



Electric Vehicle Transportation Center

The State of Electric Vehicles in Hawaii: 2016 Update

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Executive Summary

As Hawaii moves toward 100% renewable power by 2045, EVs become increasingly important in helping to balance intermittent power generation with load. With small, remote and isolated island electricity grids, utilities in Hawaii face unprecedented technical and economic challenges to meet these goals. Yet power system reliability, cost controls and stability are essential. Along with balancing intermittent renewables, the opportunity of using EVs as a grid stabilization service includes power reserves, frequency and voltage regulation. As for other regions across the U.S. with increasingly cleaner sources of power generation, the interrelationship between EV charging and power plant fuel use is essential when considering the true fuel requirements and emissions of EVs. For Hawaii, the nation's most petroleum dependent state, these changes to both ground transportation and electricity generation could have a significant impact on reducing net petroleum imports, emissions and enhancing energy security and economic stability.

The islands of Hawaii provide an ideal location to quantify the potential synergies of integrating electric vehicles into power grids characterized by high penetration of intermittent renewable energy. Modeling and analysis has become critical to help inform technical direction, planning and policy decisions. Small changes in scenario assumptions, such as the levels of electric vehicle adoption, operational changes by the utility, or renewable energy levels reveal significant impacts on future outcomes. As a result, assessing the value of grid-connected vehicle interactions becomes meaningful in achieving Hawaii's 100% renewable energy goal.

Additionally, micro-grids are on the rise nationally as an alternative to large, centralized generation and distribution networks. The technological knowledge, economics and regulations being developed in Hawaii are seen by many as a preview of what's to come elsewhere in the nation.

This report provides an update to the *State of Electric Vehicles in Hawaii* released in March 2015, a synopsis of the dynamic landscape between electrified transportation and renewable energy integration in Hawaii. Focus is placed on the interaction of passenger electric vehicles with an isolated grid characterized by exceptionally high levels of wind and solar energy. Related research and demonstration projects are summarized, and similarities and differences to national trends are highlighted.

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I. Introduction

Prepared by the Hawaii Natural Energy Institute (HNEI) as part of the Electric Vehicle Transportation Center (EVTC) Program, this report provides an update to the *State of Electric Vehicles in Hawaii* released in March 2015. Focus is placed on the interaction of passenger electric vehicles (EVs) with a small, isolated electricity grid characterized by exceptional levels of wind and solar energy. The term EVs in this report includes vehicles that rely solely on electricity, Battery EVs (BEVs), as well as those which are partially fueled with electricity; Plug-in Hybrid EVs (PHEVs) and Neighborhood EVs (NEVs). Related research and demonstration projects are summarized, and similarities and differences to national trends are highlighted.



Figure 1. Florida Solar Energy Center's Electric Vehicle Transportation Center is the lead organization for Hawaii's program. (Florida Solar Energy Center)

Funded by the U.S. Department of Transportation (U.S. DOT), the Florida Solar Energy Center (FSEC) initiated the EVTC in a partnership with HNEI and the University of Tuskegee. The EVTC serves as a focal point for the U.S. DOT, with the vision to transform the country's transportation network into a fully integrated 'smart' EV deployment coupled with a 'smart' electric grid, achieved with maximum efficiency and minimum time and disruption. HNEI's contribution to the EVTC program focuses on electrified transportation as a power grid resource, battery performance and durability, net energy and economic impacts.

Background

Hawaii is still the most petroleum-dependent state in the nation with over 80% of its energy needs from imported petroleum¹. Of that, 60% goes to the transportation sector, with jet fuel and motor gasoline each accounting for about 24%. As expected, gasoline costs are typically the highest in the nation. Electricity generation consumes almost 30% of the petroleum shipped to Hawaii. This has contributed to electricity costs that were double those in the next most expensive state in 2014, and three times higher than the national average². Currently the rates are merely double the national average³.

Hawaii Clean Energy Initiative

The Hawaii Clean Energy Initiative (HCEI) was established in law in 2008, with the goal achieving 40% of the state's electricity from renewable energy sources, along with a 30% improvement in efficiency by the year 2030. In 2015 with the signing of Act 97, the Renewable Portfolio Standards (RPS) goals were increased to 30% by 2020, 40% by 2030, 70% for 2040 and 100% by 2045. The utilities are on track for 2030 (Figure 2), but the technical and economic path forward to achieve over 40% renewables is reliant on significant technological, policy and regulatory advancements.

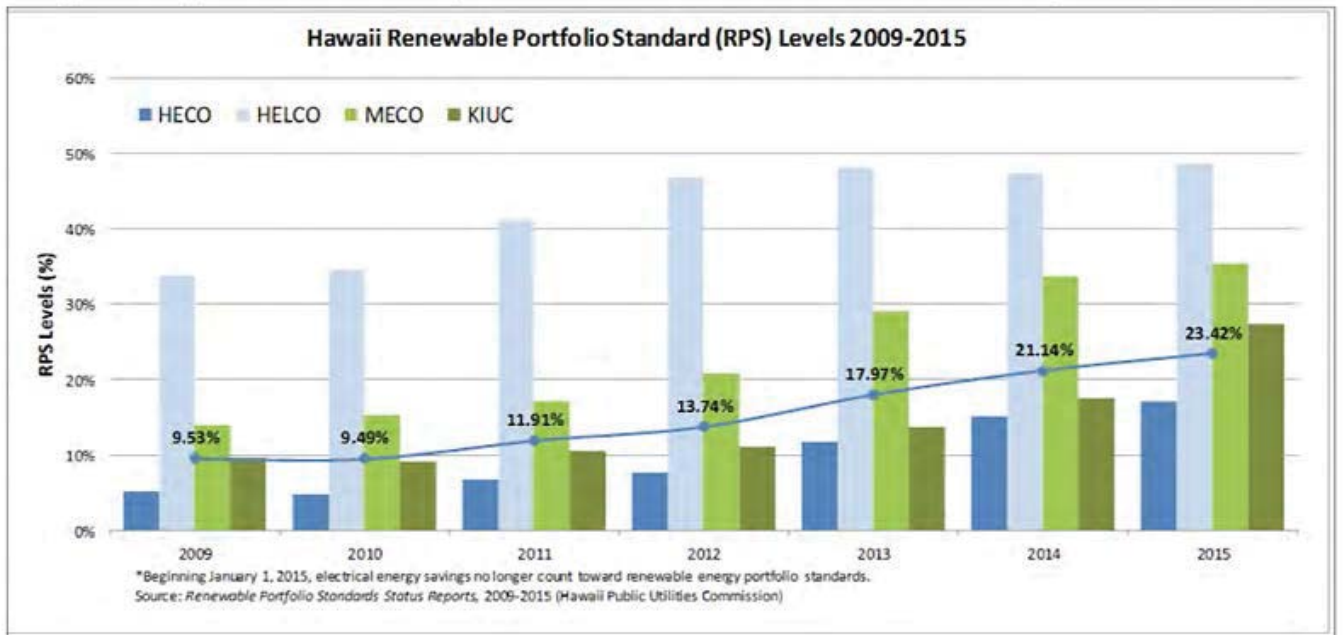


Figure 2. Renewable Portfolio Standards (RPS) achieved by county and utility, and averaged for the state: on Oahu, Hawaiian Electric Company, Inc. (HECO); on Hawaii Island, Hawaii Electric Light Company, Inc. (HELCO); Maui Electric Company, Limited (MECO), and; Kauai Island Utility Cooperative (KIUC) ⁴.

The State has revisited HCEI goals for ground transportation, but compared to progress with the electricity sector, the transition of transportation systems to cleaner technologies and fuels continues to trail behind. Additionally, the transportation sector lacks the regulatory framework to achieve these goals and some policies have proven difficult to implement, such as the installation of EV charging stations in apartment buildings and reserving space for EV charging stations in large public parking lots.

Hawaii as a Proving Ground

Hawaii provides an ideal location for EVs with limited driving distances, moderate climate and early supportive state legislation. This includes free parking in State and County lots, access to High Occupancy Vehicle lanes, requirements for condominiums and apartment buildings to allow installation of EV charging stations, and for large public parking lots to reserve at least one space for an EV charging station.

Additionally, Hawaii provides an exemplary test bed to study EV interaction on small, isolated electrical power grids with exceptionally high renewables relative to the demand for electricity (load). According to the International Energy Agency (IEA), the global deployment of non-hydro renewables (mostly wind and solar) is expected to total 3,600 GW by 2040, greater than for all other types of power plants combined⁵. As the ratio of variable renewables to firm power available 24/7 increases dramatically, as in Hawaii, it becomes increasingly challenging to integrate wind and solar into the power grid while still maintaining a stable and reliable power supply. Resulting opportunities for EV interactions with the power grid become increasingly important.

Controlled charging of EVs can:

- Improve integration and efficient use of renewable generation into the power grid, at the transmission (whole island), circuit (neighborhood) and sub-circuit (building) levels
- Improve grid reliability, efficiency and resiliency
- Provide economically stable transportation fuel alternatives
- Improve efficiencies and reduce emissions for both ground transportation and electricity generation

II. Electric Vehicle Adoption

Number of EVs

Despite continuing low oil prices, EV sales in Hawaii continue to increase. In January 2016, the number of plug-in passenger vehicles (BEVs, PHEVs and NEVs) registered in the state was 4,073, a 26% increase from January 2015⁶, (Figure 3). During this time, the number of all other passenger vehicles (virtually all gasoline-powered) fell by 4%. Although growing rapidly, the percentage of EVs in Hawaii is still very small, about 0.4% of the over one million passenger vehicles. Gasoline-powered hybrid vehicles also continue to increase in numbers in Hawaii, up from 1.8% of the total passenger vehicles in January 2015 to 2.0% in January 2016. Gasoline vehicles still account for almost 97% of all passenger vehicles, and under 1% are diesel.

The number of EVs by island reflects the population, along with travel distances and available charging stations (Figure 4)⁷.

Globally, EV sales in 2015 increased by 70% over figures for 2014, following an increase in 2014 figures of approximately 50% for EV sales over 2013⁸. Although EV sales in the U.S. continued to increase,

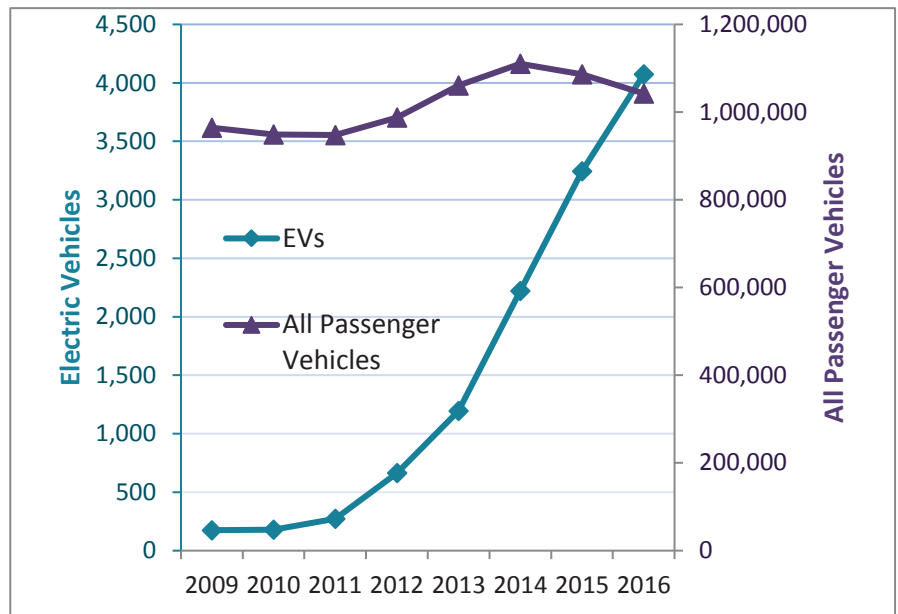


Figure 3. Registered EVs in Hawaii and total passenger vehicles, Jan. 2009 to Jan. 2016.

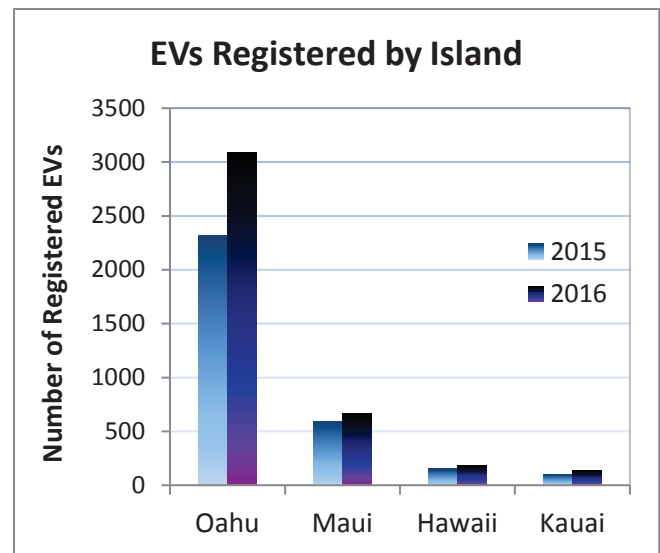
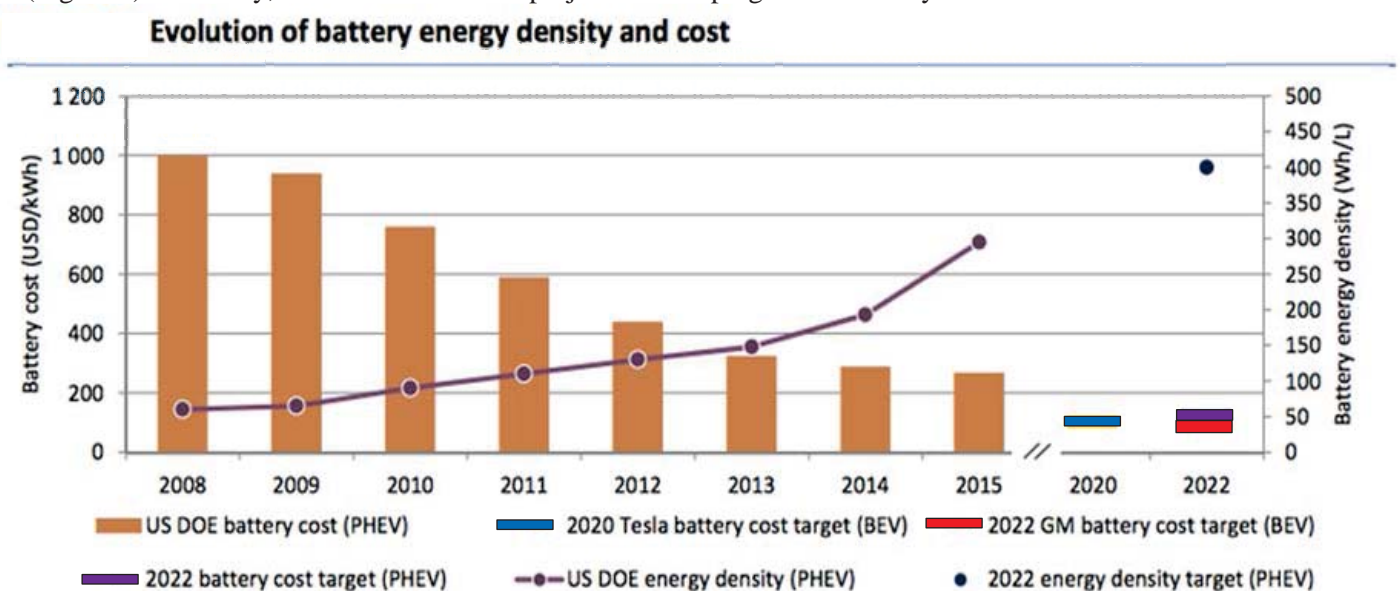


Figure 4. Number of EVs by island.

growth in EV sales declined by 4% in 2015 compared with 2014 growth. However, by April 2016, approximately 10,557 plug-in vehicles were sold, a 16% gain over April 2015 and the sixth consecutive monthly record⁹. Still, the EV share of the total global auto market in 2015 was just 0.6%.

Battery Cost and Energy Density

The potential takeover of HEI by NextEra, Inc. of Florida was rejected on July 15, 2016 by the Hawaiian Public Utilities Commission in a 2-0 vote and NextEra is now paying HEI \$90 million to cover the breakup fee. Another key factor in EV adoption is battery durability, power capacity and prices. Battery prices have dropped four-fold since 2008 and are expected to reach the DOE target of \$125/kWh by 2022 where EVs become cost competitive with ICE vehicles, according to the IEA¹⁰ (Figure 5). Tesla and GM are projecting lower battery costs. Bloomberg New Energy Finance also projects long-range EVs to cost the same as similar gasoline powered cars by 2022, and notes that EV battery prices fell 35% in 2015¹¹ (Figure 6). Globally, 35% of new cars are projected to be plug-in vehicles by 2022.

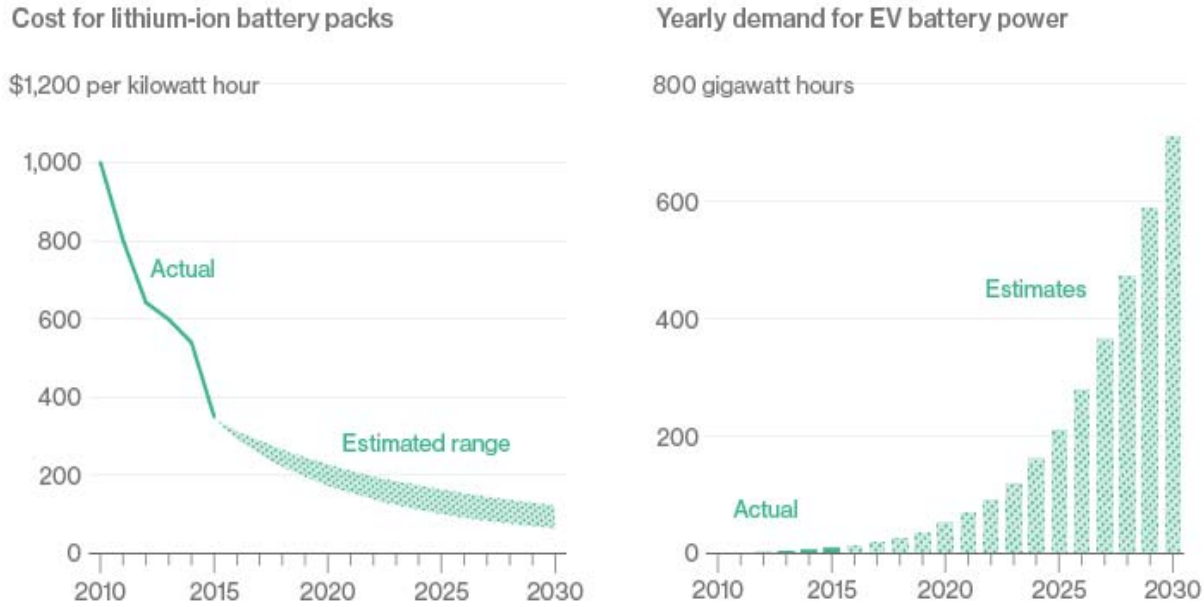


Notes: USD/kWh = United States dollars per kilowatt-hour; Wh/L = watt-hours per litre. PHEV battery cost and energy density data shown here are based on an observed industry-wide trend, include useful energy only, refer to battery packs and suppose an annual battery production of 100 000 units for each manufacturer.

Sources: US DOE (2015 and 2016) for PHEV battery cost and energy density estimates; EV Obsession (2015); and HybridCARS (2015).

Figure 5. Battery energy density and cost, from the International Energy Agency (IEA) report, *Global EV Outlook: Beyond one million electric cars*, 2016.

Batteries make up a third of the cost of an electric vehicle.
As battery costs continue to fall, demand for EVs will rise.



Source: Data compiled by Bloomberg New Energy Finance

Figure 6. Battery cost projections and demand by Bloomberg New Energy Finance, (February 2016)

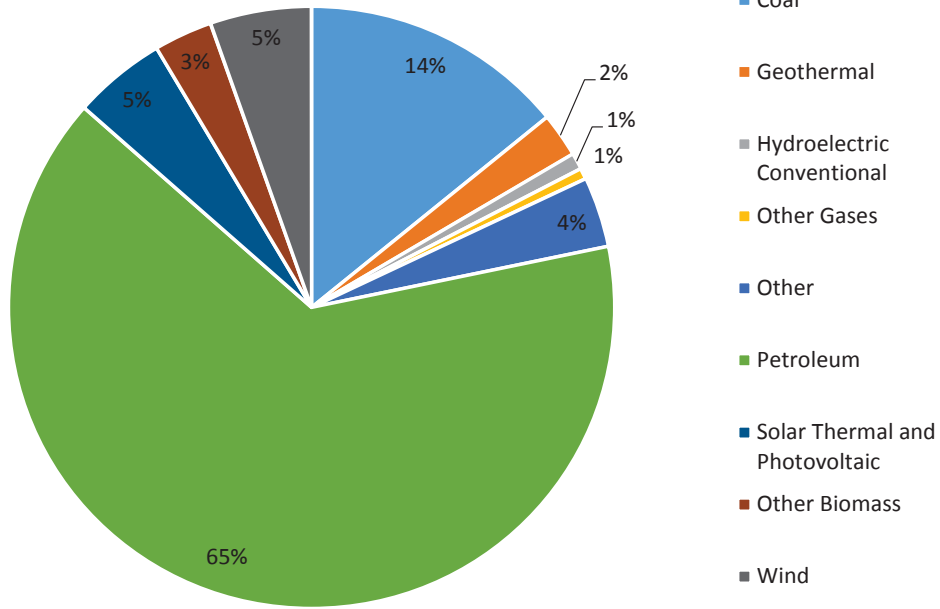
III. Fuel Considerations

As EVs become mainstream, more consumers are expected to hold fuel prices as an important consideration (as opposed to early adopters). Given that the U.S. Environmental Protection Agency (EPA) fuel economy label for EVs is based on the average cost of electricity in the U.S. (at \$0.11/kWh), for potential EV owners interested cost savings it's critical to know actual electricity rates. EV fuel economy is measured in miles per gallon of gasoline equivalent (MPGe) or kWh per 100 miles. Based on the U.S. Environmental Protection Agency (EPA) fuel economy estimates, electric passenger vehicles can exceed 100 MPGe and can achieve 30-40 kWh per 100 miles.

Electricity

The low cost of electricity relative to gasoline or diesel across most of the U.S. reduces fueling costs for EV owners. Nationally, less than 1% of electric power is generated from oil.¹³ Yet Hawaii depends heavily on petroleum with 68% of its electricity generation from oil in 2014 (Figure 7)¹⁴. As a result of Hawaii's heavy reliance on imported petroleum, the price of electricity tracks that of petroleum (Figure 8)¹⁵. By contrast, using electricity to fuel EVs across most of the nation virtually eliminates oil price volatility (Figure 11 below).

Hawaii Electricity Generation by Source



Total US Electricity Generation by Source

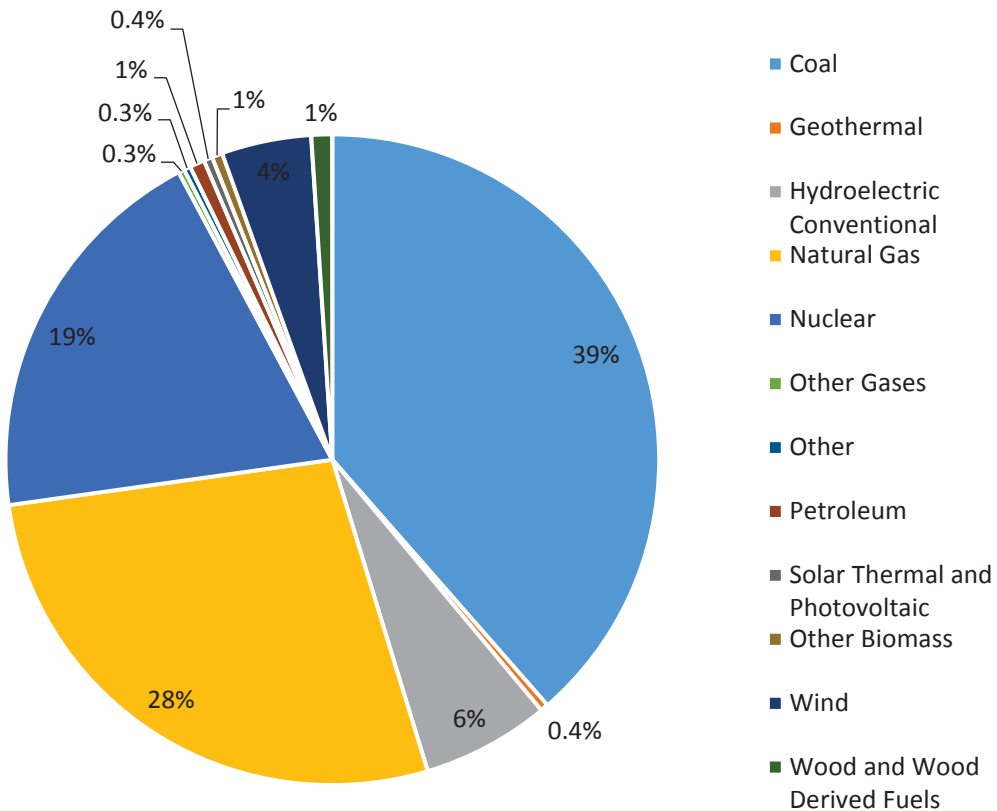


Figure 7. Hawaii and US electricity fuel sources, (source EIA and Hawaiian Electric Company data).

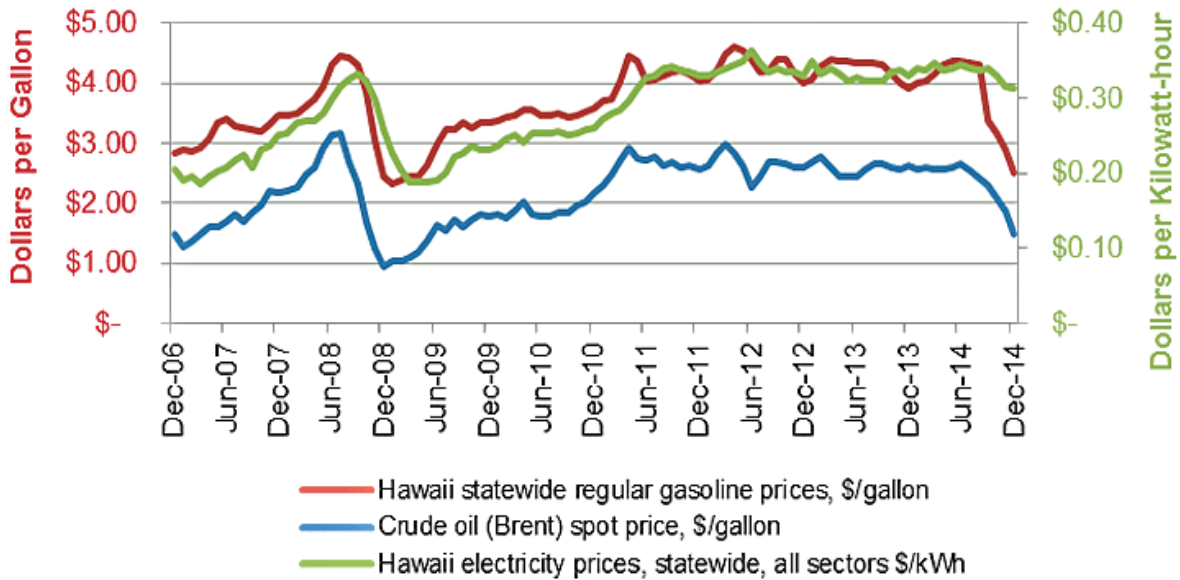


Figure 8. Electricity prices fluctuate with oil prices in Hawaii. (Source: “Hawaii Energy Facts & Figures”, State of Hawaii Department of Business, Economic Development and Tourism, May 2015.)

With the current low price of oil, average electricity rates in Hawaii were \$0.24 per kilowatt-hour (kWh) by the end of 2015, compared with \$0.34/kWh mid-2014¹⁶. Rates vary by island, with \$0.22 kWh on Oahu, \$0.27 /kWh on Maui, \$0.30/kWh on Hawaii Island, and \$0.30/kWh on Kauai (December, 2015). The average residential rate across the state was \$0.27/kWh, and the commercial rate \$0.23/kWh. According to the U.S. Department of Energy (U.S. DOE), residential electricity consumption in Hawaii is the lowest in the nation, (40% less than the national average). However electricity rates are still the most expensive in the nation, currently 124% of the national average¹⁷. In contrast to Hawaii’s \$0.24/kWh, Louisiana had the lowest rate at \$0.07/kWh in January 2016. Therefore, a Nissan Leaf using 30kWh/100 miles¹⁸ would cost approximately \$72 to drive 1,000 miles in Hawaii, but only \$21, less than a third, in Louisiana. Even with the current low oil prices, to make that trip for the same cost, a conventional car would have to get 37 MPG in Hawaii and 82 mpg in Louisiana¹⁹.

Electricity across Hawaii is provided primarily by Hawaiian Electric Industries Inc. (HEI), supplying power to 95% of Hawaii’s population through the Hawaiian Electric Company, Inc. on Oahu (HECO), Hawaii Electric Light Company, Inc. on Hawaii Island (HELCO), and Maui Electric Company, Limited on Maui (MECO). On Kauai, the electric utility is Kauai Island Utility Cooperative (KIUC), a not-for-profit owned and controlled by the members it serves. Utilities are regulated by the Hawaii Public Utilities Commission (PUC), and are required by law to meet mandated RPS clean energy goals.

The potential takeover of HEI by NextEra, Inc. of Florida was rejected on July 15, 2016 by the PUC in a 2-0 vote. NextEra is now paying HEI \$90 million to cover the breakup fee. While this bid was before the PUC, Hawaii lawmakers included \$1.2 million in the state’s 2016-2017 budget for the study of alternative utility and regulatory models, including cooperative, municipal and independent distribution system operators.

Gasoline

Gasoline and diesel fuel prices in Hawaii are typically the highest in the nation. In April, 2016, regular gasoline in the state of Hawaii averaged \$2.60 per gallon, 24% higher than the national average²⁰. With the main center of population, 63% of the gasoline is consumed on Oahu. Prices are higher on neighbor islands, ranging from \$2.41 on Oahu to \$3.12 on Maui. The national average price for diesel in the same month was \$2.18 per gallon and Hawaii's average was twice that at \$4.09 per gallon.

The U.S. DOE online "eGallon" calculates the cost of fueling a vehicle with electricity versus gasoline by state and national average. This reflects the cost of electricity that EVs need to travel the same distance as similar model gasoline vehicles would travel on a gallon of gasoline. The average across the U.S. demonstrates electricity savings at about one-half of the cost for gasoline (Figure 9)²¹. In Hawaii the cost is higher for electricity than for gasoline (Figure 10).

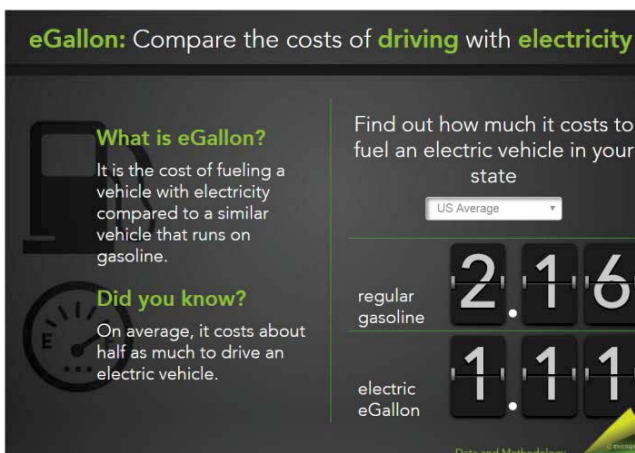


Figure 9. US Department of Energy's (DOE's) comparison of US average costs between driving an EV and a similar gasoline-fueled vehicle.

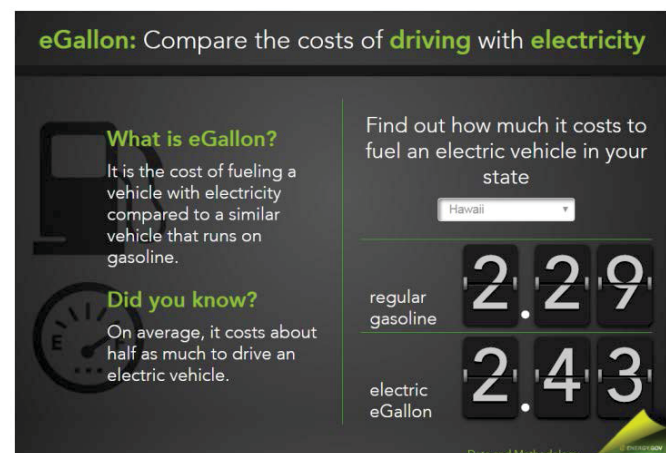


Figure 10. US DOE's comparison of average costs in Hawaii between driving an EV and a similar gasoline-fueled vehicle.

The steady average cost of electricity in the U.S. is contrasted against the fluctuations in gasoline prices (Figure 11, where the green line tracks average U.S. gasoline prices and the blue line average U.S. electricity prices, from Jan. 2001 through Feb. 2013.) Note the marked contrast with Hawaii's fluctuating electricity prices (referring back to Figure 8).

Another online resource, the "Clean Car Calculator" from the University of Santa Barbara is an online resource which allows the user to modify the assumptions including the cost of gasoline and electricity.²².

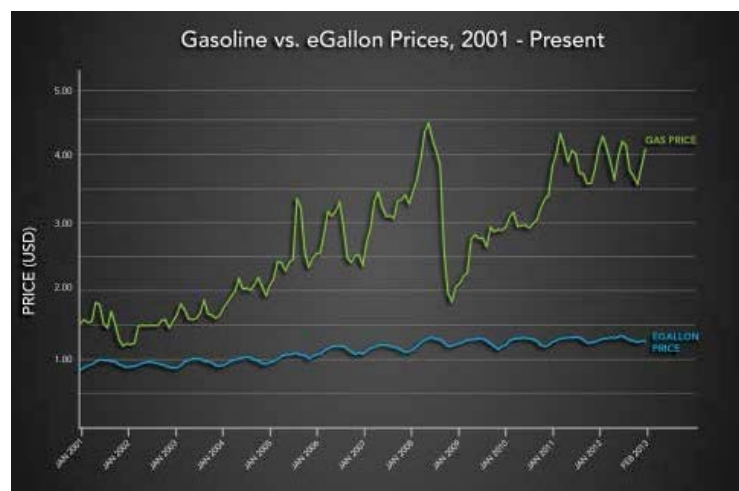


Figure 11. This US DOE chart shows how the average national prices of gasoline (the green line) and electricity (the blue line) have fluctuated over the past 10 years

The contribution of fuel costs is one of the considerations in the EVTC report entitled “Electric Vehicle Lifecycle Cost Assessment for Hawaii”. This is based on an EVTC model that can be downloaded from the EVTC website with an option to evaluate PV as a power source²³, another important consideration for EV owners in Hawaii. This model can be used to compare BEV, PHEV and conventional ICE vehicles.

Time of Use Rates

Both residential and commercial Time of Use (TOU) incentives are offered by HEI²⁴. Rates are aimed at encouraging the use of power to help balance the electric grid. Rates are lower during the middle of the day to make use of solar resources and at night when wind farms are typically productive but demand for electricity low (Figure 12). The peak rates are higher than a regular residential rate (without TOU), to help avoid the need to run additional utility generators to meet evening peak demand. From 9 p.m. to 7 a.m. the off-peak discount is about \$0.06/kwh. Otherwise rates are higher by about \$0.025/kwh on this plan, with a weekday “priority

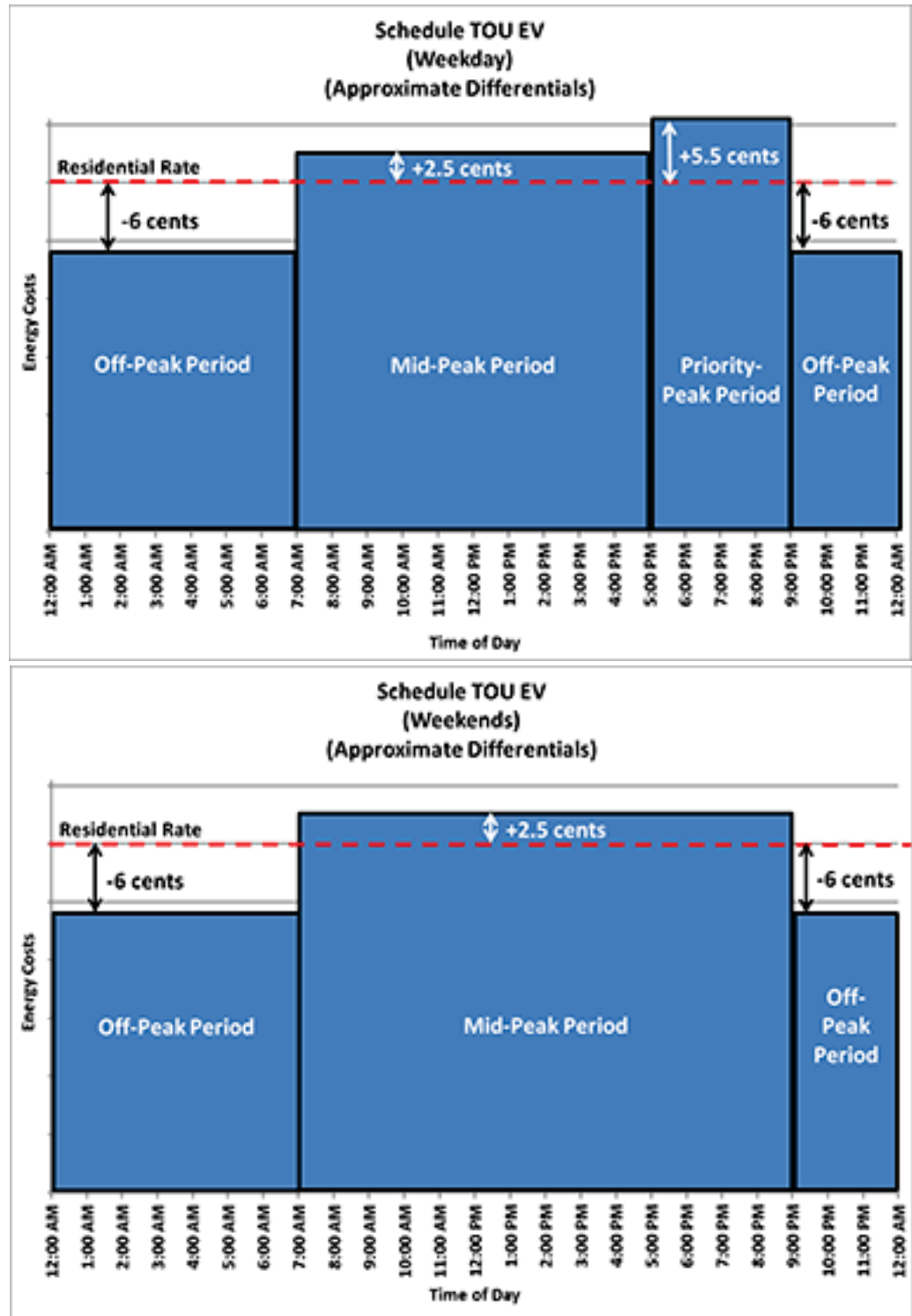


Figure 12. Oahu Time of Use (TOU) residential rates (Source Hawaiian Electric).

peak period” during the evening when the rate increases by about \$.055/kWh. HEI’s TOU is designed to result in overall savings only when EV charging and typical household electricity use are shifted to off-peak.

Commercial TOU rates require a meter to separate EV charging from the existing load to allow public charging infrastructure to be charged up to 100 kW, without a demand charge. There is a \$5.00 monthly metering charge and the lowest rates are offered from 9 p.m. to 7 a.m.

IV. EV Infrastructure

By May 2015, Hawaii had 395 Level 2 charging station ports, and 43 Level 3. Locations and specific information about each station can be found on many websites, such as the U.S. DOE’s Alternative Fueling Station Locator and the State of Hawaii’s database (Figure 13).

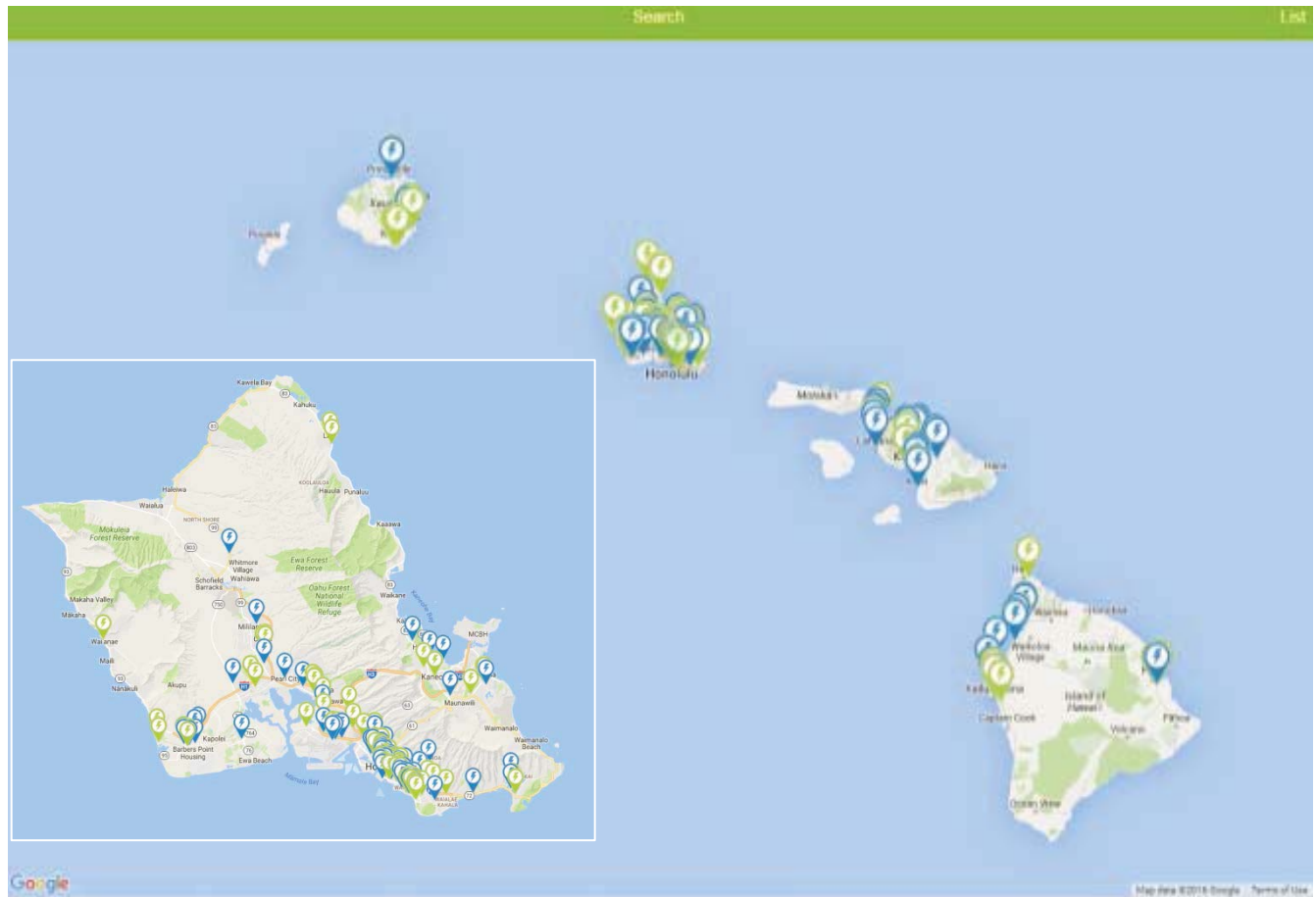


Figure 13. The State of Hawaii online EV charging stations map, with Oahu (inset).

In 2015, HEI installed four DC Fast Chargers on Oahu at easily accessed public locations (Figure 14). For 2016 HEI is planning to install up to seven more DC Fast Chargers on Oahu and Hawaii Island. For energy management on Oahu, these Fast Chargers will be used to demonstrate demand response, briefly lowering or halting charging.

A start-up company in Hawaii, FreeWire, repurposes second-life lithium-ion batteries into a mobile EV charging system. FreeWire reports the batteries are one-sixth the cost of new battery packs, (approximately \$100 per kilowatt-hour). The mobile charging uses electricity off-peak, in order to charge vehicles when and where needed during the day. FreeWire is currently working with HEI to deploy its EV charging systems at airports with a grant from the Energy Excelerator. HEI will also test demand response with this system.

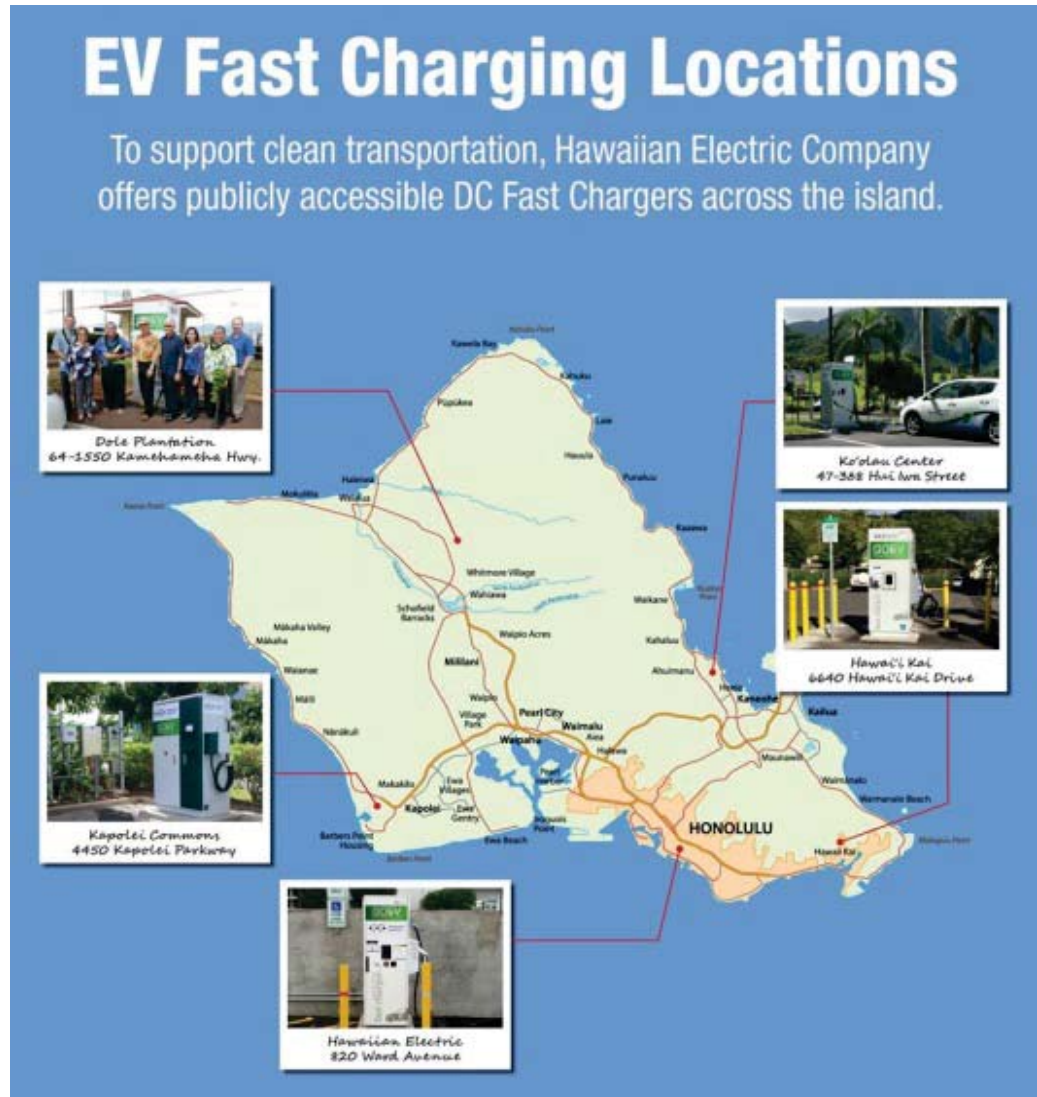


Figure 14. Hawaiian Electric (HECO) DC Fast Charging stations on Oahu.

V. EV Integration into the Power System

The value of interconnected EVs becomes significant as Hawaii moves toward 100% renewable power generation by 2045. The opportunity of using EVs to provide a grid stabilization service includes power reserves, frequency and voltage regulation, along with load balancing benefits. As Hawaii goes beyond the high wind and solar penetrations associated with renewable energy generation surpassing 40%, it will

become important to assess the value of grid-to-vehicle (G2V) and reverse charging or vehicle-to-grid (V2G) to provide these services along with additional backup capabilities required to maintain a reasonably stable and reliable power supply. This may be critical as the 100% renewable energy goals is approached, as outlined in this section of the report.

In remote areas and on islands, grid stability and reliability issues are of prime importance. Unlike the immense, interconnected grids on the mainland, the small grids on the Hawaiian Islands function in near isolation and cannot draw power from neighboring grids. This makes grid reliability, electricity supply, cost controls and stability both challenging and essential. Added to these challenges, the integration of intermittent renewable resources poses additional unique challenges given the relatively high penetration rates. Progress made in Hawaii's renewable energy "living laboratory" will help inform other remote communities including Puerto Rico, Guam, Marianas, the U.S. Virgin Islands, islands off the coast of Maine and Massachusetts, isolated communities in Alaska, and U.S. government sites such as national parks and military bases. The growing trend towards microgrids can also benefit from lessons learned in Hawaii. Utilities on the mainland also have more choices for dispatchable power generation, (i.e. generating plants that can adjust their power output accordingly to an order from the utility or plan operators), including cost-effective nuclear and large-scale hydroelectric. This leads to more options for balancing intermittent renewable power generation (along with a relatively stable price of electricity).

Renewable Generation

In 2015, more than 23% of the state's electricity was generated from renewable sources, including bioenergy, geothermal, wind and solar. Hawaii Island achieved 48.7%, Maui County reported 35.4% and Oahu 17.2 percent renewable energy²⁵. On Kauai, KIUC achieved 38% of its electricity from renewables²⁶. For short intervals in January 2016, KIUC obtained 90% from renewables on four occasions. In addition to its baseload capacities of 8% biomass, 7% hydroelectric (and diesel generation), KIUC achieved up to 77% solar in its power mix, the most solar ever integrated by a U.S. utility, according to KIUC²⁷. On an average day in January, solar was about 62% of the utility's generation, making renewables 77% of its power for that month. KIUC signed a deal in 2015 to purchase power from what is reportedly the first of its kind in the U.S. to supply fully dispatchable, utility scale solar (where the power generation can be turned on and off, and can adjust power output accordingly to an order from KIUC). The facility will include both a 13 MW PV installation and a 52 MWh battery to store energy generated during the day and allow it to feed up to 13 MW of electricity back onto the grid during the evening peak.



Figure 15. The Kauai Island Utility Cooperative (KIUC) utility scale PV farms.

In response to orders from the PUC, HEI has revised their Power Supply Improvement Plan (PSIP). The initial plan identified that accelerating the growth of the EV market could have a positive impact on the cost of electricity, spreading the fixed costs of the grid over larger usage. It was also noted that EV charging done at times of high renewable generation will help use excess energy and will help keep the marginal cost to serve the EV load low, benefiting all electricity customers. HEI's PSIP has the utilities

now aiming for a combined target of 67% renewable energy generation for Oahu, Maui and Hawaii Island by 2030, with 61% for the island of Oahu where most of the state's population resides. This includes almost tripling the amount of distributed PV power. As for the island of Kauai, KIUC is aiming for 50% renewable generation by 2023, with numerous hydropower and PV projects under consideration.

These increases in intermittent energy generation along with a rapidly growing demand for electricity for EVs means that utilities must find innovative ways to balance the grid and maintain reliability. Utilities must be able to continue providing reliable power to meet customer demands by mitigating (compensating for) the power loss from cloud cover or when the wind suddenly drops off. Similarly, to maintain reliable service across the distribution system, the utilities have to be able to deal with a potential spike in demand if thousands of EVs charge simultaneously on various circuits. Like other electricity power systems designed originally to generate power from large, centralized sources and send that power out to customers, Hawaii's utilities must become highly flexible and responsive to the new, two-way flow of power across the grid, along with the changing load profiles.

Smart Technologies

'Smart grid' and 'Smart charging' technologies enable a host of synergistic benefits offered by EVs with secure connectivity to a network. Smart chargers enable management of the charging station sessions and can set rates, mitigate energy use, report carbon usage and alert data, and process payments. Controlled charging is important in Hawaii and other regions where high levels of intermittent renewables already challenge circuit and system level stability. Concurrently transmitting data on energy generation and demand provides the necessary information to effectively manage two-way power distribution throughout the grid, as well as to increase renewables and maintain a reliable supply of electricity. This allows more reliable and efficient grid operations as more and more EVs are charged on the grid and renewable sources provide a greater portion of Hawaii's energy generation, plus increasing consumers' ability to control their energy use and costs.

Smart chargers for workplace and retail charging offer building energy management integration and are being demonstrated at the Florida Solar Energy Center for example. Integrated into intelligent building automation and management systems, smart charging systems can mitigate carbon emissions from both building power consumption and transportation. Improving efficiencies for the building as well as the EV can also reduce costs such as utility demand charges. At the residential level as well, connected home chargers may become pervasive in the future should sufficient value of controlled charging become established.

Controlled EV Charging

Assuming EVs continue to be adopted in ever growing numbers, controlled EV charging will be essential to avoid overtaxing the grid during peak demand. Intelligent, controlled charging will soon become important in Hawaii to help mitigate variations in power generation resulting from extremely high levels of PV penetration at the circuit level, through integrated smart charging, connecting demand response systems and charge scheduling programs. Workplace charging will be critical if levels of PV power generation in Hawaii continue to soar, potentially causing an overabundance of power generation mid-day. Additionally, demand response and energy management systems will become increasingly valuable by connecting the vehicle to the building's or campus's energy management system.

G2V charging of EVs offers demand response by briefly lowering or halting charging to help match renewable energy generation with load (supply and demand in other words). Another way utilities could take advantage of G2V demand response would be to help prevent transformer overheating – a potential challenge for the grid assuming EVs proliferate and EV charging becomes concentrated in certain neighborhoods. Concentrations of PV systems on certain neighborhood circuits can exacerbate load balancing issues as a result of the intermittency in PV resources. EVs also have the potential for V2G, providing energy storage to put power back onto the grid. The technology required includes two-way inverters in the vehicles to both charge and discharge the batteries, along with a smart charger or smart grid for control.

PV Growth

Hawaii continues to rank first in solar capacity per capita at 394 watts per Hawaii resident and a total capacity of 564 MW²⁸. Oahu (encompassed by the City and County of Honolulu), leads the nation with 17 % of all utility customers having installed rooftop PV systems. When only single-family homes are considered, 32 % have rooftop PV. From a capacity point of view, the island has 356MW of installed PV²⁹, another 140 MW approved for installation along with 99 MW of installed and 25MW of approved wind, on a power grid with a minimum load of roughly 900MW and maximum of 1200MW. The utilities on Oahu, Maui and Hawaii have approved or interconnected 77,000 PV systems³⁰. On Kauai 2,536 residential systems have been installed, and two of the largest solar arrays in the state have been installed in the last year. Each of these arrays is 12 MW, supplies 6% of Kauai's energy needs, reduces KIUC's oil consumption by 1.7 million gallons a year, and reduces carbon dioxide emissions by 18,000 tons per year.

HEI's maps with connected and accepted distributed generation (mostly PV) as a percent of minimum daytime and peak load on distribution circuits illustrate the variation in solar penetration from circuit to circuit, (Figures 16 and 17 shown for Oahu)³¹. On some circuits distributed generation is over 250% of daytime minimum gross load.

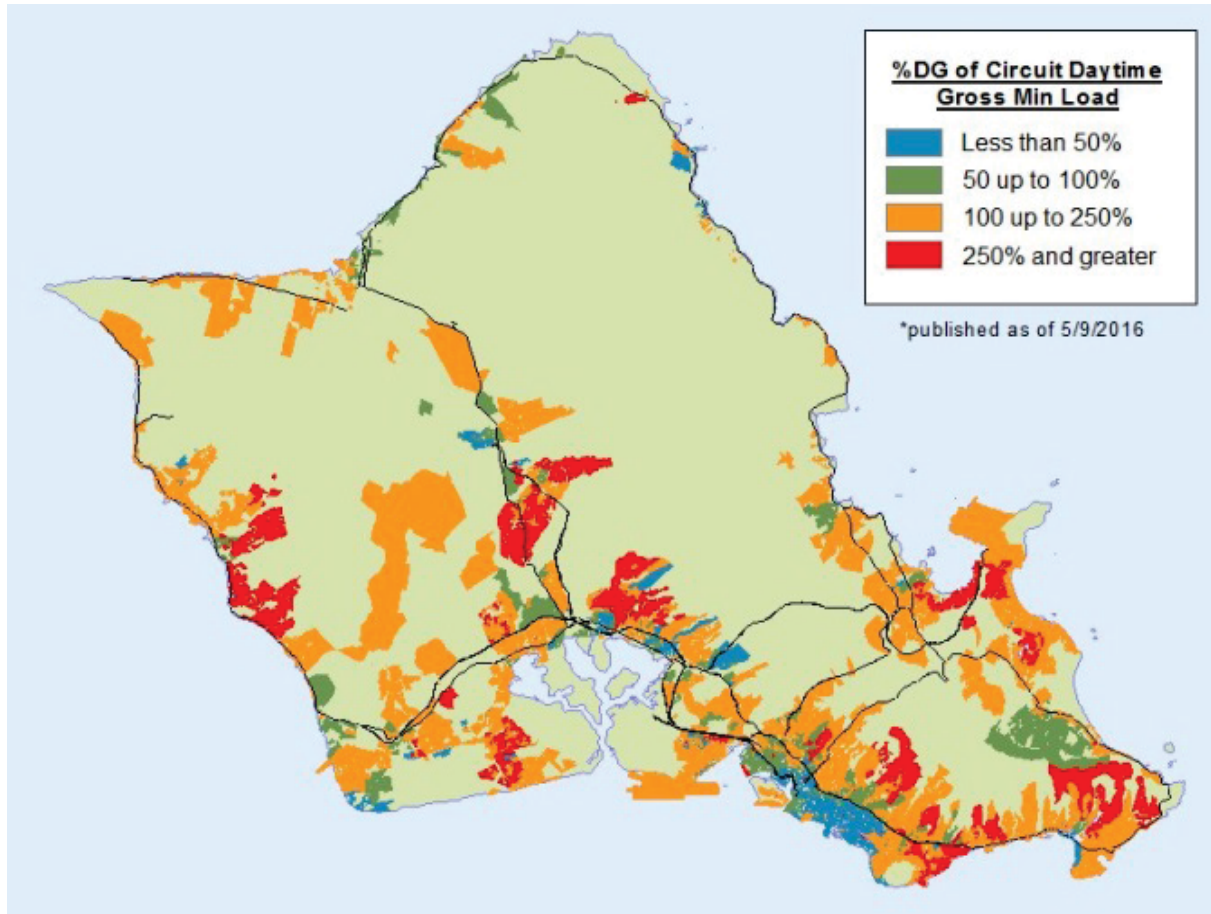


Figure 16. HECO's map for Oahu, with distributed generation (mostly PV) as a percent of minimum daytime load on distribution circuits.

The State of Hawaii still offers a 20% income tax credit on the cost of a wind system and 35% of the cost of a solar thermal or PV system. This includes both equipment and installation costs. There is also a feed-in tariff for commercial-scale renewable energy technologies, including PV, and (on-shore) wind. Under this program, qualified projects will receive a fixed rate over a 20-year contract.

Regulators in Hawaii (and Nevada) were the first in the U.S. to reduce the value of Net Energy Metering (NEM) credits new residential PV owners can receive for electricity exported back to the grid, from the full retail rate to the cost of the utility's wholesale power. The new tariff, Customer Grid Supply (CGS), sets PV compensation rates at \$0.151/kWh for Oahu, \$0.154/kWh for Hawaii, and \$0.172/kWh for Maui, approximately the value of recent power purchase agreements with HEI for utility-scale solar energy. A self-supply option, Customer Self Supply (CSS), was also introduced last fall for new PV customers, with energy storage as part of the PV system. The CCS program allows PV customers to earn credits at the retail rate of electricity, but has a restriction in the amount of electricity that can send back to the grid, without any compensation for these exports. CCS does include an expedited review from the utility in areas of high PV penetration but fewer than one tenth the number of applications for CCS have been received by the utility than for the CGS program. On Kauai, KIUC's fully subscribed NEM program has

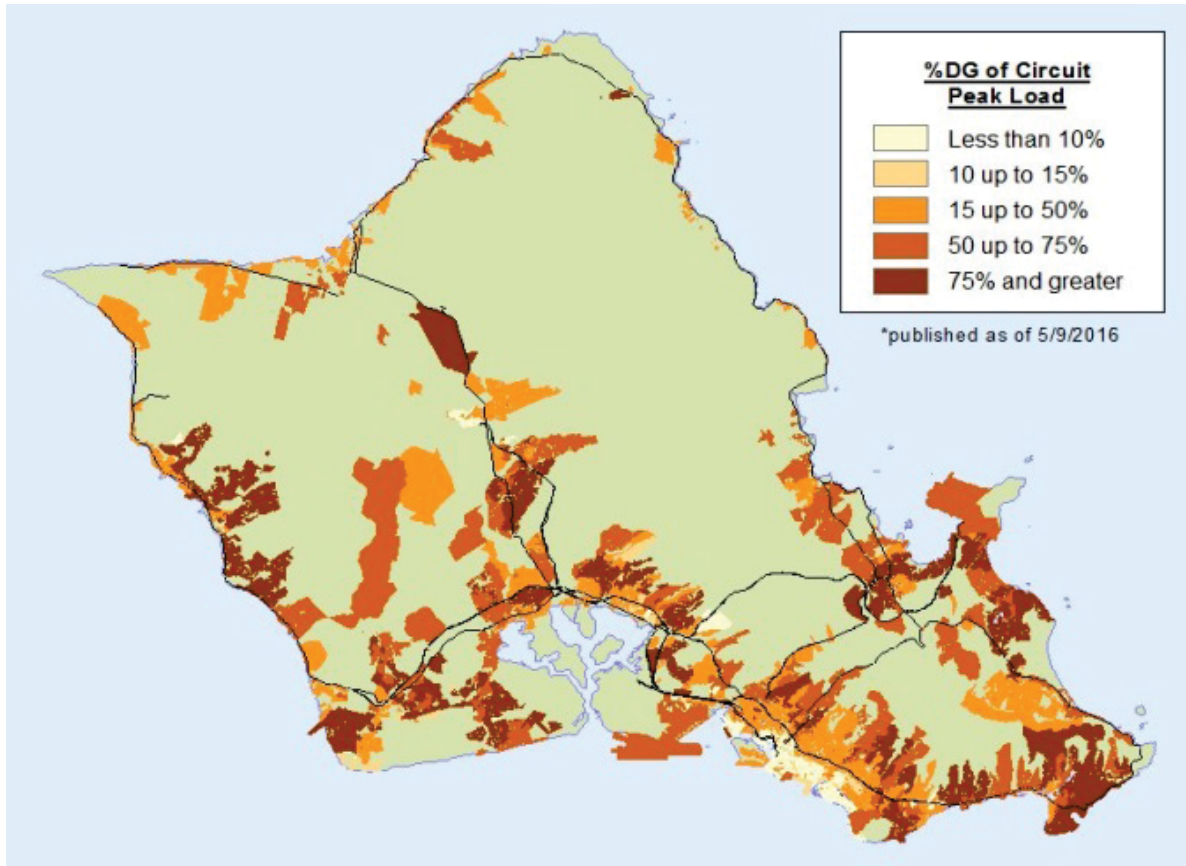


Figure 17. Connected and accepted distributed generation (mainly PV) on distribution circuits as a percent of peak circuit load on Oahu.

the utility purchasing excess power from subscribed customers at \$0.20/kWh for 20 years.³² Complementing this, KIUC's smart grid technology includes wireless meters installed at 28,000 homes and businesses, allowing customers to log into a website where they can track their energy use.

As battery prices continue to fall, PV systems combined with battery storage are being sold to commercial and residential customers. Advantages offered by power grid systems over single PV-plus-battery systems include the ability to share excess generation or storage. A report by Deutsche Bank suggests that a major opportunity for utilities over the next decade lies with residential PV and battery aggregation, coupled with intelligent software and predictive analysis³³.

VI. Emissions

In geographic areas that use relatively low-polluting energy sources for electricity generation, plug-in vehicles typically have a well-to-wheel emissions advantage over similar conventional vehicles running on gasoline or diesel. In regions such as Hawaii that depend heavily on conventional fossil fuels for electricity generation, EVs do not necessarily demonstrate a benefit over gasoline-powered hybrid vehicles, depending on the choice of vehicle.

The U.S. DOE's Alternative Fuels Data Center website uses regional electricity sources to calculate annual vehicle emissions by State³⁴. Emissions from EVs in Hawaii are higher than the national average by about 2,000 pounds of CO₂ per year, and also higher than gasoline-powered hybrids, but still lower than similar conventional gasoline vehicles, (Figure 18).

Overall, the U.S. transportation sector accounted for approximately 26% of total U.S. Greenhouse Gas (GHG) emissions³⁵. Globally, transportation GHG emissions have more than doubled since 1970 - increasing at a faster rate than any other energy end-use³⁶. In a business as usual scenario, the U.S. transportation sector's GHG emissions are expected to grow by about 10% by 2035, and will still account for a quarter of global transportation emissions at that time.

Life cycle emissions of EVs are being studied and reported, providing new insight into the regional merits of EVs. For EVs to contribute positively to pollution mitigation efforts at the global level, development of the transportation, electricity, electronic, and metal industry sectors must be jointly and consistently addressed. For Hawaii, further investigation is needed to determine the life cycle emissions and relative merits of EVs powered by planned and proposed future energy sources. In general, renewable fuel sources for electricity are seen to have GHG emissions orders of magnitude lower than fossil fuels when taking into consideration the full life-cycle emissions including plant construction, fuel production, transportation, fuel combustion and electricity transmission³⁷.

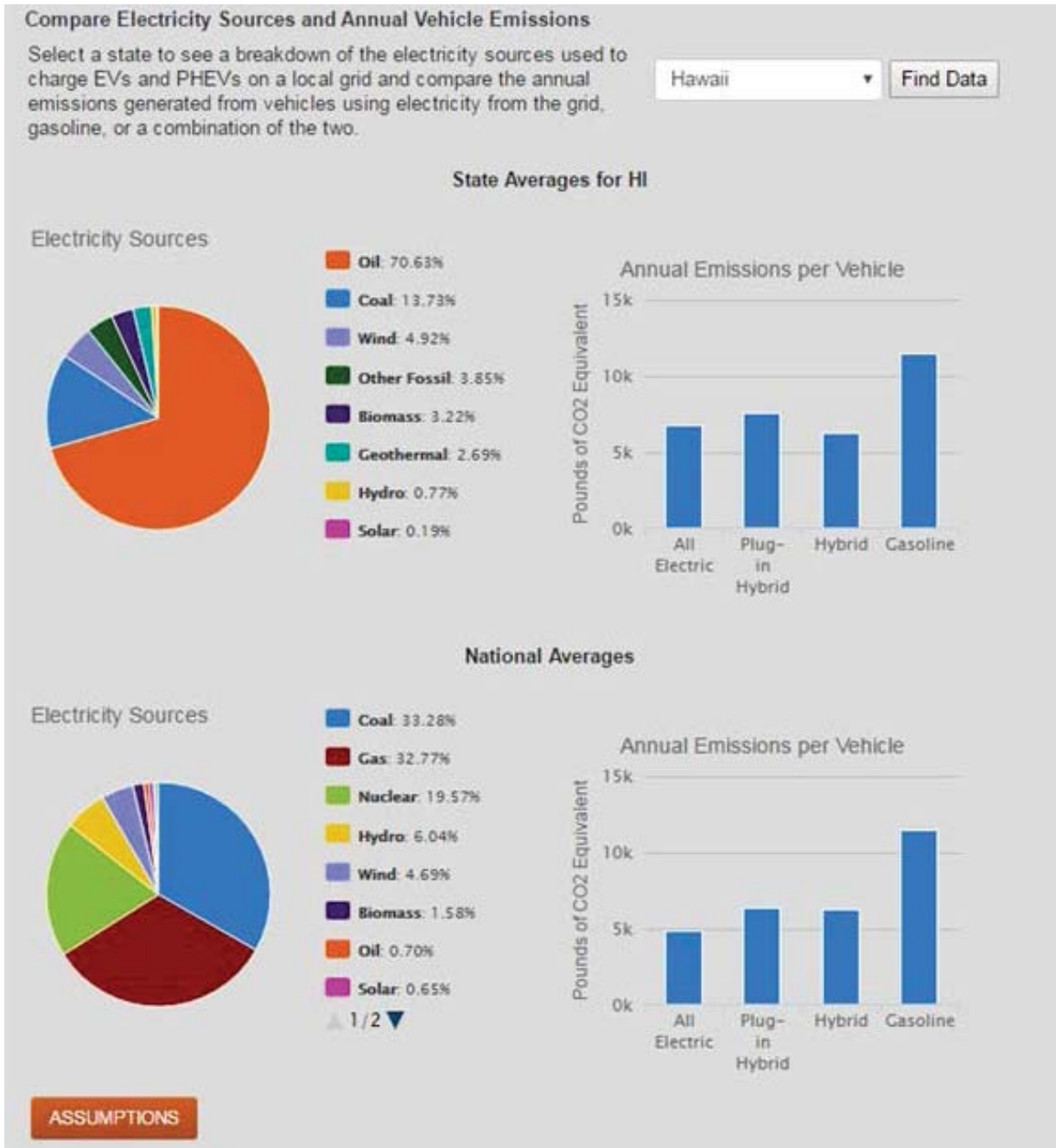


Figure 18. Emissions in Hawaii compared to the US average, (US DOE Alternative Fuels Data Center).

VII. Research and Demonstration Projects

Systems Integration - Modeling and Analysis

The traditional model of large power plants supplying an essentially steady output of electricity is being replaced rapidly in the Hawaiian Islands with the integration of intermittent, distributed generation. As

the penetration of intermittent renewables on the power grid increases, balancing power generation with load becomes increasingly challenging, making controlled EV charging progressively more important. Currently when demand for electricity to charge EVs is added to the Oahu grid, additional petroleum is used for electricity generation. As for other regions across the US, the interrelationship between EV charging and power plant fuel use as well as growing renewable power generation is important when considering the true fuel requirements and emissions of EVs.

With the accelerated renewable generation and EV adoption in Hawaii, modeling and analysis has become critical to inform technical direction, planning and policy decisions. Hawaii's EV adoption levels are projected to increase to over 80,000 EVs on Oahu alone by 2040³⁸. If the price of oil increases to the EIA high oil case, this figure is forecast to be over 160,000 EVs on the island by 2040, and over 260,000 by 2045 (or 15% and 22% of all passenger vehicles on the road respectively). Without realistic data and progressive EV TOU charging profiles, the impact of uncontrolled EV charging could be seriously detrimental to the power grid, with EV charging coinciding with peak demand for electricity (during late afternoon through evening hours). Ideally, controlled EV charging profiles can play an increasingly significant role in helping to increase clean, renewable power generation as well as to help improve operational efficiency and reliability of the power grid in Hawaii and many other regions of the US.

EVTC and HNEI modeling and demonstration projects are exploring the technical and economic value of EVs connected to a power grid with wind energy and exceptionally high levels of PV. HNEI studies also aim to address concerns shared by utilities around the country, that adequate preparation is needed to avoid stress at the circuit level of the power grid from the additional demand for electricity from often localized EV charging. The aim of the EVTC analysis is to assess the impacts on both transportation and the power grid as the number of grid-dependent vehicles increases. In the EV Energy Impacts project under the EVTC program, HNEI is conducting ongoing modeling and analysis to explore the impact of future substantial EV adoption on net petroleum imports to Hawaii, in scenarios with high-penetration of intermittent renewables on the power grid.

Technical results from the HNEI-GE modeling efforts are used by the State of Hawaii and HECO to inform policy and planning efforts to achieve Hawaii's renewable energy and energy efficiency goals for both power generation and transportation.

Oahu Electric Vehicle Charging Study

Initially building on other projects, HNEI commissioned GE to perform detailed, electrical dispatch modeling to estimate the additional fuel for power generation with high levels of EV adoption, along with the amount of excess (curtailed) energy captured by controlled charging of this large number of EVs³⁹. To compare the fuel economy of EVs to gasoline vehicles, an HNEI study was performed to estimate how far an EV could travel on the energy equivalent of a gallon of gasoline (in MPGe)⁴⁰. EV mileage and emissions were quantified under controlled charging profiles, with and without high penetrations of intermittent renewable resources on the electricity grid, based on the modeled net petroleum use by EVs on Oahu. Results were compared to different vehicle types and fuel mixes; gasoline-powered vehicles, hydrogen and fuel cell vehicles. Under the modeled future renewable energy base cases before EVs were added, 10 to 23 % of the combined wind and solar energy were curtailed when these resources exceeded

the maximum that could be absorbed into the grid. Grid-connected EVs were explored for their potential to take up the curtailed energy on the Oahu grid.

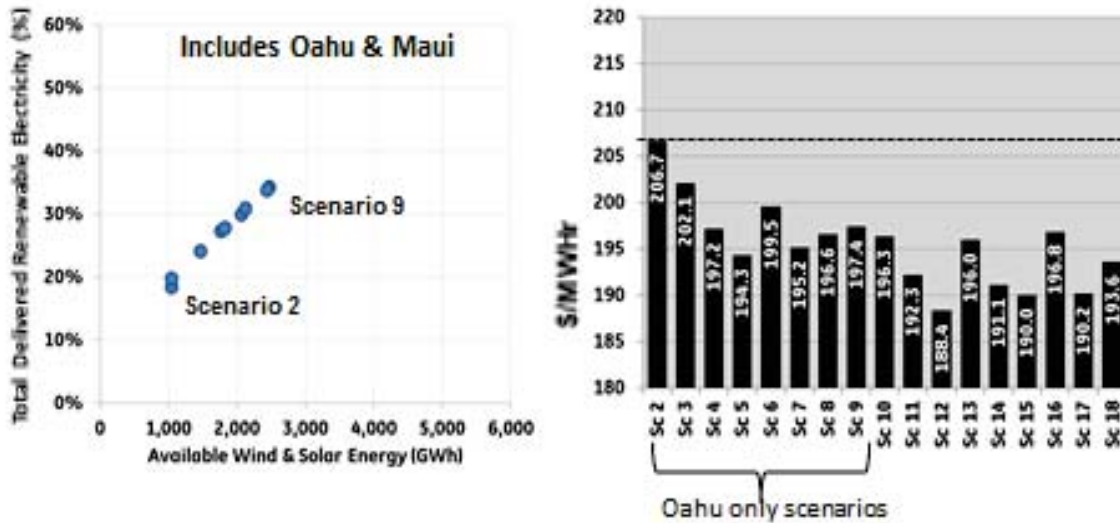
In this initial study, approximately 10 to 30 % of light-duty (passenger) vehicles on Oahu were replaced with EVs. Additional petroleum fuel for electricity generation (to balance the intermittency of wind and solar) was quantified for each future scenario's EV load. It was expected that much of this curtailed energy would be captured by strategically charged EVs. Nonetheless, it was found that day-to-day variations in total wind and solar curtailment reduced the effectiveness of controlled EV charging in capturing curtailed energy. With this very large fleet of EVs and assuming all EVs follow a practical, controlled charging profile, curtailed energy was reduced by 18 to 46 %. Further improvements in the electric grid were also indicated to reduce curtailed energy.

HNEI's EV analysis quantified the effects of curtailment on electrified transportation. Results showed that overall fuel and emissions savings could be made on Oahu by replacing average mileage gasoline vehicles (achieving less than 22 mpg) with EVs. In the modeled future scenarios, the same gasoline savings made by the very large fleets of EVs would be comparable to improving Oahu's entire passenger vehicle fleet by 1 to 4 MPG overall. To put this into perspective for Oahu's electric power system in 2012, EVs achieved approximately 32 MPGe⁴¹. Calculations were based on the U.S. DOE "(oil) well-to-wheels" standard which reflects fuel used for electricity generation. By comparison, an EV at that time on the mainland U.S. using the average fuel mix to power the electrical grid would achieve 36 MPGe well-to-wheels mileage.

Hawaii Renewable Portfolio Standards (RPS) Roadmap Study

The next phase of HNEI-GE's modeling was the "Hawaii RPS Roadmap Study"⁴², which included modifications to the utilities operations and generating plants. With these modifications, it was found that intermittent renewable energy could be integrated into the grid with significantly less curtailed energy at the transmission level. For Oahu, delivered renewable energy approaching 35% could be achieved with wind and PV additions. In scenarios where Oahu and Maui County were connected by undersea power cabling, up to 50% delivered renewable energy was achieved. Typically 1 to 3% curtailment resulted in the scenarios studied, and up to 12% depending on the combination of wind and solar energy resources (Figure 19).

Delivered renewable electricity approaching 35% can be achieved with additional wind and solar on Oahu only



- **Lowest electricity cost option (scenario 5) achieved with 300 MW wind, 260 MW distributed solar, 200 MW central solar resulting in 6.3% cost savings**
- **Highest renewable delivery (scenario 8) achieved with 200MW wind, 460MW distributed solar, 400MW central solar resulting in ~ 4.5 % cost savings**

Figure 19. The Hawaii RPS Road-map Study (HNEI/GE).

Power Supply Improvement Plan (PSIP)

Having quantified the impact of EV adoption on Hawaii’s original RPS, the updated PSIP was modeled approaching Hawaii’s RPS of 30% by the year 2030, with a focus on the island of Oahu. These near-term future scenarios include increased levels of distributed solar resources and power system upgrades including changes to thermal minimums for base load power generation (essentially enabling power plants to run at a much lower output). The PSIP renewable energy base case represents a total of 28% renewable energy capacity on the grid, with 475 MW of DPV, 276 MW of Central PV (CPV), 124 MW of wind, with the balance from waste-to-energy and biofuels. To investigate the interactions of significant EV adoption, scenarios were modeled with 5 and 10% additional loads on the grid from EV charging. An additional 100 and 200MW of DPV was also modeled to reflect Hawaii’s near term growth in rooftop solar capacity.

Fully-battery powered plug-in vehicles that rely entirely on electricity as a fuel source were the focus. (Results are applicable for PHEVs for the portion of travel powered by the battery.) To compare the fuel economy of EVs to gasoline vehicles, calculations were performed to estimate how far an EV can travel on the energy equivalent of a gallon of gasoline (in MPGe). A midsize EV was analyzed that uses 30 kWh/100 miles, and travels 11,000 miles per year.

Fuel use was quantified based on the detailed HNEI-GE high-fidelity modeling outputs for the near-future PSIP scenarios. To balance the intermittency of wind and solar, additional petroleum for electricity generation was quantified for each future scenario's EV load. To calculate the EVs fuel economy, two methods were considered; firstly, assuming EVs use electricity as does any other load, and secondly considering EVs as an additional load on the grid. Since EVs can be incentivized to replace gasoline vehicles, this second calculation was performed to assess the benefit of an EV load in reducing curtailed wind and solar energy when these resources exceed the maximum that can be absorbed into the grid.

Comparisons were made for mileage and emissions of gasoline vehicles based on an average fuel economy for passenger vehicles of 23.4 MPG⁴³. In addition, the net petroleum used by passenger EVs on Oahu was quantified.

Based on modeling results for the PSIP base case with additional 5% and 10% EV charging loads, this represents 122,121 and 243,939 EVs respectively. Clearly looking this far into the future is meant as an exercise in understanding possible EV fuel economy and power grid interactions. In order to have meaningful EV charging loads on the power grid, long-term EV adoption levels were used with the modeled (near-future) power grid.

The resulting mileage equivalent (in MPGe) to a gasoline vehicle traveling the same distance was calculated. As can be seen from the results summarized in Table 1 for PSIP +5% load and PSIP +10% load, overall fuel savings can be achieved by replacing average mileage gasoline vehicles with EVs. Adding additional distributed solar to the PSIP grid (+100MW and +200MW) slightly increases EV mileage. When EVs are considered as an additional load on the grid, the mileage is slightly higher than when considered as part of the overall load on the grid. This is because EV load helps to reduce that curtailed PV and wind power. As expected, the more EVs are added, the greater is the reduction in curtailed energy.

Under the modeled PSIP future renewable energy base case before EVs were added, only 1.2% of the combined wind and solar energy was curtailed. This clearly demonstrates the improvements expected in the power system as a result of the PSIP. When 5% and 10% loads were added to the grid, this small amount of curtailed energy was reduced by 39% and 62% respectively (Table 1). When 100MW and 200MW of DPV is added to the PSIP base case, curtailment of wind and solar increases to 2.4% and 4.2% respectively. With 100 MW of DPV added, the additional loads of 5% and 10% reduce the curtailment by 33% and 57% respectively. With 200 MW of DPV, the 5% and 10% loads reduce curtailment by 30% and 51%.

Scenario	Electricity mix from grid (MPGe)	Curtailed Energy, balance thermal generation (MPGe)	Reduction in curtailment	
			(GWh)	(%)
PSIP +5% Load	40.3	41.2	8.0	39.4%
PSIP+100MW +5% Load	40.9	42.5	14.4	32.9%
PSIP+200MW +5% Load	41.7	44.7	24.6	29.9%
PSIP +10% Load	40.3	41.0	12.5	61.6%
PSIP+100MW +10% Load	40.9	42.3	25.0	57.1%
PSIP+200MW +10% Load	41.7	44.2	41.8	50.8%

Table 1. Power Supply Improvement Plan (PSIP) Scenarios: EV fuel use in Miles Per Gallon Equivalent to gasoline (MPGe) and reduction of curtailment in (GWh and as a percentage).

In the PSIP scenarios for Oahu, for each average 23.4 MPG gasoline vehicle replaced with an EV, net petroleum savings range from the equivalent of 197 to 224 gallons of gasoline per year. For the entire ‘fleet’ of 122,121 EVs replacing the same number of gasoline vehicles (from the scenario with EV charging adding 5% to the load on the power grid), net fuel savings range from 24 to 54 million gallons per year. If we assume Oahu’s entire passenger vehicle fleet gets an average of 23.4 MPG, to achieve the same fuel savings would require an overall improvement of approximately 2 to 5 MPG for every passenger vehicle.

However, under these PSIP scenarios the EVs are surpassed by 50 MPG gasoline-powered hybrid vehicles. Compared with a 50 MPG hybrid, each EV in the modeled scenarios range from using an additional 6 to 13 gallons of gasoline per year. As larger amounts of wind and solar are added to the grid, it is reasonable to expect the EV fuel savings to become comparable to and eventually surpass 50 MPG hybrids. However, estimating future EV mileage and emissions is dependent on the power grid fuel mix and operation.

As expected, EVs in this study have lower carbon dioxide (CO₂) emissions as compared with average gasoline vehicles, but not 50 MPG hybrids. If it’s assumed EVs will be replacing 23.4 MPG gasoline vehicles running on E10, emission savings for the fleet of EVs ranged from 528 million pounds of CO₂ for the PSIP scenario with 5% additional load, up to 1,048 pounds of CO₂ for the scenario with 10% additional load and 200 MW of additional DPV. Currently, the global warming emissions of EVs in Hawaii are comparable to 36 MPG gasoline vehicles, according to a report by the Union of Concerned Scientists⁴⁴. With Oahu’s rapid increase in renewable energy, currently at 15% total renewable energy as a percentage of generation, it is clear that EVs provide an potential option to reduce fossil fuel use and emissions for a variety of transportation needs.

PSIP – Phase II

HNEI-GE grid modeling with increasing renewable energy levels is currently being conducted with up to 70% renewables, to help inform Hawaii's progress moving toward the mandated RPS goals of 30% by 2020, 40% by 2030, 70% by 2040, up to 100% by 2045. Even small changes in modeling inputs or scenario assumptions can have a significant effect on results. Examples of this include operational changes by the utility such as thermal minimums for base load power generation, along with scenario assumptions of future levels and mixtures of renewable energy. For example, preliminary results from HNEI-GE modeling underway with 50% wind and solar energy leads to significant curtailment of approximately 12% to 27%, depending on the mix of resources and changes to the utility's operations. Recent modeling by HNEI and GE of future scenarios on Oahu with advanced grid operations is demonstrating that above 40% penetration of solar energy, approximately 90% of any additional solar energy would be curtailed⁴⁵.

Benefits of modeling and analysis efforts are expected in the form of increased understanding of EVs to balance renewable energy integration on the power grid, with direct application to isolated grids, microgrids and more universal application on larger grids at the distribution or circuit level. Knowledge gained in Hawaii will play a role in helping to shape the electrification of transportation in other regions of the U.S. particularly as it relates to integration of high levels of renewables and energy storage on the power grid. With increasingly cleaner sources of power generation, EVs offer progressively more energy and emission savings over average gasoline vehicles. For Hawaii, these changes to ground transportation would have a significant effect on reducing petroleum imports to the nation's most petroleum dependent state. All in all, a net reduction in petroleum enhances U.S. energy security and economic stability.

Systems Integration - Demonstration

Several research and demonstration projects are underway in Hawaii to evaluate advanced technologies which will lead to cleaner transportation and increase intermittent renewable power generation.

JUMPSmart Maui

JUMPSmart Maui is one such demonstration project, incorporating EV solutions, smart grid, and high penetrations of renewable energy. Scheduled to conclude by the end of 2016, energy data from volunteer owners of the Nissan LEAF and residents on Maui continues to be collected and evaluated. Smart utility system controls were developed and installed to connect advanced EV charging management systems to the electric utility system controls. Utility operators are thus able to manage EV charging in order to balance power demand with distributed PV and wind energy generation, to create a more efficient, reliable grid. The findings can be scaled to the larger grids on other Hawaiian islands, as well as other parts of the nation and the world. Funded through a \$30 million investment by Japan's largest public research and development management organization, the New Energy and Industrial Technology Development Organization (NEDO), Hitachi Ltd. along with Mizuho Corporate Bank and Cyber Defense Institute developed the program. The U.S. DOE, HEI and MECO also funded significant work to support this project. Other key partners include HNEI serving as one of the Hawaii implementing organizations, the County of Maui, the State of Hawaii, Maui Economic Development Board, University of Hawaii Maui College, Advanced Energy Company USA and HNU Energy.

Phase Two of JUMPSmart Maui is now underway to test and demonstrate an EV-Power Conditioning System to charge volunteers' Nissan LEAFs as well as discharge the power to their homes and businesses, serving as a power source during power outages or when otherwise needed. EVs will be demonstrated as a battery storage device, providing a controllable power source to supply energy for household needs. This EV-Power Conditioning system will allow participants to use energy from renewable sources such as PV panels to charge their EVs more efficiently during the day, then discharge stored energy from their EV batteries during the evening, to power their homes when energy demand increases. The long-term goal is to use EVs to create a "virtual power plant" that will integrate and manage distributed energy resources such as EV batteries and PV systems within the electric grid. The distributed renewable energy resources will also be aggregated for utility use, along with stationary, grid-scale battery energy storage systems. Components, including the V2G interface to the Nissan Leaf were tested at HNEI's HECO-supported Hawaii Sustainable Energy Research Facility.

Hydrogen Refueling Support

In order to displace fossil fuels, hydrogen produced from renewable resources must be economically competitive with other transportation options. By comparison to EVs, Fuel Cell Electric Vehicles (FCEVs) running on hydrogen currently have advantages such as range and fueling time similar to gasoline powered vehicles. However, the fuel used to power FCEVs at present is also typically a fossil fuel, since about 95% of the hydrogen produced in the U.S. is made from natural gas in large central plants, according to the U.S. DOE. Previous studies conducted by HNEI have demonstrated electrolyzers, which use electricity to split water in order to form hydrogen fuel, along with hydrogen transport trailers and FCEV fueling stations. The additional steps in producing hydrogen from electricity each have an efficiency loss, contributing to the higher energy requirement to run a FCEV versus an EV. This leads to higher emissions as well as additional water considerations. Although the infrastructure to deliver hydrogen as a fuel is capital intensive, FCEVs are becoming commercially available in some states such as California.

In Hawaii, HNEI and partners are leading demonstration projects to evaluate technical and economic performance of hydrogen-powered FCEVs, plug-in hybrid fuel cell electric shuttle buses, hydrogen production from renewable sources, and hydrogen fueling technologies.

HNEI has installed and is supporting operation of a "Fast-Fill" hydrogen production and fueling station at the Marine Corps Base Hawaii (MCBH) on Oahu (Figure 20). As of August 2015, it successfully completed over 300 fills without any operational downtime, providing the same customer experience as a normal self-serve gasoline dispensing station. Along with an earlier hydrogen fueling station at Joint Base Pearl Harbor-Hickam, this station supports demonstration FCEV fleets, initially 5 GM Equinox FCEVs operated by MCBH. The state-of-the-art, high pressure Fast-Fill system (700bar) dramatically reduces the fueling time, providing a full tank of hydrogen for passenger FCEVs in less than 5 minutes. The station is also capable of dispensing hydrogen at lower pressure (350 bar) to



Figure 20. Fast-fill, dual pressure hydrogen fueling station at Marine Corps Base Hawaii (MCBH).

fuel heavy-duty vehicles such as buses. A site safety analysis was done along with development and initiation of first responder training.

Hydrogen for the station is produced by electrolysis and the supply can be augmented by a hydrogen transport trailer that moves the fuel from other DOD stations. A PV-covered parking structure adjacent to the MCBH hydrogen fueling station is planned to supplement electrical power to the fueling station. These projects demonstrate coordinated teamwork between HNEI, MCBH and a strong group of partners, funding agencies, suppliers and other participants to meet the challenges inherent with implementing leading-edge technologies on a military base.

On the island of Hawaii, HNEI's engineering and economic analysis is underway to supply hydrogen for fuel-cell battery buses currently operated at Hawaii Volcanoes National Park (HAVO) by the County of Hawaii Mass Transit Authority. The hydrogen is delivered in "drag & drop" 450 bar hydrogen transport trailers that have the ability to cascade fill vehicles without the requirement for an on-site compressor. Plug-in hybrid fuel cell electric shuttle buses are operating on regular tour routes through the park, over different grades, elevations and climatic conditions. This project is also validating fuel cell system performance in harsh environmental conditions and an air filtration monitoring system that measures the performance of the fuel cell system's air inlet filter and identifies when replacement is needed.

Alternative Fuels

Replacing fossil fuels for ground transportation is the focus in Hawaii based on the available technologies and degree of control. However, with the State's isolation, jet fuel consumes a significant portion of the imported fuels, approximately 34%. HNEI is leading an Alternative Jet Fuel Supply Chain Analysis - Tropical Regional Analysis to develop information on regional supply chains for use in creating scenarios of future alternative jet fuel production in tropical regions. A second objective of this project is to identify the key barriers in regional supply chains that must be overcome to produce significant quantities of alternative jet fuel in the Hawaiian Islands and similar tropical regions.

Energy Storage

Several large-scale, battery energy storage system (BESS) demonstration projects have been completed. Grid-connected, 1 to 2 MW battery systems and control systems are intended to help increase the reliability and stability of each electrical grid on Hawaii Island, Maui, and Oahu. On Hawaii Island, this includes frequency regulation, wind smoothing, and power quality improvement at the Hawi 10 MW wind farm with a 1MW, 250 kW-hr, Li-ion Titanate battery storage system. Analysis indicates the BESS with a frequency response control algorithm, reduces overall grid frequency variability by 30-50% (Figure 21), and the wind smoothing algorithm reduces the variability of wind farm power output over 1 minute periods by 60%.

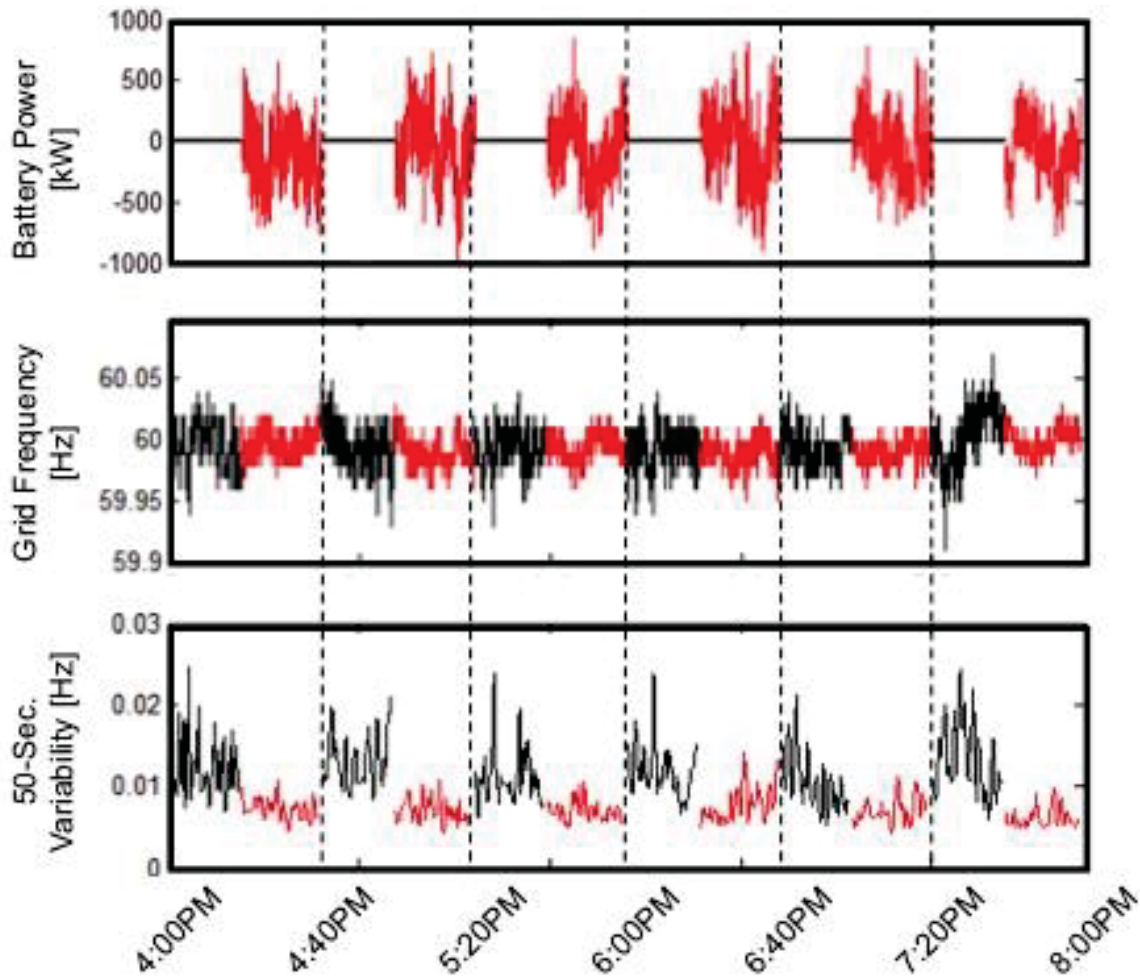


Figure 21. Battery energy storage system (BESS) power output (top), HELCO grid frequency (middle), and frequency variability (bottom) on 3/15/13. Black/red lines indicate BESS inactive/active periods.

VIII. Conclusions

The Hawaiian Islands provide an ideal “living laboratory” to demonstrate sustainable transportation and renewable energy resources and technologies. With the high cost of energy and reliance on imported fossil fuels, the urgent and complex energy needs of the state have resulted in a mandated 100% RPS by 2045 for electricity. Synergies with connected, electrified transportation provide a unique opportunity to investigate and develop engineering, economic, and policy solutions that can be implemented in other Pacific regions and across the nation. The EVTC and HNEI projects provide an integrated approach to develop technology strategies and inform policies that will have significant positive impact on the energy mix. This report provides a summary Hawaii’s progress and challenges in developing more sustainable transportation integrated with cleaner, reliable electric power, with a focus on connected transportation to reduce fossil fuel use, GHG emissions and to increase energy independence in Hawaii and beyond.

IX. Acknowledgments

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