Utility Scale Storage Applications
The Hawaii Experience

GridSTART

Grid System Technologies Advanced Research Team

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HNEI

University of Hawai'i Mānoa

Utility-Scale Storage: If, When, What Type, How Much, and Where?

Asia Clean Energy Forum

June 5, 2018
Manila, Philippines

Hawaii Natural Energy Institute (HNEI)

University of Hawaiʻi at Mānoa

Organized Research Unit in School of Ocean and Earth Science and Technology
Founded in 1974, established in Hawaiʻi statute in 2007 (HRS304A-1891)

- Conduct RDT&E to accelerate and facilitate the use of resilient alternative energy technologies; and to reduce Hawaii's dependence on fossil fuels.
- Diverse staff includes engineers, scientists, lawyers; students and postdoctoral fellows; visiting scholars

Areas of Interest

- **Policy and Innovation**
- **Grid Integration (**Grid***START*****)**
- **Alternative Fuels**
- **Electrochemical Power Systems**
- **Renewable Power Generation**
- **Building Efficiency**
- **Transportation**

Core Functions

- **State Energy Policy Support**
- **Research & Development**
- **Testing and Evaluation**
- **Analysis**
- **Workforce Development**

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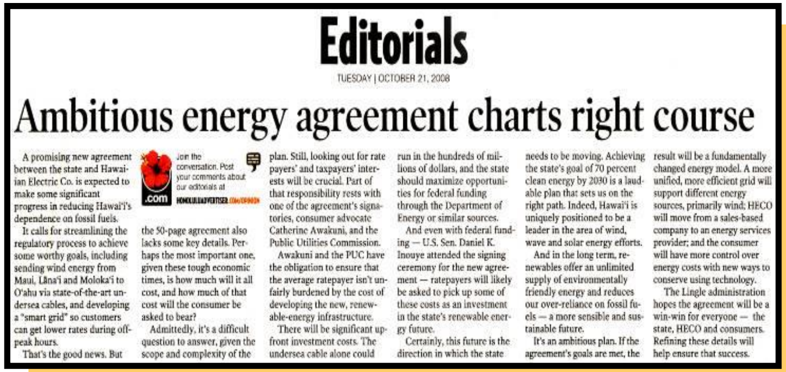
Grid System Technologies Advanced Research Team

Established to develop and test advanced grid architectures, new technologies and methods for effective integration of renewable energy resources, power system optimization and enabling policies.

- Serves to integrate into the operating power grid other HNEI technology areas: biomass and biofuels, fuel cells and hydrogen, energy efficiency, renewable power generation
- Strong and growing partnerships with national and international organizations including Asia-Pacific nations.

Lead for many public-private demonstration projects

Hawaii's Progressive Leadership in Clean Energy Policy



Editorials

TUESDAY | OCTOBER 21, 2008

Ambitious energy agreement charts right course

A promising new agreement between the state and Hawaiian Electric Co. is expected to make some significant progress in reducing Hawai'i's dependence on fossil fuels.

It calls for streamlining the regulatory process to achieve some worthy goals, including sending wind energy from Maui, Lāna'i and Moloka'i to O'ahu via state-of-the-art undersea cables, and developing a "smart grid" so customers can get lower rates during off-peak hours.

That's the good news. But the 50-page agreement also lacks some key details. Perhaps the most important one, given these tough economic times, is how much will it all cost, and how much of that cost will the consumer be asked to bear?

Admittedly, it's a difficult question to answer, given the scope and complexity of the plan. Still, looking out for ratepayers' and taxpayers' interests will be crucial. Part of that responsibility rests with one of the agreement's signatories, consumer advocate Catherine Awakuni, and the Public Utilities Commission.

Awakuni and the PUC have the obligation to ensure that the average ratepayer isn't unfairly burdened by the cost of developing the new, renewable-energy infrastructure.

There will be significant upfront investment costs. The undersea cable alone could run in the hundreds of millions of dollars, and the state should maximize opportunities for federal funding through the Department of Energy or similar sources.

And even with federal funding — U.S. Sen. Daniel K. Inouye attended the signing ceremony for the new agreement — ratepayers will likely be asked to pick up some of these costs as an investment in the state's renewable energy future.

Certainly, this future is the direction in which the state needs to be moving. Achieving the state's goal of 70 percent clean energy by 2030 is a laudable plan that sets us on the right path. Indeed, Hawai'i is uniquely positioned to be a leader in the area of wind, wave and solar energy efforts.

And in the long term, renewables offer an unlimited supply of environmentally friendly energy and reduces our over-reliance on fossil fuels — a more sensible and sustainable future.

It's an ambitious plan. If the agreement's goals are met, the result will be a fundamentally changed energy model. A more unified, more efficient grid will support different energy sources, primarily wind; HECO will move from a sales-based company to an energy services provider; and the consumer will have more control over energy costs with new ways to conserve using technology.

The Lingle administration hopes the agreement will be a win-win for everyone — the state, HECO and consumers. Refining these details will help ensure that success.

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Hawai'i Clean Energy Initiative

Hawaii Clean Energy Initiative (HCEI)

The State of Hawaii, US DOE, and local utility launched HCEI in January 2008 to transform Hawaii to a 70% clean energy economy by 2030:

- *Increasing Hawaii's economic and energy security*
- *Fostering and demonstrating Hawaii's innovation*
- *Developing Hawaii's workforce of the future*
- *Becoming a clean energy model for the U.S. and the world*

Strong Hawaii Policies

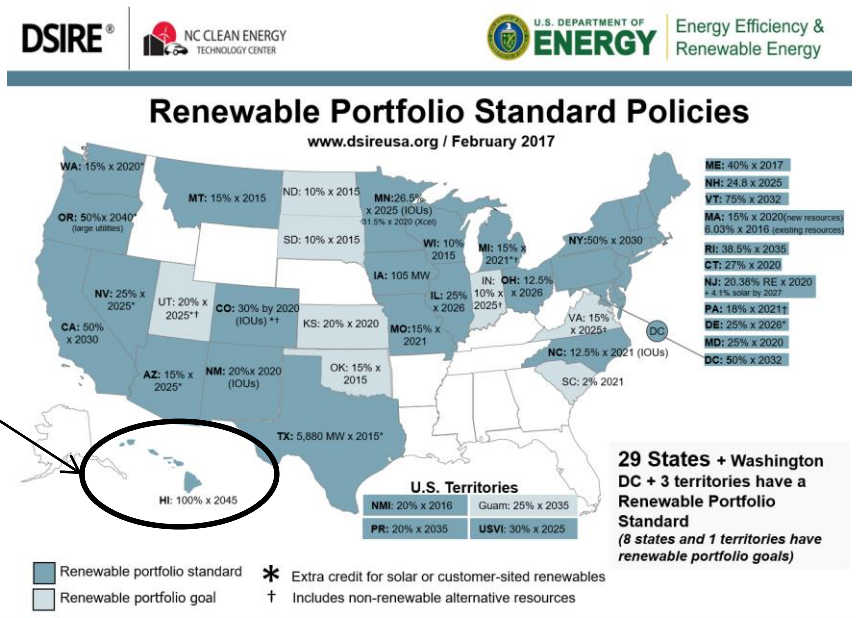
Highest RPS Target in the United States

100% by 2045

(2015 - 15%; 2020 - 30%, 2030 – 40%, 2040 – 70%)

Other key policies:

- **Tax incentives**
- **Net metering**
- **Feed in tariffs**
- **Decoupling**



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Hawai‘i Electric Systems –

4 Electric Utilities; 6 Separate Grids; % Renewable Energy

<u>Kaua‘i Island Utility Cooperative</u>

<u>System Peak: 78 MW</u>

65.6 MW PV / 7 MW Biomass / 9 MW Hydro

Installed PV: 84% of System Peak

41.7% RE in 2016

<u>Maui Electric</u>

<u>Maui System Peak: 202 MW</u>

102 MW PV / 72 MW Wind

Installed PV & Wind:

86% of Sys. Peak

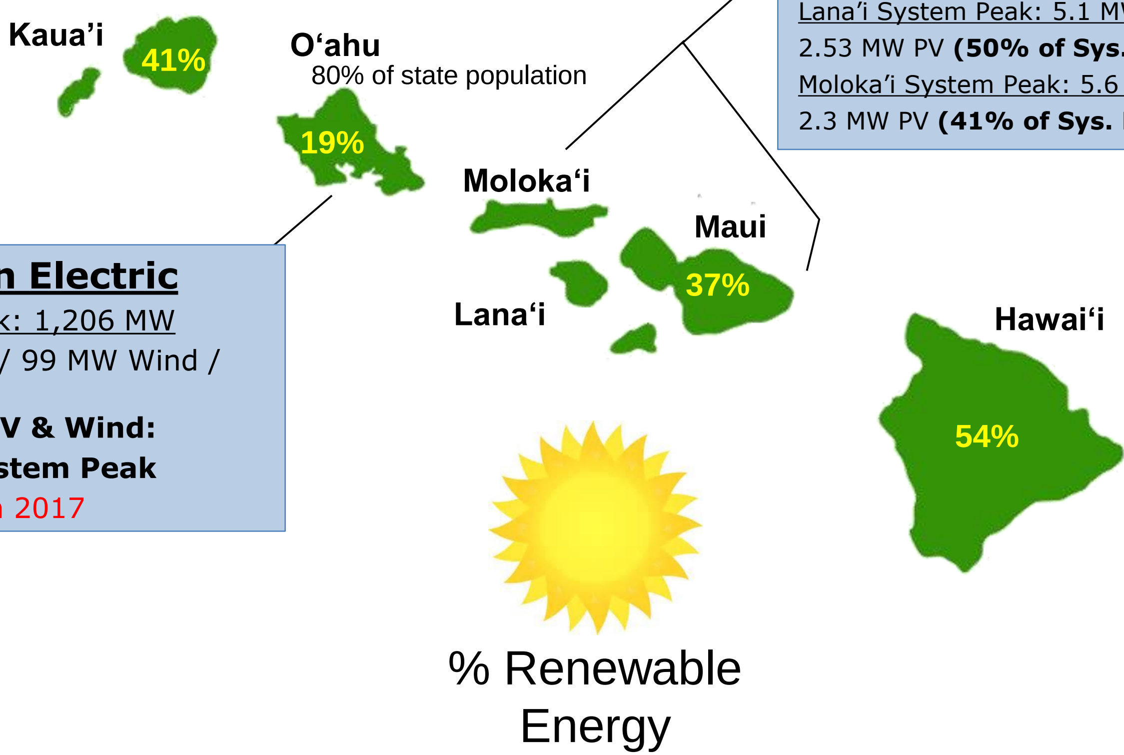
34.2% RE in 2017

<u>Lana‘i System Peak: 5.1 MW</u>

2.53 MW PV **(50% of Sys. Peak)**

<u>Moloka‘i System Peak: 5.6 MW</u>

2.3 MW PV **(41% of Sys. Peak)**



<u>Hawaiian Electric</u>

<u>System Peak: 1,206 MW</u>

512 MW PV / 99 MW Wind / 69 MW WTE

Installed PV & Wind:

50% of System Peak

20.8% RE in 2017

<u>Hawaii Electric Light</u>

<u>System Peak: 192 MW</u>

92 MW PV / 30 MW Wind / 38 MW Geothermal / 16 MW Hydro

Installed PV & Wind:

64% of System Peak

56.6% RE in 2017

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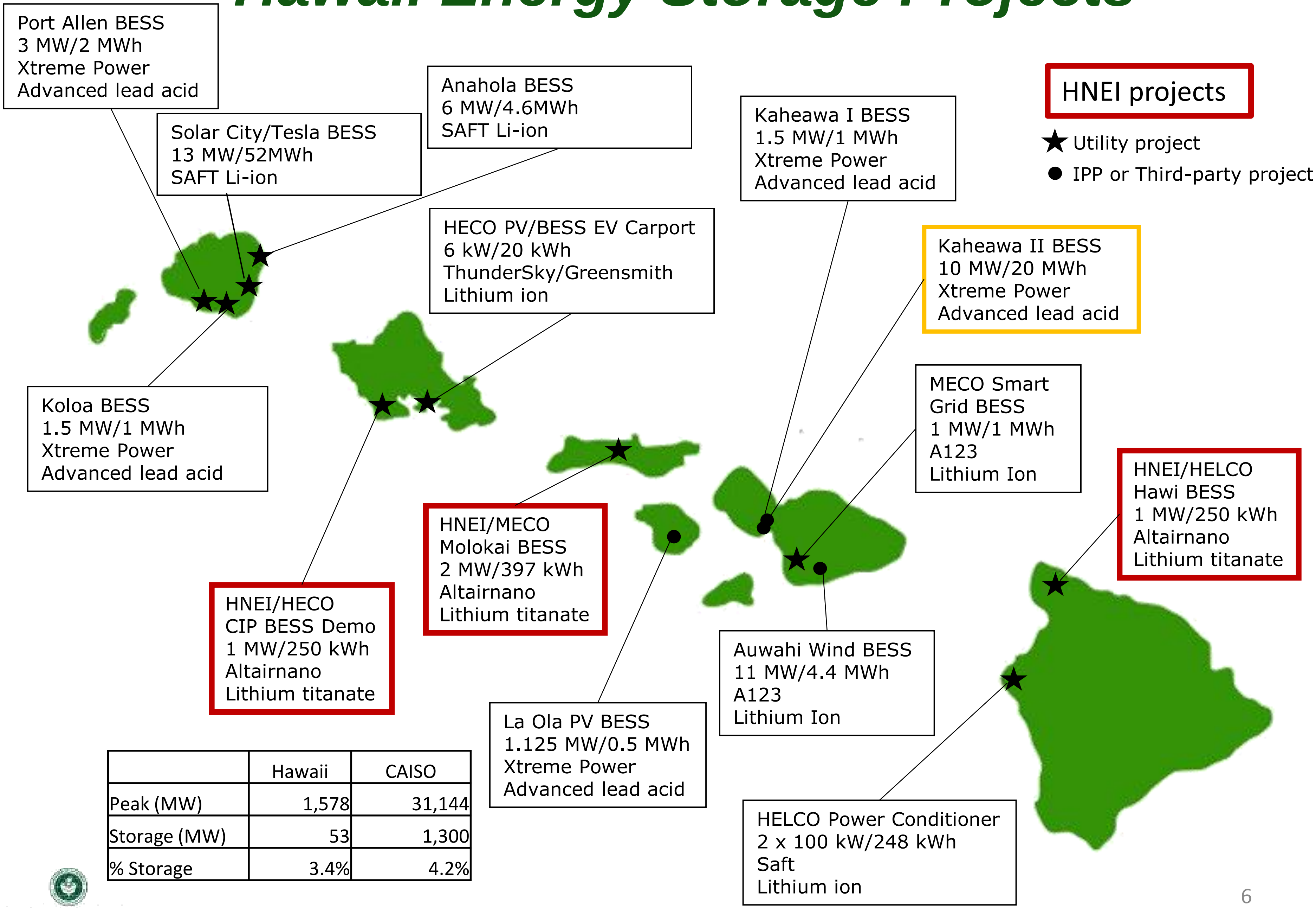
Hawaii Energy Storage Projects



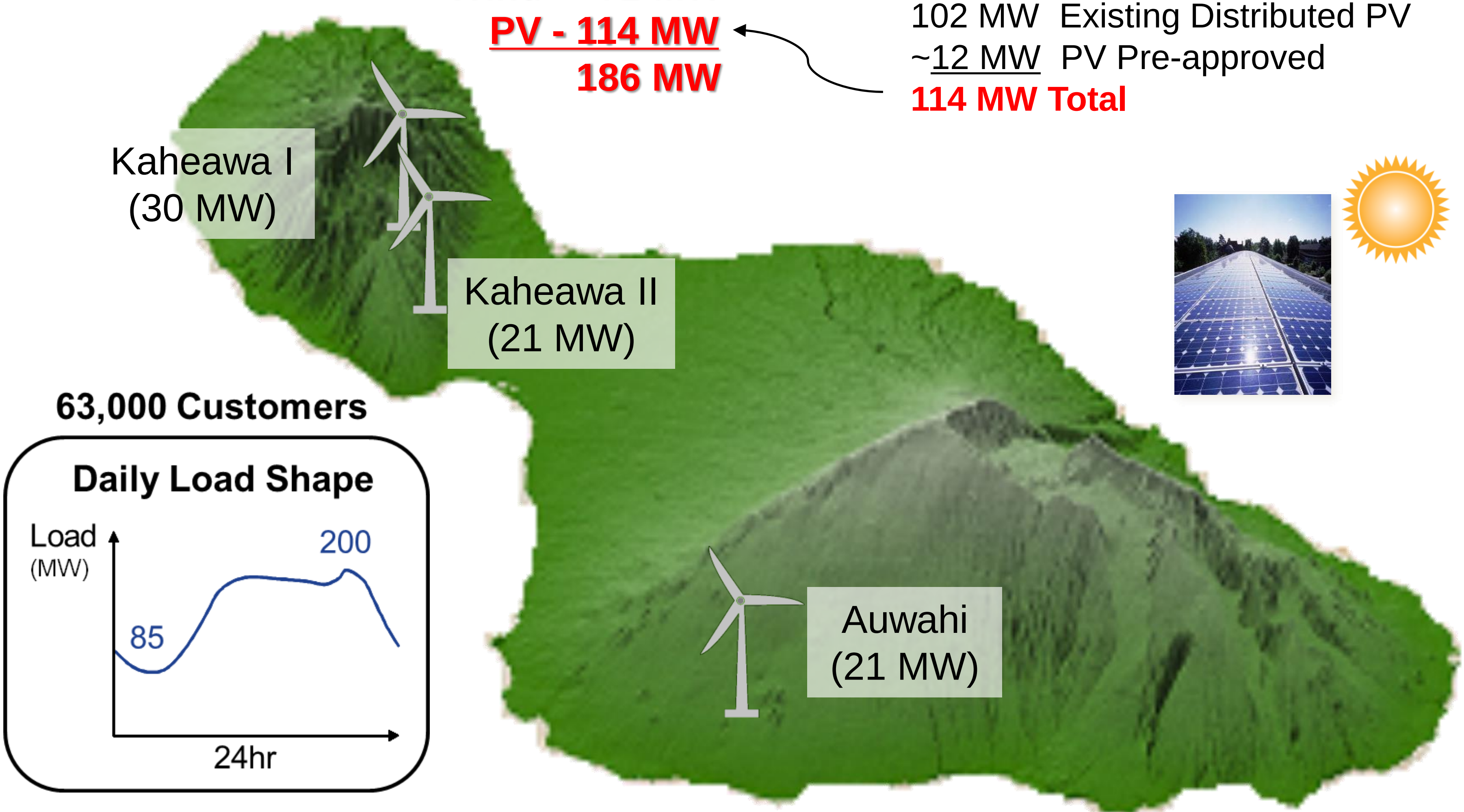
	Hawaii	CAISO
Peak (MW)	1,578	31,144
Storage (MW)	53	1,300
% Storage	3.4%	4.2%

Maui Island

Leading the way in Wind and Solar Power

Wind - 72 MW
PV - 114 MW
186 MW

102 MW Existing Distributed PV
~12 MW PV Pre-approved
114 MW Total



Mitigation Measures to Increase Wind Energy Delivered on Maui

Facility	Percent of available energy delivered (% before / % after)	% increase in delivered energy
Plant 1	97% / 99%	2%
Plant 2	72% / 84%	17%
Plant 3	27% / 45%	68%

<u>BESS Function</u>

- 10MW / 20MWh
- Manual and AGC Dispatch
- Aggressive frequency Response
- Ramp Rate Limit within a limited SOC Range

<u>MECO Operations</u>

- Include 10MW of BESS in Up Reserve
- Reduce Down Reserve of M14 & M16 by 1.5MW
- Reduced Operation of K1 and K2
- 50MW Up-Reserve Limit

Higher Power/Limited Energy BESS application to meet grid upward reserve needs was most cost effective

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HNEI/HEI (Hawaii electric utility) BESS Projects

Demonstrate BESS operating strategies for high value grid applications

Hawi BESS

Hawi, Hawaii Island (1MW, 250kWh)

- Modeling showing benefit completed in 2007
- Frequency regulation and wind smoothing
- Rapid and extended cycling

Moloka'i BESS

Molokai Secure Renewable Microgrid (2MW, 375kWh)

- Operating reserves (fault management), frequency regulation,
- Fast response decision and control (<50ms response)

CIP BESS

Campbell Park industrial feeder with high penetration (1MW)

- Power smoothing, voltage and VAr support, and frequency regulation

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Hawaii Island BESS Project

- Island-wide power flow modeling indicated that a 1 MW fast-acting battery could significantly reduce grid frequency variability
- HNEI engaged public and private entities to develop a 1MW BESS on Hawaii Island at the interface between a 10 MW wind farm and the grid
- Commissioned December 2012 with testing initiated in spring 2013

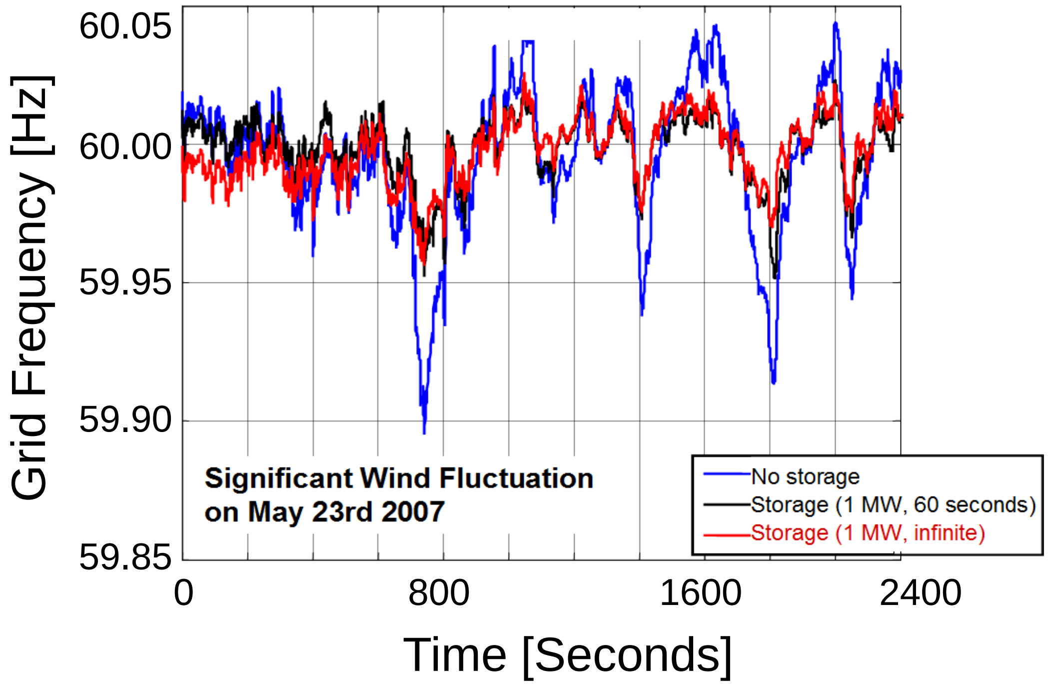

Photo courtesy of Altairnano, Inc.

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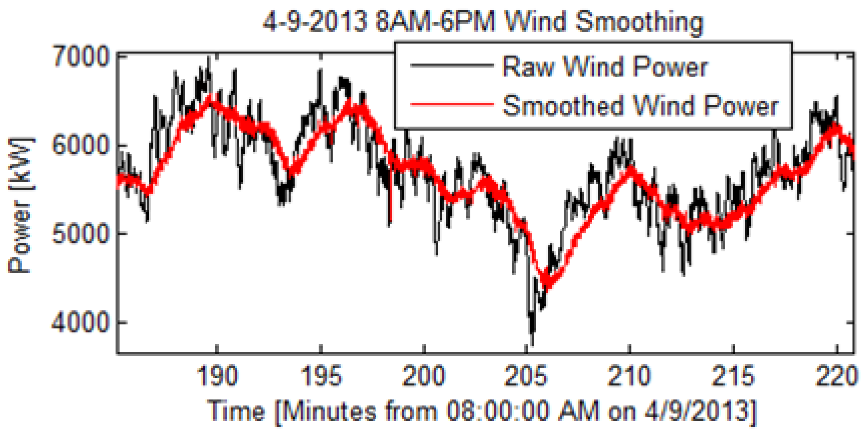
Summary Field Results (Hawaii Island BESS)

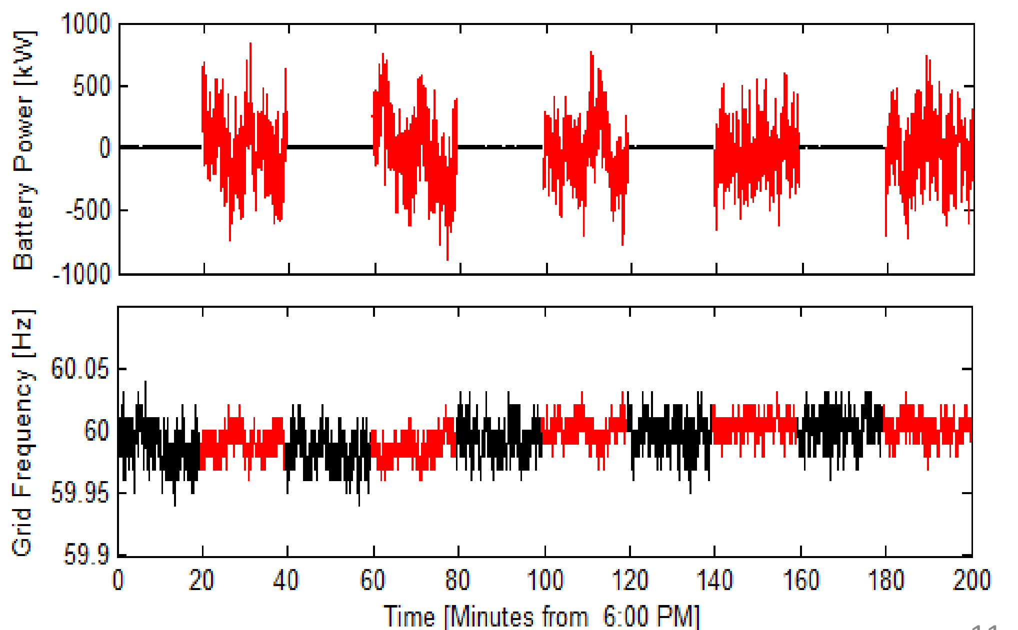


6:00 PM HST 4/9/2015 to 9:20 PM HST 4/9/2015. Max Power = 1000kW, No dead band, Gain = 30MW/Hz

Power smoothing from 10MW Hawi wind farm

Frequency regulation: Up to 40% reduction in ***f*** fluctuation

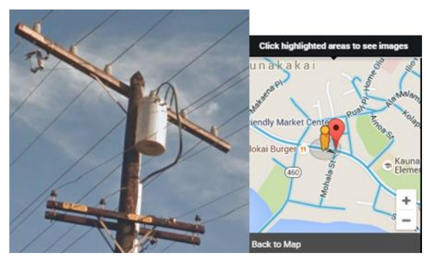
Battery response ~ 250ms

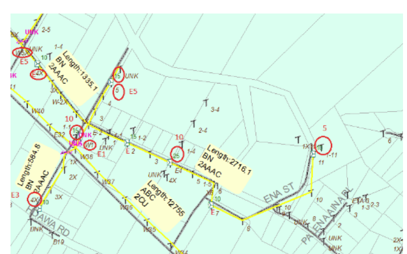


Renewable Moloka'i Initiative

- **100% Renewable Goal by 2020**
- Battery Storage
  - 2MW, 333kW-hr, Li-ion Titanate
- System Data Collection
- Production Modeling
- Load Flow & Midterm Dynamics Modeling
- Dynamic Load Bank
- PV Forecasting
- Island Grid Controller

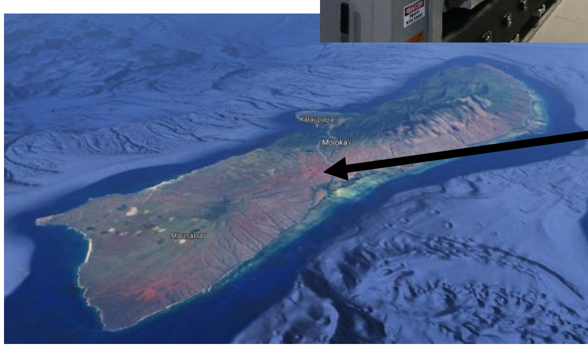
- **Peak Load: 5.4 MW (2013)**
- **Minimum Load: 3 MW (daytime, 2009)**
- **PV Installed: 1.07 MW (with 59.3Hz drop-out)**
- **PV Installed: 1.23 MW (with 57Hz drop-out)**
- **PV Planned: 0.6 MW in que**

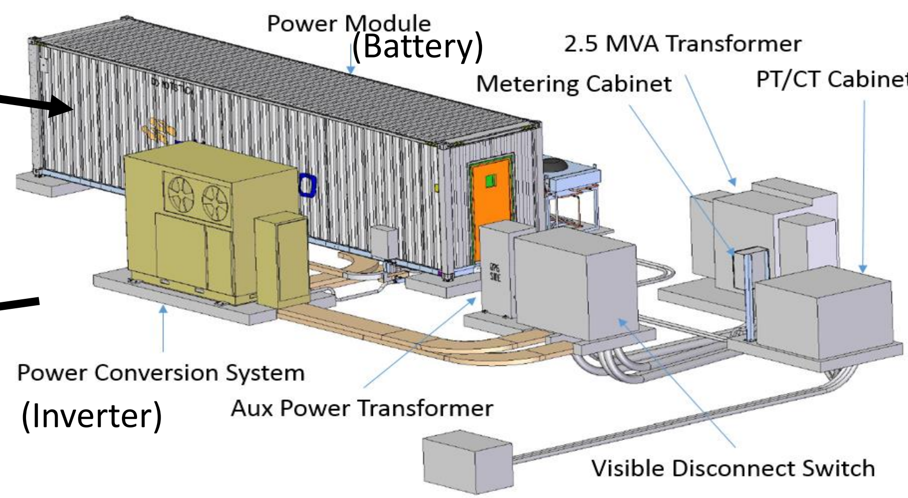




Molokai Grid Stability

- Even relatively small disturbances can trip PV units, increasing automatic load shedding customer outages on the system.
- **Proposed solution** to increase grid reliability: a 2MW fast-acting BESS.
- **The challenge**: standard 250 ms response destabilizing to grid (models)
- **The solution**: re-engineer the way the BESS and the inverter computers collaborate to share computational burden





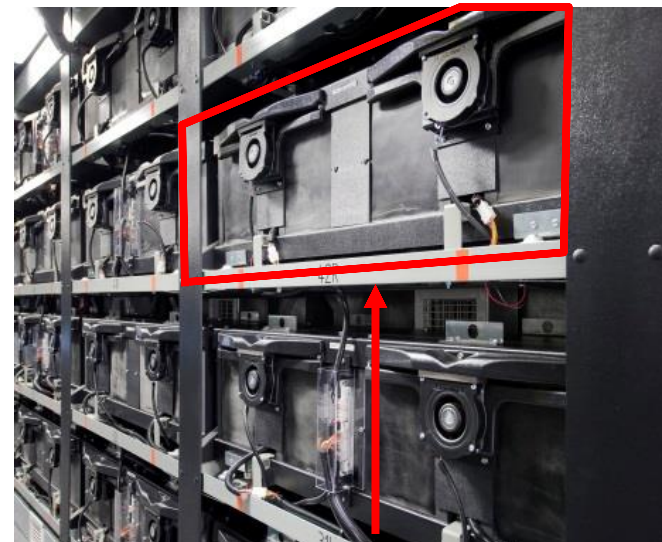
Molokai Island BESS Project

Altairnano Li-ion Titanate

Power Module

Power Conversion System

- Power module produces ± 2 MW
- Capacity of 375 kW-Hr
- Inverter rated > ± 2 MVA
- Over 12,000 full charge / discharge cycles with minimal degradation in cell capacity



Interior View

- Li-Ion Titanate 50 A-Hr Cells
- BESS has 2688 cells in 96 LRU

Designed for rapid charging and discharging

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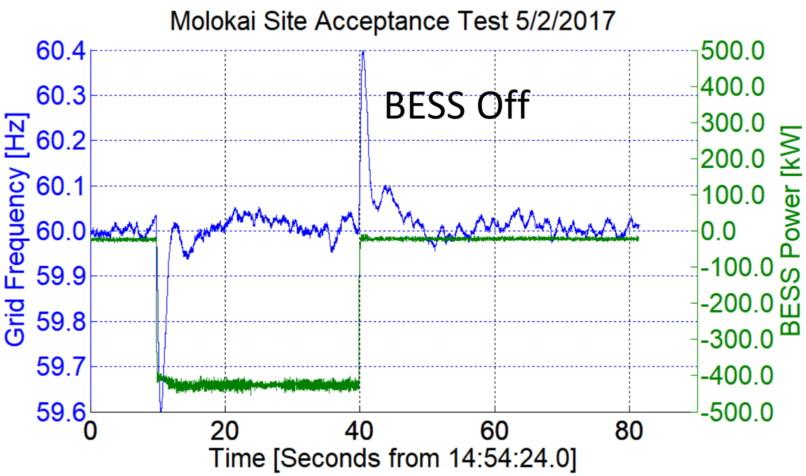
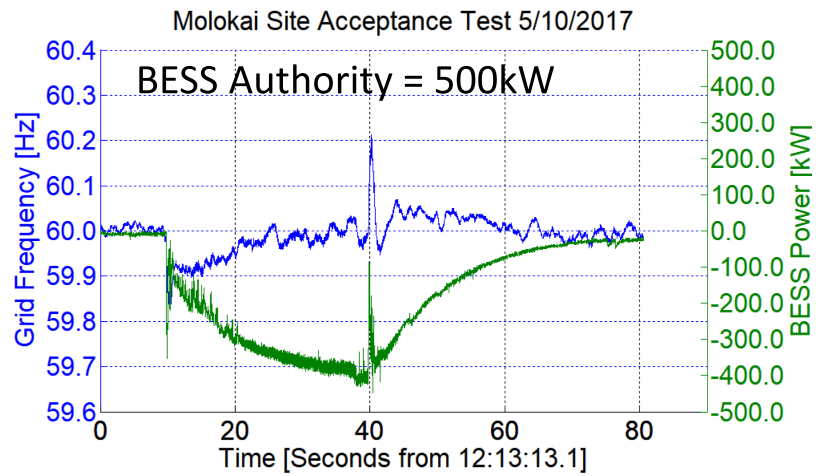
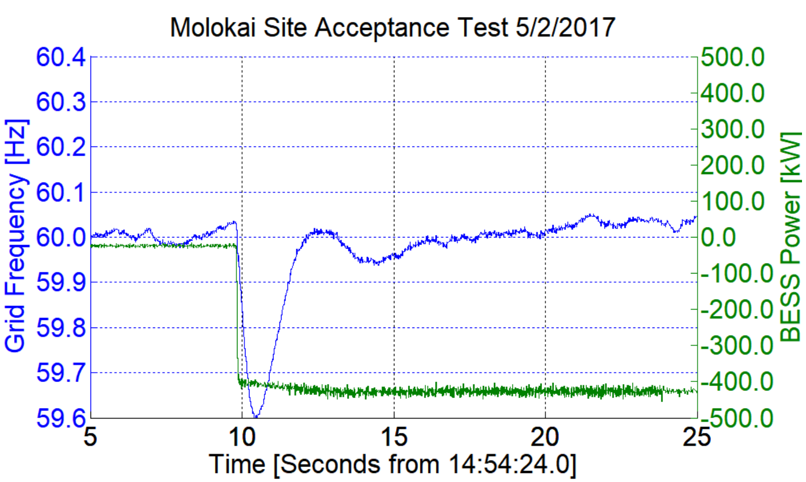
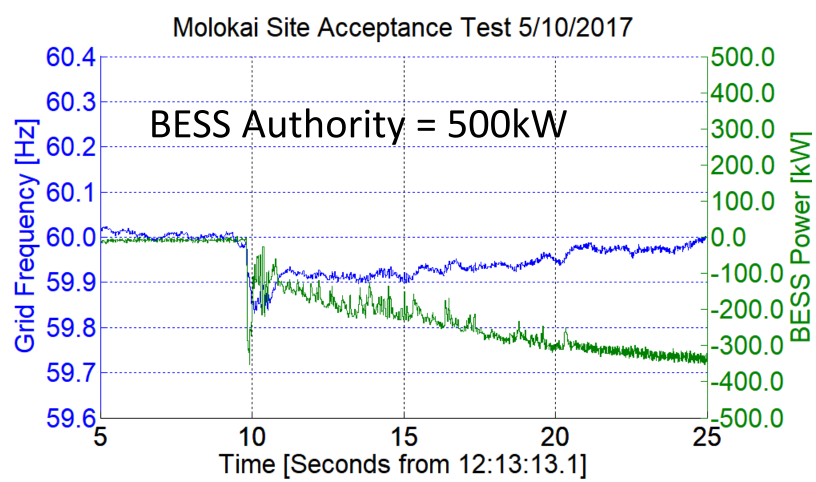
Impact of BESS with 500kW Authority and Fast Response

Expansions (bottom) show Down-Step









500kW fast response showed significant frequency improvement

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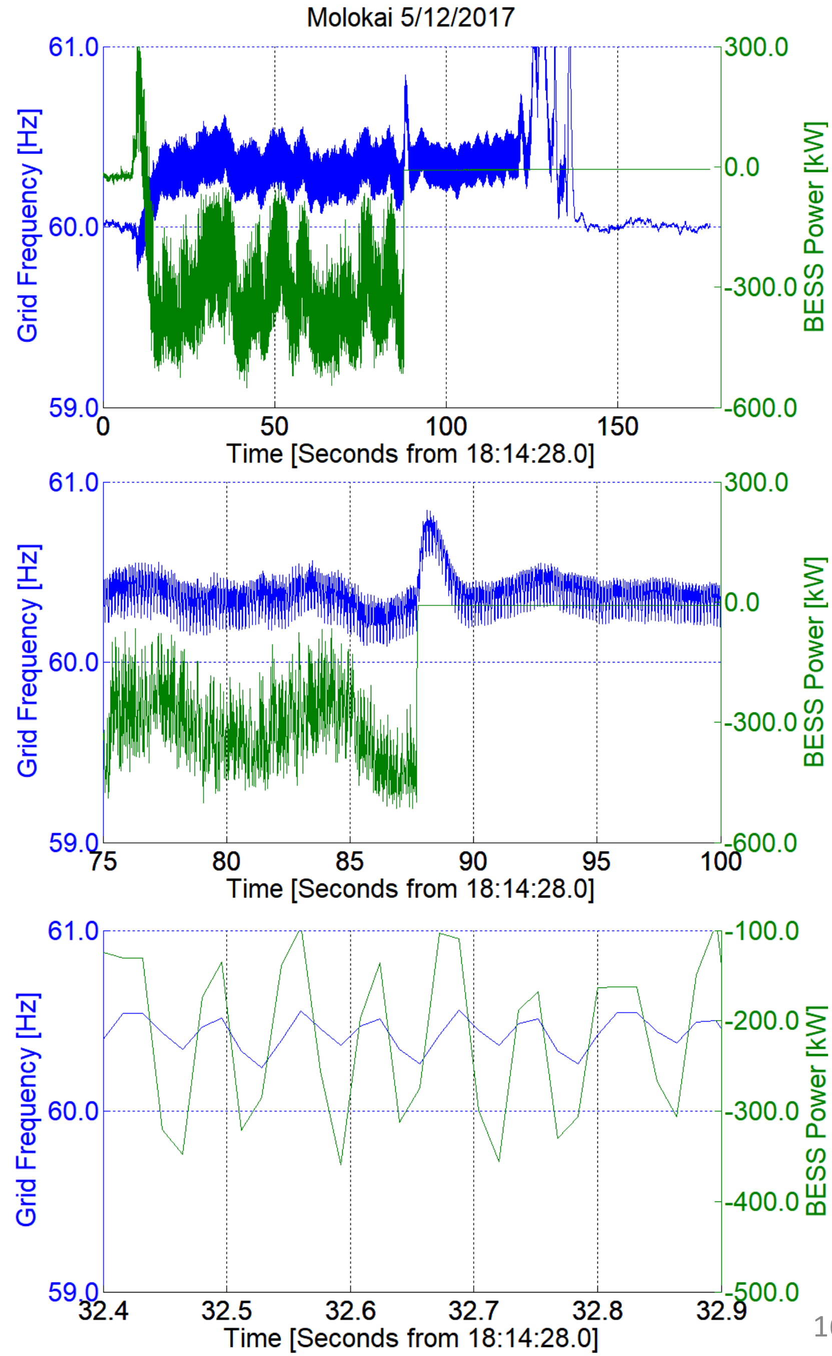
Intermittent Grid Frequency Oscillation

- A grid anomaly of unknown source has occurred 7 times since September 2016.
- In one instance, on May 12th, 2017, the BESS was online with a limit of 500kW.
- Because the oscillation rate was about twice as fast as the response time of the BESS, the oscillations were exacerbated by the BESS.
- Molokai grid operators set the BESS offline around 87 seconds after the oscillations started.
- An oscillation detection subroutine was developed to suppress BESS responses at the onset of oscillations

The real world consequences of the BESS running with a higher authority needs to be better understood.



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Observations Based on HI Experience

- Energy storage is and will be key to meeting RE goals
  - Variety of applications to integrate high levels of variable renewables
- Still a relatively early commercial technology
  - Technical and market risks remain (Kahuku fire and vendor turnover)
  - Still difficult to get standardized pricing
  - Technical performance not always as advertised
  - Battery lifetime/degradation still uncertain
- Rapid industrial scaling of industry underway and will address many of the early stage risks and uncertainties

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HNEI/GE BESS Analyses for Oahu

Objective: Quantify net benefits of various BESS configurations on Oahu System

Assumptions for Two Scenarios Analyzed

	SCEN 1 (Current W&S)	SCEN 2 (50% W&S)
Fuel Price ($/bbl)	$60/bbl WTI = ~$11/MMBtu	
Thermal Resources	Existing Units, No Adds or Retires	
Peak Load (MW)	1,225	1,225
Annual Energy (GWh)	7,734	8,450
Electric Vehicles (GWh)	44	791
Wind & Solar Capacity (MW)	809	1965
Utility-Scale Wind	123	565
Utility-Scale Solar	148	565
Distributed PV	538	840
Available W&S (GWh)	1547	4225
Available W&S (% of Load)	20%	50%

Power and Energy Rating of BESS Considered

Energy (MWh)		Power (MW)			
		25	50	100	200
Storage (Hrs)	0.50	12.5	25	50	100
	1.00	25	50	100	200
	2.00	50	100	200	400
	4.00	100	200	400	800

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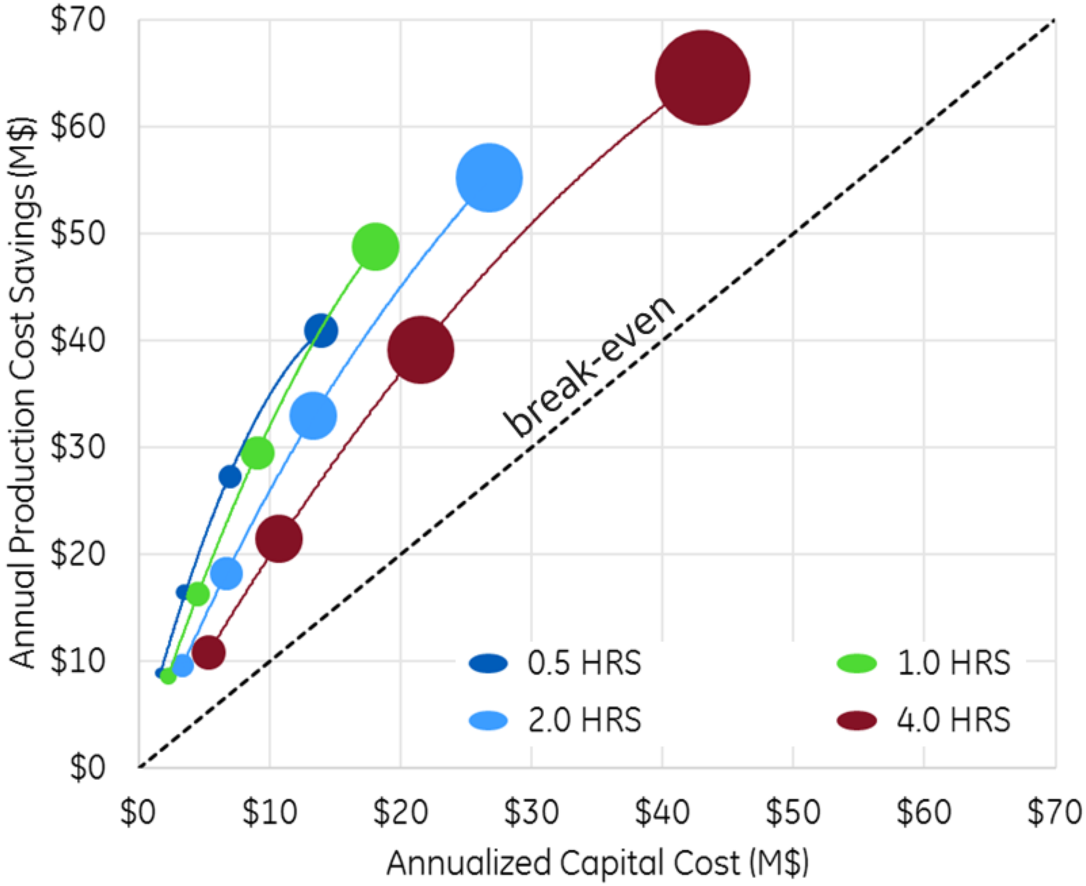
Production Cost Savings vs Annual Capital Cost by Configuration



- Larger Circle – more MWh
- Farther from Line – higher benefit-to-cost ratio
- High Power/Low Energy Configurations most cost effective

Key Findings – Oahu BESS Analysis

- ✓ Operation and control of storage can be co-optimized to provide both reserves and energy arbitrage
- ✓ Charging mostly takes place during mid-day hours, discharge during evening peak, but also some charging during overnight periods and discharging during morning ramp
- ✓ Energy storage will increase generation from wind and solar (decreased curtailment) along with more efficient operation of thermal resources (Kalaeloa CC, AES)
- ✓ Increasing power rating (inverters) is less expensive than increasing energy rating (lithium-ion cells)
- ✓ Economic cost-benefit analysis favors high-power, low-energy ratio storage configurations
- ✓ Energy storage can be economic in some (but not all) configurations with current W&S scenario, and all configurations for 50% wind and solar
- ✓ While this analysis shows that BESS can be an economic addition to Oahu's resource mix, it is ***not*** necessarily the ***most*** economic, other options to analyze and compare: *Demand Response, Increased flexibility in thermal fleet, etc.*

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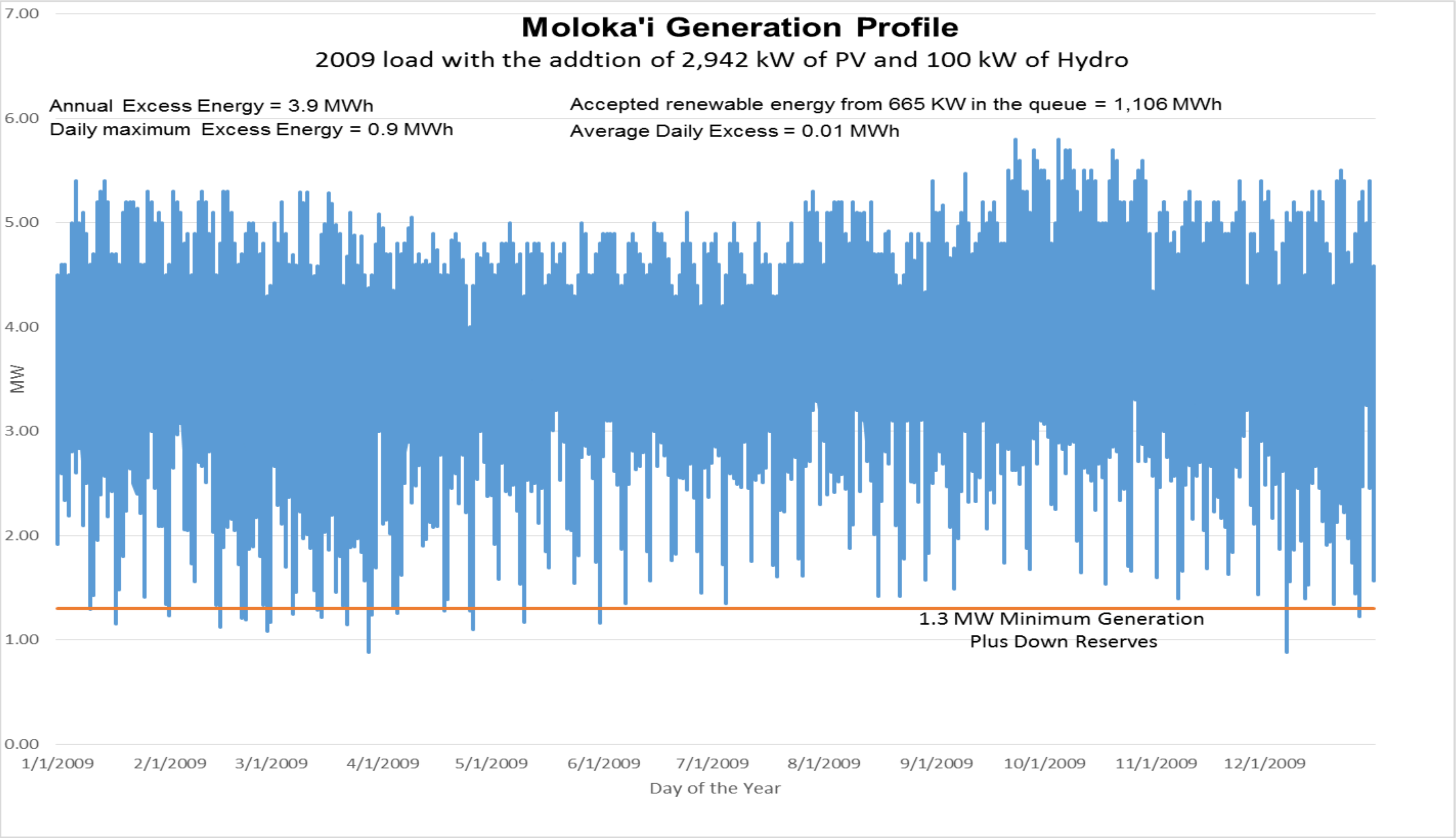
Alternatives to Storage



Small to moderate amount of excess RE curtailment is a sound integration strategy

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Mahalo!

(Thank you)

For more information, contact:

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