FINAL TECHNICAL REPORT

Executive Summary

Asia Pacific Research Initiative for Sustainable Energy Systems 2021

Office of Naval Research

Grant Award Number N00014-22-1-2045

March 1, 2022 through July 15, 2025

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

November 12, 2025

Final Technical Report
Asia Pacific Research Initiative for Sustainable Energy Systems
Grant Award Number N00014-22-1-2045
March 1, 2022 through July 15, 2025

EXECUTIVE SUMMARY

This report summarizes work conducted under Grant Award Number N00014-22-1-2045, the Asia Pacific Research Initiative for Sustainable Energy Systems 2021 (APRISES21), 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 APRISES21 comprises research, development, testing, and evaluation (RDT&E) over a range of technical areas. These include Electrochemical Technologies with a focus on fuel cells, batteries, and electronic materials; Alternative Fuels including carbonization of biomass, marine fuels, and hydrogen; and Resilient Energy Systems including development and demonstration of advanced technologies for smart microgrids and models for reliable grid systems with a focus on resource adequacy for the Hawai‘i electrical grids. Makai Ocean Engineering, under subcontract to the University of Hawai‘i, also continued their efforts to develop high-performance, low-cost heat exchangers. A stop-work order ended this grant prior to the initial end date, which limited the completion of a portion of the work proposed and planned. A brief summary of results by major task follows.

Task 1, Program Management and Outreach, supported senior faculty and project support personnel responsible for overall program management and coordination, development and monitoring of partner and subcontract agreements, and preparation of reports and outreach materials for ONR and other stakeholders.

Task 2, Electrochemical Technologies, included RDT&E in the areas of fuel cells, Li-ion batteries, and printable electronic materials. Progress in each of these areas is summarized below.

Subtask 2.1, Fuel Cell Testing and Development, HNEI’s research comprised four projects: a) the evaluation of anion exchange membrane fuel cells; b) recovery of proton exchange membrane fuel cells exposed to SO_2 in an air stream; c) refinement of methods for electrochemical impedance spectroscopy for fuel cell evaluations; and d) contaminant removal and mitigation for fuel cell technology use in harsh environmental conditions.

2.1a) The most compelling motivation for exploring anion exchange membrane fuel cells (AEMFC) technology stems from the prospect of eliminating Pt-based catalysts from both the anode and cathode. This is due to platinum group metal (PGM)-free materials exhibiting higher

intrinsic catalytic activity towards oxygen reduction in alkaline media compared to Pt-based catalysts. PGM-free cathodes in proton exchange membrane fuel cells (PEMFC) have also exhibited tolerance to air contaminants such as CO and SO_2. Work under this award focused on establishing in-house capabilities for the fabrication of catalyst coated membranes (CCMs) and catalyst coated substrates (CCS). This was accomplished, enabling rapid screening and evaluation of novel and emerging materials that are often available only in limited quantities. Twenty-one different aspects of AEMFC manufacturing and evaluation were investigated.

2.1b) The development of simple and reliable methods to recover performance after contamination is important not only for sustaining fuel cell performance in contaminated environments, but also as a part of maintenance routines. In continuation of work under previous APRISES funding, this work evaluated potential cycling as a possible recovery method. Potential cycling was comprehensively studied using a segmented cell to assess its effectiveness and applicability to restore fuel cell performance exposed to SO_2 under different operating temperatures and currents. Results supported the feasibility and applicability of a cyclic voltammetry-induced procedure for recovering the performance of SO_2 poisoned fuel cells. The efficiency of this recovery was shown to depend on the operating cell temperature and current during the contamination. Details of this work was published in the *Journal of Power Sources* and presented at four conferences.

2.1c) HNEI continued development of advanced diagnostics. In this effort, previously developed 1d+1d impedance models of a PEMFC were extended to take into account 2D transient effects in the plane perpendicular to the channel axis, along the channel/rib coordinate. The impedance spectroscopy data obtained from HNEI's segmented cell system were used for the model fitting. The results of this work showed that resolving the impedance locally can help understand 3D local current distributions in an operating PEMFC without the need for complex 3D imaging technologies. Details of this work was published in two papers in the *Materials Research Express* journal and presented at two conferences.

2.1d) Advancement of purification technology is critical to the use of fuel cell technology into harsh environmental conditions. HNEI's previous research has shown that both SO_2 and H_2S significantly impact performance due to the irreversible binding of the contaminants. Under APRISES21 funding, detailed SO_2 gas sorption testing of the $Mg_4[OAc]_{10}[C_2mim]_2$ activated carbon composite sorbent was initiated. Testing included varying environmental conditions including humidity, flow rates, gas concentrations, relative humidity, and temperature. A preliminary comparative materials cost analysis suggests a significant cost savings with the new materials. Details of this work is currently being prepared for publication in a peer-reviewed journal.

Under Subtask 2.2, Battery Characterization and Modeling, HNEI research focused on the improvement of data-driven approaches to characterize performance and lifetime of next generation lithium-ion batteries for both DOD and commercial deployments. HNEI used *in-silico*

dataset generation in conjunction with the mechanistic battery modeling framework to test different strategies towards diagnosis and early prognosis. The emphasis of work under APRISES21 was set on realistic synthetic data covering the degradation associated with battery packs directly connected to photovoltaic systems. By using synthetic data, HNEI demonstrated possible diagnosis for days with 50% or more clear sky without the need for maintenance cycles. Results reinforced the potential of synthetic data generation and training to enable big-data studies of the behavior or deployed system that will experience sporadic usage. Details of this work was published in two papers in the *Natural Communications* and *Batteries* journals, respectively.

Under Subtask 2.3, Printable Electronic Materials, HNEI investigated transparent-conductive-flexible composites (TCFCs) as multifunctional encapsulation materials for advanced energy, aerospace, and marine applications. Two primary objectives guided the study: 1) maintain at least 50% electrical conductivity on curved surfaces relative to flat substrates and 2) preserve conductivity after 24 hours at 100°C or 100 mechanical bending cycles. Developed at HNEI's Thin Films Laboratory, these TCFCs consist of micron-sized metallic particles embedded in a transparent polymer matrix. This results in a material with high optical transmittance and low out-of-plane resistance, outperforming existing commercial transparent conductors. Their ability to function simultaneously as electrode and encapsulant—resistant to moisture and oxygen—makes them ideal for organic electronics, electrostatic dissipation, and cathodic protection. Mechanical durability was validated with both uncoated and silver-coated samples retaining conductivity. TCFCs synthesized from epoxies maintained or improved electrical performance after thermal aging at 100°C for 24 hours. These findings confirm the robustness of TCFCs under realistic environmental stresses, positioning them as next-generation encapsulants that merge barrier protection, conductivity, and optical clarity. Further customization through surface treatments offers new routes for application-specific design across photovoltaics, aerospace, defense, and soft electronics.

Under **Task 3**, Alternative Fuels, HNEI continued research in three areas: constant volume carbonization of biomass, marine fuels, and hydrogen refueling technology.

Under Subtask 3.1, Constant Volume Carbonization, HNEI investigated transient plastic phase biochars (TPPB) produced from different woody feedstocks to understand the underlying factors responsible for the differences in mechanical performance of biocarbon produced from these materials. Several analysis methods were used including proximate analysis, thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR), quantitative carbon-13 nuclear magnetic resonance (^{13}C NMR), and gas chromatography-mass spectrometry (GC-MS), reactivity tests, and microscopy. Results from this study suggests that the superior mechanical performance of biocarbon produced from birch TPPB likely results from the triterpenoids acting as plasticizing agents that alter the glass transition temperature of the material. This results in more inter-particle bonding to occur during calcination increasing the

mechanical strength of the resulting biocarbon. Details of this work was submitted for publication in the *Energy & Fuels* journal and is currently under review.

Sulfur-containing compounds (SCCs) are the most abundant heteroatomic organic species (HOS) in petroleum fuels. Subtask 3.2 investigated the dynamics of SCCs in surrogate fuel systems, focusing on their oxidation stability, reactivity, and interactions. A comprehensive analysis was conducted on a selection of eleven SCCs. The investigation involved tracking the reaction and degradation processes of these SCCs at 140°C over an extended period, coupled with the analysis of resulting products to elucidate oxidation and degradation mechanisms. Interactions and reactions or binary mixtures of reactive SCCs and multicomponent SCC mixtures were examined. The study also assessed the interactions between SCCs and commercial antioxidants. Details of this work was published in the *Fuel* journal.

HNEI also continued research, development, demonstration, and assessment of hydrogen production, storage, and dispensing systems for heavy duty hydrogen vehicles, and evaluation of the operational performance of buses on the Big Island of Hawai‘i under the third subtask. Through APRISES21 funding, the team accomplished: 1) the full operational commissioning of the hydrogen station’s primary systems; 2) prepared the tube trailers for operation; 3) deployed and operated hydrogen transport trailers for fuel delivery; 4) performed repairs, upgrades, and preventative maintenance; 5) established an automated hydrogen dispensing system; and 6) demonstrated power and range increases in the buses. Various workforce training and outreach engagements were also supported as well.

Under **Task 4**, Resilient Energy Systems, HNEI continued research to enable the development of resilient, reliable, and secure energy systems operating with a high penetration of variable renewable generation technologies. The work included two closely integrated activities.

Under Subtask 4.1, Advanced Grid Technology, HNEI’s Grid System Technologies Advanced Research Team (Grid***START***) advanced the development, evaluation, and demonstration of alternative energy, distributed energy resources (DER), and enabling technologies to enhance grid reliability and resilience. Building on prior ONR-supported work, the team integrated methods such as advanced DER optimization, real-time analytics, system diagnostics, demand response, and electric vehicle (EV) and maritime electrification. Activities spanned software simulations, power hardware-in-the-loop (PHIL) testing at the Advanced Power System Laboratory (APSL), and field demonstrations on both civilian and Department of Defense (DOD) sites. Specific subtasks under APRISES21 included: a) addressing key operational and communications challenges in an advanced conservation voltage reduction (CVR) demonstration project; b) developing a holistic microgrid optimization framework for resilient and cost-effective DER and hydrogen integration; and c) demonstrating resilient DC microgrid and transportation solutions for marine environments on Coconut Island.

4.1a) HNEI, in partnership with U.S. Marine Corps Camp Butler, demonstrated the use of advanced CVR to realize energy savings on a DOD distribution feeder in Okinawa, Japan. Earlier phases developed and deployed core infrastructure, including a dedicated voltage regulator, advanced CVR control device, and supporting communications and metering systems, leading to reliable autonomous CVR operation and measurable energy savings at Camp Butler's Plaza Housing complex. Under APRISES21, the Grid***START*** team addressed challenges with reactive power dispatch by replicating and troubleshooting the field system at HNEI's APSL in Hawai‘i. This effort led to the identification and remote resolution of critical communication issues between the Volt/VAR Control (VVC) controller and photovoltaic (PV) inverters, successfully restoring full CVR operation. The project continued alternating-day CVR operations, further validating CVR effectiveness, and gathering operational data. Field testing was suspended in May due to a stop-work order, but major system milestones and technical barriers were successfully completed.

4.1b) HNEI developed and demonstrated a holistic optimization framework to design and operate resilient, cost-effective microgrids. Using the Natural Energy Laboratory of Hawai‘i Authority's (NELHA) facility on Hawai‘i Island as a real-world test case, the project created a hybrid model combining mixed-integer linear programming (MILP) with particle swarm optimization (PSO) to guide microgrid sizing, energy dispatch, and integration of DERs such as PV, batteries, and hydrogen systems. This approach enabled simulation of both everyday operations and extended outage scenarios, incorporating actual load and solar data, real-world utility rates, and NELHA's hydrogen infrastructure. The results highlighted the value of flexible DER portfolios, showing that green hydrogen and fuel cells can enhance microgrid autonomy and reliability, especially under prolonged outages, while also being financially viable over a 25-year lifespan. The project addressed practical modeling gaps by incorporating realistic hydrogen efficiency curves and provided actionable recommendations for microgrid design and operation. The framework and findings advance microgrid design for greater resilience and cost-effectiveness, with direct relevance to critical, grid-challenged regions like Hawai‘i. Details of this work was published in the *Energies* journal and in a Master of Science thesis.

4.1c) The Coconut Island DC microgrid project established a pioneering research platform on the island of Moku o Lo‘e in O‘ahu's Kāne‘ohe Bay to enhance energy security and test advanced technologies in a challenging coastal environment. Earlier phases included detailed microgrid design, installation of a 6.2 kW DC rooftop PV array, an 8 kW/8 kWh stationary battery system and commissioning of Hawai‘i's first electric pontoon research vessel (E-boat). Collaboration with international partners led to a prototype swappable battery system, later replaced with reliability with robust fixed-placement batteries in both the E-boat and a land-based EV. Under APRISES21, the team doubled solar capacity, installed 18.2 kWh batteries in the E-boat, upgraded control systems, and validated initial vehicle-to-grid (V2G) operation. System redesigns improved resilience, operational safety and energy efficiency, with DC operation yielding measurable savings for AC/LED loads. Despite the unexpected funding termination, the project solidified

Coconut Island as a model for microgrid-powered marine research, setting the stage for future advances in resilient, responsible coastal electrification and transport.

Subtask 4.2 focused on power systems analysis with a focus on resource risk assessment to ensure that the energy systems and related critical infrastructure on Oʻahu and the other Hawaiian Islands, home to the Pacific Command and the largest military bases in the Asia Pacific region, meets the reliability needs of DOD as significant amounts of variable generation technologies are integrated into the grid. This latter activity leveraged resources from the Energy Systems Development Special Fund (ESDSF) managed by HNEI (also known as "barrel tax") and supported the Memorandum of Agreement between the State of Hawaiʻi and the ASN for Energy, Installations and Environment, and also the Memorandum of Agreement between the University of Hawaiʻi (UH) and the Pacific Command.

In previous work, probabilistic analytic tools were developed to assess the reliability or island grids with very high penetration of variable renewables (solar and wind) with and without large scale energy storage. This analysis, conducted in collaboration with Telos Energy under contract to HNEI, was applied to quantify the reliability of the Oʻahu grid, pending the retirement of Oʻahu's largest generator, the AES coal plant, in September 2022. A user-friendly tool was developed to allow stakeholders to track schedule changes in replacement resources and the impact on system reliability.

Under this award, the project quantified the requirements for dispatchable firm capacity on Oʻahu and the other islands' grids as high amounts of variable renewable generation and battery storage is integrated into the grid. It was found that, even with the relatively consistent wind and solar resources such as found in Hawaiʻi, firm capacity of up to 60% of the peak load was required even when the variable renewables provided up to 90% of the total energy.

Task 5, Advanced Heat Exchanger Development, continued to support the development of high-performance thin foil heat exchangers (TFHX^{TM}) for use in seawater-refrigerant, air-water, and water-water applications. The work supported under this award was conducted between November 2024 and July 2025. In this period, Makai designed the next generation TFHX plate fabrication equipment; commissioned the new HX Testing Facility; performance tested two cassette-style 2-MWthermal TFHXs; developed concepts for large-scale seawater-water TFHXs; and prototyped new biofouling mitigation methods. Details of this work is available in Makai's report.

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. **Publications produced through these efforts are noted below and available on HNEI's website at https://www.hnei.hawaii.edu/publications/project-reports/aprises-21/.**