FINAL TECHNICAL REPORT

Asia Pacific Research Initiative for Sustainable Energy Systems 2022

Office of Naval Research

Grant Award Number N00014-23-1-2720

July 1, 2023 through May 12, 2025

September 2025

Table of Contents

EXECUTIVE SUMMARY **3**

FLEXIBLE ELECTRONICS **6**

HYDROGEN REFUELING TECHNOLOGY **9**

RESILIENT GRID SYSTEMS **18**

Coconut Island DC Microgrid Project *19*

Bidirectional EV Charging Optimization *26*

Final Technical Report
Asia Pacific Research Initiative for Sustainable Energy Systems
Grant Award Number N00014-23-1-2720
July 1, 2023 through May 12, 2025

EXECUTIVE SUMMARY

This report summarizes work conducted under Grant Award Number N00014-23-1-2720, the Asia Pacific Research Initiative for Sustainable Energy Systems 2022 (APRISES22), funded by the Office of Naval Research (ONR) to the Hawai‘i Natural Energy Institute (HNEI) of the University of Hawai‘i at Mānoa (UH). The work conducted under APRISES22 was intended to comprise research, development, testing, and evaluation (RDT&E) over a range of technical areas. These included: Electrochemical Technologies with a focus on fuel cells, batteries, and flexible electronics; Alternative Fuels including carbonization of biomass, marine fuels, and hydrogen; and Resilient Energy Systems including development and demonstration of novel technologies for advanced smart microgrids and resource adequacy studies for the Hawai‘i electrical grids. We also proposed that Makai Ocean Engineering, under subcontract to the University of Hawai‘i, continue their efforts to develop high-performance, low-cost heat exchangers. However, due to a work stop order on May 12, 2025, funds were only expended in the areas of flexible electronics, hydrogen technology, and grid technology. A brief summary of results for these three activities follows.

Under the “Electrochemical Technologies” task, funding from APRISES22 allowed HNEI to complete a semi-monolithic integration method to mate electronic layers, originally developed for rigid substrates, was successfully adapted to mechanically compliant, flexible substrates using transparent conductive composites (TCCs) as the host. TCCs are polymer laminates embedded with conductive microspheres, combining high optical transparency with out-of-plane conductivity. This dual function enables them to serve as both mechanical supports and vertical electrical interconnects, which is particularly beneficial for multilayer device architectures and applications requiring mechanical flexibility.

The primary objective of this activity was to develop processes and demonstrate the ability to transfer fully fabricated thin films from rigid processing substrates to flexible hosts without compromising electrical or structural integrity. The first milestone was to demonstrate the transfer of a 1 cm^2, 100 nm silver thin film onto a TCC substrate using a room-temperature lamination and exfoliation process. The second milestone targeted mechanical durability, with a benchmark of retaining at least 80% of initial electrical conductivity after 20 bending cycles.

Electrical measurements confirmed that as-exfoliated Ag/TCC structures retained excellent conductivity, with in-plane resistance increasing modestly from 0.686 Ω/sq to 0.749 Ω/sq after 100 bending cycles—representing over 90% retention, far exceeding the target. Out-of-plane resistance also remained stable. Microscopic inspection revealed minimal wrinkling or voiding, with minor microcracks attributed to the exfoliation process. These can be mitigated through improved process control and surface treatments. Computational modeling supported optimization of lamination parameters and is being extended to address mechanical stress at microsphere contact points. Preliminary demonstrations with thin-film solar absorbers confirmed that the process can maintain device performance after transfer. This opens the door to flexible applications such as wearable photovoltaics, conformal sensors, and flexible displays, especially where low-temperature processing is essential. Future work will focus on integrating more complex active devices (e.g., chalcopyrite and perovskite solar cells), refining exfoliation techniques, and validating long-term system performance under dynamic mechanical stress.

Overall, the findings establish semi-monolithic integration using TCCs as a promising, robust, and scalable pathway for manufacturing high-performance flexible electronics. The method preserves functionality under repeated bending, overcomes limitations of conventional monolithic stacking on sensitive substrates, and holds strong potential for applications in wearable, aerospace, and marine environments.

Under the "Alternative Fuels" task, research on constant volume carbonization of biomass and fit for purpose characterization of marine fuels was not conducted. HNEI did continue research, development, demonstration, and assessment of hydrogen production, storage, and dispensing systems for heavy duty hydrogen vehicles, and evaluation of the operational performance of buses on the Big Island of Hawai‘i. The team conducted power consumption analysis and optimization, updated and expanded operational and safety documentation, investigated corrosion and marine environmental effects, and developed dispenser software. Performance monitoring and the coordination of operations for the fuel cell electric buses also occurred. Various outreach, briefings, and engagements were supported by APRISES22 funds as well.

Under the "Resilient Energy Systems" task, HNEI advanced the development and demonstration of next-generation energy systems with a focus on distributed energy resources, microgrid applications, and electric vehicle (EV) grid integration. This research, conducted by HNEI's Grid System Technologies Advanced Research Team (Grid***START***), concentrated on targeted refinements to the Coconut Island DC microgrid to improve reliability and system monitoring; and furthering tool development through the bidirectional EV charging demonstration project.

The Coconut Island project previously established a research-ready DC microgrid in a harsh coastal setting, including rooftop PV, stationary batteries, advanced controls, and integration with an all-electric research vessel (E-boat). Building on this foundation, APRISES22 focused on improving the stability and functionality of the microgrid's monitoring system. Specific

enhancements included streamlining data polling protocols and optimizing the dashboard interface design to resolve controller freezes and enhance long-term system reliability. This effort included the professional development of an electrical engineering graduate student, who gained hands-on microgrid experience and authored a peer-reviewed publication reviewing global DC microgrid deployments. Together, these efforts extended and strengthened the novel DC microgrid research platform and the program's contribution to training the next generation of microgrid engineers.

The bidirectional EV charging demonstration project at the University of Hawai‘i at Mānoa includes two advanced bidirectional chargers with novel control algorithms developed to optimize EV charge/discharge cycles for cost savings, fleet management, and potential grid services. Under APRISES22, the project conducted analysis to examine the potential to extend this concept to residential applications by developing and refining a technoeconomic algorithm that determines the optimal sizing of rooftop PV, household batteries, and EVs with bidirectional power flow capability. The analysis highlighted the strong influence of time-of-use (TOU) pricing structures and driving schedules on the added value of bidirectional charging, with case studies demonstrating clear economic benefits across a robust range of operating scenarios. Graduate students contributed to this effort by building a user-friendly web tool that operationalizes the algorithm, combining technical training with the creation of a practical platform for homeowners, vehicle fleet managers and industry stakeholders.

This final report describes the research completed under each of these areas. Publications produced through these efforts are noted below and available on HNEI's website at https://www.hnei.hawaii.edu/publications/project-reports/aprises-22/.

FLEXIBLE ELECTRONICS

Monolithic integration, the conventional method for fabricating solid-state devices through sequential material deposition, underpins nearly all commercial thin-film technologies including photovoltaics, microelectronics, and displays. While foundational, this approach imposes strict process compatibility constraints, as each layer must be deposited without compromising the integrity of those beneath it. These limitations become especially pronounced when integrating devices onto thermally sensitive flexible substrates like plastics, often requiring significant process modifications that alter or degrade device performance. To address this, the Thin Films Laboratory at HNEI has developed a semi-monolithic integration technique that enables room-temperature transfer of fully fabricated devices onto rigid glass substrates through bonding and delamination. This semi-monolithic integration technique developed by HNEI facilitates the transfer of fully fabricated solid-state devices from their process substrate to a new host substrate without compromising functional integrity.

The primary objective of this research was to adapt and validate the semi-monolithic integration process, previously validated on rigid substrates, for use with mechanically compliant materials. The adaptation of this method to flexible structures by employing the transparent conductive composite (TCC) as the host substrate is described below. In the new structure, the TCC serve as the flexible support while simultaneously providing vertical electrical conductivity for interlayer interfacing. Mechanical compliance test of an exfoliated 100 nm silver film demonstrate preservation of over 80% of its original conductivity after 100 bending cycles, surpassing performance benchmarks. By decoupling thin film fabrication from device assembly, the results offer a compelling alternative to conventional monolithic stacking, especially useful for applications requiring mechanically compliant thin films on substrates with low thermal budgets.

The first milestone targeted the successful transfer of a 1 cm^2 metallic thin film onto flexible substrates such as polymer sheets or composite systems, using TCCs to establish electrical contact and mechanical support. The second milestone assessed the durability of the transferred films under cyclic mechanical stress, with a benchmark of retaining at least 80% of initial electrical conductivity after 20 bending or stretching cycles. These objectives were designed to evaluate the viability of this integration strategy for applications where conventional processes required for thin film and solid-state device fabrication are incompatible with soft or thermally sensitive substrates.

The following sections detail the adaptation of this process using flexible substrates to accelerate the deployment of flexible devices.

Central to this method is a novel class of transparent conductive composites comprising a flexible polymer embedded with conductive microspheres (Figure 1.1). Unlike traditional conductive flexible polymers, where conductive media are coated on top the substrate providing only *in-plane* conductivity, TCCs combine high optical transparency with high *out-of-plane* conductivity. These

characteristics make it well-suited as a flexible host substrate that provide both mechanical support and vertical electrical conductivity, offering advantages for integration and interfacial applications.

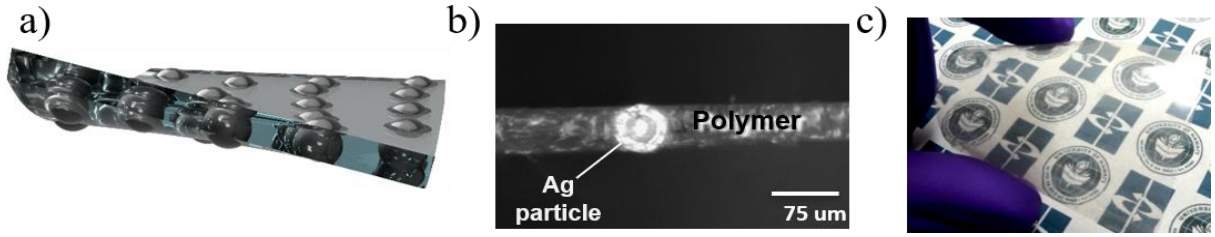

Figure 1.1. a) Concept model, b) cross-sectional microscopic image, and c) a photograph of a TCC made of conductive microsphere fillers protruding from a polymer laminate.

To adapt the semi-monolithic integration process for flexible TCC host substrates, we employed a computational model developed at HNEI to optimize lamination parameters. The model predicts ideal lamination pressure per unit area for a given microsphere concentration to achieve a target bond-line thickness with sufficient electrical contact across the lamination interface. Following room-temperature lamination and curing, the TCC served as the mechanical support for delaminating the thin film from its original processing substrate. For this early-stage trial, 100 nm silver thin films deposited on soda-lime glass (SLG) were selected as the transfer layer.

Post-transfer inspection confirmed uniform adhesion with minimal wrinkling or void regions. Electrical characterization (Table 1.1) showed that the as-exfoliated Ag/TCC structure (Figure 1.2a) exhibited an in-plane sheet resistance of 0.686 Ω/Sq and an out-of-plane resistance of 0.22 Ω·cm², compared to the in-plane resistance of 0.183 Ω/Sq for the control Ag/SLG sample. Microscopic analysis revealed that the slight reduction in conductivity was primarily due to the formation of microcracks within the metallic layer (Figure 1.2b), which is expected to be mitigated with improved exfoliation processes and surface treatments. In addition, microsphere protrusions were observed across the silver film, indicating that the elastic decompression of the microspheres during film exfoliation induce sufficient stress for film penetration. The computational model is under further development to predict elastic decompression under a range of lamination temperatures to mitigate point defects created at the microsphere locale. Mechanical flexibility and robustness of the film was tested by subjecting the sample to 100 bending cycles (radius = 5 mm). As summarized in Table 1.1, the Ag/TCC structure retained an in-plane resistance of 0.749 Ω/Sq and out-of-plane resistance of 0.20 Ω·cm², indicating conductivity retention above 90%, compliant with objectives.

Table 1.1. Summary of electrical conductivities for silver thin films under given conditions.

Condition	**In-plane resistance** (Ω/sq)	**Out-of-plane resistance** (Ω·cm^2)
Control (Ag/glass)	0.183	N.A
As-exfoliated (Ag/TCC)	0.686	0.22
Ag/TCC after 100 bending	0.749	0.20

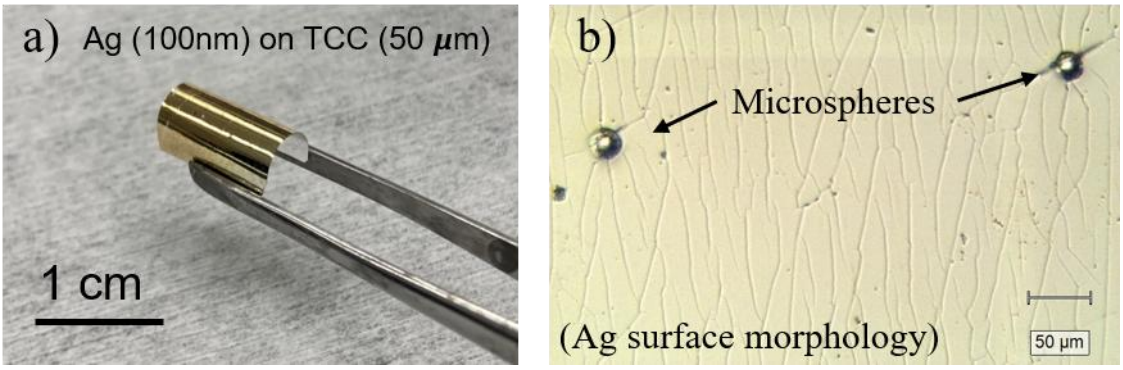

Figure 1.2. a) Image of an exfoliated Ag/TCC structure and b) post-transfer microscopic inspection of the film under 20x objective lens.

The observed conductivity retention above 90% after repeated bending cycled confirms mechanical robustness of the Ag/TCC structure and validate the potential of this approach to open new possibilities for wearable photovoltaics, conformal sensors, and flexible displays. With further refinement, including improved exfoliation techniques, surface treatments, and microsphere mechanical modeling, we expect successful transfer of fully processed devices onto flexible substrates without compromising solid-state properties. Figure 1.3 presents the preliminary demonstration of flexible solid state device exfoliation; while Figure 1.4 displays the performance measurement after thin film transfer onto a rigid host substrate.

Figure 1.3. A thin film solar absorber bonded to a polymer and delaminated from the substrate it was integrated on. The preliminary results show the capabilities of thin-film transfer. Systematic performance validations are under investigation.

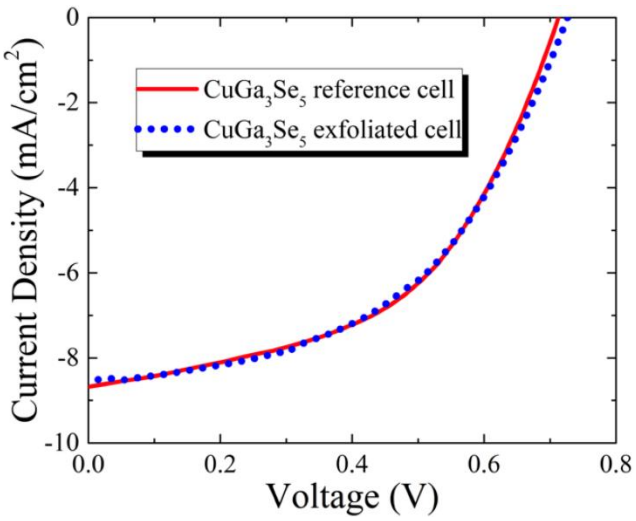

Figure 1.4. Current-voltage characteristics of a solar cell before (red line) and after (blue dots) exfoliation and transfer onto a new glass host substrate. The performance measurement after thin film transfer validates the potential for preserved functionality.

Future work will focus on integrating sensors and active devices such as chalcopyrite and perovskite solar cells. The out-of-plane conductivity enabled by TCCs is particularly advantageous for multilayer device architectures, where vertical interconnects are essential for compact and high-performance systems. These efforts will further validate system-level performance under dynamic mechanical conditions and accelerate the deployment of flexible electronic technologies in real-world applications. In summary, this project has demonstrated the potential for semi-monolithic integration, enabled by TCCs, to be a robust and versatile approach for transferring solid-state devices onto flexible substrates. The process can preserve the majority of electrical functionality under mechanical stress and opens new possibilities for conformal electronics in wearable, marine, and aerospace applications.

HYDROGEN REFUELING TECHNOLOGY

The Hawai‘i Hydrogen Power Park (“Power Park”) was established in 2003 to support the U.S. Department of Energy’s (DOE) Technology Validation Program. The Power Park was funded by the DOE through the Department of Business, Economic Development and Tourism’s Strategic Industries Division (DBEDT), with the Hawai‘i Natural Energy Institute (HNEI) at the University of Hawai‘i serving as the implementing partner. This effort conducted engineering and economic validation of pre-commercial hydrogen technologies. Power Park Phase 1 systems included a commercial scale grid-connected alkaline electrolyzer interfaced with a gas storage system and a 5 kW proton exchange membrane (PEM) fuel cell located at the Hawai‘i Fuel Cell Test Facility (HFCTF) in Honolulu.

Power Park Phase 2 was proposed to expand the capabilities of the Power Park through the testing and validation of hydrogen fueling system technologies on the Big Island of Hawai‘i. In parallel, the Hawai‘i Volcanoes National Park (HAVO) had been selected for funding through the Advanced Transportation for Parks and Public Lands (ATPPL) program by the Department of Transportation (DOT) via the Department of Interior (DOI) to purchase two hydrogen-hybrid shuttle buses for tours of the park. The project was intended to support HAVO's hydrogen fueling requirements leveraging additional investment from the State of Hawai‘i's Hydrogen Investment Capital Special Fund ("Hydrogen Fund"). In its initial formulation, the Department of Defense (DOD), through the Kilauea Military Camp (KMC), offered to serve as the host site for the fueling infrastructure for the vehicles.

While initially targeted for installation at the HAVO site, concern about environmental issues in the National Park resulted in a site change to the Puna Geothermal site. In this configuration, support for the HAVO vehicles was to be provided by leveraging a hydrogen production system installed at the Puna Geothermal Ventures (PGV) power plant utilizing renewable electricity produced at the geothermal plant to produce electrolytic hydrogen. The hydrogen was to be delivered to HAVO by tube trailer and dispensed to the HAVO vehicles from a dispenser located at the KMC site.

In 2010, in response to Navy's interest in the use of fuel cell vehicles to achieve higher vehicle efficiency and to lower fuel use, HNEI collaborated with the Naval Research Laboratory (NRL), proposing a collaborative project to DOE to investigate the potential for the intermittent operation of a grid-connected electrolyzer to produce hydrogen and provide grid services for large-scale electric grid applications. NRL served as the technical lead and overseer of the hydrogen production program with HNEI serving as the implementing partner. Ultimately, community concerns with the PGV site resulted in a final siting at the Natural Energy Laboratory Hawai‘i Authority (NELHA) site in Kona, Hawai‘i.

The PGV/NELHA hydrogen production system was procured under Award N00173-10-1-G037, P00001 through NRL. The stated objectives of the project were to optimize use of the electrolyzer and hydrogen storage system and utilize the hydrogen for transportation while also allowing greater penetration of variable renewable generation sources onto the grid, and to reduce barriers to the introduction of the hydrogen infrastructure. The variable hydrogen production was intended to support load leveling of the electricity produced by variable renewable energy sources such as wind, solar, and geothermal on the Big Island of Hawai‘i. Hydrogen produced from the system was also intended to be used as a transportation fuel.

Under this agreement, HNEI conducted cyclic testing of the hydrogen production system at Powertech Labs, located in Vancouver, Canada, to characterize the dynamic response of the system. Following modification of the system controls, it was installed at NELHA on the Island of Hawai‘i. Performance data under cyclic conditions was collected and reported jointly to ONR and DOE under the prior work.

In addition to conducting the research to characterize and control the variable load to provide grid services, additional goals included:

1. Support hydrogen vehicle demonstration projects on the Big Island of Hawai‘i;
2. Conduct technical analysis of system and subsystem performance in a real-world environment; and
3. Document liability, insurance, and permitting issues and their resolutions.

As illustrated in Figure 2.1, the concept was to produce fuel cell grade hydrogen at NELHA to be delivered to the Mass Transit Agency (MTA) base yard in Hilo to support heavy-duty FCEBs operated by the MTA Hele-On public bus service. Three trailers each with a capacity of 105 kg were procured for transporting hydrogen between the production and fueling site. The trailers were certified by the Federal Transit Administration Department of Transportation for use on U.S. public roads.

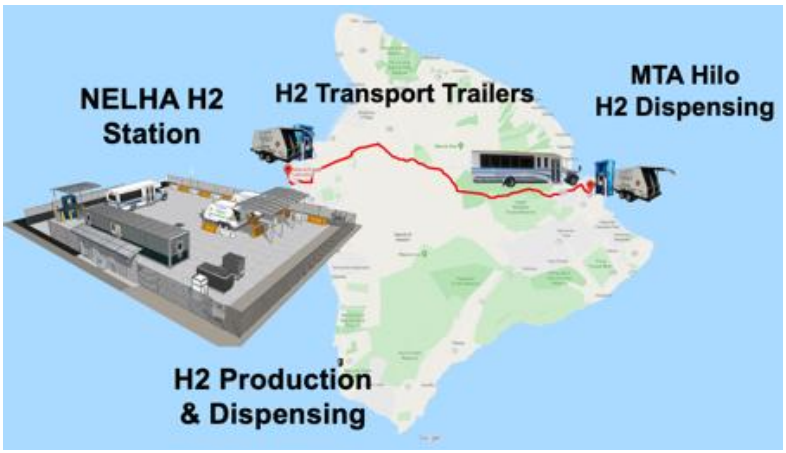

Figure 2.1. Concept diagram of the transportation of hydrogen on the Big Island of Hawai‘i.

These investments collectively supported not just capital deployment but also workforce development, operations, long-term resilience, and research activities within Hawai‘i’s unique island environment.

At the core of this project was Hawai‘i’s first public hydrogen fueling station, commissioned at NELHA. The station utilizes a Nel (formerly Proton Onsite) 65 kg/day PEM electrolyzer to produce ultra-pure hydrogen at 30 bar (440 psi). A Hydro-Pac compressor increases this pressure to 438 bar (6,352 psi), enabling storage in three DOT-certified trailers with a capacity of 105 kg each. Hydrogen fueling occurs at a nominal 350 bar (5,000 psi) through fully automated dispensers equipped with advanced safety interlocks and fail-safe mechanisms, supported by redundant underground piping and specialized interfaces designed specifically for these hydrogen transport trailers (Figures 2.2, 2.3, and 2.4). Early operations revealed critical lessons about control system responsiveness and software reliability, leading to a complete redevelopment of fueling control

software and operational protocols—a process that granted Hawai‘i full technical autonomy over its hydrogen dispensing systems.

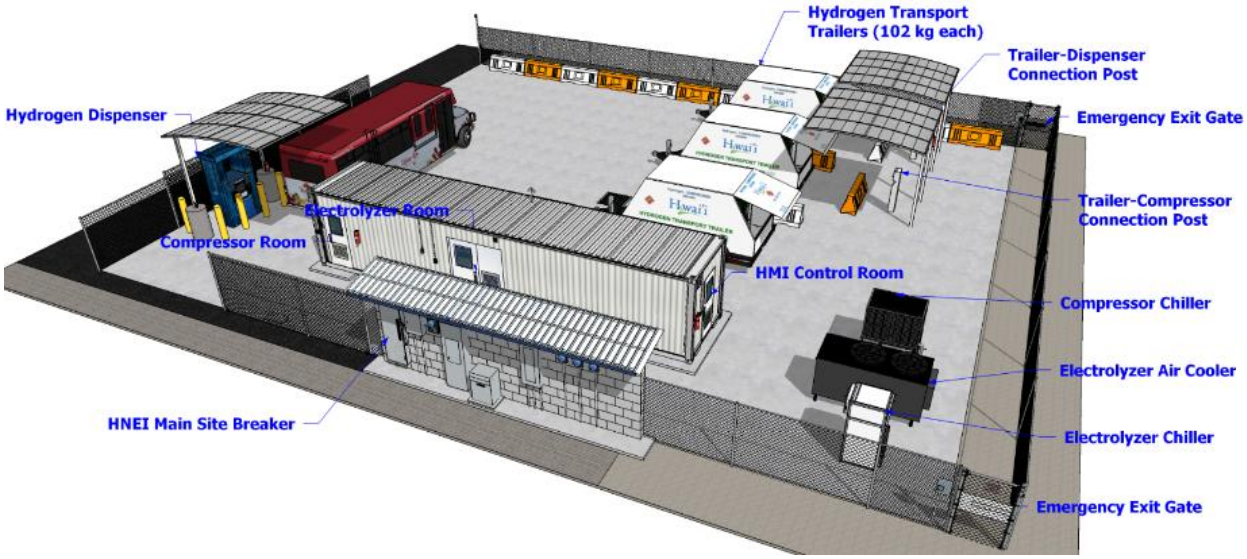

Figure 2.2. Major components of Hawai‘i’s first hydrogen fueling station at NELHA.

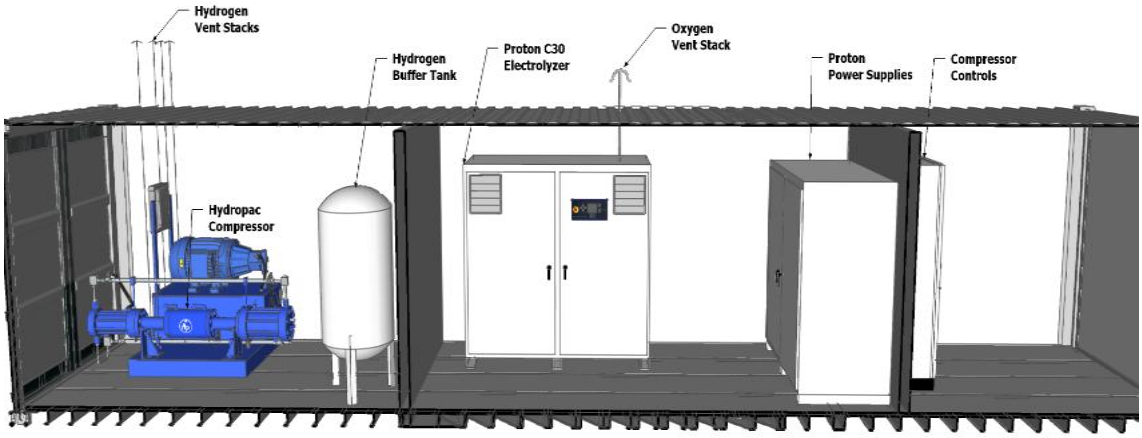

Figure 2.3. The components inside the shipping container.

Proton onsite C30 electrolyzer

Hydro-Pac compressor

Powertech/HNEI mobile hydrogen tube trailer

Figure 2.4. Process flow illustrating hydrogen being produced on site through water electrolysis and then compressed to 450 bar and stored in mobile hydrogen tube trailers.

During the initial bus deployment phase, HNEI played a critical role supporting U.S. Hybrid's startup and integration of the 21-passenger hydrogen fuel cell electric bus, resolving a range of technical challenges such as optimizing fuel cell battery charging, algorithms to allow safe charging at stoplights, mitigating DC-to-DC converter fuse failures through hardware and software improvements, and enhancing thermal management via increased radiator fan speeds at low bus speeds. Additional efforts included troubleshooting sensor interference, repairing drivetrain components, and addressing cooling system leaks, enabling the bus to enter reliable daily service routes where it demonstrated impressive performance metrics of approximately 1.2 kWh energy consumed per mile and 12.7 miles per kilogram of hydrogen over 145-mile runs.

The program also supported workforce training and public engagement through tours, workshops, and community events. HNEI supported the MTA's efforts to secure over $23 million in FTA Low/No Emission grants to acquire additional fuel cell buses and expand infrastructure.

Operating in close proximity to Hawai‘i's marine environment posed additional technical challenges. The team developed an aggressive program to address corrosion caused by the coastal salt-air atmosphere that included selecting corrosion-resistant materials and refining maintenance schedules.

In addition to station development, HNEI supported the retrofit and deployment of two fuel cell electric buses (FCEBs) in the County of Hawai‘i's Hele-On fleet. The primary vehicle (Figures 2.5 and 2.6) is a 21-passenger ADA-compliant bus designed and converted by U.S. Hybrid, powered by dual 11 kWh lithium-ion batteries, a 200 kW drivetrain, and a 40 kW fuel cell (upgraded from the original 30 kW). This bus also integrates a 10 kW export power system capable of sustaining emergency AC power for up to 30 hours on a single hydrogen fill—an innovation enhancing community resilience in emergencies or extended power outages. The secondary platform is a 19-passenger bus originally intended to serve Hawai‘i Volcanoes National Park that was upgraded with a 90 kW Hyundai fuel cell and an expanded 33 kWh battery pack to enable service on Hawai‘i's more challenging topographic routes.

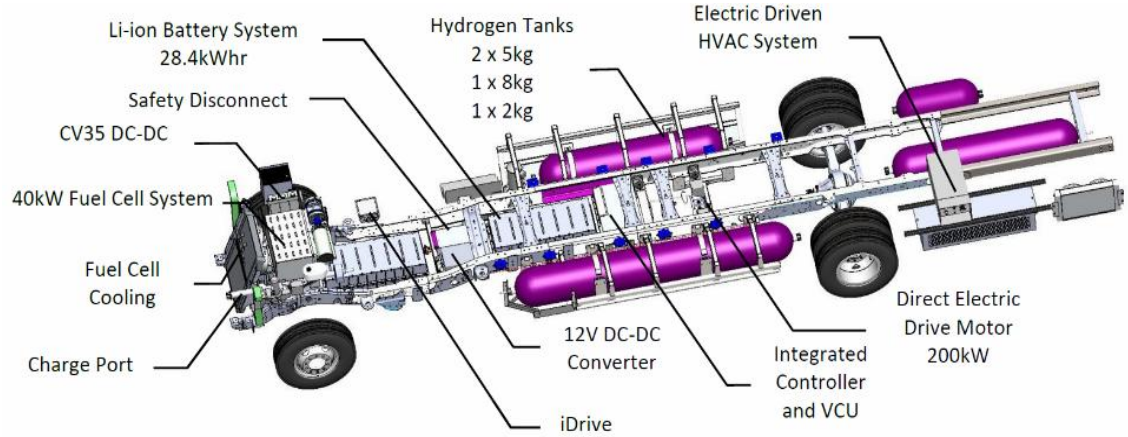

Figure 2.5. Components of a hydrogen fuel cell bus.

Figure 2.6. Hele-On Bus refueling at the 350 bar hydrogen dispenser.

Throughout the project, advanced data collection systems (Figure 2.7) captured data on bus operations and station performance. The data from this program is being used by Hawai‘i County for its strategic fleet planning and demonstrated the technical viability of hydrogen fueled transportation under real-world conditions that include varied terrain, climate, and logistical constraints.

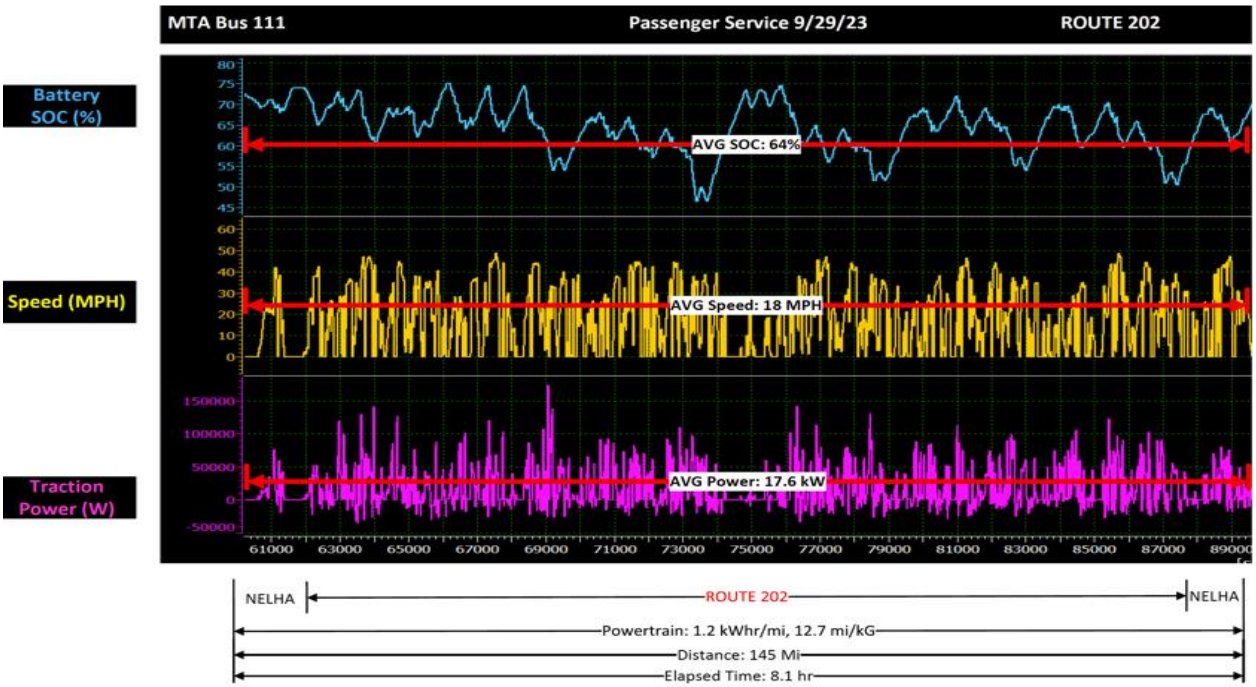

Figure 2.7. Telemetry data from the buses.

Beyond technological deployment, a core element of the program was workforce development. HNEI developed and delivered training modules tailored for bus operators, maintenance technicians, emergency responders, and fueling station staff. These programs combined classroom

instruction, hands-on equipment familiarization, and emergency drills, building a robust, locally based cadre of hydrogen-qualified personnel poised to sustain and expand hydrogen transit operations.

Community and stakeholder engagement included tours (Figure 2.8), briefing sessions, public demonstrations, and educational programs enriching local understanding and support. A number of high-profile events, such as the "Meet the Bus" launch and participation in DOE's H2 Twin Cities initiative, served to connect Hawai'i's hydrogen experience to national and international clean energy movements. Academic collaborations fostered knowledge exchange and amplified the program's contributions through peer-reviewed scientific publications addressing corrosion and hydrogen integration challenges in marine environments.

Figure 2.8. Tour of the hydrogen station.

Recognizing the strategic importance of resilience, the project advanced innovative uses of hydrogen transit technology for emergency preparedness. The export power capability embedded in the buses is able to provide critical backup power for critical community needs during grid failures—offering an additional layer of service and underscoring hydrogen's versatility beyond transportation. Additionally, the program maintained comprehensive hydrogen station operational and safety documentation, including the operations manual, safety management plan, emergency response plan, standard operating procedures, and hazardous material and waste management program to ensure safe and reliable station and fleet.

Approaching project completion in 2024-2025, HNEI orchestrated a smooth transition to ensure long-term benefits. With the closure of U.S. Hybrid's local operations in 2024, the program adapted by assuming full in-house responsibility for station system controls and maintenance. Hydrogen trailers were safely decommissioned pending certification updates. NELHA management has expressed interest in operating the hydrogen station in support of a variety of

projects including the development of a County of Hawai‘i MTA’s West Hawai‘i bus maintenance facility, workforce development, and first responder training.

Overall, the project has achieved several key goals:

- *End-to-End Hydrogen System Deployment*: Designed, demonstrated, commissioned, and operated Hawai‘i’s first public PEM-based refueling station, integrated with County bus operations;
- *Transit Fleet Integration*: Deployed and upgraded buses, documented real performance (efficiency, range, maintenance), and provided decision-quality data for County planning;
- *Technical Feasibility and Innovation*: Collected operational data at both station and bus levels, developed in-house control systems and manuals, and proved hydrogen transit viable under island conditions;
- *Workforce Development*: Trained dozens of drivers, mechanics, and first responders with sustained funding from FTA to ensure future pipeline capacity;
- *Public/Stakeholder Engagement*: Conducted tours, workshops, community events, and policy briefings, strengthening Hawai‘i’s role in global hydrogen collaboration;
- *Research/Science Contributions*: Advanced knowledge of corrosion challenges and materials performance, published peer-reviewed findings, and influenced design standards; and
- *Resilience and Continuity*: Demonstrated the viability of a bus-based export power for emergency use and transitioned infrastructure to NELHA as a lasting community and research asset.

Building on and supporting these efforts, between 2021 and 2025, portions of four awards funded by the Office of Naval Research (ONR): APRISES20 (N00014-21-1-2250), APRISES21 (N00014-22-1-2045), APRISES22 (N00014-23-1-2720), and APRISES23 (N000142412397) were used to support the operation and maintenance of the fueling infrastructure and collect data from the hydrogen fuel cell electric buses (FCEBs). These ONR funds were leveraged ongoing support from the State of Hawai‘i and the County of Hawai‘i.

Key contributions supported by APRISES22 funding included:

- Conducted ongoing analysis and optimization of NELHA station power consumption, confirming it as the largest grid load on campus and identifying operational adjustments for improved energy efficiency;
- Continued comprehensive real-world performance monitoring of FCEBs, reaffirming energy use metrics (1.2 kWh/mile) and hydrogen efficiency (12.7 miles/kg);
- Expanded and updated hydrogen station operational and safety documentation, including the operations manual, safety management plan, emergency response plan, standard operating procedures, and hazardous material and waste management program;

- Completed corrosion and marine environment research, contributing to scientific publications on material challenges in marine settings;
- Supertherm heat insulation installed on shipping container;
- Compressor PRD replacement;
- Coordinated steady bus service and station operations, refining maintenance protocols, and troubleshooting operational bugs;
- Supported initiation of passenger service for the 21-passenger FCEB (#111) on low-topography routes to familiarize operations and validate fueling procedures;
- Advanced major upgrades on two 19-passenger buses, increasing fuel cell power to 90 kW (Hyundai) and integrating 33 kWh lithium-ion batteries;
- Developed and deployed fully rewritten LabVIEW hydrogen dispenser control software (Figure 2.9) replacing the outdated OEM system after a power failure, integrating real-gas modeling, safety interlocks, and dynamic flow control;

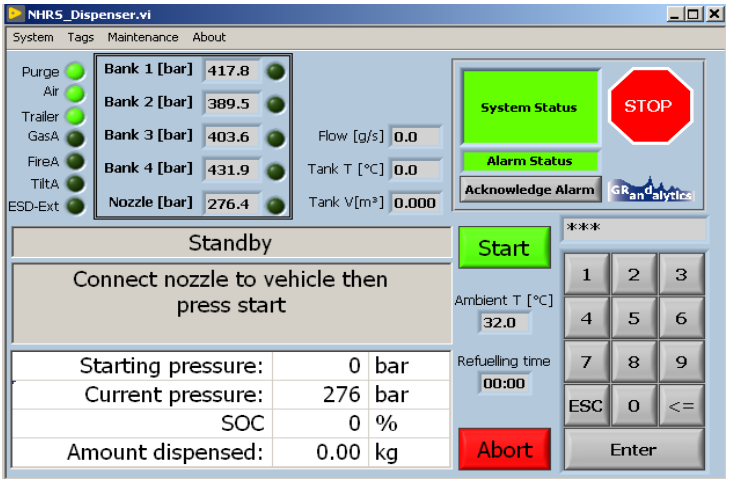

Figure 2.9. View of the internally developed dispenser PLC replacing the OEM PLC.

- Authored comprehensive user manuals featuring cause-and-effect error tables for station operators, and delivered specialized technical training sessions on new dispensing and station control systems to operations personnel—advancing operational safety and effectiveness;
- Continued active involvement in DOE's H2 Twin Cities mentoring and global hydrogen collaboration programs;
- Implemented power management protocols to cap the station load at 300 kW, optimizing utility demand charges;
- Conducted targeted outreach, briefings, and educational engagements, including briefings and tours for Sustainability Partners, the State Department of Transportation Harbors' Director, UH Sustainability & Energy Group, Arizona State University, and participation in the County of Hawai‘i Clean Energy Transition Workshop at the Blue Planet Research Center—strengthening partnerships and advancing regional clean energy goals; and

- Facilitated a bus ride with Hawai‘i County Mayor along with other key stakeholders (Figure 2.10).

Figure 2.10. Bus ride and drive with Hawai‘i County Mayor.

Publications

1. Ku, A. Y., Kocs, E. A., Afzal, S., Ewan, M., Glenn, J. R., Toma, F., Vickers, J., Weeks, B., & White, A. A. (2023). Opportunities for the materials research community to support the development of the H2 economy. *MRS Energy & Sustainability*, *10*(2), 158–173. https://doi.org/10.1557/s43581-023-00061-3

RESILIENT GRID SYSTEMS

Under APRISES22, HNEI continued development of enabling technology focused on the integration of new technology and reliable control at the grid edge. This research, conducted by HNEI's Grid System Technologies Advanced Research Team (Grid***START***) focused on improving the stability and functionality of Coconut Island's DC microgrid's monitoring system and extending the bidirectional EV charging demonstration project to residential applications by developing and refining a technoeconomic algorithm that determines the optimal sizing of rooftop PV, household batteries, and EVs with bidirectional power flow capability. Additionally, in both activities, funding supported professional development of graduate students through hands-on experience and training, and yielded a peer-reviewed publication.

Coconut Island DC Microgrid Project

Under prior funding, HNEI installed and commissioned a DC-based microgrid testbed on Coconut Island (Moku O Loʻe), a 28-acre (113,000 m²) island in Kāneʻohe Bay, Oʻahu. The site, home to the Hawaiʻi Institute of Marine Biology (HIMB), serves as an ideal location for testing energy security and grid-edge technologies due to its physical isolation and critical power needs. The island operates as an inherent microgrid through an undersea electrical connection. Its tropical marine environment, characterized by strong coastal winds and heavy salt spray, provides conditions similar to Navy coastal installations, making it suitable for testing new materials and technologies.

This project, conducted by HNEI's Grid***START*** team, pursues a dual mission: providing locally sourced and secure power on the island via a DC microgrid testbed system and equipping the island with transportation options that utilize power sourced from a DC microgrid. To achieve this, it focuses on six key goals:

1. Demonstrate the capabilities of cutting-edge energy technologies within the microgrid;
2. Improve the reliability of electricity for the crucial infrastructure, reducing the island's reliance on the aging undersea electrical connection to the local utility;
3. Establish a research platform to evaluate DC microgrid resources and components, such as energy storage, supporting grid technology, and DC-powered equipment, all in a coastal tropical environment;
4. Develop and test energy security and operational algorithms that optimize use of the microgrid's energy resources and the trade-offs between energy cost savings and resiliency;
5. Increase the island's energy security by maximizing the utilization of on-island energy resources; and
6. Offer electric-powered land and sea-based transportation options for HIMB that utilize on-island energy resources.

The project integrates a DC power distribution system into two existing buildings on the island, the Marine Mammal Research Project (MMRP) building and the adjacent Boat House, shown in Figure 3.1.

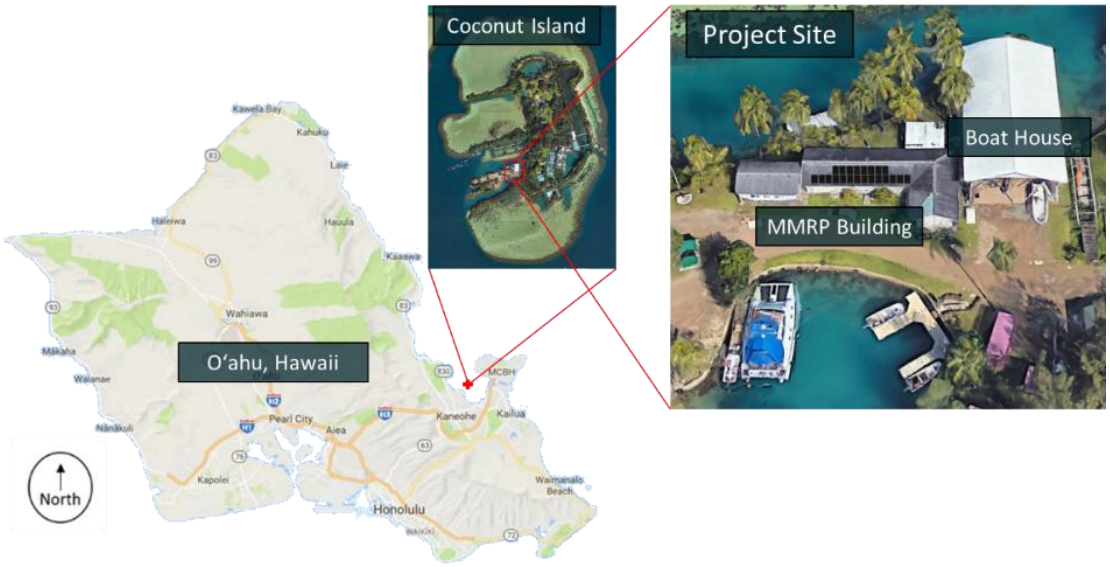

Figure 3.1. Location of Coconut Island and the DC microgrid project site.

Prior APRISES funding supported the extensive development and deployment of the Coconut Island DC Microgrid Project through several key phases:

- *Initial Planning and Design*: The project began with detailed planning, permitting, and baseline energy data collection. A conceptual DC microgrid design was developed, informed by technoeconomic simulations to determine appropriate sizing for the MMRP rooftop photovoltaic (PV) system and stationary battery energy storage system (BESS) to serve selected loads within the MMRP building and Boat House. Detailed electrical design drawings were prepared by a licensed electrical engineer for the installation of the DC microgrid components.
- *Electric Boat (E-boat) Implementation*: PV panels were installed on the E-boat rooftop to support powertrain battery charging and auxiliary equipment operation. This phase included rigorous testing and commissioning, culminating in operational sea trials to verify functionality.
- *Infrastructure Development*: Major infrastructure procurement and installation activities included: 6.2 kW DC rooftop PV system on the MMRP building; 8 kW/8kWh stationary BESS; AC/DC powered air conditioning unit; AC/DC LED lighting system; DC-to-AC inverter for critical plug loads; multi-point metering system for power flow monitoring; OPTO 22 Edge industrial controller (DC microgrid controller) and associated components; control system contactors and switch boxes; Schneider XW-Pro Inverter (capable of both DC-to-AC and AC-to-DC conversion, primarily used as an AC-to-DC inverter) with two maximum power point tracking (MPPT) charge controllers; and DC distribution system wiring. These hardware investments provided the foundation for a resilient, flexible and highly instrumented energy platform.

- *Swappable Battery Charging Station and Associated E-car and E-boat*: Grid***START***, in collaboration with the Okinawa Institute of Science and Technology (OIST) and PUES Corporation in Japan, specified, designed, and procured a prototype E-car and E-boat, along with a swappable battery system and charging station powered by the DC microgrid. The swappable battery units and charging station were installed, commissioned, and tested with the E-car and E-boat. The project faced technical challenges, including conflicts between the battery management system (BMS) protection and the charging station, as well as ineffective charge balancing between battery cells within each battery unit. HNEI provided troubleshooting and maintenance to keep the battery units operational. Due to end-of-life issues and increasing failure rates, the swappable battery units and charging station were decommissioned during the APRISES19 funding period, and fixed placement battery systems were subsequently installed in both the E-boat and E-car for reliable operation.
- *System Integration and Control*: The team implemented advanced control systems, including custom control programming using Node-RED and JavaScript, enhanced monitoring through high-voltage sensors, and comprehensive power flow monitoring capabilities.
- *DC Microgrid System Upgrades and Enhancements*: A new OPTO22 Controller was installed and commissioned as the core component of the DC microgrid, enabling robust real-time data processing and advanced automation for both AC and DC operating modes. The DC microgrid controller was enhanced with improved programming logic, a comprehensive control scheduler, and a user-friendly Node-RED interface for intuitive schedule management and seamless mode transitions (AC, DC, or hybrid). A real-time monitoring dashboard was developed, featuring Groov View visualizations, an interactive user interface, and backend integration of Node-RED and JavaScript for responsive system monitoring, remote access, and proactive issue alerting. PV system data download capabilities were enabled for historical data analysis, performance evaluation, and operational optimization.
- *Efficiency Evaluation*: After commissioning, Grid***START*** evaluated the DC microgrid's operational efficiency by periodically switching the air conditioning and LED lighting systems between DC and AC modes using the OPTO22 Controller to directly compare energy usage. Plug loads and swappable battery system were excluded, as plug loads used only AC and the swappable battery system was decommissioned. Results showed the air conditioner achieved an average efficiency gain of about 3.3% in DC mode, while LED lighting power consumption was approximately 5% lower in DC mode, highlighting further energy savings potential with optimized DC operation.
- *E-boat Energy Systems Modernization and Safety Enhancements*: The E-boat's original 11.2 kWh swappable batteries were replaced with robust, fixed 18.2 kWh units, greatly improving reliability and enabling future vehicle-to-grid (V2G) integration with the DC microgrid and bidirectional energy flow. A new battery converter, modern charge

controllers and advanced switching and fusing were installed, boosting safety, simplifying maintenance, and streamlining troubleshooting. The rooftop PV arrays were consolidated into a single, high-capacity (1,980 W peak) system with MPPT charge controllers, optimizing solar harvest, extending operational range and simplifying onboard power architecture. The separate 12 V solar system was removed and replaced with a fully integrated 48 V MPPT system, delivering nearly 8 kWh in four peak sunlight hours and supporting higher energy demands for longer missions. For improved safety, the charge controller was relocated from under the seat to beneath the aluminum boat roof in a weather-resistant National Electrical Manufacturers Association-rated (NEMA)-rated enclosure, enhancing accessibility, thermal management and system safety – further reinforced by an emergency disconnect switch adjacent to the main circuit breaker. The propulsion system was redesigned for fault tolerance, using four modular 48 V battery packs (each with its own BMS) in parallel. The E-boat operates at full capacity with three batteries, reduced to two and remains maneuverable with one. The propulsion system is independent of the 12 V auxiliary, but manual relay control ensures essential functions remain available if the 12 V system fails, prioritizing redundancy, resilience and safe operation in diverse scenarios. All critical hardware components underwent thorough pre- and post-installation testing to verify proper functionality. Initial laboratory testing of V2G functionality demonstrated the E-boat's potential for bidirectional energy flow and enhanced grid integration.

Under APRISES22, with the infrastructure in place, HNEI focused on seamless system integration and intelligent control. Custom programming in Node-RED and JavaScript enabled sophisticated automation and scheduling, while high-voltage sensors delivered enhanced monitoring precision. The installation of a new OPTO22 Controller further strengthened real-time data processing and automation across both AC and DC operational modes. The configuration and enhancement with the new OPTO22 Controller were documented. A major milestone was the development of an intuitive, web-based monitoring dashboard using Groov View, offering interactive system visualizations, remote access, and proactive alerts. The dashboard's backend, powered by Node-RED and JavaScript allows for responsive monitoring and seamless transitions between AC, DC, and hybrid modes. Additionally, the system was equipped with PV data download functionality, supporting historical analysis, and ongoing performance optimization. Together, these advancements have transformed the Coconut Island microgrid into a state-of-the-art, research-ready platform for marine energy integration, with a dashboard monitoring system that ensures operational transparency, resilience, and continuous improvement.

As part of ongoing system optimization under APRISES22 funding, the Grid***START*** team identified and resolved several performance bottlenecks within the dashboard monitoring platform. Initially, the system was configured to poll meter data via Modbus every second, which, over time, caused excessive network traffic and led to controller freezes. To rectify this issue, the project streamlined Modbus communications by reducing the number of active connections and

increasing the polling interval to five seconds. Additionally, the monitoring interface's icon was redesigned to eliminate unnecessary storage consumption on the controller's hard drive due to its previously oversized format (Figures 3.2 and 3.3). Collectively, these improvements significantly reduced Modbus traffic and controller resource usage, resulting in more stable operation and eliminating instances of system freezing.

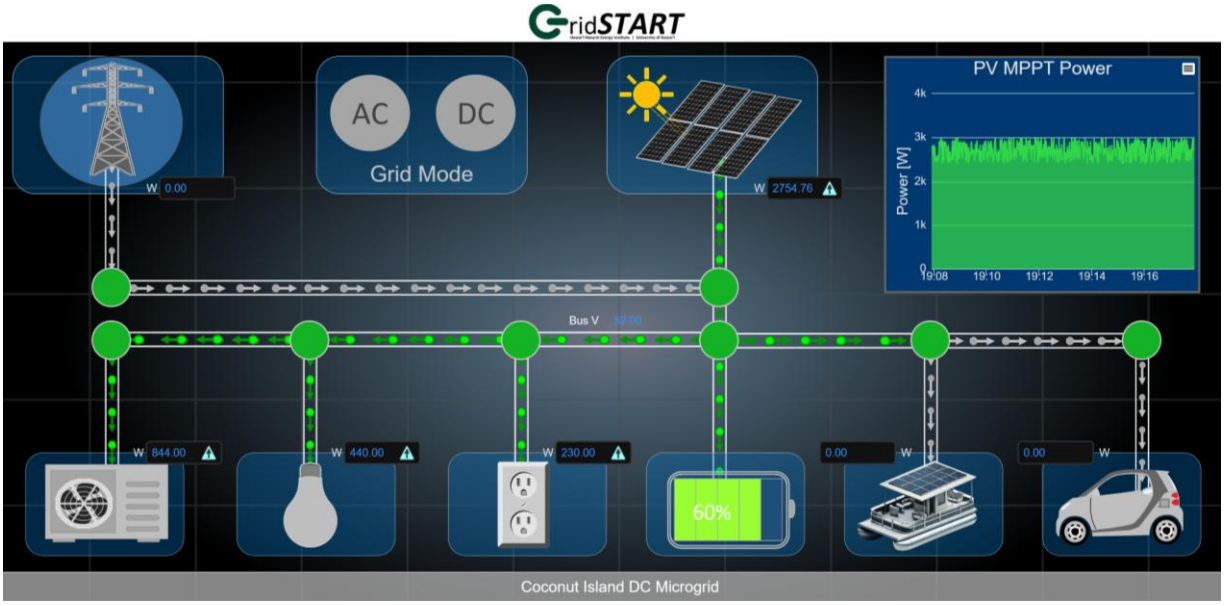

Figure 3.2. View of the updated real-time monitoring dashboard.

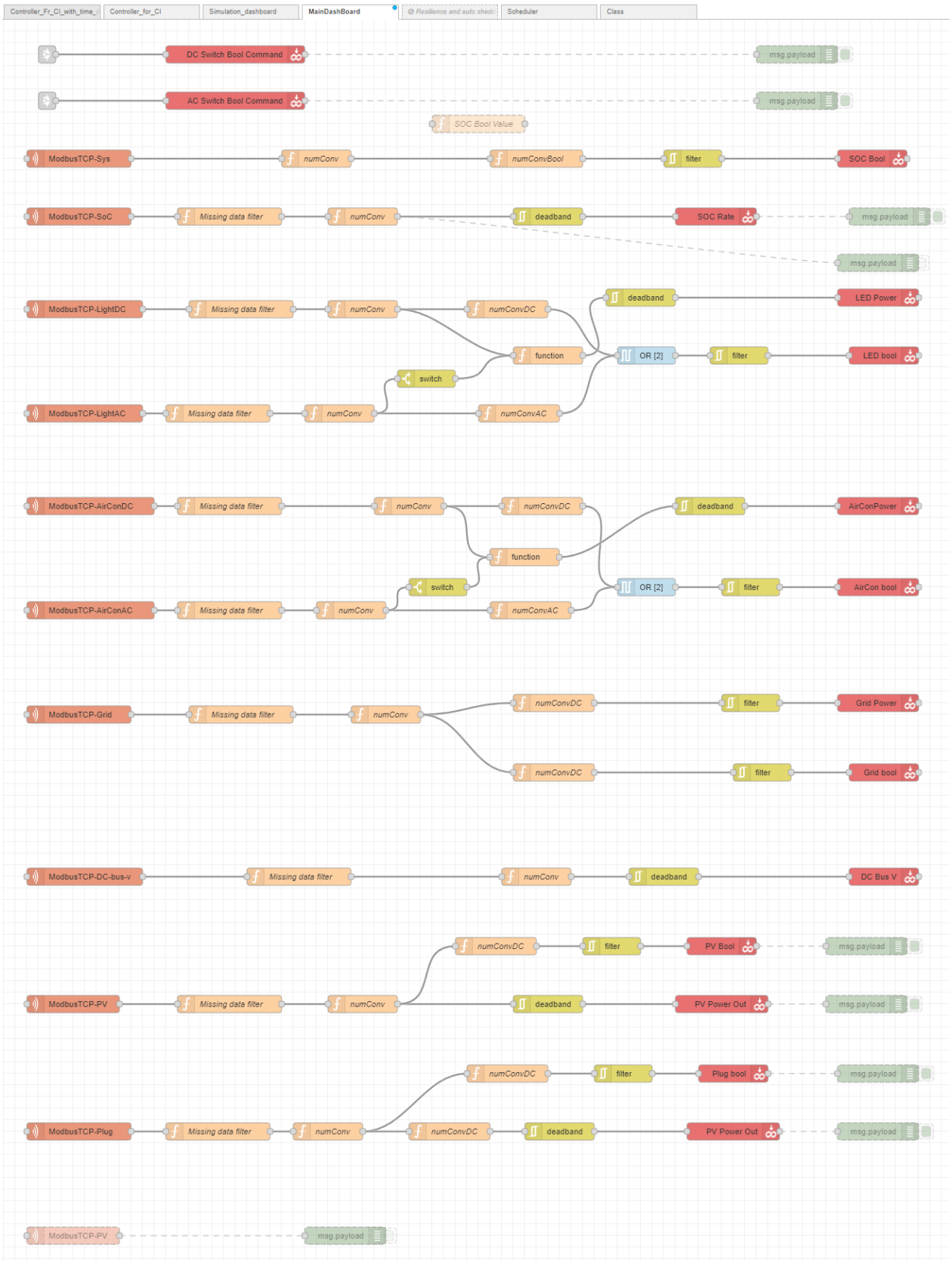

Figure 3.3. View of the dashboard's backend Node-RED and JavaScript architecture.

Beyond technical system enhancements, APRISES22 funding also enabled HNEI to foster the professional development of an electrical engineering graduate student. The student developed a foundational understanding of DC microgrid principles and operation and gained hands-on experience with the project's system design, hardware integration, and microgrid controller. As a capstone to this training, the student performed a thorough literature review of existing DC microgrid deployments and authored the peer-reviewed publication, "*DC Microgrid Deployments and Challenges: A Detailed Review of Academic and Corporate Implementations*." This paper examines real-world DC microgrid projects, their core components, and operational challenges. Through multidisciplinary training and research, the student not only developed critical technical skills, but also contributed valuable insights to the broader field of advanced microgrid systems.

Building on these technical and professional accomplishments, including the advanced dashboard monitoring system, the training of the next generation of microgrid engineers, and the ongoing maturation of a robust, research-ready DC microgrid, HNEI has charted a clear path for next-stage research and innovation. The project's early demonstrations of V2G integration highlighted the E-boat's unique role as a bidirectional energy resource, capable of not only drawing power from the DC microgrid but also supplying it back to shore, thereby leveraging vessel "downtime" for grid support and enhancing battery utilization. Utilizing APRISES22 funding, the team initiated planning and preliminary engineering needed to refine the E-boat's hardware and control systems to fully realize this V2G capability, integrating a dedicated controller and robust shore power connection to maximize the system's efficiency, flexibility, and value as both a research platform and a practical asset for near-shore operations. More specifically, permitting requirements were assessed, shore power connection and cable routing were identified, with cable-sized to ensure adequate voltage management over the extended cable run, and a preliminary design of the shore power hub to E-boat connection including DC/DC converter was also developed to ensure a safe and user-friendly E-boat to microgrid tie-in. This bidirectional energy resource approach is especially relevant for communities and institutions aiming to align maritime operations with overarching energy resilience and long-term viability goals. The pilot project demonstrates cost-competitive, ultra-quiet, and emissions-free marine mobility absent dependency on liquid fuel supply for propulsion, while simultaneously providing a replicable and scalable model for small workboats in coastal and island settings.

Regrettably, the early termination of APRISES22 funding brought these plans to an untimely halt, preventing the team from advancing the E-boat's capacity as a fully integrated, bidirectional grid asset and stalling research into cutting-edge, marine-optimized microgrid components. While the project's progress to date had begun to fill a vital gap in the market and offered invaluable lessons for institutions pursuing marine electrification and microgrid energy innovation, its sudden cessation is a missed opportunity to accelerate the deployment of secure and efficient infrastructure for island and coastal communities worldwide.

Publications

1. Adegboyega, A. W., Sepasi, S., Howlader, H. O., Griswold, B., Matsuura, M., & Roose, L. R. (2025). DC microgrid deployments and challenges: A comprehensive review of academic and corporate implementations. *Energies*, *18*(5), 1064. https://doi.org/10.3390/en18051064

Bidirectional EV Charging Optimization

The electrification of transportation presents challenges for electric grids, such as increased electricity demand and altered load patterns. However, there is significant potential to utilize the flexibility of electric vehicles (EVs) for managed charging, offering benefits and services that can enhance economic value for EV owners while improving grid reliability and energy security. Toward that end, HNEI engaged in a collaboration with IKS Co., Ltd. ("IKS") on technology development, test, and demonstration of advanced control of two bidirectional EV chargers (Hybrid Power Conditioning System or H-PCS) on the campus of the University of Hawai‘i at Mānoa (UHM). The H-PCS was developed by IKS with support from Hitachi Limited as part of the earlier JUMPSmart Maui smart grid demonstration project, in which HNEI was one of the partners.

To tackle the complex optimization problem and demonstrate the use of bidirectional EV chargers, HNEI's Grid***START*** developed, evaluated, and demonstrated the performance of novel algorithms to optimize the charge and discharge cycles of shared fleet vehicles. Its demonstration site is shown in Figure 3.4. The main goal of this project was to minimize energy costs through optimized EV fleet management. The research and development outcomes were intended to inform the university's consideration of options such as the electrification of fleet vehicles, advanced car-sharing applications, and the integration of distributed alternative energy resources on the UHM campus. Additionally, the scalable field test results can enable the assessment of larger EV fleets in car-sharing systems, particularly for providing grid ancillary services.

Figure 3.4. Demonstration site located on the University of Hawai'i at Mānoa campus.

Prior APRISES funding advanced this project through several major stages of development and demonstration:

- *Initial System Deployment*: HNEI coordinated extensively with IKS to procure and receive two H-PCS bidirectional chargers, overcoming significant international shipping delays caused by the COVID-19 pandemic. Grid***START*** designed and installed the hardware foundation of the demonstration site at UHM, including two H-PCS bidirectional chargers, transformers, a control box, and associated electrical infrastructure. Load forecasting tools were developed and integrated using campus electrical data and machine learning algorithms. HNEI's solar forecasting system was incorporated to prioritize electricity generated from solar photovoltaic (PV) systems for EV charging. A web-based car scheduling application was designed and commissioned to coordinate shared vehicle use with optimized charging schedules. HNEI's patented Advanced Real-Time Grid Energy Monitor System (ARGEMS) was also implemented as the central controller for data collection, optimization and execution of charge/discharge commands.
- *Algorithm Development and Field Commissioning*: The team finalized autonomous algorithms for cost-optimized bidirectional charging, integrating forecasting, scheduling, and EV battery telemetry. The operational system was fully commissioned, placing vehicles and chargers into daily use by authorized drivers. An autonomous lockbox key management system was developed and telematics-based EV monitoring for real-world driving data was introduced. Grid***START*** conducted comparative analyses of unidirectional and bidirectional smart charging, showing measurable cost savings and demonstrating higher benefits from bidirectional optimization. HNEI disseminated results through peer-reviewed publications and conference presentations, extending findings to international audiences. EV integration was explored into distribution grids, applying analysis tools to case studies in Vietnam for unidirectional charger deployment planning.
- *Advanced Modeling and Analysis*: Comprehensive economic analyses of campus building load profiles were conducted to evaluate the cost impacts of different EV charging strategies. A machine learning-based method (Bi-LSTM with least square optimization)

was developed for estimating EV energy consumption on pre-defined trips, validated with telemetric data. Grid***START*** provided applied training to undergraduate engineering students in optimization, programming, and grid-energy interface design.

- *System Optimization and Operational Assessment*: The EV charging management system was enhanced through continued monitoring and refinement of algorithms to maximize vehicle utility and energy cost savings. HNEI conducted detailed analysis of multiple Hawaiian Electric rate structures (Advanced Rate Design Schedules R, G, J, and Schedule P) to clarify their impacts on EV-enabled optimization scenarios. Real-world charging and discharging patterns from the project fleet were also investigated to inform refinements in models and fleet-scale optimization strategies.

Under APRISES22 funding, HNEI advanced the project on multiple fronts, with significant progress made in both technical development and graduate student training. Recognizing the advantages of bidirectional EV charging for residential applications, Grid***START*** has developed and refined a novel technoeconomic algorithm to determine optimal sizing for home stationary batteries and rooftop PV systems, in conjunction with EVs equipped with bidirectional charging capabilities. The algorithm quantifies the economic benefits of replacing a conventional gasoline-powered vehicle with an EV, as well as the additional value provided by bidirectional charging. Potential users include homeowners considering the purchase of an EV, those interested in adding rooftop PV or a home battery energy storage system (BESS), and industry stakeholders such as BESS suppliers and car manufacturers seeking insights into optimal system configurations and new EV applications.

The algorithm is designed to minimize the net present cost over the project's lifetime, accounting for the capital costs of installing rooftop PV and a household BESS, annual electricity bills (including the cost for charging an EV), and typical operation and maintenance expenses. Key inputs include the home location to accurately model PV output, household energy consumption, and a typical driving schedule. Notably, the EV driving schedule has the most significant impact on the economic value of bidirectional charging, as the EV battery can only function as a home battery when the vehicle is parked at home. Thus, the more frequently the vehicle is at home, the greater the economic benefit it can provide. However, as explained in greater depth below, when utility time-of-use (TOU) rate structures are applied, significantly more economic value may be generated through intelligent bidirectional EV charging, with increased value being more dependent on which hours it is at home in a given day, versus how many hours the vehicle is at home.

This algorithm has been applied to scenarios involving the Hawaiian Electric Company's Smart Renewable Export Program and TOU rates, as well as TOU rates in Kyushu, Japan. For the O'ahu case study, results indicate that advancements in home energy technologies, including bidirectional charging, substantially increase the economic value of such investments. Figure 3.5 presents the total net present value (NPV) of each project increment investment and home battery capital costs

associated with varying levels of technical advancement.

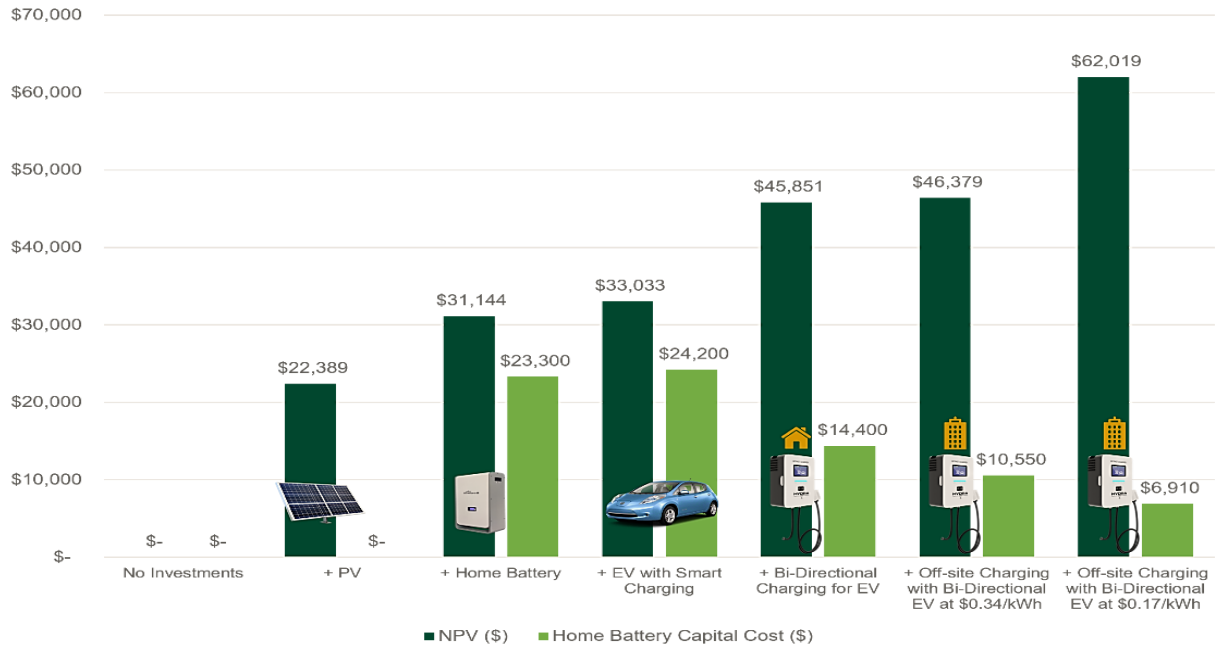

Figure 3.5. NPV and capital costs by level of technical advancement.

A significant source of economic value from bidirectional EV charging lies in its ability to perform energy arbitrage under TOU rate structures. When parked at home, it can be charged during periods of low electricity prices and then discharge stored energy back to the home or grid during high-cost peak periods. This strategy allows homeowners to capitalize on price differentials throughout the day, thereby reducing overall energy costs. The impact of TOU pricing on daily energy dispatch and the resulting economic benefits are illustrated in Figure 3.6.

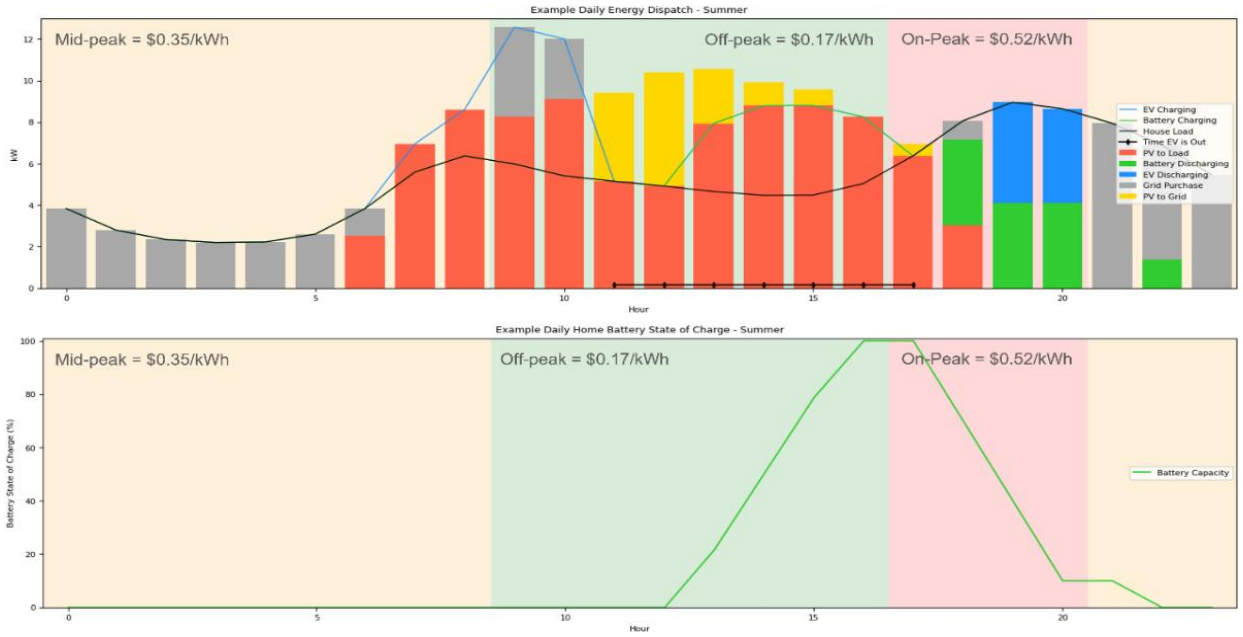

Figure 3.6. Examples of daily energy dispatch showing the impact of TOU rate structures.

The EV serves as an additional energy storage resource, helping to shift energy consumption to more cost-effective times. However, the extent of these benefits is highly dependent on the vehicle's daily driving schedule. Analysis indicates that the morning departure time is especially influential; the later the EV leaves home, the greater the economic benefit. This is because a later departure allows the EV to store more excess solar PV energy generated during the early morning hours. Figure 3.7 demonstrates how economic benefits vary with different daily driving schedules.

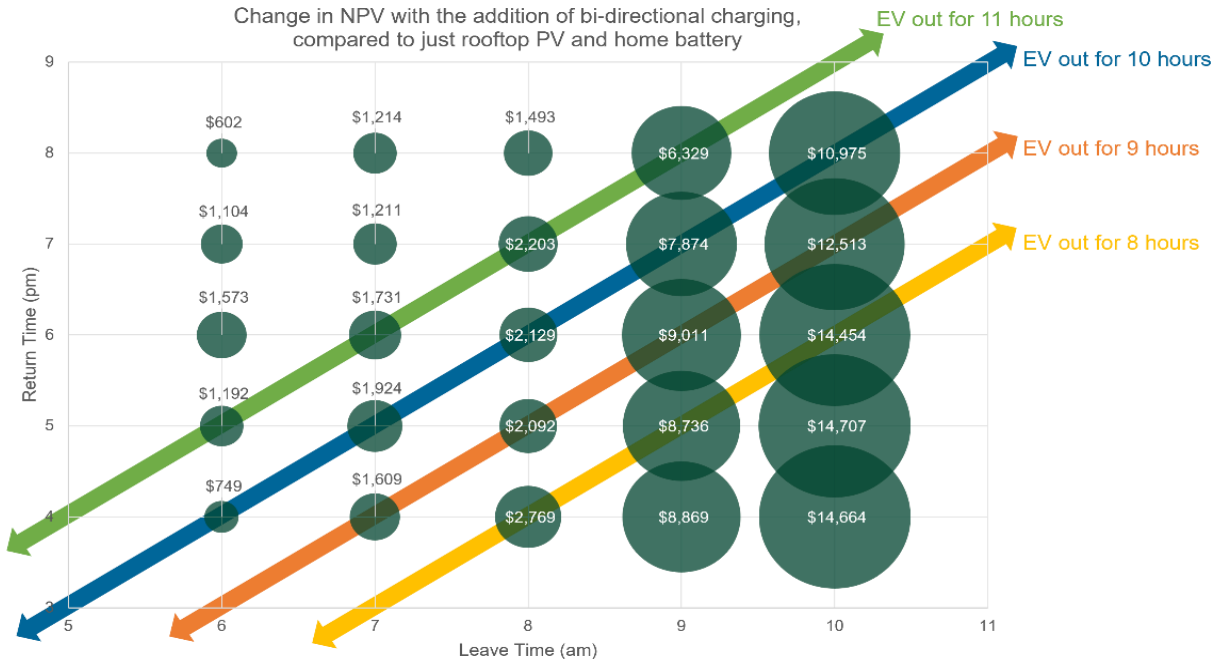

Figure 3.7. Sensitivity of economic benefits based on varying daily driving schedules.

As previously noted, more economic value may be generated through intelligent bidirectional EV charging, with value significantly increased depending upon which hours it is at home on a given day. This is evidenced by examining each of the colored diagonal lines in Figure 3.7, with each circle along a diagonal line representing the change in NPV with the addition of bidirectional EV charging compared to investment in a rooftop PV system and a home battery alone. Each colored diagonal line represents a vehicle use pattern for a specific number of hours the EV is not plugged in at home. For example, all circles along the green line represent the EV not being home for 11 total hours, however the leave/return time of the vehicle at home shifts by an hour for each circle along that line. Clearly, the NPV exhibits a consist and dramatic increase if the EV leaves the home at 9:00 AM (or later), versus leaving an hour earlier at 8:00 AM, for all cases of the EV being out for a total of 8, 9, 10 or 11 hours (yellow, orange, blue and green lines respectively). Thus, being able to charge the EV with more early morning energy from the sun, and then discharging that self-produced solar energy into the home later that day/evening, displaces the need to purchase more high-priced utility power during the on-peak period, yielding substantial economic value.

In parallel, HNEI trained graduate students in engineering and computer science through hands-on project activities. These students gained a strong understanding of system operations while developing the ability to identify and resolve complex technical issues. Their contributions included the design of a user-friendly web-based tool that operationalizes the sizing algorithm for batteries and rooftop PV systems, an effort that enhanced not only the project's decision-support capabilities but also the students' programming expertise and applied knowledge at the intersection of energy systems and user-oriented software design.