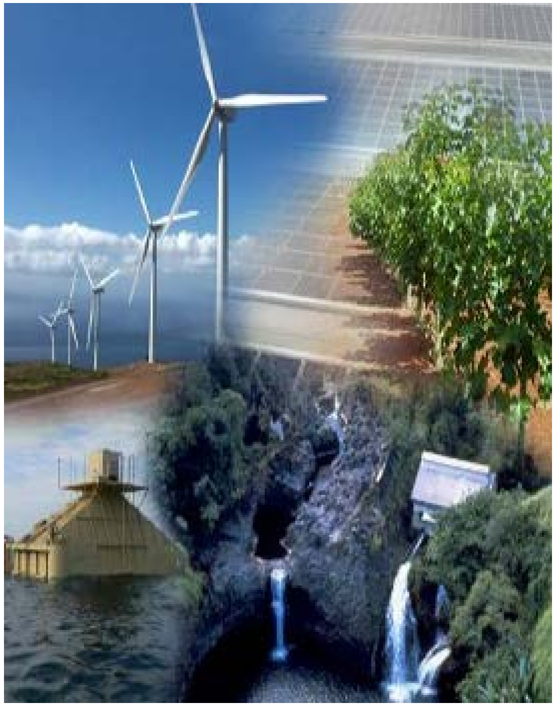
グランド再生可能エネルギー2018　国際会議
AIST-FREA スペシャルセッション

GRAND RENEWABLE ENERGY 2018
AIST-FREA Special Session

2018/6/20　パシフィコ横浜　会議センターにて

Clean Energy Transformation
The Hawaii Experience



GridSTART

Grid System Technologies Advanced Research Team

Leon R. Roose, Esq.

Principal & Chief Technologist, Grid*START*

Hawaii Natural Energy Institute
School of Ocean & Earth Science & Technology
University of Hawaii at Manoa
1680 East-West Road, POST 109
Honolulu, Hawaii 96822

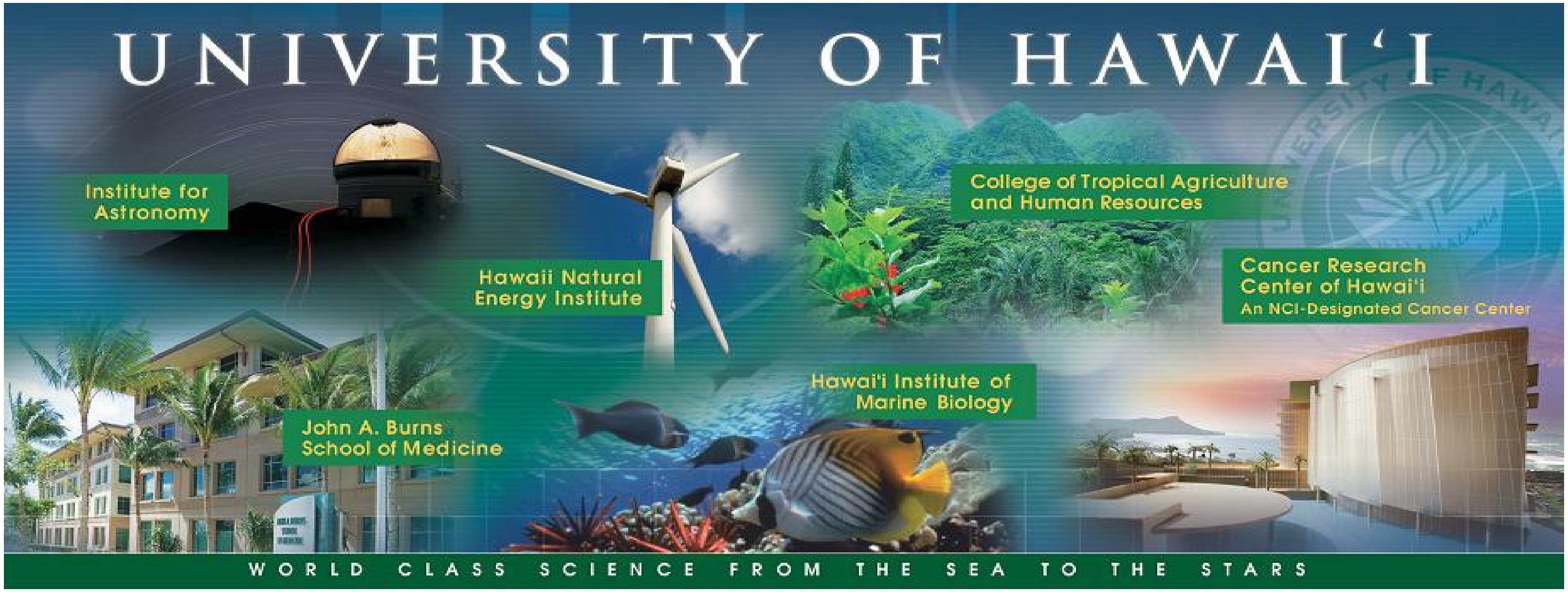
HNEI Hawai'i Natural Energy Institute

University of Hawai'i Mānoa

Grand Renewable Energy 2018 International Conference

AIST Special Session: Increasing RE Penetration Beyond Conventional Limits with Advanced DER Capabilities

June 20, 2018
Yokohama, Japan



- Established in 1907
- Statewide system with 3 universities & 7 community colleges
- Over 50,000 students
- Manoa is the largest and main research campus
  - 14,000 undergraduate students
  - 6,000 graduate students
- ***School of Ocean and Earth Science and Technology*** is the largest research unit on the Manoa campus

~$100 million extramural funding per year

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**

UNIVERSITY of HAWAIʻI
MĀNOA

GridSTART

Hawai'i Natural Energy Institute | University of Hawai'i

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.

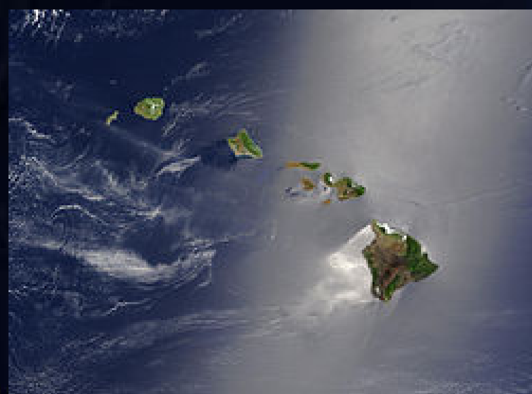
- Serves to integrate into the operating power grid other HNEI technology areas: biomass and biofuels, fuel cells and hydrogen, energy efficiency, renewable power generation
- Strong and growing partnerships with national and international organizations including Asia-Pacific nations.

Lead for many public-private demonstration projects

Hawaii is Paradise …
But it's Isolation Poses a Serious Challenge

In 2008, nearly 90% of Hawaii's energy was met using *fossil fuels*

100% of the crude oil for the State is *imported*



***Threat* to Hawaii's:**
- **Security**
- **Environment**
- **Economy**

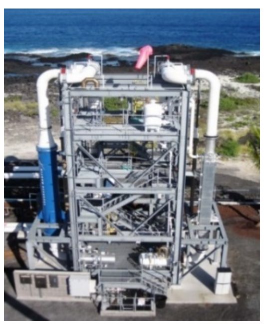
Hawaii ranks #1 in U.S. electric energy costs:

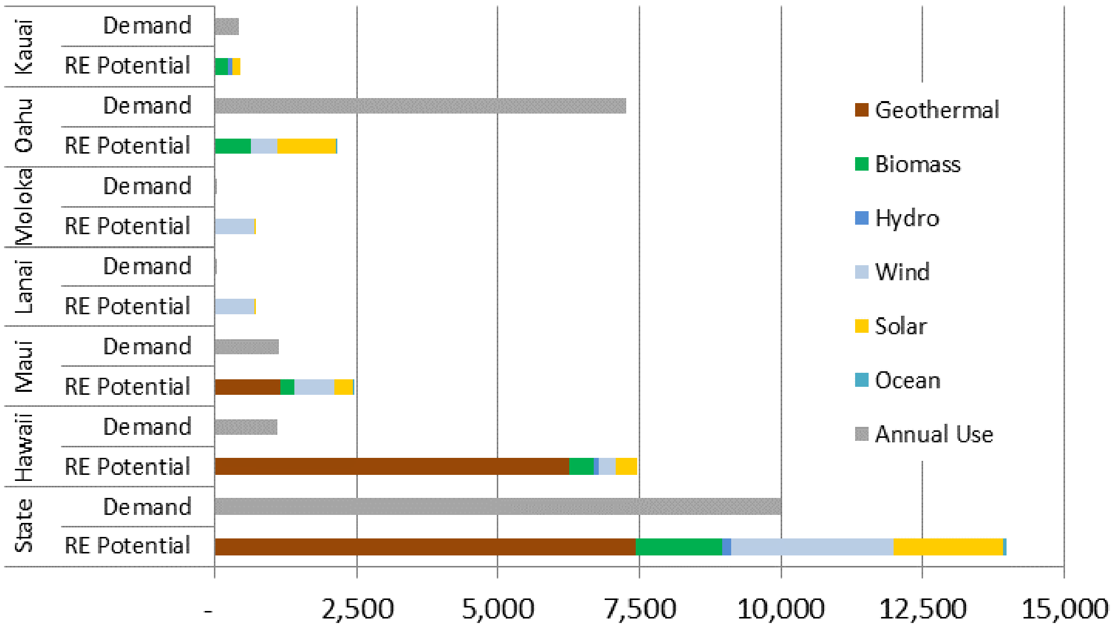
47.1 cents/kWh	Molokai
45.9 cents/kWh	Lanai
41.9 cents/kWh	Hawaii
37.8 cents/kWh	Maui
35.5 cents/kWh	Oahu
(Avg. residential rates for 2014)	
11 - 12 cents/kWh	U.S. avg.

US Dept of State Geographer
© 2013 Google
Image © 2013 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

University of Hawai'i Mānoa

Opportunity for Sustainability in Hawaii is Abundant

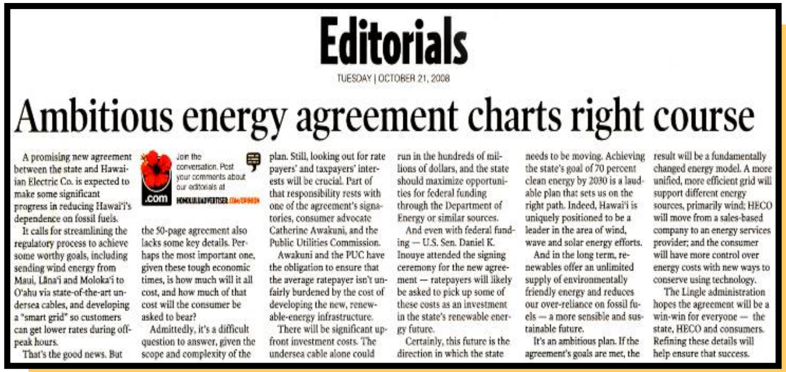




Renewable Electricity Potential and Demand by Island, Gigawatt-hours

Source: National Renewable Energy Laboratory, Hawaii Clean Energy Initiative Scenario Analysis, 2012; and DBEDT

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 up-front 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.

Join the conversation. Post your comments about our editorials at HONOLULUADVERTISER.COM/OPINION

Hawai'i Powered

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

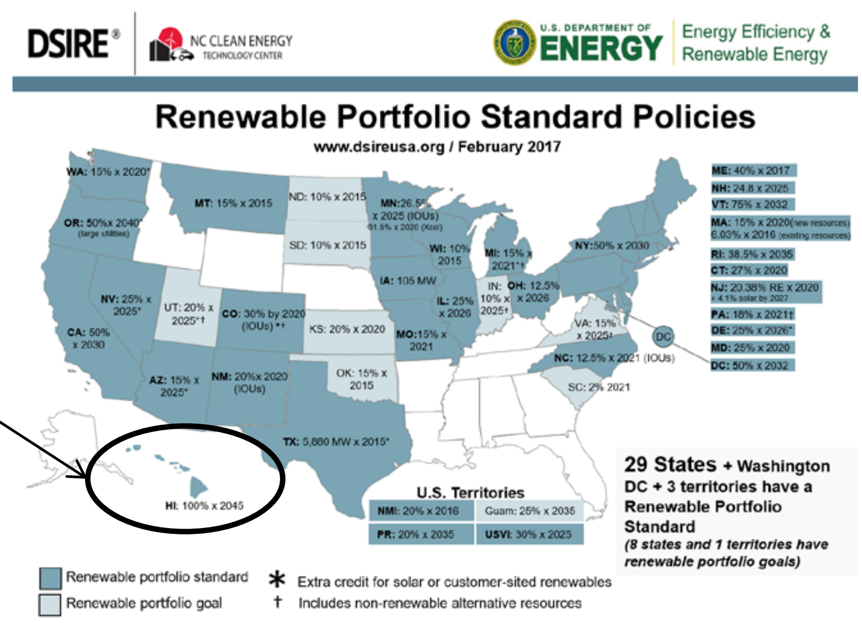
Highest RPS Target in the United States

100% by 2045

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

Other key policies:

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



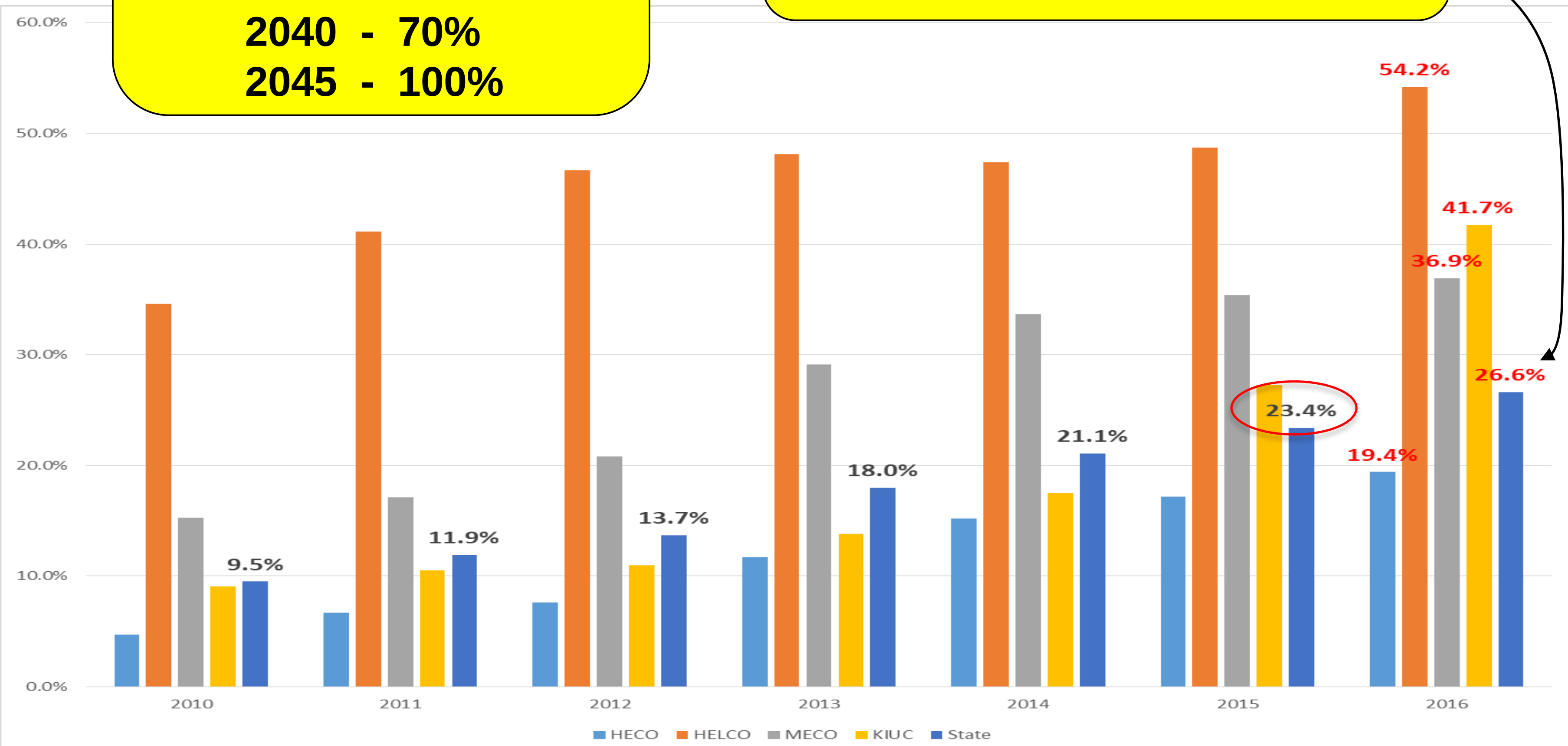
UNIVERSITY of HAWAI'I MĀNOA

Exceeding Hawaii RPS Goals

Hawaii RPS Goals

2015 - 15%
2020 - 30%
2030 - 40%
2040 - 70%
2045 - 100%

State-wide 2015 RPS Goal = 15%
RPS year-end 2016 @ 26.6%
(9.5% RPS at year-end 2009)



Source: State of Hawaii, "Hawaii Energy Facts & Figures," Hawaii State Energy Office, Honolulu, May 2017

UNIVERSITY of HAWAI'I MĀNOA

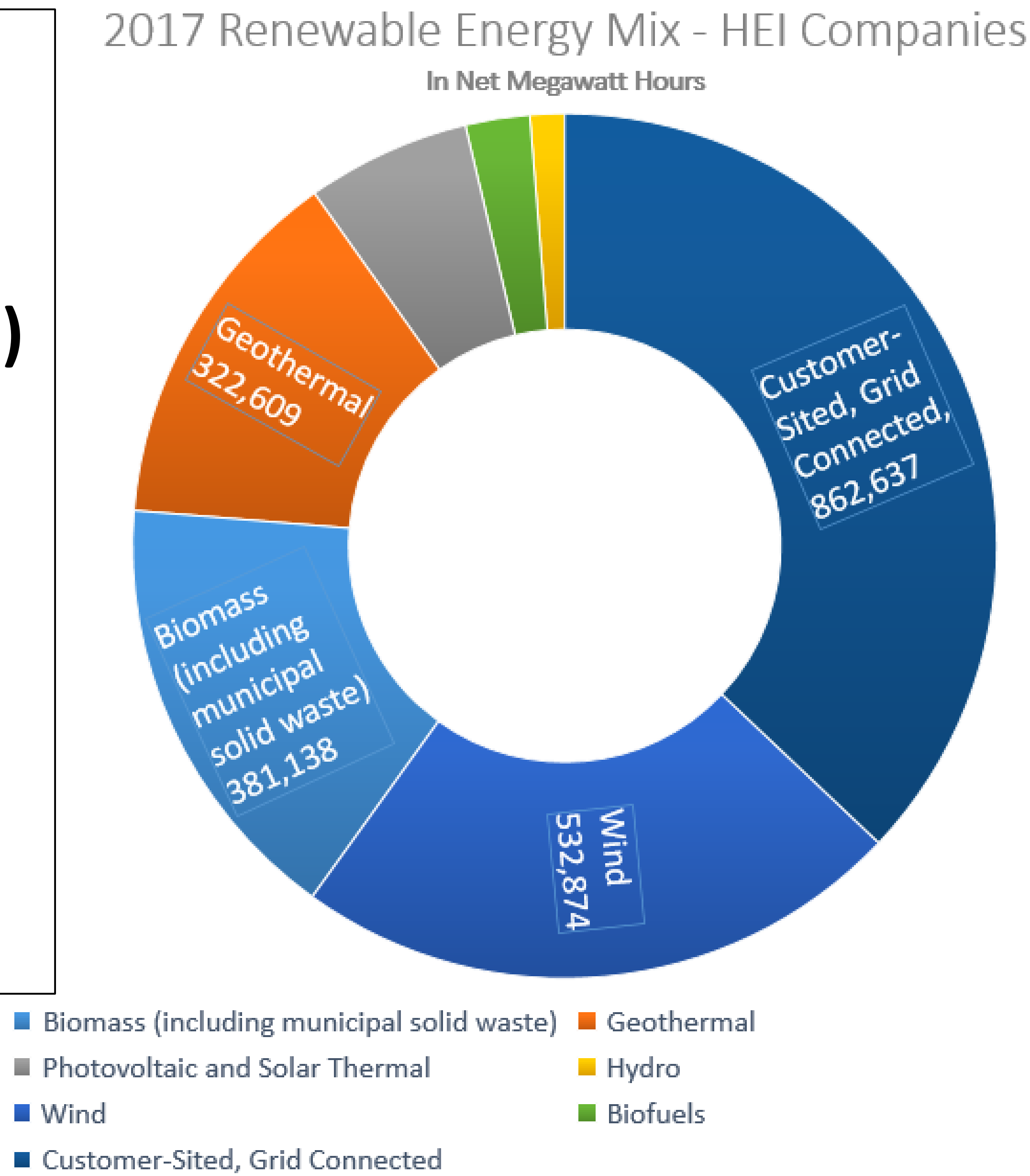
Hawaiian Electric Company RPS - 2017

27% Statewide

21% HECO (Oahu – Honolulu)

57% HELCO (Hawaii Island)

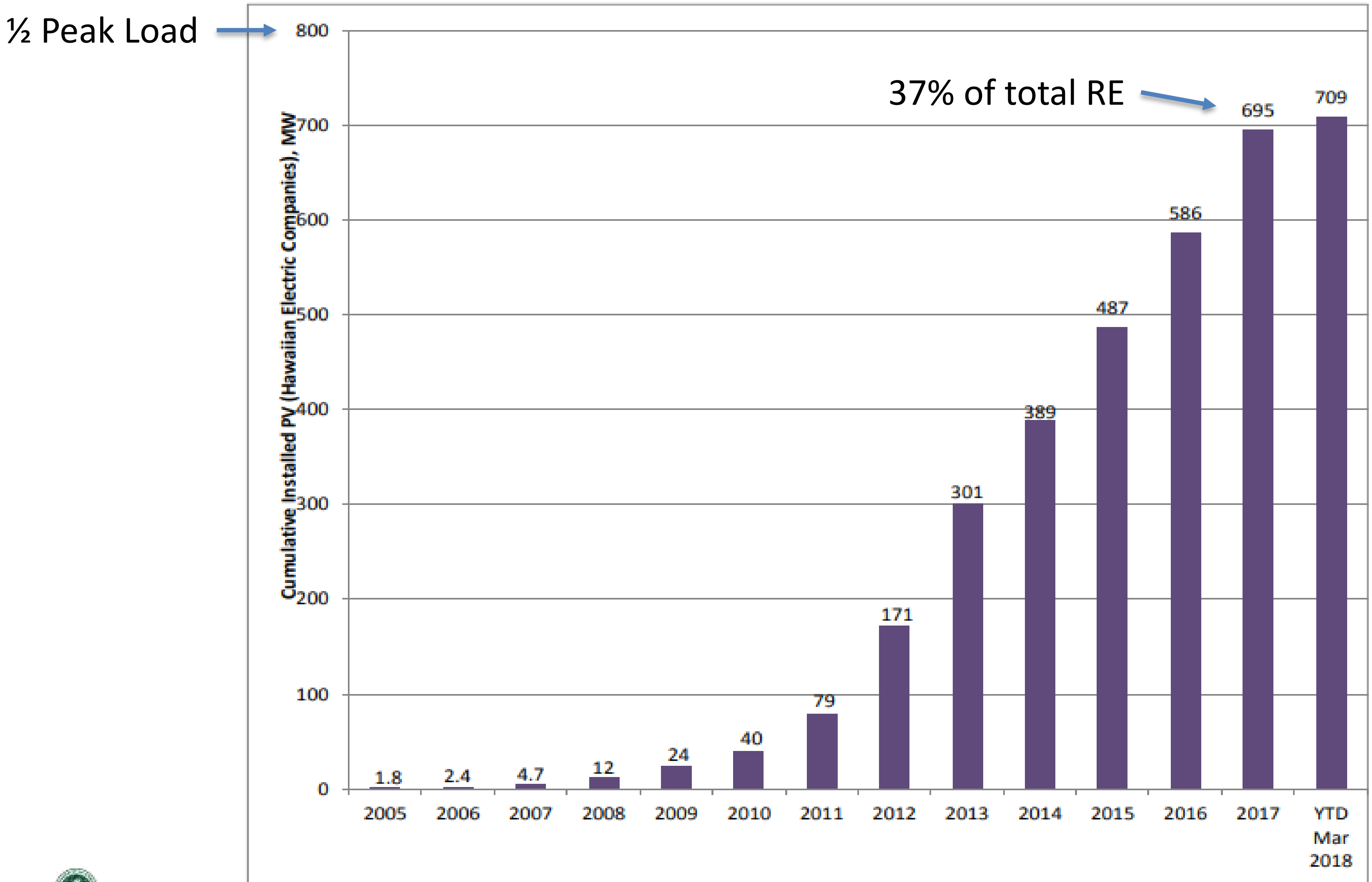
34% MECO (Maui, Molokai, Lanai)



University of Hawai'i Mānoa

Installed PV Capacity - HECO Companies

(2005 to 3/2018)



UNIVERSITY of HAWAI'I MĀNOA

Why is DG PV So Popular in Hawaii

Federal Incentives

- 30% of the cost of Solar systems with no cap. *Extended to 2019*
- *(Ramps down through 2020 to 26%, then in 2021 to 22%)*

State Incentives

- 35% of the actual cost or $5,000 per system, whichever is less. No expiration date

Average Price of Residential Electricity (EIA)

	State	Mar-18
1	North Dakota	9.65
2	Washington	9.65
3	Louisiana	9.79
4	Idaho	9.99
5	Nebraska	10.25
	.	
	.	
46	New Hampshire	19.93
47	Rhode Island	20.22
48	Connecticut	21.04
49	Alaska	21.47
50	Massachusetts	22.49
51	Hawaii	32.05
	U.S. Average	12.99

The average Hawaii resident spends about 0.37 per kilowatt-hour (kWh) and uses about 515 kilowatts (kW) per month. With an average month's electric bill totaling $190.36 it definitely makes sense to see if you can save money on power.

Key Solar Facts – Averaged for Hawaii

Average savings per year: $3539.18 ($294.93 per month)

Estimated time for the system to pay for itself: 6 years, 0 months

Is solar worth it in Hawaii? Based on the price of electricity in Hawaii (an average of 0.37 per kW) and high amounts of sun (8% more than average) compared to other states, solar power is 238% more cost effective than the rest of the nation.

Source: Decisiondata.org

University of Hawai'i Mānoa

Hawai'i Electric Systems –

4 Electric Utilities; 6 Separate Grids; % Renewable Energy

Kaua'i Island Utility Cooperative

System Peak: 78 MW

65.6 MW PV / 7 MW Biomass / 9 MW Hydro

Installed PV: 84% of System Peak

41.7% RE in 2016

Maui Electric

Maui System Peak: 202 MW

102 MW PV / 72 MW Wind

Installed PV & Wind:

86% of Sys. Peak

34.2% RE in 2017

Lana'i System Peak: 5.1 MW

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

Moloka'i System Peak: 5.6 MW

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

Hawaiian Electric

System Peak: 1,206 MW

512 MW PV / 99 MW Wind / 69 MW WTE

Installed PV & Wind:

50% of System Peak

20.8% RE in 2017

Hawaii Electric Light

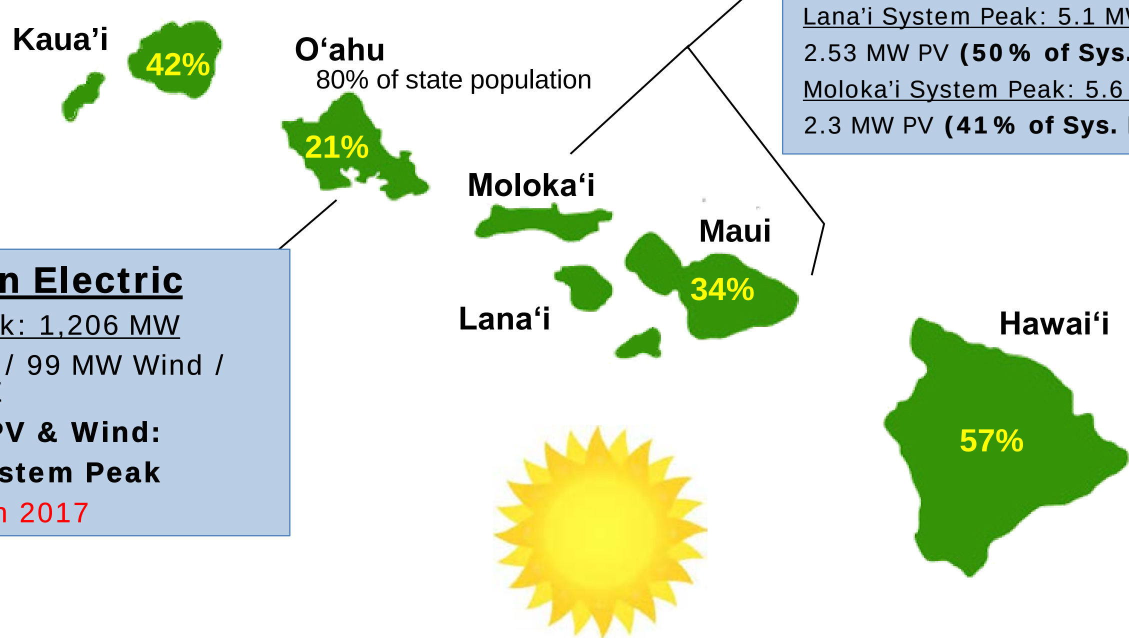
System Peak: 192 MW

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

Installed PV & Wind:

64% of System Peak

56.6% RE in 2017



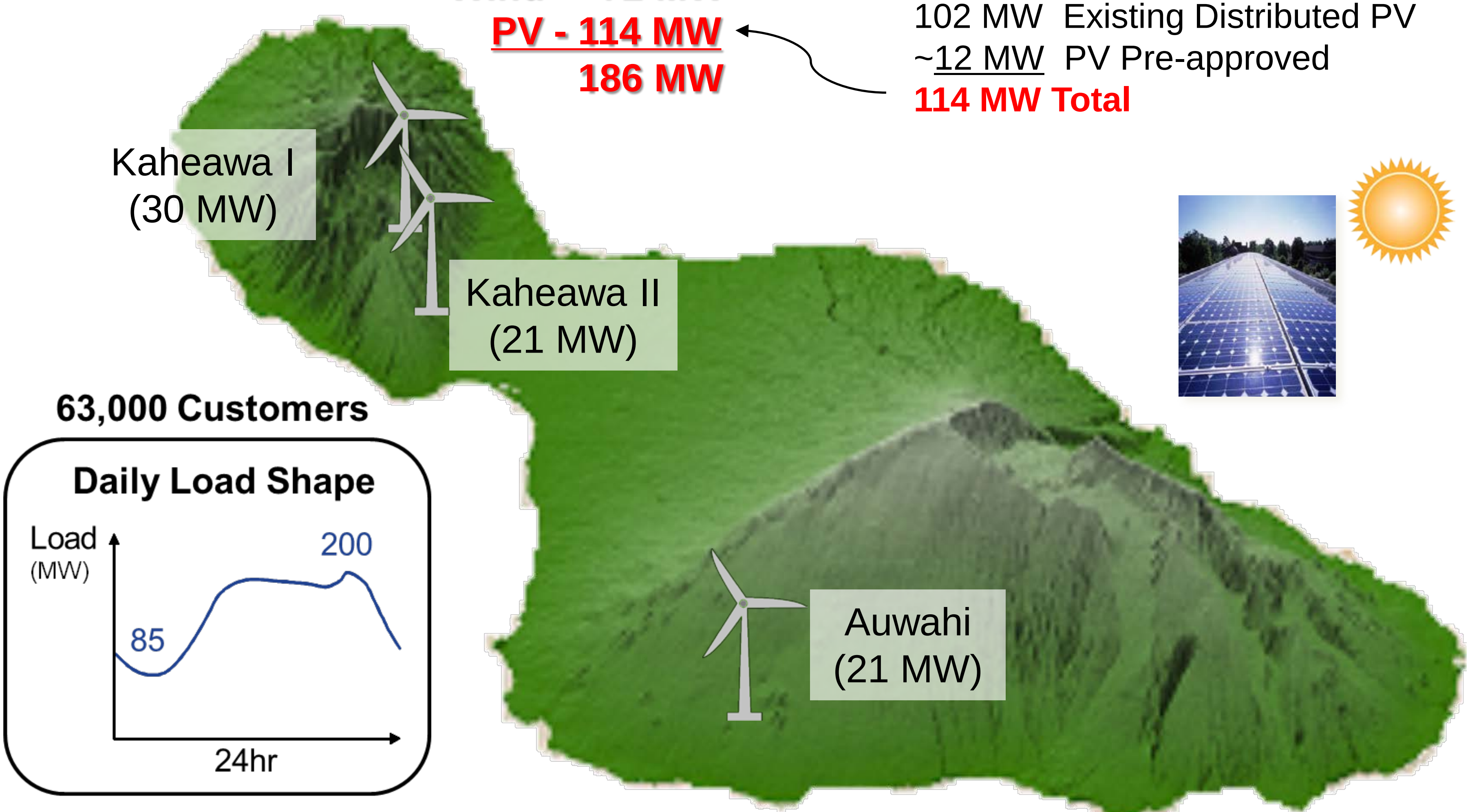
% Renewable Energy

Maui Island

Leading the way in Solar and Wind Power

Wind - 72 MW
PV - 114 MW
186 MW

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



UNIVERSITY of HAWAI'I MĀNOA

MAUI ADVANCED SOLAR INITIATIVE

OBJECTIVES

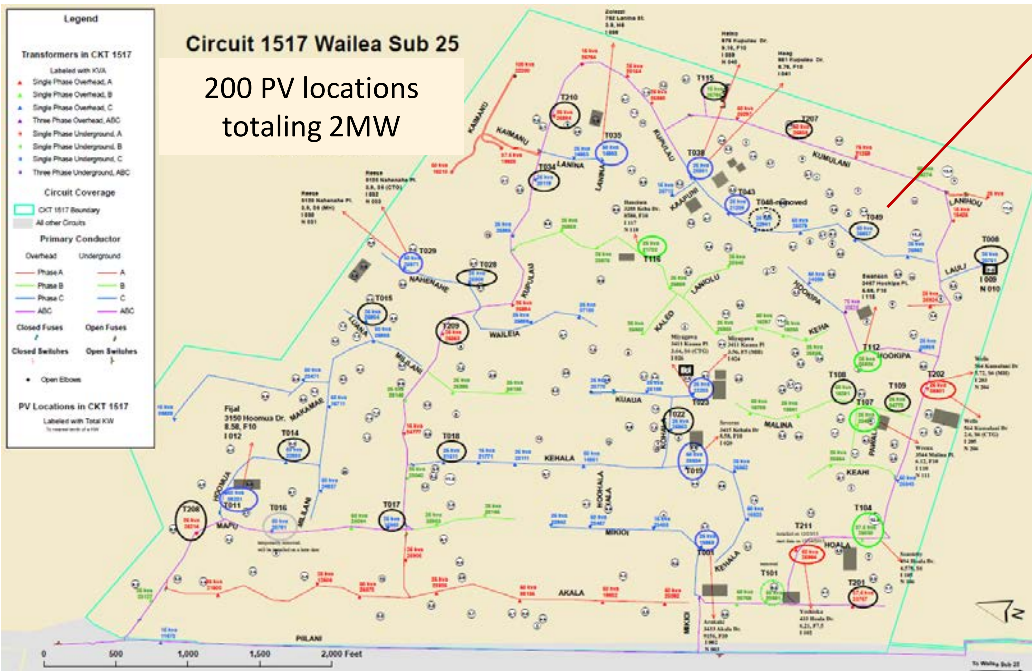
- Deploy new Smart Inverters
- Utilize Inverter Management Control Software (IMCS)
- Utilize ***standards-based*** controls and communications
- Employ detailed distribution modeling and high-resolution field data to develop advanced inverter settings

~800 customers

~300 PV systems = 2MW

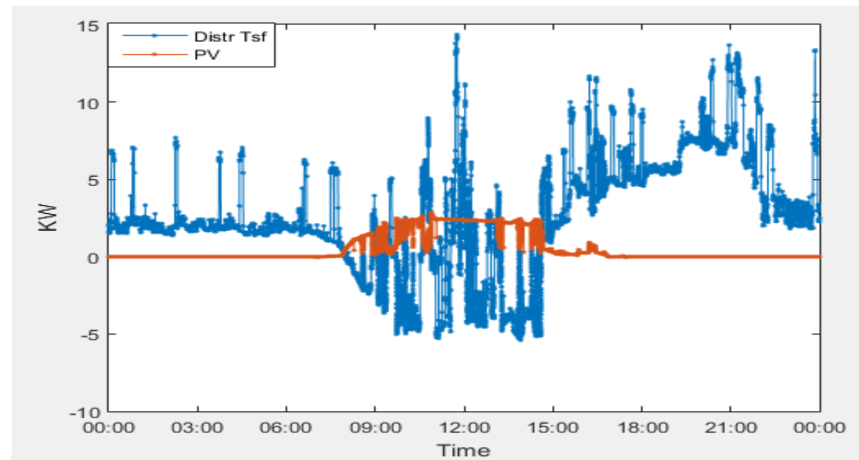
MDL = 976kW

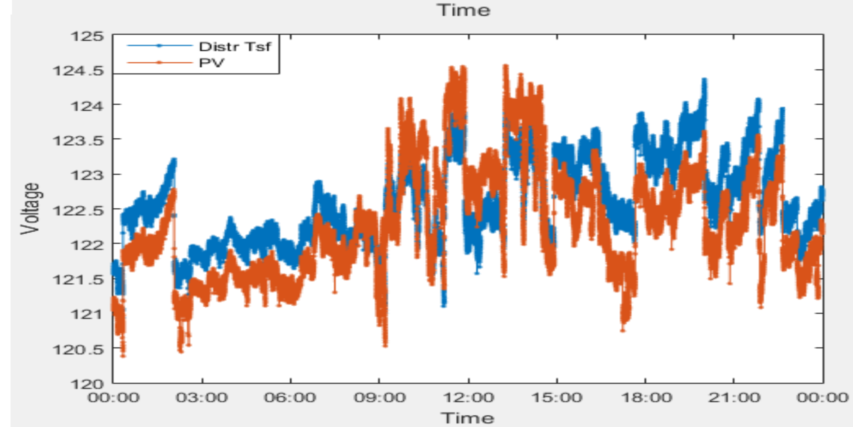
% Penetration = $\frac{2MW}{976kW} = 200\%$



UNIVERSITY of HAWAI'I MĀNOA

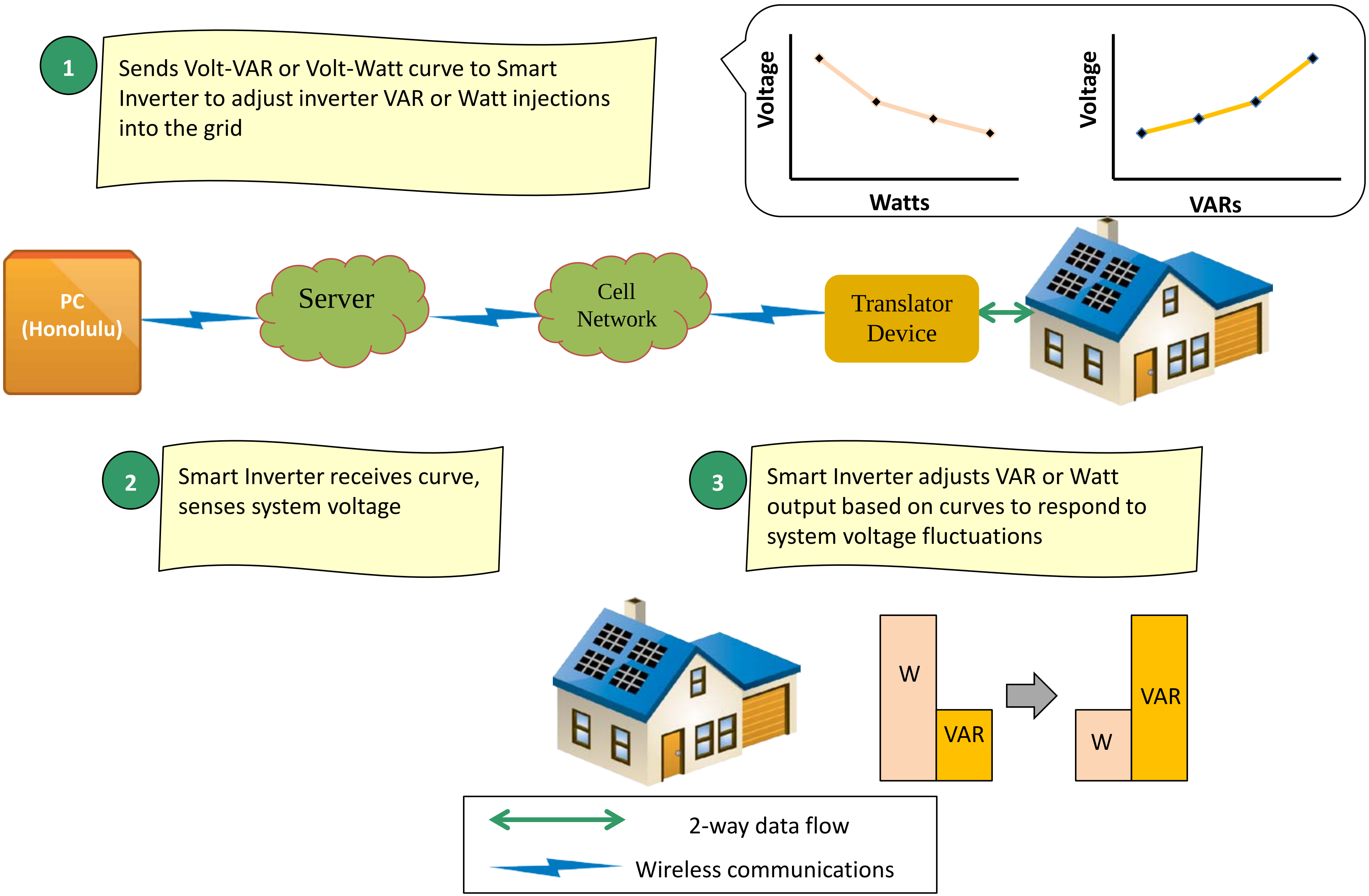
Field Performance & Data Mining





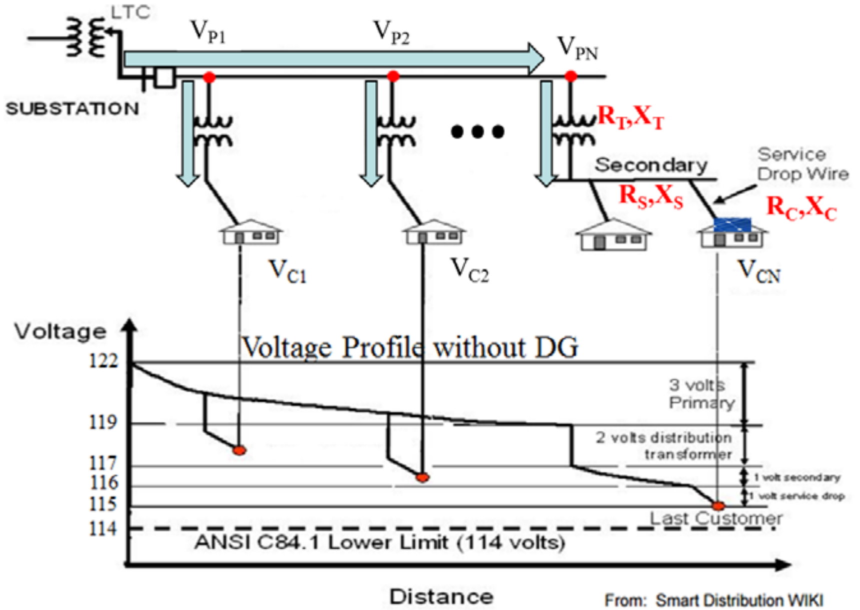
UNIVERSITY of HAWAI'I
MĀNOA

Software sends control curves to adjust inverter

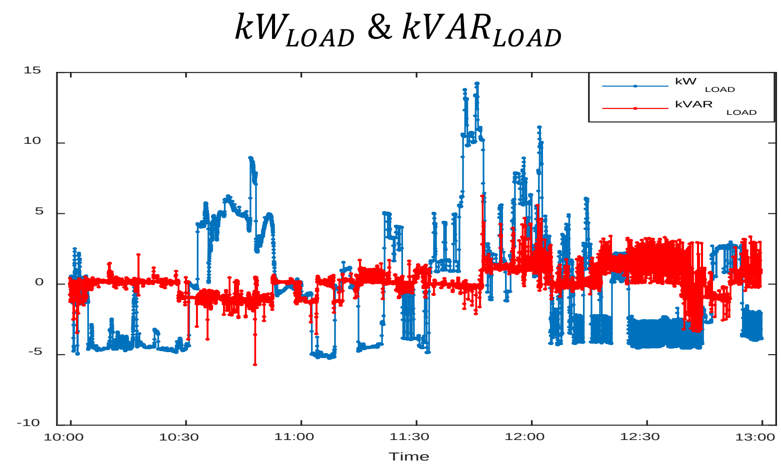


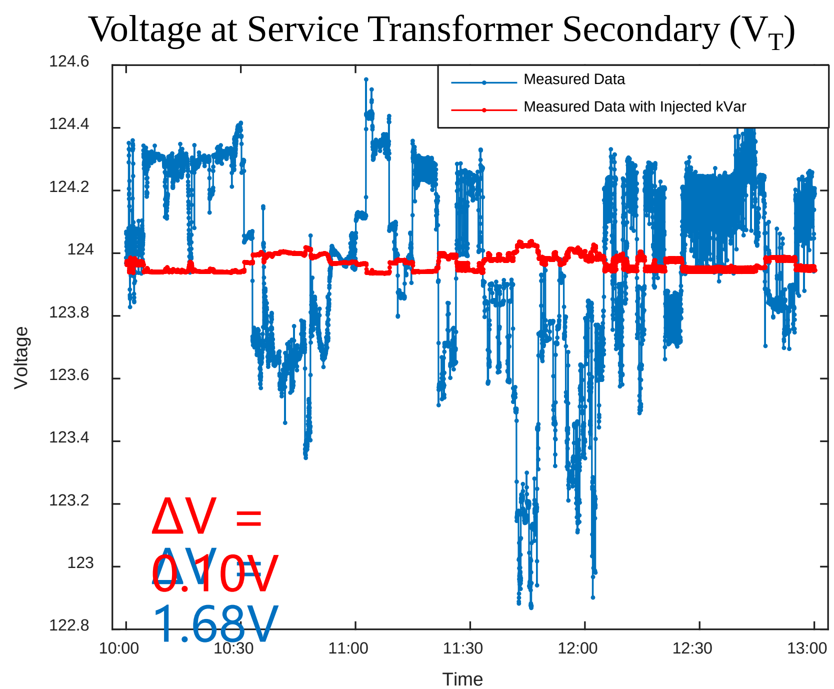
Reducing Voltage Fluctuations Across Distribution Feeders

- Improves energy efficiency and reduces peak demand by lowering voltage (within ANSI limits) on the feeder lines that run from substations to end-use loads.



Smart inverter can be controlled to stabilize the voltage

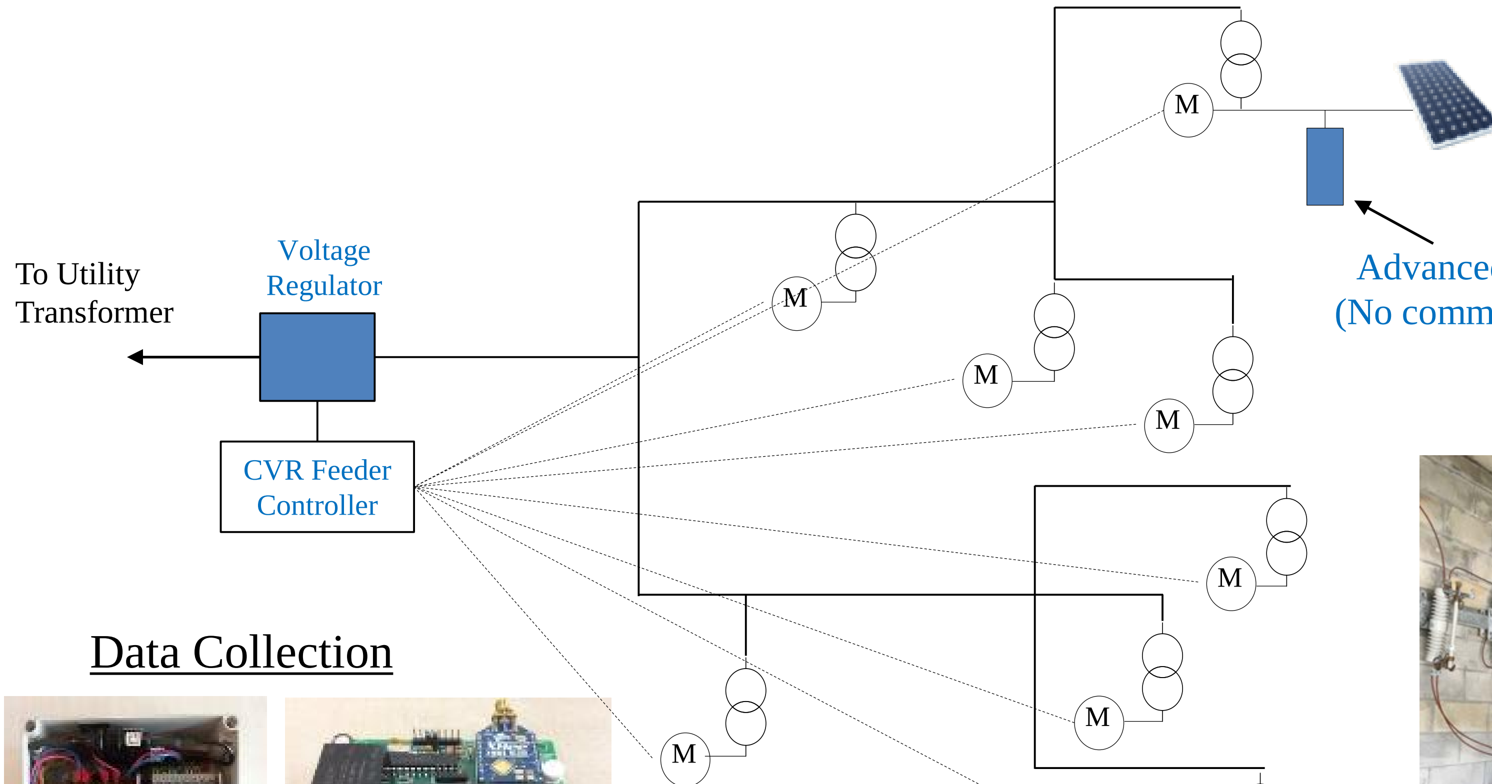




UNIVERSITY of HAWAI'I
MĀNOA

Advanced Conservation Voltage Reduction (CVR)

Okinawa Demonstration



Data Collection

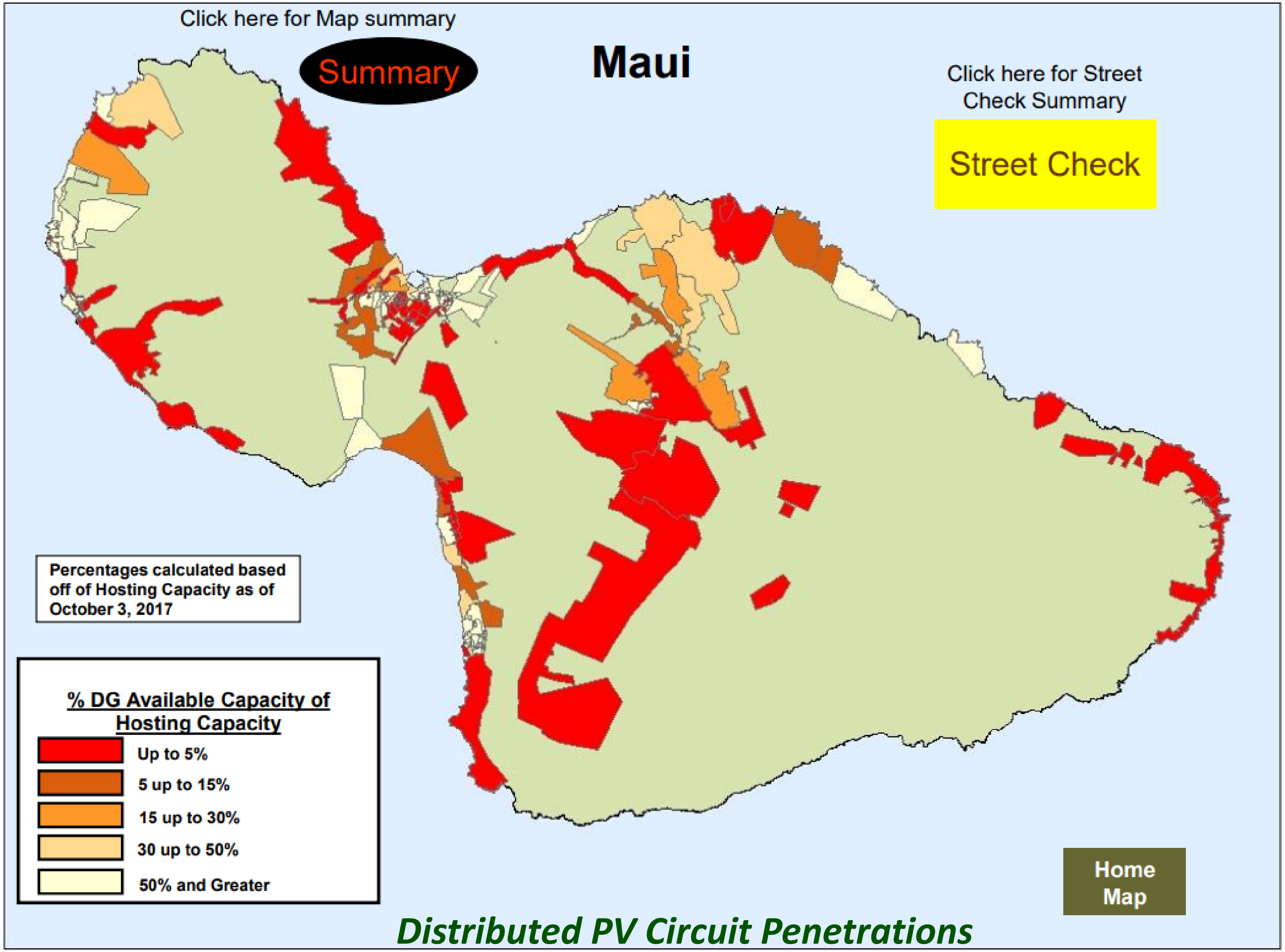
PQube

Custom

In collaboration with **Okinawa Enetech** providing equipment installation support in Okinawa

UNIVERSITY of HAWAI'I
MĀNOA

Distributed PV Circuit Penetrations



Qualified Inverter Lists

Hawaiian Electric
Maui Electric
Hawai'i Electric Light

QUALIFIED GRID SUPPORT UTILITY INTERACTIVE INVERTERS AND CONTROLLERS MEETING MANDATORY FUNCTIONS SPECIFIED IN RULE 14H

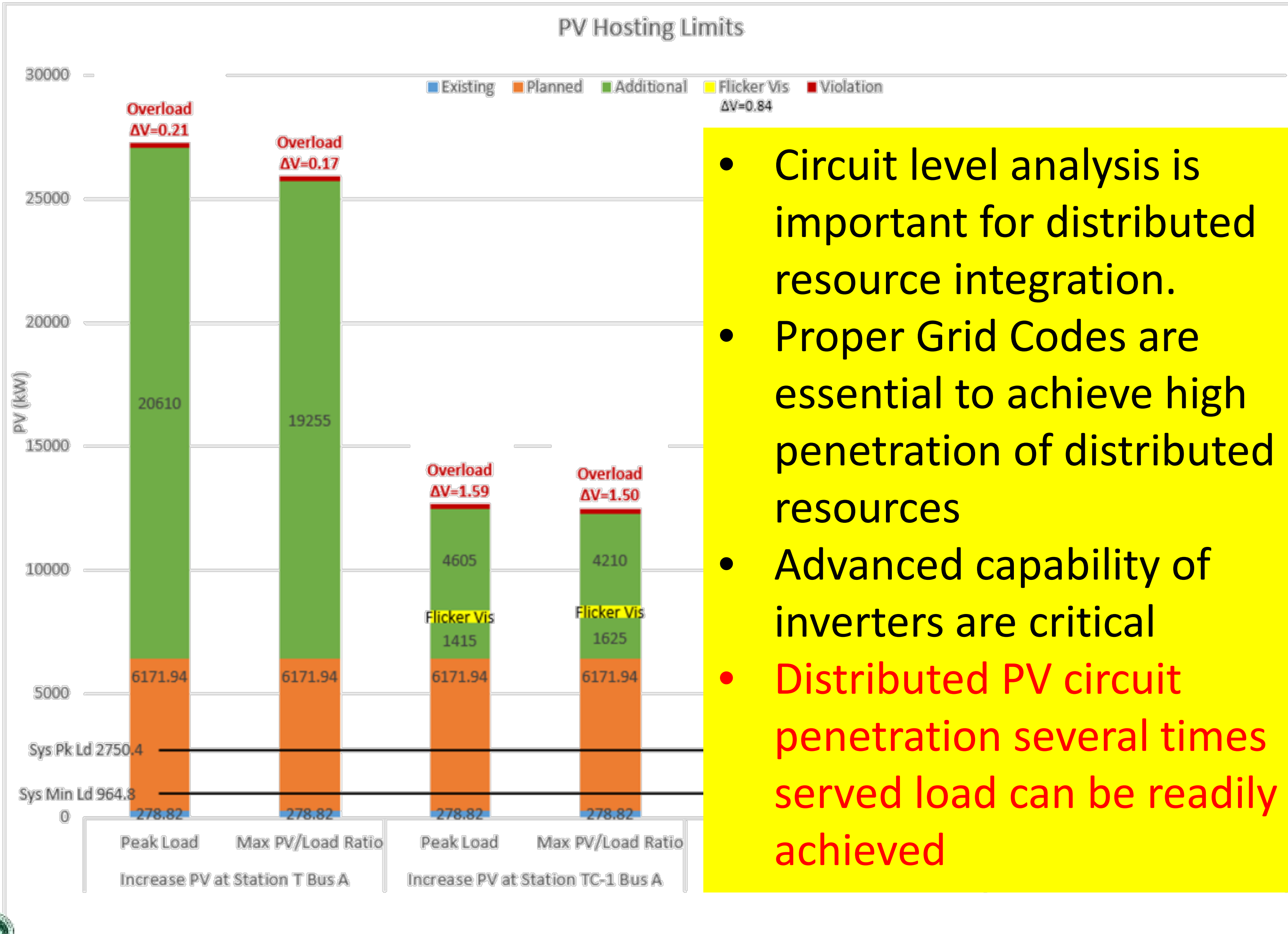
(EQUIPMENT THAT MEETS CUSTOMER GRID SUPPLY AND STANDARD INTERCONNECTION AGREEMENT (SIA))

Technology Type:	Manufacturer:	HI SRD Certification	Model:
Inverter	Apparent Energy	No Information Submitted	SG424 (120V/208V/240V)
Inverter	Canadian Solar	No Information Submitted	CSI-36KTL-CT (DSP FW Ver 0.30)
Inverter	Chilicon Power LLC	No Information Submitted	CP-250-60/72-208/240-MC4-MTC (FW 232 or greater)
Inverter	Chilicon Power LLC	No Information Submitted	CP-250-60-208/240-MC4 (FW 232 or greater)

https://www.hawaiianelectric.com/Documents/clean_energy_hawaii/list_of_advanced_legacy_equipment.pdf

UNIVERSITY of HAWAI'I MĀNOA

Circuit Level PV Hosting Capacity



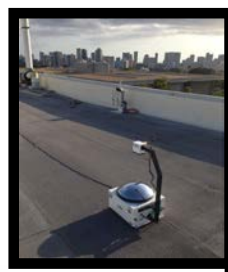
- Circuit level analysis is important for distributed resource integration.
- Proper Grid Codes are essential to achieve high penetration of distributed resources
- Advanced capability of inverters are critical
- Distributed PV circuit penetration several times served load can be readily achieved

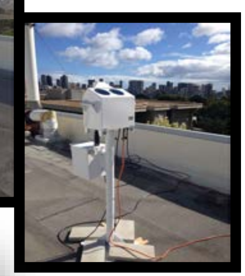
UNIVERSITY of HAWAI'I MĀNOA

Moloka'i Island 100% RE Grid Initiative

- **100% Renewable Goal by 2020**
- Battery Storage
  - 2MW, 375kW-hr, Li-ion Titanate
- System Data Collection
- Load Flow & Midterm Dynamics Modeling
- Production Modeling
- Dynamic Load Bank
- PV Forecasting
- Island Grid Controller

- **Peak Load: 5.4 MW (2013)**
- **Daytime Min Load: 3 MW**
- **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**





Hawaii ranks #1 in U.S. electric energy costs:

47.1 cents/kWh	**Molokai**
45.9 cents/kWh	**Lanai**
41.9 cents/kWh	**Hawaii**
37.8 cents/kWh	**Maui**
35.5 cents/kWh	**Oahu**
(Avg. residential rates for 2014)	
11 - 12 cents/kWh	**U.S. avg.**

Opportunity to extend this initiative as a scalable model to other Asia-Pacific regional sites

University of Hawai'i Mānoa

Solar Power Forecasting for Hawai'i

HNEI Cloud Monitoring and Solar Power Forecasting System

Regional numerical weather prediction model

- Every night, a multi-day forecast is generated
- Required for accurate predictions longer than ~6 hours ahead
- Creates a framework for shorter-term forecasts from satellites and sky cameras

Satellite images

- Every 15 minutes, images from a geostationary satellite (GOES-WEST) are used to generate 1-km resolution forecasts most accurate in the 30 minutes to 6 hours ahead forecasting range
- Provides boundary conditions for ground-based local forecasts

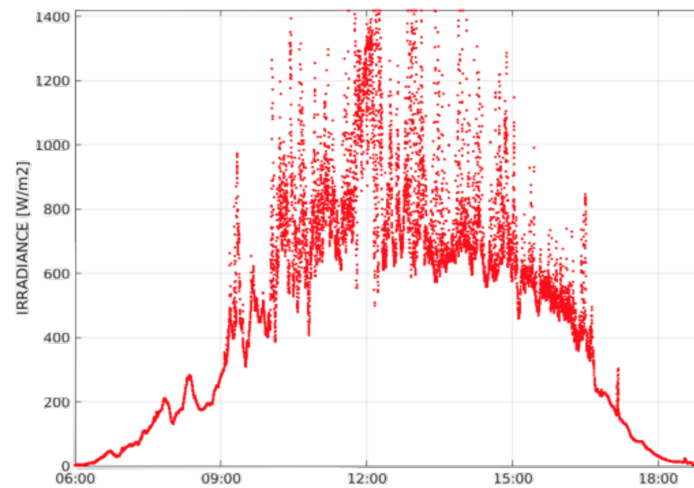
Ground-based instruments

- Every minute, images from a novel sky mapping system developed at HNEI, combined with irradiance observations from pyranometers, are used to generate high resolution, local irradiance conditions
- Every 2-4 minutes, short-term forecasts are generated from the ground-based data

HNEI Ground-based sky imaging and irradiance measuring system

From the data provided by this system:

- Determine cloud positions, velocities and attenuation levels
- Use that information with a clear sky solar model to generate high resolution irradiance nowcasts and forecasts maps
- From irradiance maps → PV power predictions

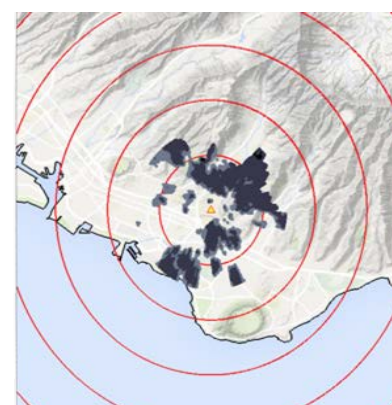


Goal:

- To facilitate widespread, overlapping field deployment
- Low production cost using off–the–shelf instrumentation, open–source single–board computing hardware, and DIY technologies
- "Swarm" approach – low cost multiple camera system can remain resilient and functioning with individual camera failures.

Development Timeline:

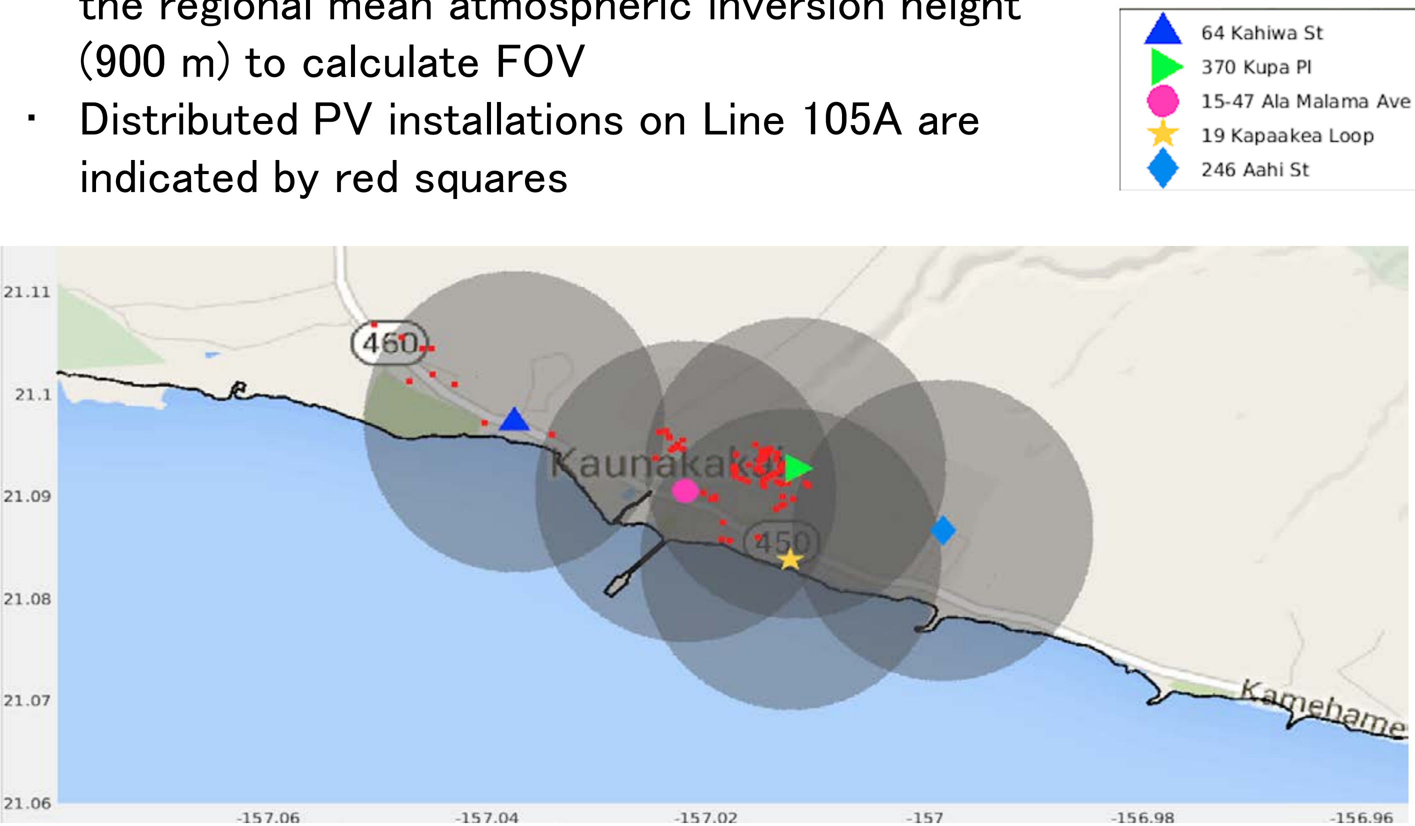
- Completed – Software design and prototype testing
- August 2018 – First operational deployment on the island of Moloka'i

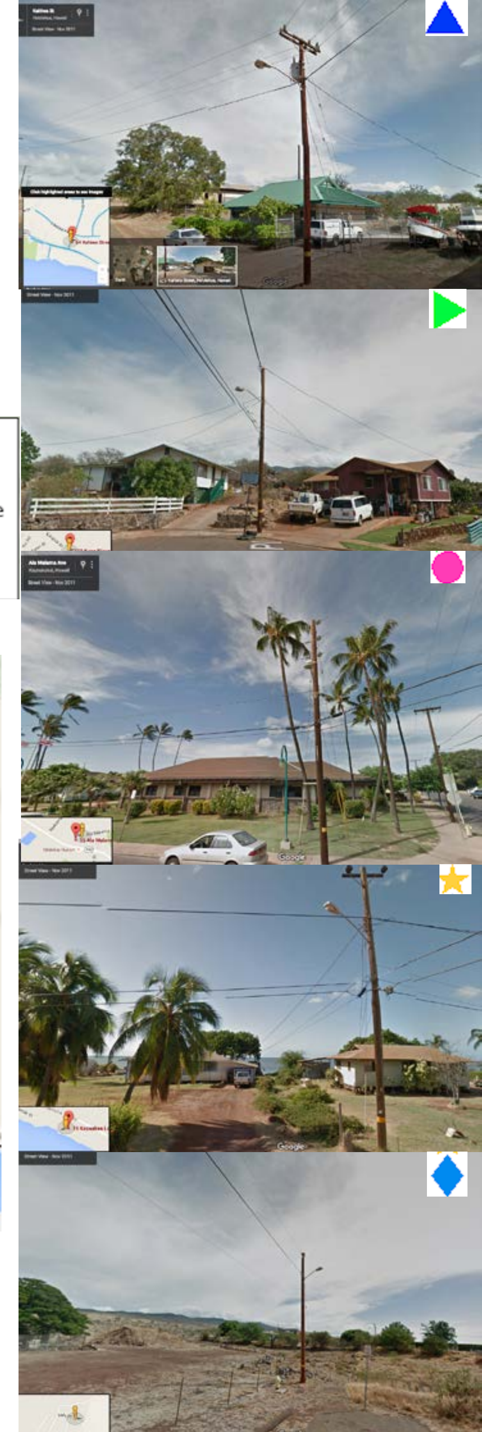


University of Hawai'i
Mānoa

Moloka‘i Field Deployment

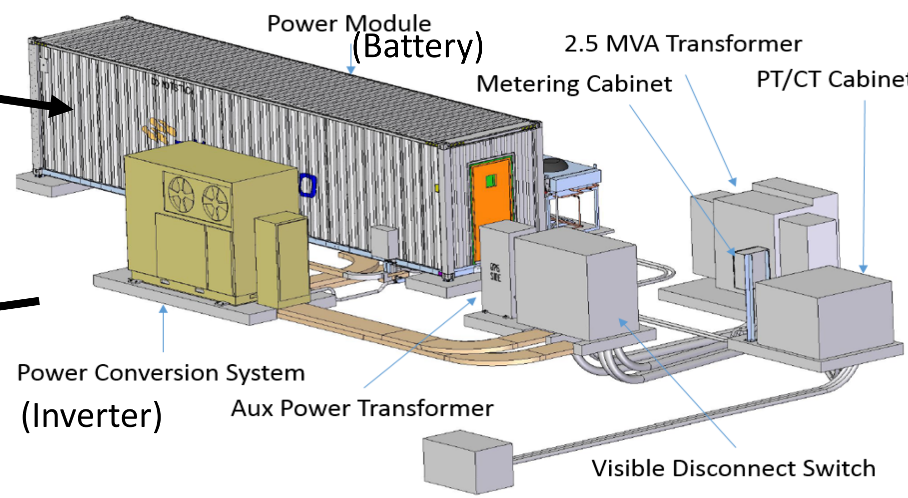
- Deployment focuses on Circuit 105A using 5 camera systems mounted on utility power poles
- Camera FOVs (shown by grey circles) are related to the cloud base height (CBH) – below, we use the regional mean atmospheric inversion height (900 m) to calculate FOV
- Distributed PV installations on Line 105A are indicated by red squares





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



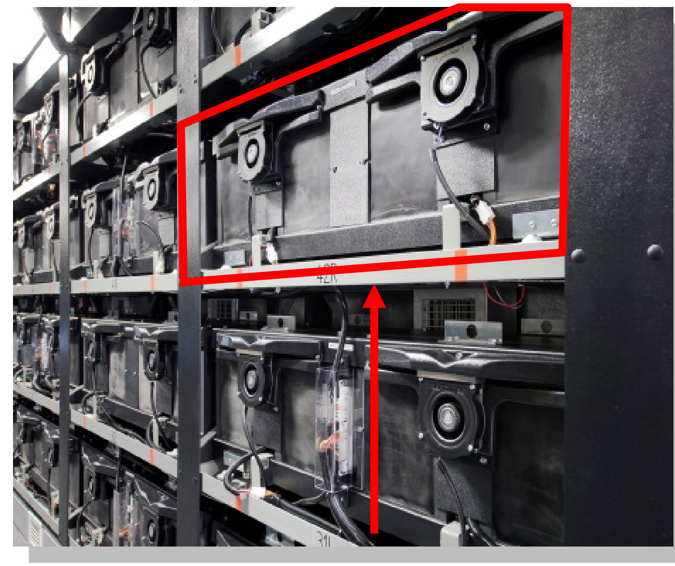
Molokai Island BESS Project

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

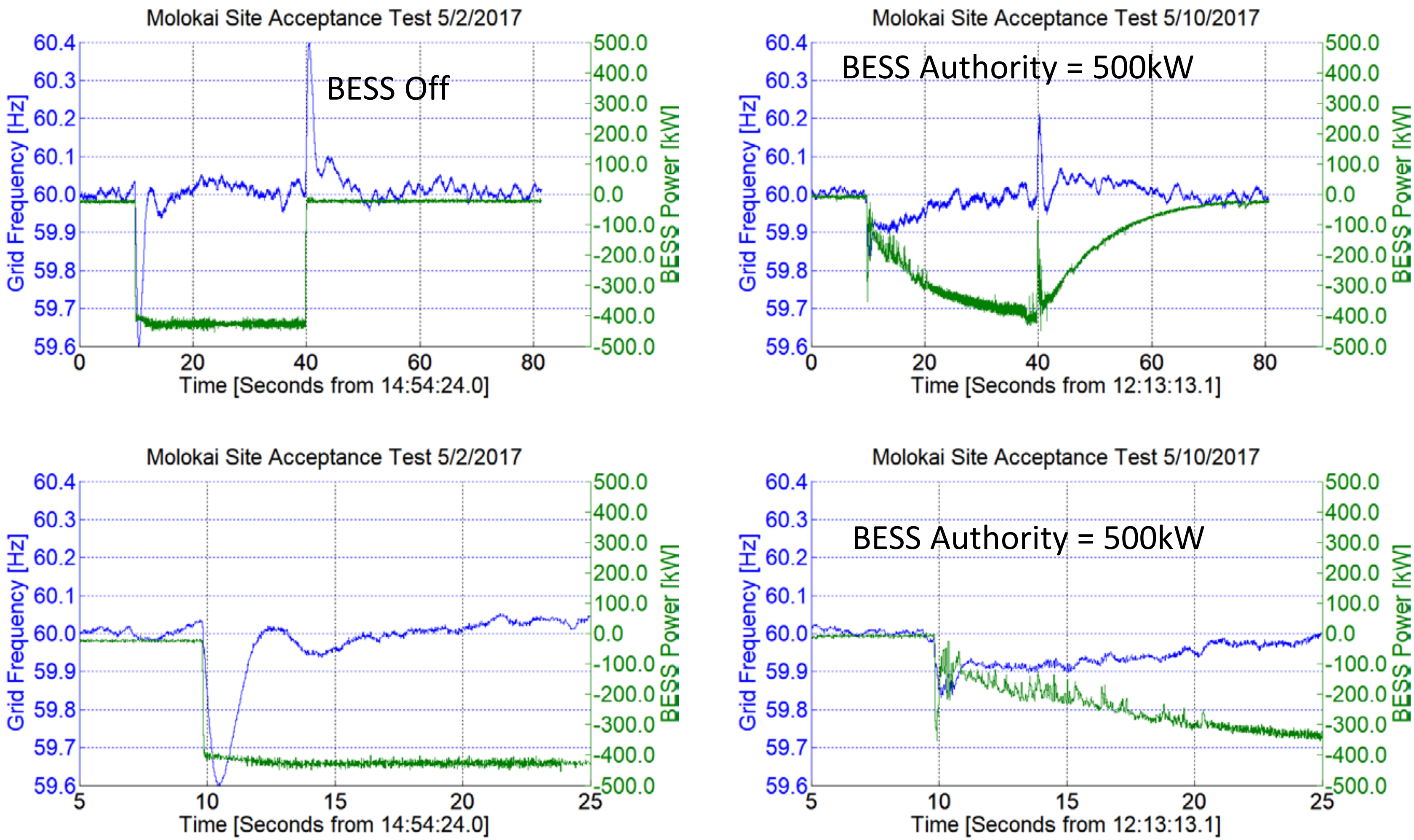
- Li-Ion Titanate 50 A-Hr Cells
- BESS has 2688 cells in 96 LRU

Designed for rapid charging and discharging

UNIVERSITY of HAWAI'I MĀNOA

Impact of BESS with 500kW Authority and Fast Response

Expansions (bottom) show Down-Step



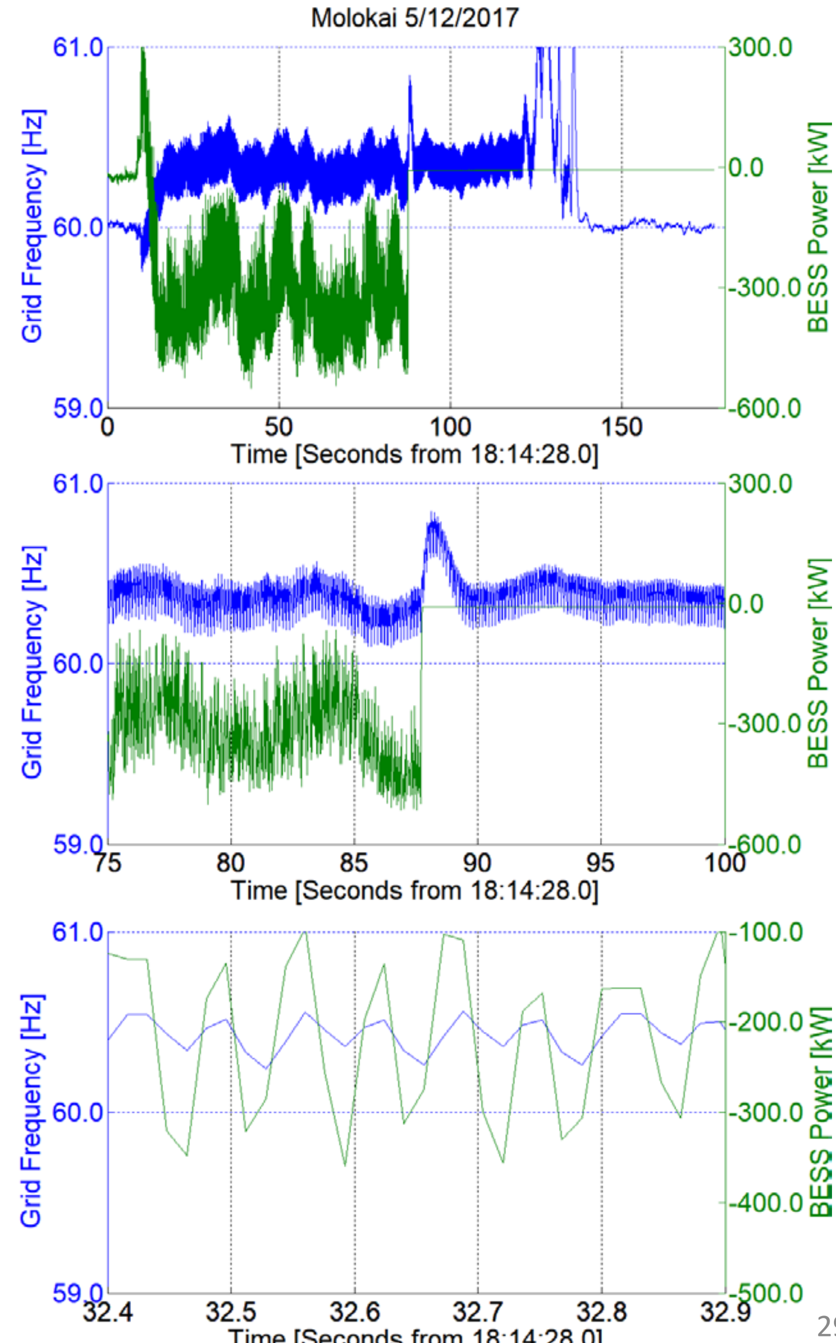
500kW fast response showed significant frequency improvement

UNIVERSITY of HAWAI'I MĀNOA

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

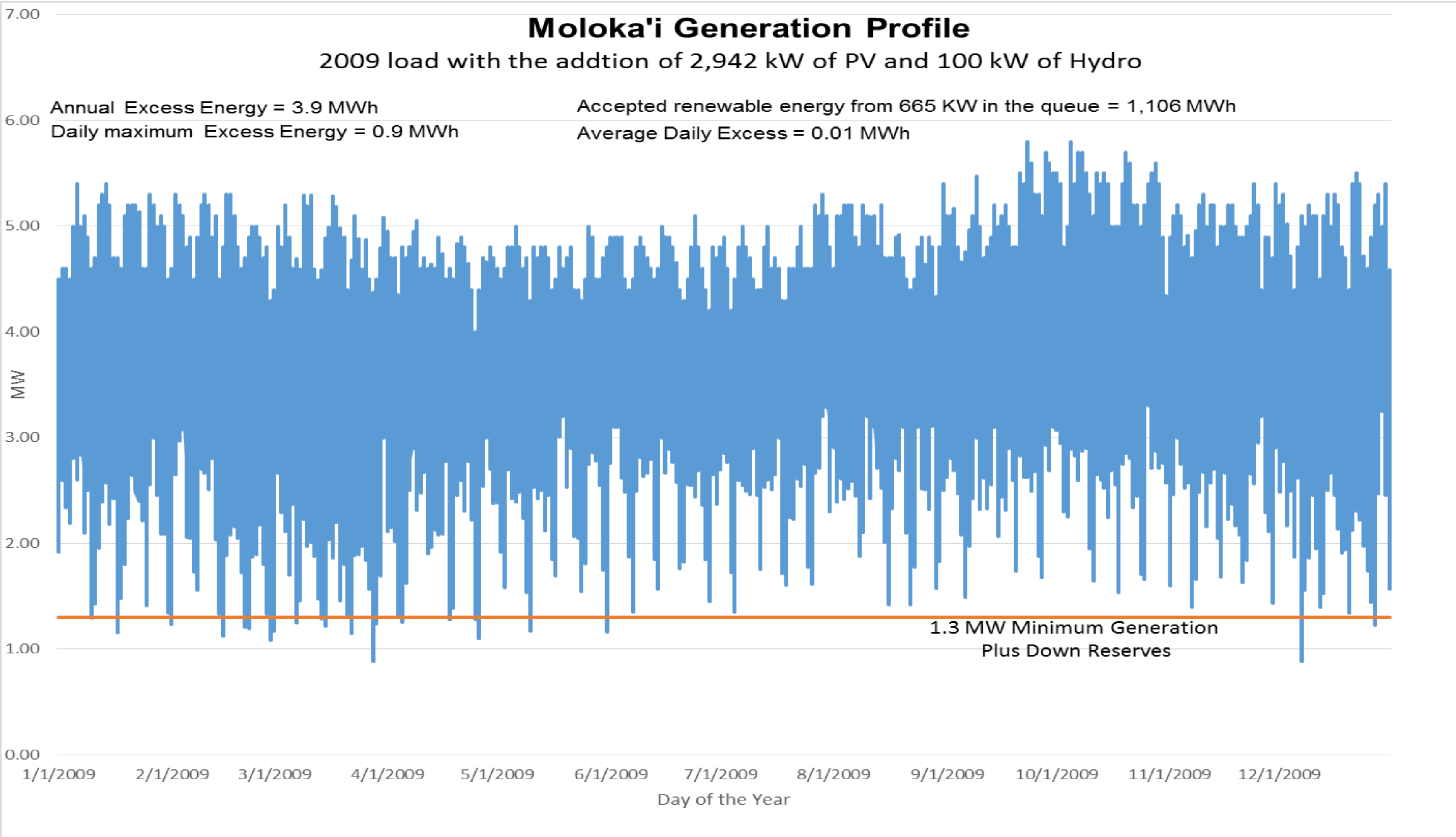
The real world consequences of the BESS running with a higher authority needs to be better understood.



UNIVERSITY of HAWAI'I MĀNOA

Alternatives to Storage

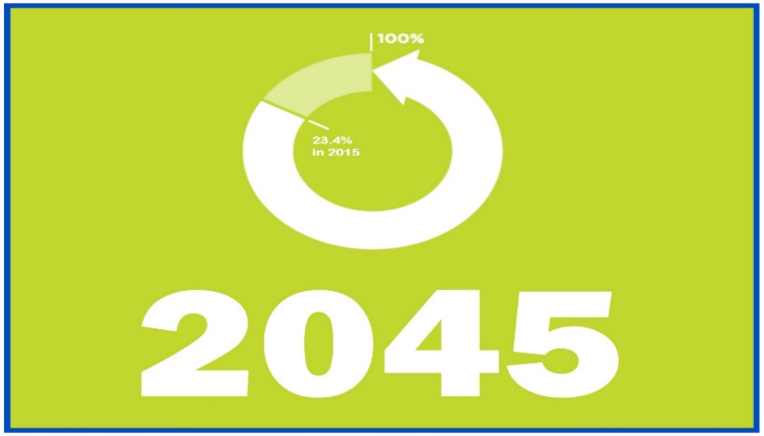
Dynamic Load Bank



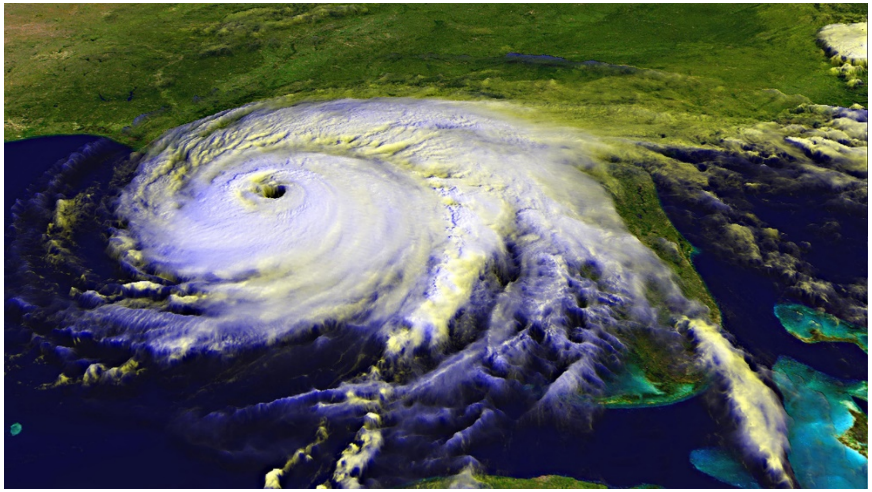
Small to moderate amount of excess RE curtailment is a sound integration strategy

UNIVERSITY of HAWAI'I
MĀNOA

Leadership in Energy Policy & Innovation



Environment, Climate Change



Jobs, Energy Security

Economic Development & Innovation

UNIVERSITY of HAWAI'I MĀNOA

Mahalo!

(Thank you)

For more information, contact:

GridSTART

Grid System Technologies Advanced Research Team

Leon R. Roose, Esq.
Principal & Chief Technologist
Grid***START***

Hawaii Natural Energy Institute
School of Ocean & Earth Science & Technology
University of Hawaii at Manoa
1680 East-West Road, POST 109
Honolulu, Hawaii 96822

Office: (808) 956-2331
Mobile: (808) 554-9891
E-mail: lroose@hawaii.edu
Website: www.hnei.hawaii.edu