FINAL SCIENTIFIC / TECHNICAL REPORT

Hawaii Energy Sustainability Program

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By the

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EXECUTIVE SUMMARY

This report summarizes work conducted under Grant Award Number DE-EE0003507, the Hawaii Energy Sustainability Program (HESP), funded by the US Department of Energy (DOE) to the Hawaii Natural Energy Institute (HNEI) of the University of Hawaii at Manoa. The objective of HESP was to support the development and deployment of distributed energy resource (DER) technologies to facilitate increased penetration of renewable energy resources and reduced use of fossil fuels in Hawaii's power grids. All deliverables, publications and other public releases have been submitted to the DOE in accordance with the award and subsequent award modifications. These deliverables are well aligned with the goals and objectives of the project.

HESP tasks include a Project Management Plan, Energy Modeling and Scenario Analysis, Development and Testing of DERs and Renewable Energy Systems, and Policy Analysis and Assessments. The latter task included a range of technical and economic analyses supporting the Hawaii Clean Energy Initiative (HCEI), conducted or managed by HNEI.

The initial objective of the energy modeling and scenario analysis was to investigate economic and operational feasibility of interconnecting Maui County and Oahu electric grid systems. Under subsequent award modifications additional studies including analysis of the Hawaii Renewable Energy Portfolio Standards, EV analysis, and an Ancillary Services study were added. Task 3, Development and Testing of DER and Renewable Energy Systems included work on photovoltaics, battery energy storage, hydrogen separation and storage, biomass conversion, and energy efficiency. Task 4, Policy Analysis and Assessments included several analyses of bioenergy from constrained bioenergy plantations in Hawaii, an assessment to examine the costs and benefits of importing LNG to Hawaii, support for the Hawaii Clean Energy Programmatic Environmental Impact Study; as well as an initial look at Alternative Ownership Options for the Utility, an Economic Study of Hawaii RPS and Development of Metrics for Measuring Progress under HCEI.

This report provides a brief summary of the technical projects. Full technical reports, peer-reviewed publications and key presentations can be found on HNEI's website at http://www.hnei.hawaii.edu/publications/project-reports#HESP. At the time of publication of this report, additional journal papers and conference presentations are in development. These works will also be posted to the website upon completion.

Task 1: Project Management Plan

A Project Management Plan was created and updated following several approved no-cost extensions and re-scoping to accommodate ongoing task developments. These plans were submitted as deliverables to DOE.

Task 2: Energy Modeling and Scenario Analysis

Under this Task, a number of economic, technical and operational feasibility studies for high penetration of wind and photovoltaic (PV) resources on Hawaii grid systems were completed. These analyses included interconnection of the Maui County and Oahu electric grid systems to assess the impact of two way flow of electricity between islands, assuming different resource mixes, recent and proposed changes to the utility's power system and operating protocols. Additional studies evaluated Hawaii RPS options, evaluated ancillary services options and examined the impact of controlled charging of electric vehicles (EVs) to reduced curtailment (i.e., spillage) of wind and solar energy. HESP provided support or partial support for these studies with cost share Hawaii Energy Systems Development Special Fund (Hawaii- ESDSF). Final technical reports, summarized below can be found online at: http://www.hnei.hawaii.edu/publications/project-reports#HESP.

Oahu/Maui Interconnection

The Oahu/Maui Interconnection Study, conducted by GE Energy Consulting (GE) in collaboration with HNEI and the Hawaiian Electric Company analyzed operational feasibility and economic impacts of interconnecting the power grids of Maui County with that of the Oahu system. The analysis was performed using production simulation models of the Oahu and Maui power systems originally developed for the Oahu Wind and Transmission Integration Study (OWITS) and the Hawaii Solar Integration Study (HSIS), previously funded under the Hawaii Distributed Energy Resource Technologies for Energy Security project, Award DE-FC26-06NT42847. Considerations included deployment of micro-grids, transmission congestion, management and economic dispatch of high saturations of distributed energy resources (DERs), environmental dispatch of resources, and storage technologies. For more information see *Interconnection of Grid Systems for Maui and Oahu Counties: Different Mixes of Renewable Generation and Several Possible Future Scenarios*.

Hawaii Renewable Portfolio Standards

Jointly funded by HESP and the Hawaii ESDSF, the Hawaii Renewable Portfolio Standards (RPS) study identified and evaluated cost-effective pathways to support the growth of renewables on Oahu and Maui, with a goal of achieving the Hawaii RPS targets. This study was designed to be holistic in scope, encompassing a broad spectrum of power system operations, economics, and reliability impacts associated with high levels of renewable penetration. The study evaluated different resource mixes including varying amounts of utility scale wind and solar generation, as well as increasing amounts of distributed rooftop PV. These resource mixes were evaluated with and without

transmission and various grid configurations that interconnect Oahu and Maui, as well as other off-island resources.

This study included an assessment of the impact of recent and proposed changes to the power system, including conventional thermal plant additions and retirements and changing the primary fuel to liquefied natural gas (LNG). Wherever possible, this study quantified the impacts of these changes on the electric power system, with specific emphasis on renewable energy penetration, wind and solar curtailment, system economics, and grid reliability. For more information see *Hawaii Renewable Portfolio Standards Study*.

RPS II Study

Jointly funded by HESP and the Hawaii ESDSF, this study focused on near term (2017) grid stability considerations: frequency response, short circuit ratio calculations and development of a metric to accelerate measurement of overall grid stability under a wide range of renewable energy and operational scenarios. Operational considerations include thermal cycling, ramp rates, operating reserve requirements, and power plan thermal minimums. Economic considerations include Power Purchase Agreements, capital costs of new infrastructure, reverse metering, etc. Key stakeholders serve as an advisory committee to review project scope, assumptions, findings and key deliverables to ensure relevance to Hawaii's utility, policy, and regulatory challenges and opportunities. For more information see *Oahu Distributed PV Grid Stability Study Part 1: System Frequency Response to Generator Contingency Events, Oahu Distributed PV Grid Stability Study, Part 2: System Frequency Response to Load Rejection Events.* This work is continuing under the ESDSF and the third report, *Oahu Distributed PV Grid Stability Study Part 3: Grid Strength* will be posted upon completion, estimated for March 2017.

Ancillary Services Definitions and Capability Study

Jointly funded by HESP and the Hawaii ESDSF, HNEI contracted GE to identify, define and quantify ancillary services available to support integration of new generation resources for bulk power systems and particularly the Hawaiian Islands. Results, incorporated into the Hawaii Reliability Standards Working Group's work product were intended to support proposals for new reliability standards; to support development of recommendations for revised generation interconnection technical requirements; and to inform the Hawaii utilities' Integrated Resource Planning process. The reports (parts 1 and 2), available on the HNEI website are entitled *Ancillary Services Definitions and Capability Study.*

Assessment of the Variability of the Energy Resource for Wind and Solar Power on Oahu

Jointly funded by HESP and the Hawaii ESDSF the variability of wind and solar energy resources on Oahu is being analyzed over periods of days, months, years, and decades to support operational forecasting needs. The objective of this project is to quantify the longer term (20 year) variability of solar and wind resource across the Hawaiian Islands to aid in optimizing the location and mix of renewable energy sources. In-situ surface and observational satellite data over a period of 20 years is being used, along with regional

high-resolution, Weather Research and Forecasting model runs to obtain results in areas where observational data (particularly wind data) may be lacking. Continuing under ESDSF funding, the final technical report, *Assessment of the Variability of the Energy Resource for Wind and Solar Power on Oahu* will be posted online on completion, anticipated for September 2017.

Task 3: Research and Development on Distributed Energy Resources and Renewable Energy Systems

Under this task, HNEI has developed or characterized technology in the areas of PV, storage systems, hydrogen, and biomass conversion. Final technical reports can be found online at: http://www.hnei.hawaii.edu/publications/project-reports#HESP.

3.1 Photovoltaic Systems

Under Subtask 3.1 PV module performance in subtropical climates was evaluated and improved solar forecasting techniques were developed.

Photovoltaic Performance

To evaluate the performance of a variety of grid-connected PV systems deployed under a previous DOE award, HNEI developed and implemented a methodology to streamline data acquisition and databasing. This methodology automatically feeds performance data from the field sites to a central NetCDF-formatted database. In addition, the multi-domain data format improves database access by the MATLAB data visualization and analysis tools. For more information see: *Performance and Analysis of Photovoltaic (PV) Technologies at Selected Sites*.

Development of Solar Forecasting Techniques

HNEI developed statistical techniques to characterize irradiance variability and continued development of a forecasting system.

The statistical analysis of irradiance patterns and variability on time scales from seconds to months was developed using pyranometer observations collected on four of the main Hawaiian Islands. The statistical analysis of pyranometer observations was done in preparation for development of a solar forecasting system. Dominant time scales and variability, seasonal/diurnal irradiance patterns, and the size and duration of ramp events are necessary information for building, calibrating, and validating such a system. These results can also be used to determine the uncertainty for energy production in Hawaii, which could be used for grid management.

A solar forecasting system was developed to forecast solar irradiance based three separate components: a numerical weather prediction (NWP) model, a satellite remote sensing component, and a ground based observations component. Each component generates a

forecast that is most accurate at a specific forecasting horizon and spatial scale. The satellite component is for regional, intraday forecasts (minutes to hours ahead) that cover the entire Hawaiian Island using a variety of satellite data. The NWP is used for regional, intraweek forecasts (hours to a few days ahead), employing the Weather Research and Forecasting model. The ground based component is for local, intra-hour forecasts (seconds to 1 hour), using ground based cameras and complementary instruments to monitor local sky conditions to generate solar forecasts within 10 to 15 km of the instrumentation. For more information see: *Development of a Solar Forecasting System and Characterization of Irradiance Variability in Hawaii.*

3.2 Energy Storage Systems

Battery storage systems were tested for management of intermittency of renewable generation on the power grid. Control systems were developed for grid-connected battery systems, and battery cell chemistry was characterized for performance attributes and degradation.

Batteries for Grid Management

Under funding from the Office of Naval Research, HNEI led a team to deploy and assess the performance of fast-acting 1MW/250kWh grid-tied battery energy storage systems (BESS) for system control and power quality support at both the transmission and distribution levels. The objective of the ONR program was to identify high-value grid-scale BESS applications that optimize the benefit to the grid/customer while also maximizing the lifetime of the BESS under real world operating conditions. HESP funding supported development of control algorithms for real-time frequency regulation and wind smoothing for the first deployed battery, operating on the Island of Hawaii since December 2012. Using power from the BESS, the frequency regulation algorithm balances instantaneous grid-wide mismatches between generation and load within 100 ms, and the wind smoothing algorithm attempts to mitigate strong variations in wind power within 200 ms. Under most conditions, the frequency regulation algorithm was able to reduce grid frequency variability by 30% to 40%. The wind smoothing algorithm had the effect of noticeably smoothing the raw wind power and the BESS power. For more information see: *Development of Real-time Closed-loop Control Algorithms for Grid-scale Battery Energy Storage Systems*.

Characterization of Emerging Cell Chemistries for Battery Energy Storage Systems

Under this testing effort, in coordination with a similar BESS program under HNEI's Hawaii Energy and Environmental Technologies 2010 Initiative, funded by the Office of Naval Research (ONR) (Award Number N00014-11-1-0391), the long-term performance of four different cells technologies were compared. Coordinated with One lithium titanate oxide (LTO) based cell from Altairnano (under ONR funding) and three graphite-based cells from SAFT America (under DOE funding) were tested. Continuous cycle-aging was undertaken for a year and a half, reaching over 1000 cycles by the end of the project. The LTO based cell from Altairnano demonstrated excellent performance with less than 1% capacity loss. The graphite based cells from SAFT exhibited less attractive performances:

the LFP based cell suffered from 7% capacity loss, the high-power NCA based cell lost 19% of its initial capacity and the high-energy NCA based cell lost the most capacity, 37%. In order to provide the best possible comparison of the tested technologies, both HESP and HEET tested cells are described in the final HESP technical report, *Characterizing Emerging Cell Chemistries for Battery Energy Storage Systems*.

3.3 Procurement and application of hydrogen storage technologies

This activity supported procurement of a mobile hydrogen storage and delivery system in support of a demonstration fleet of fuel cell electric vehicles (FCEVs) supported by ONR. Under this subtask, HNEI commissioned a transportable storage unit comprised of 16 lightweight carbon fiber composite storage cylinders with a total hydrogen carry capacity of 70 kg at a service pressure of 223 bar (3,234 psi). The hydrogen fueling station was provided by funding from ONR, under a project where HNEI installed a 350/700 bar "Fast Fill" hydrogen dispensing system to fuel a small fleet of FCEVs at Marine Corps Base Hawaii. Hydrogen is partially supplied by an electrolyzer at the site which produces 12 kg of hydrogen per day. For more information see: *Procurement and Application of Hydrogen Storage Technologies*.

3.4 Biomass

This subtask includes an effort to demonstrate a novel fixed film column anaerobic digester and activities on the cost-effective processing of biomass.

Anaerobic digestion of primary sewage effluent

A hybrid anaerobic digestion system was demonstrated at an existing wastewater treatment plant under subcontract by HNEI to RealGreen Power. Comprised of an up-flow packed-bed anaerobic reactor and a down-flow trickling-filter reactor connected in series, the system was shown to effectively treat primary clarifier effluent. When a clarifier and sand filter were added to the system, the effluent water quality achieved values of BOD5 and total suspended solids (TSS) that were below the EPA's water discharge limits of 30 mg/l and equivalent to highly efficient activated sludge systems. Best results were achieved at a hydraulic retention time of seven hours and with internal recycle applied to both the anaerobic and aerobic reactors. A scale-up evaluation of the system to treat three million gallons per day indicated total land use of approximately 0.6 acre, which is on the same scale currently used at the host wastewater treatment facility to treat primary clarifier effluent using activated sludge technology. An energy balance showed that the tested system would utilize only 48% of the energy currently used to operate the activated sludge system. For more information see: *Anaerobic Digestion of Primary Sewage Effluent*.

Labscale Evaluation of Immobilization of Media

The performance of a high-rate anaerobic digestion system was characterized utilizing corncob biochar as biofilm support. Anaerobic digestion of waste-trap grease wastewater was successfully achieved with this three-phase, up-flow system, on a total scale of 10-liters, at defined hydraulic retention times (HRT) and packing densities. Performance was evaluated in terms of chemical oxygen demand reduction (COD), total volatile organic acid

variability, and TSS reduction, as well as headspace gas composition and production rate. High resolution images of biofilms revealed extensive biofilm coverage. Microbial analysis of their underlying composition revealed evidence of broad populations of anaerobic bacteria that ferment organic substrates. Major end products are acetate, ethanol, and hydrogen as well as archaeal populations that produce methane gas. Under conditions of a two day HRT and organic loading rate of 9.75 kg COD m-3 d-1 total and soluble COD reductions of 92 and 95% were achieved TSS reductions of 75%. The total volatile organic acids in the feed were almost completely digested and a total gas production rate of 6.1 m3 m-3 d-1 was achieved with a methane composition of 73%. For more information see: *Labscale Evaluation of Immobilization Media.*

Processing of Biomass

The fast pyrolysis behavior of tropical biomass species was examined in terms as a function of temperature and volatiles residence time on product distributions and elemental composition of the products. Initially a reactor was designed and commissioned and a range of residence times and temperatures was determined. Pyrolysis product distributions of bio-oil, char and permanent gases were determined at each reaction condition. The elemental composition of the bio-oils and chars was also assessed. The samples pyrolyzed in this study were two hardwoods: leucaena and eucalyptus, and three grasses: banagrass, energy-cane and sugarcane bagasse. Samples of banagrass and energy-cane were also pretreated before being pyrolyzed. For more information and detailed results, see the full report titled *Fast Pyrolysis of Tropical Biomass Species and Influence of Water Pretreatment on Product Distributions.*

3.5 End-use Energy Efficiency and Demand Response

This project focused on building energy efficiency and occupant energy consumption behavior for both residential and commercial buildings. HNEI in collaboration with the Environmental Research and Design Laboratory at the School of Architecture at UH collected building performance data, simulated building energy consumption and analyzed results.

Audit Procedures for Improving Residential Building Energy Efficiency

Energy consumption patterns were characterized based on 28 homes within Forest City, a 7,000 unit residential complex on the island of Oahu. The areas of focus were monitoring and assessing energy consumption and resident comfort, residential energy consumption modeling, and energy consumption database development. Strategies to lower energy consumption and improve resident comfort were recommended. For more information see: *Energy Audit Procedures*.

Energy Audit Results for Residential Building Energy Efficiency Forest City Phases I and II

Energy audit results from two phases of monitoring and assessment on Forest City residential homes were analyzed. Energy consumption was measured for each of 36 homes, capturing: 1) whole house consumption, and 2) circuit consumption for the solar

water heater, air conditioner, clothes dryer and refrigerator. The relationships between temperature, humidity, comfort, and energy consumption were assessed including energy efficiency technologies, with recommendations given to Forest City management and residents for tenant education and building improvements. For more information see: *Energy Audit Results for Forest City Phase I and Phase II.*

Energy Simulation for Buildings: Development and Training

Training curriculum was created for whole building energy simulation. This included architectural design workflow developed for use in natural ventilation studies employing computational fluid dynamics analysis. Energy simulation training activities included development of a semester course and web-based training curriculum, whole-day workshops, and summer internships. UH faculty and staff developed skills in the instrumentation and monitoring of buildings, and core expertise in building simulation and modeling, with a focus of transferring the knowledge gained to future students, as well as professionals, in the design and building industries. Additional support for this subtask was provided by State and County jobs training funding. For more information see: *Energy Simulation Training*.

Characterization of Commercial Sites Selected for Energy Efficiency Monitoring

HNEI collaborated with energy professionals and the County of Kauai to conduct commercial building energy efficiency activities. Initially, Energy Service Performance Contracting, (ESPC) criteria was redefined to support deep-dive audits, and to test and evaluate advanced energy efficiency technologies used in institutional-scale buildings. The Kauai police department facility was selected for the study, which included potential technologies such as solar thermal absorption chillers, building energy management systems, and advanced lighting. The County's pilot Enterprise Energy and Carbon Management system was used to track energy consumption and to establish baselines for comparison with future energy reductions. HNEI supported the County by engaging in the evaluation of technologies, solutions, and mechanisms to optimize energy savings particularly for this municipal facility. HNEI also supported development of the County's partnership with the electric utility, Kauai Island Utility Cooperative (KIUC) with a Memo of Understanding between the County and KIUC signed in August of 2013. For more information see: *Characterization of Commercial Sites Selected for Energy Efficiency Monitoring*.

Commercial Energy Efficiency −Kauai Main Police Facility

Comprehensive monitoring and data collection were performed by Loisis and Ubbelohde Associates under subcontract to HNEI, to systematically characterize operation of the Kauai police facility's energy and environmental control systems, to identify retrofit recommendations and operational strategies to improve energy performance. A detailed building simulation model was developed to simulate actual conditions, particularly HVAC performance. Building data including environmental conditions, HVAC and lighting measurements field-collected for the initial assessment were used to calibrate the model. Upon validation, detailed analyses of alternative retrofits were made, followed by detailed lighting recommendations, including lighting redesign and plans. HVAC system

analysis, plans, recommendations and guidelines were completed. Additional work was done to develop a benefit-cost analysis to allow the County to prioritize its investments in the facility. County staff are working to determine the extent of measures to implement and have begun work on some of the items identified. For more information see: *Kauai Main Police Facility Retrofit Analysis*.

Task 4: Policy Analyses and Assessments

Under Task 4, HNEI conducted or managed a number of analyses of bioenergy conversion and end-use options for constrained bioenergy plantations in Hawaii, and various economic and policy studies supporting the Hawaii Clean Energy Initiative (HCEI). Under this task, HNEI also supported the US Department of Energy (DOE) in development of the Hawaii Clean Energy Programmatic Environmental Impact Study (PEIS). Individual projects are summarized below. Final reports can be found at: http://www.hnei.hawaii.edu/publications/projects-other-reports#hesp.

4.1 Bio-energy Analysis

Assessments were conducted to support biofuels development in Hawaii. This included research to explore options for processing and refining of biomass. In addition, energy conversion technology and co-product development was investigated to support Hawaiian Commercial and Sugar Company (HC&S), at the time of the study, the last operating sugar plantation in the state.

Two studies were conducted to analyze aspects of processing and refining of biomass. Fuel drying was the focus of the first study as an important part of most bioenergy value chains. A challenge to implementing biomass-based energy systems is managing the moisture content using low cost methods. Eucalyptus ambient air drying was examined and both empirical and finite element models were development to describe moisture content over time as a function of solar insolation, ambient temperature, precipitation, and relative humidity. The second study focused on torrefaction of biomass, identified with industry as a process of interest to enable transportation of biomass materials. A lab-scale torrefaction unit was constructed and used to acquire rate data using leucaena and energy cane samples. Using this data, a second, larger, laboratory-scale unit was designed and fabricated to generate larger quantities of torrefied biomass for additional tests. Torrefaction of nine different biomass materials (leucaena, eucalyptus, sugarcane bagasse, sugarcane, processed sugarcane, purple banagrass, processed banagrass, energy cane, and processed energy cane) was conducted at five temperatures. The resulting torrefied products and parent materials were characterized and tested for mass loss conversion kinetics, higher heating value, Hardgrove Grindability Index, equilibrium moisture content, saturated moisture content, and accessibility to microbial decay. Both of these biomass processing and refining studies are summarized in the report titled *Bio-Energy Analysis.*

Biomass Derived Energy Products and Co-Products Market and Off-take Study
Stillwater Associates LLC were engaged by Hawaiian Commercial and Sugar (HC&S) to investigate the cost and marketability of the transportation products and co-products that HC&S could produce from sugar cane via four renewable fuel conversion processes. These processes, which include Fischer Tropsch, Lipid Production, Butanol, and Pyrolysis, provide finished fuels and/or fuel basestocks that need further processing in an oil refinery on Oahu to convert these into finished fuels. Projections were made based on annual net cane production and short tons raw value of sugar, with all associated co-products such as additional fermentable sugars in cane juice, bagasse, and leafy trash. The volumetric projections for biofuels were made using proprietary conversion yield information. This was based on available feedstocks to provide some perspective of the scale of operations being proposed, so that capital requirements could be estimated. For more information see the full report submitted to HNEI, *Biomass Derived Energy Products and Co-Products Market and Off-take Study*.

4.2 Economic Analysis

This effort consisted of assessing the costs and potential benefits of using LNG in Hawaii to generate electricity, development of a measurement system to characterize progress towards achieving the HCEI goals, development of a Clean Energy Programmatic Environmental Impact Study for Hawaii, a report on municipal and cooperative utility ownership models for the islands or Oahu and Hawaii, and a study to assess the overall economic and policy considerations in meeting the RPS goals.

Liquefied Natural Gas for Hawaii
HNEI engaged FACTS Inc. (part of FACTS Global Energy), to conduct a study to: 1) assess the potential demand for LNG in Hawaii, 2) evaluate the costs and benefits of LNG compared to other fossil fuels, 3) identify the potential impacts of LNG on the state's economy and energy future, 4) identify and assess regulatory policies and practices to consider for the importation of LNG to Hawaii. For more information see: *Liquefied Natural Gas for Hawaii: Policy, Economic and Technical Questions*.

Metrics for Measuring Progress under Hawaii Clean Energy Initiative
HNEI supported the Hawaii Energy Policy Forum, which retained KEMA, Inc. to develop metrics to measure Hawaii's progress towards its clean energy goals under the HCEI. The initial phase of the process consisted of a series of facilitated meetings from a broad spectrum of Hawaii stakeholders to identify what information should be measured in order to characterize Hawaii's progress. A second phase defined seventeen measures grouped into four general categories: overall status/progress indicators; attainment of underlying objectives; status of attainment of state standards; and progress on projects and programs. Under the third and final phase metric definitions were refined; detailed data necessary to calculate the metrics were documented; and methods to maintain and update the data on an ongoing basis were identified. The key focus of this third phase was to review the available data and highlight any gaps between the data required for the metrics and the data available. An Excel model was developed to store data, and to calculate and track the status of each metric. For more information see: *Metrics for Measuring Progress under Hawaii Clean Energy Initiative: Hawaii Clean Energy Status Model 2013.*

Hawaii Clean Energy Programmatic Environmental Impact Study

In coordination with the USDOE, the State of Hawaii, and other stakeholders, HNEI contracted New West Technologies to conduct a PEIS. The objective of the PEIS was to analyze the potential environmental impacts, and best management practices to minimize or prevent those impacts, associated with 31 clean energy technologies and activities. These were grouped into five categories: (1) Energy Efficiency, (2) Distributed Renewable Energy Technologies, (3) Utility-Scale Renewable Energy Technologies, (4) Alternative Transportation Fuels and Modes, and (5) Electrical Transmission and Distribution. The PEIS provides federal and local agencies, policymakers, energy developers, and the public with information and guidance on adhering to all laws and permitting requirements, implementing well-planned best management practices and mitigation measures, and consideration of community and cultural concerns that can be used to make decisions about renewable energy and energy efficiency deployment. This study was co-funded by the Hawaii energy systems development special fund. For more information see: *Hawaii Clean Energy Final Programmatic Environmental Impact Statement*. The documents can also be downloaded from the State of Hawaii website at http://energy.hawaii.gov/testbeds-initiatives/hawaii-clean-energy-peis/peis-documents, under PEIS Documents, Hawaii Clean Energy Final Programmatic Environmental Impact Statement.

Evaluation of Alternative Ownership Options for Electric Utility Assets on the Islands of Oahu and Hawaii

Under joint funding from HESP and the Hawaii ESDSF, HNEI contracted with Filsinger Energy Partnership to support the state legislature and develop an overview of the municipal and cooperative utility ownership models for the islands of Oahu and Hawaii. The report includes potential benefits and challenges associated with acquiring, financing, and operating the utilities, along with recommendations of necessary steps and analyses associated with further pursuing either ownership option. For more information see: *Evaluation of Alternative Ownership Options for Electric Utility Assets on the Islands of Oahu and Hawaii.*

Economic Study of Hawaii's Renewable Portfolio Standard

Under joint funding from HESP and the Hawaii ESDSF, HNEI contracted with the UH Economic Research Organization to model long-term changes to electricity demand and the effects of large-scale renewable energy adoption to Hawaii's overall economy. Continuing under other funding, various scenarios from the HNEI/GE study are being considered with economic and policy impacts assessed in relation to comparable fossil fuel resources. The Hawaii Computable General Equilibrium Model (H-CGE) is being used to simulate the production and consumption of electricity, calibrated to future oil price forecasts provided by the US Energy Information Administration's Annual Energy Outlook 2015 (based on Brent crude). The impact of new electric power load profiles (using GE modeling inputs), storage capacity, and rate design will be assessed given existing data on consumer price response in Hawaii (and elsewhere where relevant) to identify policy changes impacting load profile. Continuing under the ESDSF support, the final report *Economic Study of Hawaii's Renewable Portfolio Standard* will be posted on HNEI's website when completed, anticipated for September 2017.