intermittent renewable generation technologies. The evaluation included identifying different operating strategies for the hydrogen energy system to mitigate system frequency excursions, displacement of fossil generation on grid, and reduced curtailment of renewable energy sources such as wind, solar and geothermal, while at the same time providing value-added products that may mitigate system costs and further increase the use of renewable energy resources.

The system includes an electrolyzer that operates as a controllable variable load to provide ancillary services to the grid and hardware for production of value-added products such as hydrogen, for use as transportation fuel, and stationary power production. It was identified that an important component of an experimental test plan would be to evaluate the performance and durability of operating electrolyzers in a dynamically changing mode over time. HNEI sought and successfully procured funding to demonstrate this concept.

8.3 PV System Demonstration

These demonstration efforts were continued under Task 11. Descriptions of the test sites selected, test protocols, and test results are presented there. In addition, details are given for the development and testing of solar forecasting for Hawai'i.

8.4 Technologies for Energy Efficient Buildings

This subtask aimed at the development and demonstration, in a laboratory environment, a specific portfolio of technologies that enhance the functions and features of the Energy Optimization System (EOS) originally developed at GE Global Research. This was in support of HNEI's contribution to the Hawai'i Clean Energy Initiative to improve overall end-use energy efficiency by improving building system and appliance operating efficiencies, as well as by reducing peak demand through usage monitoring and demand response equipment installed in residential and commercial structures. GE's EOS program focused at the residential level on the following three areas: 1. Defining system requirements and specifications; 2. Developing advanced/enhanced functions and features of the energy management/optimization system; and 3. Performing laboratory validation tests and analysis.

The first focus area was on development of functional requirements and conceptual designs for the different component technologies that comprise the EOS. Three EOS conceptual system architectures (distributed, centralized, and hybrid) were developed, compared and evaluated with emphasis on the distributed architecture for laboratory validation. Functional requirements and specifications for all key EOS component technologies/modules were defined. These key components are self-learning and adaptive home models through system identification, utility feedback analytics, and direct load control and smart appliances coordination. Highlights of requirement specifications were summarized in report submitted to DOE (see the Subtask 8.4 deliverable, indicated in the Topical Reports Submitted section below). Details of the requirement specifications are documented in a separate specification document (EcoDashBoard Home Energy Management System *Requirements Specification*, GE Global Research, September 30, 2009), referenced by this report.

The second focus area was development of enhanced functions/features of the EOS. Specifically, advanced functions/features include self-learning and adaptive home models, utility feedback analytics, and direct load control and smart appliances coordination. A home thermal model was developed to allow the EOS to predict how the home will react to stimuli such as weather, HVAC operation, and homeowner occupancies. The model was constructed and updated using a system identification technique to enable self-calibrating and updating the model automatically for new and retrofit homes. The model can also be used to track changes to the home structure over time as a tool for monitoring/diagnostics. Utility feedback analytics were also designed to provide the utility with valuable information such as sheddable load and available distributed generation (solar PV, wind, etc.). Direct load control and smart appliances coordination algorithms were developed and validated in GE Global Research's Smart Grid Laboratory.

The third focus area was on the laboratory testing, validation and analysis. The three most applicable test scenarios were tested in the lab with a stressed power grid condition, simulated with a high electricity price. The three test scenarios were: direct load control (DLC) for emergency load shedding; peak power reduction in response to critical peak pricing (CPP) signal; and energy optimization for energy reduction and utility bill savings. Test results met expectations. All three scenarios can be applied with pre-defined priorities per utility and consumer's needs and preferences. They are complimentary energy management techniques/algorithms that can be implemented/ deployed individually or in any combination of the three.

Topical Reports Submitted Under This Task

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai'i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Task 8 Deliverable – Letter Report (Testing of Distributed Energy Resource, Microgrid, and End Use Efficiency Technologies), 12/18/2012
- Subtask 8.4 Deliverable (Technologies for Energy Efficient Buildings), 12/10/2009

Task 9: Public Policy Analysis and Assessment

This task followed on the efforts conducted under Task 3 and continued with work aimed at linking technology with public policy and economics. Three specific subtasks were completed under this task and each of these is described in the following subsections.

9.1 Hawai'i Bioenergy Master Plan

Under this subtask, HNEI consulted with relevant stakeholders and worked with the State of Hawai'i Department of Business, Economic Development, and Tourism (DBEDT) in the development of a state biomass energy strategic plan. The basic goal of this master plan was to develop a Hawai'i renewable biofuels program for managing the State's transition to energy self-sufficiency, based partly on biofuels used for power generation and transportation.

The impetus for this master plan was recognition of the importance of increased use of renewable biomass energy resources in Hawai'i. The 2007 State of Hawai'i Legislature passed House Bill 1003 HD3 SD2 CD1, signed into law as Act 253, SLH 2007. Part III of the Act specifically called for the preparing of a bioenergy master plan. DBEDT was charged with preparation of the plan, "in consultation with representatives of the relevant stakeholders," and to provide an interim and a final report on the development of the Plan. HNEI was called in by DBEDT to carry out the master plan preparation. HNEI proceeded to form a project team (consisting of various departments within the University of Hawai'i, Hawai'i state agencies, and private organizations) to prepare the plan.

The outcomes addressed by the master plan included the following:

1. Strategic partnerships for the research, development, testing, and deployment of renewable biofuels technologies and production of biomass crops;
2. Evaluation of Hawai'i 's potential to rely on biofuels as a significant renewable energy resource;
3. Biofuels demonstration projects, including infrastructure for production, storage, and transportation of biofuels;
4. Promotion of Hawai'i 's renewable biofuels resources to potential partners and investors for development in Hawai'i as well as for export purposes; and
5. A plan to implement commercially viable biofuels development.

The issues addressed included the following items:

1. Specific objectives and timelines;
2. Water resources;
3. Land resources;
4. Distribution infrastructure for both marine and land;
5. Labor resources and issues;
6. Technology to develop bioenergy feedstock and biofuels;
7. Permitting;
8. Financial incentives and barriers, and other funding;
9. Business partnering;
10. Policy requirements necessary for implementation of the master plan; and

11. Identification and analysis of the impacts of transitioning to a bioenergy economy while considering applicable environmental concerns.

Work efforts for completion of the bioenergy master plan first included preparation of a detailed work plan for development of the final report. A major element of this work plan was delineation of a comprehensive task list. The next step was preparation and submittal of a draft (interim) bioenergy master plan. After public review and comment, the Final Draft Bioenergy Master Plan report was submitted in December 2009. The report was organized into three volumes, each of which is described below:

- Volume I – This volume consisted of four parts: an overview, perspectives on the bioenergy industry, potential and actions (addressing the five outcomes prescribed by Act 253), and conclusions.
- Volume II – This volume included the full text of nine separate issue reports prepared to meet the requirements of Act 253.
- Volume III – This volume presented stakeholder review comments and team responses.

The completed Hawai‘i Bioenergy Master Plan report can be seen on the HNEI website. It can be accessed from the Research and Publications sections of the site. As presented there, the report has convenient links for direct access to individual volumes of the report and individual sections within each volume.

9.2 Economic and Environmental Modeling of Island Energy Systems

Although petroleum manufacturing accounts for 4.4% of economic activity in Hawai‘i (a $4.6b industry relative to a $105.9b economy, in 2011 figures), fluctuating oil prices can have a dramatic effect on real economic activity. More specifically, Hawai‘i is particularly vulnerable to increases in oil prices, because unlike most other U.S. states, Hawai‘i meets nearly 80% of its electricity needs through oil-burning. Hawai‘i, led by the State Energy Office, currently plans a significant shift away from fossil fuels towards renewable energy sources. Decision-makers will need to understand the sector-level and economy-wide impacts of policy decisions. To this end, this work developed two complementary models: 1) a statewide economy model with a focus on energy consumption and supply, and 2) a detailed electricity sector model.

The Hawai‘i Computable General Equilibrium Model (H-CGE) is based on a Social Accounting Matrix of macro-economic and sector-level activity for a baseline year; in this case, 2005. The 2005 State of Hawai‘i Input-Output (I-O) Study developed by the State of Hawai‘i Department of Business, Economic Development and Tourism, is the most recent I-O table available for Hawai‘i. A total of sixty-eight sectors are represented in this dataset including petroleum manufacturing, electricity, ground transportation, water transportation, and aviation. In addition, there are eleven agents of final demand including households, visitors, and federal and state governments. The sectors are aggregated for reporting purposes, based on modeling results and recommendations from the project team.

H-CGE is a dynamic model, projecting in five-year intervals to the year 2030 under three oil price scenarios provided by the Energy Information Administration's (EIA) *Annual Energy Outlook2010*: reference, high and low. The benefit of a general equilibrium framework is that it shows interaction between consumers and producers, including price feedbacks and capital accumulation over time.

The Hawai‘i Electricity Model (HELM) is a detailed "bottom-up" representation of the electricity sector. HELM is calibrated to existing electricity units in the year 2005 for Hawai‘i's four counties: the City & County of Honolulu, Maui County, Kauai County, and Hawai‘i County. HELM is a cost-minimization linear program model (i.e., a partial equilibrium representation of the electricity sector for the State) that uses H-CGE consistent assumptions regarding the world price of oil and electricity demand for the state to determine electricity generation type to the year 2030 (in five-year intervals). Electricity generation fuels include diesel, fuel oil, coal, municipal solid waste, geothermal, hydro, biodiesel, biomass, solar PV, and wind.

The Subtask 9.2 Deliverable report, indicated in the Topical Reports Submitted section below, provides a detailed overview of both H-CGE and HELM, discussing current model calibration, model harmonization and integration, and future scenario building. Section II of the report presents H-CGE; Section III presents HELM; and Section IV discusses how the models are integrated. In conclusion, Section V proposes scenarios for analysis and subsequent necessary model development.

9.3 Analysis of Integrated Tropical Biorefineries

The report submitted for this subtask evaluated the current technological status of biorefinery component technologies for the conversion of locally grown biomass into fuels (ethanol, gasoline, bio-diesel, renewable diesel, jet fuel, etc.) and electricity in the State of Hawai‘i . The examined conversion technologies were categorized into three platforms: biochemical, chemical, and thermochemical conversions. The technological status (lab-, pilot-, demo- and commercial scale), the required inputs (feedstock, thermal and electrical energy) and production outputs (fuel and electricity) and costs, as well as the energetic process efficiency and known drawbacks of each conversion technology were assessed qualitatively and quantitatively. Three scenarios defined by the quantities of feedstock that could be produced on 15,000, 36,000 and 100,000 acres of land were considered for supplying an island-scale biorefinery with locally grown biomass. The potential for fuel and electricity production as well as advantages and drawbacks of each platform conversion technology were summarized, based on the medium scale scenario (36,000 acres of land).

Based on the results of the three scenarios defined above, the following conclusions were drawn:

- The medium scale scenario (36,000 acres biomass supply) is considered the most viable in the near future. At this scale, both biochemical and thermochemical based biorefineries could realize economies of scale. The smaller scale (15,000 acre) scenario would be suitable for fewer feedstock-technology options, e.g. banagrass as boiler fuel. The large scale scenario may require development of intermediate processing facilities to increase fuel density and decrease transportation cost. These additional system complexities may be more approachable in the longer term.

- In general, the biochemical conversion technology platforms with the highest level of technological readiness are limited to the production of ethanol, a fuel with relatively low versatility. Thermochemical conversions can provide a more versatile range of fuels (e.g., fuel oil, diesel, gasoline and jet fuel) but generally exhibit a lower technological readiness and often require a larger plant size to be economically viable.
- Thermochemical conversion facilities can process a wide range of feedstock, including agricultural, forest and municipal wastes as well as purpose grown fiber crops. Conversely, biochemical processing plants are usually very specific in feedstock requirements and may rely heavily on large-scale monocultures.
- Energy-dense bio-oil from fast pyrolysis or torrefied-biomass pellets have the potential for direct use in existing power stations to replace/supplement low sulfur fuel oil (LSFO) and/or coal in the short term.

The complete Subtask 9.3 Deliverable report can be accessed as indicated in the Topical Reports Submitted section below.

Topical Reports Submitted Under This Task

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Subtask 9.1 First Deliverable (Detailed Work Plan for Development of a Hawai‘i Bioenergy Master Plan), 07/28/2009
- Subtask 9.1 Second Deliverable (Draft Bioenergy Master Plan for the State of Hawai‘i), 12/24/2009
- Subtask 9.2 Deliverable (Statewide and Electricity-Sector Models for Economic Assessments of Hawai‘i Clean Energy Policies), 08/30/2012
- Subtask 9.3 Deliverable (Analysis of Integrated Tropical Biorefineries), 12/06/2012

Task 10: Energy Modeling and Scenario Analysis

Efforts under this task included preparation of a report covering the O‘ahu wind integration study. The basic concept addressed in this study involved the integration of wind power generated on Lāna‘i and Moloka‘i onto the O‘ahu electrical grid, along with wind and PV power generated on O‘ahu. Other research was directed to the issue of power system simulation using high-performance computing. Each of these subtasks will be discussed in the following paragraphs.

10.1 O‘ahu Wind Integration Study

Hawai‘i is an island state that relies heavily on imported fossil fuels to meet its energy needs. In 2008, Hawai‘i imported 42.6 million barrels of petroleum to meet 90% of its energy demand in all sectors, and was the most petroleum dependent state in the nation. In 2008, this cost the state approximately $8.4 billion, which was approximately 13% of the Gross State Product. Most of the imported oil is used for transportation fuel and approximately 30% is used to generate electricity.

Hawai‘i’s dependence on oil makes the State vulnerable to disruptions in supply. Further, the volatility in oil prices translates into volatility in electricity prices. As oil prices increase, Hawai‘i consumers face increases in energy prices as well as the price of most basic goods and services that are imported into the state and shipped between islands. High-energy prices also challenge the competitiveness of Hawai‘i’s tourism industry, which is a key sector in the State’s economy.

In October 2008, the Hawaiian Electric Companies entered into an Energy Agreement with the State of Hawai‘i and the U.S. Department of Energy as part of the Hawai‘i Clean Energy Initiative. Hawai‘i is already near the top in the nation in the use of indigenous renewable energy resources relative to the State's total electricity production. As part of this agreement, aggressive Renewable Portfolio Standards (RPS) goals were established that ultimately require 40% of Hawaiian Electric utilities’ electricity to be generated from renewable sources by 2030 (10% by 2010, 15% by 2015, and 25% by 2020), which is one of the highest standards in the country. A cornerstone of this agreement is Hawaiian Electric’s commitment to integrate 400 MW of wind power located on the islands of Molokai and/or Lanai that could be transmitted to the load center on O‘ahu through an undersea cable system, known as the “Big Wind” projects. (This project is now being considered as one option out of many offered by the broader focus on interisland cable.)

Integrating 400 MW of variable energy resources into the O‘ahu electrical system required an in-depth analysis to: 1) determine the viability of the O‘ahu system to accept the wind energy, 2) evaluate benefits of the project to the O‘ahu system, 3) identify potential impacts to the system reliability, and 4) evaluate strategies to improve system performance. Studies of this nature utilize sophisticated modeling tools to analyze performance of an electrical system through production cost and system dynamic simulations.

Results of this study suggest that 400 MW of off-island wind energy and 100 MW of on-island wind energy can be integrated into the O‘ahu electrical system while maintaining system reliability. Integrating this wind energy, along with 100 MW of solar PV, will eliminate the need to burn approximately 2.8 million barrels of low sulfur fuel oil and

132,000 tons of coal each year. The combined supply from the wind and solar PV plants will comprise just over 25% of O‘ahu’s projected electricity demand.

10.2 Scenario Analyses for Other Hawaiian Grids

In accordance with Amendment 9 to this Cooperative Agreement, resources previously allocated to the effort for this subtask (Subtask 10.2) were reallocated to Task 11.

10.3 System Simulation using High-Performance Computing

Under this task, two reports were completed and submitted. Each of these is described in the following paragraphs. Refer to the Topical Report Submitted section below to see the complete reports.

Numerically Efficient Parallel Algorithms

Work under this activity, conducted by researchers at New Mexico Tech under contract to HNEI, addressed the development of numerically efficient parallel algorithms for analysis of grid systems. The report for this effort presented an approach based upon probabilistic load flow to study the effect of wind generation and variation in loads on an electric power grid. A probabilistic approach was adopted due to the variation and uncertainty associated with wind generation and power consumption. As the modern power grid advances and evolves to accommodate larger amounts of renewable generation, such as wind farms, statistical analysis becomes an appropriate approach to study such intermittent systems. Probabilistic load flow is based upon standard load flow in which complex power balance equations are solved, but instead of one solution a distribution of solutions is found by taking the randomness of wind generation and loads into consideration.

A new method of selecting random variables from historical data was implemented by finding the times of day where power generated or consumed is above or below a given threshold, and correlating the data to incorporate the effects of sites that are geographically close to each other. This is in contrast to other methods where data have been separated into monthly, weekday and weekend intervals. By breaking up the loads into these smaller intervals, a narrower (lower variance) distribution is created from which random load and wind speed data are selected, and in turn creates narrower distributions for variable outputs. The IEEE 24-bus test system was utilized to demonstrate the proposed approach and impact of taking multiple intervals when selecting random variables.

Results were presented for a basic load flow implementation from which histograms were computed for voltages, phase angles, line powers and slack bus fluctuations. This method results in one generator picking up the entire power mismatch of the system. To create more realistic scenarios, economic dispatch was implemented to allow the power mismatch between wind generation and consumption to be distributed among multiple generators based on the minimization of the total cost to run all generators. Results of the study are distributions for all quantities (magnitudes and phase angles of voltages, real and reactive power at generators, loads, and line powers) that can be used for finding the likelihood of low-voltage conditions, overloaded lines, etc., which are useful for system planning and studies. These distributions show that by taking specific intervals of wind and load data separated by size, which correlates to specific times of the day, the variance of the solution tends to decrease. This implies more conclusive results. In addition, the variance of the power output of the generators under economic dispatch gives a measure of how widely their power outputs will need to swing and if there are any cases where more generation would need to be installed.

Model Abstraction Techniques for Large-Scale Power Systems

Work under this activity, conducted by researcher at New Mexico Tech under contract to HNEI, addressed the development of techniques applicable to the analysis of large-scale electric power systems. In particular, techniques were selected and implemented that lend themselves to assessment of the impact of wind energy. The first part of the report summarized “established" techniques such as small-signal stability based on eigenvalues and participation factors, trajectory sensitivities, and tracking operating conditions as wind speed and consumption vary. An example analysis was provided for the IEEE 24-bus reliability test system with a wind farm integrated. The wind farm was taken to be composed of variable-speed wind turbines, and doubly-fed asynchronous/induction generators (DFAG/DFIG) in particular. The second part of the report summarized nontraditional approaches based upon “probabilistic testing for stochastic systems" and “stochastic safety verification using barrier certificates." These approaches were investigated for use in the study of electric power systems with wind farms as stochastic systems, but scalability and applicability remain in question.

Topical Reports Submitted Under Task 10

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Subtask 10.1 Deliverable (O‘ahu Wind Integration Study), 04/01/2011
- Subtask 10.3 Deliverable 1 (Numerically Efficient Parallel Algorithms), 10/29/2012
- Subtask 10.3 Deliverable 2 (Model Abstraction Techniques for Large-Scale Power Systems), 10/29/2012

Task 11: Research and Development on Distributed Energy Resource and Renewable Energy Systems

This task builds from and continues the efforts begun under Task 8. An important element kept in mind throughout both of these tasks was the complementary focus of making use of developments implemented in the State of Hawaiʻi i for related activities on the mainland. Specific subtasks within this task address the areas of: 1) PV systems, 2) energy storage systems, and 3) end-use energy efficiency and demand response. Each of these subtasks will be discussed in the following paragraphs.

11.1 Photovoltaic Systems

PV Test Sites and Test Protocols

Under this subtask, HNEI developed and deployed PV test beds on three different islands in Hawaiʻi. This effort allows collection of high-resolution, time-synchronized data for different PV systems under different climatic conditions. The PV systems at these locations vary in terms of PV module technology, mounting structure, PV system configuration, power, dimensioning, and geographical location. The analysis of the experimental data collected from these PV systems leads to the evaluation of PV performance, determination of the main parameters affecting the PV systems operating in the islands, and an estimate of the impact of weather conditions on system performance.
The anticipated amount of irradiation at the test sites was estimated using GIS data sources to identify climatic conditions at the three tests sites located on three different islands. The selected locations represent three climatic sub regions: 1) a mix between Kona coast of Hawaiʻi and Lower to Rainy Mountain slopes on the Leeward side with a relatively low to medium solar environment on the Island of Hawaiʻi, 2) Lower Mountain slopes on the Leeward side with medium to high solar resource on Oʻahu, and 3) Windward Lowland climate as in the north Interior Lowlands on Maui with medium to high-solar environment.

The PV test bed located on the Island of Hawaiʻi was designed to conduct side by side comparisons of individual PV modules selected from different technologies. Maui and Oʻahu test sites are PV arrays with string inverters. The Oʻahu site supports side by side comparison of two PV module technologies. Five PV module technologies from seven different manufacturers were tested including amorphous, micro-amorphous, mono and poly-crystalline, and intrinsic thin layer technologies. Two models of string inverters and two models of micro inverters were selected to connect to the grid and to perform the maximum power point tracking of the PV systems tested at the three sites. The PV modules are south facing, with a 20^o tilt, either roof mounted or attached to open rack structures.

The PV systems were carefully instrumented to collect high-speed and time-synchronized data on the PV system and the local environment. Each sensor was selected for the best-value unit with high-accuracy. All test sites are equipped with similar instrumentation and a data acquisition system to minimize the variation in the measurements between sites. All of the data acquisition systems are part of an internet based-network including a data server where all data sets are securely transferred into a database for data analysis and visualization.

All of the PV systems, weather station systems, and data acquisition systems were successfully deployed in 2010 and 2011 and are still in operation collecting essential data to evaluate and understand PV performance in the State of Hawai‘i . Detailed analysis of this data are presented in the following paragraphs.

PV System Performance at Selected Test Sites

Analysis of the data collected over a 12 month period has allowed an evaluation of the climatic conditions, the performance of the PV, and a comparison of the main parameters affecting PV system performance.

The solar resource was characterized at each test location, with irradiation levels measured in the PV plane of array. The irradiation levels were found to be approximately 3.6 kWh/ m^2/day on the Island of Hawai‘i, 5.8 kWh/ m^2/day on O‘ahu, and 6.1 kWh/ m^2/day on Maui. This shows an irradiation range in the state comparable to much of the continental US.

All test sites exhibit a small seasonal variation ±1.2 kWh/ m^2/day as a result of Hawai‘i’s latitude. The site on the Island of Hawai‘i has variable climatic conditions with approximately the same number of cloudy days and sunny days. Cloudy days collect most of the solar energy at low irradiance levels < 500 W/ m^2. Sunny days collect most of the solar energy at high irradiance levels with a peak at 950 W/ m^2. At this site, two predominant irradiance levels were measured at 300 and 900 W/ m^2. The sites on Maui and O‘ahu are characterized by mainly sunny conditions with high irradiation, and a predominant irradiance level at 950 W/ m^2.

To compare performance of the PV modules, the DC Performance Ratio (PR) was selected for the analysis. The PR gives the operational efficiency relative to the efficiency specified by the manufacturer at standard test conditions, and is the measured DC energy output from the PV divided by the theoretical DC energy output from the PV produced at the test location. The PV performance observed in this study can be characterized by a small seasonal variation ranging from ±2% to ±3%, and a slightly higher PR, (6% higher), as compared with other published findings. PV modules tested individually at the overcast location on the Island of Hawai‘i have higher performance (89.5% to 94.5%) than the PV arrays tested at the sunny sites on Maui and O‘ahu (86.1% to 88.5%), for all days-analysis. Determination of the causes of this relatively high PR value merit additional study, to aid in the selection of optimal PV technologies and possibly system configurations for specific climatic conditions.

The impact of weather conditions on PV performance was investigated by analyzing data from days with different levels of solar irradiation. It was observed at the overcast site on the Island of Hawai‘i that for all modules, micro inverters, and irradiance levels, the PR is higher on cloudy days and lower on sunny days, compared to the PR for all days. Weather conditions affect each module differently at low irradiance levels showing a slight decrease in PR on cloudy days and an increase in PR for all days and sunny days, compared to the peak PR value reached at irradiance levels between 450 and 650 W/ m^2, depending on the PV technology. This is due to higher light reflection on sunny days. On sunny days, lower irradiance levels correspond to sunrise and sunset when the sun light has high incidence angle, is highly filtered by the atmosphere, and reflected off the surface of the module. Higher impact of the light reflection is observed on the amorphous technology modules. Modules showing the smallest amount of PR degradation at low irradiance levels on cloudy days exhibit the highest impact of the weather conditions on their average performance.

At low irradiance levels, all PV arrays tested at the sunny sites exhibited a significant amount of PR degradation, estimated to be approximately 20% on cloudy days, and at approximately 30% to 40% on sunny days, compared to the peak performance reached at irradiance levels above 700 W/ m^2. Of the three PV arrays, the micro-amorphous array was affected the most. And the least affected was the roof-mounted poly-crystalline array on Maui, with no impact from weather conditions observed on the performance for irradiance levels above 700 W/ m^2.

The last observed parameter is the dimensioning of the PV system (the rated power of the inverter in comparison to the power of the PV system). It determines the irradiance level above which the PV power is limited by the inverter capacity. This limitation was observed at irradiance levels greater than 1,100 W/ m^2, at all test sites. However, the impact of inverter saturation on PV performance was estimated to be minimal, due to low solar energy collected at irradiance levels above 1,100 W/ m^2. Additional study could be conducted to estimate the potential impact of frequent saturation on inverter durability and long term performance.

Separating the impact of the inverter parameters from PV system configuration, and from climatic conditions, merits additional study to improve future development and deployment of PV systems in Hawai‘i.

Collection of Solar Data and Solar Forecasting

The integration of PV systems into the electric grid poses problems due to the natural variability of the resource, insolation. Clouds are the primary factor in modulating insolation, because they directly attenuate solar beam irradiance. We present the ongoing development of a forecasting system that predicts cloud locations and solar irradiance at minute-to-hour time scales, employing ground-based sky imagery and Geostationary Operational Environmental Satellites (GOES) radiometry.

The sky imager based system gives local (~15 km), high-resolution solar forecasts from 1 to 30 minutes ahead. The satellite based system forecasts solar conditions for the entire island chain from 15 minutes to 6 hours ahead. Both systems involve the following steps: identifying cloud-containing pixels in imagery; calculating cloud motion vectors; transforming cloud locations and motion vectors into three-dimensional space; horizontally advecting 3-D locations; and calculating cloud shadows. From cloud shadow predictions, we forecast binary clearness indices. The clearness index is the ratio of the insolation to the top of the atmosphere irradiance. In future work, observations from both systems will be combined with a numerical weather prediction system using four-dimensional variational data assimilation techniques to produce forecasts of surface irradiance from minute-to-day time scales.

Along with the forecasting system, statistical functions were developed in MATLAB to characterize ground measurements of insolation from pyranometer instruments deployed at various PV test bed sites in Hawaiʻi. The information provided by these functions can be used to determine the amplitude, frequency, persistence, and time scales of fluctuations in insolation measurements, which can then be used to calibrate and validate the forecasting system.

The Subtask 11.1 Deliverable 5 report (Corrected), indicated in the Topical Reports Submitted section below, provides details concerning: 1) development and application of the satellite based system, including an example forecast; 2) algorithms designed to utilize sky imagery, but require a different cloud detection method that is also described; and 3) the calibration and validation tools that are being developed and their application to pyranometer data from a PV test bed site on the island of Hawaiʻi.

11.2 Energy Storage Systems

This subtask includes considerations of technologies for subscale testing, testing of cell-level technology, and a business case in Hawaiʻi. Each of these subsections will be discussed in the following paragraphs.

Distributed Energy System: Subscale Testing

This effort consisted of two elements: 1) validation and commissioning, and 2) qualification testing. Over the next decade, it is estimated that 150 to 300 GW-Hr of Distributed Energy Storage (DES) capacity will be required to help support the modernization of our nation's electrical grid. The rapid growth of wind and solar power that the Hawaiian Islands has experienced is a key driver to improve the development and deployment of community-scale DES. A properly implemented DES co-located with solar PV power generation can significantly improve power quality at the point of connection, and even increase the value of the energy generated. Variable power output by a PV system can be stored by a battery system and delivered to the grid at fixed rates and at specific times.

HNU Energy (an HNEI subcontractor) is developing DES technologies to address issues related to un-firm power from individual renewable sources. HNU Energy has a grid-tied test bed site to demonstrate various renewable technologies. HNU Energy has integrated solar PV and energy storage at the residential level by storing the energy and then deploying the energy to the grid at prescribed times. A report submitted to HNEI (see Subtask 11.2 Deliverable 1 Part I, indicated in the Topical Reports Submitted section below) describes this system (the inverter and battery) as well as how it is integrated into the test bed site. This report also discusses how the DES was validated and commissioned.

Following commissioning of the DES, qualification testing was carried out by HNU Energy. The DES provided output power continuously for eight days with no interruptions. There were nine periods in 23 days when the battery was fully discharged. This could be addressed with a software modification to manage the battery's state-of-charge (i.e., slowly reduce the DES output when the state-of-charge is low). The data also showed that the current Sunny Island based DES reduced the variability of the power output by nearly a factor of six. For details, see the report covering this effort in Topical Reports Submitted section below.

Distributed Energy System: Cell-Level Technology Testing

As the scale of energy storage applications for electric grids increase, the number of cells used in these battery systems also increase. Thus, the reliability and safety of large battery systems hinge on effective management and control of these systems. Besides the issues of cell consistency and the process to select cells for battery pack assembly that are critical to overall battery system performance, it is equally important to understand how the battery control and management strategy affects battery system performance. The elements under this section were designed to address the latter aspects, with some preliminary testing of battery string performance to guide our research.

Under funding from this award, staff from HNEI conducted battery testing to investigate how control strategies applied to cells and strings impact system performance. Testing to determine the cell variability and performance were funded and reported under a separate DOE grant (DE-EE0003507). The baseline performance of each cell was established in order to investigate these cells in multi-cell configurations.

For the work under this cooperative agreement, a unique test protocol and analysis approach was developed in HNEI’s electrochemical laboratory that can be used to study string performance issues beyond the conventional laboratory cell testing To study multi-cell configurations and their performance issues, the basic configuration is a three-cell string typically noted in the industry as 3S1P. The 3S1P configuration provides the basis for quantitative analysis using a minimum number of cells while maintaining sufficient complexity in performance variability to support achieving the project objectives.

Under this task, three-cell (3S1P) strings, one from Altairnano and one from SAFT, were tested under RPT conditions (cycling at C/25, C/5, C/2, 1C, 2C and >2.5C rates with extended rest periods and residual capacity measurements) that are designed to show the impact of the three control strategies (string level, cell level, or State of Charge [SOC] range) on string performance.

The performance of two types of cells provided by Altairnano and SAFT in a 3S1P string configuration was evaluated. Reference performance tests were used to characterize the baseline performance characteristics of the ALT and SVL cells. The test results show the design differences between the two types of cells. The ALT design (nLTO//NMC) optimizes high energy and power, while minimizing capacity fade. The SVL design optimizes cell performance for high-power applications.

A 3S1P string consisting of each type of cell was tested to derive the string performance characteristics utilizing three different control schemes. The observed differences among the three control schemes show sensitivity to the cell imbalance and test protocols. The cell imbalance was predetermined by design with one of the three cells intentionally under-charged by 5% (in SOC). By combining the cell imbalance and control scheme, the performance of the strings can be compromised. Although the tests are quite preliminary, the results are useful to illustrate the points regarding the impacts on string performance attributed to cell design, cell imbalance in a string configuration, and the test protocols as implemented by control schemes. The results obtained from the analysis of three control schemes would be useful in matching the cell technology and design to a given application in electrical energy storage for grid and distributed energy storage systems. For details, see the report covering this effort in Topical Reports Submitted section below.

Business Case in Hawai'i for Storage Options

The value of energy storage and its relationship to other ancillary services must be understood to address the specific needs of the Hawai'i electrical grids. Determining the value of storage systems is challenging as Hawai'i does not have an established market for the sale and purchase of generation and ancillary services. This study was focused on determining the possible suite of technologies and services that can support the integration of a high percentage of intermittent renewable energy into the grid system.

HNEI, in cooperation with the Hawai'i Reliability Standards Working Group, contracted with GE to conduct a study to define and quantify the ancillary services including storage services necessary to integrate new renewable resources. The report prepared for this effort presented the following results:

- A listing of the ancillary services required to maintain system flexibility and reliability;
- The interconnection requirements between ancillary services, interconnection standards (grid codes), and reliability standards;
- Identification of technologies capable of providing each ancillary service;
- Identification of physical requirements of ancillary services; and
- Considerations for specifying and acquiring ancillary services, including attention to the risks involved with the various storage technologies and demand-response programs.

For details, see the report covering this effort in Topical Reports Submitted section below.

11.3 End-Use Energy Efficiency and Demand Response

This subtask was called the UH Watt Watcher Program and was a collaboration between HNEI and the University of Hawai'i School of Architecture to develop skills and resource capacity within the University for building energy design, evaluation and management. In its first project, the UH Watt Watcher program teamed with Forest City Military Communities-Hawai‘i to evaluate energy usage in military housing on O‘ahu.

The Watt Watcher Team monitored homes for approximately one month each. In each home, temperature and humidity were recorded, while at the same time energy consumption was recorded on the individual circuits for the air conditioner, the domestic water heater system and the clothes dryer. Other energy consuming equipment, appliances and devices were noted; along with anecdotal self-description of the residents own usage patterns.

The single most compelling observation resulting from this data is the dominance of the air conditioning load in the overall energy consumption. *On average, air conditioning accounts for 44% of the energy consumption in the monitored homes and can reach 69% of the monthly consumption.*

The Watt Watcher Team instrumented 32 homes. Energy data were successfully captured on 28 homes; four yielded little or no data due to equipment malfunction. Of the 28 homes, 22 yielded useful information for all four pairs of current transducer (CT) instrumentation: total energy, domestic hot water, air conditioner and clothes dryer. The refrigerator was monitored using a plug-in Kill-AWatt® meter. The first two sets of houses (MT-01 to 08, and the PH homes) measured in this study were instrumented with the TED energy monitor device and did not yield consistent data. A few of those data sets were for only 2 or 9 days instead of 30 days.

Recommendations for future projects included the following:

- Choose a compressor with good grill protection of cooling fins – the few that we've seen with good protection were in good condition.
- Specify anticorrosion coating compressor fins.
- Air handler located in an indoor closet is good; in the garage is the very worst. If not well sealed, hot and sometimes contaminated air (exhaust fumes, etc.) will be distributed into the home.
- High Temperature differential between floors: need a better balance of ducts/grill size – zoning and distribution.
- Ensure that the latent cooling capacity of fan coil matches the latent cooling load of home.
- We recommend the use of transfer grills for bedrooms for well-balanced supply and return. Otherwise, check that the door is sufficiently undercut (Gentry uses transfer grills). If the bedroom door is closed and the door is not undercut adequately, there is no place for the air to flow out; therefore little air gets pumped into the room, leaving it warm and humid. The pressure in the room should be less than 3 pa higher than the hallway (we have seen 5-7 pa).
- Observation: With security systems, residents can't set alarms if windows are open – an inherent behavioral deterrent to natural ventilation. When people do open windows, security systems beep.

- Replace missing piece to close off air filter access slot – many of these are missing and the gap sucks in hot, humid air – this is particularly dangerous in the homes where the air handler is located in the garage which can have toxic fumes. (e.g., Hawai‘i Loa neighborhood on the MCB).

For details, see the reports covering this effort in Topical Reports Submitted section below.

Topical Reports Submitted Under This Task

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawai‘i Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Subtask 11.3 Deliverable 1 (Energy Consumption Data, Analysis Phase I Interim Report), 08/29/2012
- Subtask 11.3 Deliverable 2 (Energy Consumption Data Analysis Phase I Final Report), 08/29/2012
- Subtask 11.1 Deliverable 5 (Report Summarizing Development and Testing of Solar Forecasting for Hawai‘i), 09/20/2012
- Subtask 11.2 Deliverable 1 (Distributed Energy System Validation, Commissioning and Qualification Test Report), 10/29/2012
- Subtask 11.2 Deliverable 3 (Report on Business Case in Hawai‘i for Storage Options), 10/30/2012
- Subtask 11.2 Deliverable 2 (String Tests of 3S1P Configurations for Electric Energy Storage Applications), 12/10/2012
- Task 8 Deliverable plus Subtask 11.1 Deliverables 1 and 3 (PV Test Sites and Test Protocols), 12/20/2012
- Task 8 Deliverable plus Subtask 11.1 Deliverables 2 and 4 (PV System Performance at Selected Test Sites), 12/2x/2012

Task 12: Policy Analyses and Assessments

This activity built upon and continued the initial work done under Task 9, which was implemented under an earlier amendment to this cooperative agreement. For Task 12, a new and expanded set of subtasks was established and this includes the elements described in the following paragraphs.

12.1 Bioenergy Analyses

A variety of issues were explored in the arena of bioenergy analysis applicable for the State of Hawai‘i. The specific concerns addressed were as indicated in the subsections below.

Analysis of Land Suitable for Algae Production (item 1)

Algae are considered to be a viable crop for biofuel production because of their projected high productivity rates, their ability to grow in a wide range of water qualities, and their potential for cultivation on land unsuitable for food production. Increased demand for biofuels has increased interest in growing algae in Hawai‘i for biofuels.

The scope of the report covering this section was to assess land area in Hawai‘i with potential for producing algae phototrophically in open ponds. The study did not address many of the implementation issues that will be critical to such endeavors, including water availability and cost, land availability, land use priorities, impacts on environmental quality, economic impacts, and algae production costs. The impact of each of these issues merits additional study whether to provide information to guide government policy or investment in algae production ventures. For detailed information contained within the report, see Subtask 12.1 (item 1) under the Topical Report Submitted section below.

Roundtable on Sustainable Biofuels Certification Readiness Study: Hawai‘i Biofuel Projects (item 2)

The Roundtable on Sustainable Biofuels (RSB) Principles and Criteria for Sustainable Biofuel Production and accompanying certification systems are fully developed to the point where organizations are currently certified or seeking certification with global recognition. HNEI commissioned the Hawai‘i Biofuel Foundation to undertake this work which aims to develop a roadmap to certification of a biofuel entity in Hawai‘i through compliance with the RSB Principles and Criteria and other RSB standards.

The biofuel projects in Hawai‘i are maturing to the point where they could achieve certification to the RSB Standard. There is also strong support from government and the business community to ensure that any projects are environmentally and socially sustainable. Driven by the Hawai‘i Clean Energy Initiative to source 70% of the state’s energy needs from clean energy by 2030 and with consideration of the renewable fuels program described in the Hawai‘i Bioenergy Master Plan there is a strong platform for bioenergy projects generally, to be supported in Hawai‘i.

The report prepared for this effort [see Subtask 12.1 (item 2) under the Topical Report Submitted section below] concluded that there is a strong correlation between County, State and Federal Laws and Regulations and the Principles and Criteria of the RSB Standard, particularly when an Environmental Assessment is conducted in accordance with the *National Environment Policy Act of 2006* and the State of Hawaiʻi environmental review law Chapter 343, HRS and Title 11-200 administrative rules for the environmental review process. The report pointed out, however, that the RSB Standard has requirements that are not supported by or achieved through simple compliance with laws and regulations, and a list of specific issues is identified.

Observational Field Assessment of Invasiveness for Candidate Biofuels in Hawaiʻl (item 3)

Five biofuel crops were observed from May-August 2012 for evidence of escape and invasiveness. Observations were made around field plantings of banagrass, Jatropha (*Jatropha curcas*), *Eucalyptus grandis*, African oil palm (*Elaeis guineensis*) and arboreal Leucaenas found on Oʻahu, Maui, Hawaiʻi and Molokaʻi. Observations are reported on distance and degree of spread away from plantings. Risks are assessed and recommendations are made for each species, based on our current field experience and evidence of invasiveness in Hawaiʻi. Behavior of these plants could change in the future. Growers should adopt standard mitigation practices in order to minimize invasion risks and impacts of biofuel crops. For details on this effort, see Subtask 12.1 (item 3) under the Topical Report Submitted section below

State Agency Land Leases (item 4)

In order to develop and prepare a single, clear and consistent policy on the use and lease of state lands for agriculture, grazing, forestry, and bioenergy feedstock production as mandated by the Hawaiʻi Bioenergy Master Plan, HNEI requested a summary of selected land areas currently managed under lease by the State of Hawaiʻi through certain of its agencies and departments. Based on these areas and leases, HNEI asked for a summary of the instruments, processes and policies by which land is leased, with priority given to those unites managing extended land areas necessary for bioenergy/biofuel feedstock production, in response to an Action Item in the legislatively mandated 2009 Hawaiʻi Bioenergy Master Plan to "Develop and prepare a single, clear, consistent policy on use and lease of State lands for agriculture, grazing, forestry, and bioenergy feedstock Production." The following indicates the initial steps in responding to that Action Item.

The coauthors of the report resulting from this effort [see Subtask 12.1 (item 4) reports under the Topical Report Submitted section below] identified relevant departments and agencies and selected typical leases and prototypes, and then identified relevant provisions in each for comparison. These are: method and authority to dispose of public lands; procurement process for leases; valuation of lease; lease restrictions generally; sublease and assignment; special provisions for special leases (energy, agricultural uses, for example).

Biofuel Feedstock Inter-Island Transportation (item 5)

At full scale, shipment of liquid feedstock (transporting 130,000 short tons/year) via fuel barge has the lowest transportation cost of the methods investigated, at fifteen cents per gallon of crude oil equivalent and an aggregate cost of $3.3 million per year. Shipment via International Standards Organization (ISO) tank containers (aka "isotainers") is a close second at twenty cents per gallon crude oil equivalent, and an aggregate cost of $4 million per year. Transporting bagasse in bulk solid form (250,000 short tons/year) via open-top containers is five times more costly, largely because bagasse is relatively "fluffy," requiring many containers to be in circulation simultaneously. Transporting solid bagasse in bulk form via dedicated barge would probably compete well in cost relative to the other options, but a cost estimate could not be obtained for this study. In practice, actual projects would likely start with containerized bagasse or pyrolysis oil and then transition to the dedicated barge transport methods as the volume of activity increases. All four transportation options considered in this study will require investment in equipment, port capacity, trial and error of new practices, and some research and development.

Viewed in terms of Hawai'i's existing inter-island transportation infrastructure, transport of liquefied feedstock required a relatively low 5-6% increase in activity over current transportation capacity. Solid feedstock presented more of an impact, requiring that an entire new barge be placed into service in addition to the three serving Maui currently. As far as harbor capacity, the Hawai'i State Department of Transportation has already studied options to increase liquid fuel transport capacity to accommodate biofuels potential. Solid feedstock transportation options have not been studied as rigorously. For details on this study see Subtask 12.1 (item 5) under the Topical Report Submitted section below.

Geographic Information System Resources to Support Biomass/Bioenergy /Biofuel Decision Making (item 6)

HNEI assessed potential biomass/bioenergy/biofuel resources that can be produced in Hawai'i, this included: *Leucaena*, *Eucalyptus*, and banagrass for fiber; sugarcane for both sugar and fiber; and algae for oil or other intermediate products. The objective of the resultant report (see Subtask 12.4 under the Topical Report Submitted section below) was to provide computer-based, GIS tools on biomass/bioenergy/biofuel resources for use in improving the effectiveness of decision making. A total of 58 GIS layers were produced in total. Data sets include information on soil suitability, slope, sugar and fiber resources, and selected biofuel production resources. These data were provided to the Hawai'i Statewide GIS Program for posting on their website.

Life Cycle Analysis of Bioenergy Production Systems (Item7)

The report submitted for this subtask was prepared to better understand the bioenergy pathways and value-chain components that can be used to expand the future use of bioenergy in the State of Hawai'i . The Hawai'i Bioenergy Master Plan identified a need for life-cycle analysis (LCA) as an important and valuable analytical tool that is needed to support decision making among both policy makers and various business and commercial interest stakeholders. The report provided information on the various pathways that convert biomass feedstock into usable forms of energy, the conditions that make Hawai'i unique and the pathways and value chain components relevant to Hawai'i 's conditions, the use of LCA methodology to track costs and impacts associated with the various pathway or value chain components, and the existing LCA information in the public domain and their relevancy to the objectives in the Master Plan. Through the identification of the potential pathways, value-chain components, and discussing the information on LCAs to date, readers can gain an appreciation for the technology and infrastructure developments that will be needed to enable market transformations, reduce risk, and increasing the potential for success.

12.2 Energy and Economic Model Development

Hawai‘i is currently faced with numerous opportunities and issues associated with expanding the use of indigenous renewable resources for energy production and use to meet the objectives of the Hawai‘i Clean Energy Initiative, and to insure compliance with the current Renewable Portfolio Standards. HNEI has been working on analysis of these activities with the State of Hawai‘i Public Utilities Commission, with DBEDT as part of a State Energy Program grant award, and under prior funding cycles of this Cooperative Agreement.

HNEI has developed new analytical energy systems models that can be utilized for energy-related policy analyses. The goal of this effort is to understand in greater detail the economic and environmental implications of the various legislative proposals at the federal and state levels of government as well as the new initiatives between the state government and the major utility of the state. These efforts can also incorporate additional integration of federal efforts with state policy and regulatory initiatives. Where possible, HNEI utilized existing, publicly-available models and purchased licenses for these models where needed. Other analytical tools were developed internally in order to address specific state-based issues as they relate to the agreements between the major utility and the state administration. For this section, HNEI utilized its relationships with a variety of university and state organizations such as the University of Hawai‘i Economic Research Organization (UHERO) to analyze future choices that the state faces. See the following subsections for specific results of these efforts. For details, see Subtask 12.3 First and Second Deliverables under the Topical Report Submitted section below.

Model Refinement for Economic Assessments of Hawai‘i Clean Energy Policies: Scenario Selection

The July 30, 2010, preliminary report on model development outlined the Hawai‘i Computable General Equilibrium (H-CGE) and Hawai‘i Electricity Model (HELM) developed for this project (see Subtask 9.2). The models presented preliminary output for the baseline calibration. The link from H-CGE to HELM (the electricity forecast demand) was presented and, currently, the link from HELM to H-CGE (overall economy impacts of various energy portfolios) is under development.

In addition, the HELM dataset largely consisted of “placeholders” within the July Report. The dataset has been updated with publicly available sources and is “complete” in the sense that it is ready for stakeholder review.

While H-CGE and HELM can be developed to address a wide variety of energy policy scenarios, given the adoption by the Hawaiʻi State Legislature of more stringent RPS targets, and the exclusion of energy efficiency from the RPS with the creation of the Energy Efficiency Portfolio Standard (EEPS), the study team will assess the optimal energy technology selection to achieve 40% renewable energy by the year 2030. This work will serve as a baseline by which to later address the EEPS (potentially next year's scope of work).

The RPS will be modeled within HELM based on the constraints of two regulated electric utilities in the state: one operating solely on the island of Kauai (KIUC) and the other utility operating on all other islands (HECO, MECO, and HELCO). The scenario will be assessed under: 1) the case that an undersea cable is built connecting Maui County to the City & County of Honolulu, and 2) that each island has an isolated grid system. Within the "cable scenario," installation costs will be reflected through amortized "loan payback" by taxpayers. Thus, the macroeconomic impacts of the cable, as well as the renewable energies that it allows (i.e., greater wind penetration) will be accounted for within the model.

An Assessment of Greenhouse Gas Emissions-Weighted Clean Energy Standards

This effort quantified the relative cost-savings of utilizing a greenhouse gas emissions-weighted Clean Energy Standard (CES) in comparison to an RPS. Using a bottom-up electricity sector model for Hawaiʻi , it was demonstrated that a policy that gives "clean energy" credit to electricity technologies based on their cardinal ranking of lifecycle greenhouse gas (GHG) emissions, normalizing the highest-emitting unit to zero credit, can reduce or transfer the costs of emissions abatement by up to 90% in comparison to a typical RPS. A GHG emissions-weighted CES provides incentive to not only pursue renewable sources of electricity, but also promotes fuel-switching among fossil fuels and improved generation efficiencies at fossil-fired units. CES was found to be particularly cost-effective when projected fossil fuel prices are relatively low.

Topical Reports Submitted Under This Task

More extensive details for the elements completed under this task can be seen by referring to the HNEI website (http://www.hnei.hawaii.edu/). See the PUBLICATIONS section of the website: DOE PROJECT REPORTS: Hawaiʻi Distributed Energy Resource Technologies for Energy Security: DE-FC26-06NT42847 – selecting this link will lead to a list of all reports submitted under this agreement. Specific reports for this task are found by reference to the following list:

- Subtask 12.1 (item 1) (Analysis of Land Suitable for Algae Production -- State of Hawaiʻi), 08/23/2011
- Subtask 12.3 First Deliverable (Model Refinement for Economic Assessments of Hawaiʻi Clean Energy Policies: Scenario Selection), 08/29/2012

- Subtask 12.3 Second Deliverable (An Assessment of Greenhouse Gas Emissions-Weighted Clean Energy Standards), 08/29/2012
- Subtask 12.4 Deliverable (Geographic Information System Resources to Support Biomass/Bioenergy/Biofuel Decision Making), 09/06/2012
- Subtask 12.1 (item 2) (Roundtable on Sustainable Biofuels Certification Readiness Study: Hawai‘i Biofuel Projects), 09/17/2012
- Subtask 12.1 (item 3) (Observational Field Assessment of Invasiveness for Candidate Biofuels in Hawai‘i), 09/19/2012
- Subtask 12.1 (item 4)* (State Agency Land Leases), 10/09/2012
- Subtask 12.1 (item 5) (Biofuel Feedstock Inter-Island Transportation), 10/18/2012
- Subtask 12.2 (Letter Report Describing the Analyses and Reports that were Forecast to be Completed under Task 12), 10/29/2012
- Subtask 12.5 (Bioenergy Production Pathways and Value-Chain Components), 12/06/2012

---

*The Subtask 12.1 (item 4) report was a massive document that required being broken down into five separate parts (Part I through Part V), owing to limitations in document upload size at the University of Hawai‘i HNEI website.