Wendy F. Hensel
President

UNIVERSITY of HAWAIʻI®
Ke Kulanui o Hawaiʻi

DEPT. COMM. NO. 218

December 29, 2025

The Honorable Ronald D. Kouchi,
President and Members of the Senate
Thirty-Third State Legislature
Honolulu, Hawaiʻi 96813

The Honorable Nadine K. Nakamura, Speaker
and Members of the House of Representatives
Thirty-Third State Legislature
Honolulu, Hawaiʻi 96813

Dear President Kouchi, Speaker Nakamura, and Members of the Legislature:

For your information and consideration, the University of Hawaiʻi is transmitting one copy of the Annual Report from the Hawaiʻi Natural Energy Institute (Section 304A-1891, Hawaiʻi Revised Statutes) as requested by the Legislature.

In accordance with Section 93-16, Hawaiʻi Revised Statutes, this report may be viewed electronically at:
https://www.hawaii.edu/govrel/docs/reports/2026/hrs304a-1891_2026_hnei_annual-report.pdf.

Should you have any questions about this report, please do not hesitate to contact Stephanie Kim at (808) 956-4250, or via e-mail at scskim@hawaii.edu.

Sincerely,

Wendy F. Hensel
President

Enclosure

2444 Dole Street, Bachman Hall
Honolulu, Hawaiʻi 96822
Telephone: (808) 956-8207
Fax: (808) 956-5286
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UNIVERSITY OF HAWAIʻI SYSTEM ANNUAL REPORT

REPORT TO THE 2026 LEGISLATURE

Annual Report from the
Hawaiʻi Natural Energy Institute

HRS 304A-1891

December 2025

Hawaiʻi Natural Energy Institute

School of Ocean and Earth Science and Technology

University of Hawaiʻi at Mānoa

Annual Report to the 2026 Legislature

HRS 304A-1891

Annual Report on Activities, Expenditures, Contracts Developed, Advances in Technologies, Work in Coordination with State Agencies and Programs, and Recommendations for Proposed Legislation, required in accordance with HRS 304A-1891 (Act 253, SLH 2007).

1. INTRODUCTION

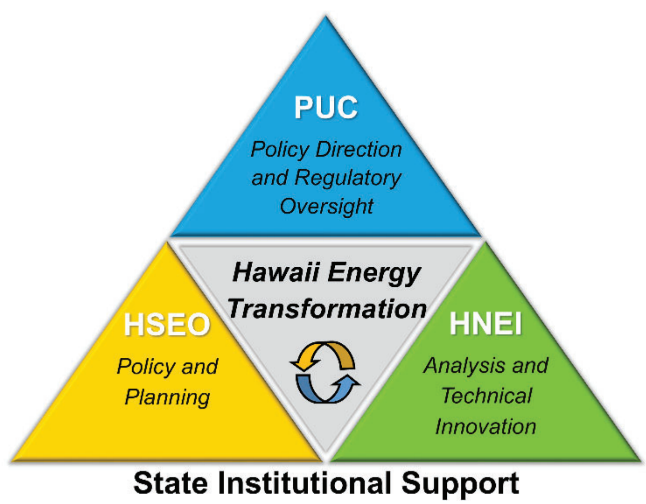
The Hawaiʻi Natural Energy Institute (HNEI) was created in 1974 to facilitate the development of the state's natural energy resources and reduce fossil fuel use in Hawaiʻi. Early efforts included resource assessments, demonstration projects, and research and development in the areas of alternative fuels, bioenergy, solar, and geothermal systems. In the early 2000s, HNEI took a growing leadership position in the development of public-private partnerships to accelerate the acceptance and integration of renewable energy technologies into Hawaiʻi's energy mix. HNEI emerged as a leader for sustainable energy development and the deployment and demonstration of emerging energy technologies.

In 2007, the Hawaiʻi Legislature (Act 253) established HNEI in state law with an expanded mandate to coordinate with state and federal agencies to demonstrate and deploy renewable energy, energy efficiency, and peak demand reduction technologies. Act 253 (2007) also established the Energy Systems Development Special Fund (ESDSF) and directed that it be managed by HNEI. Three years later, in 2010, Act 73 authorized 10 cents of the $1.05 tax imposed on each barrel of petroleum product imported into Hawaiʻi be deposited into the ESDSF. In 2022, pursuant to Section 269-33(e), $0.03 (3 cents) per barrel of the ESDSF allocation was redirected to the Hawaiʻi Public Utilities Commission (PUC) to support the development of EV infrastructure. As of December 31, 2024, HRS 243-3.5 Environmental response, energy, and food security tax; directs 5 cents of the tax on each barrel shall be deposited into the ESDSF established under Section 304A-2169.1. These funds are intended to match funds from federal and private sources, and to award contracts or grants for developing and deploying renewable energy technologies (HRS Secs. 304A-1891-1894 and Sec. 304A-2169.1).

Hawai‘i's energy transformation has been driven by bold state policies that now include a mandate for 100% renewable electricity and carbon neutrality by 2045 (HRS Secs. 269-92 & 225P-5). A core part of HNEI's mission, going beyond traditional academic research, is to support Hawai‘i in its clean energy transformation by helping facilitate cost effective and practical solutions to deliver renewable energy for the state and its citizens. As part of this effort, HNEI robustly supports analysis to inform energy policy and decision making in Hawai‘i. The analysis conducted by HNEI and its contractors is used by the utility and PUC in their decision making. HNEI also serves as a critical bridge to certain Federal initiatives in supporting the State's 100% renewable portfolio standard and clean transportation initiatives. HNEI is recognized as an independent organization providing trustworthy and practical information to support safe, reliable economic development of renewable energy systems and technologies.

The foundation of HNEI's strength lies in its people, its partners, and its contractors. The diversity of talents, education, experience, and entrepreneurial spirit of this team creates flexibility in performing a range of renewable energy development and analysis activities. HNEI brings together experts from a broad set of disciplines and organizations to develop solutions that significantly impact energy transformation initiatives in Hawai‘i. HNEI coordinates closely with the Hawai‘i State Energy Office (formerly with the State Energy Coordinator), the PUC, the state's investor-owned utility (Hawaiian Electric Company, HECO), and various commercial and industrial entities. HNEI has also successfully garnered extramural funding from a range of federal sources leveraging the value of state funds to meet needs and opportunities within the state. HNEI maintains strong working relationships with the members of Hawai‘i's Congressional delegation and other government and non-government organizations in the Asia Pacific region. By engaging in a wide range of disciplines and with a variety of stakeholders, HNEI is able to tackle urgent and complex clean energy needs of our State, the nation, and partners in the Pacific region.

To accomplish this mission, HNEI integrates analysis, research, engineering, economics, and science to develop and demonstrate technologies, strategies, and policies that will significantly impact energy transformation initiatives in Hawai‘i and beyond.



2. HAWAIʻI NATURAL ENERGY INSTITUTE STAFFING/FUNDING OVERVIEW

As an Organized Research Unit in the School of Ocean and Earth Science and Technology at the University of Hawaiʻi at Mānoa (UH), HNEI receives state funding via the Hawaiʻi General Fund through the university budget, sufficient to support its Director, up to three administrative support staff, and partial salaries (60% to 80%) of seven tenure or tenure-track faculty (permanent faculty). HNEI has received approval to refill the two vacant administrative support staff positions, hire a shared faculty with UH's Department of Ocean and Resource Engineering for marine energy, and intends to seek one additional tenure track faculty to support the state's decarbonization goals. An unsuccessful search for the latter was conducted in 2024. HNEI staffing for 2025 is summarized in Table 1 below.

Table 1. HNEI total staffing by position type for 2025.*

Director: Richard E. Rocheleau	
Permanent Faculty (FTE)	7
Other Permanent Staff (APT)	1
Temporary Faculty	16
Other Temporary Staff [(a)] (APT, RCUH)	26
Training [(b)]	13

(a) Includes postdoctoral researchers
(b) Includes graduate and undergraduate students, and visiting scientists
**In 2025, HNEI also provided full or partial financial support to two temporary staff and three graduate research assistants employed by other UH departments.*

As summarized in Table 2, HNEI receives funding from multiple sources, with the primary source being from extramural awards from various federal agencies. In recent years, the majority of these funds have been from the Office of Naval Research, the U.S. Department of Energy, and Naval Facilities Engineering Command, but HNEI also receives funds from other U.S. Federal agencies and industry as well. Funding from other UH departments from collaborative projects is also included in our extramural totals. In 2025, due to federal priority changes and funding cuts, HNEI received stop work orders on a number of awards and contracts, including awards from the Office of Naval Research, U.S. Department of Energy, and U.S. Agency for International Development (USAID), which resulted in a reduction of approximately $24M. A complete breakdown of HNEI's extramural awards for FY 2023 through FY 2025 is shown in Tables 3 through 5.

In addition to supporting HNEI's permanent faculty, extramural funds from these sources support temporary faculty and staff including engineers, scientists, and support personnel as well as postdoctoral researchers, graduate and undergraduate students, and visiting scientists within HNEI. Due to the multidisciplinary nature of HNEI's work, these extramural funds also support faculty, students, and postdoctoral researchers in other departments and colleges.

HNEI also receives a small amount of tuition return. HNEI's extramural awards also generate indirect "Research and Training Revolving Funds," of which approximately 25% is returned to

HNEI to facilitate operations and research. In addition to addressing national and international needs, many of the projects funded by the entities identified directly or indirectly support Hawaiʻi's clean energy goals.

As part of its responsibilities under Act 253, HNEI also administers the Energy Systems Development Special Fund (ESDSF), allocated from the environmental response, energy, and food security tax ("Barrel Tax") pursuant to HRS Section 243-3.5. Funding from the ESDSF serves as an invaluable source of funding for HNEI. The primary uses of the ESDSF over the last three years were to: 1) provide cost share to federally funded energy research when non-federal cost share is required to secure the funds; 2) provide funds to address explicit PUC and legislative requests, including unfunded legislative mandates; and 3) to support select community engagement efforts, such as the annual Hawaiʻi Energy Conference (the 2025 conference was held on Maui in May) and the Hawaiʻi Energy Policy Forum (HEPF), whose activities include the annual legislative energy briefing, such as upcoming one scheduled tentatively scheduled for January 2026 at the state capital. Every three years, HNEI prepares a report summarizing ESDSF projects and expenditures. The last such report was submitted to the legislature in December 2023.

While HNEI does not typically initiate legislation, the Institute actively engages in activities to inform legislators and other Hawaiʻi government organizations with unbiased information and analysis on matters relevant to pending issues, bills, and proposals. Some of this is managed through the HEPF with much of it conducted directly by HNEI faculty, staff, and consultants. These activities are summarized in Appendices A and B. For example, HNEI continues to provide support to the PUC, including detailed analytic studies for evaluation of utility proposals. HNEI is also a founding member and supporter of the HEPF, a collaborative energy planning and policy group comprising approximately 100 representatives from business, academia, government, and non-profit organizations. In 2021, HNEI assumed responsibility for coordination and management of the HEPF activities. In collaboration with the Forum, the Institute is currently preparing a series of briefs for the pending legislative session.

A breakdown of HNEI funding by type for the past three fiscal years is shown in Table 2 below.

Table 2. Funding by source and year, FY 2023 to FY 2025.

	FY 2023	**FY 2024**	**FY 2025**
General Funds	$1,259,349	$1,182,434	$999,938
Tuition and Fees S Funds	$32,870	$28,684	$19,203
Extramural Awards*	$5,543,660	$18,714,930	$15,960,925
Research and Training Revolving**	$446,794	$539,496	$460,534

**Federal funding cuts resulted in ~$24M lost in 2025 to extramural funding due to stop work orders.*
***RTRF funds are based on the previous year's expenditures.*
Note: In FY 2026, HNEI has received $4,117,077 in extramural awards to date.

Table 3. Summary of HNEI Extramural Funding, FY 2023.

Office of Naval Research, Fuel Cells	$200,000
NAVFAC, Wave Energy Test Site	$3,637,609
FAA, Sustainable Aviation Fuels	$400,000
U.S. Dept. of Energy, Island Energy Resilience via NREL	$105,000
U.S. Dept. of Energy, Thin Films and Printable PV	$450,000
U.S. Dept. of Energy, Grid Technology via UAF	$154,988
USAID, International via RTI International	$257,485
Deloitte & Touche, International	$238,579
Nuvera Fuel Cells, Fuel Cells	$99,999
FY 2023 Total	**$5,543,660**

Table 4. Summary of HNEI Extramural Funding, FY 2024.

Office of Naval Research, Sustainable Energy Systems	$10,999,994
Office of Naval Research, Fuel Cells	$150,000
FAA, Sustainable Aviation Fuels	$250,000
U.S. Dept. of Energy, Fuel Cells	$4,000,000
U.S. Dept. of Energy, Microgrid Training	$999,838
U.S. Dept. of Energy, Grid Technology via UAF	$97,769
U.S. Dept. of Energy, Semi-Monolithic Devices for Hydrogen	$1,000,000
U.S. Dept. of Energy, 2D Materials for Solar Films	$250,000
U.S. Dept. of Energy, Wave Energy via NREL	$183,500
National Science Foundation, Materials Research	$21,563
U.S. Dept. of Agriculture, Hawai‘i Climate Smart Commodities	$60,805
SINTEF (Norway), Biocarbons	$48,795
Deloitte & Touche, International	$145,664
DAI Global, International	$227,778
Element Energy, Battery Testing	$200,178
USAID, International via Tetra Tech	$79,046
FY 2024 TOTAL	**$18,714,930**

Table 5. Summary of HNEI Extramural Funding, FY 2025.

Office of Naval Research, Sustainable Energy Systems	$8,000,000
Office of Naval Research, Fuel Cells	$150,000
NAVFAC, Grid Technology	$1,200,000
FAA, Sustainable Aviation Fuels	$150,000
U.S. Dept. of Energy, Hawai‘i Marine Energy Center	$5,702,224
U.S. Dept. of Energy, Wave Energy via OSU	$31,087
U.S. Dept. of Energy, 2D Materials for Solar Films	$250,000
U.S. Dept. of Energy, Grid Technology via UAF	$38,310
National Science Foundation, Materials Research	$120,821
BWM of North America, Battery Testing	$50,160
TVS Motor Company, Battery Testing, International	$150,000
VoltR, Battery Testing, International	$118,323
FY 2025 Total	**$15,960,925**

3. RESEARCH SUMMARIES

Extramural funds garnered by HNEI support programs across a broad range of technologies and end uses. Areas of activity in 2025 included: Hawai‘i Energy Analysis; Hawai‘i Energy Systems; Grid Technology Development; Alternative Fuels including sustainable aviation, biofuels, solar, and hydrogen; Electrochemical Power Systems including fuel cells and battery technology; Advanced Materials; Ocean Energy; and International projects.

In 2025, HNEI conducted or provided leadership for 48 discrete projects, of which approximately 33% are funded or co-funded by the ESDSF. The various activities and key accomplishments under each of these projects are documented in the summaries contained within the eight Appendices of this report. These "Research Highlights" summaries provide a concise description of active HNEI research projects in an easily accessible format. Many contain links to more detailed reports, papers, and descriptions of HNEI's work activities that are also available on its website (https://www.hnei.hawaii.edu/). Updates to projects are available on our website during the year. Sources of funding for each project is also identified within the summaries.

Brief summaries of what is included in each of the eight Appendices and a full listing of their corresponding page numbers follows.

Appendix A: Hawaiʻi Energy Analysis – Community Support

HNEI and its contractors conduct analysis across a range of issues relevant to the community and energy stakeholders. These may result from legislation, but are often selected based on discussions with legislators or state agencies, such as the Hawaiʻi State Energy Office or the Hawaiʻi Public Utility Commission (PUC). They may also arise from interactions with the utility, but only where they address state or PUC interests. During this reporting period, the work relied heavily on models and data developed by HNEI and its primary consulting partner, Telos Energy. The focus of the efforts in this section tends to be analyses related to more immediate problems facing Hawaiʻi's electricity grids and policy makers. The work described in Appendix A1 summarizes HNEI's ongoing support of the Integrated Grid Planning process, while Appendix A2 is a summary of HNEI activities related to management of the Hawaiʻi Energy Policy Forum. With a re-envisioning of the engagement of a broad array of stakeholders, this was a major activity this past year. Appendices A4 and A5 summarize ongoing efforts to support community activities including the Molokaʻi Community Energy Resilience Action Plan (CERAP) .

Appendix B: Hawaiʻi Energy Systems – Future Energy Systems

As part of its work to support the state's progress to achieve very high penetration of renewable energy, HNEI and its contractors continue to assess the impact of the transition to variable renewable generation on the reliability of the islands' grids. While the integration of battery energy storage is enabling reliable grids (resource adequacy), as we transition to high use of variable renewable sources, these studies also provide clear evidence that the need for significant amounts of firm-dispatchable generation will remain. With the aging generation fleet in the Hawaiian Electric system, there will be a need for investment in this area. Appendices B1 and B2 summarize grid reliability issues under conditions of high variable generation and summarizes firm power needs during this transition including an analysis of firm power needs to ensure reliability as HECO retires existing systems. Appendix B3 discusses HNEI's activities to evaluate the proposed repowering using liquefied natural gas (LNG). This analysis was initiated in 2025, but is expected to continue through 2026. Appendix B4 extended the reliability assessments to include the role of multi-day storage technology, while Appendix B5 summarized recent reliability events on the various island grids. Finally, Appendices B6 and B7 discuss issues around future solar penetration including new methodologies to estimate photovoltaic hosting capacity.

Appendix C: Grid Technology Development

With its high penetration of distributed rooftop solar and the pending utility scale solar + storage projects, Hawaiʻi is at the forefront of tackling the problem of renewable energy integration. The geographic isolation of the islands' electricity grids and the rapid growth of renewable generation can make Hawaiʻi's electricity grids susceptible to the effects of intermittent and variable renewable energy sources, but also can serve as ideal test beds for energy solutions for the nation.

HNEI’s portfolio includes a range of grid technology development efforts, ranging from development of new devices and methodologies to deployment and assessment of emerging technologies to better understand their value. Funding for these projects includes the Office of Naval Research and the U.S. Department of Energy, with projects of high relevance to Hawai‘i leveraged with funding from the ESDSF.

Appendices C1 through C7 summarize seven grid or microgrid relevant technology development efforts. These include: development and demonstration of a high efficiency DC microgrid at Coconut Island (C1); demonstration of advanced conservation voltage reduction technology demonstrated at the Marine Corps Base on Okinawa (C2); completion of a virtual power plant project on Maui (C3); a project to better understanding of the dynamic response of inverter dominated power systems (C4); development and deployment of a bidirectional electric vehicle (EV) charging system on the UH campus for optimized ride sharing (C5); and development of new tools for microgrid design (C6 and C7).

Appendix D: Alternative Fuels

Alternative fuels are an important component of Hawai‘i’s efforts to reduce its dependence on imported petroleum and an essential piece for reducing Hawai‘i’s greenhouse gas footprint. Within this topical area, HNEI conducts research, testing, and evaluation that seeks to support the potential for alternative fuels production in Hawai‘i. HNEI projects in this area includes one focused on sustainable aviation fuel production (Appendix D1) and a project initiated this year to assess the viability of various oil seed tree crops (Appendix D2). HNEI is also actively researching the production of novel biocarbon materials using a slow pyrolysis process (Appendix D3), and novel processes for production of solar fuels with primary emphasis on photoelectrochemical hydrogen production (Appendix D4). Appendix D5 provides an update to HNEI’s efforts to provide technical support and fuel (hydrogen) for several electric-fuel cell hybrid buses to be operated by the Hawai‘i Island Mass Transit Agency (Hele-on bus). As noted in the Appendix, HNEI is currently negotiating to transfer the station to NELHA to better support their proposed hydrogen projects.

Appendix E: Electrochemical Power Systems

HNEI has been conducting state-of-the-art research, development, and testing of fuel cell and battery technologies for over two decades. The primary objective of these efforts has been to understand the performance and durability of these electrochemical technologies for both commercial and military applications, including fuel cell powered and electric vehicles, fuel cell powered unmanned (autonomous) aerial and undersea vehicles, and for grid services. Appendix E summarizes the ten distinct projects HNEI conducts in this area. Appendix E1 summarizes a critical ongoing partnership with the Naval Research Laboratory to develop reliable fuel cell power systems for unmanned aerial vehicles. Appendices E2 through E6 describe different efforts for the development of more efficient, lower-cost fuel cells, including both proton-exchange and anion-exchange membrane technologies. Finally, Appendices E7 through E9 describe three projects intended to inform the use of Li-ion energy storage systems; and E10 summarizes a recently initiated effort to develop sodium battery technology. More detailed descriptions of each of these efforts are found in Appendix E.

Appendix F: Advanced Materials

The two projects included in the Advanced Materials appendix are focused on the development of novel techniques for the production of thin-film materials for electronic and solar application low-cost photovoltaics (Appendices F1 and F2).

Appendix G: Ocean Energy

HNEI has been engaged in a cooperative effort between the U.S. Navy and U.S. Department of Energy to support testing of pre-commercial wave energy conversion devices in a real-world operational setting since 2015. The Navy's Wave Energy Test Site (WETS), located offshore from Marine Corps Base Hawaiʻi, is a premier open water test site in the U.S. Appendix G1 summarizes HNEI's support and recent and planned activities at the site. Appendix G2 provides an update of work funded by the U.S. Department of Energy supporting HNEI's efforts to develop its own wave energy technology. The U.S. Department of Energy also recently re-funded the Hawaiʻi Marine Energy Center, which is described in Appendix G3.

Appendix H: International

In 2017, HNEI was the recipient of a multimillion-dollar award from the Office of Naval Research (ONR) titled "Asia Pacific Regional Energy Systems Assessment (APRESA)," intended to facilitate development of clean, resilient, and efficient energy systems throughout the Asia Pacific region. HNEI has leveraged this initial ONR-funded effort to develop a wide range of partnership and new funding sources derived from United States Agency for International Development (USAID) and World Bank programs. Appendix H1 provides an overview of the APRESA award and brief summaries of a number of projects under this award, including ones in Vietnam, Thailand, Indonesia, Cambodia, and the Philippines. This important project ended in May 2025. Appendices H2 and H3 provide additional detail for two of the many projects initiated in Southeast Asia under APRESA. Appendices H4 summarizes a project supported jointly by USAID and ONR. Appendices H5 through H8, describe several of the later projects initiated under APRESA focused on the Pacific Island communities. Finally, Appendix H9 summarized a recent effort supported by the U.S. Department of State focused in the Caribbean area.

APPENDICES

Appendix A: Hawaiʻi Energy Analysis – Community Support

Appendix B: Hawaiʻi Energy Systems – Future Energy Systems

Appendix C: Grid Technology Development

Appendix D: Alternative Fuels

Appendix E: Electrochemical Power Systems

APPENDICES

Appendix E: Electrochemical Power Systems (cont.)

Appendix F: Advanced Materials

Appendix G: Ocean Energy

Appendix H: International

A1: Support of Integrated Grid Planning

Objective and Significance: In 2018, under guidance from the Hawai‘i Public Utilities Commission (PUC), the Hawaiian Electric Company (HECO) initiated the Integrated Grid Planning (IGP) process to determine the types of resources and grid services the utility should invest in over the coming years to meet the goals of legislatively mandated Renewable Portfolio Standards. A Technical Advisory Panel (TAP) was established to provide a third-party, technical, and unbiased review of HECO's modeling and analysis efforts to ensure that the best tools and methodologies are being used. The TAP consists of experts from around the country including members from national laboratories, industry groups, and other utilities. Based on direction from PUC Order No. 36725, *Providing Guidance on the IGP*, HNEI chaired the IGP's TAP from its inception in 2018 to October 2021 and continued to stay engaged in the TAP throughout 2022-2024.

In 2025, HECO released its annual update to the IGP and continued to pursue resource procurement for Stage 3 solar, battery storage, and thermal resources as identified in the plan. In addition, in the second half of 2025, HECO and the PUC initiated the next IGP planning cycle to take place over the next three to four years. HNEI continues to participate in the planning process via the TAP.

Key Results: HNEI's involvement in the IGP and its previous leadership role in the TAP helped to ensure that HECO is moving forward in addressing grid issues related to increasing amounts of renewable energy, which includes both distributed behind-the-meter (BTM) generation, utility-scale generation, and utility-scale and BTM storage. The TAP provides HECO with independent and technical oversight from outside experts, helping ensure that the utility is using industry-accepted methods, inputs, and assumptions.

Key activities of the TAP have focused on assisting HECO in revising their approaches to analysis. These have included advice in regard to the suite of tools and process for integration of those tools and methodologies. HNEI and its subcontractor Telos Energy developed a modeling framework (Figure 1) which was adopted as the IGP modeling framework by HECO. HECO also adopted probabilistic modeling methods first implemented by HNEI to quantify the resource adequacy of future proposed systems and leveraged HNEI's experience when reviewing the proposed energy reserve margins and associated reliability metrics.

Background: By Order No. 35569, issued on July 12, 2018, the PUC opened the instant docket to investigate the IGP process (Docket #2018-0165, Instituting a Proceeding Order No. 30725 to Investigate Integrated Grid Planning). Pursuant to Order No. 35569, the Companies filed their IGP Workplan on December 14, 2018. The Workplan described the major steps of the Companies' proposed IGP process, timelines, and the methods the

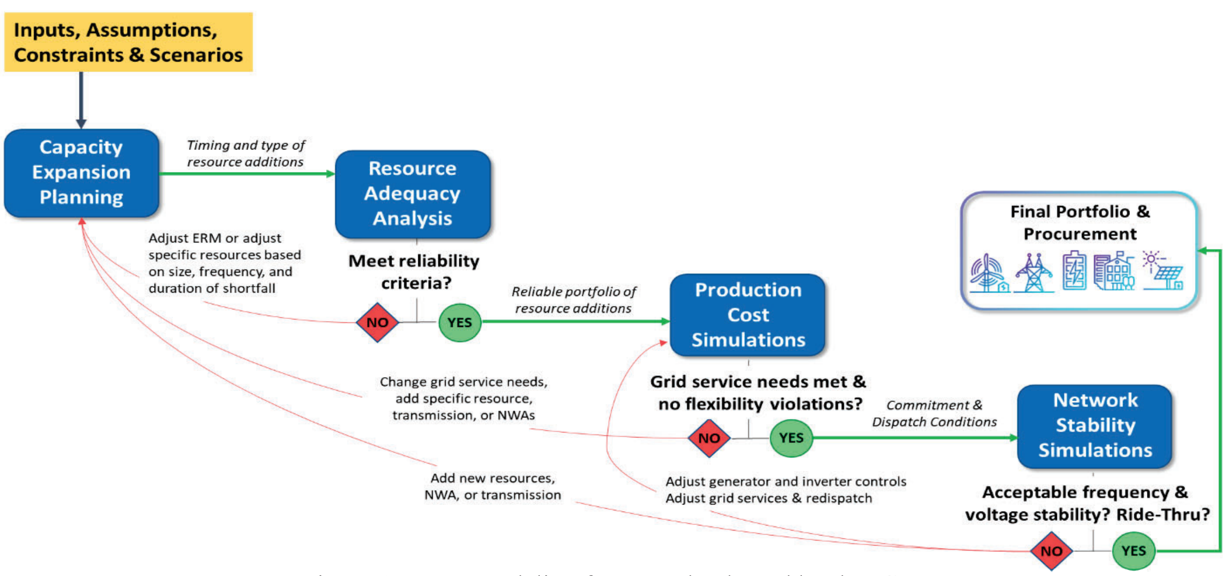


Figure 1. HNEI modeling framework adopted by the IGP.

Companies intend to employ, including various Working Groups. On March 14, 2019, the PUC issued Order No. 36218, which accepted the Workplan and provided the Companies with guidance on its implementation.

PROJECT STATUS/RESULTS: Throughout 2020-2023, HECO continued to develop its IGP, working in consultation with stakeholder groups and the TAP. Throughout that period, HNEI continued to play a very active role in all aspects of the IGP process and TAP providing regular suggestions, independent modeling assessments, and written comments in the PUC docket. At the end of 2023, the final IGP was submitted by HECO, with an annual update filed in 2024.

During 2024, the PUC made final orders on the IGP filing, as well as proposed actions for future IGP planning cycles. The PUC also formally accepted HECO's IGP in 2024, authorizing the utility to proceed with resource procurement activities outlined in the Preferred Resource Portfolio.

In 2025, HECO issued its first annual update to the IGP. This update included revised project timelines, modifications to anticipated replacement resources, and updates to offshore wind planning assumptions in response to evolving policy guidance and emerging federal leasing considerations.

Throughout 2025, HNEI remained actively engaged in the IGP process, focusing on monitoring ongoing developments and supporting the refinement of planning assumptions. The project team reviewed HECO's IGP Annual Update report, along with filings in related regulatory dockets, including those concerning rate design, electric vehicle integration, Stage 3 resource procurements, and the utility's Pathways to Net Zero study. HNEI reviewed these materials to assess consistency with prior system modeling and to identify areas where underlying assumptions, resource capabilities, or forecast conditions may have changed in ways that affect long-term system planning. These reviews ensured a clear understanding of how evolving resource portfolios, load forecasts, and customer programs may influence grid needs in the next planning cycle.

The utility also initiated the next IGP cycle in the second half of 2025, began early scoping activities, stakeholder engagement, and methodological refinements intended to incorporate lessons learned from the initial cycle. As this new cycle progresses, HNEI continues to support the development of robust analytical frameworks, improved data inputs, and enhanced evaluation methods that will guide resource planning decisions through the end of the decade.

In parallel, HNEI conducted detailed assessments of other major planning efforts underway in the state, including the Hawaiʻi State Energy Office's Decarbonization Study and the Alternative Fuels Study. Both analyses provide important context for long-term generation planning, fuel strategy, and the assumptions which will inform future capacity expansion and system modeling exercises.

HNEI also expanded its participation in statewide planning by serving on the advisory panel for the Hawaiʻi Electric Reliability Administrator (HERA), initiated by the PUC in 2025. This role provides additional visibility into system performance, emerging reliability challenges, and new processes that will intersect with the next IGP cycle.

Recognizing the rapid evolution of planning practices nationally, HNEI continued to review IGP methodologies across North America to identify best practices and analytical tools that may be applicable to Hawaiʻi. These insights support ongoing collaboration with HECO to strengthen future planning frameworks.

Looking ahead to the 2026 IGP cycle, HNEI anticipates close engagement in the development and vetting of updated inputs and assumptions—particularly those related to changes in federal tax incentives, offshore wind planning, liquefied natural gas (LNG) considerations, and other emerging factors—which will shape the state's long-term energy strategy.

Funding Source: Energy Systems Development Special Fund; Office of Naval Research

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: December 2025

A2: Hawaiʻi Energy Policy Forum

OBJECTIVE AND SIGNIFICANCE: Through this project, HNEI supports and manages the Hawaiʻi Energy Policy Forum (HEPF) in its mission to advance Hawaiʻi's energy transition by engaging energy stakeholders in fact-finding, analysis, information sharing, and advocacy, thereby enabling informed decisions.

BACKGROUND: HEPF was established in 2002 by the University of Hawaiʻi's College of Social Sciences (CSS) Public Policies Center (PPC) as a collaborative energy planning and policy group consisting of Hawaiʻi's electric utilities, oil and synthetic natural gas suppliers, environmental and community groups, renewable energy industry, academia, and federal, state, and local government.

In its first five years, the Forum was instrumental in promoting reform for the State's utility regulatory agencies (i.e., the Public Utilities Commission (PUC) and the Division of Consumer Advocacy). It also commissioned studies, reports, and briefings to raise the level of dialogue around energy issues for legislators and the general public.

The Forum's mission is to share ideas and information, recommend and advocate policies and initiatives, and promote civic action to achieve a clean, sustainable, and secure energy future for Hawaiʻi. To this end, it conducts research, briefings, forums for informative and deliberative dialogue and policy development, annual legislative briefings, outreach, and public education.

In past years, the Forum regularly sponsored and organized legislative briefings at the Capitol prior to the opening of each legislative session, an annual Hawaiʻi Clean Energy Day event, and sponsors programs to develop reliable information and educate and raise awareness in the community.

PROJECT STATUS/RESULTS: Originally managed by the CSS PPC, the HEPF program was assumed by HNEI. During the initial years of HNEI management, HEPF focused on the development of online informational resources for members and the public focusing on compilation of the significant new federal policies related to energy which includes a description of the policy, policy type, relevant sector, funding opportunities, and managing agency. The legislative briefing in January 2024 focused on gaps in Hawaiʻi's energy infrastructure and how the Infrastructure Investment and Jobs Act could be used to address the most vulnerable aspects of that infrastructure.

Beginning in 2024, but more substantially over 2025, HEPF reconstituted its Steering Committee to identify and prioritize the most pressing energy policy issues facing the state. Through a structured process engaging a broad range of stakeholders, the committee identified a broad list of topics and ultimately selected eight areas that warranted focused analysis and policy development: affordability, reliability, resilience, battery recycling, public education, building performance standards, biofuels, and electric vehicle (EV) infrastructure.

To advance this work, the Forum created eight topic-specific subcommittees and expanded participation to include technical experts, utility and industry representatives, and other stakeholders. Each subcommittee met multiple times throughout the year to develop a scope of work outlining the research needs, objectives, and policy questions for their assigned topic. These scopes now serve as the foundation for a multi-year research plan intended to provide legislators and decision-makers with actionable insights.

Throughout the year, the Steering Committee has remained highly engaged in shaping the research agenda and ensuring that the outcomes directly support policymaking and Hawaiʻi's energy transition.

Three priority topics—*reliability*, *affordability*, and *building performance standards*—were selected for immediate analysis.

- *Reliability* analysis continued efforts previously initiated by HNEI and has already generated significant findings, including the conclusion that 500 MW, or more, of firm capacity will be needed to maintain grid reliability on Oʻahu, even at high levels of intermittent renewables. Complementary to this work, the study initiated efforts to explore firm power fueling options and their impact on costs and emissions.
- On *affordability*, the first phase of work—an analysis of rooftop solar hosting capacity—has

been initiated. Additional evaluation of impacts to affordability is currently out for competitive bid, with project work expected to begin in early 2026.
- For *building performance standards*, an RFP has been issued, and the assessment is also expected to begin in 2026.

The battery recycling subcommittee has also been particularly active and has produced a policy brief detailing both short- and long-term strategies for addressing end-of-life lithium-ion batteries in Hawai‘i.

In January 2026, HEFP will host a legislative briefing where the eight subcommittees will provide status updates, share the research findings of the Forum’s 2025 efforts, and outline the research planned for the coming year. Updates to these efforts will be posted to the HEPF and HNEI websites.

Funding Source: Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu; Jennifer Potter, jmpotter@hawaii.edu

Last Updated: November 2025

A3: Disposal and Recycling of Clean Energy Products in Hawaiʻi

OBJECTIVE AND SIGNIFICANCE: Hawaiʻi's pursuit to become fully renewable by 2045 will produce substantial streams of clean energy product waste over the next 30 years and beyond. In recent years, Hawaiʻi has seen a large uptake in the use of solar photovoltaic (PV) panels and storage lithium-ion batteries (LIB). Due to the risk of explosion and flammability of these batteries at end-of-life (EOL) and the increasing risk of decreased access to ocean shipping, it is crucial for the state to develop a process to manage these waste streams in a manner that is both safe and environmentally sound.

The primary objectives of this work are to: 1) quantify this waste stream; 2) review best practices for disposal, recycling, or secondary use of clean energy products produced; 3) evaluate potential stewardship structures; and 4) recommend structures for laws that could be enacted to implement each stewardship program.

BACKGROUND: The 2021 Hawaiʻi State Legislature passed House Bill 1333 requiring HNEI, in consultation with the Hawaiʻi State Department of Health, to conduct a thorough study on best practices for disposal and recycling of discarded clean energy products in Hawaiʻi. The legislation directed that this study address: 1) the amount of PV and solar water heater panels that will need to be disposed of or recycled; 2) other types of clean energy materials expected to be discarded; 3) the type and chemical composition of those clean energy materials; 4) best practices for collection, disposal, and recycling of those clean energy materials; 5) whether a fee should be charged for disposal or recycling of those clean energy materials; and 6) any other issues the Hawaiʻi State Energy Office and Department of Health consider appropriate. This initial report was submitted to the legislature in December 2022.

Additional follow on studies have continued to add depth to recommendations for the disposal and recycling of clean energy materials in Hawaiʻi. One of the more significant conclusions was that the state should develop an independent stewardship structure/framework that includes a public option for processing EOL LIBs.

PROJECT STATUS/RESULTS: This project's research findings include: 1) determining the material composition of equipment; 2) quantifying the cumulative PV and battery storage installed since 2005; 3) quantifying the projected disposal loading rate of aging materials to 2045; 4) assessment of waste treatment options; 5) assessment of fee options with recommendations; 6) assessment of developing LIB deactivation and/or preprocessing facilities; and 7) identifying the structure and requirements of potential stewardship frameworks to meet Hawaiʻi's unique needs.

As noted in our **initial report**, we found that:

- PV systems are composed of both recyclable materials and trace amounts of precious and toxic metals, while LIBs include trace amounts of metals and minerals, recyclable metals, graphite carbon, plastics, and electrolyte;
- Recycling of these materials require complex pathways including strict storage and shipping requirements;
- It was estimated that, as of 2021, up to 225,000 tons of PV-related clean energy materials was deployed in the state, equivalent to approximately 8.8% of the total municipal solid and commercial and demolition waste generated in a single year (2021);
- Based on a 15-20 year lifespan for PV and 10-15 year lifespan for batteries, the quantity of waste is expected to increase during the latter half of this decade; and
- Covering the cost of off-island disposal for PV panels and LIBs is likely to require one or more revenue-generating schemes.

HNEI's **supplemental report** expanded on initial efforts, adding insights gained from participation in national recycling working groups and interviews with key mainland stakeholders. It highlighted the high costs associated with disposal of LIBs in Hawaiʻi due to shipping risks.

The possibility of enhanced restrictions or outright banning of ocean shipping of EOL LIBs is identified as an existential threat to Hawaiʻi's disposal of LIBs. This report also identified and reviewed several revenue-generating disposal and recycling schemes including waste generator or producer responsibility, state encouraged/assisted recycle, and/or visible fees. It was concluded that no single strategy could be used in Hawaiʻi, but rather a stewardship program that could pursue many in parallel would be needed.

A **follow on study** assessed the state of EOL PV panel and LIB waste streams and highlighted the high costs associated with disposal of LIBs in the state. A lack of any tracking mechanisms caused the working group to estimate accumulation amounts of these products by evaluating import and export data. Unlike certain states on the mainland, Hawaiʻi does not have land-based access to states where processing of EOL PV panels and LIBs are permitted. This requires operators to initially transport these EOL products via ocean transport. The need to deactivate and/or pre-process LIBs on-island was identified as needed to ensure long term access to ocean transport.

In 2025, this project was expanded to include a **comprehensive study** on "waste" EOL lithium batteries that: 1) discusses the overall logistic pathway; 2) discusses insurance requirements of each treatment pathway; 3) presents three frameworks of stewardship structures that manage and fund collection, transport, storage, sorting, treatment, and shipment; and 4) identifies the requirements and pros and cons of shipping batteries "as is" or performing a deactivation treatment prior to shipment. This report was submitted to the Hawaiʻi State Energy Office in support of their recycling working group.

Of the three stewardship structures presented, the one the authors considered the most practical and effective is a state sanctioned non-government aligned professional responsibility organization that can/will oversee a broad portfolio of public/private efforts to manage the capture and processing/ pretreatment of used "waste" EOL LIBs. The working group also recommended a framework that not only oversees/manages the collection, on-island transport, temporary storage, sorting, and deactivation of used "waste" EOL lithium batteries, but is also empowered in law to raise the funds that will be necessary to support the capture and disposal of over 95% of all used "waste" EOL lithium batteries produced in Hawaiʻi.

A request for proposals (RFP) was posted to engage an independent entity to provide a comprehensive analysis of the requirements for each stewardship structure considered, as well as provide mock bills that could be used to empower them in law. The selection process is expected to conclude in December 2025 with a contract executed in January 2026 with an expected completion date of August 2026.

Of the three methods reviewed to pretreat the used "waste" EOL lithium batteries for marine transport, the most practical for Hawaiʻi was felt to be a state-supported wet shredding operation that is easily accessible to the public. The working group also strongly noted that additional privately run treatment/shipping pathways should also be encouraged and supported by the stewardship structure as long as they meet standards acceptable to the stewardship.

This work has led to the publication of the four reports linked below, with another forthcoming, estimated for a Spring 2026 release.

1. ***Recommendations on Waste Management of Clean Energy Products in Hawaiʻi***, December 2022
2. ***Policy Recommendations on Waste Management of Clean Energy Products in Hawaiʻi***, December 2023
3. ***Waste Management of EOL PV Panels and LIBs in Hawaiʻi***, December 2024
4. ***Options for Lithium Battery Disposal in Hawaiʻi: Requirements and Analysis***, December 2025

Funding Source: Energy Systems Development Special Fund

Contact: Michael Cooney, mcooney@hawaii.edu

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A4: Molokaʻi Community Energy Resilience Action Plan

Objective and Significance: In previous years, stakeholders in Molokaʻi developed the Community Energy Resilience Action Plan (CERAP). The CERAP is a first of its kind initiative in Hawaiʻi and represents an independent, island-wide, community-led, and expert-informed collaborative planning process to increase renewable energy on Molokaʻi. HNEI supported the CERAP process by providing technical expertise, data, modeling capabilities, and technical reviews throughout the project.

Background: For many years, Molokaʻi residents have raised concerns regarding power system reliability, affordability, equity, and lack of meaningful engagement. The community felt that previous planning efforts, such as Hawaiian Electric (HECO)'s Power System Improvement Plan (PSIP) and Integrated Grid Planning (IGP), did not adequately incorporate Molokaʻi's priorities or cultural values.

Several renewable energy projects proposed over the past decade—including utility-scale wind and inter-island transmission cables—were ultimately withdrawn due to community opposition. In 2020, when HECO initiated procurement for a new renewable project on Molokaʻi, community organizations requested that the Hawaiʻi Public Utilities Commission (PUC) pause the process until a community-developed planning effort could identify local goals and priorities.

Project Status/Results: Sustainable Molokaʻi and the Molokaʻi Clean Energy Hui began a multi-year, community-driven planning effort (CERAP 1.0), with HNEI providing technical support and analysis. During CERAP 1.0, HNEI advised stakeholders on power system planning, resource screening, and data collection. HNEI also developed a simplified dispatch model to evaluate candidate portfolios of renewable energy and storage resources.

The model allowed stakeholders to test scenarios, visualize impacts on the grid, and understand trade-offs between renewable generation, storage, and fuel use. In January 2023, HNEI met with Sustainable Molokaʻi on-island to refine analysis, increase community accessibility to the data, and identify opportunities related to federal incentives (e.g., Inflation Reduction Act tax credits).

In June 2023, Sustainable Molokaʻi and the Molokaʻi Clean Energy Hui, with HNEI serving as the lead technical partner, completed **Molokaʻi CERAP 1.0** and submitted it to the PUC (Docket #2019-0178). This community-led, island-wide plan provided a roadmap based on ten renewable energy projects to achieve "100% renewable energy for Molokaʻi that is feasible, respectful of Molokaʻi's culture and environment, and strongly supported by the community" (Figure 1).

Building on this foundation, in 2024 and 2025, the project advanced into CERAP 2.0, shifting from conceptual planning to evaluating specific project opportunities. CERAP 2.0 aims to be "a community-driven process to validate, iterate, and refine our community's chosen projects to deliver high-performing renewable energy to serve and secure abundance for current and future generations." The community is now prioritizing projects that align with the roadmap established in CERAP 1.0 and reflect Molokaʻi's core values—particularly sustainability, local benefit, and protection of ʻāina.

HNEI continues to provide technical assistance as a member of the Technical Advisory Group, reviewing project concepts, feasibility considerations, and renewable energy options under evaluation by the Molokaʻi Hui.

Through a structured community and technical review process, the Hui identified two priority renewable energy projects for further feasibility analysis: 1) a floating photovoltaic (FPV) system at the Molokaʻi Reservoir and 2) a pumped hydro energy storage facility.

Both projects were vetted through community meetings and reviewed by technical advisors. Together, the community and the Hui established goals, preliminary design considerations, and a timeline that includes detailed technical feasibility studies during CERAP 2.0.

HNEI participated in multiple project working sessions, providing neutral technical perspective, and reviewing assumptions related to system performance, siting constraints, and grid integration requirements.

CERAP 2.0 is now coordinated with the U.S. Department of Energy's C2C (Communities to Clean Energy) program and the Energy Transitions Initiative Partnership Project (ETIPP), allowing Molokaʻi to align community-driven planning with federal resources, technical experts, and potential funding pathways.

HNEI will continue to support the Molokaʻi Clean Energy Hui as the CERAP 2.0 effort moves into feasibility assessment and project development, and will engage with the PUC and HECO to ensure that community priorities are incorporated into future planning and procurement decisions.

Funding Source: Energy Systems Development Special Fund; Office of Naval Research

Contact: Richard Rocheleau, rochelea@hawaii.edu; Jennifer Potter, jmpotter@hawaii.edu

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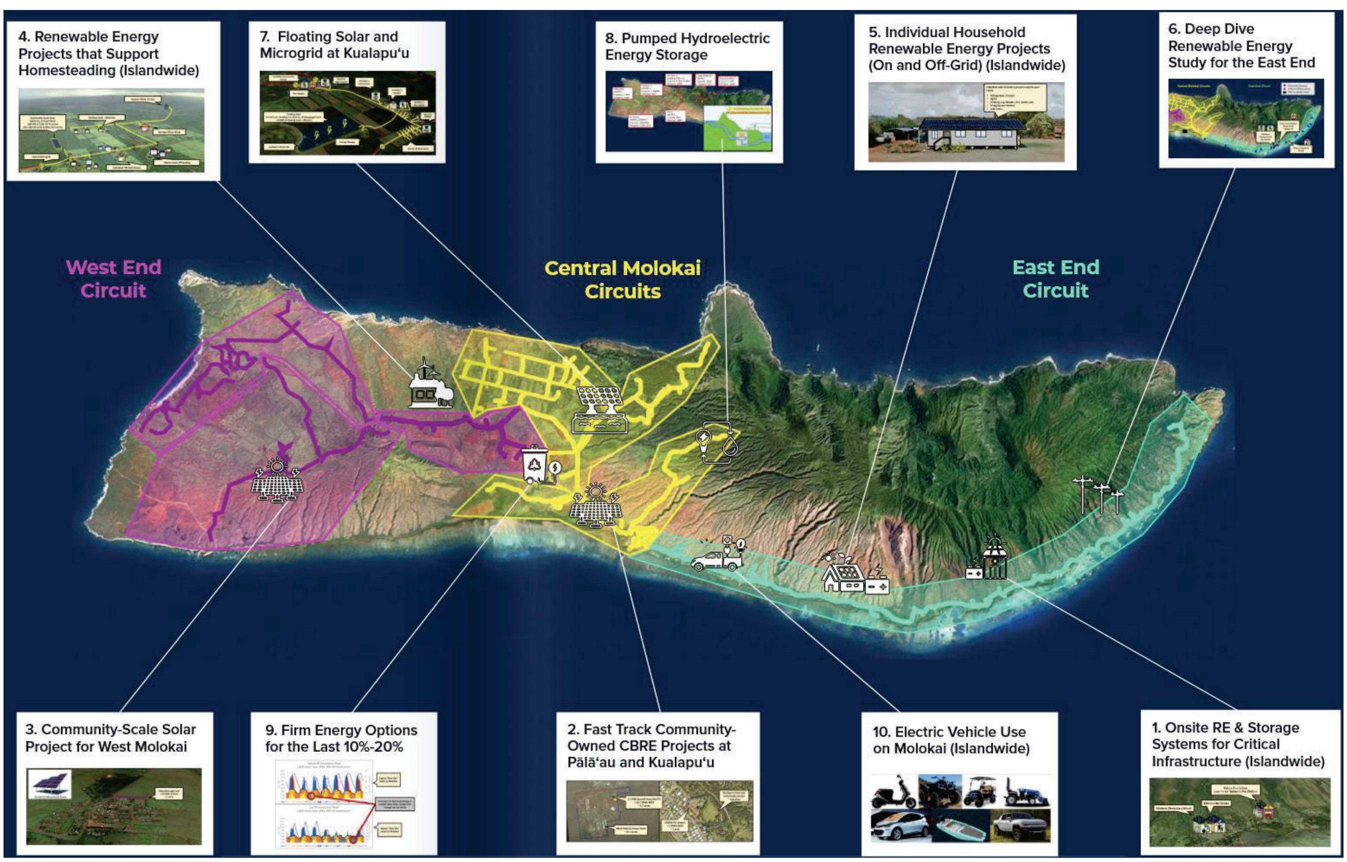


Figure 1. Molokaʻi's Clean Energy Roadmap, excerpted from CERAP 1.0.

A5: Community Outreach and Technical Assistance

OBJECTIVE AND SIGNIFICANCE: The objective of this effort is to provide technical and policy support to community groups across Hawaiʻi, empowering them to engage effectively in the state's energy transition. The project bridges technical expertise with community knowledge and priorities, helping ensure that Hawaiʻi's path toward 100% renewable energy is inclusive, equitable, and grounded in local values.

BACKGROUND: HNEI's community engagement and policy support efforts build upon long-standing collaborations with local organizations and stakeholders committed to advancing clean energy transitions. In coordination with the Energy Transitions Initiative Partnership Project (ETIPP) program, HNEI works with Upcountry Maui communities to develop strategies for resilient, locally relevant energy systems. In parallel, participation in the Energy Equity Hui ensures that underrepresented voices are reflected in statewide policy discussions, while presentations to the Ka Ipu Kukui Fellows provide emerging community leaders with insights into Hawaiʻi's renewable energy goals and opportunities.

These partnerships foster a more collaborative and informed approach to energy planning, aligning technical solutions with the social, cultural, and economic contexts unique to each community. By making complex policy and regulatory processes accessible to community leaders and residents, this work supports informed participation and locally driven energy solutions.

PROJECT STATUS/RESULTS: By supporting initiatives such as the Upcountry ETIPP, Hawaiʻi's Energy Equity Hui, Molokaʻi Clean Energy Hui, the Ka Ipu Kukui Fellows, and the Maui Community Energy Alliance, this work strengthens local capacity to participate in regulatory, policy, and planning processes that shape Hawaiʻi's energy future.

In 2025, HNEI provided targeted technical and policy support to several community initiatives.

Upcountry ETIPP: Conducted webinars explaining the Public Utilities Commission (PUC) processes and energy planning frameworks; supported community understanding of time-of-use (TOU) rates through presentations and written Q&A responses; collaborated with local leaders on data requests and program strategies for Phase 2 of ETIPP; and contributed to the review of ETIPP program results.

Energy Equity Hui: Participated in monthly meetings representing HNEI, contributing technical insights and policy perspectives to discussions on equitable energy access and affordability.

Ka Ipu Kukui Fellows: Delivered presentations on Hawaiʻi's clean energy goals, highlighting pathways and challenges in achieving 100% renewable electricity and encouraging future leaders to engage in policy and planning efforts.

Maui Community Energy Alliance: Supported the Technical Committee in conducting a comprehensive assessment of renewable energy options for Maui, examining the benefits and trade-offs of technologies including, but not limited to, hydrogen, geothermal, and solar PV with battery storage. The findings were synthesized into a public-facing overview, published on the MCEA website, to enhance community understanding and transparency in local energy planning.

Additionally, HNEI provided policy and regulatory support by providing strategic policy advice to community groups considering intervention in PUC dockets, helping them navigate regulatory procedures and develop informed, effective positions.

Through these activities, HNEI strengthened community understanding of Hawaiʻi's energy system and increased local capacity to participate meaningfully in shaping the state's clean energy transition.

Funding Source: Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu; Jennifer Potter, jmpotter@hawaii.edu

Last Updated: November 2025

B1: Clean Firm Resource Needs in Hawaiʻi

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to inform procurement and legislation for both variable and firm renewable energy. The study sought to determine the minimum amount of firm capacity that the system would require at various levels of wind, solar, and storage. The results of this study help frame the ongoing discussions and planning related to the role of dispatchable firm capacity in ensuring reliability of the island's grids. This analysis can also be used to inform decisions on oil-fired power plant retirements, guide procurement of new resources, and quantify challenges of relying solely on variable renewable energy and storage alone for a 100% renewable grid.

KEY RESULTS: The findings of this analysis indicate that on Oʻahu, even with a very high penetration of variable renewable energy and storage, there will be a minimum firm capacity need of 600-750 MW to ensure resource adequacy. In this future clean energy system with high variable renewables, these firm resources would run sparingly but when they do run, it could be for multiple consecutive days at a time. Today, this firm resource is provided by the existing Hawaiian Electric (HECO) oil plants but these plants are aging and becoming less reliable. Some or all of them will need to be retired and replaced with more reliable, more flexible forms of firm generation.

The analysis was extended to each of the other islands with results confirming that firm capacity needs are approximately 50% of peak load for each of the islands. In 2025, the analysis was expanded to assess planned retirements and include actual proposed firm resources, including the 250 MW Stage 3 Waiau Repower project proposed by HECO and the 99 MW Puʻuloa reciprocating engine plant proposed at Joint Base Pearl Harbor-Hickam (JBPHH). This work is described in more detail in Appendix B2.

BACKGROUND: With the deployment of wind, solar, and battery technologies on the island grids over the past ten years, there has been considerable interest and debate on the need for dispatchable firm renewable energy technologies. Dispatchable firm capacity refers to power generation that is available for sustained periods of time, irrespective of weather conditions or the availability of wind and solar resources.

In the 2022 legislative session, the Hawaiʻi State Senate and House of Representatives introduced a series of bills that sought to promote—and in some cases mandate—increased adoption of dispatchable firm renewable energy. These bills also proposed to limit the percentage penetration of any one type of renewable energy source to forty-five percent of all generation for each island, except for geothermal generated energy. While these laws are not in statute today, there is continued interest in firm renewable energy and will likely be a topic of future legislative sessions.

On March 1, 2022, HECO issued a request for proposals (RFP) seeking 500 to 700 megawatts of energy from firm renewable generation resources with a targeted online date between 2029 and 2033. According to HECO, "while solar and wind energy resources will help us hit our near-term clean energy milestones, we'll also need firm renewable resources available for customers when the sun isn't shining, or the wind isn't blowing."

Through the Stage 3 procurement, six projects were selected, representing 700 MW of firm, renewable capable resources. Selected projects are currently in contract negotiations with the utility. The selected projects include a repower of the Waiau plant on Oʻahu, a proposed 250 MW replacement of Waiau steam units with aeroderivative gas turbines, and a 99 MW reciprocating engine plant at JBPHH. More recently, the Hawaiʻi State Energy Office is also proposing to potentially incorporate efficient combined cycle liquefied natural gas (LNG) resources to serve the firm resource needs over the next 20 years.

PROJECT STATUS/RESULTS: Based on the interest in dispatchable firm energy and the broad range of proposed solutions, HNEI developed a simplified screening methodology to estimate the amount of firm renewable capacity that may be required (Figure 1). The analysis was first conducted for Oʻahu and the methodology was later extended to the islands of Kauaʻi, Maui, Molokaʻi, Lānaʻi, and Hawaiʻi. The simplified screening process was verified with robust probabilistic resource adequacy and detailed operational modeling of specific resource mixes.

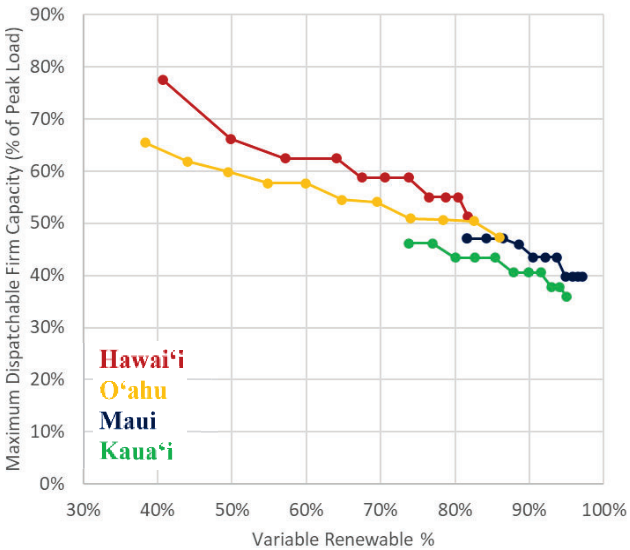


Figure 1. Minimum firm capacity needs by island at increasing levels of variable renewables

Figure 2. Representative high and low solar weeks and the need for firm renewables.

The study team evaluated a number of potential future resource mixes that included up to 90% variable renewable mixes of solar plus storage and wind. These scenarios were then modeled using the screening tool to estimate the amount of firm capacity and energy needed to meet load, assuming maximum technically feasible usage of the solar, wind, and battery energy storage (BESS).

The scenarios and firm capacity resources were modeled using 21-years of historical weather resources (1998-2018) creating dispatch profiles for nearly 184,000 hours of chronological operations. Representative operations, for a high-solar and a low-solar week are shown in Figure 2, illustrating the need for significant firm generation during extended periods of low renewable resources.

The metrics available from the analysis include the amount of curtailment of variable wind and solar resources at each resource level, as well as the utilization (capacity factor) of the firm resources. Particular attention was given to the maximum dispatch of the unit, used to estimate the overall firm capacity need. Operational metrics like number of starts, ramp needs, operating hours, and capacity factor by incremental block were also evaluated.

The estimated firm capacity need, at different levels of variable renewable availability are shown in Figure 1 for each of the major islands as a percent of system peak load. At 70% availability of variable renewables, for example, the firm capacity need ranges from approximately 45% to 60% of peak load. These values can be used as a proxy for the firm renewable resource needs of the system.

Even at very high penetrations of variable renewable energy—as high as 90% of annual energy, there is still a substantial need for firm capacity, as much as 40% to 50% of the system's peak demand. While increased solar, wind, and battery energy storage will not eliminate the need for firm resources, increased deployment will reduce the required fuel usage and have a direct impact on GHG emissions.

In 2024, the HNEI project team updated this analysis to evaluate the required operating flexibility (quick dispatch and ramp rate, for example) of the new firm resources.

The study evaluated three types of firm resources: 1) baseload resources which were unable to cycle on or off or load follow; 2) inflexible resources which had long startup/shutdown times and limited ramp rates; and 3) flexible resources that could start/stop and ramp quickly.

Results of this analysis show that when forecast errors of solar resources are introduced, there may be an increased need for quick-start resources. The impacts of forecast error and generation flexibility will be evaluated in future modeling work for the existing and proposed firm generation resources.

Today, there are limited low or zero emission resources available to provide the required dispatchable firm energy. Generation using biomass or biodiesel would require large amounts of feedstock requiring imported fuels. Geothermal is available on Hawai‘i Island, but is not well characterized for the other islands. While hydrogen and other forms of multi-day storage have been considered for firm capacity, the technical viability and costs of these technologies remain highly uncertain.

This study has been intended to be a screening analysis of the potential firm renewable needs for future Hawaiian Islands' energy systems. During 2025, this work was expanded to include specific options for repowering on O‘ahu, including the Waiau gas turbine repowering, deployment of the Pu‘uloa internal combustion engine (ICE) units, and additional evaluation of long-duration energy storage (LDES). Analysis of the proposed import of LNG has also been initiated. The results of these analyses are included in other summaries within Appendix B.

Funding Source: Office of Naval Research; Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: November 2025

B2: Oʻahu Thermal Retirement and Repower Analysis

OBJECTIVE AND SIGNIFICANCE: HECO's steam oil plants are aging, with more than 70% of HECO's generation fleet now over 30-years old. A significant fraction of that generation, over 700 MW, is scheduled to retire over the next fifteen years (Figure 1). New firm resources must be introduced to maintain reliability as we continue to transition to a solar dominant system.

This study analyzes how much of the existing thermal fleet can be retired while preserving reliability across various portfolios of solar and short duration battery storage, with and without additional firm thermal capacity or long-duration energy storage (LDES). Results will provide context to discuss alternative solutions to maintaining system reliability in the face of a changing Oʻahu generating fleet.

KEY RESULTS: Previous analysis showed that Oʻahu extended will require considerable thermal capacity on the grid to ensure reliability during periods of low renewable resource generation. For example, the retirement of Waiau Units 3-8 would require additional solar, sufficient to provide an additional 2500 GWh per year—beyond the Stage 2 deployments, to maintain reliability if no replacement or repowering takes place. This is much higher than projected solar deployment in this approximately 5-year timeframe. However, the 250 MW proposed repower of Waiau units along with the commissioning of the Puʻuloa plant would be sufficient to allow for the full retirement of the existing Waiau units plus partial retirement of Kahe (Units 1 and 2).

The analysis also found that the addition of Puʻuloa and a partial repower of Waiau could maintain reliability over the next several years while creating optionality for other more fuel efficient combined cycle power plants or liquefied natural gas (LNG) fuel options that may have longer development timelines.

BACKGROUND: Over the past several years, the community has expressed concern over Oʻahu's electric system reliability, driven in part by the retirement of the AES coal plant and the delays and cancellations in the deployment of the Stage 1 and Stage 2 utility scale solar plus storage systems that were expected to help offset the impact of retiring fossil units. As more of the state's aging steam oil fleet approaches the end of its operating life, evidenced by the plan to retire Waiau and Kahe generating units in the coming years, the system must maintain reliability while continuing to adhere to decarbonization plans.

In 2024, Hawaiian Electric (HECO) completed the Integrated Grid Planning (IGP) process and identified the need for up to 500-700 MW of new firm resources, which informed the Stage 3 request for proposals (RFP). HECO is currently proposing a retirement and replacement plan for the Waiau by 2030 and the majority of Kahe between 2035-2040 (Figure 1). Timely action is essential to avoid reliability gaps.

Under the Stage 3 RFP, two firm resources were selected to bolster reliability on Oʻahu: a repowering of Waiau with six new combustion turbines (approximately 42 MW each) and the Puʻuloa reciprocating engine project providing roughly 100 MW at Joint Base Pearl Harbor-Hickam (JBPHH). These projects are currently under review by the Hawaiʻi Public Utilities Commission (PUC).

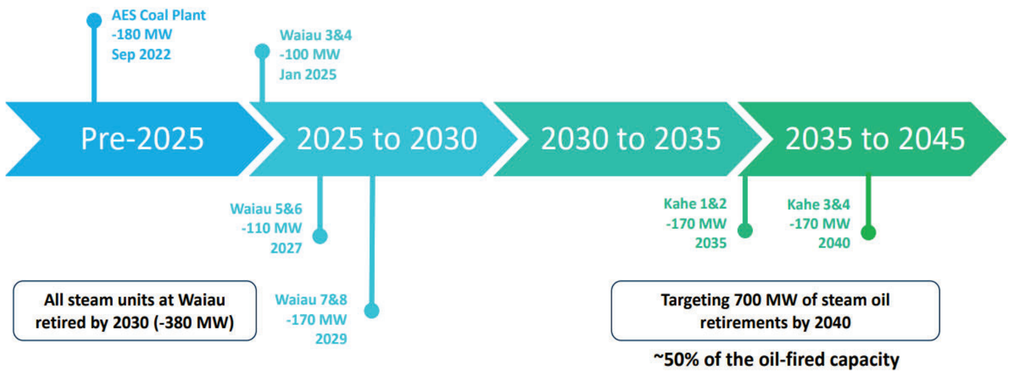


Figure 1. Proposed timeline for Waiau and Kahe power plants.

In parallel, stakeholders have expressed interest in alternatives such as LDES, and how firm resources should fit within broader decarbonization priorities. In addition to the proposed repowering, the Governor and the Hawaiʻi State Energy Office are pursuing a policy of LNG that would necessitate different repowering options for Oʻahu.

PROJECT STATUS/RESULTS: HNEI conducted a series of probabilistic resource adequacy analyses to identify various combination of resources sufficient to maintain reliability during Oʻahu's transition. Analysis utilized detailed power system models incorporating 26-years of hourly historical weather, HECO's 2026 planned maintenance, and simulated forced generator outages to evaluate reliability of a future power system with incremental retirements of the Waiau and Kahe units.

All scenarios modeled included incremental solar and storage buildouts up to 2500 GWh beyond what is expected when the Stage 2 projects are completed.

Three portfolios were evaluated: the incremental addition of solar plus storage only; additional solar and storage plus 350 MW of new combustion turbine and/or reciprocating engine generation, and additional solar plus storage plus 350 MW of 100-hour LDES capacity.

For each portfolio and scenario, the system's loss of load expectation (LOLE), expected unserved energy, and other resource adequacy metrics were calculated to determine the reliability of the system at different stages of retirement. Minimum requirements to ensure loss of load expectation below 0.1-0.2 days per year were identified.

Figure 2 shows LOLE, measure in days per year, for various additions of solar (columns) and different increments of retirement (rows) assuming no repower or new generation is added to the system. The green blocks represent combinations of solar and retirement that exceed current LOLE, while numbers in yellow are approximately at the historical criterion used by HECO in previous planning cycles. Red values (and all boxes below red) represent an unreliable outcome.

	Plant Name	Cumulative Retirement	Current PV+BESS	+500 GWh PV+BESS	+1500 GWh PV+BESS	+2500 GWh PV+BESS
Incremental Retirement		0				
	AES	180				
	W3-4	274	0.21	0.04		
	W5-6	382	0.95	0.24	0.01	
	W7	466		0.91	0.10	0.03
	W8	551			0.47	0.12
	K1	635				0.37
	K2	720				
	K3	805				
	K4	889				
	K5	1024				
	K6	1159				

Figure 2. LOLE at varying levels of renewable buildout and thermal retirements with no additional firm capacity.

Based on these results, if solar and storage are the only new resources added, approximately 2,500 GWh of additional capacity is needed to sustain reliability, corresponding to approximately 70% RPS, if Waiau Units 3-8 are retired. However, even at this full build-out, the system could not reliably retire any Kahe units.

The analysis was repeated with the same solar scenarios plus a build or repower of 350 MW of firm capacity, which could include the proposed repower of Waiau Units 3-8 and the JBPHH (Puʻuloa) units. These results indicate that the proposed repowering provides sufficient reliability through the Waiau retirements, even with no additional solar and storage beyond the Stage 2 projects. Additional simulations, not shown in the tables, indicates that completion of the Puʻuloa plant and a partial repower of Waiau (approximately 100 MW) would meet LOLE criteria and offer potential flexibility for the repower of the remaining Waiau units.

	Plant Name	Cumulative Retirement	Current PV+BESS	+500 GWh PV+BESS	+1500 GWh PV+BESS	+2500 GWh PV+BESS
Incremental Retirement		0				
	AES	180				
	W3-4	274				
	W5-6	382				
	W7	466				
	W8	551				
	K1	635				
	K2	720	0.10	0.01		
	K3	805	0.28	0.08		
	K4	889	1.41	0.31	0.04	
	K5	1024		1.94	0.29	0.08
	K6	1159			1.51	0.36

Figure 3. LOLE at varying levels of renewable buildout and thermal retirements with 350 MW thermal capacity additions.

Alternatively, as shown in Figure 4, 350 MW of 100-hour LDES could provide grid reliability through the Waiau retirement without new generation. With LDES in place, the system could reliably retire Waiau Units 3-8 with completion of the Stage 2 solar and storage. Additional discussion of the potential for use of LDES is included in Appendix B4.

	Plant Name	Cumulative Retirement	Current PV+BESS	+500 GWh PV+BESS	+1500 GWh PV+BESS	+2500 GWh PV+BESS
Incremental Retirement		0				
	AES	180				
	W3-4	274				
	W5-6	382				
	W7	466				
	W8	551	0.01			
	K1	635	0.42	0.05		
	K2	720		0.58	0.03	
	K3	805			0.24	0.03
	K4	889				0.26
	K5	1024				
	K6	1159				

Figure 4. LOLE at varying levels of renewable buildout and thermal retirements with 350 MW 100-hour LDES.

This analysis indicates that, under HECO's current retirement schedule, solar and storage are unlikely to be deployed in sufficient quantity or on the timeline necessary to maintain reliability and resource adequacy to allow the retirement of the Waiau units. This shortfall underscores the critical importance of repowering Waiau, as delaying a decision on technology, scale, or fuel type increases the likelihood of near-term reliability challenges and constrains the system's operational flexibility.

A repowering strategy of approximately 250 MW at Waiau, combined with the development of the Puʻuloa plant, would provide sufficient firm capacity to enable retirement of Waiau's existing units and could also support the potential retirement of Kahe Units 1 and 2, depending on actual load growth.

Given the later timeframe proposed for the Kahe retirement, a partial repower of Waiau could meet near term reliability needs while creating additional options for firm generation that requires longer lead time to develop. For example, repowering the remaining Waiau with a high-efficiency combined cycle configuration would reduce reliance on Kahe and other aging, lower-efficiency generators, lower fuel consumption and emissions, and potentially extend the remaining useful life of the Kahe units by shifting them into more limited operational roles. This option, as opposed to a full repower, may also make conversion of some units to LNG more cost effective, while preserving near term reliability.

While Hawaiʻi would realize meaningful reliability benefits under any capacity additions or fuel choice, the system will only capture these advantages if decisions are made promptly and implementation milestones are met. Timely action remains essential to ensuring that repowering efforts strengthen system reliability, reduce overall emissions, and align with the State's long-term transition objectives.

Funding Source: Office of Naval Research; Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: November 2025

B3: Analysis of LNG Fuel Options in Hawaiʻi

OBJECTIVE AND SIGNIFICANCE: Recent analysis by the Hawaiʻi State Energy Office (HSEO), combined with policy direction from Governor Green, has prompted an active policy and stakeholder discussion regarding the potential role of liquefied natural gas (LNG) in Hawaiʻi's energy transition. The State's study concluded that LNG may offer both economic and environmental benefits and outlined a proposal to repower existing generating units and develop LNG import infrastructure and new or repowered generation on an accelerated timeline.

To support informed decision-making on these issues, the Hawaiʻi Energy Policy Forum (Appendix A2) managed by HNEI is convening key legislative leaders, HSEO, and a diverse group of electric sector stakeholders to facilitate discussion of the potential role LNG should in the State's energy future. In parallel, HNEI has initiated a technical review of the related HSEO study and produced independent quantitative analysis to identify critical issues related to the report's assumptions and underlying drivers that may affect the projected costs and benefits of LNG deployment in Hawaiʻi.

KEY RESULTS: HNEI's analysis indicates that, under specific sets of assumptions and market conditions, LNG has the potential to provide economic benefits for Hawaiʻi's ratepayers and to reduce emissions relative to existing petroleum-based fuels. These outcomes are highly sensitive to fuel-price dynamics, global economic factors, infrastructure timing, post-2045 firm power assumptions, and system-level interactions, underscoring the need for careful evaluation as well as utilizing pragmatic assumptions.

BACKGROUND: In January 2025, HSEO released the "Alternative Fuels, Repowering, and Energy Transition Study," which evaluated multiple fuel options for the electricity sector and concluded that developing LNG import infrastructure and transitioning certain generators to LNG would best support the State's cost and emissions reduction goals. The study found that "LNG emerged as the near-term fuel with the potential to cost-effectively reduce the State's greenhouse gas emissions during the transition to economy-wide decarbonization in 2045, but more analysis is needed to quantify a range of potential benefits and to identify how those benefits can be maximized to residents at the appropriate level of infrastructure buildout." Building on this assessment, Governor Green signed a Clean Energy Memoranda to expand collaboration with JERA, a Japanese energy developer, and proposed a two-billion-dollar investment in LNG import facilities and new power generation assets.

PROJECT STATUS/RESULTS: Given these developments, HNEI conducted an independent technical review of the HSEO study in the second half of 2025 and developed alternative grid modeling to test sensitivities related to fuel costs, infrastructure timelines, renewable deployment, and system reliability risks.

HNEI's analysis is intended to provide a detailed and impartial review of the assumptions underpinning HSEO's "Alternative Fuels, Repowering, and Energy Transition Study," with the goal of supporting informed dialogue and decision making regarding the potential adoption of LNG in Hawaiʻi's electric sector. To meet this objective, HNEI has developed a comprehensive and flexible analytical framework capable of evaluating a wide range of LNG transition pathways and quantitatively evaluating the assumptions that most strongly influence projected benefits.

The HNEI technical analysis is based on a suite of hourly production-cost simulations covering the period from 2030 through 2045. These simulations model system operations under various load, fuel, repowering, and renewable-energy trajectories. Complementing this modeling foundation is an interactive scenario tool that allows decision makers to adjust variables such as delivered fuel prices, repowering technologies (combined cycle and combustion turbines), fuel options for existing and future units (LNG, low sulfur fuel oils (LSFO), or ultra-low-sulfur diesel (ULSD)), the sequencing and timing of repowering activities, and the capital cost assumptions for new LNG and power generation infrastructure. This combination of high-resolution operational modeling and adjustable scenario parameters enables exploration of a diverse set of system configurations and fuel-mix strategies.

During this process, HNEI identified several assumptions within the HSEO study that the HNEI team believes merit more comprehensive examination and community discussion before significant policy or investment decisions are made. These include:

- The feasibility of completing LNG import infrastructure and Phase 1 repowering activities by 2030;
- Reliability risks associated with delays in repowering generating units;
- Uncertainty regarding the relative price stability of LNG compared to oil in global energy markets;
- Development and load forecasts;
- Potential cost escalation for construction, repowering projects, and LNG import facilities; and
- Post-2045 fuel assumptions.

HNEI is currently coordinating with HSEO, the Governor's Office, legislative committees, the Division of Consumer Advocacy, Hawaiian Electric, and other stakeholders to support an informed and technically grounded discussion at the upcoming Hawaiʻi Energy Policy Forum briefing.

HNEI will publish its findings and a summary of stakeholder perspectives in early 2026 to support ongoing deliberations about Hawaiʻi's energy transition strategy.

Funding Source: Office of Naval Research; Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: November 2025

B4: Multi-Day Energy Storage for O‘ahu Reliability

OBJECTIVE AND SIGNIFICANCE: In 2025, HNEI and Telos Energy conducted a study examining the extent to which long-duration energy storage (LDES) could serve as a clean firm capacity resource to ensure reliability in O‘ahu. This work was pursued in part due to growing interest at the Hawai‘i Public Utilities Commission to investigate use cases for long duration (e.g. 100-hour) storage.

KEY RESULTS: Results from this analysis show that a 100-hour battery storage system can provide a moderate contribution of firm capacity of approximately 50% to 60% effective load carrying capability (ELCC) at renewable portfolio standard levels of 45%, 55%, and 70%. The finding that the ELCC of 100-hour storage remains relatively constant as solar and short-duration storage increases is consistent with previous HNEI/Telos work showing the need for resources capable of dispatching for long periods of time to maintain reliability even at high RPS percentage levels. While these results show reliability benefits of 100-hour LDES relative to existing 4-hour battery energy storage systems, it is less than similar deployment of firm generation such as combustion turbines (CT). These results were presented at the Energy Systems Integration Group (ESIG) Forecasting & Markets workshop in Nashville, TN in June 2025 and at the IEEE Power & Energy Society general meeting in Austin, TX in July 2025.

Modeling indicated that 350 MW of 100-hour storage can enable retiring 250-360 MW of existing fossil fuel resources while maintaining a 0.1 days/year loss of load expectation (LOLE) criteria. This indicates the potential for multi-day storage to complement the deployment of planned solar and storage resources, however, procurement decisions still require evaluation of costs and impact on other generations sources, relative to new or repowered oil-fired generation.

Total carbon emissions were compared for the cases with 100-hour storage or new oil-fired combustion turbines. Results indicated that an addition of 350 MW of 100-hour storage results in 1.5-2% increase in annual oil consumption for electricity generation (140,000-280,000 barrels of oil) relative to a scenario with only solar and storage additions. In contrast, an addition of 350 MW of new oil-fired combustion turbines results in a 3-4.4% decrease in annual oil consumption (200,000-326,000 barrels of oil) due to the improved efficiency of new combustion turbines relative to the existing oil-fleet.

BACKGROUND: LDES technologies have seen growing interest across the energy industry, for their potential to provide firm capacity and reduce the need for new generation capacity. Both renewable and short (e.g. 4-hour) duration storage resources have declining firm capacity values at high penetration due to saturation in low-resource risk periods.

To date, LDES resources have had limited assessment to determine their firm capacity value using traditional resource adequacy and ELCC methods. This is largely attributed to the low level of new builds for existing technologies (e.g., pumped storage hydro and compressed air) and the nascent state of new technologies (e.g., iron-air batteries). Additionally, while not ubiquitous across LDES technologies, the long duration technologies tend to have lower round-trip efficiency, reducing their economic viability.

However, demand for additional firm capacity, brought on by renewed load growth coupled with retention of the energy storage investment tax credits, appears to have buoyed the interest in deploying LDES in the United States. With Hawai‘i's aspirations to reduce dependency on imported fossil fuels, LDES needs to be evaluated for the islands to determine its ability to contribute to the State's long-term reliability.

PROJECT STATUS/RESULTS: In this work, the HNEI/Telos team conducted a probabilistic resource analysis to determine the incremental retirements enabled by deploying 100-hour storage on O‘ahu. In addition, the ELCC of the 100-hour storage was calculated to compare against other dispatchable resources such as 4-hour storage and new combustion turbines. The HNEI/Telos team used Telos Energy's PLEXOS model of O‘ahu to perform hourly chronological production cost and probabilistic resource adequacy simulations of the island system assuming increasing RPS levels. This approach allows tracking of long-duration storage asset state of charge where charging and discharging cycles may be days or weeks apart. By complementing the production cost modeling with resource adequacy assessments, the ability of multi-day storage to ensure system adequacy under varying renewable energy and generator outage conditions is also considered.

Due to the nascent nature of multi-day storage, there are limited standard modeling approaches and limited or no real-world historical operating data. Therefore, an exploration of different modeling techniques was conducted to balance simulation realism with expected unit performance so that the firm capacity values and reliability benefits of multi-day storage could be properly assessed. Challenges in the modeling included:

1. *Low round-trip efficiency*: Standard modeling methods struggle to reflect multi-day storage operations due to low efficiency (40%) biasing the model to not charge the assets;
2. *Long durations and short optimization windows*: Energy system modeling uses a timestep wherein unit commitment and dispatch decisions are made. It is common to evaluate a single day plus one day ahead, whereas multi-day LDES assets may need to be charged well in advance of an event, limiting the usefulness of advanced forecasting; and
3. *Real-world operational considerations*: Limited information from grid-scale application of multi-day storage means there is little information to replicate operations to reflect how these assets perform in real-world environment.

Several LDES scheduling analyses were evaluated prior to performing the resource adequacy analysis to determine how to best model multi-day storage. Based on multi-day storage scheduling analysis and discussions with Form Energy, it was determined that multi-day storage assets will likely operate primarily as long-term reliability assets with a small amount of energy allocated to day-to-day and hour-to-hour fluctuations. This means restricting the discharge of the asset to primarily reduce unserved energy (load shed) risks. Once the multi-day storage scheduling approach was established, the team assessed the capability of multi-day storage to enable retiring existing oil-fired capacity.

Following selection of the LDES scheduling approach, the final step in the assessment was to perform a retirement analysis to identify how much existing oil-fired capacity on Oʻahu could be retired assuming the addition of 100-hour storage to the grid at increasing RPS levels. The modeling efforts investigating near-term retirement decisions are not intended to supplant HECO plans for replacing the existing Waiau units. Instead, they are intended to inform the potential to utilize multi-day storage in place of new generation to maintain reliability.

The reliability improvement with the addition of 350 MW of 100-hour storage was calculated at various levels of solar + storage additions corresponding to 45%, 55%, and 70% RPS levels, corresponding to an expansion of utility-scale solar and 4-hr storage to 440 MW, 880 MW, and 1,320 MW. For context, today, Oʻahu has approximately 220 MW of utility-scale solar and 4-hour storage.

Figure 1 shows the LOLE for Oʻahu in days/year for six scenarios of retirement and solar + storage additions. The analysis shows that solar and storage alone can enable the retirement of Waiau 8 but only is if existing solar + storage is expanded by 500%.

	Plant Name	Cumulative Retirement	45% RPS	55% RPS	70% RPS
Incremental Retirement		0			
	AES	180			
	W3-4	274	0.04		
	W5-6	382	0.24		
	W7	466		0.10	
	W8	551		0.47	0.12
	K1	635			0.37
	K2	720			
	K3	805			
	K4	889			
	K5	1024			
	K6	1159			

Figure 1. Loss of load expectation for Oʻahu with incremental oil capacity retirements at increasing RPS levels with only solar + storage additions.

Figure 2 shows the incremental retirements enabled by adding the multi-day storage to Oʻahu at the same RPS levels as shown in Figure 1. In this analysis, the LDES scheduling was selected to ensure that the multi-day storage acts as a reliability asset, but does not overly constrain it to only operate during emergencies.

	Plant Name	Cumulative Retirement	45% RPS	55% RPS	70% RPS
Incremental Retirement		0			
	AES	180			
	W3-4	274			
	W5-6	382			
	W7	466			
	W8	551			
	K1	635	0.05		
	K2	720	0.58	0.03	
	K3	805		0.24	0.03
	K4	889			0.26
	K5	1024			
	K6	1159			

Figure 2. LOLE for O'ahu with incremental oil capacity retirements at increasing RPS levels with 350 MW of 100-hour storage.

As shown in Figure 2, the addition of 350 MW of 100-hour storage to the O'ahu grid enables 250-360 MW of incremental oil capacity retirements relative to the case with only solar and 4-hour storage.

The largest impact from the multi-day storage is at the 45% RPS level, where 360 MW of retirements are enabled. The ability for 100-hour storage to reduce the LOLE is less at higher RPS levels. This is due in part to the risks of back-to-back generator outages. In this case, energy limited resources are depleted without time to recharge.

Finally, the model results were summarized with an effective load carrying capability (ELCC) metric commonly used resource planning. For this analysis, the ELCC of 350 MW of 100-hour storage was calculated at the same RPS levels shown in Figures 1 and 2. For comparison to a new fuel-based unit, the ELCC of new oil-fired combustion turbines was also calculated.

Figure 3 shows the ELCC of 100-hour LDES and a similar repower using combustion turbines. This shows that 100-hour storage maintains an ELCC above 50% even at high solar penetration. Relative to new combustion turbines, 100-hour storage enable fewer retirements of existing oil-fired capacity due to its lower ELCC value.

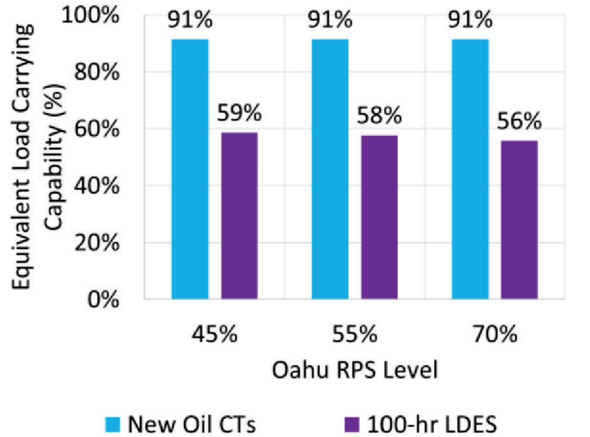


Figure 3. Equivalent Load Carrying Capability (ELCC) of 100-hour storage versus new oil combustion turbines on O'ahu at increasing RPS levels.

It should be noted that the resource adequacy analysis indicates that 100-hour storage deployed on O'ahu at the various RPS levels results in a net increase in oil consumption. This is attributed to the low round-trip efficiency (40%) of the multi-day storage assessed. Even at a relatively high penetration of renewables, the multi-day storage resource requires increased oil generation to charge the resource to maintain state of charge targets and be ready to operate during reliability events. This contrasts with the effect of adding 350 MW of new combustion turbines, in which case the total system oil consumption is reduced. This reduction is attributed to the significant efficiency improvements of new combustion turbines relative to existing oil steam turbines.

HNEI continues to monitor the development of LDES technologies, which includes 100-hour batteries, and further its technical capabilities in modeling these assets to provide guidance to industry, the PUC, and stakeholders. The end goal is to provide a deeper technical understanding of how to model LDES and how to include it in future assessments of both economic and reliability plans.

Funding Source: Office of Naval Research; Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: November 2025

B5: Recent Reliability Challenges

OBJECTIVE AND SIGNIFICANCE: HNEI regularly monitors grid operations and hourly generation data provided in PUC dockets and is providing independent reviews of reliability events. This analysis has shown that, while Hawaiʻi's power grids face reliability challenges, the transition to renewables is generally not to blame. Over the past year, higher than normal failures at oil-fired power plants have challenged grid reliability on Oʻahu and Hawaiʻi Island, but new solar and storage systems are proving a valuable reliability asset.

KEY RESULTS: While recent reliability events on Oʻahu occurred during a period of cloudy weather with low solar and wind generation, the root cause of the rolling blackouts was not the performance of the renewables, but rather unexpected outages of several of the utility's oil-fired generating plants at a time when others were offline for maintenance. A period of challenging operations in July 2024 showed that new solar and storage resources are an important contributor to grid reliability.

In 2025, these results were presented at the IEEE Power & Energy general meeting on a panel presentation about managing grid reliability on island power systems.

BACKGROUND: In the early winter and spring of 2024, the electric grids on Oʻahu and Hawaiʻi Island experienced rolling blackouts. Unlike normal customer disruptions caused by damage to transmission or distribution lines, these events occurred due to island-wide generation supply shortages. Simply stated, there was not enough generation or stored energy available on the islands to serve the demand.

This occurred four times in 2024, once on Oʻahu (January 8th) and three times (January 30th, February 13th, and April 15) on Hawaiʻi Island. The Oʻahu power grid had another close call on July 31, 2024 when calls for conservation were initiated by the utility due to depleted reserves, however, rolling blackouts were avoided and customers were not impacted.

While Maui customers have not experienced rolling blackouts recently, their grid is also operating under very limited reserves. According to Hawaiian Electric (HECO), Maui has "high future risk with insufficient margins, no room for unexpected events." With pending oil-plant retirements in 2027-2029, significant reliability concerns are likely if new resources cannot be brought online.

These types of reliability events, referred to in the power industry as resource adequacy shortfalls, are exceedingly rare on the U.S. mainland, where grids are larger and more interconnected. Across much of North America, utility and grid planners try to ensure these types of system-wide supply deficiencies occur no more frequently than once every ten years. While still rare in Hawaiʻi, they do occur more often because the island's grids are smaller and isolated from neighbors. On Oʻahu, for example, planners design to expect no more than one shortfall every four years or so.

In 2025, there was a notable improvement in grid reliability across all islands, with no involuntary load shed events occurring on Oʻahu, a slight decrease in generator forced outages, and Hawaiʻi Island is returning its generating fleet to normal service for the year.

PROJECT STATUS/RESULTS: Over the past year, HNEI has been analyzing utility operating data, including hourly load and generation by power plants. In doing so, the project team tracks generator performance, outage rates, maintenance schedules, and operating reserves.

This analysis showed that, while the January 8th outages on Oʻahu occurred during a period of cloudy weather with low solar and wind generation, the transition to renewables was not to blame. Instead, the root cause of the rolling blackouts was unexpected outages of several of the utility's oil-fired generating plants at a time when others were offline for maintenance. During the event, HECO lost significant generation capacity in quick succession due to flooding at the Waiau power plant and failures at the H-Power waste-to-energy plant. Results of this analysis were written in an Op-ed in a local news outlet.

The July 31st reliability event was caused by multiple generator outages occurring in quick succession at HECO's three largest power plants. Similar challenges are being experienced on the other islands. For example, when rolling blackouts were required on the Big Island on January 30th, approximately 57% (160 MW of a total capacity of 280MW) was out of service, due to operational issues at the Hamakua Energy Plant, ongoing low generation from the Puna Geothermal plant, and other outages and maintenance needs across the island.

Whether due to age alone or a combination of other factors, the utility's generators are facing increasing maintenance needs and more frequent mechanical failures. The decreasing reliability of these plants, as measured by how often they become unavailable without warning, has been a significant and increasing problem for the past several years. **Error! Reference source not found.** shows the percentage of firm generation, weighted by capacity, which was on unexpected, forced outage each year since 2007. On O'ahu this "weighted forced outage" rate has increased from below 5% in 2007 to 20% in 2023. However, recent trends in 2024 and 2025 show availability of HECO's generating fleet is starting to improve.

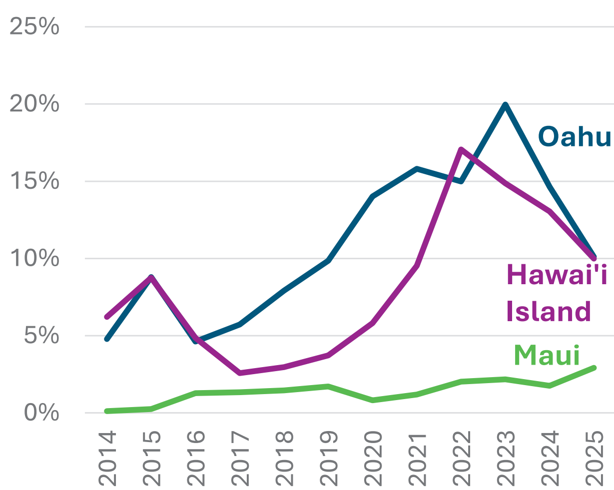


Figure 1. Increasing unavailability of HECO firm generators due to unplanned outages.

However, there are also emerging reliability risks that need to be considered, related to the operations of new solar and storage resources. As the inverter-based resources on O'ahu continues to grow, the potential impact of improper or poorly tuned inverter controls has the possibility of taking resources out of service, or potentially even leading to large grid disturbances. An example of this occurred in late August when one of the new solar + storage projects was taken offline due to reliability concerns (**Error! Reference source not found.**).

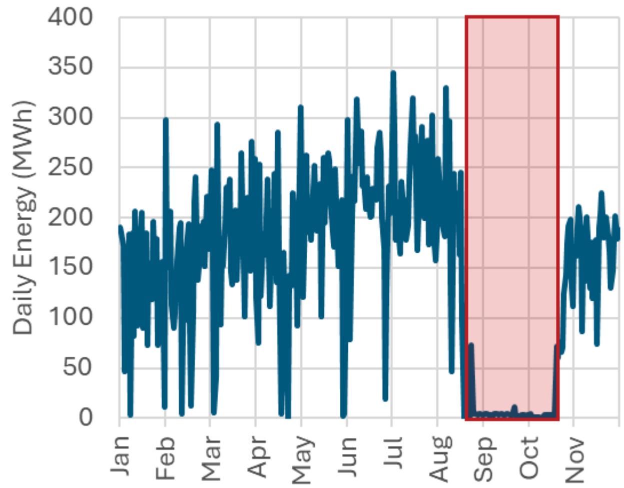


Figure 2. Hybrid solar and storage resource taken offline during August to October 2025.

HNEI will continue to monitor grid operations and reliability across the Hawai'i power grids and share its findings with the PUC, the utility, and the interested public. The project team will also look to share its findings with the broader power industry as Hawai'i's experience offers valuable lessons for other regions as they transition to cleaner energy sources.

Funding Source: Energy Systems Development Special Fund; Office of Naval Research

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: November 2025

Hawai‘i Natural Energy Institute Research Highlights

Appendix B: Hawai‘i Energy Systems – Future Energy Systems

B6: Granular Hosting Capacity Methods

Objective and Significance: HNEI's Grid System Technologies Advanced Research Team (Grid***START***) explored ways to increase distributed photovoltaic (DPV) penetration, specifically for feeders that are reaching their hosting limits. This project assessed a granular hosting capacity (HC) methodology that assigned HC limits to individual service transformers and assessed the benefits of inverter volt-var controls to show the potential for DPV expansion without major grid upgrades.

Background: Hawaiian Electric (HECO) currently determines DPV HC at the primary feeder level by aggregating all loads and PV at the service transformer and evaluating only the primary distribution voltage. While effective for broad assessment, this approach can obscure available capacity and restrict new DPV projects as feeder limits are reached.

Project Status/Results: Key limitations addressed by included:

1. Feeder-wide HC limits allow "bad actor" transformers with low HC to effectively reduce capacity for other transformers with higher HC;
2. Fixed secondary voltage drop assumptions (typically 2.5%) do not reflect actual variations, potentially limiting or overestimating hosting space; and
3. Aggregation prevents accurate modeling of volt-var response for DPV inverters, now required for new PV systems in Hawai‘i.

This study used HNEI's Maui Meadows feeder model, detailing the low-voltage "secondary" networks down to the customer level. The granular method assigned HC limits to each transformer, avoiding low HC transformers from limiting the HC of other transformers on the feeder. Voltage was checked at each customer connection, removing the need for HECO's secondary voltage-drop assumption, and volt-var impacts were evaluated locally. A stochastic framework placed PVs at each customer incrementally to simulate thousands of DPV build-out scenarios and configurations.

Granular HC modeling increased total feeder DPV hosting by 34% (+891 kW) over the HECO-defined baseline for Maui Meadows, supporting 3,538 kW PV unevenly distributed, vs. the feeder-level cap of 2,647 kW. Adding volt-var controls for new PV systems raised HC an additional 3%. If all PV systems, including those of legacy net energy metering (NEM) customers, were volt-var capable, total capacity would rise by an additional 6%. The proposed granular method can safely unlock more DPV integration without any physical infrastructure changes, though detailed secondary modeling remains resource-intensive and is not readily available. Utilities could focus secondary-level models on high-value or near-limit feeders.

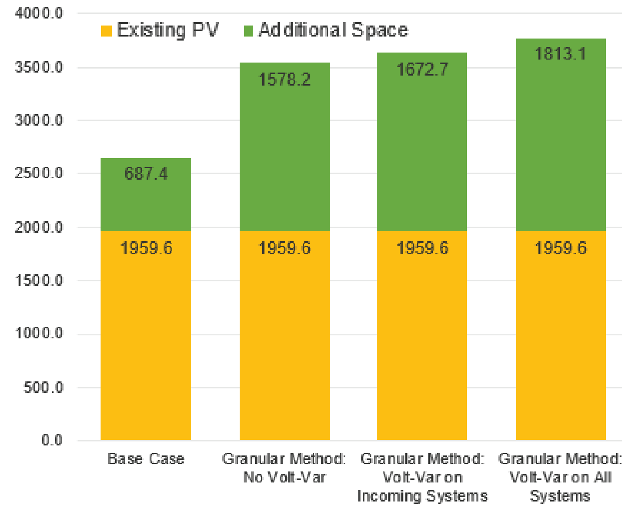


Figure 1. Summary of HC growth (in kW) with advanced modeling methods.

Nearly half of HECO's existing DPV capacity was installed under the original full-retail NEM program. On O‘ahu, these NEM subsidies currently cost non-NEM customers approximately $70 million per year more than if NEM customers were billed under the current DER program. Transitioning NEM customers to a revised DER structure could free up those funds to expand DER HC. However, there is currently no plan to transition NEM agreements to the current program, and such a transition may face significant legal scrutiny, as seen in other jurisdictions.

Additional analysis to incorporate the value of local batteries has been initiated. Preliminary results indicate that storage combined with DER can further increase hosing capacity, by significant amounts. This work is continuing.

Funding Source: State of Hawai‘i

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

B7: Validation of Synthetic Historical Solar Data on O‘ahu

OBJECTIVE AND SIGNIFICANCE: As Hawai‘i's power system increasingly relies on weather-dependent generating resources like solar photovoltaics (PV), accurate solar production profiles are of particular importance for estimating power purchase agreement (PPA) levels and for conducting resource adequacy assessment. With the high penetration of battery energy storage systems on O‘ahu, accurate estimation of solar is critical to ensure sufficient availability to meet peak demand.

In this project, the HNEI/Telos Energy team used 25-years of solar data from the National Solar Radiation Database (NSRDB) to produce O‘ahu site-specific solar production profiles for the existing utility-scale solar plants. The electricity production was calculated based on the plant specific configurations and location-specific modeled weather parameters. These modeled solar profiles were then compared against the actual operations of five existing solar plants using hourly generation data provided by the Hawaiian Electric Company.

KEY RESULTS: This analysis compared modeled solar production to reported solar production for the five utility-scale solar plants that have been operational for multiple years on O‘ahu.

Results indicate that the synthetic profiles overestimate solar production at both the monthly and annual levels for four of the five plants. Figure 1 presents the annual energy of simulated and reported solar production averaged across each year the plant was operational.

Plant Name	Plant Capacity (MWac)	Avg Simulated Annual Energy (GWh)	Avg Actual Annual Energy (GWh)	% Difference
Kawailoa Solar	49	122.1	75.8	61%
Waipio PV	46	109.7	84.6	30%
Lanikuhana Solar	14.7	34.3	28.8	19%
West Loch	20	49.0	38.0	29%
Waianae	27.6	63.6	62.8	1%

Figure 1. Average annual output for simulated and actual plant production.

Excluding Kawailoa Solar[1], for which unique curtailment constraints may apply, the synthetic data overestimated solar production by between 1-30% over the 2019-2023 period. These results are preliminary, but warrant further investigation using detailed plant performance and ground-based measurements.

Other operating issues, such as outages or panel misalignment (for single axis tracking systems), may contribute to the differences. Initial discussions with developers of the NSRDB dataset revealed that the synthetic solar data struggles to capture the development of clouds over a region like O‘ahu or other the Hawaiian Islands. Small islands, in general, present a challenge where microclimatic conditions can be difficult to replicate using meteorological re-analysis methods employed by National Renewable Energy Laboratory (NREL) to produce the NSRDB.

Additional information on plant specific performance factors and site-specific ground-based measurements are being pursued to complete the validation.

BACKGROUND: In 2020, the HNEI/Telos team conducted a preliminary validation of NSRDB based solar plant simulations using production data from five existing solar plants: Kalaeloa Solar 2 (5 MWac), Kalaeloa Renewable Energy Park (KREP) (5 MWac), Waihono (6.5 MWac), Wai‘anae Solar (27.6 MWac), and Aloha Solar 1 (5 MWac) sites. In total, these sites represented 49.1 MWac of installed solar capacity.

This comparison was finite due to the limited overlap of the synthetic NSRDB and actual plant production, restricting the comparison to only a 5-month period in 2018. As shown in Figure 2, the 5-month period (July to December 2018) showed good alignment between the existing plants and the simulated data. However, these plants are smaller than the more recent utility-scale solar deployments, had no tracking systems, and operated with low inverter loading ratios (low DC overbuild relative to AC).

[1] Kawailoa Solar shares an interconnection with the 69 MW Kawailoa wind plant. Kawailoa solar is curtailed before Kawailoa wind.

Plant Name	Plant Capacity (MWac)	Avg Simulated Annual Energy (GWh)	Avg Actual Annual Energy (GWh)	% Difference
Kalaeloa Solar 2	5	5.4	5.4	-1%
KREP	5	4.1	4.0	3%
Waihono	6.5	5.7	5.8	-2%
Waianae Solar	27.6	34.2	31.3	9%
Aloha Solar I	5	4.8	4.5	7%

Figure 2. Comparison of capacity factors of simulated and actual solar production for the July to December 2018 period.

While limited in scope, this initial assessment showed good alignment between simulated and actual solar data. However, due to the increasing penetration of solar plus storage and its importance to resource adequacy, this analysis was revisited in 2025.

<u>PROJECT STATUS/RESULTS</u>: This project is ongoing as the HNEI/Telos team renews efforts to acquire additional data on site-specific solar performance. The goal is to determine whether the discrepancy in solar production between synthetic and reported data is due to underlying meteorological data issues (e.g., not capturing midday cloud cover), operational issues, or issues associated with reporting. Once the issue is determined, corrections will be made available for public and utility use.

Key charts for each of the five solar sites in Figure 1 are shown below. On each chart, a black line indicates what the expected output (capacity factor) expected based on the associated PPA. This is an important metric since underperformance relative to the PPA results in a higher cost to the consumer since the "missing" energy must be supplied by other sources.

Lanikuhana Annual Performance

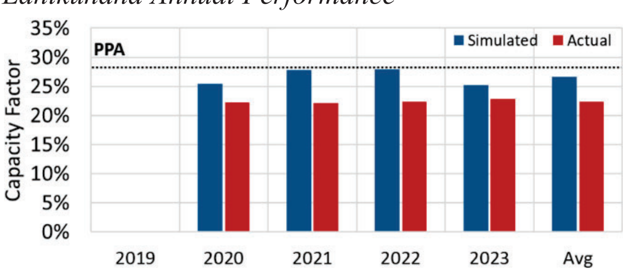


Figure 3. Lanikuhana annual capacity factor for simulated, actual, and expected production based on the PPA.

Waipio PV Annual Performance

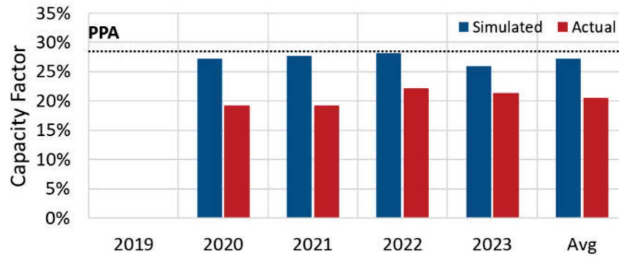


Figure 4. Waipio PV annual capacity factor for simulated, actual, and expected production based on the PPA.

Kawailoa PV Annual Performance

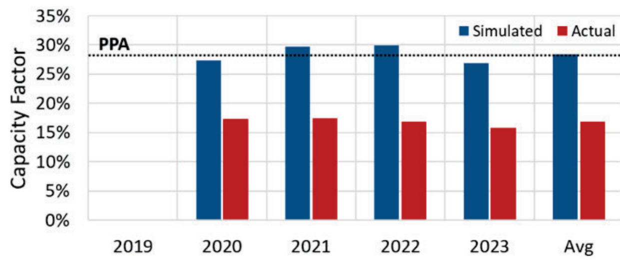


Figure 5. Kawailoa PV annual capacity factor for simulated, actual, and expected production based on the PPA.

West Loch Annual Performance

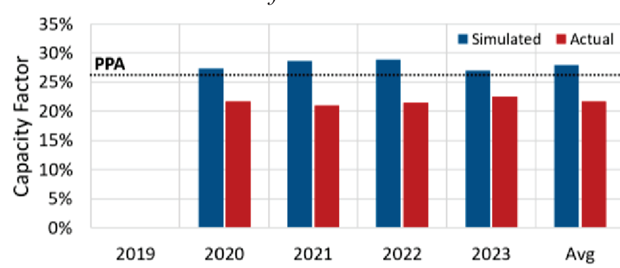


Figure 6. West Loch annual capacity factor for simulated, actual, and expected production based on the PPA.

Wai'anae Annual Performance

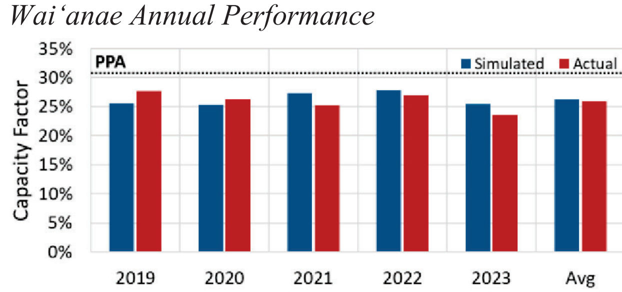


Figure 7. Wai'anae annual capacity factor for simulated, actual, and expected production based on the PPA.

Except for Wai'anae (Figure 7), the simulated annual capacity factors are well above the reported data.

It is important to note that differences between modeled and reported performance are not limited to the HNEI modeling. Based on the reported outputs, the plants also significantly underperform relative to the PPA contract terms. While some of this underperformance is attributable to curtailment, HECO reports for 2023 indicate an O'ahu fleet-wide curtailment of renewable energy of only 3%, or 22,491 MWh. Excluding Kawailoa PV, the remaining four plants experience average actual production ~19% lower than expected based on PPAs. Kawailoa PV was on average 38% lower than it's PPA amount. This is a strong indication that other factors are contributing to the differences.

While more data is required to confirm the noted behavior, this initial review clearly indicates that the synthetic data for the current utility-scale plants overstates solar production potential. This has significant implications for not only for production cost and resource adequacy modeling, but on actual ratepayers' costs. Overstating the availability of low-cost solar may then result in understating the need for storage or thermal generation to meet resource adequacy needs.

Given the importance of solar plus storage assets to O'ahu's future resource procurements and meeting statewide RPS goals, HNEI continues to pursue collaboration with HECO and relevant solar developers to ensure that synthetic solar data are properly calibrated to reflect actual solar conditions and resource performance is better reflected in energy system models.

Funding Source: Office of Naval Research; Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu

Last Updated: November 2025

Hawaiʻi Natural Energy Institute Research Highlights

Appendix C: Grid Technology Development

C1: Coconut Island DC Microgrid

<u>Objective and Significance</u>: HNEI's Grid System Technologies Advanced Research Team (Grid***START***) developed a DC-based microgrid test bed on Coconut Island. The project demonstrated the reliability, resilience, and efficiency of a DC microgrid serving two buildings by comparing lighting, cooling, and plug load performance with conventional AC operation. Results advanced understanding of DC system applications for remote and islanded environments.

<u>Background</u>: Coconut Island is home to the University of Hawaiʻi's Hawaiʻi Institute of Marine Biology (HIMB). HIMB's remote location and commitment to sustainable infrastructure made it an ideal location for testing microgrid technologies and off-the-shelf energy system components.

Project goals included deploying innovative energy systems, establishing a research platform for resilient DC microgrid technologies in tropical marine conditions, and developing solar-powered transport solutions.

<u>Project Status/Results</u>: Grid***START*** collaborated with the University of Indonesia to design a DC-DC converter (DCON) converting 48 V from the photovoltaic (PV) and battery energy storage system (BESS) to 200-350 V for DC loads. The microgrid powered DC lighting, air conditioning, and refrigeration with minimal grid dependence.

All DC microgrid components were installed and commissioned in a dedicated electrical control room housing switches, breakers, controls, converters, wiring, and the BESS. The 6.2 kW rooftop PV array and 8 kWh BESS were fully integrated, enabling autonomous operation and islanded-mode testing of critical loads.

Figure 1. DC microgrid components in the electrical room (left) and system's controller box (right).

The microgrid's stand-alone capability for maintaining critical loads during grid outages was also developed with enhanced advanced control and safety upgrades. A new OPTO22 controller with Node-RED and Node JS programming enabled automated scheduling between AC, DC, and hybrid modes. A microgrid dashboard provided real-time monitoring, performance visualization, and system alerts. Efficiency testing indicated a 3.3% improvement in air conditioner performance and a 5% reduction in lighting power consumption under DC operation relative to AC mode.

Additionally, solar-powered maritime transportation was enabled through an electric boat (E-boat). The E-boat's energy system was upgraded with 18.2 kWh fixed batteries, consolidated PV arrays to one system, and a NEMA-enclosed charge controller with emergency disconnects for improved safety and heat management. The boat's propulsion system used four battery units with independent management, allowing partial functionality during faults and enabling bidirectional energy flow with the microgrid. Initial vehicle-to-grid trials confirmed two-way operation, supporting future integration via dedicated shore power controls. The 24-foot E-boat platform provides a unique opportunity for near-shore research, offering a quiet, liquid fuel free vessel for daily operations and a replicable model for sustainable marine logistics.

Future research could identify improvements in BESS control, load balancing, and marine PV designs that could raise solar output to 3 kW. The project was terminated following loss of APRISES funding halted these advancements but key design, control and operational benchmarks were validated for DC microgrids and electric maritime systems.

Figure 2. The E-boat's powertrain fixed battery system (left) and shade structure PV system (right).

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

C2: Advanced Conservation Voltage Reduction Development and Demonstration

OBJECTIVE AND SIGNIFICANCE: HNEI Grid***START*** is demonstrating advanced conservation voltage reduction (CVR) as an energy efficiency strategy on the 13.8 kV distribution circuit serving the Plaza Housing complex at U.S. Marine Corps (USMC) Camp Butler in Okinawa, Japan. The project showcases innovative voltage control through a field demonstration that utilizes real-time data to reduce overall energy consumption and improve distribution efficiency for a range of military base loads.

BACKGROUND: CVR reduces energy usage by optimizing customer service voltage. For every 1% voltage reduction, energy use was reduced by approximately 0.7% to 0.9% (CVR factor). HNEI, in close collaboration with USMC facilities personnel, focused on a feeder section with seven distribution service transformers to demonstrate these benefits.

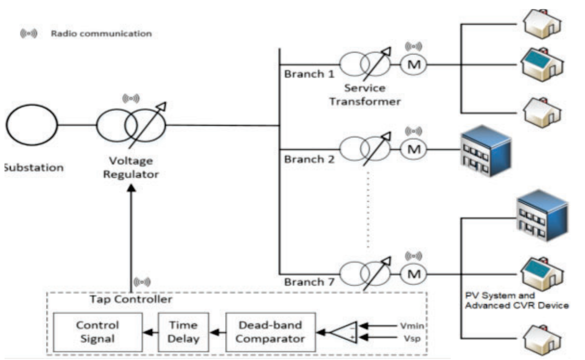


Figure 1. System architecture of CVR demonstration.

PROJECT STATUS/RESULTS: A pad-mounted voltage regulator (VR) was installed to manage voltages on the test section, simulating substation load tap changer operation on a localized scale. To address variable voltage points along the feeder, a patented advanced CVR device was developed and deployed at a critical low-voltage location (TH-415), enabling autonomous local voltage control via reactive power dispatch and inverter management. The project integrated new and existing grid technologies, including a VR with custom control, metering systems, mesh network communications and a 5 kW photovoltaic (PV) system at TH-415. Initial development included algorithm validation using hardware-in-the-loop testing and the creation of a control dashboard. Construction work encompassed circuit reconfiguration and installation of electrical components. System commissioning involved technical troubleshooting and field validation of the CVR system and devices.

Various operational improvements were made, including upgrades to system control and data protocols, enhancement of metering communications, implementation of a local NTP for data synchronization, and continuous system maintenance. The CVR system runs in scheduled alternating on/off cycles, producing observed monthly energy savings with CVR factors between 0.75% to 0.93% for the seven transformers, equating to 1.82 to 2.26 MWh per month.

In response to evolving cybersecurity requirements, communications were migrated off the Camp's AMI network in mid-2024. Following Typhoon Khanun in 2023, which led to a temporary VR shutdown, comprehensive testing and analysis confirmed equipment integrity, and the VR was re-energized in April 2024. The controller for the patented advanced CVR device was subsequently relocated and upgraded, and persistent communication issues were resolved through laboratory simulation and code revision in early 2025, restoring proper control and reactive power dispatch.

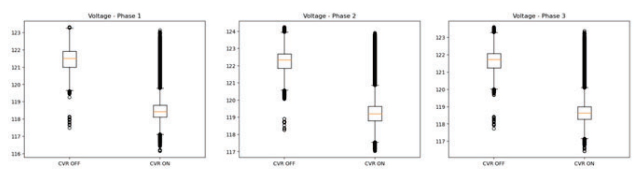


Figure 2. The impact of advanced CVR on voltage statistics at the VR secondary side.

The project's initial findings successfully validated advanced CVR strategies for military base distribution systems, achieving measurable and sustained energy savings. With the support of USMC personnel, the system continues to operate and generate data that will be used to validate advanced CVR's long-term savings. Final field testing and validation will be conducted once applicable funding is secured. The demonstrated infrastructure and operational insights contribute to best practices for distribution voltage optimization, localized control, and resilient grid operation in similar environments.

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

C3: Hawaiʻi Virtual Power Plant (Hi-VPP) Demonstration

OBJECTIVE AND SIGNIFICANCE: HNEI Grid***START*** developed the Hawaiʻi virtual power plant demonstration project (Hi-VPP) to evaluate the economic and operational value of distributed battery and solar (BESS + PV) resources when aggregated as a virtual power plant (VPP). The project's primary aim is to optimize these assets for both customer benefit and grid support, offering insight into reducing electricity costs and advancing demand response strategies for Hawaiʻi.

BACKGROUND: Following the completion of the JUMPSmart Maui (JSM) smart grid project, HNEI acquired Sunverge Solar Integration System (SIS) BESS + PV units through an Equipment Transfer Agreement with NEDO of Japan. These assets were installed at Haleakalā Solar's business office in Kahului, Maui to support field testing and demonstration of multi-scenario VPP operations using real, behind-the-meter energy storage and solar generation resources.

PROJECT STATUS/RESULTS: HNEI developed optimization algorithms that integrate building energy load and rooftop solar power generation forecasts to determine the optimal charging and discharging schedules of BESS units. These algorithms reduce electricity costs for building owners while meeting utility-initiated demand response requirements. A methodology (Figure 1) was also created to evaluate potential customer participation benefits under Hawaiian Electric Company's VPP program, which uses an incentive-based demand response scheme.

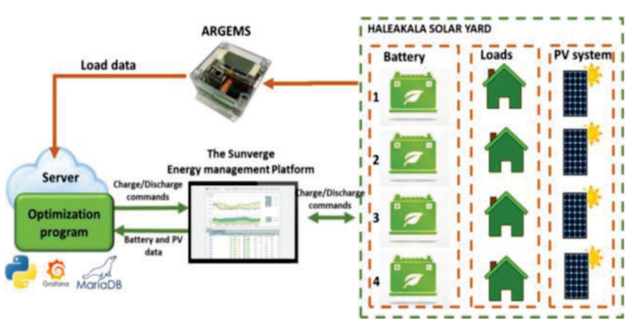


Figure 1. System overview of the methodology.

Building on results and data from the completed field demonstration, Grid***START*** further developed and validated Python-based economic optimization and sizing algorithms that integrate recent demand response programs, such as the "Bring Your Own Device" (BYOD) and Power Partnership offerings, with one year of simulated and measured load and PV data. Algorithm improvements addressed both economic dispatch and optimal system sizing for customers considering VPP participation, evaluating cost-minimizing operational strategies under time-of-use and incentive-rate scenarios.

A Python-based graphical user interface (GUI) has been created to allow prospective VPP participants to estimate the optimal configuration and size of PV and battery systems and assess the financial benefits of VPP participation. The modeling tool, designed to reflect the latest utility program rules, provide actionable insights for participants and utilities aiming to expand VPP adoption and grid flexibility.

Figure 2. User interface for optimal sizing of residential solar PV and battery storage system.

Over the course of the project, the field testing validated optimization methods for integrating building loads, PV generation, and BESS operations across typical and demand response event scenarios. System performance, customer utility cost outcomes and technical functionality were all assessed using live monitoring and control platforms. The field demonstration activities and all field site operations concluded with the completed decommissioning and removal of equipment in early 2025, marking the formal close-out of on-site experimental work.

Funding Source: Office of Naval Research; U.S. Department of Energy

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

C4: Assessing Dynamic Response of Converter-Dominated Power Systems

<u>Objective and Significance</u>: This objective of this project is to develop and strengthen local expertise in modeling and validating advanced solutions for today's power grid, which increasingly integrates inverter-based resources (IBR). The overarching goal is to determine the level of model detail required to accurately represent the dynamic behavior of converter-dominated power systems (CDPS), thereby improving their stability assessment and control design across multiple time scales.

<u>Background</u>: The Hawaiʻi power grid is an exceptional testbed for investigating the complex dynamics and transitional states between CDPS and the broader power grid. The effort also encompasses high-fidelity electromagnetic transient (EMT) modeling and sequence-domain analysis to capture fault behavior more accurately, including grounding effects, protection interactions, and other key dynamics in converter-dominated systems. Together, these activities are enhancing the stability, efficiency, and resilience of Hawaiʻi's power infrastructure and helping ensure its readiness for a sustainable energy future.

The Natural Energy Laboratory of Hawaiʻi Authority's (NELHA) Hawaiʻi Ocean Science and Technology (HOST) Park features the world's most extensive seawater distribution system, which relies heavily on converter-based generation and complex loads, including significant variable frequency drives (VFD), photovoltaic (PV) arrays, and a hydrogen production facility equipped with a converter-driven electrolyzer (198 kW). These characteristics make the HOST Park an ideal example of a CDPS integrated with the larger grid.

<u>Project Status/Results</u>: NELHA collaborated with HNEI to use the HOST Park's power system as a case study for this project. Key tasks include installing power-quality meters and collecting field data; developing and validating baseline root-mean-square (RMS) and EMT models; and using these models to study dynamic interactions among converter-based resources and loads. Building on these efforts, the modeling work has been extended to include sequence-domain analysis for evaluating fault response, voltage unbalance, and protection coordination under both grid-connected and islanded conditions. These studies provide critical insights into the behavior of converter-dominated microgrids and support efforts to improve their dynamic stability and resilience.

HNEI has developed a comprehensive PowerFactory model for detailed RMS and EMT studies of the NELHA Research Campus microgrid. Nonlinear loads were modeled using µPMU data, while VFDs and PV systems were parameterized from SCADA records and equipment specifications. Figure 1 shows the SEL-735 monitoring system configured at the NELHA Research Campus to collect high-resolution validation data. Separate daytime and nighttime models were created to capture PV generation and diurnal load effects, both validated against field measurements.

Figure 1. SEL-735 power quality meters (top) and communication interface (bottom) configured at the NELHA Research Campus.

Building on this foundation, HNEI conducted sequence-domain EMT simulations to evaluate fault responses, grounding behaviors, and protection coordination under grid-connected and islanded conditions. This expanded analysis provides valuable insights into the dynamic performance, fault behavior, and protection coordination of converter-dominated systems, supporting future improvements in modeling standards, control strategies, and operational guidelines across Hawaiʻi's renewable-rich grids.

Funding Source: U.S Department of Energy via a subaward from University of Alaska Fairbanks

Contact: Saeed Sepasi, sepasi@hawaii.edu

Last Updated: November 2025

C5: Bidirectional EV Charging Demonstration Project

Objective and Significance: The objective of this project is to develop, evaluate, and demonstrate novel algorithms to optimize the charge/discharge of shared fleet vehicles for energy cost minimization. Project experience and results will advance energy research and inform the university's consideration of options such as fleet electrification, advanced car-share applications, integration of distributed energy resources on campus, and the optimal campus energy management.

Background: HNEI partnered with IKS Co., Ltd. (IKS) on technology development, testing and demonstration of advanced control of two bidirectional electric vehicle (EV) chargers, or hybrid-power conversion systems (H-PCS), at the University of Hawai'i at Mānoa (UH). The H-PCS was developed by IKS with support from Hitachi Limited as part of the earlier JUMPSmart Maui smart grid demonstration project, where HNEI was a partner. These chargers were installed beside parking stalls near the Bachman Annex 6 building (Figure 1).

Figure 1. Location of bidirectional EV chargers.

Project Status/Results: Two EVs are currently used by designated university personnel through a secure web-based scheduling system developed by HNEI Grid***START***. The H-PCS control algorithms ensure that vehicles are efficiently assigned and available for transportation needs while autonomously minimizing campus electricity costs via intelligent EV charge and discharge commands. Stored EV battery energy is strategically dispatched to reduce overall power supply expenses. These autonomous controls also demonstrate potential to support utility operations by providing grid ancillary services for compensation. Algorithms integrate data from campus load forecasts and solar PV generation, enabling the system to maximize solar energy use for EV charging and building loads while minimizing reliance on grid purchases.

After field operation began in July 2023, the team advanced this demonstration through testing, data analysis, and algorithmic refinement. Field studies applied Hawaiian Electric rate schedules (Advanced Rate Design Schedules R, G, J, and P) to evaluate energy-cost impacts of different charging strategies, while minimum driving-range thresholds ensured reliability and reduced range anxiety. Economic analyses across five UH Mānoa buildings (Biomedical Sciences, Business Administration, Gilmore Hall, Pacific Ocean Science and Technology, and Queen Lili'uokalani Center) and residential scenarios with 15 EVs under various time-of-use (TOU) rates showed that bidirectional charging delivered the lowest costs.

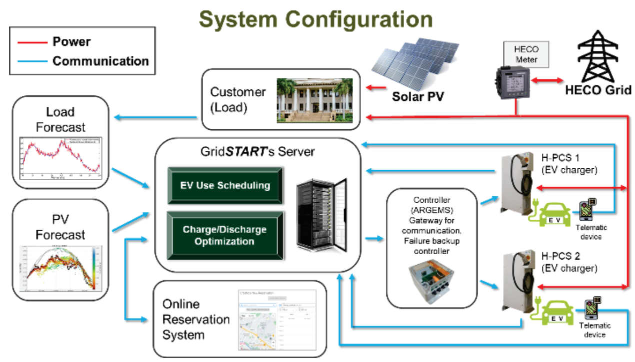


Figure 2. The project's functional system diagram.

A machine-learning approach using a probabilistic bidirectional long short-term memory (Bi-LSTM) model with Monte Carlo and least-square optimization was developed to estimate EV energy use. Complementary dashboards displayed trip data and predicted energy profiles using Google API inputs for terrain and weather. A techno-economic algorithm and web interface were created to optimize PV and battery sizing with bidirectional EVs, confirming cost and energy storage size reductions for both home and campus applications.

The project also trained students in optimization, Python programming, and system integration—culminating in a web-based design tool and [presented research](#) at the 2024 IEEE KPEC Conference.

Funding Source: Office of Naval Research; U.S. Department of Energy

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

C6: Holistic Optimization of Microgrids

OBJECTIVE AND SIGNIFICANCE: This project advances an optimization framework for microgrids that integrates multiple distributed energy resources (DERs), including photovoltaic (PV) systems, battery energy storage systems (BESS), fuel cells, electrolyzers, and hybrid energy storage systems (HESS), to identify cost-optimal and resilient configurations (Figure 1).

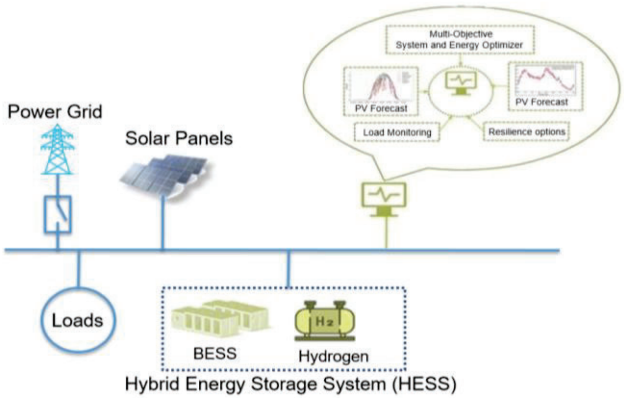


Figure 1. System architecture of a microgrid with HESS.

BACKGROUND: Microgrids and distributed renewable systems are increasingly central to building reliable and resilient energy systems. However, most conventional commercial optimization platforms, such as HOMER Pro, offer limited flexibility for modeling hybrid systems that combine both electrical and hydrogen-based energy storage. These limitations restrict the ability to capture realistic operational dynamics, cost interactions, and the temporal variability inherent to renewable generation and load behavior.

Our method uses a two-stage mixed-integer linear programming (MILP) formulation designed for precision, scalability, and realism. The first stage compresses annual high-resolution data into representative daily profiles for efficient computation, while the second stage refines component sizing and dispatch using the full-year time series. This structure enables accurate assessment of renewable resource penetration, operational cost, and grid interaction under diverse scenarios. Ultimately, this work supports Hawai‘i's transition toward 100% renewable and zero-emission energy systems by advancing flexible, data-driven design tools for microgrid development.

PROJECT STATUS/RESULTS: Building on earlier work that explored a hybrid MILP-particle swarm optimization (PSO) approach, this phase advances to a fully MILP-based optimization model that enhances computational transparency, solution accuracy, and integration of detailed operational constraints. The updated model employs a two-stage MILP structure that efficiently manages large time-series datasets while accurately representing the coupling among generation resources, storage systems, and grid interaction.

By integrating high-resolution data and physical models for PV, BESS, electrolyzers, fuel cells, and hydrogen tanks, the model enables precise evaluation of system sizing, dispatch strategies, and economic performance. This capability supports a wide range of microgrid and hybrid energy applications.

The updated two-stage MILP model has been successfully developed and validated for optimal microgrid sizing and operation. The model integrates PV systems, BESS, electrolyzers, fuel cells, and HESS within a unified optimization environment.

In the first stage, the representative-day optimization efficiently reduces computational complexity by condensing annual 15-minute resolution data into monthly weekday, weekend, and peak-day profiles. The second stage refines component capacities and dispatch schedules using the full-year dataset to capture seasonal and operational variability with high fidelity.

Preliminary results demonstrate the model's capability to determine cost-optimal configurations that minimize grid dependence and enhance renewable utilization while maintaining operational reliability. Comparative testing indicates improved accuracy and scalability relative to conventional commercial tools. This enhanced model also provides a foundation for future resilience-focused applications, including outage management, critical load support, and carbon-neutral microgrid design in both grid-connected and islanded modes.

Funding Source: U.S. Department of Energy

Contact: Saeed Sepasi, sepasi@hawaii.edu

Last Updated: November 2025

C7: AI-Based Net-Load Forecasting Framework for Renewable-Rich Facilities

Objective and Significance: Accurate net-load forecasting is essential for reliable and efficient energy management in facilities with significant renewable integration. This project introduces an artificial intelligence (AI)-driven forecasting framework to generate precise 24-hour-ahead predictions of electricity demand (gross load), solar photovoltaic (PV) generation, and net load at 15-minute resolution, with forecasts updated as new data become available.

Background: As renewable energy penetration increases, net electricity demand has become more variable and harder to predict. This variability introduced by human activity, intermittent solar production, and changing weather conditions often leads to forecast uncertainty that traditional statistical or regression-based methods cannot fully capture.

By combining lightweight transformer architectures for load forecasting with AI-based PV forecasting models trained on temperature and irradiance features, the project delivers a unified, operational pipeline capable of generating complete gross load, PV, and net-load forecasts within one minute. Initially validated using high-resolution metered data from a building at the University of Hawaiʻi at Mānoa, this approach is readily adaptable to other campuses, facilities, and commercial complexes, providing a scalable, ready-to-deploy solution for data-aware, resilient, and sustainable grid operations that support Hawaiʻi's clean energy transition.

Project Status/Results: Building on HNEI's prior work in machine-learning-based load forecasting, this project advances that foundation by introducing an AI-driven approach for end-to-end net-load forecasting. The methodology combines advanced AI models with behavioral insights to better capture how energy use and solar production vary throughout the day and across weather conditions. By continuously learning from recent data, the system adapts to changing operating patterns, improving reliability, and making forecasts more applicable to real-world renewable systems. This initiative represents an important step toward practical, AI-enabled forecasting tools that support real-time energy management, battery control, demand response, and microgrid operations across a range of facilities and scales.

An operational prototype of the AI forecasting model has been developed to produce rolling 24-hour-ahead forecasts for gross load, PV generation, and net load at 15-minute resolution. Figure 1 illustrates the workflow and integration of the forecasting modules. The prototype, trained using one year of high-resolution metered data, effectively captures seasonal and weather-driven variability with strong accuracy. It achieves an average symmetric Mean Absolute Percentage Error (sMAPE) of approximately 6.8% for 24-hour forecasts, maintaining stable performance across both day and night periods.

Key advancements of this work include separate daytime and nighttime models, weekday-specific training, and anomaly-based normalization using the most recent seven days of data. The system produces full 24-hour forecasts in under one minute on a standard desktop CPU, with PV models pre-trained on GPU. The modular design supports integration of additional weather and distributed energy resource (DER) inputs. Ongoing work focuses on improving AI model training and feature engineering to further increase accuracy, robustness, and scalability for deployment in campus- and building-scale microgrids.

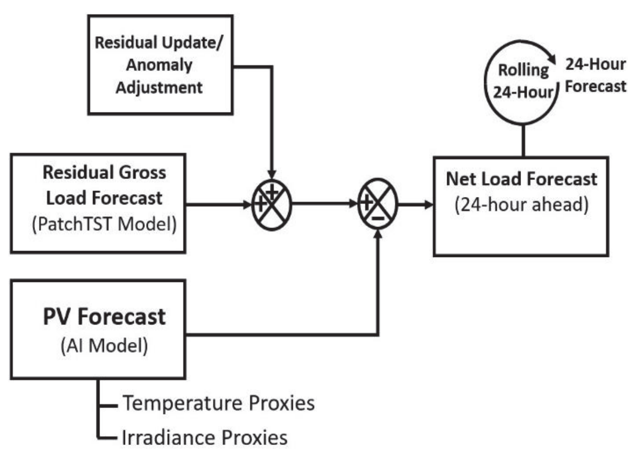


Figure 1. AI-based forecasting workflow integrating PatchTST load and PV models to generate rolling 24-hour-ahead net-load forecasts.

Funding Source: Energy Systems Development Special Fund

Contact: Saeed Sepasi, sepasi@hawaii.edu

Last Updated: November 2025

<u>Objective and Significance</u>: The University of Hawaiʻi (UH) is a member of the Federal Aviation Administration's (FAA) Aviation Sustainability Center (ASCENT), a team of U.S. universities conducting research on the production of sustainable aviation fuels (SAF). Within this framework, HNEI conducts research that supports developments and decisions related to supply chains for alternative, renewable, sustainable, jet fuel production in Hawaiʻi. Results may inform similar efforts in other tropical regions.

<u>Background</u>: In 2019, commercial aviation in Hawaiʻi used nearly 700 million gallons of jet fuel, all of which is derived from petroleum. In 2024, as the state recovered from the combined effects of the pandemic and the Lāhainā wildfires, jet fuel consumption was approaching 2019 levels (Figure 1).

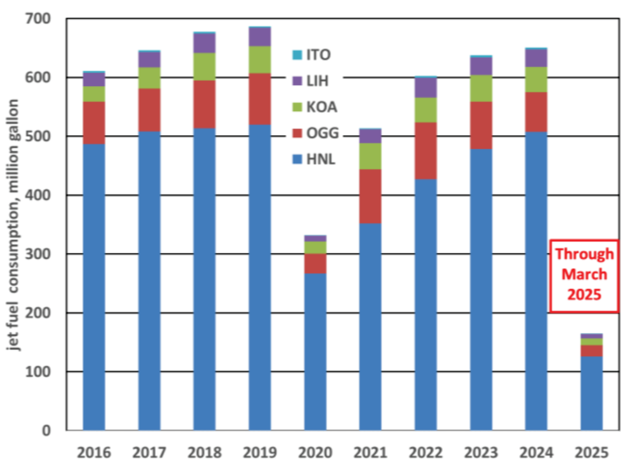


Figure 1. Commercial jet fuel consumption in Hawaiʻi.

<u>Project Status/Results</u>: This project was initiated in October 2015 and is now continuing into its 10th year. Activities undertaken in support of SAF supply chain analysis include:

- Conducting literature review of tropical biomass feedstocks and data relevant to their behavior in conversion systems for SAF production;
- Engaging stakeholders to identify and prioritize general SAF supply chain barriers (e.g., access to capital, land availability, etc.);
- Developing geographic information system (GIS)-based technical production estimates of SAF in Hawaiʻi;
- Developing fundamental property data on biomass resources; and
- Developing and evaluating regional supply chain scenarios for SAF production in Hawaiʻi.

Literature reviews of both biomass feedstocks and their behavior in SAF conversion processes have been completed and published. Based on stakeholder input, barriers to SAF value chain development in Hawaiʻi have been identified and reported. Technical estimates of land resources that can support agricultural and forestry-based production of SAF feedstocks have been completed using GIS analysis techniques. Samples from Honolulu's urban waste streams and candidate agricultural and forestry feedstocks have been collected and subjected to physicochemical property analyses to inform technology selection and design of SAF production facilities.

An overview of the work completed under this project follows and a more <u>comprehensive writeup</u> can be found on HNEI's website.

Urban Waste: Fuel Properties of Oʻahu's Construction and Demolition Waste Streams

A sampling and analysis campaign was undertaken to characterize fuel properties of construction and demolition waste (CDW) streams on Oʻahu. Complete results were summarized and published in **<u>Construction and Demolition Waste-Derived Feedstock: Fuel Characterization of a Potential Resource for Sustainable Aviation Fuels Production</u>** in the *Frontiers in Energy Research* journal.

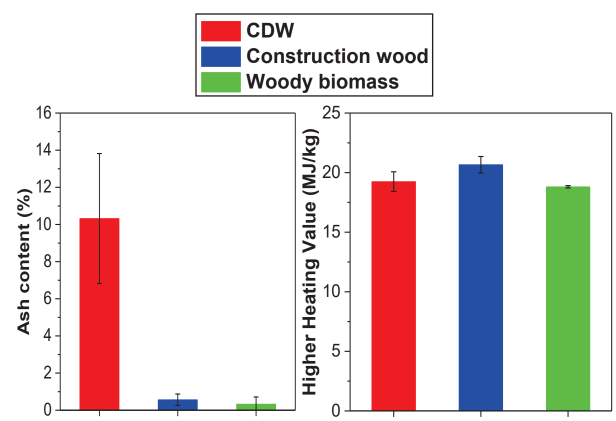


Figure 2. Ash content (left) and heating value (right) of the combustible fraction of CDW compared to construction wood and woody biomass.

As shown in Figure 2, although the combustible fraction of the CDW samples have elevated ash levels compared to clean biomass materials, their heating values were comparable, indicating the presence of higher energy density materials. As with most refuse derived fuels, the amount of ash in the fuel and its composition is of particular importance—since ash impacts energy facility operations, maintenance, and emissions.

Tests of clean wood fuel from the invasive species (**Leuceana spp., common name koa haole**) and **synthetic CDW (sCDW) material** were conducted at a commercial gasification technology provider facility to evaluate product composition and yields and identify contaminants. The data indicates that managing the gas quality through feedstock treatment/blending or product gas cleanup will be required.

Urban Waste: Resource Logistics

Utilizing urban waste resources as feedstock for SAF production has the advantages of both reducing amounts of material entering the limited landfill space and reducing dependence on imported energy. Integrating solid waste management and SAF production with a view of treating the state as a single management unit rather than four individual county units could be a beneficial approach to meet waste management, energy resiliency, and greenhouse gas abatement goals and improve economies of scale.

One approach for integrated solid waste management for SAF production would transport waste resources from neighbor islands and consolidate them with waste from the City & County of Honolulu (C&C) to fuel a gasification and Fischer-Tropsch (FT) conversion facility located on Oʻahu. Six different scenarios of non-recycled urban waste utilization for SAF production are listed in Table 1.

Table 1. Solid waste utilization scenario assumptions for SAF production and HPOWER. ("Yes" indicates that waste category is included or HPOWER is operated; "No" indicates that waste category is excluded or HPOWER is not operated.)

Scenario	1	2	3	4	5	6
HPOWER	No	Yes	No	Yes	No	Yes
Food Waste	Yes	Yes	No	No	No	No
Mixed Plastics	Yes	Yes	Yes	Yes	No	No
Combustible C&D Materials	Yes	Yes	Yes	Yes	Yes	Yes
Mixed Organics	Yes	Yes	Yes	Yes	Yes	Yes
Mixed MSW	Yes	Yes	Yes	Yes	Yes	Yes
Yard Trimmings	Yes	Yes	Yes	Yes	Yes	Yes
Paper	Yes	Yes	Yes	Yes	Yes	Yes

Estimates of production potential from the six waste utilization scenarios (Figure 3) show that Scenarios 1, 3, and 5, which don't include HPOWER operation, yield the highest SAF production values ranging from 38 to 45 million gallons annually. A preliminary assessment of life cycle greenhouse gas emissions per MJ for each of the six scenarios was also completed and the results show that the estimated emissions range from 32 to 53 gCO_2e/MJ.

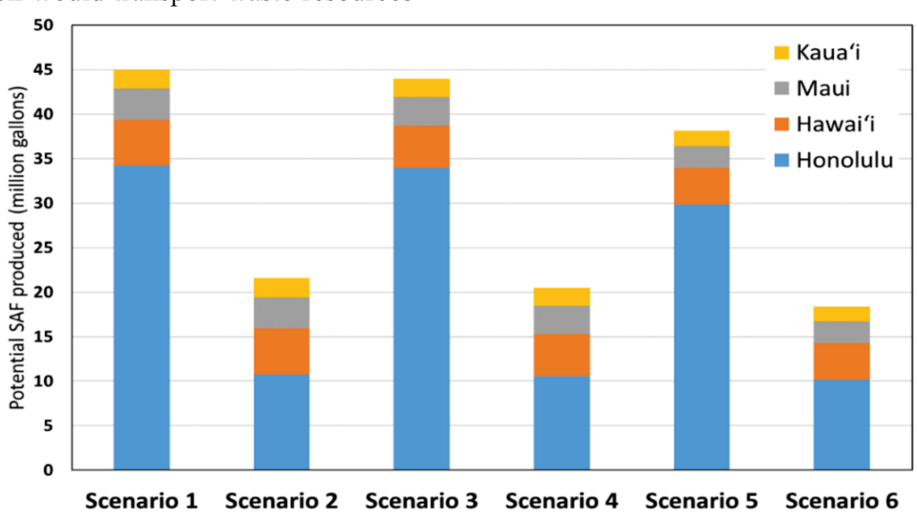


Figure 3. Technical SAF potential from combustible urban waste for six utilization scenarios.

Biomass: Exploration of Hawai'i Feedstocks

Bringing Hawai'i's agricultural lands back into production can support diversification of the economy and support rural development. Biomass feedstocks for sustainable aviation fuel production are options that can contribute to this revitalization. This work was summarized and published in **Review of Biomass Resources and Conversion Technologies for Alternative Jet Fuel Production in Hawai'i and Tropical Regions** in the *Energy and Fuels* journal.

The EcoCrop model was used to complete an assessment of plant production requirements to agro-ecological attributes of agricultural lands in the State. Land use constraints included agricultural zoning, land capability classes (an indicator of soil quality), slope, service by irrigation systems, and current agricultural activities. The analysis focused on sites capable of rain-fed production to avoid using irrigated lands that could support food production. Oil seed crops, woody crops, and herbaceous crops were all considered.

The EcoCrop model provides an estimate of each energy crops' productivity across the agricultural landscape. Aggregated yield of biobased feedstock and conversion efficiency from feedstock to final energy product were used as the basis for SAF technical potential estimates under the four scenarios listed below:

- Scenario 1 - agricultural zoning, slope less than 20%, land capability class 1 to 6
- Scenario 2 - agricultural zoning, slope less than 20%, land capability class 1 to 6, excluding land serviced by irrigation systems,
- Scenario 3 - agricultural zoning, slope less than 20%, land capability class 1 to 6, excluding land serviced by irrigation systems and land currently in agricultural use, and
- Scenario 4 - agricultural zoning, slope less than 20%, land capability class 1 to 6, excluding land serviced by irrigation systems and land currently in agricultural use other than pasture.

All scenarios assume a EcoCrop suitability index >0.5 on a scale of 0 to 1 using rainfed conditions. A report detailing these results is currently being drafted.

Biomass: Pongamia Logistics

EcoCrop energy crop modeling identified pongamia as having the greatest oil production potential based on suitable growing area and yield. The geographic distribution of suitable growing areas across the state provides an opportunity to select pongamia primary processing sites that minimize transportation costs. Seeds in their pods would be harvested and transported to a primary processing location where the seed and pod could be separated—oil could be extracted from the seed, and oil and de-oiled seed cake could be upgraded. Land zoned for industrial use (brownfield site) on each island was considered as potential primary processing sites. Greenfield sites were also considered—identified as land zoned for agriculture with slope less than 5%, and a minimum contigous area of 125 acres. This would accomodate the space needed for processing, storage, and possible colocation of complementary industries utilizing the de-oiled seedcake and pod to develop coproducts.

Greenfield site options are more numerous than brownfield locations and may afford reductions in transportation requirements. Brownfield sites are anticipated to offer access to pre-existing utilities that could reduce costs of developing the processing facilities. The locations for minimum cost sites depend on the production scenarios for pongamia. Pongamia production system planning would require verification of industrial zoning, farmer acceptance of pongamia production, community acceptance, and economic viability of all value chain participants.

Biomass: Evaluation of Pongamia

Of the sustainable aviation fuels currently approved by ASTM and the FAA, those based on the use of oils derived from plants and animals have the highest SAF yield and the lowest production costs. Pongamia (*Millettia pinnata*) (Figure 4) is a tree, native to the tropics, that bears an oil seed and has plantings established on O'ahu, Maui, and Hawai'i Island. Pongamia is largely sourced from wild collection in many parts of the world. Pongamia production, processing, and use as an agricultural crop for SAF production would require a value chain. Several projects have been undertaken to provide information needed to develop this value chain. Results of these are summarized below.

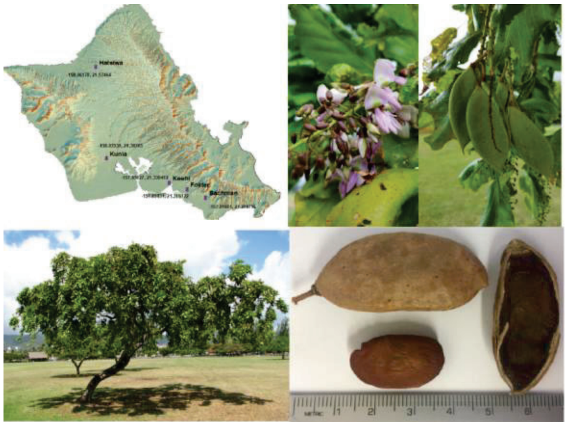


Figure 4. Locations and images of Pongamia.

Economics of Producing Pongamia in Hawai'i

Figure 5 proposes common agricultural activities for orchard production of pongamia and illustrates material and energy flows crossing the orchard boundary. Outputs from the orchard include harvested pongamia seed in pod, pongamia trees when the orchard is removed, and land, air, and water emissions. Growing pongamia trees in Hawai'i will require extensive land preparation. These cultural costs are higher initially and then decline as the trees mature. When the trees begin producing seed pods, the cost of harvesting will be incurred.

Production costs are evaluated over a 25-year time period. For a one-acre plot of land, results indicate the net revenues will be negative for the first four years of production. In year 5, revenues from the sale of Pongamia seed pods will exceed culture and harvest costs and results in positive net revenues through year 25.

Processing: Pongamia Decortication and Oil Extraction

A nascent oil seed production agricultural sector would require processing facilities. Pongamia seed pods would be transported by truck to processing facility locations. Processing would require pods and seeds to be separated (decortication) and the seeds to be crushed to extract oil. Both processes would be colocated, taking advantage of shared utilities, transportation facilities, workforce, and administration. A cost analysis for production facilities is currently underway.

Biomass: Pongamia Fuel Properties

Pongamia is a potential resource for renewable fuels in general and sustainable aviation fuel in particular. The physicochemical properties of reproductive material (seeds and pods) from pongamia trees grown in different environments at five locations on O'ahu were characterized. Proximate and ultimate analyses, heating value, and elemental composition of the seeds, pods, and de-oiled seed cake were determined. Pongamia oil was found to have similar characteristics as other plant seed oils (canola and jatropha) and would be expected to be well suited for hydro-processed production of sustainable aviation fuel. These results were published in **Fuel Properties of Pongamia (*Millettia pinnata*) Seeds and Pods Grown in Hawai'i** in the *ACS Omega* journal.

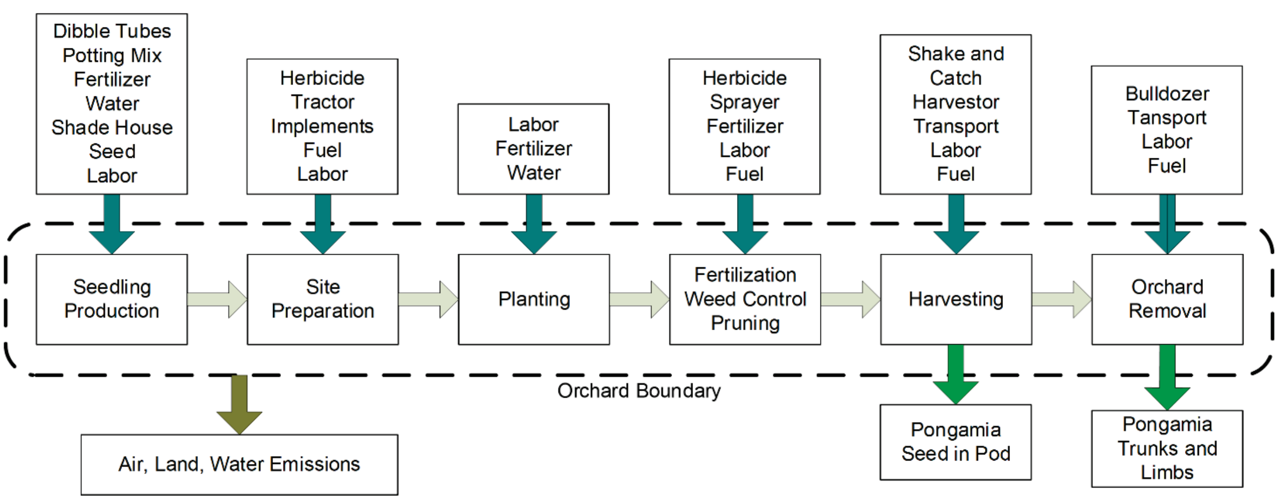


Figure 5. Common agricultural activities propsed for orchard production of pongamia and material and energy flows crossing the orchard boundary.

Biomass: Pongamia Coproduct Development

Additional studies were devoted to developing coproducts from pongamia pods. Leaching and torrefaction experiments were performed to remove inorganic constituents and reduce the oxygen content of the pods. A 2^3 factorial design of the leaching treatment determined the impacts of process operating parameters (i.e. rinse water temperature, rinse duration, and particle size) on the composition and physicochemical properties of the pods and the water. The higher heating value of the pods was found to increase from 16 to 18-19 MJ/kg after leaching, while the ash content was reduced from 6.5% to as low as 2.8% wt, with significant removal of sulfur, chlorine, and potassium.

Pongamia pod leaching processes and pod torrefaction processes were summarized and published in **Water leaching for improving fuel properties of pongamia Pod: Informing process design** and **Upgraded pongamia pod via torrefaction for the production of bioenergy**, both in the *Fuel* journal, respectively.

Biomass: Pongamia Invasiveness Assessment

Pongamia is a tree, native to the tropics, which bears an oil seed and has plantings established on Oʻahu. Under this project, an observational field assessment of trees in seven locations on Oʻahu was conducted by Professor Curtis Daehler (UH Dept. of Botany) to look for direct evidence of pongamia escaping from plantings and becoming an invasive weed. Although some pongamia seedlings were found in the vicinity of some pongamia plantings, particularly in wetter, partly shaded environments, almost all observed seedlings were restricted to areas directly beneath the canopy of mother trees. This finding suggests a lack of effective seed dispersal away from pongamia plantings. Based on its current behavior in the field, pongamia is not invasive or established outside of cultivation on Oʻahu. Because of its limited seed dispersal and low rates of seedling establishment beyond the canopy, the risk of pongamia becoming invasive can be mitigated through monitoring and targeted control of any rare escapes in the vicinity of plantings. Vegetative spread by root suckers was not observed around plantings on Oʻahu, but based on reports from elsewhere, monitoring for vegetative spread around plantations is recommended; unwanted vegetative spread might become a concern in the future that could be addressed with localized mechanical or chemical control. A detailed technical report titled "***Observational Field Assessment of Invasiveness of Pongamia (Millettia pinnata), A Candidate Biofuel Crop in Hawaiʻi***" summarized this work and is available on HNEI's website.

Biomass: Other Feedstocks

Other potential feedstocks for Hawaiʻi, kukui (*Aleurites moluccanus*) and kamani (*Calophyllum inophyllum*) nut oils, were also explored. Kukui and kamani nut oil are different from the pongamia seed oil, in that the primary fatty acid is linoleic acid (C18:2). The results of the study conducted on kukui were published in **Comprehensive Characterization of Kukui Nuts as Feedstock for Energy Production in Hawaiʻi** in the *ACS Omega* journal.

Funding Source: Federal Aviation Administration; Energy Systems Development Special Fund

Contact: Scott Turn, sturn@hawaii.edu

Last Updated: November 2025

D2: Oil Seed Tree Crop Investigation

OBJECTIVE AND SIGNIFICANCE: The purpose of this project, initiated in 2025, is to establish long-term plantings of kukui and pongamia at agricultural experiment stations operated and maintained by the College of Tropical Agriculture and Human Resources (CTAHR) of the University of Hawai‘i.

These plantings will be used to produce information needed to evaluate the two tree crops' including:

1) Potential for oil seed production under documented growing conditions;
2) Carbon storage in both standing biomass and soil;
3) Response to cultural practices (e.g. plant density, irrigation, fertilization, etc.); and
4) Capacity to provide ecosystem services.

BACKGROUND: Current commercial production of sustainable aviation fuel (SAF) uses renewable lipids as feedstock. Adoption of SAF has an important role towards meeting the State of Hawai‘i's legislative goal to decarbonize by 2045 and demand for SAF feedstocks represents a potential market for local agriculture. Currently, the most common sources of SAF feedstock lipids include used cooking oil, tallow from animal processing, and palm oil. Oil seeds such as sunflower, safflower, and camelina have been or are currently under investigation in Hawai‘i. Jatropha and oil palm have also been investigated, but have not progressed beyond limited trial plantings.

Two trees that have potential for plant oil production in Hawai‘i are kukui (*Aleurites moluccanus*) and pongamia (*Milletia pinnata*). Prior HNEI research confirmed that kukui bears a nut that contains >60% oil[2] and pongamia produces a seed with oil content >30%[3]. Both are presently grown in Hawai‘i, however, published information on their production potential here is not available.

Data packages are based on terrestrial crop data collection requirements for purpose-grown energy crops. Establishing kukui and pongamia plots with these data packages in mind will provide the basis for future competitive grant proposals for extramural funds. Beyond SAF research, the establishment of these plantings will also provide benefits to the broader community by informing orchard management, agroforestry design, and the land rehabilitation supply chain.

PROJECT STATUS/RESULTS: Work under this project is just beginning. Year 1 will include kukui germplasm collection and greenhouse production of kukui seedlings. Pongamia saplings will be sourced from commercial vendors. Plot allocations at CTAHR experiment stations at Waimānalo and on Kaua‘i have been requested. Baseline data on carbon storage in standing biomass and soil will be collected and reported. Cultural practices, such as plant density, irrigation, and fertilization, used to plan and install the plantings will be documented and reported. These results will inform life cycle evaluations of the tree installations.

Year 2 will include maintenance of the plots installed in Year 1. Cultural practices will be documented and reported. Annual carbon storage data in standing biomass and soil will be collected and reported.

Additional efforts will occur in Year 3 and the ensuing years. After plot installations, cultural practices to maintain the plots and the trees will be done annually (or more frequently) and these activities will be documented for the life cycle record. Annual carbon storage data in standing biomass and soil will be collected and reported. As the trees mature, the growth and development will be monitored, tracked, and recorded, e.g. reproductive phenology, proportion of flowers forming fruits and fruits reaching maturity, weight of harvestable nuts, etc. Maturing trees will also provide a working laboratory for complementary fundamental and applied research needed for agroecological characterization and modeling.

Funding Source: Energy Systems Development Special Fund

Contact: Scott Turn, sturn@hawaii.edu;
Darshi Banan, dbanan@hawaii.edu

Last Updated: November 2025

[2] Fu, J., Weber, S., & Turn, S. Q. (2023). Comprehensive characterization of Kukui Nuts as feedstock for energy production in Hawai‘i. ACS Omega, 8(25), 22567–22574. https://doi.org/10.1021/acsomega.3c00860

[3] Fu, J., Summers, S., Morgan, T. J., Turn, S. Q., & Kusch, W. (2021). Fuel properties of pongamia (*milletia pinnata*) seeds and pods grown in Hawai‘i. *ACS Omega*, *6*(13), 9222–9233. https://doi.org/10.1021/acsomega.1c00635

D3: Novel Biocarbons

OBJECTIVE AND SIGNIFICANCE: Biomass can be a renewable resource to produce energy, fuels, chemicals, and materials. The goal of this project is to develop processes to 1) produce biochars and biocarbons from biomass feedstocks and 2) control and tune their properties by selection of biomass feedstocks and process conditions.

BACKGROUND: Slow pyrolysis is a thermochemical process that converts biomass into solid carbonaceous materials. The maximum temperature used during slow pyrolysis will dictate the extent to which the material is carbonized. Low temperature slow pyrolysis (200-500°C) results in the formation of biochar. High temperature slow pyrolysis (900-1200°C) produces biocarbon. The pyrolysis temperature is the dominant process parameter to control critical properties (e.g. volatile matter, carbon and fixed carbon contents, reactivity, surface area, density, tensile/compressive strength, grindability, etc.). One limitation to improving biochar/biocarbon properties is that biomass carbonization proceeds via a charring mechanism (no molten phase). The lack of a molten phase during carbonization limits the capacity to engineer critical material properties.

Biochar and biocarbon have numerous applications including fuel for cooking, adsorbents for air/water purification, a carbon sequestering soil amendment, and a carbon neutral coal/coke replacement in industrial applications. All are applicable in Hawai‘i and can be produced from low value biomass materials.

PROJECT STATUS/RESULTS: Research at HNEI has identified certain constant-volume/pressurized reaction conditions that result in the formation of biochar with drastically altered morphology compared to the parent biomass. This unique biochar experiences a transient plastic phase (TPP) during carbonization, representing a new biomass carbonization pathway. The underlying mechanisms of TPP formation and utility are still being explored.

The current research effort uses parametric research design to independently study the effects of pressure, temperature, water content, reactant gas, biomass type, biomass particle size, and metal impregnation on the formation of TPP biochar. In addition to standard analytical tools (proximate analysis, true density, ultimate analysis), powder compaction experiments have been developed to characterize material plasticity and mechanical strength. These fundamental insights have been leveraged to increase biocarbon mechanical strength, a critical bottleneck for commercial applications.

Experimental results demonstrate that TPP formation proceeds through a molten phase. Elevated pressure serves to keep water in the condensed phase, inhibiting condensation reactions and enabling molten phase formation. TPP formation conditions were identified for a range of biomass types, including hardwoods, softwoods, and herbaceous materials.

Results from powder compaction experiments show that TPP biochar has increased plasticity along with a reduced glass transition temperature. Experiments comparing the mechanical strength of TPP and standard biocarbon materials show the TPP material is 10 times stronger, and twice as dense. Efforts to maximize the mechanical strength of TPP biocarbon achieved another 10x improvement, the strongest biocarbon material reported in the scientific literature (Figure 1). These mechanical properties exceed values required for numerous industrial applications.

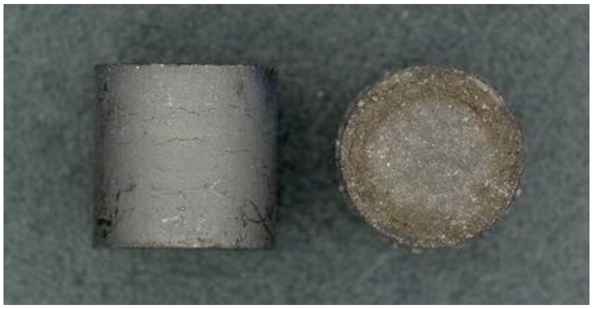


Figure 1. Biocarbon pellets produced from TPP biochar.

This novel production pathway overcomes technical barriers limiting biomass utilization as feedstock for biocarbons that can displace fossil carbon products. Potential applications include metallurgical reductants, binders, electrodes, or high value specialty materials. Two patent applications have been filed to protect this intellectual property and licensing opportunities are available. Current activities focus on developing experimental results to inform process design and to demonstrate the technology at large scales.

To date, this project has produced the following five publications:

- 2025, R.L. Johnson, et al., **Investigation into the role of feedstock in the carbonization of transient plastic phase biochar**, *Energy & Fuels*. In review.
- 2025, K. Castillo, et al., **Experimental optimization of pellet tensile strength from spruce biochar produced at elevated pressure**, *Energy & Fuels*, Vol. 39, Issue 3, pp. 1668-1678.
- 2024, B. Babinszki, et al., **Volatile matter characterization of birch biochar produced under pressurized conditions**, *Journal of Thermal Analysis and Calorimetry*, Vol. 149, pp. 10915-10926. (Open Access: **PDF**)
- 2023, R.L. Johnson, et al., **Biocarbon production via plasticized biochar: role of feedstock, water content, catalysts, and reaction time**, *Energy & Fuels*, Vol. 37, Issue 20, pp. 15808-15821.
- 2023, R.L. Johnson, et al., **Use of plasticized biochar intermediate for producing biocarbons with improved mechanical properties,** *ACS Sustainable Chemistry & Engineering*, Vol. 11, Issue 15, pp. 5845-5857.

Funding Source: SINTEF Energy Research; Office of Naval Research

Contact: Scott Turn, sturn@hawaii.edu;
Robert Johnson, robertlj@hawaii.edu

Last Updated: November 2025

D4: Solar Fuels Generation

OBJECTIVE AND SIGNIFICANCE: The objective of this research is to improve the durability and efficiency of *chalcopyrite* and *perovskite* thin-film photo-absorbers for photoelectrochemical (PEC) production of *solar fuels*, to reduce the production cost of renewable hydrogen.

BACKGROUND: Sometime referred as "Artificial Photosynthesis," PEC technology combines advanced photovoltaic (PV) materials and catalysts into a single device that uses sunlight as the sole source of energy to split water into molecular hydrogen and oxygen. In a typical PEC setup, the solar absorber is fully immersed into an electrolyte solution and fuels are generated directly at its surface. Fuels produced with this method can be stored, distributed, and finally recombined in a fuel cell to generate electricity, with water as the only byproduct.

PROJECT STATUS/RESULTS: Under two consecutive U.S. DOE awards received in 2014 and 2017, HNEI partnered with the University of Nevada, Las Vegas, Stanford University, the National Renewable Energy Laboratory, and Lawrence Livermore National Laboratory to establish a unique tool chest of theoretical modeling, state-of-the-art synthesis, and advanced material and interface characterization to provide deeper understanding of PEC materials and engineer high-performance devices.

Focusing on the *chalcopyrite* material class, our group was able to synthesize solar absorbers capable of generating photocurrent densities relevant to high solar-to-hydrogen (STH) efficiencies (>12%). We also demonstrated that tungsten oxide (WO_3) films only few atoms thick could increase the stability of *chalcopyrites* in acid by a factor of 2 when compared to uncoated samples.

A key challenge remains materials integration into "multi-junction" (MJ) PEC water splitting devices—an integration scheme in which thin film materials are monolithically stacked on top of each other to maximize STH efficiency. With such architecture, the deposition process of each layer must not damage the previously deposited layers and interfaces in any way. Our results showed that *chalcopyrites* are not compatible with monolithic MJ integration.

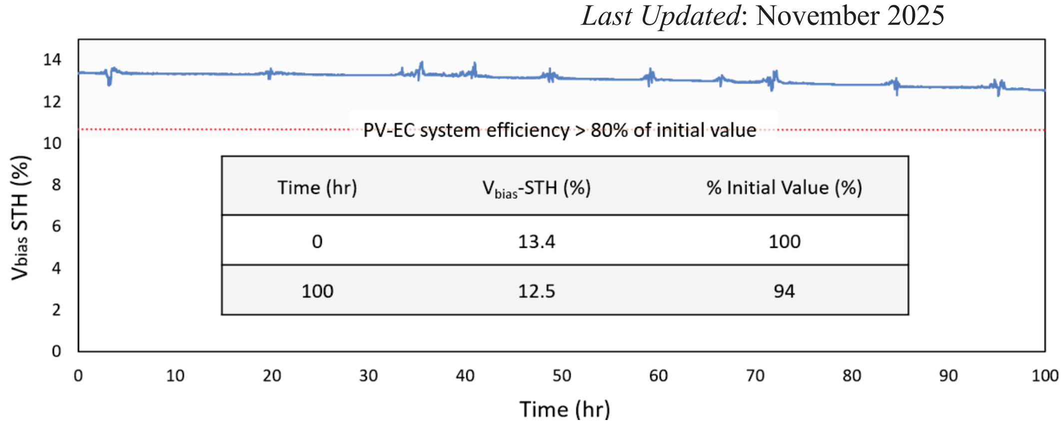
In 2023, HNEI and its partners received additional DOE funding to develop a novel integration scheme in which material classes can be combined regardless of their nature while preserving their intrinsic performance. Such a scheme, pioneered by HNEI and known as *semi-monolithic* integration, relies on 2D materials-assisted exfoliation and room temperature bonding techniques to transfer fully integrated cells from their original substrates onto new handles. With this integration scheme, sub-cells can be successively transferred onto a new host to create a fully functional MJ structure. By design, semi-monolithic integration allows to circumvent all material incompatibilities, enabling new MJ architectures otherwise not possible with conventional monolithic integration. With this integration scheme, HNEI was able to combine two promising—yet thermally incompatible—material classes, *chalcopyrites* and *perovskites,* into tandem cells producing hydrogen with an initial efficiency of 13.4% and capable of maintaining over 90% of its efficiency for over 100 hours of operation.

To date, this research has produced the publications and presentations listed on the following page.

Funding Source: U.S. Department of Energy

Contact: Nicolas Gaillard, ngaillar@hawaii.edu

Last Updated: November 2025



ADDITIONAL PROJECT LINKS

PAPERS AND PROCEEDINGS:

1. 2022, K. Outlaw-Spruell, J. Crunk, W. Septina, C.P. Muzzillo, K. Zhu, N. Gaillard, **Semi-monolithic Integration of All-Chalcopyrite Multijunction Solar Conversion Devices via Thin-Film Bonding and Exfoliation**, ACS Applied Materials and Interfaces, Vol. 14, Issue 49, pp. 54607-54615.
2. 2021, N. Gaillard, **A perspective on ordered vacancy compound and parent chalcopyrite thin film absorbers for photoelectrochemical water splitting**, Applied Physics Letters, Volume 119, Issue 9, Paper 090501.
3. 2021, I. Khan, C.P. Muzzillo, C.L. Perkins, A. Norman, J. Young, N. Gaillard, A. Zakutayev, **$Mg_xZn_{1-x}O$ contact to $CuGa_3Se_5$ absorber for photovoltaic and photoelectrochemical devices**, JPhys Energy, Vol. 3, Issue 2, Paper 024001. (Open Access: **PDF**)
4. 2021, D.W. Palm, C.P. Muzzillo, M. Ben-Naim, I. Khan, N. Gaillard, T.F. Jaramillo, **Tungsten oxide-coated copper gallium selenide sustains long-term solar hydrogen evolution**, Sustainable & Energy Fuels, Vol. 5, Issue 2, pp. 384-390.
5. 2020, A. Sharan, F.P. Sabino, A. Janotti, N. Gaillard, T. Ogitsu, J.B. Varley, **Assessing the roles of Cu- and Ag-deficient layers in chalcopyrite-based solar cells through first principles calculations**, Journal of Applied Physics, Vol. 127, Paper 065303.

PRESENTATIONS:

1. 2024, N. Gaillard, **Semi-Monolithic Integration of Dissimilar Material Classes into Efficient Water Splitting Devices**, Presented at the Electrochemical Society PRiME Meeting, October 6-11, Honolulu, Hawaiʻi, Symposium L04, Abstract 3947.
2. 2024, K. Outlaw-Spruell, C. Muzzillo, K. Zhu, N. Gaillard, **Semi-Monolithic Multijunction Devices for Unassisted Photoelectrochemical Water Splitting**, Presented at the Electrochemical Society PRiME Meeting, October 6-11, Honolulu, Hawaiʻi, Symposium L04, Abstract 3932.
3. 2024, N. Gaillard, **Semi-Monolithically Integrated Photoelectrochemical Devices for Unassisted Water Splitting**, Presented at the 245th Electrochemical Society Meeting, May 26-30, San Francisco, California, Symposium I02, Abstract 1990.
4. 2024, K. Outlaw-Spruell, C. Muzzillo, K. Zhu, N. Gaillard, **Anisotropic Conductive Adhesive for Semi-Monolithic Integration of Multi-Junction PV and PEC Devices**, Presented at the Materials Research Society Spring Meeting, April 22-26, Seattle, Washington, Symposium EN05.07.04.

D5: NELHA Hydrogen Station

OBJECTIVE AND SIGNIFICANCE: The overall objective of the project has been to evaluate the technical and financial performance and durability of the hydrogen production and dispensing station equipment, and support a fleet of hydrogen Fuel Cell Electric Buses (FCEB) operated by the County of Hawaiʻi Mass Transit Agency (MTA).

BACKGROUND: Under a series of awards, HNEI developed and commissioned a 65 kg/day hydrogen production and dispensing station at the Natural Energy Laboratory Hawaiʻi Authority (NELHA) on the Island of Hawaiʻi (Figure 1). The system was designed to dispense hydrogen at 350 bar (5,000 psi) to support refueling of heavy duty fuel cell electric buses (FCEB) intended for public service.

The knowledge gained in this project was intended to inform the MTA on benefits and issues associated with transitioning from a diesel bus fleet to a zero emissions FCEB fleet in support of the County of Hawaiʻi's clean transportation goals.

PROJECT STATUS/RESULTS: In 2021, HNEI commissioned a 65 kg/day hydrogen production and dispensing station at NELHA. The station uses a Proton Onsite (now Nel) electrolyzer to produce hydrogen at an outlet pressure of 30 bar (440) psi with a HydroPak compressor to compress the hydrogen to 450 bar (6,600 psi). The first on-site fill of an electric-fuel cell hybrid bus (FCEV) for public transportation took place on March 24, 2022.

The hydrogen dispensing system is connected to a fueling trailer via an underground hydrogen piping distribution system. The hydrogen dispenser is fully automated and programmed to "fail safe" for unattended operation.

The station includes a power monitoring system, which can monitor and control station operations by interfacing with the NELHA supervisory control and data acquisition (SCADA) system which monitors the NELHA microgrid and solar electric inputs. The total power consumption of the hydrogen system including the electrolyzer, compressor, and balance of plant is ~210 to 240 kW when operating at the maximum production rate of 65 kg/day (2.73 kg/hr). This corresponds to approximately 78-88 kwh/kg of compressed hydrogen.

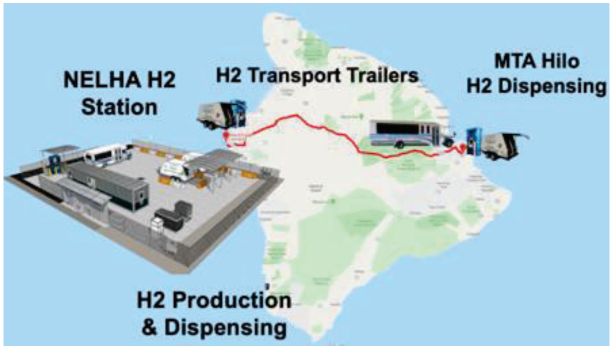


Figure 2. Concept map of hydrogen distribution.

As illustrated in Figure 2, the concept was to produce fuel cell grade hydrogen at NELHA and deliver it to the MTA base yard in Hilo to support heavy-duty

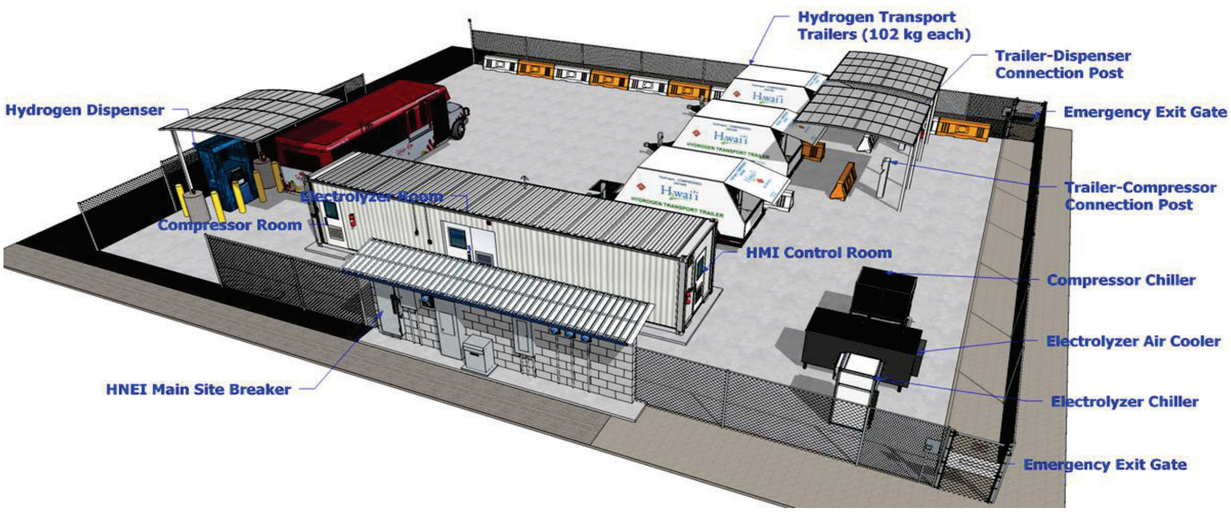


Figure 1. A diagram of the main components of the HNEI NELHA hydrogen station.

FCEBs operated by the MTA Hele-On public bus service. Three hydrogen transport trailers (HTT) each with a capacity of 105 kg were procured for transporting hydrogen between the production and fueling site.

In addition to technical demonstration, the station has supported community engagement and education of hydrogen technologies, such as the "Meet the Bus" community engagement event and educational tours.

The Hele-On 21-passenger FCEB (Bus #111) (Figure 3) was previously purchased with funds from the Energy Systems Development Special Fund. This bus, manufactured by Eldorado National, and converted to a hydrogen-electric drive train by U.S. Hybrid, is ADA-compliant.

Figure 3. The Hele-On 21-passenger FCEB.

Onboard hydrogen is stored in composite lightweight carbon fiber cylinders located under the bus with a capacity of 19 kg. The fuel cell power system is integrated with two 11 kWh (total 22 kWh) LG Lithium-ion battery packs to provide motive power to a 200 kW electric drive system. At cruising speed, the fuel cell maintains the battery state of charge within an optimal range to preserve performance and extend battery life.

Within the last year, the fuel cell power system was upgraded by replacing the original 30 kW Hydrogenics fuel cell with a new state-of-the-art 40 kW U.S. Hybrid fuel cell. Data on bus and fuel cell performance has been collected and is being analyzed.

Work on this project has also produced three peer-reviewed publications:

- 2023, A. Ku, et al., **Opportunities for the materials research community to support the development of the H2 economy**, MRS Energy & Sustainability, Vol. 10, Issue 2, pp. 158-173.
- 2020, M. Virji, et al., **Analyses of hydrogen energy system as a grid management tool for the Hawaiian Isles**, International Journal of Hydrogen Energy, Vol. 45, Issue 15, pp. 8052-8066.
- 2020, A. Headley, et al., **Valuation and cost reduction of behind-the-meter hydrogen production in Hawai'i**, MRS Energy & Sustainability, Vol. 7, Paper E26.

Negotiations are currently underway to transfer owenership of the station to NELHA, a state agency under the Department of Business, Economic Development and Tourism (DBEDT). Transition of assets, along with ongoing operations and maintenance, are currenlty being addressed between HNEI and NELHA.

Funding Sources: U.S. Department of Energy; Office of Naval Research; NELHA; U.S. Hybrid; State of Hawai'i Hydrogen Fund; County of Hawai'i; Energy Systems Development Special Fund

Contact: Richard Rocheleau, rochelea@hawaii.edu;
Aaron McCall, apmccall@hawaii.edu

Last Updated: November 2025

E1: Enabling Durable Fuel Cell Operation via Contaminant Mitigation

OBJECTIVE AND SIGNIFICANCE: Fuel cells offer the opportunity to significantly increase the flight duration of electric powered unmanned aerial vehicles (UAVs). With fuel cell power systems, increases of 5-10x in flight duration are possible for the same volume and weight constraints as high energy lithium batteries. Under this project, HNEI continued support to Naval Research Laboratory (NRL) efforts to develop lightweight, high efficiency fuel cell systems for UAVs including developing components that enhance contaminant tolerance. Contamination mechanisms in proton exchange membrane (PEM) fuel cells can become quite complex with many sources (air, fuel, system materials) and problems can be compounded by the contaminant reaction products that impact many key fuel cell materials.

BACKGROUND: The partnership between HNEI and NRL began in 2009 and HNEI continues to support NRL's fuel cell (FC) development effort via diagnostic testing, evaluation of needs, and design recommendations. More recently, HNEI has shifted focus from testing support to working on the design, development, and demonstration of PEMFC components that enhance contaminant tolerance at elevated operating temperatures. Most industry efforts to address contamination have focused on low temperature (60-90°C) PEMFCs. High temperature (140-200°C) PEM (HTPEM) fuel cells, while not as fully developed, offer the benefits of higher contaminant tolerance and lower cost membranes compared to low temperature PEMFCs. Additionally, the higher operating temperatures can help reduce system complexity and provide opportunities for volume reduction, e.g. heat exchanger size reduction, a major consideration for use of FCs for small UAVs (0.5-5 kW).

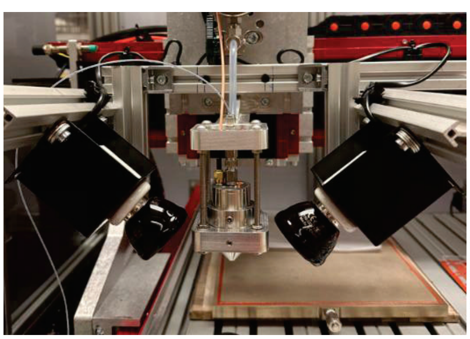
PROJECT STATUS/RESULTS: Under prior work, HNEI established an electrode fabrication system similar to one originally developed by NRL allowing the fabrication of custom catalyst coated membranes for small UAV-scale FCs. HNEI's fabrication is based on ultrasonic spray deposition and is adapted from the NRL protocol to work with high temperature materials with improved contamination resistance.

Within the past year, we began in-house production of gas diffusion electrodes with varying catalysts and other materials. Several modifications were made to the spray coating system, improving the reproducibility. Testing of these electrodes was conducted and a literature review was completed, identifying specific contaminants and concentration levels for further examination. Due to federal funding cuts in May 2025, this work was halted prior to initiating contaminant screening, however, work has now resumed under new funding from the Office of Naval Research.

Funding Source: Office of Naval Research

Contact: Edward Bruffey, ebruffey@hawaii.edu

Last Updated: November 2025



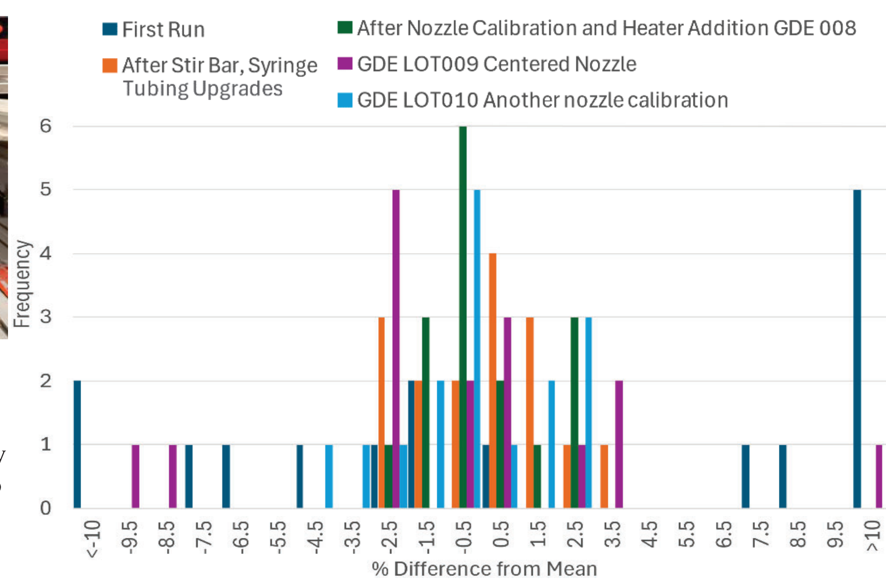


Figure 1. Radiant heater modification to ultrasonic spray coating system (left). Histogram showing improvements to electrode catalyst loading reproducibility of spray coated decreased from ±15% to ±2.5% with spray coated modifications (right).

E2: Materials Enablers for Advanced Manufacturing of Attritable Fuel Cells

OBJECTIVE AND SIGNIFICANCE: Hydrogen fuel cell systems are well suited to power small unmanned systems. Since cost remains an issue for these small systems, our focus is to develop design simplification that leads to cost reductions, while retaining the best possible performance. Hence, the concept of an attritable fuel cell, with "attritable" effectively being defined by the degree to which a product's performance is intentionally reduced to achieve lower cost. More specifically, the objective of this project is to eliminate the bipolar plate in the stack assembly and replace it with an embedded current collector in each cell with a unitized assembly incorporating the electrodes, current collectors, and flow path and gas manifolding.

BACKGROUND: Hydrogen fuel cells can produce electric power with a low thermal signature and operate with minimum maintenance, providing an important complement to battery electric systems and internal combustion engines. The key advantage over the incumbent technologies is the 4-8x gravimetric energy storage density of the hydrogen fuel over batteries, which translates into 4-8x endurance/range for systems and low signature DC power with improved start times over internal combustion engines. Key technical challenges remain for hydrogen fuel cells, namely cost, heat rejection, and volumetric storage density of hydrogen as compared to logistic fuels.

A large fraction of cost of system fabrication for small-scale fuel cells is associated with the bipolar plates and the labor costs associated with building the device because of the large part count. We are seeking to move fuel cell (FC) manufacturing closer to battery manufacturing, in which continuous reel-to-reel process are used to manufacture the electrode, which are then rolled or stacked into containers that require very little handwork or parts registration.

PROJECT STATUS/RESULTS: To meet our goals, a new lamination processes leveraging the latest advances in flexible electronics manufacturing is being developed. This proposed process preserves electrochemical activity, uses new methods to simplify fabrication and assembly, and incorporates new materials enablers to achieve a significant cost decrease over state-of-the-art FCs. The approach allows for multiple cells to be connected on a single plane and aggregated into one unitized FC produced continuously.

To date, a successful demonstration of a multi-cell planar array FC was completed—validating the ability to use flexible printed circuit boards (PCB) as a current collector in a laminated structure for development of multi-cell planar arrays of FCs. The demonstration was completed with a 2-cell prototype with 1 cm x 10 cm high temperature (HT) FCs using flexible PCB-based current collectors. The flexible PCBs were produced with 2 oz copper and a Dupont HN polyimide coverlay, validating the materials further usage assembling planar arrays of HT proton exchange membrane FCs operating at 160°C with free phosphoric acid in contact with the current collectors. Future work will expand upon past year successes scaling up to a 100 W demonstration module.

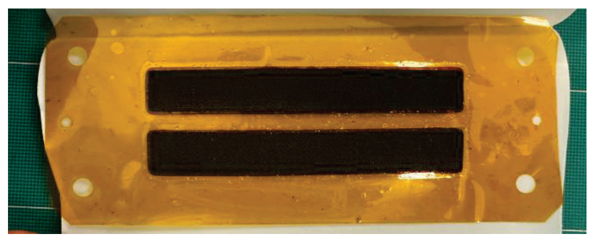


Figure 1. Demonstrated ability to fabricate a 2-cell membrane electrode assembly using flexible PCB technology.

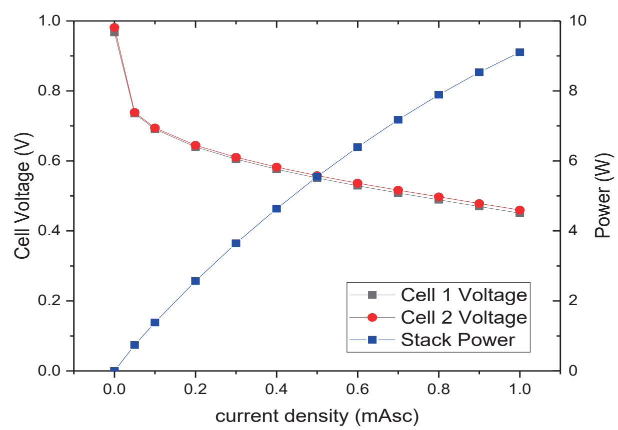


Figure 2. 2-cell performance curves from successful demonstration of planar current collector designs laminated with 2-cell membrane electrode assembly.

Funding Source: Office of Naval Research

Contact: Keith Bethune, bethune@hawaii.edu

Last Updated: November 2025

E3: Transition Metal Carbide Catalysts for Electrochemical Applications

Objective and Significance: The objective of this project is to develop transition metal carbide catalysts for electrochemical applications. These carbide catalysts have the potential to improve the performance of a variety of electrochemical devices including fuel cells, water electrolyzers, and vanadium redox flow batteries.

Background: The commercial application of a number of electrochemical technologies would benefit from the availability of low cost, efficient, and durable catalysts. Pt-group-metal catalysts are used in most commercially available fuel cells and water electrolyzers. Unfortunately, they have the short-comings of high cost, low earth abundance, and limited lifetime. Transition metal carbides are attractive candidates because they possess an electronic structure similar to Pt, which promotes high activities, good electrical conductivity, low cost, high abundance, and outstanding thermal and chemical stabilities. However, carbide synthesis is a challenge for achieving high surface area particles due to the inevitable aggregation during the high-temperature carburization.

Project Status/Results: This work is exploring a simple and environmentally friendly synthesis process for carbides that involve in-situ carburization of a metal precursor and a carbon material. V_8C_7/XC72 and V_6C_5/XC72 were synthesized by adjusting the synthesis process (Figure 1a). It should be mentioned that the V_8C_7/XC72 here was obtained at lower temperatures compared with previous work. There is no evidence of the presence of any vanadium oxide in both V_8C_7/XC72 and V_6C_5/XC72. Molybdenum carbide was also synthesized. As shown in Figure 1b, no crystal structure changes after acid leaching in 3 M H_2SO_4 at 80°C, indicating that Mo_2C is acid resistant.

The literature reveals that the molybdenum carbide is very reactive toward sulfur-containing molecules oxidation. Preliminary results showed that carbon black supported vanadium carbides exhibited good electro-catalytic activity toward the electrochemical oxidation of aqueous SO_2, which would be promising SO_2-active catalysts.

Future studies will include validation of the electrochemical oxidation of aqueous SO_2 at these catalysts by ex-situ cyclic voltammetry in acidic medium, integration of the contaminant-active catalyst in MEA using the ultrasonic spray coater at HNEI, and evaluation the contaminant tolerance of a PEM fuel cell to SO_2 with an in-situ catalytic conversion layer to demonstrate its practical application.

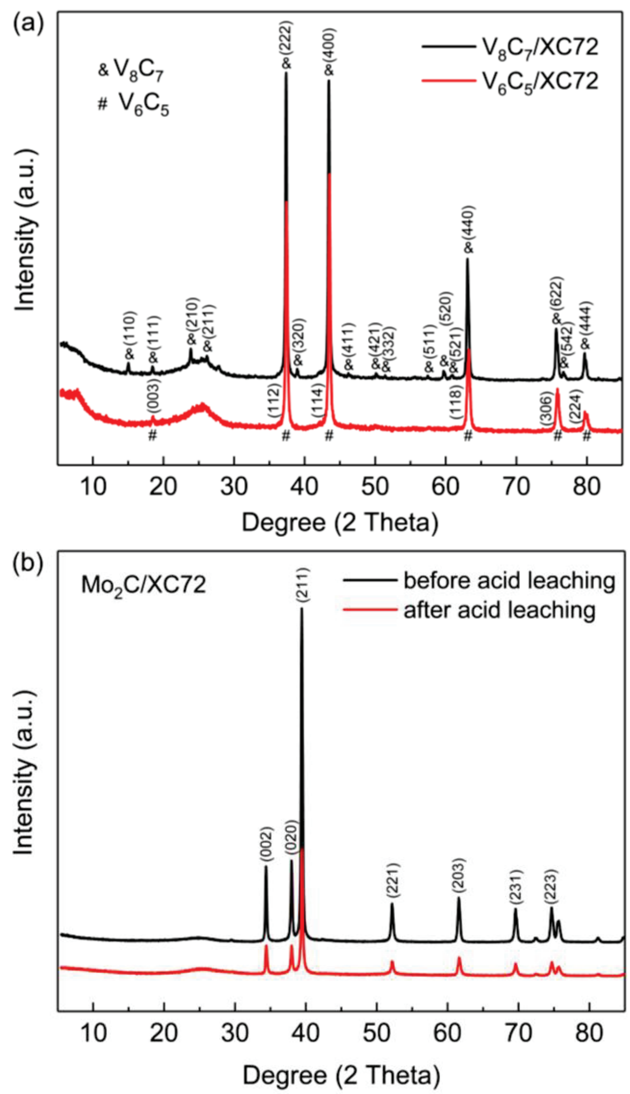


Figure 1. XRD patterns of (a) vanadium and (b) molybdenum carbides.

Funding Source: Office of Naval Research

Contact: Jing Qi, qijing@hawaii.edu

Last Updated: November 2025

E4: Proton Conducting Electrolytes for HT-PEMFCs

<u>OBJECTIVE AND SIGNIFICANCE</u>: The objective of this project is to develop a novel inorganic electrolyte with high proton conductivity under high temperature and low humidity to be used in the cathode catalyst layer of high temperature proton exchange membrane fuel cells (HT-PEMFC) to overcome the phosphoric acid (H_3PO_4) leaching issue. Operation of PEMFCs at HTs would facilitate meeting U.S. Department of Energy's (DOE) technical targets for performance, power and energy density, cost, and liability by inhibiting the poisoning effects of air pollutants and fuel impurities and simplifying the system's water and heat management.

<u>BACKGROUND</u>: PEMFCs are considered a promising clean energy technology for transportation and stationary applications. Contaminants in air and hydrogen fuel are a major challenge for the Pt catalysts in a typical PEMFC when it is operated in the realistic atmosphere. HT operation (150-200°C) of PEMFCs has been considered as one of the potential solutions to mitigate the poisoning effects due to the high conversion rate or weak adsorption of the contaminants. HT operation also facilitates the heat transport and the mass transfer of oxygen and hydrogen because of the large temperature difference and the absence of liquid water in membrane electrode assembly (MEA), respectively. With those advantages, HT-PEMFCs also eliminate the humidifier and simplify the air and fuel supply and the cooling system. However, the current perfluorosulfonic acid (PFSA, Nafion®) polymer electrolytes are limited in application below 90°C. The high temperature polymer PBI doped with H_3PO_4 (H_3PO_4/PBI) has been used as the PEM and the electrolyte in the catalyst layer of HT-PEMFC. However, H_3PO_4 leaching is a major issue during operation, especially from the cathode catalyst layer.

Recently, inorganic materials with "water in solid" or "electron hole defects" have been developed as proton conducting electrolytes for the proton batteries or the electrochemical sensors. The hydrogen bond switching among the ligand water or defect sites provide a fast proton transport network in mutilayer structures or on the particle surface. These proton conducting materals can also be used in the catalyst layers of the HT-PEMFC.

<u>PROJECT STATUS/RESULTS</u>: At HNEI, novel inorganic materials have been developed as a proton conducting electrolyte for HT-PEMFCs. These include a multilayer structure material, referred to as "VP"; and another based on ceramic nanoparticles, referred to as "SP." Some of the candidates electrolytes show a good proton conductivity at 20-200°C and low relative humidity. The selected condidates will be integrated in the cathode catalyst layer of HT-MEAs to overcome H_3PO_4 leaching and contaminants poisoning issues for the contaminant tolerant PEMFCs.

The yields of the proton conducting electrolyte powders have been improved from ~5% in the initial work to ~50% by optimizing the conditions of synthesis and scale up of the materials production to 10 grams per batch. The proton conductivity of the materials was preliminarily evaluated with single cell hardware and then a special conductivity test platform. The properties of the materials (thermal and chemical stability, composition and solubility, and the particles size impact on the proton conductivity) were initially analyzed and evaluated. Microscope images of the proton conducting powder/particles are shown in Figures 1 and 2.

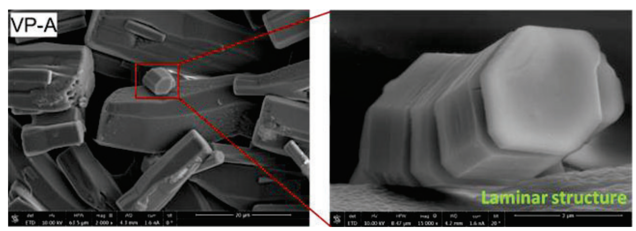


Figure 1. The scanning electron microscopy (SEM) images of VP powders.

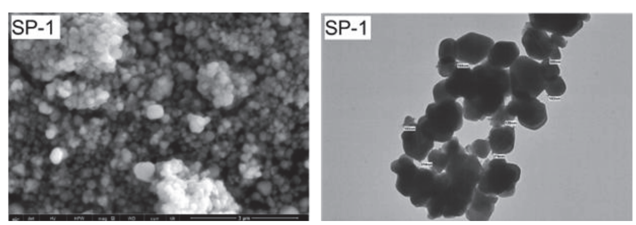


Figure 2. The SEM and transmission electron microscopy (TEM) images of SP particles.

The electrolyte powder pellets demonstrate a proton conductivity of ~10^{-3} ~10^{-5} Scm^{-1} in the range of from room temperature to 200°C and low relative humidity. Figure 3 shows the representative results of the two materials without humidification. It can be seen that the conductivity of both pellets increases with the rise of temperature, and SP material has better performance than the VP-A material within the overall testing temperature range.

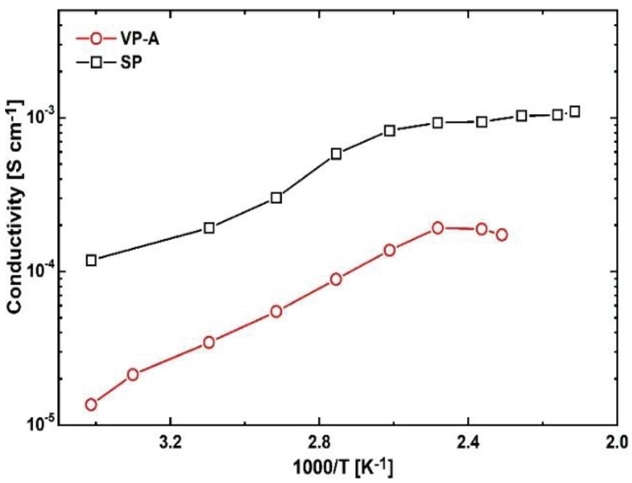


Figure 3. The proton conductivity of the proton conducting material pellets at temperature 20-200°C without humidification.

Both of the materials are insoluble in water or low concentration acids, and thermal stable up to 300°C in inert or air environment. VP-A is electrochemically stable within the PEMFC cathode operating potential range but not below -0.1V or H_2/Pt environment. The proton conductivity in boundary/interface increases with the particle size decrease.

This effort was partly supported by a multi-year collaboration of industrial and academic partners, titled "High Performing and Durable MEAs with Novel Electrode Structures and Hydrocarbon Proton Exchange Membranes" funded by the U.S. Department of Energy (DOE). Unfortunately, this award was terminated due to policy changes at DOE.

In the future, the properties and performance of the materials will be further studied and improved with the optimization of the synthesis procedures. The powder/particle will be reduced in size to meet the MEA catalyst layer requirements and then integrated into the cathode catalyst layers of HT-MEAs. The performance of HT-PEMFC with the selected proton conductive materials will also be evaluated at 150-200°C.

Funding Source: Office of Naval Research; U. S. Department of Energy

Contact: Yunfeng Zhai, yunfeng@hawaii.edu

Last Updated: November 2025

E5: Anion Exchange Membrane Fuel Cell

OBJECTIVE AND SIGNIFICANCE: Interest in anion exchange membrane fuel cells (AEMFCs) is driven by the potential for lower cost and increased durability. The goals of this project are to: 1) evaluate the performance of AEMFCs with platinum group metal (PGM) content and PGM-free cathode catalysts under various operating conditions; 2) study effects of membrane electrode assembly (MEA) components on mass transport, water management, and durability; and 3) develop electrochemical diagnostic and analysis methods applicable for AEMFC evaluation.

BACKGROUND: The most compelling motivation for exploring AEMFCs technology stems from the prospect of eliminating Pt-based catalysts from both the anode and cathode. This is due to the fact that PGM-free materials exhibit higher intrinsic catalytic activity towards oxygen reduction in alkaline media compared to Pt-based catalysts (Figure 1).

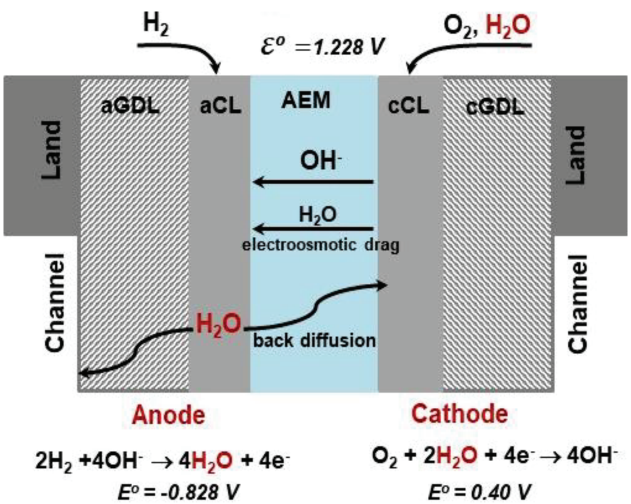


Figure 1. Schematic representation of an AEMFC.

Operation in an alkaline environment is less corrosive and can improve durability. Finally, AEMFCs are notable for their ability to operate with liquid fuels and oxidants, a feature that enhances their versatility for a range of applications and derivative technologies.

AEMFC operation requires oxygen and water at the cathode, while water is produced at the anode, an arrangement that is the exact opposite of that in proton exchange membrane fuel cells (PEMFCs). This fundamental difference introduces additional complexity and makes it difficult to directly apply PEMFC MEA fabrication methods to AEMFCs. Enhancing AEMFC performance and durability largely depends on the design of catalyst layers with optimized porosity, hydroxide ion conductivity, and thickness to ensure the formation of effective three-phase boundaries and efficient transport of reactants.

The main approach to improve AEMFC performance and durability is a design of catalyst layers with optimal porosity, hydroxide ion conductivity, and thickness to insure development of three phase boundaries, and sufficient reagents transport, as well as adequate choice of gas diffusion layers (GDLs) for better water management. In addition, there is a lack of harmonized testing protocols and procedures and development of electrochemical diagnostics and approaches are critical for AEMFCs.

PROJECT STATUS/RESULTS: To date, HNEI's efforts under this project has allowed us to reach the following results:

- **In-house capabilities for manufacturing catalyst-coated membranes and catalyst-coated substrates** were established, enabling rapid screening and evaluation of new materials;
- **Break-in procedures for AEMFCs were optimized,** recognizing their differences from PEMFCs. Based on literature review and discussions with manufacturers, holding the cell voltage at 0.4 V under operating conditions was selected as the most effective approach.
- **Operational parameters, particularly gas humidification,** were shown to significantly impact AEMFC performance. Reduced anode humidification improved power density, achieving values up to 800 mW cm^{-2};
- **Compression ratio studies identified an optimal range of 20-25%** to ensure MEA durability and stable performance;
- **Variability in MEA performance was observed,** with higher electrochemical surface area (ECA) and lower high-frequency resistance (HFR) correlating with better results. Ink preparation temperature and deposition conditions were identified as critical factors influencing catalyst layer quality;
- **Pretreatment of CCMs in KOH was necessary for ionomer alkalization.** A short-term KOH soak (3 hours) was found to be as

effective as longer treatments, simplifying MEA preparation; and

- **The application of PtRu/C bimetallic catalysts improved hydrogen oxidation reaction activity** and overall fuel cell performance compared to conventional Pt/C catalysts.

Due to funding cuts resulting from various policy decisions, the continuation of this work is being reevaluated.

Funding Source: Office of Naval Research

Contact: Tatyana Reshetenko, tatyanar@hawaii.edu

Last Updated: November 2025

E6: Catalyst-Modified PEMFCs for Hydrogen Peroxide and Power Co-Generation

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to modify a proton exchange membrane fuel cell (PEMFC) to allow electrochemical synthesis of hydrogen peroxide. The process simultaneously produces energy and aqueous solutions of varied hydrogen peroxide concentrations while being scalable.

BACKGROUND: Hydrogen peroxide is considered among the world's top 100 most important chemicals as it is very versatile and is mainly an eco-friendly disinfectant. Over 95% of hydrogen peroxide is produced from an anthraquinone-oxidation process, which is very costly—mainly since it can only economically work at large scale. Moreover, it is a batch process that requires further separation and dilution processes, which also necessitate enormous amounts of energy to conduct. These dilution processes are vital as a safety measure to transport hydrogen peroxide over a range of distances due to its explosive nature as an oxidant. The substantial risks associated with the transportation of hydrogen peroxide alone produces a major need for scalable, onsite production of this chemical. If successful, onsite production would also provide the means for wastewater treatment in rural communities.

PROJECT STATUS/RESULTS: A rotating ring-disc electrode (RRDE) measurement system, was used to conduct ex-situ experiments to identify a stable catalyst which could perform effectively and maintain integrity under the challenging conditions within a fuel cell. After achieving a stable catalyst, further experiments were conducted to optimize the operational parameters for the co-generation of hydrogen peroxide and electricity. It was observed that the catalyst, when used without applying potential holds, produced the highest yield of hydrogen peroxide. However, introducing potential holds led to a significant increase in current suggesting enhanced efficiency for electricity generation. Despite a slight reduction in hydrogen peroxide production with the potential holds, the trade-off was a marked improvement in overall current performance.

These results elucidate possible preferred conditions to maximize the production of hydrogen peroxide and electricity at an applied potential near 0.3 V with an indirect measurement of hydrogen peroxide yield up to 89%.

With the ex-situ work having demonstrated a set of operational parameters sufficient for inducing significant peroxide formation while simultaneously producing electricity, work began by scaling up to a working single cell PEMFC. An industry standard 50 cm^2 fuel cell test hardware was selected as a starting point, as this hardware has been well-characterized over the years. We established a test protocol to systematically evaluate and optimize the production, removal, and capture of aqueous hydrogen peroxide from the system. Several parameters were explored to evaluate the impact on the hydrogen peroxide yields and the resultant power production from the cell.

Generally, we found it difficult to distinguish whether low reaction efficiency is occurring or high reaction efficiency with decomposition of peroxide occurring prior to measurement. Ex-situ RRDE-based experiments were able to achieve upwards of 60-80% production efficiencies while the best achieved in-situ prior to end of the grant was 1-3%, which may be sufficient for water purification applications. However, ultimately the goal is to achieve >50% faradaic efficiencies.

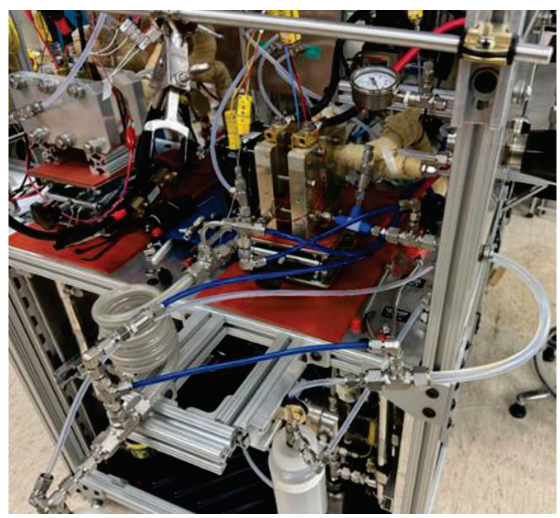


Figure 1. In-situ test hardware and hydrogen peroxide effluent collection equipment.

Funding Source: Office of Naval Research

Contact: Edward Bruffey, ebruffey@hawaii.edu

Last Updated: November 2025

E7: Path Dependence of Battery Degradation

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to characterize the impact of different stresses on the durability of lithium- and sodium-ion batteries using large experimental campaigns and design of experiments. Studies address, among others, the impact of fast charging and grid-vehicle interactions on the performance of batteries for electric transportation. The knowledge gained in this project informs best practices to successful battery durability, safety, fast charging, or vehicle-to-X integration.

BACKGROUND: Electrification of transportation and grid-storage are crucial to combat climate change. Understanding and mitigating battery degradation is key to improving durability of electric transportation and the reliability of power grids. Complexity stems from the fact that battery degradation is path dependent. This implies that usage affects not only the degradation pace, but also the type of degradation the batteries experience. Lithium-ion batteries are known to degrade slowly at first before a rapid acceleration of which starting time will depend on the mix of degradation mechanisms and thus on how the battery was used. To maximize the utility of large battery systems, it is essential to understand the impact of all the stress factors associated with an application and their combined effects.

PROJECT STATUS/RESULTS: Work with the Defence Science and Technology Group (DSTG, Australia) involving an experimental campaign of more than 700 cells tested for three years under a HNEI-defined design of experiments to predict the degradation of MW systems and maximize durability and reliability in the field was completed.

Further research is continuing with collaborative work with Sandia National Laboratories, the University of Aachen (Germany), and the University of Oviedo (Spain) to address the performance and safety of newly released commercial sodium-ion batteries. Research conducted for this project is completed in the **PakaLi Battery Laboratory**.

This work has led to 15 publications and 10 presentations, all available on the **project page** with the most recent linked on the following page.

Funding Sources: Office of Naval Research; Defence Science and Technology Group (Australia); Sandia National Laboratories; VoltR (France)

Contact: Matthieu Dubarry, matthieu@hawaii.edu

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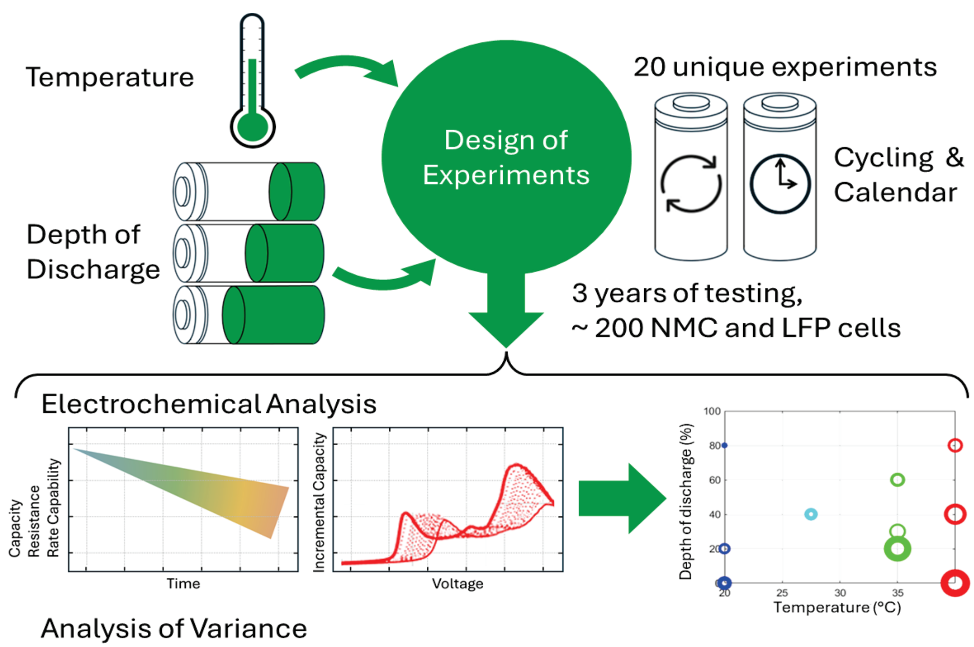

$$Q, R, RC = a.T + b.DOD + c.T.DOD + d.T^2 + e.DOD^2$$

Figure 1. Summary overview of the project's DSTG study.

Additional Project Links

Papers and Proceedings:

1. 2026, R.M. Wittman, et al., **Initial characterization and cycling of two batches of commercial hard-carbon/$Na_xNi_yFe_zMn_{1-y-z}O_2$ sodium ion 18650 batteries as a potential replacement for lithium-ion batteries**, EES Batteries. (Open Access: **PDF**)
2. 2025, M. Dubarry, et al., **Impact of Temperature and Depth of Discharge on Commercial Nickel Manganese Oxide and Lithium Iron Phosphate Batteries After Three Years of Aging**, Batteries, Vol. 11, Issue 7, Paper 239. (Open Access: **PDF**)
3. 2025, S. Klick, et al., **Failure Mode and Degradation Analysis of a Commercial Sodium-Ion Battery With Severe Gassing Issue**, Batteries & Supercaps, Paper e202400546. (Open Access: **PDF**)
4. 2023, R. Wittman, et al., **Characterization of Cycle-Aged Commercial NMC and NCA Lithium-ion Cells: I. Temperature-Dependent Degradation**, Journal of The Electrochemical Society, Vol. 170, Issue 12, Paper 120538. (Open Access: **PDF**)
5. 2023, A. Gismero, et al., **The Influence of Testing Conditions on State of Health Estimations of Electric Vehicle Lithium-Ion Batteries Using an Incremental Capacity Analysis**, Batteries, Vol. 9, Issue 12, Paper 568. (Open Access: **PDF**)
6. 2022, P.M. Attia, et al., **Review—"Knees" in Lithium-Ion Battery Aging Trajectories**, Journal of The Electrochemical Society, Vol. 169, Issue 6, Paper 060517. (Open Access: **PDF**)
7. 2021, D. Beck, et al., **Inhomogeneities and Cell-to-Cell Variations in Lithium-Ion Batteries, a Review**, Energies, Vol. 14, Issue 11, Paper 3276. (Open Access: **PDF**)
8. 2020, M. Elliott, et al., **Degradation of electric vehicle lithium-ion batteries in electricity grid services**, Journal of Energy Storage, Vol. 32, Paper 101873.
9. 2020, G. Baure, et al., **Durability and Reliability of EV Batteries under Electric Utility Grid Operations: Impact of Frequency Regulation Usage on Cell Degradation**, Energies, Vol. 13, Issue 10, Paper 2494. (Open Access: **PDF**)

Presentations:

1. 2025, R.M. Wittman, et al., **Analysis of Iron Manganese Nickel Oxide/Hard Carbon Na-Ion Battery Degradation Modes and Mechanisms**, Presented at the 248th ECS Meeting, Chicago, IL, October 12-16.
2. 2024, R.M. Wittman, et al., **Analysis of Commercial Na-Ion 18650 Cell Performance: Cell-to-Cell Variation and Long-Term Cycling**, Presented at the 246th ECS Meeting, Honolulu, HI, October 6-11.
3. 2022, R. Wittman, et al., **Path Dependence of Li-Ion Battery Degradation During Cycling to 80% Capacity**, Presented at the Material Research Society Spring Meeting, May 8-13.
4. 2021, R. Wittman, et al., **Characterizing Materials and Electrochemical Changes in a Range of 18650 Li-Ion Cells Cycled to 80% Initial Capacity**, Presented at the 239th ECS Meeting, Chicago, IL, May 30-June 3.

E8: Battery Intelligence: Diagnosis and Prognosis

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to develop approaches, tools, and protocols to improve batteries diagnosis and prognosis via non-invasive in-operando techniques.

BACKGROUND: Battery diagnosis and prognosis is a difficult task. Lithium- and sodium-ion batteries are much more complex than traditional batteries and their degradation is path dependent as different usages (current, temperature, state of charge range/window, etc.) will lead to different type of degradation. In addition, since large battery packs are composed of thousands of cells, the use of complex models or multitude of sensors is precluded.

Traditionally, battery diagnosis is handled via two opposite approaches. The academic route aims for maximum accuracy and achieves it by inputting a lot of resources. The second route, the one usually used on deployed systems, uses as little resources as possible and must not be destructive. As a result, it is ineffective in predicting the true state of health.

PROJECT STATUS/RESULTS: This assessment led HNEI to define and develop a third industry-compatible intermediate route to reach an accurate diagnosis with cost-effective and non-destructive methods, using only sensors already available in battery packs while requiring limiting computing power. HNEI developed a mechanistic modeling framework where a battery digital twin is built from individual electrode data and where the battery degradation is emulated by the scaling or the translation of one electrode versus the other. Using this framework, the voltage variations associated with the degradation mechanisms can be predicted.

Machine learning and artificial intelligence are also starting to play a crucial role in diagnosing and prognosing batteries. However, their accuracy is limited by the little to no training data available to validate algorithms. To solve this issue, HNEI applied the mechanistic modeling approach to develop the first synthetic training datasets. Recent work highlighted the possible opportunistic diagnosis of battery usage for photovoltaic-connected batteries using models trained and validated on synthetic datasets.

This project is currently ongoing with four industrial collaborations on different aspects of the problem including blends, silicon content, relaxation, and metal plating. Research conducted for this project is completed in the **PakaLi Battery Laboratory**.

A full suite of software and models were developed. The main model has been licensed by more than 150 organizations worldwide. This work has also led to a patent and over 55 publications, all available on the **project page** with the most recent linked on the following pages.

Funding Sources: Office of Naval Research; SAFT (France); Element Energy; ACCURE (Germany); VoltR (France), TVS Motor (India), BMW (Germany)

Contact: Matthieu Dubarry, matthieu@hawaii.edu

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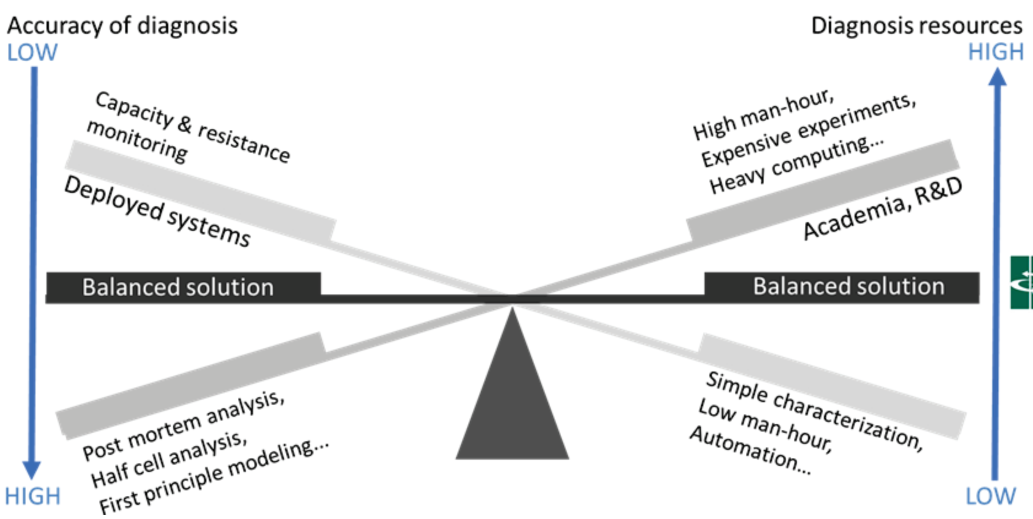


Additional Project Links

Papers and Proceedings:

Battery Testing

1. 2025, T. Rüther, et al., **Battery pack states, properties, and characterization techniques beyond cell level**, Cell Reports Physical Science, Vol. 6, Paper 102919. (Open Access: **PDF**)
2. 2025, A. Fernando, et al., **Model-Free Emulation of the Impact of Kinetics and Temperature on Commercial Li-ion Batteries**, Journal of Power Sources, Vol. 654, Paper 237796.
3. 2024, D. Beck, A. Greszta, A. Roberts, M. Dubarry, **Improved Mechanistic Degradation Modes Modeling of Lithium and Sodium Plating**, Batteries, Vol. 10, Issue 12, Paper 408. (Open Access: **PDF**)
4. 2024, M. Dubarry, et al., **Communication—Forecast of the Impact of Degradation Modes on a Commercial Hard Carbon/$Na_3V_2(PO_4)_2F_3$-based Na-ion Battery**, Journal of the Electrochemical Society, Vol. 171, Issue 8, Paper 080541. (Open Access: **PDF**)
5. 2024, A. Fernando, et al., **Voltage relaxation characterization methods in lithium-ion batteries**, Measurement: Energy, Vol. 3, Paper 100013. (Open Access: **PDF**)
6. 2024, A. Fernando, et al., **Benchmark dataset for the study of the relaxation of commercial NMC-811 and LFP cells**, Cell Reports Physical Science, Vol. 5, Issue 1, Paper 101754. (Open Access: **PDF**)

Battery Modeling

1. 2025, P.O. Mmeka, M. Dubarry, W.G. Bessler, **Physics-Informed Aging-Sensitive Equivalent Circuit Model for Predicting the Knee in Lithium-Ion Batteries**, Journal of the Electrochemical Society, Vol. 172, Issue 8, Paper 080538. (Open Access: **PDF**)
2. 2025, G. Darikas, M. Dubarry, A. Barai, M. Amor-Segan, D. Greenwood, **Assessment of the Impact of Silicon on Loss of Active Material Quantification in Blended Silicon/Graphite Negative Electrodes**, Journal of the Electrochemical Society, Vol. 172, Issue 8, Paper 080536. (Open Access: **PDF**)
3. 2025, F. Yasir, S. Sepasi, M. Dubarry, **Big Data Study of the Impact of Residential Usage and Inhomogeneities on the Diagnosability of PV-Connected Batteries**, Batteries, Vol. 11, Issue 4, Paper 154. (Open Access: **PDF**)
4. 2024, M. Dubarry, et al., **Investigation of the impact of different electrode inhomogeneities on the voltage response of Li-ion batteries**, Cell Reports Physical Science, Vol. 5, Paper 102138. (Open Access: **PDF**)
5. 2024, D. Beck, et al., **Electrode Blending Simulations Using the Mechanistic Degradation Modes Modeling Approach**, Batteries, Vol. 10, Issue 5, Paper 159. (Open Access: **PDF**)
6. 2024, N. Costa, et al., **ICFormer: A Deep Learning model for informed lithium-ion battery diagnosis and early knee detection**, Journal of Power Sources, Vol. 592, Paper 233910. (Open Access: **PDF**)

Presentations:

5. 2025, P.O. Mmeka, et al., **A Physically-Informed and Aging-Sensitive Equivalent Circuit Model for Predicting the Knee in Lithium-Ion Batteries**, Presented at the 248th ECS Meeting, Chicago, IL, Oct. 12-16.
6. 2025, M. Dubarry, **Recent Advances on Degradation Modes Modeling for Li-Ion and Na-Ion Batteries**, Presented at the 247th ECS Meeting, Montréal, Canada, May 18-22.
7. 2024, T. Hofmann, et al., **Transfer Learning from Synthetic Data for SOH Estimation**, Presented at the 246th ECS Meeting, Honolulu, HI, Oct. 6-11.
8. 2024, M. Dubarry, et al., **Investigation of the Impact of Different Electrode Inhomogeneities on the Voltage Response of Li-Ion Batteries**, Presented at the 246th ECS Meeting, Honolulu, HI, Oct. 6-11.
9. 2024, D. Beck, et al., **Electrode Blending Simulations Using the Mechanistic Degradation Modes Modeling Approach**, Presented at the 246th ECS Meeting, Honolulu, HI, Oct. 6-11.

E9: Battery Electrode Optimization

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to improve battery performance by understanding local degradation mechanisms and by tuning the electrode architecture.

BACKGROUND: Advanced energy conversion devices typically rely on composites electrodes made of several materials interacting with one another. Understanding their individual and combined impact on degradation is essential in the pursuit of the best possible performance and safety.

PROJECT STATUS/RESULTS: In this project, we use our expertise in Li-ion battery diagnosis as well as designs of experiments (DoE) to optimize formulations and to investigate the importance of process parameters while minimizing resources.

Defining new approaches to minimize experiments and time to reach an optimal battery electrode composition is highly beneficial to the field. To this end, we used a DoE mixture design that was applied for the first time in open literature to electrode formulation. Consequently, the relationship between electrode composition, microstructure, and electrochemical performance was uncovered.

Recent work focused on battery cooling and the development of a segmented thermal dummy cell that thermally behaves like a battery without the risks associated with its usage. Taking a segmented approach will allow to account for the impact of thermal gradients, a major issue impacting cell durability and safety.

Most efforts over the past year were devoted to the development of the second prototype of the segmented thermal dummy cell that demonstrated heating and cooling rate similar that of the ones of real lithium-ion batteries. In addition, our expertise in battery degradation was used to help researchers at the Naval Research Laboratory characterize the impact of local temperature gradients on individual electrodes and by researchers at Sandia National Laboratories to investigate the impact of overcharge.

Research conducted for this project is completed in the **PakaLi Battery Laboratory**. This work has led to three publications and several presentations, which are linked on the following page.

Funding Sources: Office of Naval Research; U.S. Department of Interior; Trevi Systems

Collaborations: University of Montreal (Canada); University of Nantes (France); Naval Research Laboratory; Sandia National Laboratories

Contact: Matthieu Dubarry, matthieu@hawaii.edu

Last Updated: November 2025

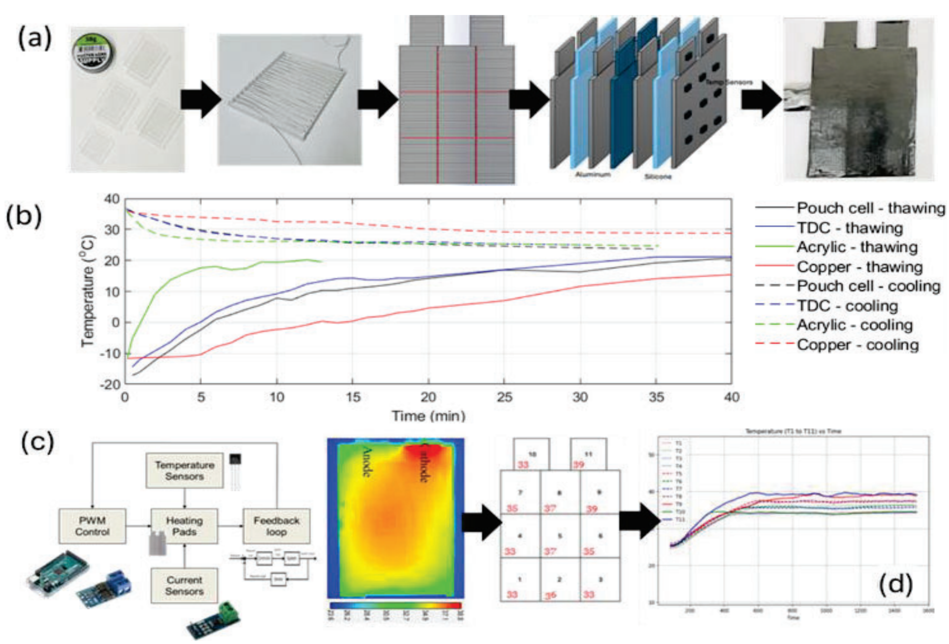


Figure 1. Generation 1 TDC with (a) the fabrication of the segments and assembly into the device; (b) comparison of the thawing and cooling rate between the TDC, a real pouch cell, an acrylic panel, and a copper plate; (c) the control scheme allowing the simulation of inhomogeneous heating; and (d) an example of inhomogeneous heating.

Additional Project Links

Papers and Proceedings:

1. 2021, R. Carter, T.A. Kingston, R.W. Atkinson III, M. Parmananda, M. Dubarry, C. Fear, P.P. Mukherjee, C.T. Love, **Directionality of thermal gradients in lithium-ion batteries dictates diverging degradation modes**, Cell Reports Physical Science, Vol. 2, Issue 2, Paper 100351. (Open Access: **PDF**)
2. 2020, O. Rynne, M. Dubarry, C. Molson, E. Nicolas, D. Lepage, A. Prébé, D. Aymé-Perrot, D. Rochefort, M. Dollé, **Exploiting Materials to Their Full Potential, a Li-Ion Battery Electrode Formulation Optimization Study**, ACS Applied Energy Materials, Vol. 3, Issue 3, pp. 2935-2948.
3. 2019, O. Rynne, M. Dubarry, C. Molson, D. Lepage, A. Prébé, D. Aymé-Perrot, D. Rochefort, M. Dollé, **Designs of Experiments for Beginners—A Quick Start Guide for Application to Electrode Formulation**, Batteries, Vol. 5, Issue 4, Paper 72. (Open Access: **PDF**)

Presentations:

1. 2025, R. Carter, T.A. Kingston, P.J. West, J. Knuerr, J-S. Park, V. Cooley, L.V. Morris, M. Dubarry, G.H. Waller, C.T. Love, **The Role of Thermal Variations in Battery Degradation: In-Situ Detection in 18650s Correlated to Fundamental Phenomena Investigation in Single-Layer Pouch and Coin Cells**, Presented at the 248th Electrochemical Society Meeting, Chicago, IL, October 12-16.
2. 2025, M.M.U. Ishtiaque, J. Ramamurthy, Q. Alahmad, M. Dubarry, C.L. Pint, T.A. Kingston, **Correlating Thermal Gradient and Ionic Migration Directionality to Lithium-Ion Battery Electrochemistry**, Presented at the 247th Electrochemical Society Meeting, Montréal, Canada, May 18-22.
3. 2023, C.T. Love, et al., **Evidence of the Interplay of Temperature on Local and Global Battery Phenomena**, presented at the 244th Electrochemical Society Meeting, October 8-12. *Keynote presentation*.
4. 2022, N. Sahin, et al, **Optimization of Prussian Blue Analogues for Na-Ion Desalination Batteries**, Poster presented at the Material Research Society Spring Meeting, May 8-13. *Best poster award Symposium EN05*.
5. 2022, C. T. Love, et al., **How Dynamic Thermal Evaluation of Battery Electrodes and Materials Better Replicate In-Service Operating Conditions**, Presented at the Material Research Society Spring Meeting, May 8-13.
6. 2021, T.A. Kingston, et al., **Altering the Degradation Mode in Li-ion Batteries Through Directional Application of an Interelectrode Thermal Gradient**, Presented at the International Mechanical Engineering Congress & Exposition, November 1-5.
7. 2021, C. T. Love, et al., **Electrode Specific Degradation Tailored By the Directionality of Thermal Gradients in Li-Ion Batteries**, Presented virtually at the 240th ECS Meeting, Orlando, FL, October 10-14.
8. 2021, C. T. Love, et al., **Directionality of Thermal Gradients in Li-Ion Batteries Dictates Diverging Failure Modes**, Presented virtually at the 239th ECS meeting, Chicago, IL, May 30 - June 3.
9. 2019. O. Rynne, et al., **Influence of the Formulation on the Microstructure and Thus Performance of Li-Ion Batteries**, Presented at the 235th ECS Meeting, Dallas, TX, May 26-30.

E10: Sodium Battery Development

OBJECTIVE AND SIGNIFICANCE: Electrochemical energy storage, paired with Hawaiʻi's strong solar resources, represent a feasible means of addressing the majority of Hawaiʻi's grid-scale energy demand. While lithium-ion batteries are ideal for portable applications such as electric vehicles and laptops, grid-scale applications place a greater emphasis on the cost of energy storage, creating an opportunity for alternative battery chemistries with lower cost materials.

Sodium-ion batteries represent a promising alternative to lithium-ion batteries, however, further research is needed to explore new electrode materials, understand their underlying physics, and measure their performance in battery systems, which is the aim of this project.

BACKGROUND: The two primary components of a sodium-ion battery are the positive electrode and the negative electrode. One promising positive electrode material is Prussian blue. However, the charge transport within Prussian blue nanoparticles and how it influences battery performance is not fully understood.

Unlike lithium ions which can wedge their way between the atomically separated layers of graphite, sodium ions are larger and do not fit into the graphite lattice. Therefore, different materials are required for sodium-ion batteries than lithium-ion batteries. One material that has shown promise for the negative electrode of sodium-ion batteries is hard carbon.

Within HNEI, there is an ongoing effort to synthesize biocarbons, and we hypothesized that perhaps these materials can mimic the properties of hard carbon. The electrochemical properties of biocarbon materials, and how novel manufacturing techniques could influence battery performance, are largely unexplored. However, if results are succesful, the novel biocarbon manufacturing process could represent a new lost-cost method for the manufacture of battery electrodes.

PROJECT STATUS/RESULTS: To explore the electrochemical performance of positive electrode materials, a Prussian blue analog was synthesized under room temperature conditions within HNEI's PakaLi Battery Laboratory (Figure 1, left). After synthesis, the Prussian blue nanoparticles were size filtered to vary the particle size with the goal of determining their influence on sodium ion intercalation physics.

On the negative electrode, biocarbon materials were obtained from HNEI's biomass research group. The carbon materials were ground into fine powder, integrated into sodium half-cells in a coin-cell form factor, and cycled electrochemically using a potentiostat to determine their electrochemical performance as compared with positive controls made using commercial hard carbon. Initial results are shown in Figure 1 (right).

The biocarbon material performed similar, to within the error of the measurement, to commercial hard carbon that was made using petrochemical products and was specifically designed for sodium-ion batteries, as measured during five discharge cycles. For a first test, the results were extremely promising. It seems as though the biocarbon can be an effective electrode for a sodium-ion battery.

Future work will characterize the materials in more detail to determine the suitability of the novel biocarbon process for manufacturing sodium-ion batteries at commercial scale.

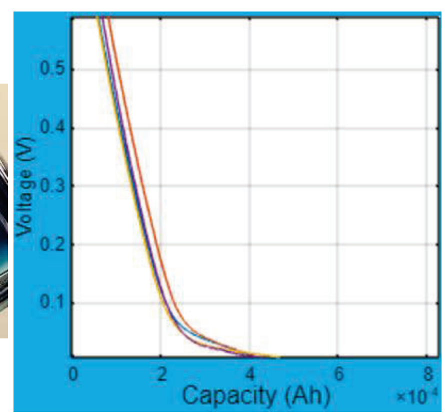


Figure 1. The Prussian blue analog that was synthesized (left) and the battery discharge data results showing that a sodium-ion biocarbon electrode is comparable to commercial hard carbon (right).

Funding Source: Office of Naval Research

Contact: Bob Lansdorp, lansdorp@hawaii.edu

Last Updated: November 2025

Hawai‘i Natural Energy Institute Research Highlights

Appendix F: Advanced Materials

F1: Printable Photovoltaics

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to develop high-throughput ink-based fabrication techniques for lightweight thin film photovoltaics (PV). This approach has the potential to reduce manufacturing costs and enable PV integration on non-conventional substrates such as polyamides or woven fabrics.

BACKGROUND: Crystalline silicon has been leading the PV market for over 20 years. These panels, found on rooftops and centralized production plants, are easily recognizable by their architecture, with interconnected wafer-like solar cells laminated under a flat sheet of glass. Although well-suited for stationary electrical production, the mechanical rigidity and weight of silicon PV modules becomes a burden for mobile applications, where portability is more critical than performance. To this end, R&D efforts have focused on methods to integrate ultra-light and flexible thin film solar materials onto lightweight/flexible substrates, including plastics (polyamides) and fabrics. Such devices can generate enough electricity to power small electronic devices for both civilian and military applications such as phones, electronic tablets, and sensors.

PROJECT STATUS/RESULTS: With support from the Office of Naval Research, the research team at HNEI's Thin Films Laboratory is developing a unique method to print thin film PV using liquid molecular inks, which contain the raw chemical elements necessary for the synthesis of the solar absorber. This low-cost printing process is intended to replace conventional vacuum-based deposition tools, which are costly to operate and maintain.

The research is currently focused on a multi-compound alloy ($CuInSe_2$, CISe)—a material which meets the mechanical and weight requirements for lightweight, flexible PV. HNEI's results demonstrate that high-quality CISe solar absorbers can be achieved with this printing technology, leading to solar cells with power conversion efficiency over 8%.

HNEI demonstrated that additives directly incorporated into the molecular ink, such as aluminum nitrate, can passivate native defects in CISe during fabrication, yielding to efficiency as high as 11% (Septina, 2021). Using state-of-the-art photoelectron spectroscopy techniques available at the University of Nevada, Las Vegas, the HNEI team discovered that aluminum nitrate reacted with oxygen during CISe growth to form nano-sized amorphous alumina (Al_2O_3) grains. This new process was found to passivate defects notably at grain boundaries and to improve the surface energetic properties of the CISe solar absorber.

To date, this research has produced the following publication:

- 2021, W. Septina, et al, ***In situ*** **Al_2O_3 incorporation enhances the efficiency of $CuIn(S,Se)_2$ solar cells prepared from molecular-ink solutions**, Journal of Mater. Chem. A, Vol. 9, Issue 16, pp. 10419-10426.

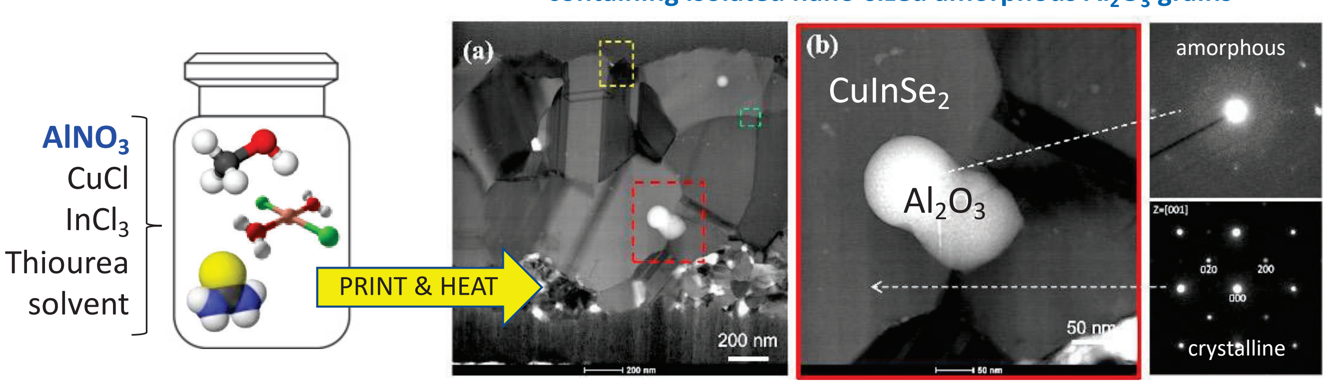
Funding Source: Office of Naval Research

Contact: Nicolas Gaillard, ngaillar@hawaii.edu

Last Updated: November 2025

Molecular ink

Cross-section of a 11% efficient CISe printed solar cell containing isolated nano-sized amorphous Al_2O_3 grains



F2: Two-Dimensional Materials for Thin Film Manipulation

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to develop methodologies to facilitate the manipulation of thin films utilizing two-dimensional (2D) interfacial layers. This approach has the potential to facilitate the physical transfer of high-efficiency devices, such as photovoltaics, from their original substrates to novel platforms, including clothing, vehicles, and buildings.

BACKGROUND: Monolithic integration—the process by which solid-state devices are made by sequentially depositing layers of materials on top of each other—is used in all commercial thin film-based technology. Despite its wide acceptance, however, monolithic integration presents two major limitations.

First, process compatibility is a challenge since the deposition of each layer must not damage the previously deposited underlying layers. As such, the thermal, mechanical, and chemical compatibility between layers and their deposition processes restricts materials selection, limiting the adoption of promising materials. Second, monolithic integration almost always leads to the formation of additional phases at the interface of two materials. The electronic and chemical properties of interfaces also generally differ significantly from those of a simple combination of the two constituting layers, which impacts device performance.

An integration scheme that combines materials regardless of their nature, while preserving or even enhancing their intrinsic performance, could revolutionize the manufacturing of technologies that rely on material stacking, including photovoltaic (PV) devices. Such an integration approach, using 2D materials for thin film manipulation, is being developed in this program.

PROJECT STATUS/RESULTS: HNEI and the University of Nevada, Las Vegas have partnered with the Lawrence Livermore National Laboratory and National Renewable Energy Laboratory to develop 2D material-assisted thin film exfoliation, focusing on the chalcopyrite class (e.g., $Cu(In,Ga)Se_2$, CIGSe) and transition metal dichalcogenides (e.g., MoS_2 and $MoSe_2$).

In this work, we use the so-called *metal-mediated exfoliation* (MME) process to isolate MoS_2 monolayers from commercial bulk crystals (Figure 1a). Theory suggests a certain degree of electrical charge transfer in the topmost MoS_2 layer when placed in contact with a metal, such as gold, which polarizes and produces a van der Waals-like interaction at the metal/MoS_2 interface greater than that of the bulk crystal.

The MME process begins with template stripping of a gold metal layer from its substrate using temperature release tape (TRT). The gold tape is then immediately brought into contact with a MoS_2 crystal. The gold tape (and its MoS_2 monolayer) is then separated from the crystal and pressed to a target substrate (Figure 1b). Finally, the TRT is removed with heat and the gold layer chemically etched, leaving being the MoS_2 monolayer attached on the new substrate (Figure 1c).

Current efforts are focused in increasing the size of isolated MoS_2 monolayers (currently 5 mm × 5 mm) to facilitate integration into novel optoelectronics devices with interfacial properties controlled down to the atomistic level.

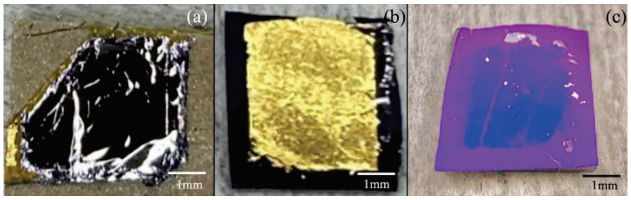


Figure 1. HNEI's MME process for MoS_2.

Results of this work, "**Periodically Strained 2D Materials for Tunable Optoelectronic Applications**," was presented at the 2024 Electrochemical Society PRiME Meeting.

Funding Source: U.S. Department of Energy

Contact: Nicolas Gaillard, ngaillar@hawaii.edu

Last Updated: November 2025

Appendix G: Ocean Energy

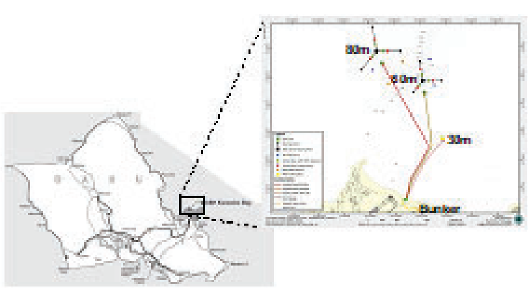
G1: Research Support to the U.S. Navy Wave Energy Test Site

OBJECTIVE AND SIGNIFICANCE: HNEI provides key research support to the U.S. Navy Wave Energy Test Site (WETS) in the form of environmental monitoring, independent WEC device performance analysis, and critical marine logistical support. The results achieved at WETS have far reaching impacts in terms of advancing wave energy globally.

BACKGROUND: Wave energy has the potential to support global renewable energy goals, yet it faces daunting challenges related to commercializing technologies that must produce cost-competitive electricity while surviving an energetic and corrosive marine environment. The nascent commercial wave energy sector is thus critically dependent on available test infrastructure to advance development of wave energy conversion (WEC) devices and related technologies.

Wave energy also has potential to supply persistent power to small-scale or non-grid-connected applications, including ocean observation, charging of autonomous vehicles, aquaculture, at-sea mineral scavenging, and providing renewable power to remote or island communities.

For these reasons, the U.S. Navy established WETS in the waters off Marine Corps Base Hawai‘i (shown below) as the United States' first grid-connected wave energy test site. With the buildout completed in mid-2015, WETS consists of test berths at 30m, 60m, and 80m water depths, and can host point absorber and oscillating water column (OWC) devices up to a peak power of 1 MW.



Since 2010, HNEI has been supporting research and testing at WETS under funding from U.S. Department of Energy (DOE) and the U.S. Navy (Naval Facilities Engineering Systems Command, NAVFAC). Through a cooperative effort between the Navy and DOE, WETS hosts companies seeking to test their pre-commercial WEC devices in an operational setting. Site support has included several major site infrastructure repairs. More recently, HNEI has expanded research efforts related to smaller-scale WECs for offshore, non-grid-connected applications of wave energy, as well as fund all WETS enhancements.

PROJECT STATUS/RESULTS: HNEI works with the Navy and DOE to directly support WEC testing at WETS in three key ways:

1. *Environmental impact monitoring* including acoustic signature measurement and protected species monitoring;
2. Independent *WEC device performance analysis*, including wave forecasting and monitoring, power matrix development (power output versus wave height and period), numerical and hydrodynamic modeling; and
3. *Logistics support*, including a regimen of regular WEC and mooring inspections, past support to modify a site-dedicated support vessel for use at WETS, through local partner Sea Engineering, Inc., assisting WEC developers with deployment planning, and supporting developers for maintenance actions during their WEC deployments at the site.

Current research efforts are foscues in three primary areas:

1. Development of a power generation and management system for a floating OWC device of UH design for applications such as ocean observation and AUV recharge;
2. Advancement of a novel breakwater system with integrated OWC power generation; and
3. Concept development and testing of a floating flap-type WEC.

The latter two of these underwent major test campaigns at Oregon State University's wave basin/flume facilities in 2025, providing the data necessary to validate recent numerical modeling.

Since mid-2015, the following major activities have occurred at WETS, with HNEI in both supporting and leading roles.

June 2015 to December 2016: Northwest Energy Innovations deployed an Azura device at 30m berth.

March 2016 to April 2017: Sound and Sea Technology deployed a Fred. Olsen Lifesaver at 60m berth. This project was not grid-connected.

February to August 2018: HNEI led a second deployment of Azura, with modifications designed to improve power performance, including enlarging the float and adding a heave plate at the base.

October 2018 to March 2019: HNEI led an effort to redeploy Lifesaver at 30m with modifications to moorings and integration of a University of Washington sensor package and subsea charging capability, which drew its power from the WEC itself. This use of wave energy to power an offshore sensing suite was an important national first.

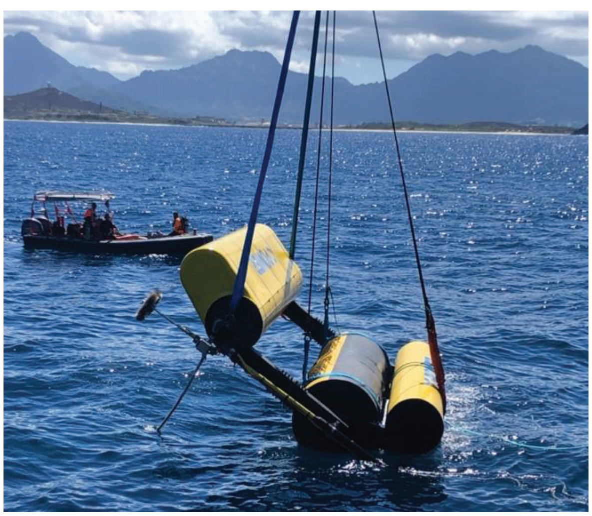
May/June 2019: HNEI led a major redesign and reinstallation effort for the WETS deep berth moorings. 60m berth was reinstalled and 80m berth repairs held, subject to WEC developer demand.

November 2019: Completion of Kupaʻa, a site-dedicated support vessel by research partner Sea Engineering, Inc. This vessel adds significantly to our ability to perform various functions at WETS.

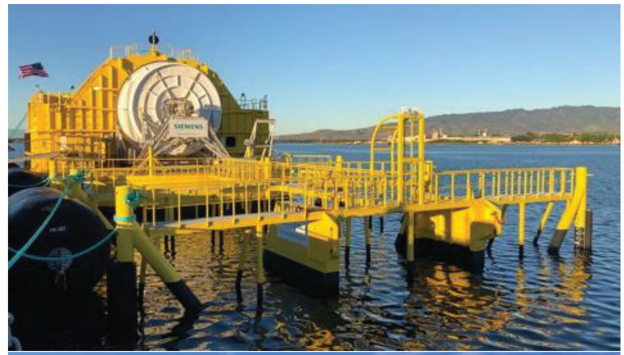
While issues stemming from COVID, funding, and technical challenges have substantially delayed planned WEC deployments over the past few years, three deployments have recently taken place.

The first, Oscilla Power's (Seattle) Triton-C community-scale WEC, was deployed at the 30m berth. This device arrived in Hawaiʻi in October 2021. In August 2022, new anchors were deployed at the WETS 30m berth and a new electrical/data junction box was installed in September 2023. Unfortunately, the device has not been able to complete the intended full deployment, due to a variety of technical setbacks and weather delays. It remains at Marine Corps Base Hawaiʻi following a brief at-sea test, with no further deployment planned. A decommissioning plan is now in development.

The second was C-Power's SeaRay device. This is a small stand-alone (non-grid-connected) 1 kW device designed to feed power to a subsea battery system that in turn provides power to an acoustic sensing system from Biosonics, as well as a seafloor AUV docking station from Hibbard Inshore. The device was deployed at WETS in October 2023, but suffered some early damage. It was redesigned and redeployed in June/July 2024 and successfully demonstrated wave power extraction and battery charging. However, it experienced faults that ultimately led to a shortening of the deployment and cancellation of the planned demonstration of AUV recharging and powering of the Biosonics system.



Lastly, Ocean Energy's (Ireland) OE35 WEC device was deployed at the 60m berth. This device has been in Hawai'i since December 2019, however, underwent drydock repairs in August/September 2022 after extensive delays. A new generator was installed in April/May 2024, and it was deployed to WETS in July of that year. Prior to it becoming operational, the device experienced additional structural damage (similar to what had happened during its transit to Hawai'i). For this reason, the operation to connect its umbilical cable to the WETS shore cable was ultimately cancelled in late 2024. Currently, the device remains at the WETS 60m berth and a recovery plan is in development.



At this time, no additional WEC deployments are scheduled at WETS. It is likely that the site will enter an extended period of inactivity, however, HNEI will continue to inspect and maintain site infrastructure during this quiet period. DOE has plans for substantial funding of new offshore WEC testing that is likely to reinvigorate activity at WETS, but these plans are currently on hold due to budgetary uncertainty.

Funding Sources: Naval Facilities Engineering Command, Expeditionary Warfare Center; U.S. Department of Energy

Contact: Patrick Cross, pscross@hawaii.edu

Last Updated: November 2025

G2: The Hawai‘i Wave Surge Energy Converter (HAWSEC)

Objective and Significance: The objective of the Hawai‘i Wave Surge Energy Converter (HAWSEC) project, funded by the U.S. Department of Energy (DOE), is to mature a wave energy converter (WEC) concept developed by the HNEI-led team, that could ultimately produce cost-effective renewably generated electricity for coastal communities. The project is expected to make important advances in the emerging wave energy field.

Background: The HAWSEC concept, developed by an HNEI led team, and funded by DOE is based on the oscillating wave surge converter (OWSC), or flap-type, WEC. Such systems rely on the surge motion of the waves close to shorelines, where wave direction becomes more consistent than offshore. The flap moves back and forth in the waves and drives hydraulic cylinders to pump water through a hydro turbine to generate electricity. Its inherent scalability could support smaller-scale generation for isolated communities or islands, or larger-scale devices (likely deployed in arrays) to generate power to feed into coastal power grids. The small-scale version of the flap is shown in Figure 1.

Figure 1. HNEI’s HAWSEC system in Oregon State University’s wave basin for testing.

Project Status/Results: This project was initated in August 2020. HAWSEC development has proceeded along the following broad set of tasks:

1. Numerical modeling of small-scale version, nominally a 1m x 1m flap, to optimize design;
2. Fabrication and local testing of the small-scale system, both the hydraulic system and the flap itself, in nearshore waters on O‘ahu;
3. Controlled tank testing of the small-scale system at Oregon State University’s (OSU) Hinsdale wave basin;
4. Validation of numerical modeling with test results from OSU;
5. Numerically scaling up to medium scale, nominally a 3m x 3m flap, and completing a design of the HAWSEC at this scale;
6. Undergoing a Go/No-Go decision with DOE;
7. Fabrication of the power takeoff (PTO) for a medium scale system;
8. Laboratory testing of the medium-scale PTO; and
9. Validation of medium-scale numerical models with test data, and modeling and performance prediction for a full-scale version of HAWSEC.

We explored both a high-head/low-flow and a low-head/high-flow hydraulic system—utilizing the same flap in the first half of the project. We ultimately settled on an optimized configuration with a hydro turbine selected to best align with the optimized head and flow before scaling up for additional testing in the latter stages of the project.

A hydraulic bench test setup was completed in our lab on the UH campus in early 2022, including a linear actuation system that is capable of simulating realistic wave forcing. Lab testing was carried out between January and May 2022, resulting in readiness to ship the full system for wave basin testing at OSU.

Nearshore testing of the flap in local waters at Makai Research Pier was conducted in May 2022 (Figure 2), with encouraging results that further de-risked the upcoming basin tests.

Controlled wave basin testing at OSU was completed in two phases, without and with a power takeoff (hydraulic) system, in June and October/November 2022 (Figure 3). Excellent results were obtained, particularly for the high-head PTO, where the power produced exceeded expectations. Due to this, the high-head PTO—in which a hydraulic cylinder pumps water at high pressure through a nozzle to rotate a Pelton wheel turbine—is the selected approach for the second phase of the project, where the device will be scaled up in size with the goal of conducting subsequent testing and validation.

Figure 2. Flap testing at the Makai Research Pier.

Figure 3. Controlled wave basin testing at OSU.

In February 2024, we successfully completed the Go/No-go briefings with DOE and received a favorable determination later that year. However, administrative and process delays have slowed the project since then. This extended timeline stemmed from substantial procurement challenges in Budget Period 1 and a shipping-related setback, which cost the project several months. Despite these delays, the project is meeting its technical objectives and has resulted in a WEC concept that is of high interest to DOE and to our partners at the National Renewable Energy Lab (NREL).

Execution of the second budget period, with the scale up and testing of the larger PTO, has been on hold since the start of the new administration. We look forward to resuming this project once DOE budgetary issues are resolved.

This work also led to collaboration with NREL on a new project utilizing our small-scale flap for a PTO development of their own and subsequent deployment at Makai Pier, which is expected to begin in early 2026.

Funding Source: U.S. Department of Energy

Contact: Patrick Cross, pscross@hawaii.edu

Last Updated: November 2025

G3: Hawaiʻi Marine Energy Center (HMEC)

OBJECTIVE AND SIGNIFICANCE: The objective of the Hawaiʻi Marine Energy Center (HMEC) is to advance and promote marine energy solutions for Hawaiʻi and the islands of the Pacific. The team's intent is to develop HMEC as a regional hub for marine energy expertise in the National Marine Energy Center (NMEC) framework that the U.S. Department of Energy (DOE) has established.

These efforts include expanding HNEI's earlier wave energy research efforts, establishing new research tasks, enhancing testing capabilities, strengthening communications and outreach related to marine energy, and establishing new marine energy test facilities and infrastructure to complement the existing U.S. Navy Wave Energy Test Site (WETS).

BACKGROUND: In 2008, DOE established the Hawaiʻi National Marine Renewable Energy Center (HINMREC) at HNEI. This was one of four university-based NMECs focused on various forms of marine energy advancement. HINMREC's unique focus was research on ocean thermal energy conversion (OTEC) technologies and assisting the Navy with the establishment of WETS. HNEI has been involved in supporting research and testing objectives at WETS, the nation's first grid-connected open water wave energy conversion test facility located off Marine Corps Base Hawaiʻi, since 2010 with funds from both DOE and the U.S. Navy (Naval Facilities Engineering Systems Command, NAVFAC) (Appendix G1).

Funding for HINMREC ended in 2019. However, new funding from DOE in 2024 allowed the four NMECs to expand ongoing operations, make improvements to infrastructure, and build relationships to advance marine energy in their regions. As part of this new impetus, HINMREC was rebranded to HMEC.

In a complementary dual effort, in 2024, DOE awarded HNEI two grants to fund operations and activities at HMEC. If fully funded, these award would fund the HMEC activities for a five-year period.

PROJECT STATUS/RESULTS: Work under these awards began in late 2024 and their overall goals are to:

1. Establish communications and educational outreach at multiple levels, including developing and delivering a series of short courses ranging from introductory to deeper dive topics;
2. Establish and expand local and regional relationships with governmental entities and industry in Hawaiʻi and the Pacific Islands and national laboratories;
3. Maintain and expand marine energy-relevant test facilities, including pursuing the addition of the Kilo Nalu Observatory (KNO) and Makai Research Pier (MRP) into DOE's Testing and Expertise for Marine Energy (TEAMER) network;
4. Advance marine energy-relevant research and development to address several demonstrated industry needs;
5. Enhance marine energy-relevant test infrastructure and laboratory test equipment to enhance HMEC's capabilities; and
6. Coordinate with DOE, the other NMECs, and the University Marine Energy Research Community (UMERC) on various forms of marine energy research collaboration.

Over the past year, HMEC has made important progress on each of these objectives.

Under #1, in order to provide the short courses, HNEI had extensive discussions with potential content providers, developed a survey to help us shape content, and selected topics for our first year. Our initial offerings will be a 1-week course on ocean thermal energy conversion (OTEC) and a 1-week marine energy introductory course. These will be offered during UH's Summer 2026 semester and held in person. During subsequent years, we plan to offer courses that take a deep dive into the modeling, design, and deployment of oscillating water column (OWC) and oscillating wave surge-type wave energy converters (WECs).

HMEC also established a robust STEM outreach effort, including:

- A marine energy focused partnership with UH's STEM Pre-Academy, which offers learning opportunities for Hawaiʻi educators at the middle school level. This effort resulted in two workshops and the creation of new demonstration capabilities related to waves and wave energy conversion;
- Instruction of a wave energy class at Kapiolani Community College;
- Participation in two UH Mānoa open houses; and
- Provision of three wave energy internships during Summer 2025 to one UH undergraduate and two local high school students.

In pursuit of #2, we have solidified pre-existing relationships with Sandia National Laboratories, Pacific Northwest National Laboratory, and the National Renewable Energy Laboratory (NREL) to enhance our research outcomes. HNEI conducted outreach with our federal Congressional delegation and familiarized ourselves with the Hawaiʻi State Energy Office to increase their awareness of our work in marine energy. We also strengthened existing relationships and developed new ones with industry, having participated in multiple collaborative proposals. Local companies Sea Engineering, Oceanit, Makai Ocean Engineering, and PacMar all represent current and/or potential future partners in our work.

Additionally, we placed an early emphasis on establishing relationships with potential research and demonstration partners in Guam, due in part to the potential to expand these relationships to other Pacific Islands. In 2025, this included participation in the University of Guam's Conference on Island Sustainability in April, which included a well-received discussion on HMEC's marine energy initiatives, which could ultimately address the power and freshwater needs of islands.

To achieve #3, we developed a catalog of existing marine energy test infrastructure that may be of interest to researchers within the NMEC framework. We are also currently in the early stages of discussions regarding the environmental permitting that will be necessary for the establishment of KNO and MRP into the TEAMER open water test facilities network. If added, this would allow those facilities to be utilized by researchers around the world by applying for funding through the TEAMER program. This utilization might include testing or demonstration of small-scale wave energy converters, environmental sensors of relevance to marine energy projects, or other marine energy-relevant ocean deployment projects. Moreover, this would result in additional funding to UH to support test objectives.

Advancing R&D efforts towards #4 are specifically focused in the following five projects:

a. Advance WEC control strategies, with an emphasis on both OWC and oscillating wave surge converter (OWSC) concepts, including numerical modeling, laboratory testing, and an ocean test in the latter stages of the project. To date, control strategies with the most promise for WEC performance improvement have been identified for the OWC WEC type, in collaboration with Sandia National Laboratories. This task supports a PhD candidate who is making great progress with the task lead and her advisor. The candidate presented a paper on this work at the European Wave and Tidal Energy Conference in Madeira, Portugal in September 2025. The second portion of this task will focus on a flap-type WEC and will begin at a later date in the overall award.
b. Conduct fully coupled numerical fluid-soil-structure interaction (FSSI) analyses as applied to marine energy converter anchoring—leading toward more cost-effective designs and lower energy costs associated with marine energy. This project has focused on the validation of a numerical model using pre-existing data from wave flume tests and has produced a versatile model that can next be used to examine a number of test cases.
c. Extend existing 7-14-day wave forecast models to longer time scales—from monthly to interannual—by examining wave conditions as they relate to dominant climate cycles, such as El Nino/La Nina. Efforts on this project have generated a statistical analysis which shows that a focus on the El Nino/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) will account for a large majority of the seasonal and interannual variability in the wave forecast.

These two climate cycles are now being studied as they relate to the longer-term wave forecast. This work promises to produce a tool that will be valuable in terms of long-range forecasts for operational planning and WEC/mooring design.

d. Numerically study the downrange effects of WEC arrays on the wave field as it impacts nearby coastlines and coastal infrastructure—utilizing advanced non-hydrostatic methods. This project has yet to begin as it is scheduled for a later date in the overall award.

e. Develop a "high-flow" power takeoff (PTO) system for an OWSC-type WEC (flap), utilizing numerical modeling, design, and laboratory testing to validate performance. This complements the "high-head" approach undertaken in another HNEI DOE project—the Hawai'i Wave Surge Energy Converter (HAWSEC) (Appendix G2). This study is producing encouraging results in numerical space related to ultimate device power performance. Laboratory testing is the next step, and efforts to procure, fabricate, or 3D print the necessary test components are now underway.

Objective #5 deals with the procurement of various equipment that will enhance HMEC's testing capabilities. HNEI's first identified upgrade was a hydraulic test bench and a data acquisition system (MODAQ2), developed to our needs by NREL, which has been approved by DOE. Several other items were identified and we are currently in the process of requesting DOE approval. We hope to have all identified items procured during the first half of the coming calendar year.

In order to fulfill #6, HMEC has become thoroughly integrated into the DOE NMEC community. Regular meetings occur with DOE's Water Power Technologies Office (WPTO) and the other NMECs on a wide variety of topics of relevance to enhancing academic and industry partnerships aimed at advancing marine energy solutions toward commercial readiness, with the long-term aim of ensuring that these solutions contribute to the renewable energy mix of the future. This collaboration allowed us to refine our key strategic goals for the next five years. We are currently in the process of building those goals into a Strategic Vision Report for submission to DOE as a deliverable. Our overarching goal is to identify marine energy solutions of relevance to the Pacific Islands, with an emphasis primarily on wave energy, with a growing emphasis on OTEC, both of which are highly relevant in the tropical Pacific.

Additionally, in August, HNEI's participation in UMERC's annual conference included presentations on **high-flow hydraulic pump characteristics for OWSC applications**, HMEC's marine energy curriculum enhancements, and developments of relevance to the advancement of **two OWC wave energy converter concepts**—a fixed breakwater with integrated OWC generation and a floating OWC for autonomous vehicle recharge.

Funding Source: U.S. Department of Energy

Contact: Patrick Cross, pscross@hawaii.edu

Last Updated: November 2025

H1: Asia Pacific Regional Energy System Assessment (APRESA)

Objective and Significance: The objective of the Asia Pacific Regional Energy System Assessment (APRESA) program was to develop comprehensive energy system assessments in the Asia Pacific region regarding energy transition strategy, policy, regulation, technology options, demonstrations, implementation plans, and training based on the specific requirements or needs of the targeted jurisdictions and strategic alliances.

Background: In August 2017, HNEI was awarded a grant from the Office of Naval Research (ONR) to support energy system transitions in select locations throughout the Asia Pacific region. During the nearly eight years of APRESA activities, HNEI established substantive strategic partnerships with national, regional, and local jurisdictions, as well as private and public stakeholders including numerous utilities, universities, and other research and international aid and development entities, such as the World Bank, Asian Development Bank, Australian Infrastructure Financing Facility for the Pacific, The Asia Foundation, The Maureen and Mike Mansfield Foundation, U.S. Agency for International Development (USAID), and U.S. Department of Defense (DOD) organizations in the areas of interest. Based on the programmatic success of these strategic partnerships, ONR extended the APRESA program past its initial five-year period.

Project Status/Results: The APRESA program ended in May 2025. HNEI's **final technical report** and **associated works** resulting from these efforts, including technical reports, peer-reviewed papers, and presentations, are available on our website.

Nations where engagement and support activities occurred through APRESA include Vietnam, Thailand, Laos, Indonesia, Philippines, Cambodia, the Republic of Palau, the Cook Islands, the Republic of the Marshall Islands, the Federated States of Micronesia, and the Republic of Fiji. The criteria for selection of jurisdictions included: 1) those with significant rates of projected demand growth requiring rapid energy system expansion and transformation; 2) strategic trade and geopolitical opportunities to the United States; 3) potential to integrate renewable energy technologies; and 4) a collaborative environment to conduct the work.

In addition to the deep local partnerships formed in these jurisdictions, this program led to a highly successful collaborative relationship with USAID and its implementation of prime contractors throughout the region. With significant experience providing technical expertise in the energy space, HNEI was uniquely positioned to partner with USAID and provide energy intelligence in identifying tailored solutions for jurisdictions in need. This collaborative approach, leveraging the capabilities, resources, and know-how of HNEI and USAID implementing contractors in the Asia Pacific region is consistent with the U.S.' whole-of-government strategy to grow sustainable and secure energy markets across the region.

HNEI's collaborations and interventions under this grant helped deliver technical expertise to policymakers in emerging economies that can aid in achieving lower-cost, cleaner energy solutions that catalyze competitive markets and reduce carbon emissions—ultimately enabling their populations to enjoy universal, reliable, and cleaner electricity services.

A brief summary of results by projects based in Hawaiʻi and then by region/country follows. Many of these are also described in further detail in separate project summaries in Appendix H.

Hawaiʻi

A number of projects based in Hawaiʻi were implemented with the intent to support secure energy development in the state and allow transition to the broader Asia Pacific region. These efforts included:

- Development and enhanced scaling of the Aloha+ Challenge dashboard website that tracks multiple global and statewide sustainability goals and targets, and buildout of a "template," which led to dashboard launches in several Pacific Island Countries;
- Evaluation of indoor air quality through field measurement and computational fluid dynamics modeling to achieve indoor comfort and safety with reduced energy requirements;
- Anonymously measuring human-based activity with the intent of better understanding space utilization and energy management;
- Exploring a building assessment intended to provide a test platform for the built-environment

that could also support Navy ROTC on the UH Mānoa campus; and
- Providing in-kind and financial support for a global conference to identify potential plans for future hydrogen energy development in island communities.

Vietnam
HNEI established partnerships with several institutions in Vietnam to support their development of a sustainable and resilient energy system. Efforts in this region included:

- Supporting a community group to develop a workshop platform and present eight publicly accessible seminars covering a range of energy themes to raise awareness of renewable energy and energy efficiency (Appendix H2);
- Providing financial support and guidance to map the innovation opportunities associated with renewable energy sector development;
- Providing technical planning, capacity building, and scenario modeling in support of development for Vietnam's Eighth Power Development Plan's (PDP8)—the country's power sector strategy for 2021-2030 with an outlook to 2050; and
- Initiating an effort to support the development of the country's grid modeling capabilities.

Thailand
HNEI established collaborations with several Thai universities, utility providers, grid operators, and energy regulatory commission. Efforts in this region included:

- An assessment of small biomass systems as a firm power option in islanded settings including the design, development, and implementation of a bioreactor system to hybridize a community PV grid system and extend hours of electricity availability;
- Development of a capacity building program to provide hands-on training for utility engineers at a large Thai distribution grid operator (Appendix H3); and
- Providing technical collaborations and studies tailored to Thailand's needs, which enabled comprehensive advancements in grid planning, energy production forecasting, microgrid operations, and regulatory standards.

Laos
Our team supported technical capacity building, grid modernization, and policy advancement in the Lao People's Democratic Republic (LPDR). Efforts in this region included:

- Supporting the design and implementation of Laos' first market-based solar pilot auction to facilitate procurement of grid-connected solar PV projects from independent power producers; and
- Assisting in developing technical interconnection and performance requirements and grid codes for solar and wind projects in the Lao power grid, including conducting workshops and targeted capacity building.

Indonesia
HNEI worked with Indonesian energy partners to provide technical training, capacity building, and collaborative research supporting grid modernization and energy transition. Efforts in this region included:

- Capacity building sessions focused on strategies for sourcing alternative energy in grids with high levels of variable and intermittent energy resources;
- Collaborative DC microgrid research with the University of Indonesia advance technology on HNEI's Coconut Island microgrid project (Appendix C1); and
- Providing technical support and capacity building across a broad range of priority areas to Indonesia's Sustainable Energy for Indonesia's Advancing Resilience (SINAR) program.

Philippines
Collaborations established under APRESA assisted the Philippine power sector in their ongoing goal to modernize and build resilience. Efforts in this region included:

- Providing technical guidance for the development of a department circular aimed at strengthening the national net metering framework to encourage wider adoption of distributed solar generation; and
- Supporting the Energy Secure Philippines (ESP) program by delivering advanced regulatory frameworks, practical training, and targeted technical assistance, which directly enhanced

the expertise and operational capabilities (Appendix H4).

Pacific Island Countries (PICs)
HNEI expanded and established new partnerships in its collaborative work with multiple PICs, with specific efforts in the Republic of Palau, the Cook Islands (Rarotonga), the Republic of the Marshall Islands (Majuro), the Federated States of Micronesia (Yap), and the Republic of Fiji. Efforts in this region included:

- Providing technical and regulatory support to Palau in three areas: 1) the development of energy regulatory frameworks, 2) conducting modeling and analysis of the national electric system, and 3) creating requirements and improved processes for connecting new sources to the grid (Appendix H5);
- Providing technical and regulatory support to a state-owned power company in the Cook Islands in three areas: 1) building and refining the utility's regulatory and planning frameworks, 2) conducting modeling and analysis of the Rarotonga grid, and 3) establishing methodologies for evaluating how much additional distributed generation could be accommodated by the system (Appendix H6);
- Providing training to the national utility in the Republic of Fiji on integrating variable generation and shared lessons learned from Hawai‘i's island grids (Appendix H7);
- Providing technical assistance and capacity building to support the Republic of Marshall Islands' agencies as they seek to update their energy law and prepare for future changes to the power system (Appendix H8); and
- Providing on-island training state-owned utility staff in Yap State of the Federated States of Micronesia covering topics, such as system planning approaches from Hawai‘i's island grids, management of high levels of variable generation, updated interconnection standards, BESS applications, EV integration, energy resilience considerations, and strategies for competitive resource procurement.

Southeast Asia and Indo-Pacific Region
Funding from this award played a key role in establishing and strengthening collaborative technical engagement throughout Southeast Asia and the Indo-Pacific region. Efforts in these regions included:

- Making sustained contributions to the Association of Southeast Asian Nations (ASEAN)'s Interconnection Masterplan Study (AIMS) III process by providing direction on study scope, data collection, modeling assumptions, and technical review;
- Supporting the Southeast Asia Smart Power Program in several of their core activities and also providing country-specific technical support and training to national authorities and utilities in Laos and Cambodia;
- Contributing to key Asia-Pacific Economic Cooperation (APEC) Working Group meetings, workshops, and capacity building events aimed at advancing energy system integration, policy development, and technology deployment throughout the Asia Pacific region;
- Hosting the 50th meeting of the APEC Expert Group on New and Renewable Energy Technologies (EGNRET) in Honolulu;
- Participating in many forums and capacity building events with the Asian Development Bank (ADB) and the U.S. Department of State's Asia Enhancing Development and Growth through Energy (EDGE);
- Participating in sustainable aviation fuels (SAF) workshops held in Thailand Indonesia; and
- Conducting a literature review and analysis of a tropical oilseed tree to evaluate its potential as a sustainable bioenergy resource.

Funding Source: Office of Naval Research

Contact: Richard Rocheleau, rochelea@hawaii.edu;
Leon Roose, lroose@hawaii.edu;
Scott Turn, sturn@hawaii.edu

Last Updated: November 2025

H2: Saigon Energy Hub (SEHub)

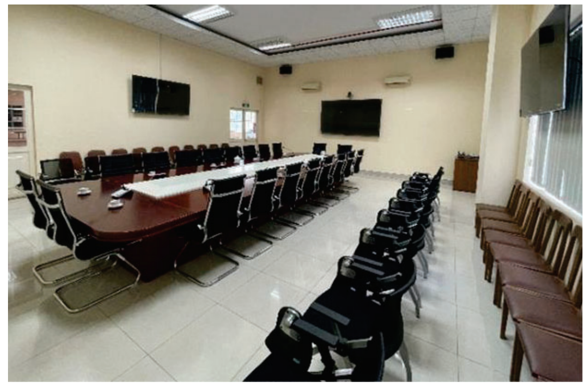
OBJECTIVE AND SIGNIFICANCE: HNEI collaborated with Ho Chi Minh City's Institute for Regional and Urban Studies (IRUS) to design and implement the Saigon Energy Hub (SEHub), a virtual, publicly accessible, education platform offering energy-related forums to raise the community awareness of the needs, feasibility, and benefits of energy efficiency (EE) and renewable energy (RE).

BACKGROUND: Included among the objectives of the Hawai‘i Natural Energy Institute's Asia Pacific Regional Energy System Assessment (APRESA) award from the Office of Naval Research, was to develop partnerships with national, regional, or local jurisdictions, private and public stakeholders, including universities and other research organizations in the Asia Pacific region to enhance the reliability, stability, and resilience of the energy systems.

Initiated in July 2018, with a two-day bilingual, technical workshop, it was determined to move forward with a solar-enabled energy solution project as it represented strategic interests for both HNEI and IRUS as well as the majority of other workshop participants. Originally planned for an outdoor public park venue, due to project interruptions resulting from COVID-19, the Park project was unable to move forward.

PROJECT STATUS/RESULTS: The project was amended and replaced with SEHub to consist of several EE and RE themed workshops to be conducted at Ho Chi Minh City Union of Science and Technology Association (HCM-USTA)'s Headquarters. In 2023, the reconfigured SEHub project began with the planning, design, and outfitting of the workshop platform. IRUS outfitted two meeting spaces with video and audio devices and fixed connection equipment system to present both online and offline workshops (Figure 1).

This was followed by an implementation phase where IRUS presented eight publicly accessible workshops on various EE and RE themes through the workshop platform. This series, held from March through December 2024, spanned over 38 hours with 10 speakers and 310 participants, with participants representing a range of stakeholders including researchers, technology associations, business owners, and policy makers. The workshop topics covered carbon credits, offshore wind power, legal framework regarding energy savings, energy management, integrated infrastructure and transit oriented development, geographic information system (GIS) as an effective urban management tool, and sea current power.



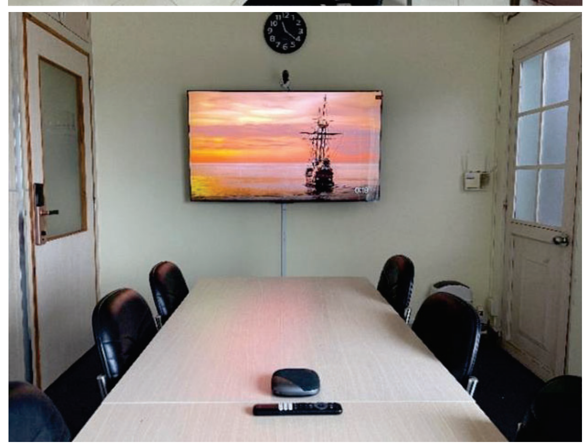


Figure 1. The two meeting workshop spaces in the HCM-USTA's building.

The SEHub project contributed to: 1) community awareness regarding RE and EE; 2) knowledge and experience dissemination among stakeholders including universities, research institutes and centers, businesses, NGOs, NPOs, and local communities; and 3) capacity building for local Vietnamese partners in the fields of RE and EE.

Funding Source: Office of Naval Research

Contact: Richard Rocheleau, rochelea@hawaii.edu; Eileen Peppard, epeppard@hawaii.edu

Last Updated: November 2025

Hawaiʻi Natural Energy Institute Research Highlights

Appendix H: International

H3: Provincial Electricity Authority of Thailand (PEA) Collaboration

OBJECTIVE AND SIGNIFICANCE: HNEI's Grid System Technologies Advanced Research Team (Grid***START***) delivered capacity building and direct technical support to the Provincial Electricity Authority of Thailand (PEA). These efforts have strengthened PEA's capacity to adopt, manage, and scale distributed energy technologies across Thailand's evolving power sector.

BACKGROUND: PEA, the main electric distribution utility serving 74 of 77 provinces, is integrating and maximizing the value of locally available energy resources through various initiatives, including the development of resilient microgrids. With support from the Office of Naval Research (ONR) through the Asia Pacific Regional Energy Systems Assessment (APRESA) grant, HNEI has designed and led technical training programs, field-based demonstrations and hands-on workshops for PEA engineers, supporting grid modernization, microgrid development and the advancement of electric vehicle (EV) charging solutions.

PROJECT STATUS/RESULTS: Since Spring 2020, Grid***START*** has provided training programs for selected PEA engineering interns in Hawaiʻi, with each cohort receiving tailored lectures and hands-on mini-projects focused on distributed energy resources and smart grid technologies. The lectures address topics such as distributed energy resource integration and advanced smart grid applications, while the mini-projects include activities such as developing controls for EV chargers, analyzing PV hosting capacities, studying virtual power plant (VPP) energy management and optimizing microgrid design and operation.

Early 2025 saw the expansion of the collaboration, where HNEI conducted a ten-day hands-on course in Bangkok for thirty PEA engineers. This intensive workshop covered microgrid fundamentals, control strategies, regulatory standards, and technoeconomic optimization, utilizing scenarios from the Mae Hong Son microgrid and simulation and control platforms such as XENDEE, Re-Opt, and ETAP.

In May 2025, four PEA engineers completed an immersive internship at HNEI in Hawaiʻi, gaining expertise in ETAP software fundamentals, system modeling, load flow, and transient analysis for the Mae Hong Son field site, supported by software-in-the-loop (SIL) and hardware-in-the-loop (HIL) testing. These activities culminated in technical presentations and feedback sessions.

Figure 1. Training from the ten-day hands-on course.

Figure 2. Final presentations from the 2025 PEA internship.

In addition to these training initiatives, the team's support has extended to technical assistance during equipment commissioning for PEA's microgrid development on Koh Phaluai island in the Gulf of Thailand.

The combined efforts have equipped PEA with enhanced expertise in advanced grid operation, distributed energy system management and practical microgrid deployment. APRESA concluded in May 2025, however, HNEI intends to maintain its partnership with PEA, providing technical exchange to support Thailand's grid modernization goals.

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

Hawaiʻi Natural Energy Institute Research Highlights

Appendix H: International

H4: Support to the Energy Secure Philippines (ESP) Program

OBJECTIVE AND SIGNIFICANCE: HNEI, under contract with the Research Triangle Institute (RTI), provides technical and regulatory support to the Energy Secure Philippines (ESP) Program, the Philippines Energy Regulatory Commission (ERC) and Department of Energy.

BACKGROUND: This collaboration builds on earlier efforts under Clean Power Asia and the Office of Naval Research's Asia Pacific Regional Energy Systems Assessment (APRESA) grant, through which HNEI developed national frameworks for off-grid net energy metering (NEM) and battery energy storage systems (BESS), led multiple capacity-building workshops and strengthened institutional capacity to enhance power sector resiliency. The $34 million ESP Program seeks to advance economic growth and energy resilience by catalyzing $750 million in private investment for 500 MW of new capacity.

PROJECT STATUS/RESULTS: HNEI's Grid***START*** provided assistance emphasizing advancing policy, regulatory frameworks, and technical capacity in off-grid NEM, delivering detailed reports, draft rules and capacity-building sessions in Manila. These initiatives helped shape national policy direction on distributed energy and storage, supporting ESP's mandate for modernization and sectoral resilience.

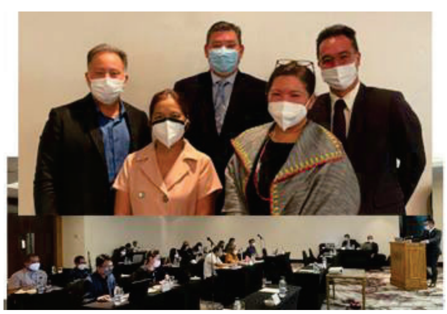


Figure 1. Presentation of NEM and BESS reports to the ESP and the ERC workshop in Manila in 2022.

HNEI continued assisting ESP and partner agencies through 2024 and 2025, broadening its technical scope and stakeholder reach. In early 2024, discussions with RTI refined the remaining scope of work to include: 1) a design review for an electric-powered fishing boat; 2) training sessions for select distribution utilities (DUs) and local government units (LGUs); 3) technical training for the Siargao Women's Center; 4) a distribution system assessment for Siargao Electric Cooperative (SIARELCO); and 5) a resiliency assessment and conceptual strategies for the Armed Forces Philippines (AFP) General Headquarters at Camp Aguinaldo. Field visits to Manila, Bohol, Iloilo and Siargao in June 2024 enabled coordination with local leaders and helped align on technical priorities under the refined scope.

In August 2024, HNEI presented its energy resiliency assessment methodology to AFP stakeholders at Camp Aguinaldo, outlining initial findings and strategies for system vulnerability reduction. Then in November 2024, the team delivered two in-person trainings in Iloilo for the MORE Electric and Power Corporation and Negros Electric and Power Corporation, followed by a session for the Iloilo LGU on energy planning and technology integration. Together, these efforts strengthened institutional capacity at national and local levels.

Figure 2. HNEI and utility partners discussions in Iloilo.

Although certain planned activities, including the e-boat design review, select DU trainings, and Siargao capacity-building workshops were cancelled after USAID operations suspended in early 2025, core technical deliverables were completed and foundations established for sustained impact. Work on the AFP resiliency framework was rescoped to ensure continuity of critical support in the deployment of Mobile Energy Systems at AFP Camp Aguinaldo. Despite these adjustments, collaborative achievements under ESP have helped build a more robust, resilient and adaptive energy sector for the Philippines.

Funding Source: U.S. Department of State ESP Program; Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

Hawaiʻi Natural Energy Institute Research Highlights

Appendix H: International

H5: Energy Regulatory and Technical Support for Palau

OBJECTIVE AND SIGNIFICANCE: Through support from the Office of Naval Research (ONR), HNEI providing technical, regulatory, and policy assistance to the Republic of Palau. HNEI's Grid***START*** continues to support the Palau Energy and Water Administration (PEWA) and the Palau Public Utilities Corporation (PPUC) in advancing the country's energy transition, focusing on system planning, grid operations, and interconnection requirements critical for increased integration of very high levels of locally available, but intermittent and variable energy resources.

BACKGROUND: In 2022, Palau set a national goal to secure 100% of its energy needs through locally available alternative energy resources by 2050. Achieving this target depends on securing financing for major alternative energy initiatives and deploying systems capable of managing intermittent and variable energy resources. A 15.3 MW solar photovoltaic (PV) plus 12.9 MWh battery energy storage system (BESS) commissioned in 2023 through foreign direct investment became the largest of its kind in the Western Pacific region. Additional utility-scale BESS and distributed rooftop PV installations are under development, accelerating the nation's energy transition efforts while increasing its operational and regulatory complexity.

Figure 1. PV arrays at Palau's SPEC PV+BESS plant.

PROJECT STATUS/RESULTS: By the end of 2024, HNEI had completed extensive capacity building, power system analyses and regulatory support for PEWA and PPUC. Work included drafting a new national grid code, conducting multiple training sessions in Palau and Hawaiʻi and performing preliminary grid modeling to assess the impacts of inverter-based resources (IBRs).

In early 2025, the team applied advanced production cost modeling (PCM) using the SAInt software platform to analyze system-wide generation dispatch, BESS investment strategies, and operational cost impacts across Palau's thermal and distributed resources. The modeling identified options to improve system flexibility through optimized storage operation.

Concurrently, HNEI also launched a PV hosting capacity (HC) study for Palau's distribution network. The "Airport Feeder" was selected as the pilot circuit following a field survey with PPUC personnel to map transformers, feeders, wire sizes and customer-sited rooftop PV systems. Using the collected data, Grid***START*** constructed a detailed power flow model of the feeder in PowerFactory, integrating in-house stochastic analysis algorithms to evaluate distribution-level connection limits.

Figure 2. Grid***START*** and PPUC personnel conducting a field survey of transformers.

We also initiated development of a "User's Handbook" to assist the PPUC in implementing the newly adopted grid code and establishing online procedures for streamlined PV interconnection review. The handbook was nearing completion when portions of ONR funding concluded, which also precluded planned training on advanced system planning tools and data analytics. The analytical work completed to that point using the SAInt and PowerFactory platforms nonetheless created a durable technical foundation to guide future grid modernization and capacity-building efforts in Palau. Throughout 2025, coordinating with key partners, including the Asian Development Bank, Japan International Cooperation Agency, Okinawa Enetech and Tokyo Electric Power Company, HNEI ensured that technical assistance remained aligned with Palau's national energy priorities. While ONR support concluded in 2025, HNEI plans to maintain collaboration with Palau as resources permit under future funding opportunities.

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

H6: Energy Regulatory and Technical Support for Cook Islands

OBJECTIVE AND SIGNIFICANCE: Through funding from the Office of Naval Research (ONR), HNEI's Grid***START*** provided technical, regulatory and policy support to Te Aponga Uira (TAU), the government-owned electric utility on Rarotonga, the capital of the Cook Islands nation in the South Pacific.

BACKGROUND: The Cook Islands Economic Development Strategy 2030 has a RPS target of 60% by 2030. TAU on Rarotonga has approximately 5,000 customers and is responsible for approximately 90% of the Cook Islands' electricity generation. The power grid on Rarotonga serves a peak demand of approximately 5.5 megawatts (MW), with most generation coming from diesel, and an increasing share supplied by customer-owned rooftop photovoltaics (PV) as well as utility-scale PV plus battery energy storage system (BESS) projects financed by international partners.

Figure 1. Te Mana o Te Ra PV + BESS Project (1 MW, 5.6 MWh) at Rarotonga International Airport.

Building on longstanding collaboration, Grid***START***'s support encompasses strategic planning, technical training, and advanced modeling assistance to strengthen TAU's ability to manage grid modernization, variable and intermittent energy integration, and regulatory development as the Cook Islands transitions toward higher shares of alternative energy.

PROJECT STATUS/RESULTS: By the end of 2024, HNEI completed training for TAU leadership in Honolulu and held technical and policy sessions in Rarotonga with the Prime Minister, TAU management, and the Board of the Cook Islands Investment Corporation (CIIC), laying foundations for advanced modeling and regulatory support activities in 2025.

Figure 2. TAU leadership with Prime Minister Brown.

In 2025, advanced technical support for TAU was provided through a series of analytical and modeling initiatives. Building on TAU's PowerFactory model, the team completed a stochastic hosting capacity study of Rarotonga's distribution feeders and refined key assumptions for daytime minimum loads, enabling more accurate assessment of distributed PV integration potential.

Concurrently, TAU management and engineers were invited to a three-day training workshop for the Scenario Analysis Interface for Energy Systems (SAInt) software to build the first production cost model of the TAU grid and performed scenario-based simulations linking generation, storage operation, and reserve management. Technical results demonstrated that coordinating BESS deployment could reduce curtailment and lower annual operating costs while supporting TAU's alternative energy targets.

Beyond these technical achievements, HNEI and TAU collaborated on coordinated planning exercises and policy framework review. The work reinforced TAU's capacity in strategic planning and grid operations, further aligning utility objectives with national energy targets.

While ONR funding support concluded in 2025, HNEI plans to maintain collaboration with TAU as resources permit under future funding opportunities.

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

H7: Energy Regulatory and Technical Support for Fiji

OBJECTIVE AND SIGNIFICANCE: In partnership with the Pacific Power Association (PPA) and through funding under an Asia Pacific Regional Energy System Assessment (APRESA) grant from the Office of Naval Research, HNEI provided technical, regulatory and policy support to Energy Fiji Limited (EFL), the national utility of the Republic of Fiji.

BACKGROUND: Fiji generates approximately 60% of its electricity from hydro sources, while the remainder is supplied by thermal power and emerging variable and intermittent energy sources. EFL's planned expansion of solar generation presents opportunities and challenges for grid management, especially as VRE sources and BESS become more prominent. Meeting Fiji's ambitious alternative energy targets requires broad ranging technical capacity, effective power system planning, and regulatory frameworks informed by leading-edge island contextual experiences.

Figure 1. Wind Turbines at Butoni Wind Farm, Fiji.

PPA is an inter-governmental agency whose objective is to improve the quality of power in the Pacific region through a cooperative effort among the utilities, private sector, and regional development partners. HNEI's relationship with PPA began in 2023, when the team was invited to present at PPA's 30th annual conference in Saipan, sharing technical insights and forging new connections with regional stakeholders.

Figure 2. PPA's 30th Annual Conference in Saipan.

This project built on HNEI Grid***START***'s collaboration with PPA to deliver targeted capacity building engagements for Pacific island utilities pursuing ambitious energy transitions. By drawing on lessons learned from Hawaiʻi and leveraging regional expertise, we are supporting EFL's effort to plan, procure and operate new solar projects and battery energy storage systems (BESS) in Fiji.

PROJECT STATUS/RESULTS: Since 2023, HNEI has worked closely with PPA to design and implement energy sector capacity building initiatives across its member utilities. This partnership enabled direct engagement with EFL, as PPA facilitated connections and responded to EFL's request for training to advance Fiji's goal of meeting all electricity demand from non-conventional sources by 2030, with a substantial increase in solar capacity as a cornerstone of this effort.

In April 2025, a two-day virtual training workshop tailored for EFL staff was delivered, focusing on integrating VRE generation, procurement strategies, lessons learned from Hawaiʻi's energy transition, and practical approaches for operation and planning solar projects on an island grid. Core topics included:

- Hawaiʻi's journey to high variable and intermittent energy penetration;
- Grid resource planning and operations with high shares of solar and non-fossil generation;
- BESS applications for reliability and resilience;
- Updated grid interconnection requirements and distributed PV program evolution;
- Regulatory and policy frameworks for competitive resource procurement; and
- Power system resilience and risk management under rapidly changing conditions.

The training featured detailed case studies and technical lessons from Hawaiʻi's island utilities, discussion of specific regulatory and procurement approaches, and shared modeling tools where appropriate. HNEI collaborated closely with EFL team members to identify further technical support needs, setting the stage for potential follow-up activities under alternative funding streams.

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

H8: Energy Regulatory and Technical Support for Majuro, Marshall Islands

OBJECTIVE AND SIGNIFICANCE: In partnership with the Pacific Power Association (PPA) and through funding under an Asia Pacific Regional Energy System Assessment (APRESA) grant from the Office of Naval Research, HNEI provided technical, regulatory and policy support to Marshalls Energy Company (MEC), the national utility of Republic of the Marshall Islands (RMI).

BACKGROUND: RMI depends heavily on imported fuels to meet electricity needs. To enhance energy security and economic resilience, RMI's 2018 Energy Roadmap set targets to increase indigenous energy supply and efficiency. The government is pursuing new energy policies and regulatory measures to guide this transition. MEC, the state-owned utility serving Majuro and outer islands, operates multiple independent power systems. Majuro's largest system recorded a peak demand of 9.8 MW in 2023, projected to reach 14 MW over the next several years, with solar representing only a small portion of current generation. Significant increases in VRE penetration and battery energy storage systems (BESS) are anticipated, requiring stronger technical capacity and regulatory frameworks.

PPA is an inter-governmental agency whose objective is to improve the quality of power in the Pacific region through a cooperative effort among the utilities, private sector, and regional development partners. HNEI's relationship with PPA began in 2023, when the team was invited to present at PPA's 30th annual conference in Saipan, sharing technical insights and forging new connections.

Figure 1. PPA's 30th Annual Conference in Saipan.

This project built on HNEI Grid***START***'s collaboration with PPA to deliver targeted capacity building engagements for Pacific island utilities pursuing ambitious energy transitions. Drawing on lessons learned from Hawaiʻi and leveraging regional expertise, we supported MEC's effort to plan and operate new solar and energy storage projects on a small isolated island grid with aging existing infrastructure.

PROJECT STATUS/RESULTS: Since 2023, HNEI has worked closely with PPA to design and implement energy sector capacity building initiatives for member utilities. This partnership enabled direct engagement with MEC, as PPA facilitated connections and supported RMI's request for technical assistance and training to advance its national energy priorities.

In February 2024, HNEI met with the National Energy Office, the Environmental Protection Authority and MEC to better understand local challenges and needs.

In April 2025, the team delivered a two-day, in-person capacity building workshop at MEC headquarters in Majuro, featuring presentations, interactive discussions, and hands-on exercises on system planning, lessons learned from Hawaiʻi's energy transition, and implementing grid technologies for island systems. It also included site visits and direct exchanges with MEC engineers and management. The core topics presented included:

- Drivers for Hawaiʻi's energy transition and enabling regulatory frameworks;
- Distributed energy resources feeder hosting capacity methods;
- BESS integration for reliability and resilience;
- Grid modernization and planning for rapid energy transition;
- Competitive procurement approaches for new energy resources; and
- Grid***START***'s generation resource mix modeling tool for MEC's grid.

Follow-up discussions are ongoing to explore further collaboration, including potential support for developing an RMI grid code, and continued technical assistance under future funding opportunities.

Funding Source: Office of Naval Research

Contact: Leon Roose, lroose@hawaii.edu

Last Updated: November 2025

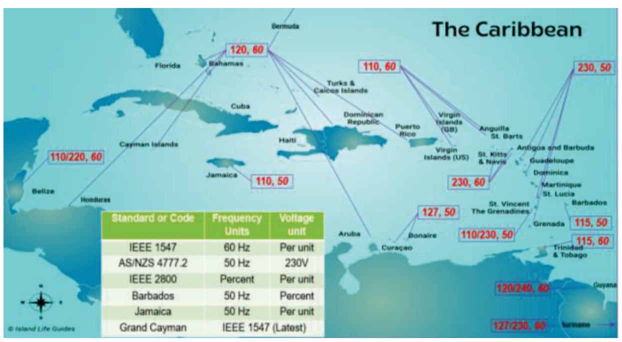
Hawai‘i Natural Energy Institute Research Highlights

Appendix H: International

H9: Energy Security and Resilience in the Caribbean Islands

OBJECTIVE AND SIGNIFICANCE: In February 2023, HNEI was contracted by Deloitte & Touche LLP (Deloitte) to deliver technical assistance under the U.S. Department of State’s Power Sector Program Technical Assistance to Support the Partnership to Address Climate Change 2030 (PACC 2030). This initiative serves as the framework for U.S. government support of energy security and resilience in the Caribbean islands, with HNEI’s activities concluding in 2025.

BACKGROUND: The Caribbean region faces significant energy challenges, with the highest dependency on imported liquid fuel for power generation and the highest average electricity prices in the Western Hemisphere.



Standard or Code	Frequency Units	Voltage unit
IEEE 1547	60 Hz	Per unit
AS/NZS 4777.2	50 Hz	230V
IEEE 2800	Percent	Per unit
Barbados	50 Hz	Percent
Jamaica	50 Hz	Per unit
Grand Cayman	IEEE 1547 (Latest)	

Figure 1. Caribbean electricity voltages and frequencies.

This situation creates vulnerability to global supply shocks and unreliable electricity service. Following years of energy engagement under the Caribbean Energy Security Initiative (CESI), the federal government announced PACC 2030 during the U.S.-hosted Summit of the Americas in June 2022. PACC 2030 was designed to drive results and outcomes across Caribbean energy security, resilience, and energy integration, focusing on geothermal development, regulatory capacity, and technical innovation as regional priorities.

PROJECT STATUS/RESULTS: From 2023 through early 2025, HNEI Grid***START*** provided analytical and advisory support to enhance regional capacity for energy integration, utility regulation and power sector resilience in the Caribbean.

Key activities and deliverables included:

- Six days of virtual training on the integration of high levels of variable generation, covering topics such as planning, operational design, power system management, grid codes, and energy resource forecasting for the Caribbean Electric Utility Services Corporation (CARILEC) and Organization of Caribbean Utility Regulators (OOCUR);
- Four days of in-person and hybrid training in Trinidad and Tobago focused on grid flexibility and procurement of grid services;
- A technical report for Saint Kitts and Nevis outlining grid code recommendations, reliability benchmarks, criteria, and integration of distributed generation;
- Two technical reports for Trinidad and Tobago: one report provided technical assistance for PV system integration, including planning, interconnection requirements, and procurement, while the other addressed risk management and infrastructure preparedness, discussing resiliency solutions, strategies, planning, and relevant case studies; and
- Facilitating the launch of the Caribbean Grid Code Accelerator at CARILEC’s annual conference in October 2024, supporting the development of a unified regional grid code standard.

In January 2025, the team delivered a technical report for Jamaica Public Service (JPS) offering recommendations on EV strategy and planning, grid readiness, analytical tools for system planning, variable and intermittent energy integration, distributed resources, battery energy storage systems adoption, tariff modeling, smart metering, and lessons learned from advanced utility analytics.

Activities for PACC 2030 ended in early 2025 as the contract was completed.

Funding Source: U.S. Department of State

Contact: Leon Roose, lroose@hawaii.edu

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