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CANCUN MEXICO September 30-October 4, 2018
ECS and SMEQ Joint International Meeting

A04-213, Lithium-Ion batteries, Characterization 1, Tuesday, 2 October 2018

# Battery Durability and Reliability under Electric Utility Grid Operations: Representative Usage Aging

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Battery Durability and Reliability under Grid Operations

# Integrate **field data** with **lab testing** to predict lifetime BESS

## Objective/Significance

Evaluate degradation & lifetime of BESS in support of grid scale deployment

Improve economic understanding of future commercial & base deployments

## Approach

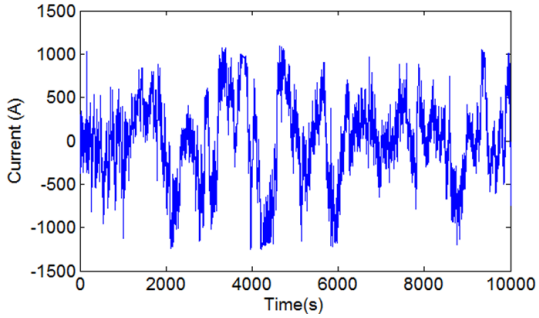
Assess battery performance in BESS and under controlled conditions

Analyze degradation using non-destructive methods

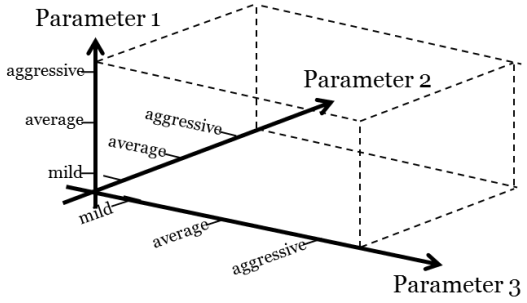
Link controlled and deployed degradation to forecast remaining useful life

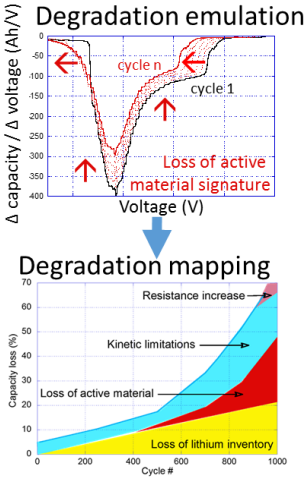
**Field data** → **Usage analysis** → **Laboratory testing** → **HNEI custom analysis**

Understand how the cells were utilized in the field



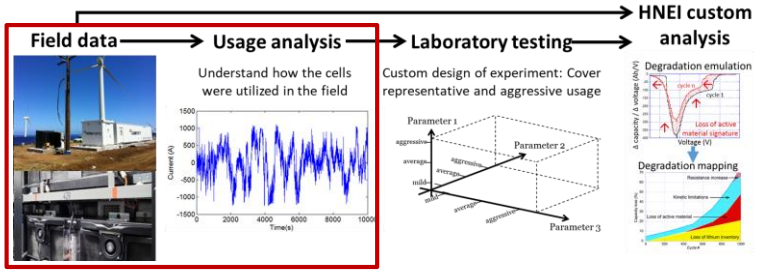

Custom design of experiment: Cover representative and aggressive usage



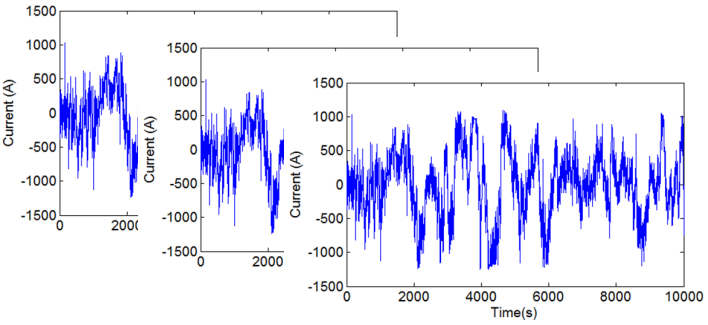



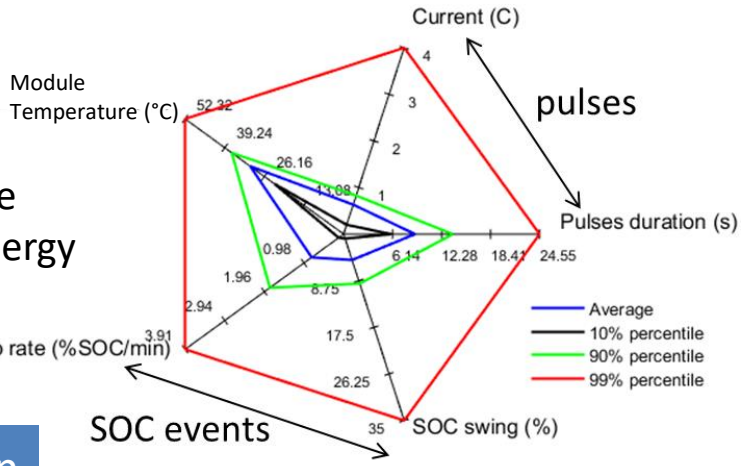
# Battery Durability and Reliability under Electric Utility Grid Operations

## Usage analysis

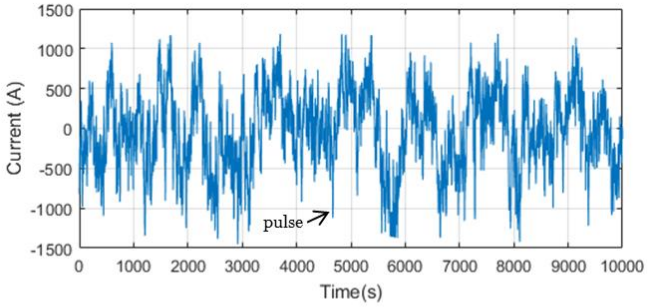


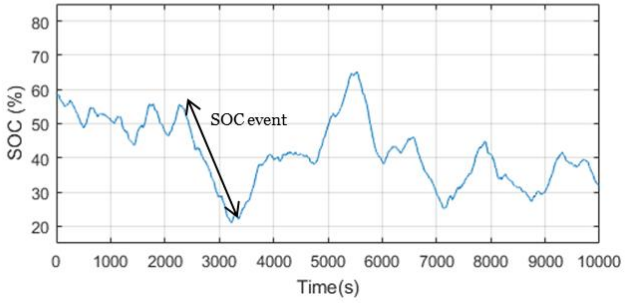

**In three years:**
In use 90% of the time
Stored 1.5 GWh of energy
>5000 battery cycles

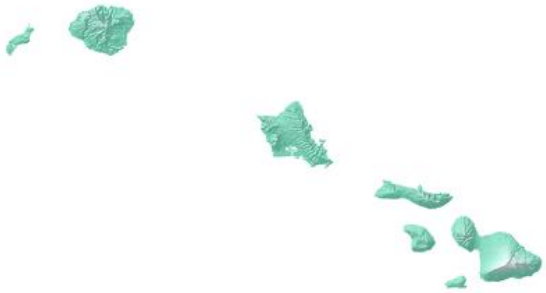



Usage of the cells can be described by 5 parameters:
9 second pulses,
C/2 current,
5% SOC swings,
0.75% SOC/min ramp rate, and 35°C



Big Island, HI (grid: 190MW)
Altairnano GEN1 50Ah cells,
1MW/250kWh,384(7P)S1P
Commissioned in December 2012
Frequency regulation, Wind Smoothing

Hawaiian Electric

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

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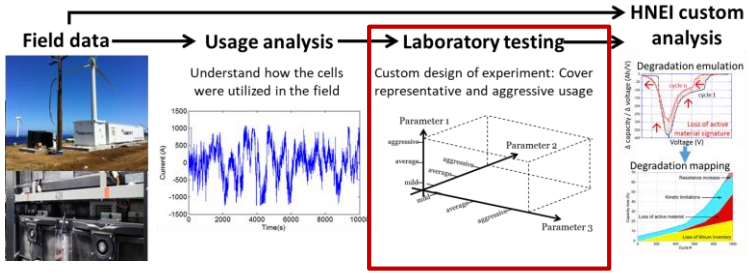
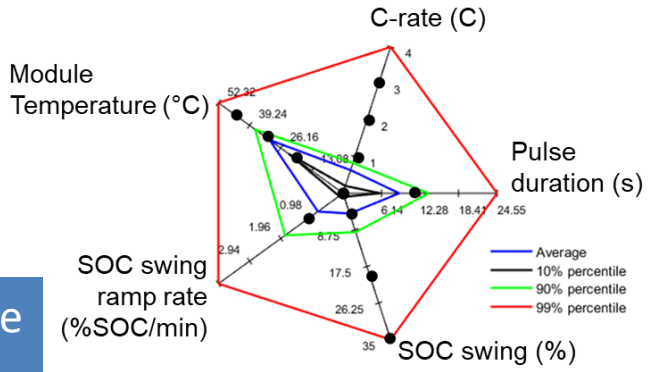
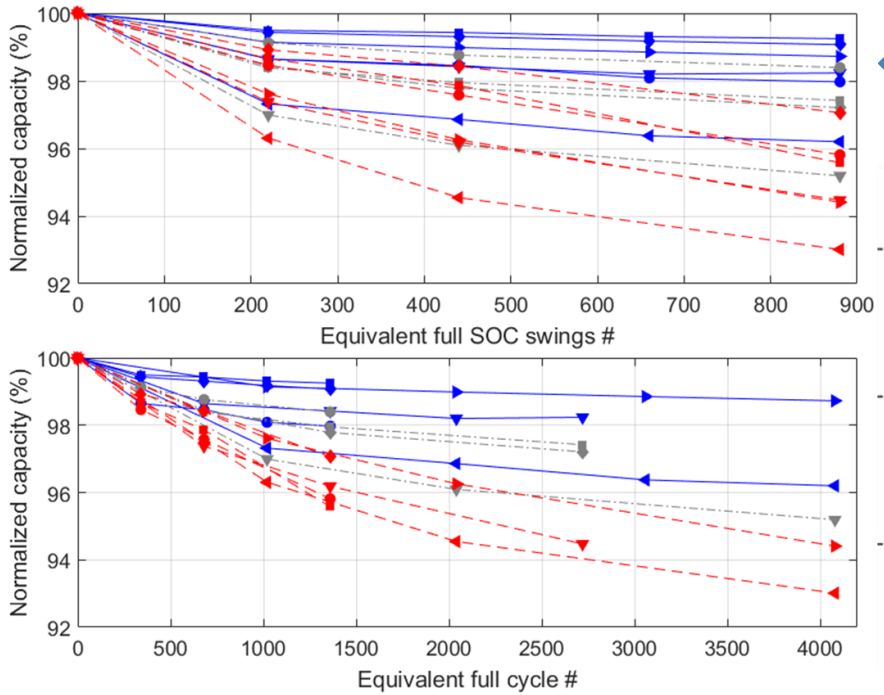
# Laboratory testing – Cycle aging

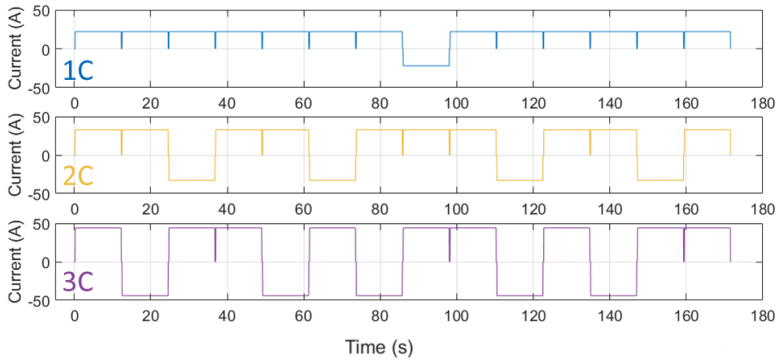


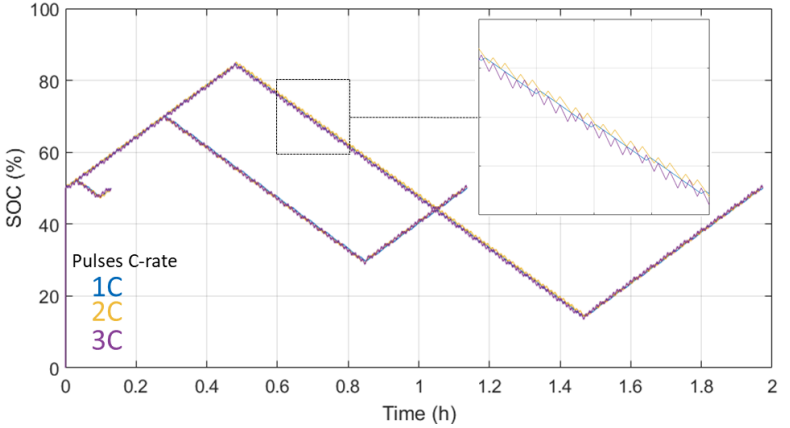




3 C rates,
3 temperatures,
3 SOC swings,
1 pulse duration,
1 SOC ramp rate

After 880 full SOC swings / 4000 cycles, the cells lost up to 7% of their capacity.
Impact of T, C and ΔSOC

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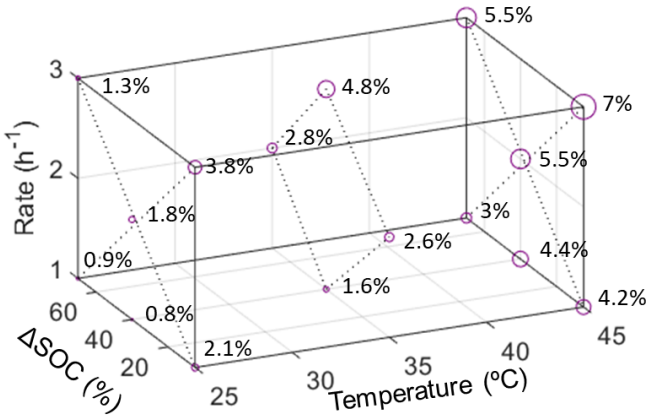
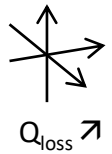
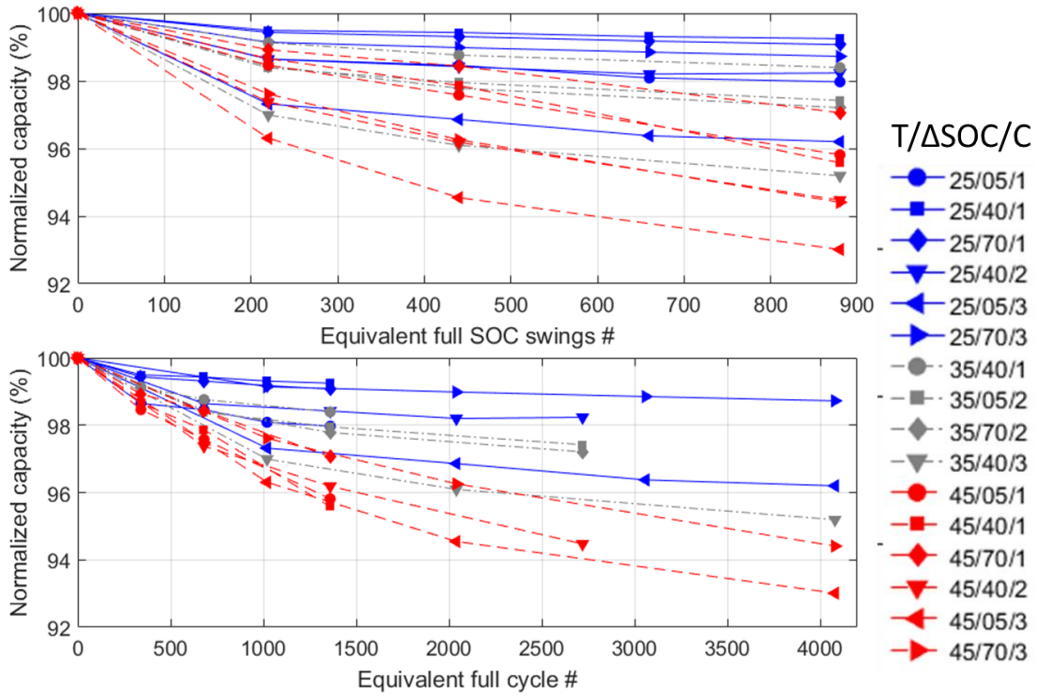
# Laboratory testing – Cycle aging

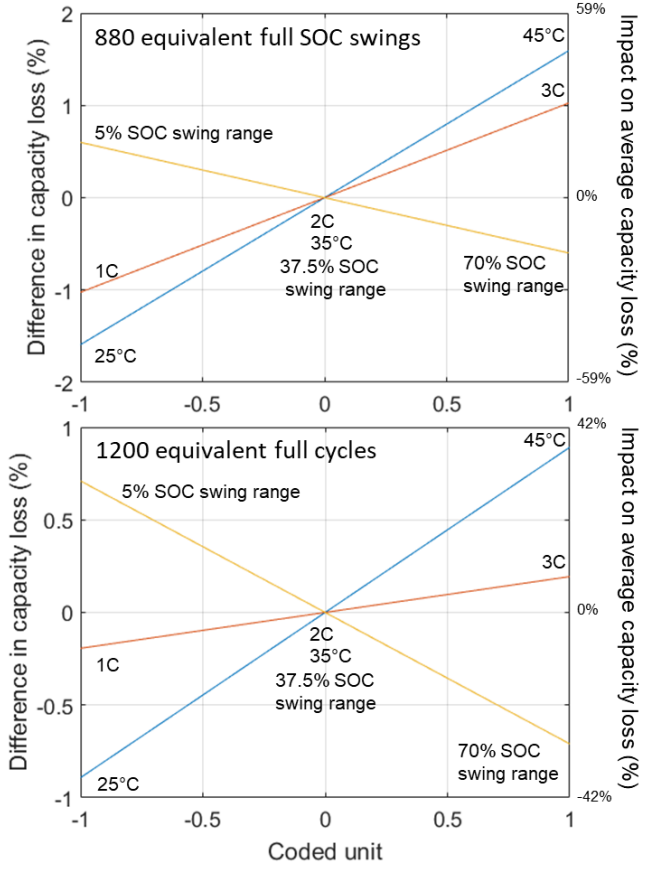



**Design of experiment methodology**

→ decompose impact of each effects




Temperature increase responsible for most degradation, followed by current increase and SOC swing decrease.

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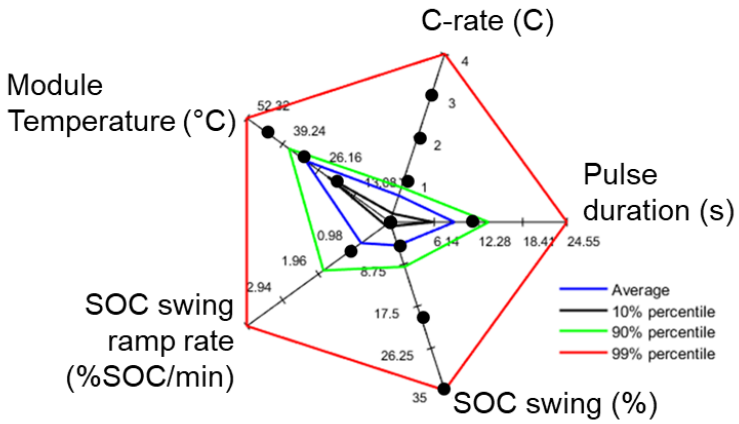
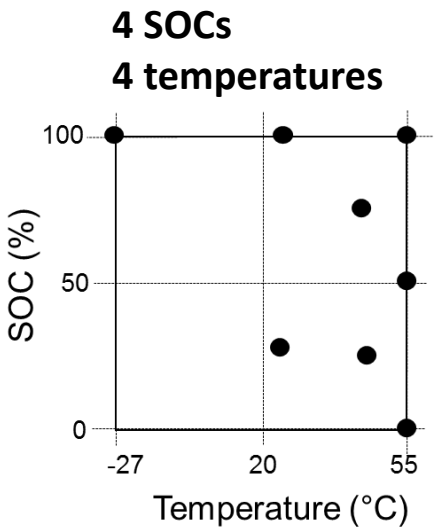
# Laboratory testing – Calendar aging

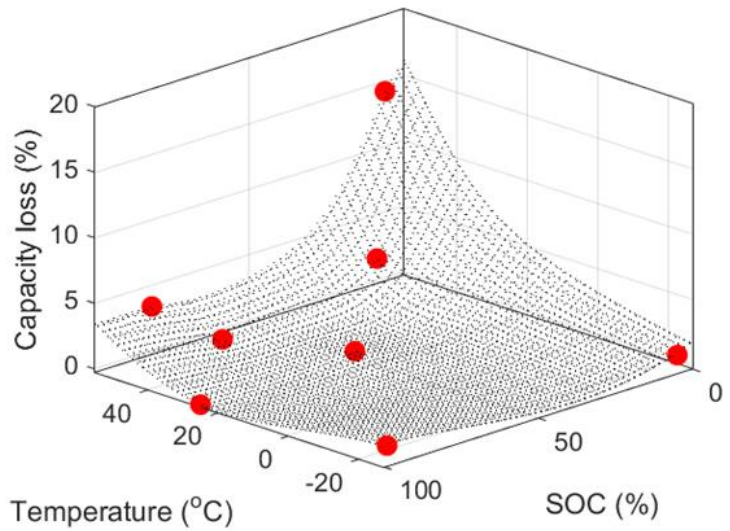


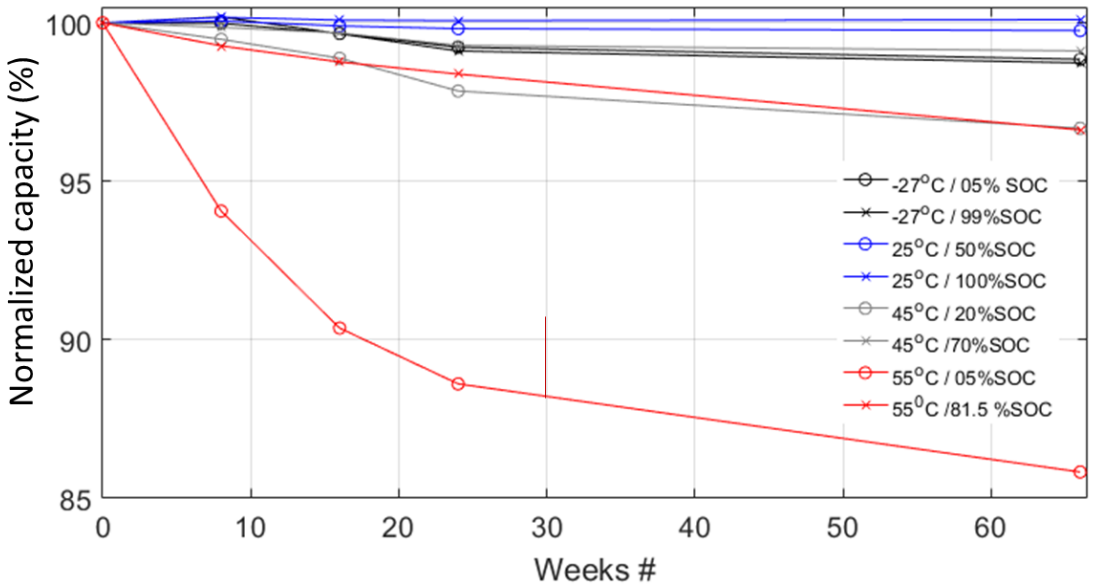




~ 1% loss after 16 months for T ≤ RT

Above RT, lower SOCs becomes aggravating factor

>10% loss at HT and LSoC replicated.

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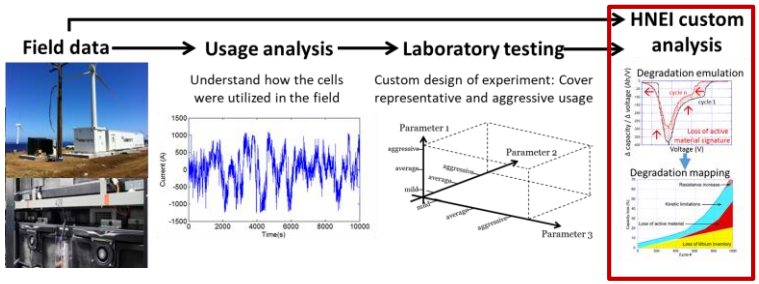
# HNEI custom analysis: Incremental capacity analysis



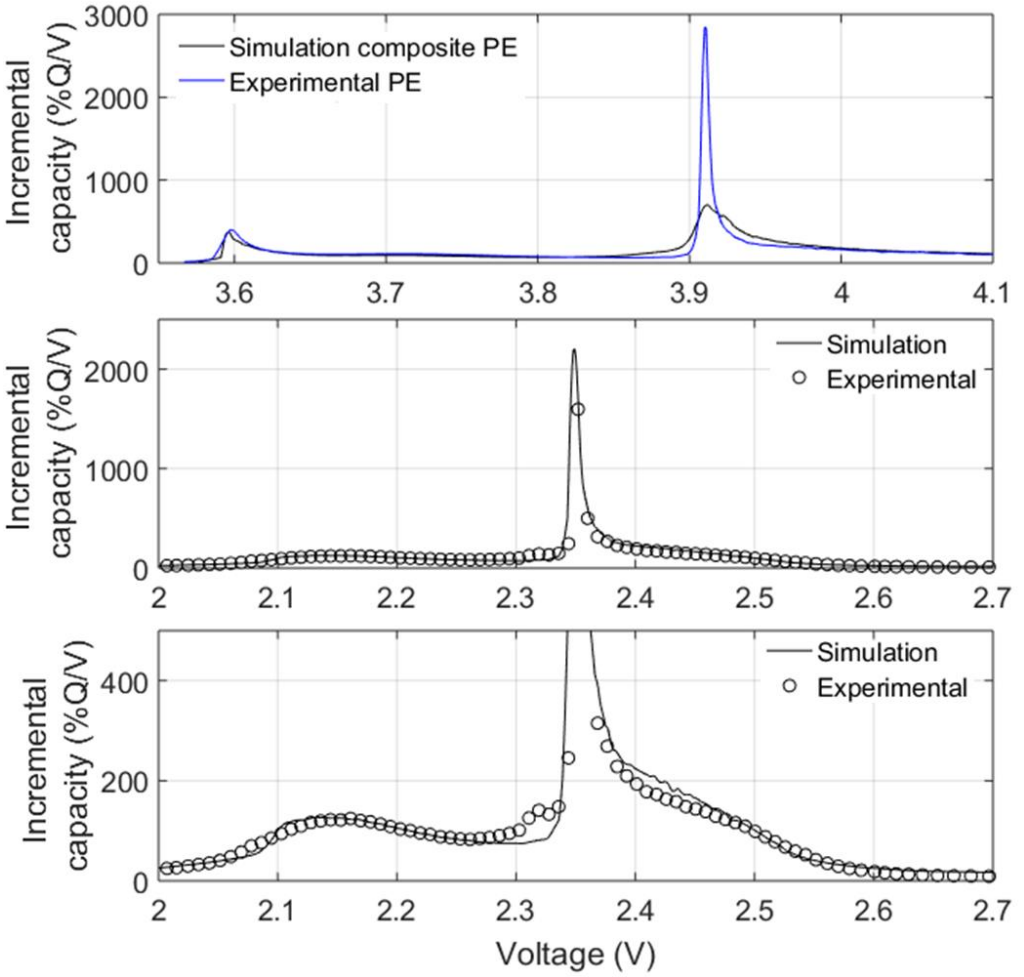

## Composite PE: LCO+NCA

No access to individual components

Fit with reference materials

Good fit except for intensity 3.9V peak

## Mechanistic modeling

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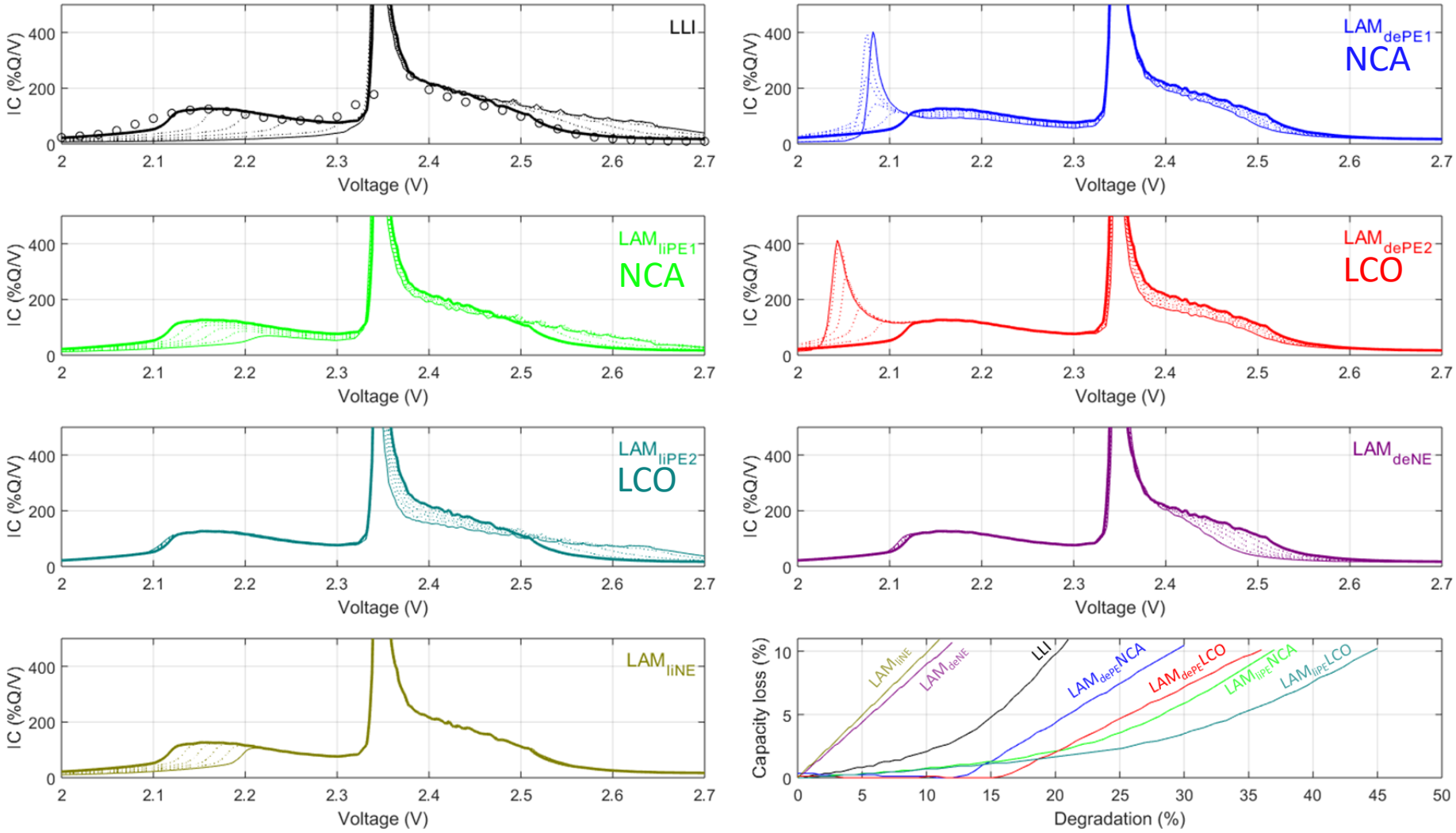
# HNEI custom analysis: Incremental capacity analysis

## Mechanistic modeling: Use fit to predict voltage response under different degradations

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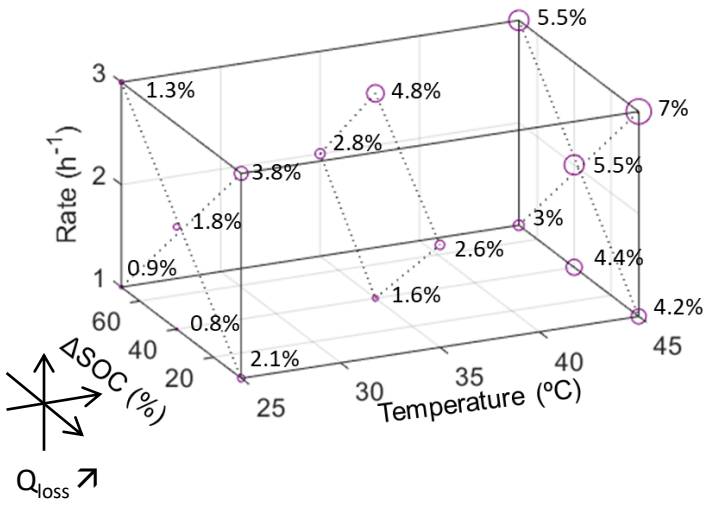
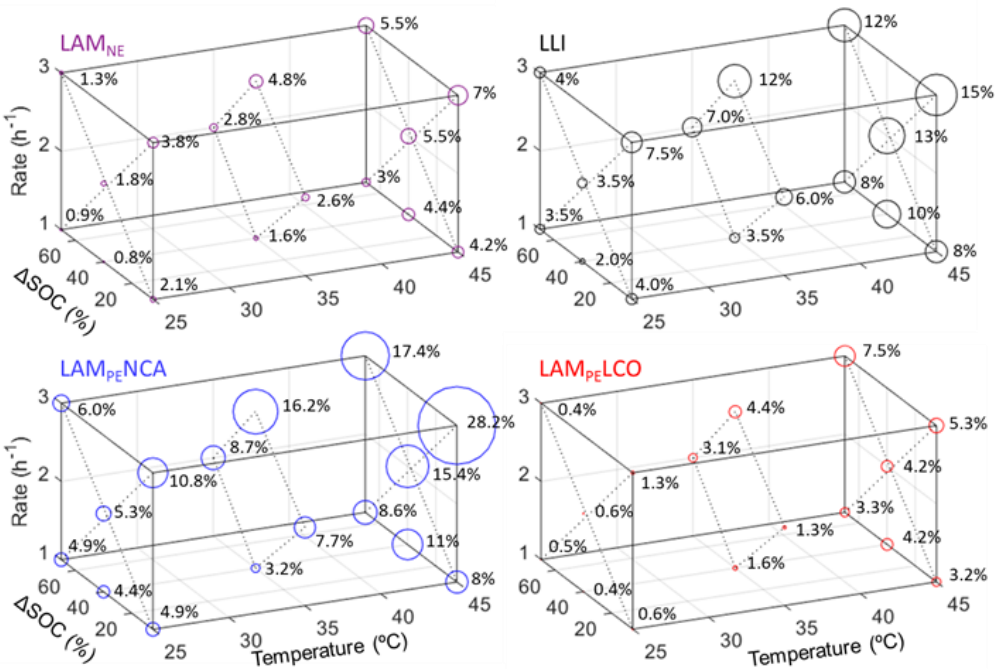
Assessed the impact of each active component of the cell

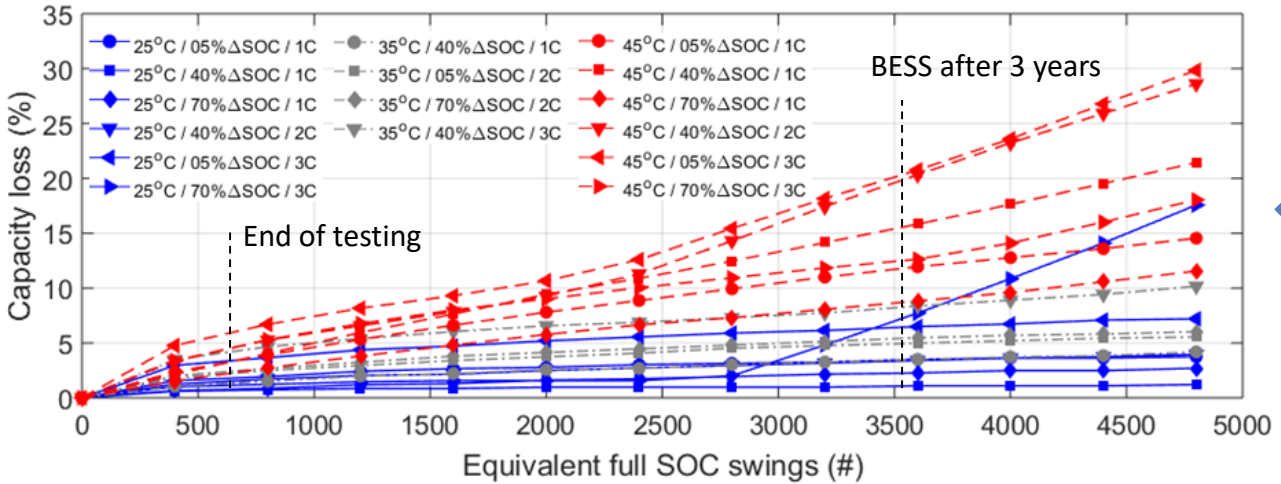
# Incremental capacity analysis – Cycle aging




**Use IC curves to quantify $LAM_{NE}$, $LAM_{PEs}$ and LLI**



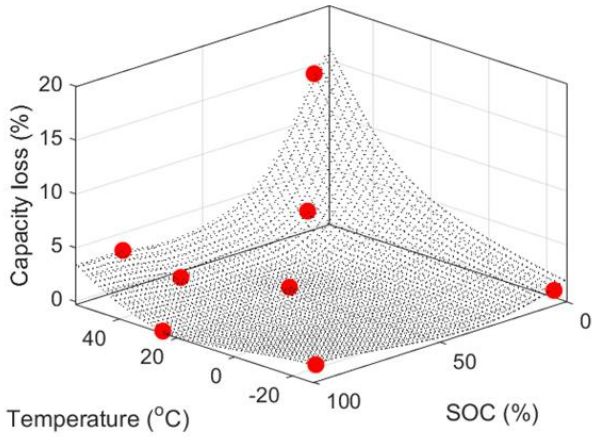

Degradation is much more important than that shown by capacity loss

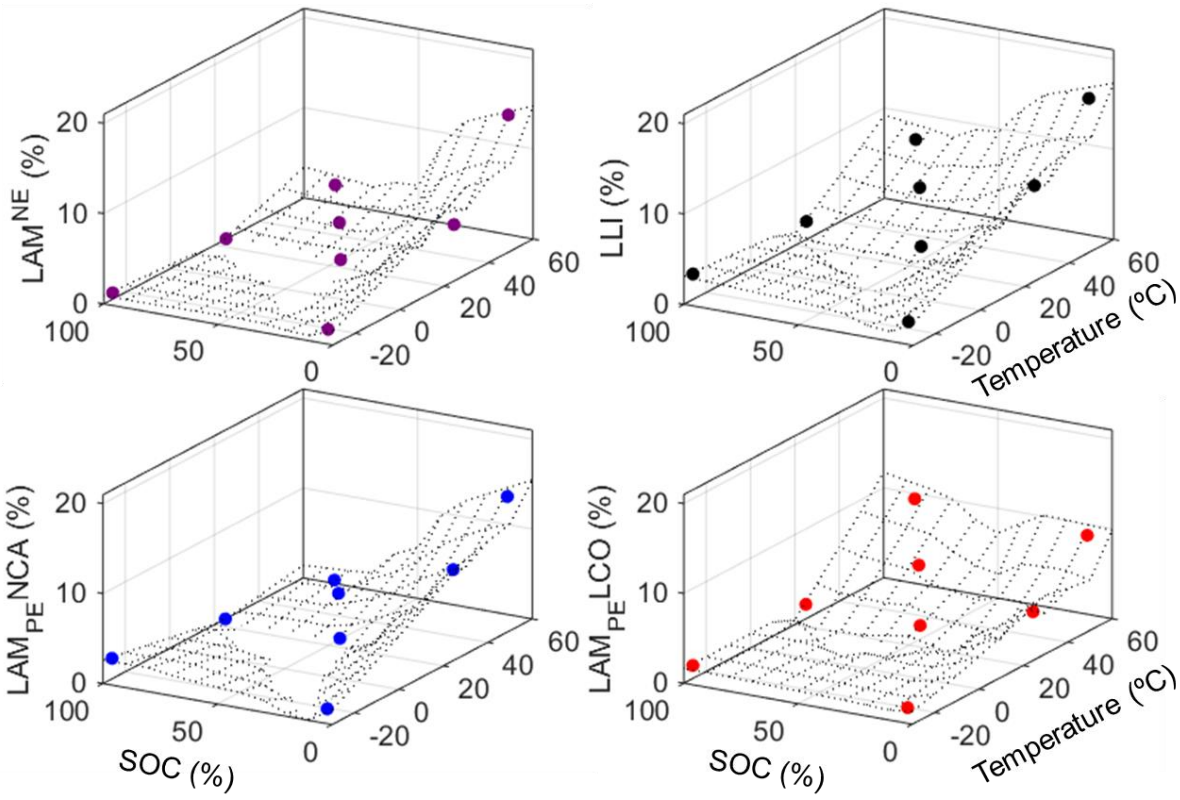



**Use mechanistic understanding**
to predict capacity fade

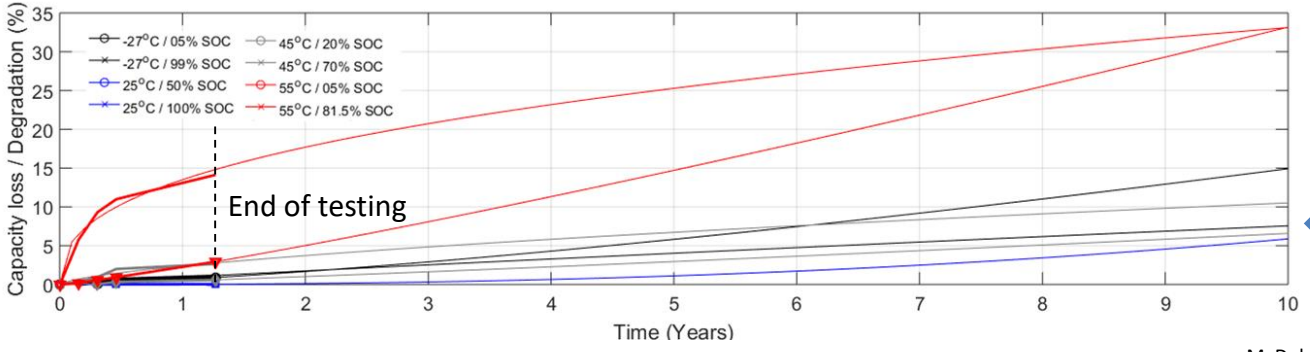
# Incremental capacity analysis – Calendar aging

**Use IC curves to quantify $LAM_{NE}$, $LAM_{PEs}$ and LLI**




Degradation is much more important than that shown by capacity loss




**Use mechanistic understanding**
to predict capacity fade

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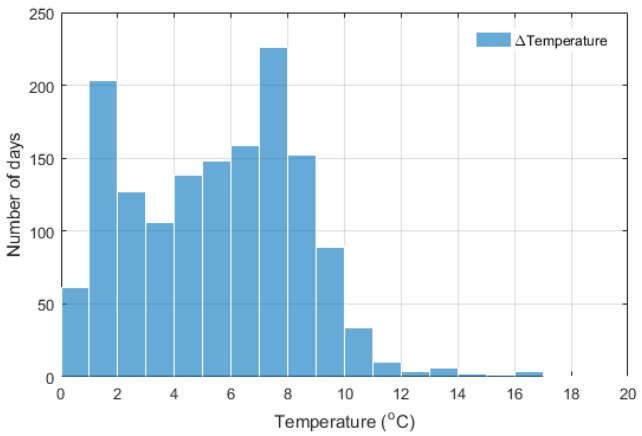
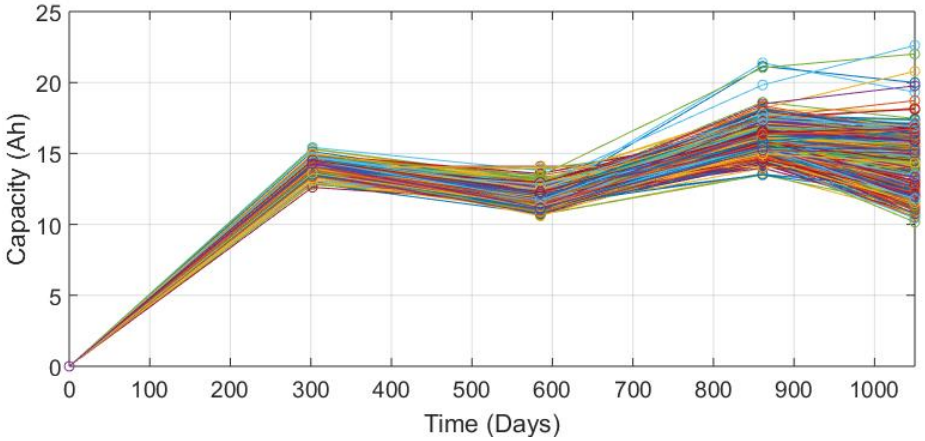
# Conclusions & Perspective

## Conclusions

### Found major impact for temperature, and SOC swing

Temperature impact could explain the spread observed in the field




### Big degradation despite small capacity losses

Significant $LAM_{PE}$ (both components) and LLI. Not yet associated with capacity loss

Path dependent degradation: different signature cycle / calendar and T / SOC.

## Perspective

Model performance based on laboratory testing

Compare lifetime performance model to field data to determine BESS SOH

Optimize BESS control strategies to limit degradation

# Acknowledgments

This work was supported by the Office of Naval Research (ONR) Asia Pacific Research Initiative for Sustainable Energy Systems (APRISES), award # N00014-13-1-0463 and N00014-16-1-2116.

The authors are grateful to the Hawaiian Electric Company for their ongoing support to the operations of the Hawaii Sustainable Energy Research Facility.

*Thank you for your attention! Questions ?*

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ICESI

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January 5-10, 2019
Hilton Waikoloa Village, HI, USA
http://www.soest.hawaii.edu/PPSS-2019/

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

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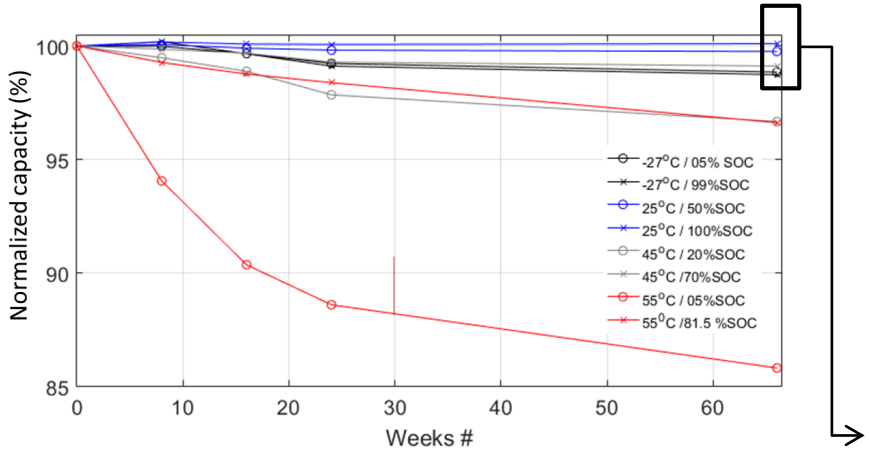
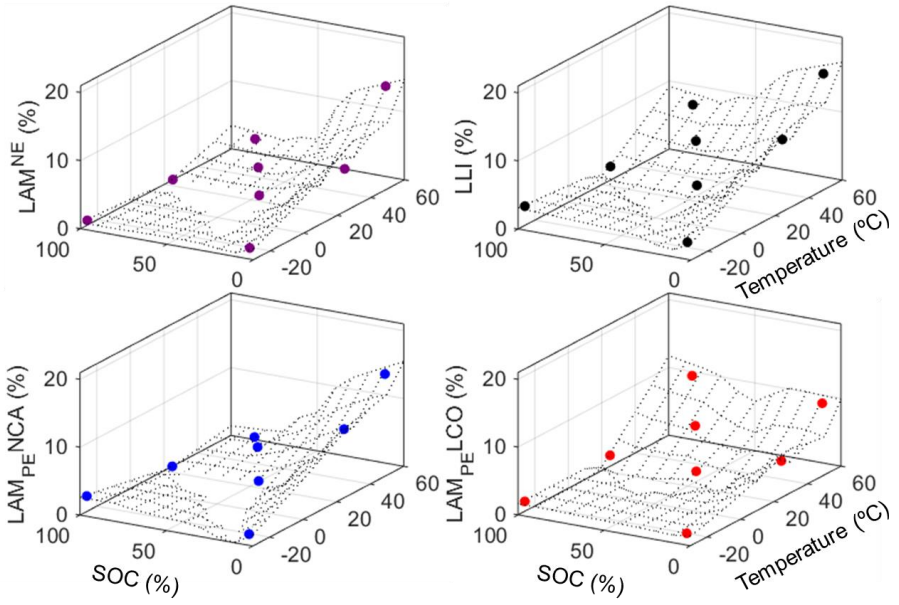
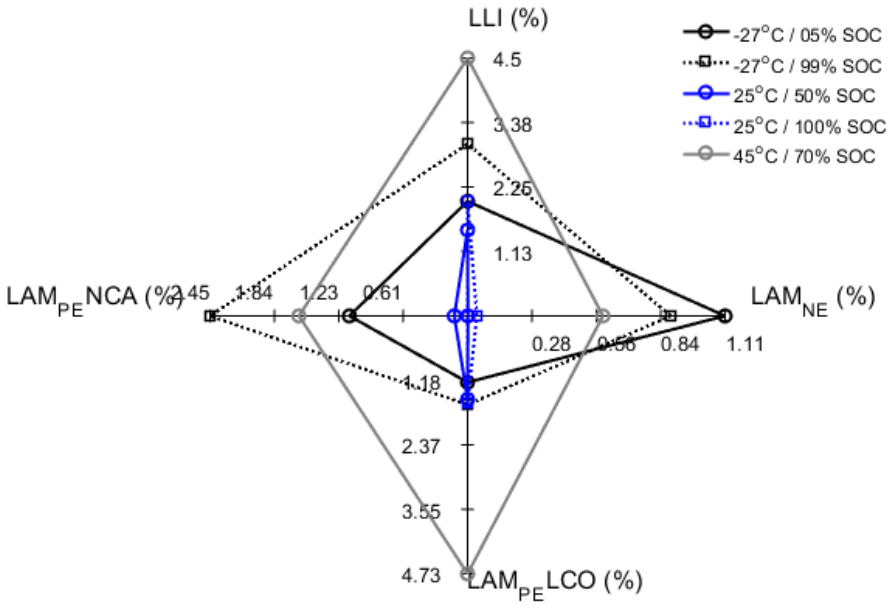
# Incremental capacity analysis – Calendar aging

## Aging path dependence




**Calendar aging** induces different degradations
Significant degradation despite small capacity loss




Different that cycle aging degradation
Highlight importance to test a particular battery for a given application

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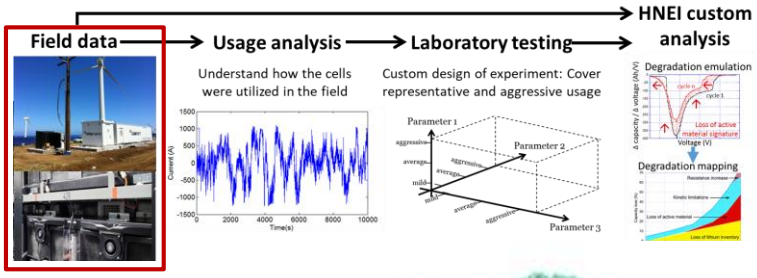
# Battery Durability and Reliability under Electric Utility Grid Operations

## Field data




O'ahu, HI (grid: 1.1TW)
1MW/250kWh,
Commissioned in February 2016
Altairnano GEN2 60Ah cells, 384(7P)S1P
Volt-VAR, Power quality


Moloka'i, HI (grid: 5.5MW)
2MW/330kWh, Commissioned in February 2016
Altairnano GEN2 60Ah cells, 416(7P)S1P
Reserve, Fault response


Big Island, HI (grid: 190MW)
1MW/250kWh, Commissioned in December 2012
Altairnano GEN1 50Ah cells, 384(7P)S1P
Frequency regulation, Wind Smoothing


Demonstrated over 8000 full cycles equivalent operation

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