IBA 02 - Characterization, Testing, Data Analysis, Protocols, and Procedures

Battery Durability and Reliability under Electric Utility Grid Operations

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Battery Durability and Reliability under Grid Operations

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

Hawaiian Electric

GridSTART

Objective/Significance

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

Improve economic understanding of future commercial & base deployments

Approach

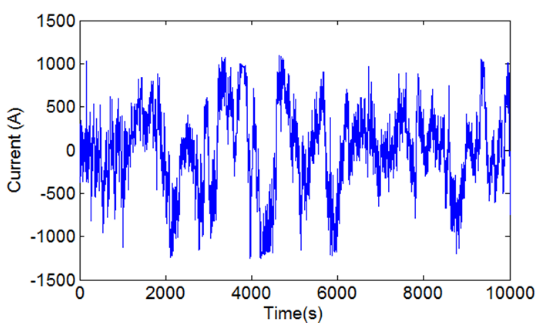
Assess battery performance in BESS and under controlled conditions

Analyze degradation using non-destructive methods

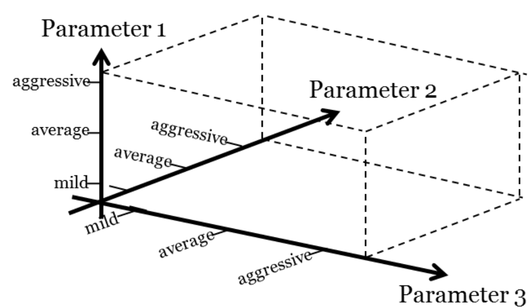
Link controlled and deployed degradation to forecast remaining useful life

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

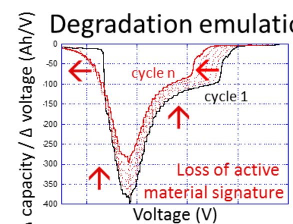
Understand how the cells were utilized in the field



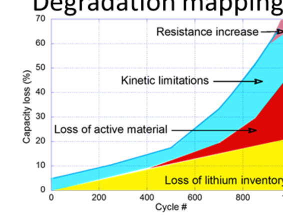
Custom design of experiment: Cover representative and aggressive usage



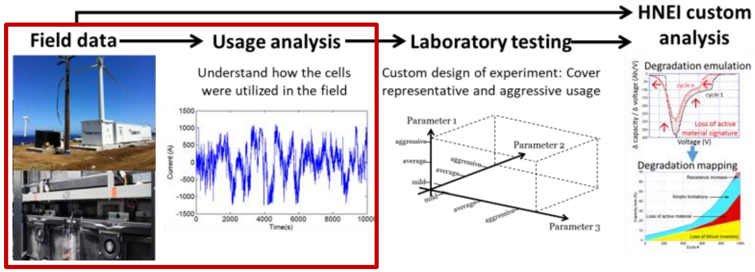
Degradation emulation

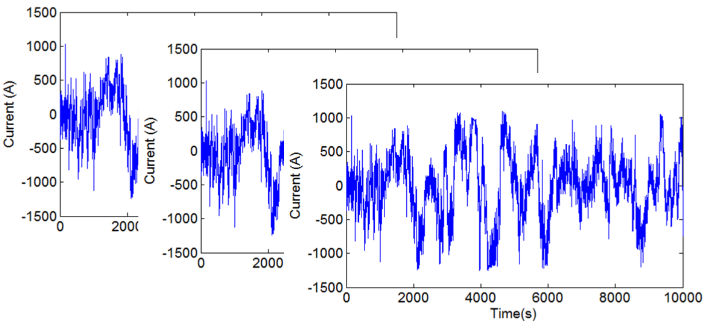


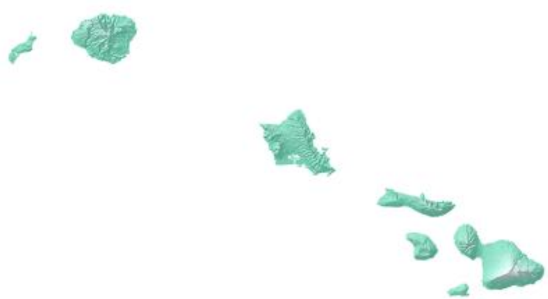
Degradation mapping



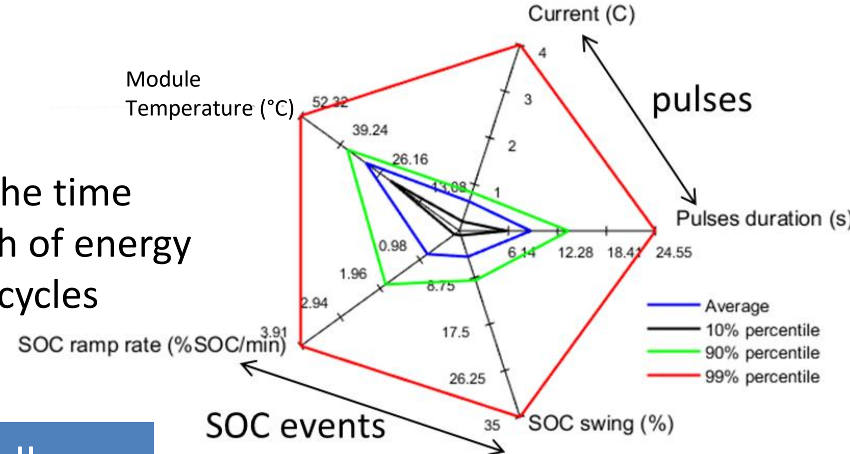
Usage analysis



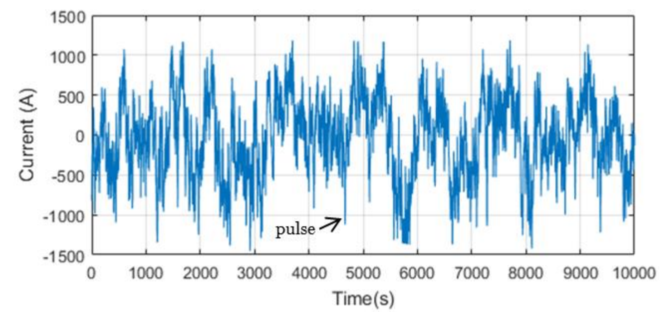




In three years:
In use 90% of the time
Stored 1.5 GWh of energy
>5000 battery cycles



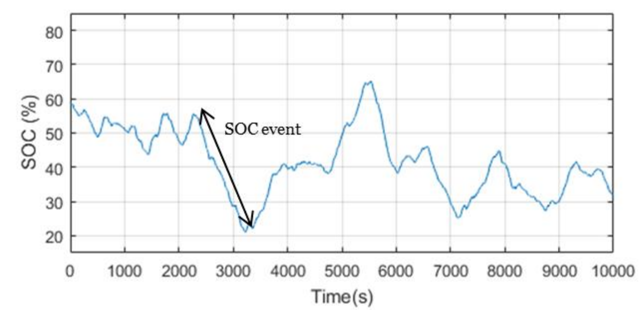
Usage of the cells can be described by 5 parameters:
9 second pulses,
C/2 current,
5% SOC swings,
0.75% SOC/min ramp rate, and 35°C



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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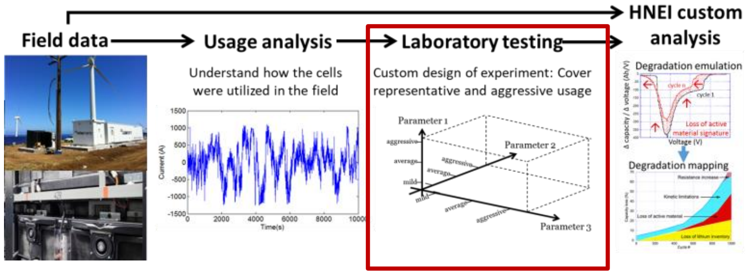
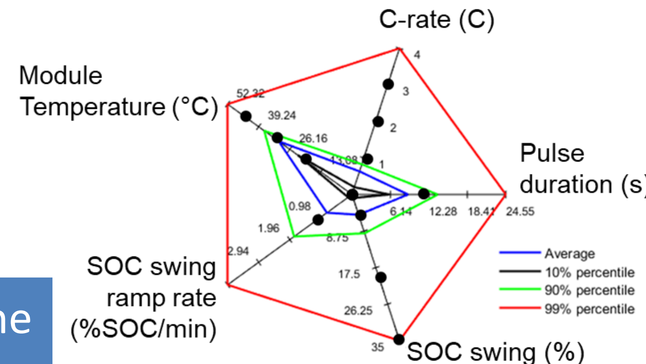
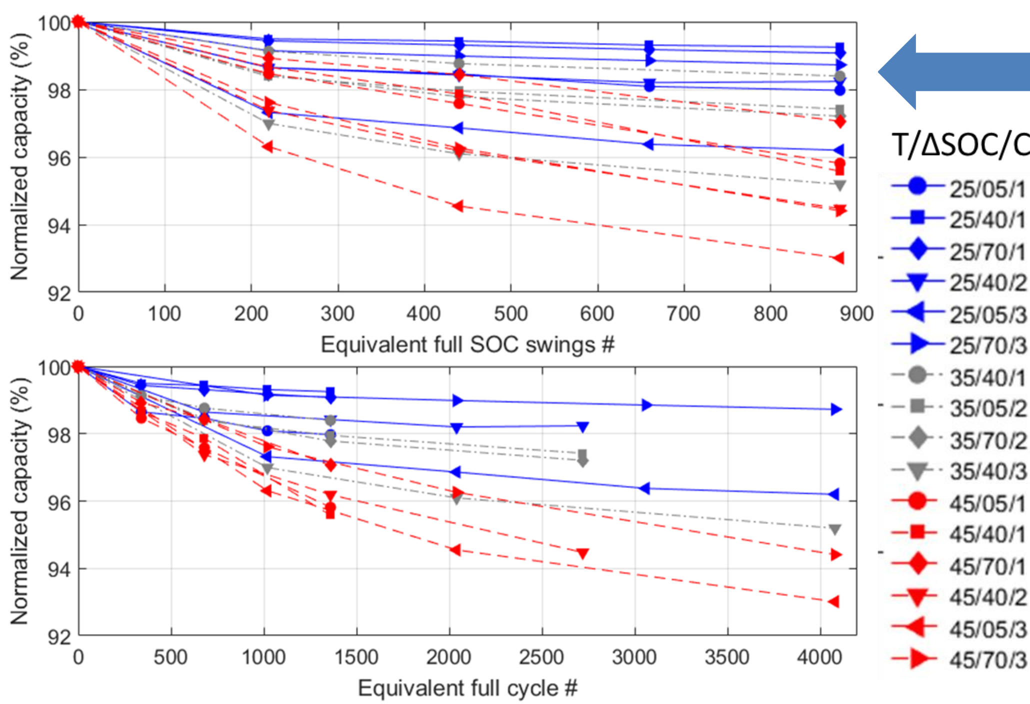
Laboratory testing – Cycle aging

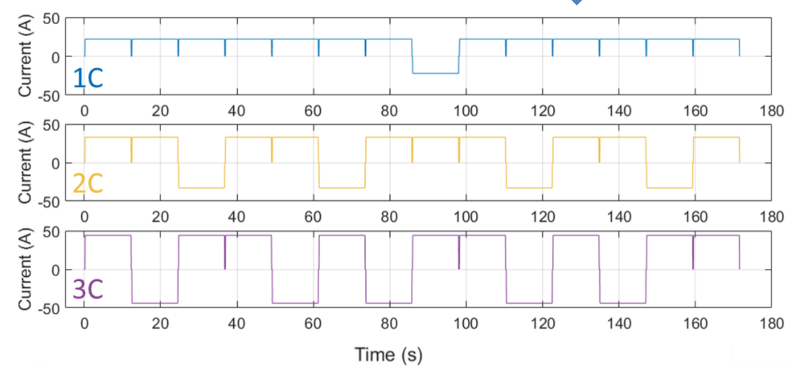


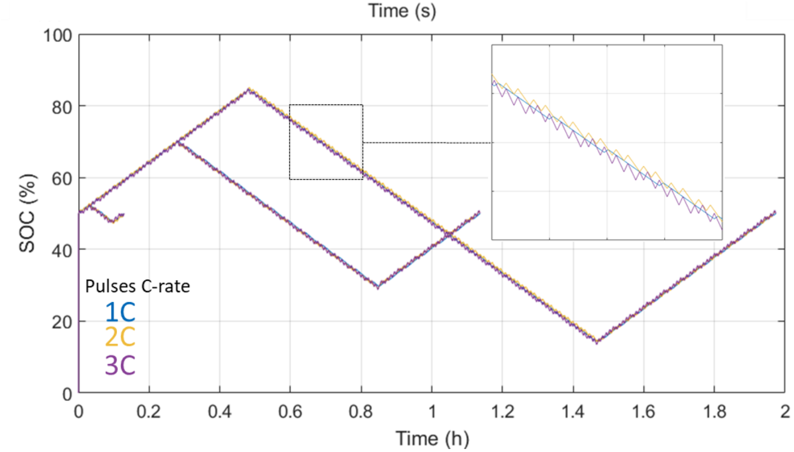


3 C rates,
3 temperatures,
3 SOC swings,
1 pulse duration,
1 SOC ramp rate

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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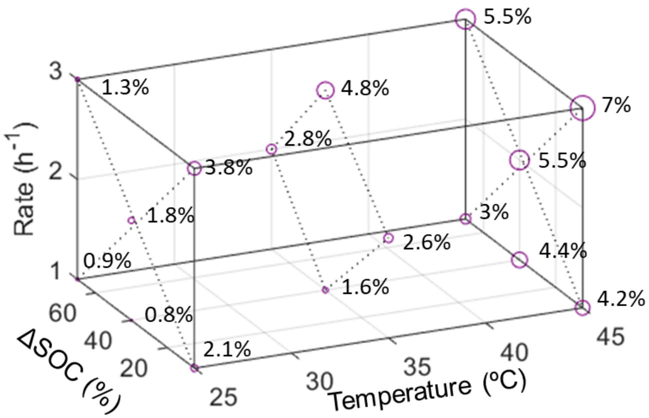
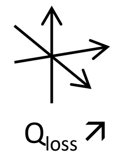
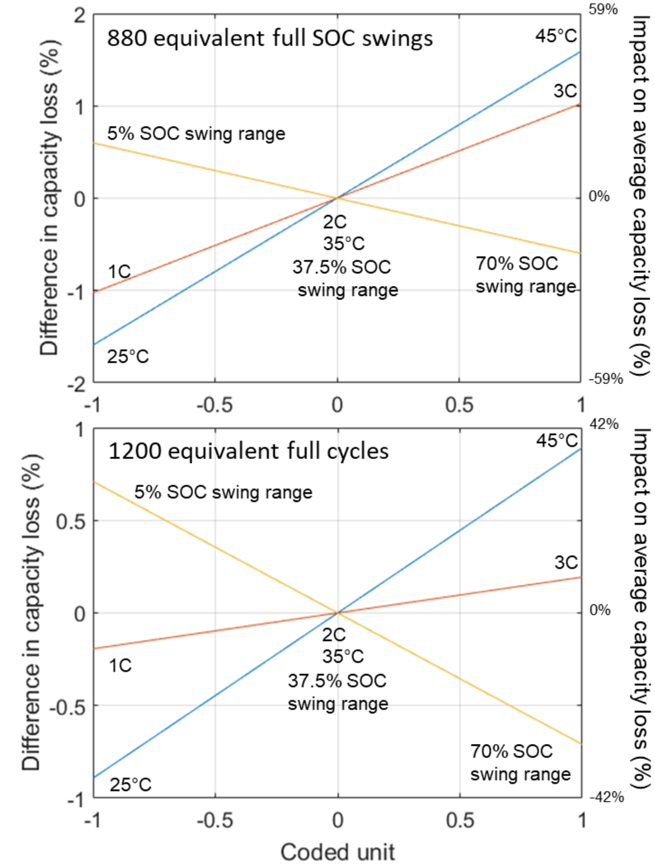
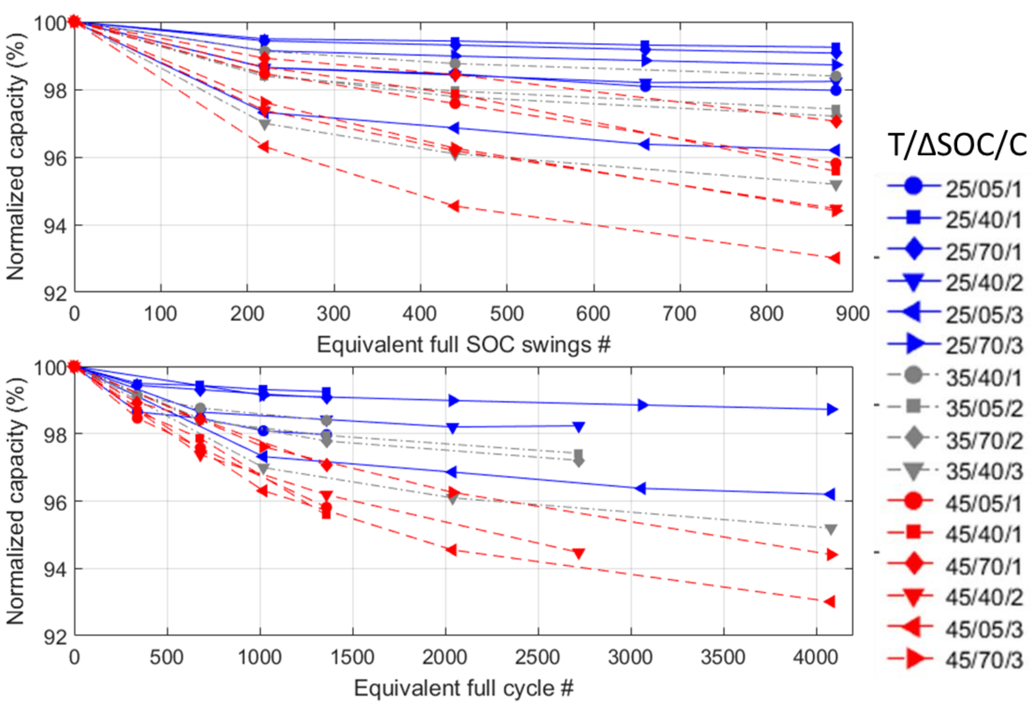
Laboratory testing – Cycle aging





Design of experiment methodology
→ decompose impact of each effects





Temperature increase responsible for most degradation, followed by current increase and SOC swing <u>decrease</u>.

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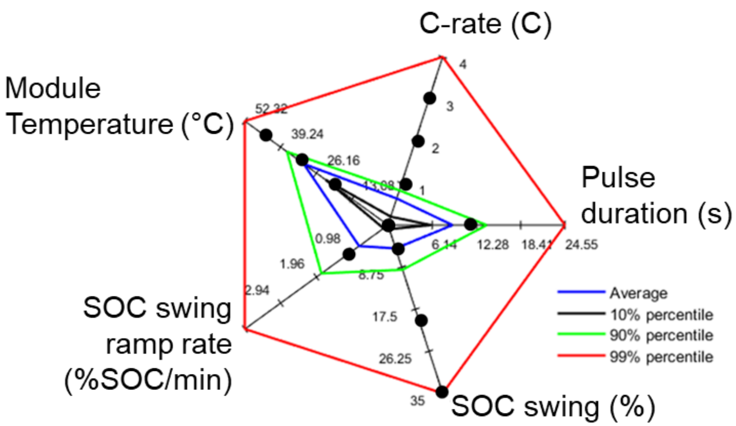
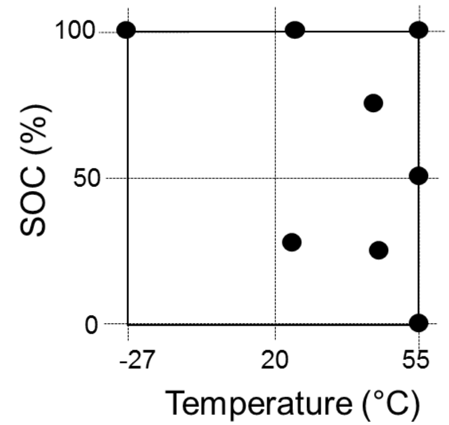
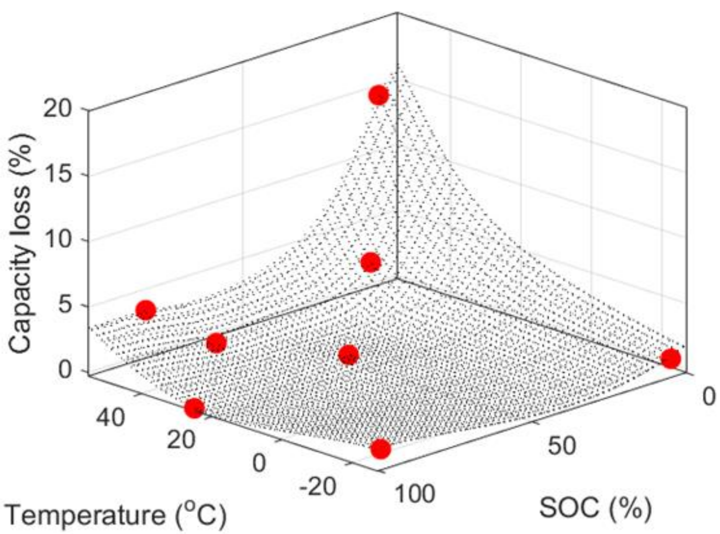
Laboratory testing – Calendar aging

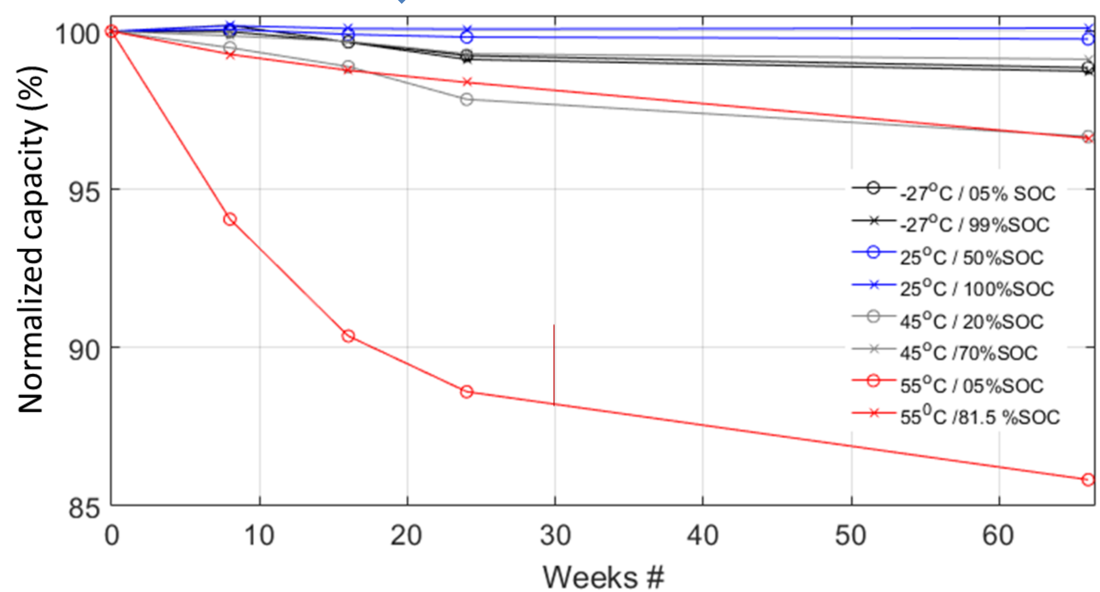


4 SOCs
4 temperatures



~ 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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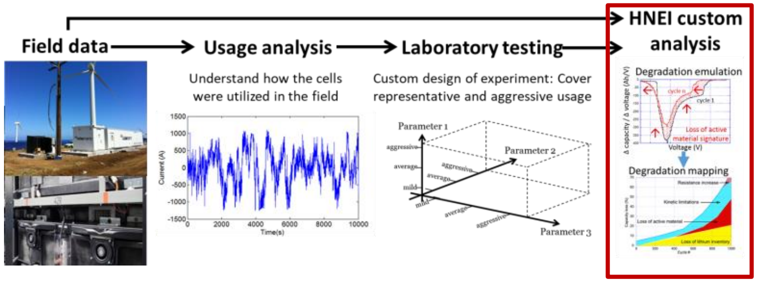
HNEI custom analysis: Incremental capacity analysis

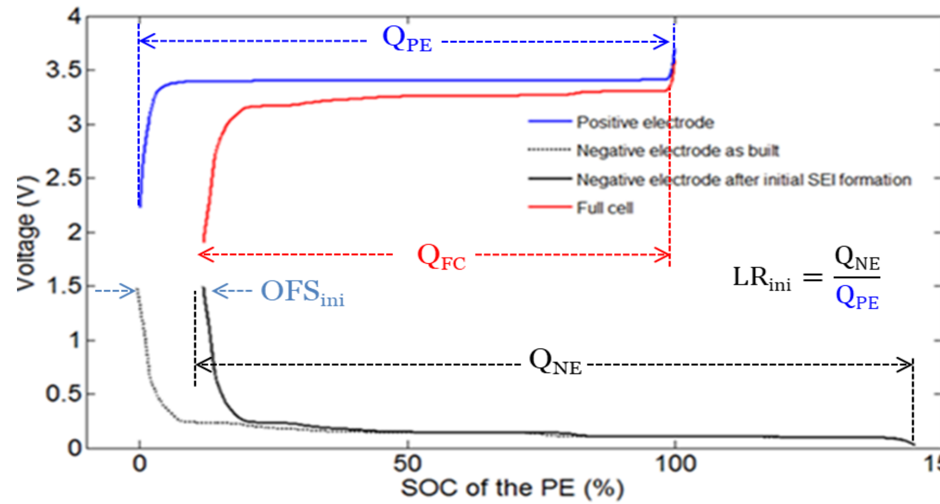


Composite PE: LCO+NCA

No access to individual components

Fit with reference materials

Mechanistic modeling



$$LR = \frac{100\% - \%LAM_{deNE} - \%LAM_{liNE}}{100\% - \%LAM_{dePE} - \%LAM_{liPE}} LR_{ini}$$

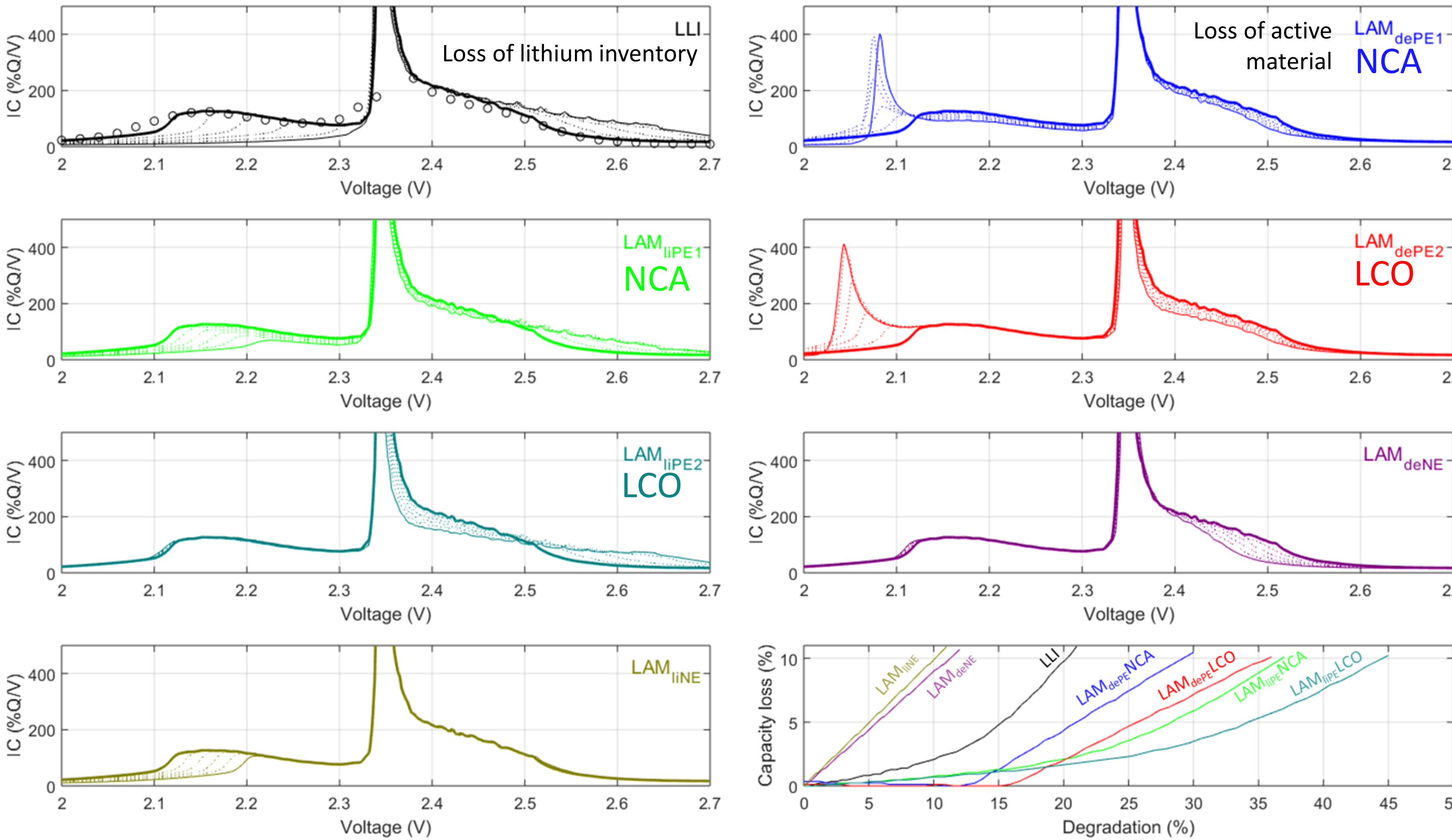
$$OFS = OFS_{ini} + LR\ \%LAM_{liNE} - \frac{LR}{LR_{ini}}\ \%LAM_{dePE} + \%LLI_{ch} - \%LLI_{dis}$$

Emulation of degradation modes on voltage:
- Loss of lithium inventory (LLI),
- Loss of active material (LAM) on positive and negative electrodes (PE & NE).

M. Dubarry et al. Journal of Power Sources 219 (2012) 204-216
M. Dubarry et al. / Journal of the Electrochemical Society, in preparation

HNEI custom analysis: Incremental capacity analysis

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



Assessed the impact of each active component of the cell

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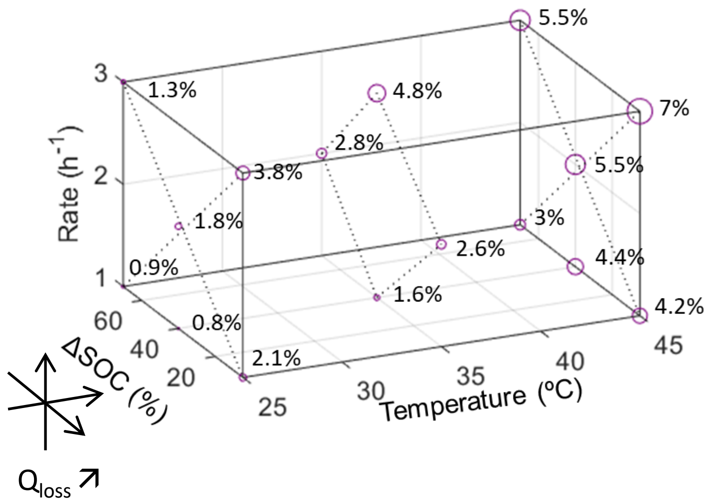
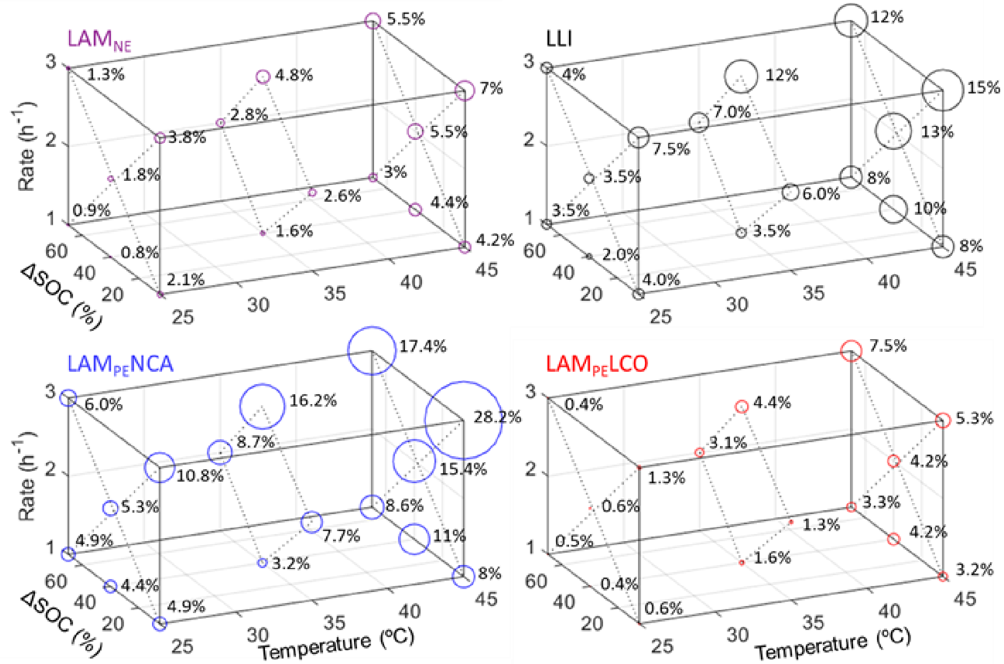
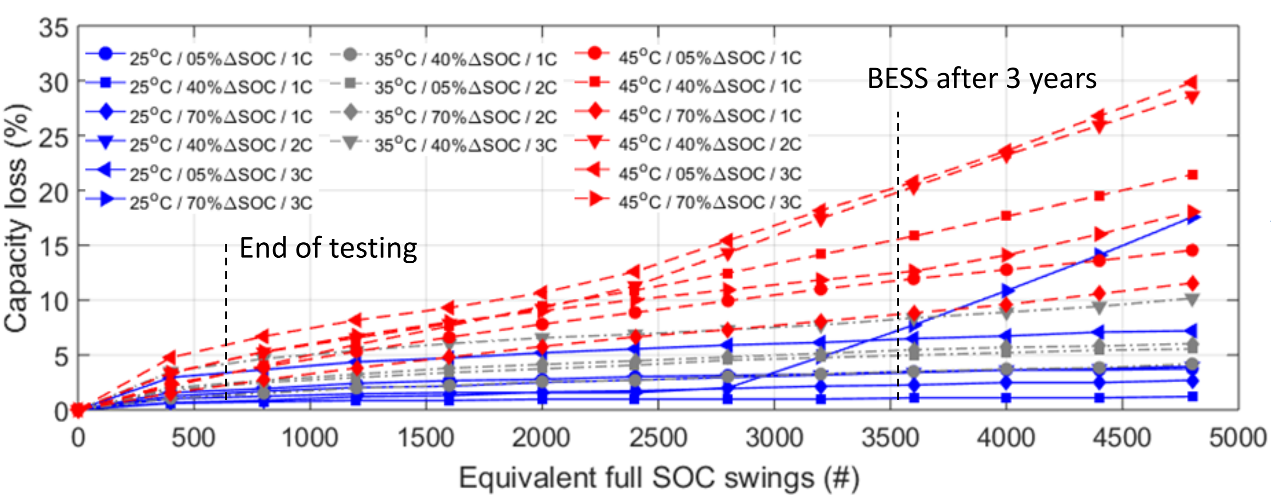
Incremental capacity analysis – Cycle aging



Degradation is much more important than that shown by capacity loss

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

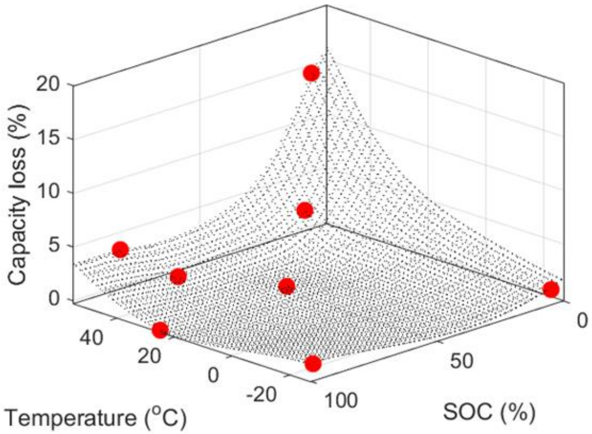


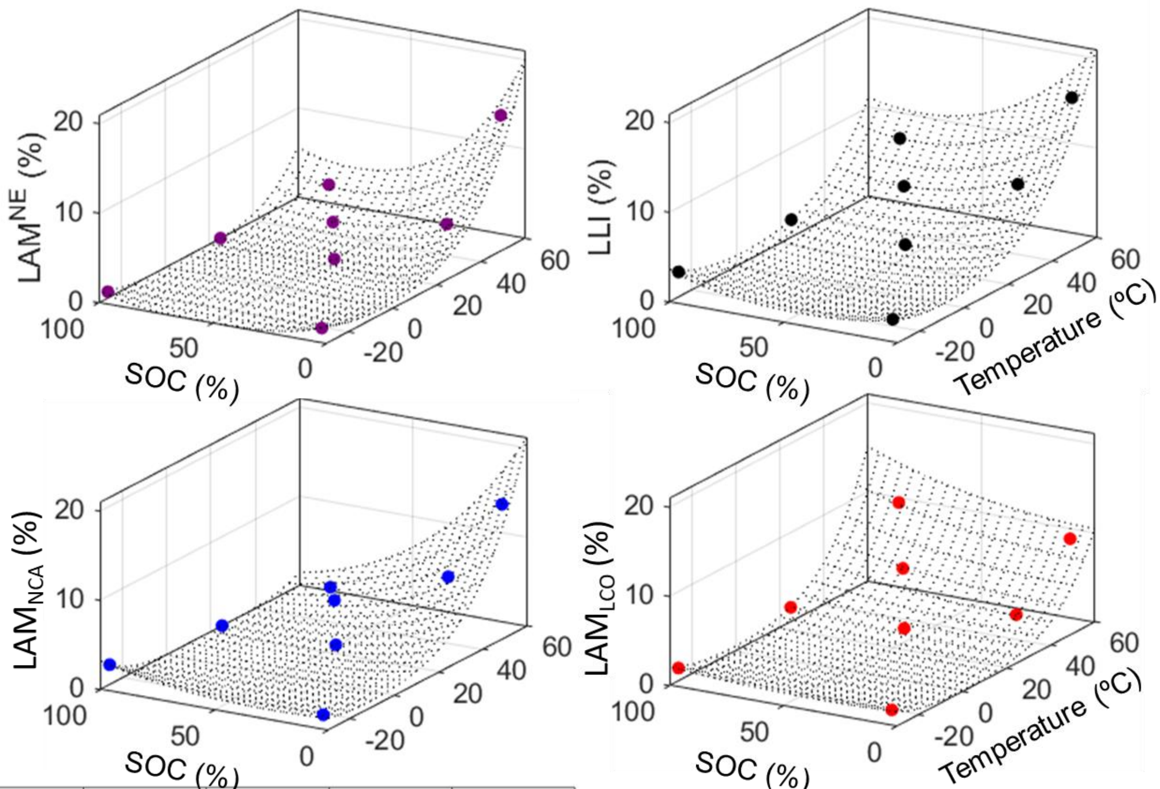


Use mechanistic understanding to predict capacity fade

Incremental capacity analysis – Calendar aging

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





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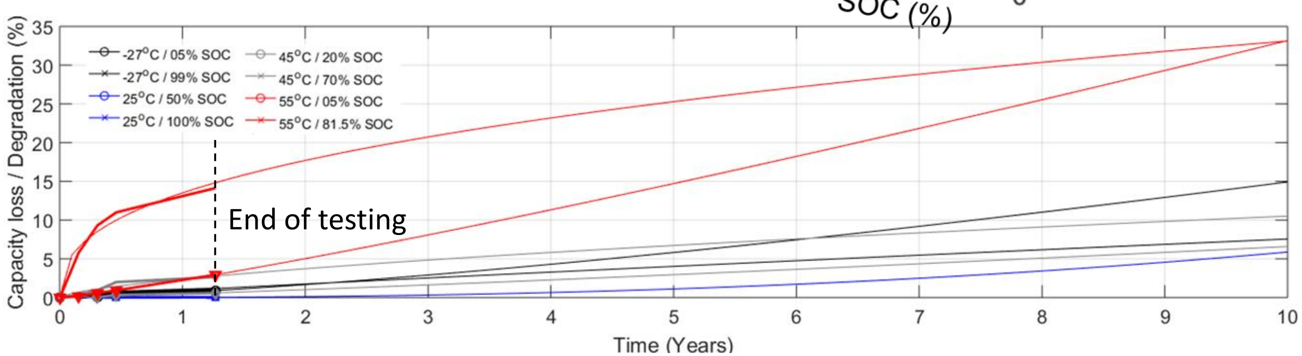

Use mechanistic understanding to predict capacity fade

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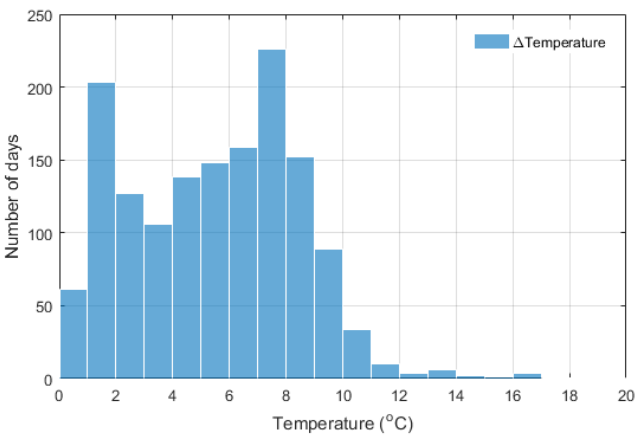
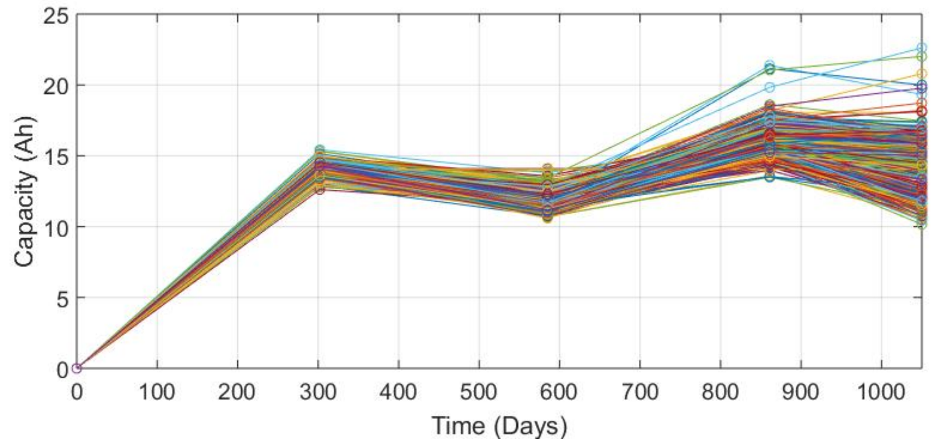
Conclusions & Perspective

Conclusions

Found major impact for temperature, and SOC swing

Explain 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

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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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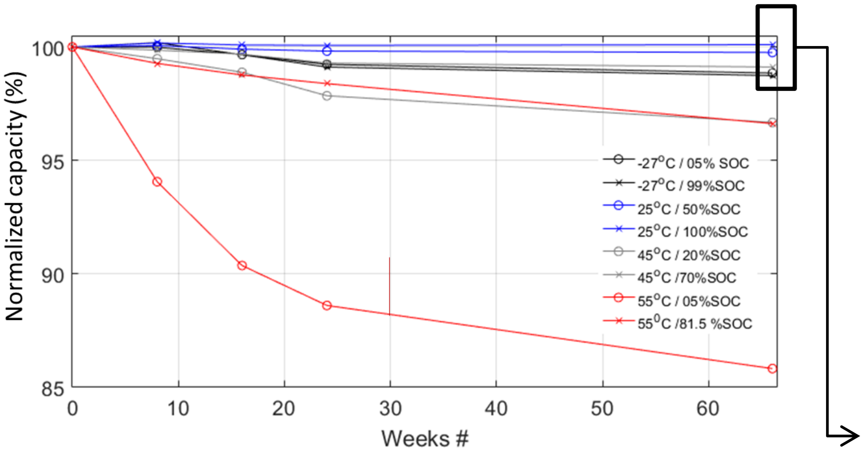
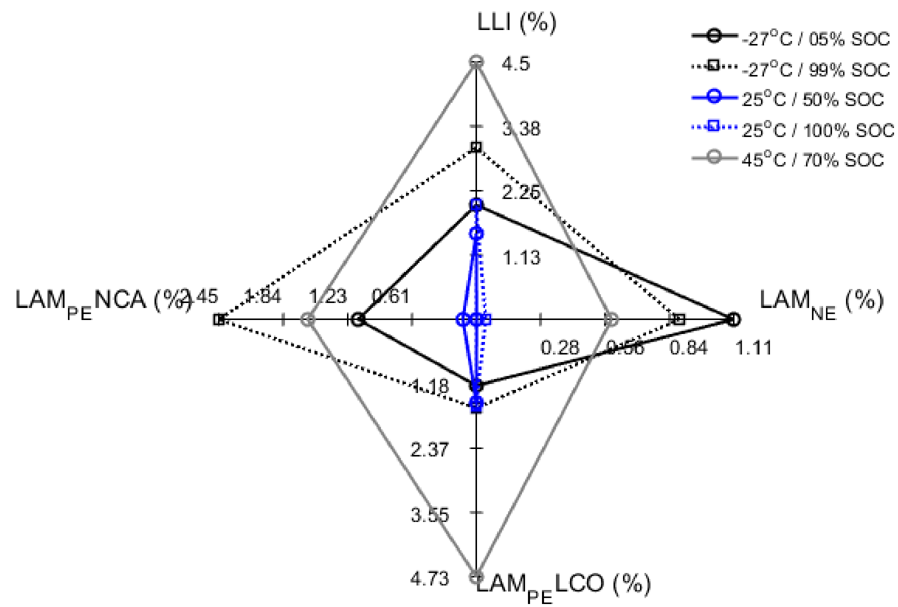
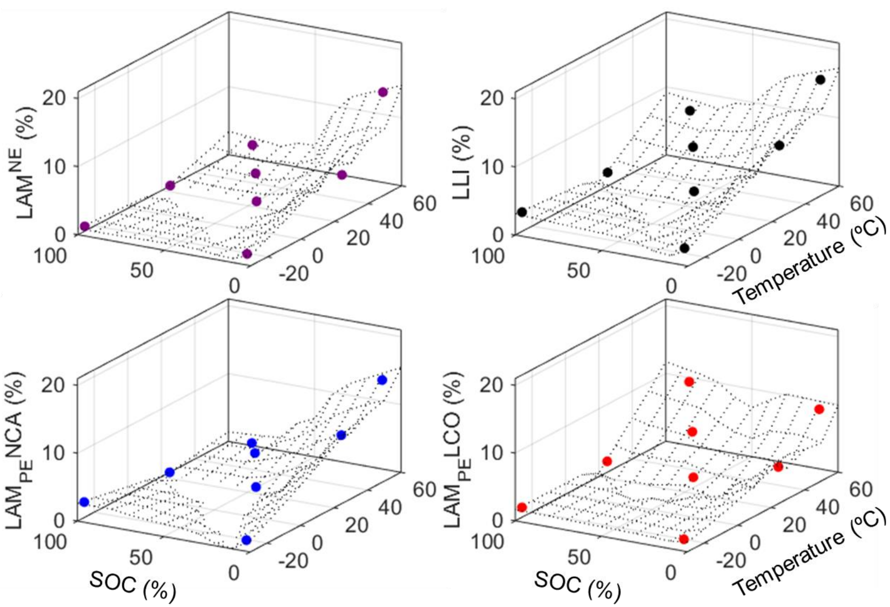
Incremental capacity analysis – Calendar aging

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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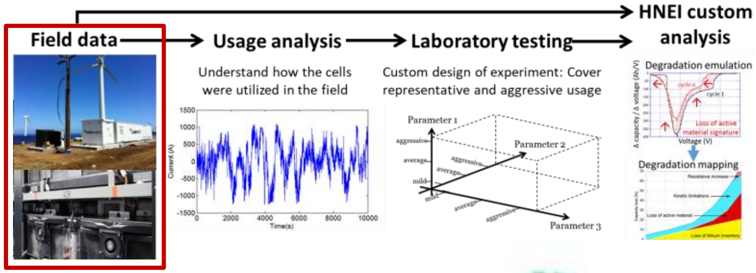
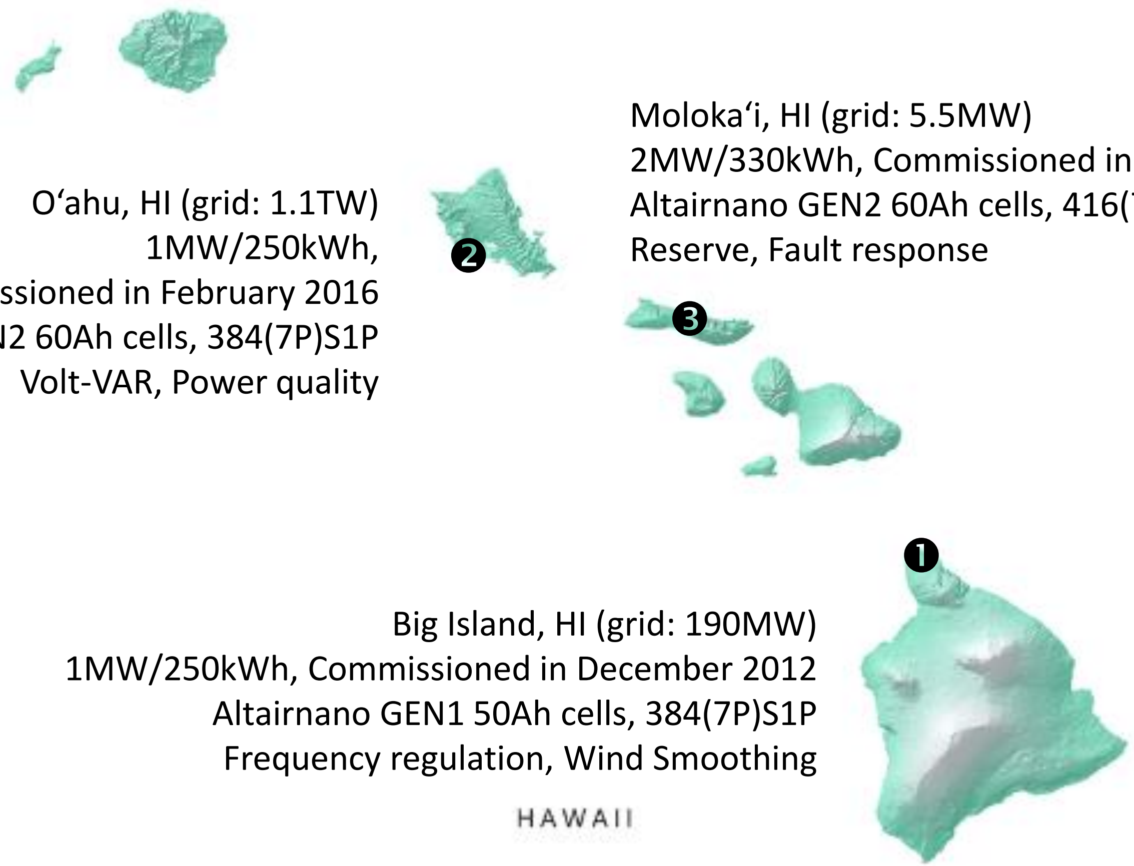
Field data





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

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

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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