EPRI ELECTRIC POWER RESEARCH INSTITUTE

Quick Insights

Solar Plus Storage PPAs in Hawaii

RESEARCH QUESTION

Is solar-plus-storage becoming a commercially viable option for renewable generation plant development? What lessons can we learn from the Hawaiian Electric Companies' recent announcement of seven new solar-plus-storage projects?

KEY POINTS

- Hawaiian Electric Companies recently submitted plans for seven new solar-plus-storage plants to the Hawaii Public Utility Commission, totaling 262 MW of solar photovoltaics (PV) coupled with battery energy storage sized at an equal ac power capacity rating with four-hour duration (262 MW/1048 MWh).
- The power purchase agreement (PPA) prices (8 to 12 cents/kWh) are significantly lower than the current cost of fossil fuel generation on the islands, which is about 15 cents/kWh, and suggest commercially-competitive solar plus storage is viable today in Hawaii. As costs for both solar and storage technologies continue to decline, similar plants may start to be developed in other areas with relatively high cost of generation and eventually in broader markets with growing renewable penetration.
- The PPAs associated with these projects utilize the Hawaiian Electric Companies' recently-developed Renewable Dispatchable Generation PPA structure, which pays the project owner a monthly lump sum payment and gives the utility dispatch control of the plant. This contracting mechanism enables the utility to dispatch both the solar and the storage as needed for system operations, allowing them to integrate more renewable energy and provide flexibility, while addressing some of the financing risks previously associated with curtailment.
- As Hawaii works toward a goal of 100% renewables, the proposed plants' dispatchability and large storage capacities are expected to contribute to the islands' operating reserves and power quality, as well as shift solar output to when it is needed most. The plants are projected to decrease petroleum use and greenhouse gas emissions as they displace generation from fossil-fuel units during peak electricity demand hours after sundown.

BACKGROUND

Historically, the Hawaiian Islands have relied predominantly on petroleum for electricity generation; in 2017, 68% of Hawaii's utility-generated electricity was petroleum-based[1] compared to less than 1% of the electricity generated in the rest of the United

1 Energy Information Administration (EIA). *Hawaii Electricity Profile 2017*, Table 5: https://www.eia.gov/electricity/state/hawaii/

States.[2] Due to the high cost of importing petroleum for electricity production, Hawaii's electricity prices have been two to three times higher than the U.S. average, with residential rates of nearly $0.30/kWh.[3]

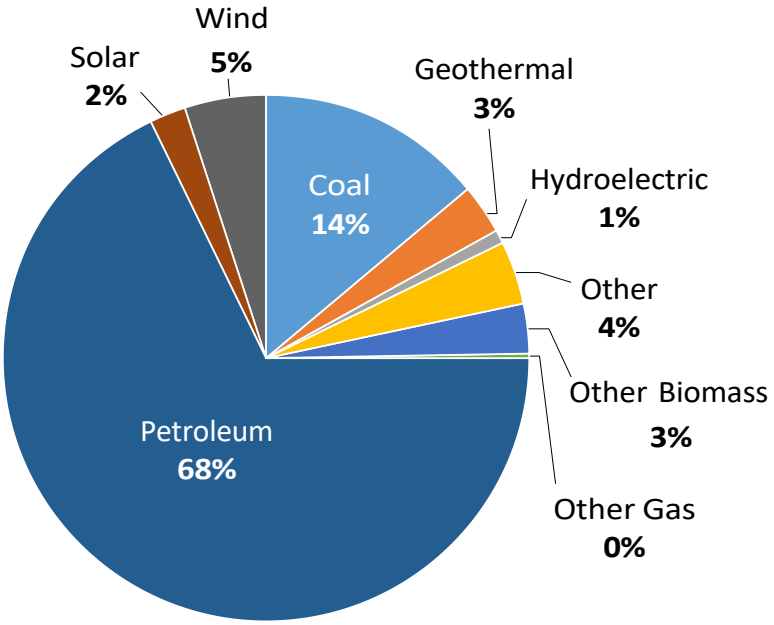

Figure 1: Hawaii Utility-Supplied Electricity Generation by Source, 2017.[4] Note: This does not include customer-sited generation, such as distributed PV.

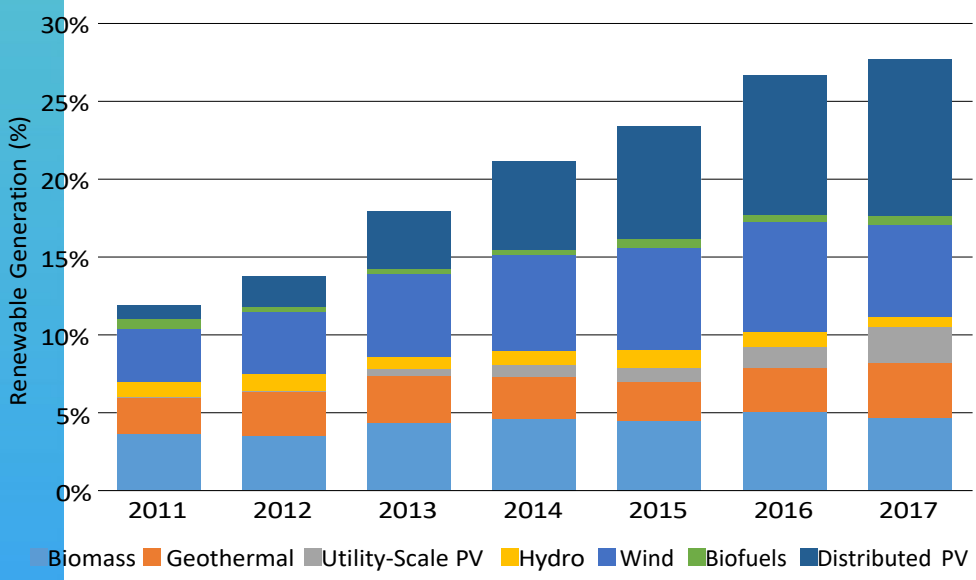

Figure 2: Renewable Generation in Hawaii[5]

2 EIA. *What is U.S. electricity generation by energy source?* https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

3 EIA. *Average Price of Electricity to Ultimate Customers by End-Use Sector, by State, 2017 and 2016.* https://www.eia.gov/electricity/annual/html/epa_02_10.html

4 EIA. *Hawaii Electricity Profile 2017.* https://www.eia.gov/electricity/state/hawaii/

5 Based on data from Hawaii State Energy Office. http://energy.hawaii.gov/renewable-energy

In an attempt to reduce the state's dependence on relatively high-cost imported fuels, in 2015, Hawaii established a renewable portfolio standard (RPS) of 100% of net electricity sales by December 31, 2045,[6] becoming the first state to implement a legislative goal of 100% renewable electricity. The electric utilities in Hawaii have made progress towards this goal—as of 2017, the state utilities[7] and customer-sited grid-connected systems generated more than 27% of Hawaii's electricity from renewable generation, with HECO near 21%, MECO more than 34%, HELCO nearing 57%, and KIUC more than 44%.[8]

SUMMARY OF PROPOSED SOLAR-PLUS-STORAGE PROJECTS

To continue working toward the goal of 100% renewable energy, in October 2017 the Hawaiian Electric Companies (HECO, MECO, and HELCO) began a request for proposals (RFP) process for "variable renewable dispatchable generation" seeking the capability to provide up to 485,000 MWh/year for Oahu, 270,000 MWh/year for Maui, and 95,000 MWh/year for Hawaii Island. The RFP was technology agnostic and allowed for proposals both with or without battery energy storage systems (BESS). Projects that did include BESS were required to provide "a storage capacity of not less than the greatest amount of projected energy during the facility's projected most productive continuous four-hour period during the year".[9] Furthermore, for all projects, it was stated that the PPAs would be structured under the Hawaiian Electric Companies' recently-developed Renewable Dispatchable Generation (RDG) PPA structure, which treats variable resources such as solar and wind as dispatchable and allows the utility to control dispatch of the plant.

After a thorough evaluation of proposed projects based on both price-related and non-price-related criteria,[10] at the end of 2018 the Hawaiian Electric Companies proposed seven projects to the Hawaii Public Utilities Commission (PUC). All of the projects are solar PV plants that include BESS sized at an equal ac power capacity rating with four-hour duration. The chart below summarizes the seven projects proposed for development to the Hawaii PUC:

Project Name	Island	Developer	Solar PV Capacity	Storage Energy Capacity	PPA Unit Price ($/kWh)
Waikoloa Solar	Hawaii	AES	30 MWac	120 MWh	$0.08
Hale Kuawehi	Hawaii	Innergex	30 MWac	120 MWh	$0.09
Kuihelani Solar	Maui	AES	60 MWac	240 MWh	$0.08
Paeahu Solar	Maui	Innergex	15 MWac	60 MWh	$0.12
Hoohana	Oahu	174 Power Global	52 MWac	208 MWh	$0.10
Mililani I Solar	Oahu	Clearway	39 MWac	156 MWh	$0.09
Waiawa Solar	Oahu	Clearway	36 MWac	144 MWh	$0.10

These PPA prices in the 8 to 12 cents/kWh range are higher than recent solar-plus-storage announcements in Arizona and Nevada, which were in the range of 3.1-4.5 cents/kWh. There may be several reasons for this, such as the difference in the ratio of solar capacity to storage capacity, as well as differences in PPA terms, business models, and solar resource. The lower PPA prices in Arizona and Nevada are associated with plants with an approximate 4:1 solar-to-storage ratio, while the Hawaii plants have a 1:1 ratio, as mentioned above. See the recently published *Quick Insights: Declining PPA Prices for Renewables plus Storage Plants* for more discussion about this and other trends in solar plus storage PPA prices.[11]

6 Hawaii State Legislature, HB 623. https://www.capitol.hawaii.gov/session2015/bills/HB623_CD1_.htm

7 Two primary electric utilities service the state: Kauai Island Utility Cooperative (KIUC) and Hawaiian Electric Industries Inc. (HEI). HEI includes Hawaiian Electric Company, Inc. (HECO), which serves Oahu; Maui Electric Company, Limited (MECO), which serves Maui, Molokai, and Lanai; and Hawaii Electric Light Company, Inc. (HELCO), which serves Hawaii Island. (Hawaii State Energy Office, *Hawaii Energy Facts & Figures*, June 2018. https://energy.hawaii.gov/wp-content/uploads/2018/06/HSEO_2018_EnergyFactsFigures.pdf).

8 Hawaii State Energy Office. http://energy.hawaii.gov/renewable-energy

9 RFP for Variable Renewable Dispatchable Generation on the island of Oahu; RFP for Variable Renewable Dispatchable Generation on the island of Hawaii; RFP for Variable Renewable Dispatchable Generation on the island of Maui. https://www.hawaiianelectric.com/clean-energy-hawaii/selling-power-to-the-utility/competitive-bidding-for-new-generation

10 See Appendix L of above RFPs for Selection Criteria details.

11 *Quick Insights: Declining PPA Prices for Renewables plus Storage Plants*. EPRI, Palo Alto, CA: 2019. 3002014791.

The proposed projects are projected to result in a considerable decrease in petroleum and coal consumption over the length of the PPAs and to increase the companies' aggregate contribution towards the RPS by nearly 8 percentage points. Based on a review of the dockets[12] submitted to the Hawaii PUC, the following table summarizes these estimated impacts:

Project Name	PPA Term (years)	Contribution towards Individual Utility's RPS	Contribution towards Consolidated Utilities' RPS	Liquid Fuel Savings[13] (barrels over PPA term)	Coal Savings (tons over PPA term)	Greenhouse Gas Savings (tons over PPA term)
Waikoloa Solar	25	7.1%	0.8%	551,086	N/A	185,258
Hale Kuawehi	25	7.7%	0.8%	497,126	N/A	180,500
Kuihelani Solar	25	14.6%	1.9%	1,987,751	N/A	931,400
Paeahu Solar	25	3.9%	0.5%	597,761	N/A	279,194
Hoohana	20	1.9%	1.4%	1,555,687	465	747,601
Mililani I Solar	20	1.7%	1.2%	914,644	654	432,341
Waiawa Solar	20	1.6%	1.2%	1,084,388	29	517,436

SOLAR AND STORAGE SYSTEM DESIGN ELEMENTS

Based on the submittal to the Hawaii PUC, these solar-plus-storage plants are all based on single-axis tracking PV and lithium ion batteries. All of the power used to charge the BESS is required to come from the solar panels such that the facilities will never draw power from the grid to charge the storage. This allows the plants, which all have a commercial operation date before December 31, 2022, to apply the full federal investment tax credit (ITC) for solar to the BESS as well, with the intention that they can begin construction in 2019, enabling safe harbor of the 2019 ITC.

In their filings with the Hawaii PUC, the Hawaiian Electric Companies explicitly state that two of the solar plants will be dc-coupled with their co-located storage; it is not clear in the dockets whether the other projects have the same design. By connecting the solar panels to the batteries on the dc side of the inverters, some costs are saved because the number and overall capacity of the inverters is reduced and the storage can charge from the solar generation more efficiently.

DC-coupling storage and solar may increase the optimal dc-to-ac ratio of the solar plant, which is the ratio of the rated dc power of the solar panels to the rated ac power of the inverters. For plants with a dc-to-ac ratio greater than one that do not include storage, during times of high solar irradiance the inverter produces at its nameplate ac rating and foregoes some amount of dc power, known as "clipping." With dc-coupled storage, the battery is able to absorb the power that would be "clipped." Therefore, it may be beneficial in some cases to further oversize the dc collector field to increase the amount of time the battery charges from the would-be "clipped" power, in order to produce more ac power, reduce power variability, and/or be ready to provide grid support as needed. In the two dc-coupled cases, the dc-to-ac ratio is 1.5 (i.e., the dc rating the of the PV panels is 50% larger than the ac rating of the plant inverters). This is higher than for typical solar-only plants, which in 2016 was about 1.3.[14]

Under the RDG PPA arrangement, the utilities dictate when the storage systems are charged and discharged, allowing them to use the storage systems in the manner optimal for the grid. However, the storage systems are limited to one full cycle per day and, in one case, the storage must be kept at a low average state of charge (<40% when resting), presumably to preserve the health of the batteries over time. These requirements fit well with the proposed use cases for the storage, which mostly involve shifting daytime solar generation a few hours later to the afternoon/evening load peak. In addition to shifting energy in time, the PPAs specify that the storage systems will also be used to provide the following services:

12 Dockets 2018-0430, 2018-0431, 2018-0432, 2018-0433, 2018-0434, 2018-0435, and 2018-0436, https://dms.puc.hawaii.gov/dms/dockets?action=loadByYear#

13 Liquid Fuel Savings includes low-sulfur fuel oil, medium-sulfur fuel oil, diesel fuel, ultra-low sulfur diesel, biodiesel, and naphtha, depending on the island that the plant is being built on.

14 M. Bolinger, et al. *Utility-Scale Solar 2016: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/utility-scale_solar_2016_report.pdf

- Frequency response
- Reactive power voltage regulation
- Solar ramp rate control
- Synthetic inertia
- Other power quality services

These storage systems will be used to provide frequency response in both directions. When the frequency of the island's grid drops below a set point, the storage will increase its power output to help restore the frequency, as long as it has enough stored energy to do so and without violating the maximum power output limit of the entire facility. When the grid frequency gets too high, the storage will reduce its power output and, if the solar panels are generating power at that time, charge from the solar, lowering the facility's net power output.

All of the plants, regardless of size, specify that their storage systems will control the ramp rate of the facility as a whole to 2 MW/minute except for when actively responding to a frequency response event. This is intended to mitigate problems that could arise from a sudden drop in solar generation due to a passing cloud, for example. As the islands' grids accept increasing amounts of intermittent renewable generation toward their 100% target, this will become an important part of maintaining stability and power quality.

The details of the synthetic inertia provided by the facilities will be determined based on forthcoming interconnection requirements studies.

RDG PPA DESIGN

Under existing "as-available" PPA structures in Hawaii, energy is accepted and curtailed based on the seniority of the renewable plants, limiting the ability of the utility to dispatch the plants according to optimal grid performance. The RDG PPA structure used for these proposed projects is a new and innovative contracting mechanism developed by the Hawaiian Electric Companies that intends to allow them to integrate more renewable energy, provide flexibility, and address financing risks previously associated with curtailment. The RDG PPA payments are structured as a monthly lump sum payment to the project owner regardless of the actual energy dispatched from the plant; in turn, the utility has the ability to dispatch both the solar and the storage as needed for system operations. The PPA prices reported above by the Hawaiian Electric Companies are a "unit price" based on the lump sum payment divided by the net energy potential, or expected output, of the plant.

To guarantee that the plant is properly maintained and available for production when called upon, there are several performance metrics that the facility must meet to receive the full lump sum payment amount. If these are not met, then liquidated damages will be assessed against the plant and the payment will be reduced. These metrics are specified in detail in the PPAs[15] and include:

- the Equivalent Availability Factor performance metric, which evaluates the availability of the PV system for dispatch by the utility;
- the Guaranteed Performance Ratio performance metric, which evaluates the efficiency of the PV system;
- the BESS Capacity performance metric, which confirms the capability of the BESS to discharge as required by the terms of the PPA;
- the BESS Equivalent Availability Factor performance metric, which determines whether the BESS is meeting its expected availability; and
- the BESS Equivalent Forced Outage Factor performance metric, which evaluates whether the BESS is experiencing excessive unplanned outages.

15 Dockets 2018-0430, 2018-0431, 2018-0432, 2018-0433, 2018-0434, 2018-0435, and 2018-0436, https://dms.puc.hawaii.gov/dms/dockets?action=loadByYear#

The implementation of the RDG PPA mechanism allows the utility to more effectively integrate the plants in their system operations, while removing the financial risks to the plant owner that might be associated with curtailment in an energy-only PPA structure. According to the dockets filed with the PUC, the resulting PPAs of 8–12 cents/kWh are among the lowest ever procured in the State of Hawaii, with six of the seven coming in as the lowest to date for renewable electricity. This compares to the 15 cents/kWh current cost of fossil fuel generation in Hawaii.[16] The PPA prices are fixed for the duration of the PPA term and anticipated to result in lower effective rates for customers as they displace more expensive petroleum-fired plants and decrease the utilities' exposure to fuel price volatility.

IMPLICATIONS

Each of the solar-plus-storage plants is expected to reduce the cost of providing electricity to customers by displacing the need for the existing primarily oil generation while also offsetting the need for some future investment relative to Hawaii's Power Supply Improvement Plan,[17] which will bring the state closer to its 100% RPS target. In each project docket, the customer bill impact was analyzed for the proposed project and, while these depend on modeling assumptions and system conditions over the life of the project, each project showed a reduction in a typical residential customer's monthly 500-kWh bill, ranging from $0.91 to $13.01, depending on the system and the year analyzed.[18]

The relatively low PPA prices (relative to other sources on the islands), despite the large amount of flexible battery energy storage, indicate that solar plus storage could be a major component of Hawaii's grids going forward. However, these solar-plus-storage plants are still subject to the day-to-day and seasonal variability in solar generation that applies to solar-only plants, though to a lesser degree for those with a larger dc-to-ac ratio. Four hours of storage duration, while greatly increasing the operational flexibility of the solar plants, is not enough to completely smooth out generation and guarantee energy when it is needed. A broader mix of supply- and demand-side technologies that will continue to evolve is likely required to most economically achieve Hawaii's 100% renewable energy goal.

Furthermore, it is due in part to the relatively high electricity prices seen in Hawaii that these PPA prices are expected to result in savings for customers. In parts of the world with significantly lower electricity prices, the impact would likely be different. However, the experience gained from these large-scale solar-plus-storage projects, as well as the implementation of a new and innovative PPA structure, are likely to carry into other projects throughout the U.S. and globally as the cost of solar and storage technologies continue to decrease.

NEXT STEPS/ONGOING EPRI RESEARCH

EPRI continues to conduct research on solar plant and storage system designs and integration, and investigate the economics of emerging technical design options. Much of this research is highlighted in the recently published *Quick Insights: Declining PPA Prices for Renewables plus Storage Plants*.[19] Some specific examples include:

Integrated Grid: Energy Storage and Distributed Generation (EPRI Program 94)

- Development of Storage Value Estimation Tool (StorageVET[20]) and *Energy Storage Valuation 2017* report[21] with the ability to run scenarios to simulate and optimize customized renewable-plus-storage projects in support of economic evaluations.

16 Hawaiian Electric Company. *New solar-plus-storage projects set low-price benchmark for renewable energy in Hawaii: Seven contracts submitted to regulators for review*. January 3, 2019. https://www.hawaiianelectric.com/new-solar-plus-storage-projects-set-low-price-benchmark-for-renewable-energy-in-hawaii

17 Hawaiian Electric Company. *Integrated Grid Planning*. https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning. December 23, 2016.

18 Dockets 2018-0430, 2018-0431, 2018-0432, 2018-0433, 2018-0434, 2018-0435, and 2018-0436, https://dms.puc.hawaii.gov/dms/dockets?action=loadByYear#

19 *Quick Insights: Declining PPA Prices for Renewables plus Storage Plants.* EPRI, Palo Alto, CA: 2019. 3002014791.

20 https://www.storagevet.com/

21 *Energy Storage Valuation 2017: Update on Methods, Interim Results, and StorageVET*. EPRI, Palo Alto, CA: 2017. 3002010849.

- Engagement with utilities, energy storage developers, and the research community to develop common valuation metrics through the Energy Storage Integration Council (ESIC).

Generation Sector: Renewables Technology (Program 193)

- Analysis of the cost and value of utility-scale PV-and-storage projects and some of the tradeoffs among three configuration strategies: independent, AC-coupled, and DC-coupled.
- Evaluation of the "PV Plant of Tomorrow," including the increased likelihood of integration of storage with solar PV plants as variable renewable penetration increases.
- Analysis of trends in renewable energy technologies, such as *Renewables Insights: The Impact of Solar Photovoltaics (PV) DC:AC Ratio* (3002014245) and *Renewables Insights: Examination of Nevada Power Company's Record Low Solar and Solar + Storage PPA Announcement* (3002014458).

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