FINAL TECHNICAL REPORT

Executive Summary

Asia Pacific Research Initiative for Sustainable Energy Systems

Office of Naval Research

Grant Award Number N00014-18-1-2127

March 1, 2018 through December 31, 2022

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

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EXECUTIVE SUMMARY

This report summarizes work conducted under Grant Award Number N00014-18-1-2127, the Asia Pacific Research Initiative for Sustainable Energy Systems 2017 (APRISES17), funded by the Office of Naval Research (ONR) to the Hawai‘i Natural Energy Institute (HNEI) of the University of Hawai‘i at Mānoa (UH). The work conducted under APRISES17 comprises research, develop, testing, and evaluation (RDT&E) of a variety of distributed energy systems and novel energy technologies. APRISES17 also included significant effort directed toward power grid integration using Hawai‘i as a model for applicability throughout the Pacific Region. Areas of emerging energy technologies researched under APRISES17 included electrochemical energy systems, primarily fuel cells and battery systems; biorenewable resources with activities in novel biocarbons and marine fuels; resilient energy systems including analysis for the O‘ahu grid system and development of advanced smart microgrids; and energy efficiency technologies for the build environment. Makai Ocean Engineering, under subcontract to the University of Hawai‘i, also continued their ongoing efforts to develop high-performance, low-cost heat exchangers. A brief summary of results by major task follows.

Task 1, Outreach and Program Management, supported senior faculty to provide overall program management and coordination, developed and monitored partner and subcontract agreements, and developed outreach materials for both technical and non-technical audiences. All subawardees completed the contracted work.

Task 2, Electrochemical Technologies, included RDT&E in the areas of fuel cells, water purification technology, and Li-ion batteries. Substantial progress was made in each of these areas.

Under APRISES17, HNEI continued its collaboration with the Naval Research Laboratory (NRL) supporting development of NRL proprietary fuel cell technology for unmanned aerial vehicles. During this reporting period, HNEI provided consulting and computational modeling support to NRL’s program which focused on developing new fuel cell architectures aimed targeting the Navy’s growing interest in the development of attritable, lower cost technologies.

HNEI also continued its research to develop more robust fuel cell technologies, which included studies of the behavior of PEMFC under exposure of sulfur dioxide, exploring the applicability of platinum group metal free (PGM-free) electrocatalysts, and continued efforts on developing

advanced methods for fuel cell characterization. A number of peer-review publications were produced as a result of this work. HNEI also continued efforts focused on the development of novel transition metal carbide catalysis, minimizing the acid concentration in the electrolytes for vanadium flow batteries, and a novel water purification process. During this period, HNEI filed a U.S. provisional patent for the use of fuel cell materials and designs in membrane distillers for water purification. During the period of APRISES17, significant effort was expended on the relocation of HNEI's Hawai'i Sustainable Energy Research Facility (HiSERF) from Hawaiian Electric property to the UH campus. While this move was initiated due to a lease issue, the move allowed HNEI to upgrade and modify its laboratory equipment to further its fabrication and analysis capabilities and adapt to new challenges emerging in fuel cell research and development.

In the area of Battery Energy Systems, HNEI, under this award, finalized the testing and characterization of commercial Li-ion titanate batteries under representative grid conditions, continued development of non-invasive characterization methodologies for Li-ion batteries, and began evaluating Prussian blue analogues for desalination batteries. HNEI demonstrated that its diagnosis approach of quantifying thermodynamic degradation modes is effective. This work produced eight peer-reviewed publications and results were disseminated at various conferences and workshops.

Task 3, Biorenewable Resources, continued research supporting two subtasks.

HNEI's objectives, under Subtask 3.1, were to evaluate pressurized carbonization as a tool to treat and stabilize materials representative of waste streams from contingency bases; identify pressurized carbonization reaction conditions that produce transient plastic phase solid products; and characterize the products from pressurized carbonization of waste under different test conditions. Subtask 3.2 efforts included conducting comprehensive measurements of the composition and properties of biodiesel derived from waste frying oil and investigated the impacts of antioxidant concentration on its oxidative stability. Under this award, a modified American Society of Testing and Materials (ASTM) method was employed to study the oxidation process and its impacts on fuel properties. Results are summarized and will be published in a forthcoming manuscript.

Task 4, Resilient Energy Systems, included efforts to develop tools and provide analysis of reliability in Hawai'i's energy systems as the islands continue their transition from a system that is predominantly thermal generation using fossil fuels to one with the majority of the generation from variable sources such as wind and solar. Task 4 also included a range of projects focused on the development, testing, and integration of secure microgrid technologies into larger grid systems.

In 2019-2020, the Hawaiian Electric Company (HECO) received approval from the Hawai'i Public Utilities Commission for the development of utility scale 'dispatchable' renewable energy projects on each of the islands. The projects selected each involve large scale ground-mounted

photovoltaics with approximately 4 hours of storage behind the grid-connecting inverter. HNEI, in collaboration with Telos Energy, has been engaged in developing new tools and conducting analysis to better understand the impacts of these significant change to grid operations in Hawai‘i. Efforts under this award included: 1) developing novel stochastic methodology to assess impact, risk, and reliability on high renewable grids; 2) developing a new screening tool to quantify stability risk to the grid as thermal generation is replaced with solar; 3) assessing O‘ahu’s grid near term reliability due to AES Hawai‘i’s retirement and delays in new solar and storage projects; and 4) initiating a study to determine the minimum amount of “dispatchable firm” power that the O‘ahu grid system would require to ensure reliability during extended periods of low resource (solar and wind). This work was funded under APRISES17 with a cost share from the State of Hawai‘i and has been presented to HECO, the Hawai‘i Public Utilities Commission, and various stakeholders.

Technology development activities supported under this award included the Coconut Island DC microgrid; the Advanced Real-Time Grid Energy Monitor System, a platform for grid power monitoring, analytics, and controls; a Solar Forecasting system; the demonstration of an advanced Conservation Voltage Reduction system; and the construction of HNEI’s Advanced Power Systems Laboratory.

The Coconut Island DC Microgrid Project was initiated under previous APRISES funding with the objective of demonstrating the performance and resilience of a DC microgrid designed to serve critical loads within two buildings on Coconut Island, including reliable power to critical loads during interruptions of grid supplied power, and providing the island with clean electrified transportation options powered primarily by the sun. Under APRISES17 funding, HNEI completed wiring for the entire system, an electric power flow metering system was procured and installed, installed and tested a new DC to AC inverter, commissioned inverters and charge controllers, and contracted the microgrid controller installation.

Development of the Advanced Real-Time Grid Energy Monitor System (ARGEMS) project continued and was transitioned from conceptualization and fundamental hardware and core software development to use cases and applications of the system involving analytics, modeling, and controls for in-field deployment, test, and evaluation. Under this award, HNEI added and deployed software interfaces on the ARGEMS to monitor and control additional devices, improved the volt/var control algorithms, and improved the reliability and command line interface of the system. A U.S. patent for this system was awarded in October 2021.

Due to the importance of continued solar capacity growth in the state, HNEI sought to develop methods and technologies that reduce the uncertainty of solar power generation by researching the variability to capture and characterize solar resource and the development of solar forecasting methods and technologies. Under previous APRISES funding, HNEI developed an operational solar forecasting system for the Hawaiian region. During this period, a new methodology was developed to allow for improved modeling and prediction of irradiance under clear-sky conditions,

which is a crucial first step in solar resource prediction. A peer-reviewed paper was recently published that further discusses this methodology.

HNEI also continued efforts on the demonstration of an advanced Conservation Voltage Reduction (CVR) project in Okinawa, Japan. Under previous APRISES awards, control algorithms and communications between field meters and the CVR controller were validated in a hardware-in-the-loop test platform and the on-site construction was scoped and procured. Commissioning of the voltage regulator was delayed until March 2022 due to COVID-19 restrictions. The project faced several challenges due to failures of the pQube meters that were installed to measure the voltage at each transformer. This award funded the pQube meter exchange and heater installation and commissioned, tested, and operationalized the reactive power voltage management hardware and control systems installed at the TH-415 transformer connected to the 5 kW PV system. The operation of the advanced CVR system will be evaluated under future APRISES funding.

The buildout of HNEI's Advanced Power System Laboratory (APSL), a state-of-the-art facility for conducting hands-on research on renewable energy integration in a real-time simulated grid environment, continued under APRISES17. An electrical lab safety consultant conducted a thorough safety design review of the lab's design drawings and identified potential safety risks and proposed design changes for hazard mitigation, which have been integrated into the final construction. Upon completion of the design drawings, HNEI initiated the building permit application process and received approval for its construction. As of 2022, buildout of the laboratory is 90% complete with an expected full completion occurring in 2023.

Task 5, Advanced Heat Exchanger Development, continued to support the development of high-performance thin foil heat exchangers. Under subcontract to HNEI, Makai Ocean Engineering has been developing Thin Foil Heat Exchangers (TFHX) for use in seawater-refrigerant, air-water, and water-water applications. In this report period, Makai advanced the TFHX design, reduced the TFHX fabrication time and cost; and added empirical thermal, hydraulic, and structural/mechanical performance data to the TFHX database. This work allowed for the use of new materials to expand capabilities and implement qualities control processes, while adding to Makai's expertise in the fundamental principles of laser welding and further understanding of the TFHX technology. Additional detail is provided in this report and in Makai's final technical report, available on the HNEI website.

Task 6, Energy Efficiency, continued efforts to evaluate energy use and indoor air quality with natural and mechanical ventilation mechanisms. HNEI utilized the two net zero energy buildings located on the University of Hawai'i at Mānoa campus that were funded under previous APRISES awards to conduct this study. Over a multi-year period, HNEI collected data to evaluate energy consumption for operating heating, ventilation, and air conditioning (HVAC) systems "on-demand", determine the impact on carbon dioxide concentrations from HVAC operating hours, and evaluate the impact of building users' post-pandemic awareness of natural ventilation

mechanisms. It was found that proper user training to concurrently utilize natural ventilation and HVAC systems was essential in allowing CO_2 levels to remain low.

This final report describes the work that has been accomplished under each of these tasks, along with summaries of task efforts that are detailed in journal and other publications, including reports, conference proceedings, presentations, and patent applications. All works produced through these efforts are available on HNEI's website on https://www.hnei.hawaii.edu/publications/project-reports/aprises-17/.