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A1 - Energy Storage Applications and Considerations
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Durability and Reliability of EV Batteries under Electric Utility Grid Operations
Bidirectional Charging Impact Analysis

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HiSERF

Objectives & Motivations

Large EV penetration projected in the near future

Significant energy storage for the electric power grid

- Grid-to-vehicle (G2V) and Vehicle-to-grid (V2G)

G2V and V2G could provide a wide range of services

BUT will induce additional usage of the battery

- Concerns about range anxiety, battery lifetime,…

In most EV impact studies: battery = black box

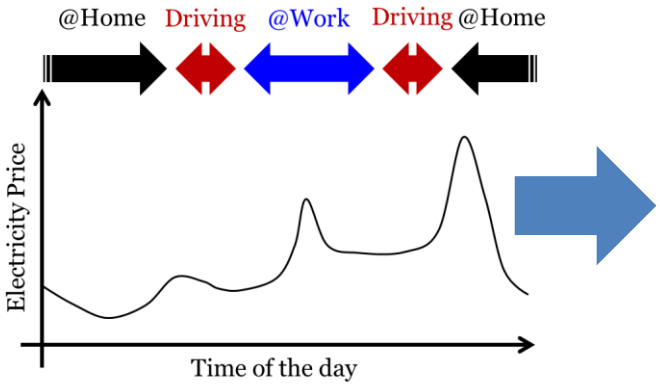
- No real understanding of long-term impact of V2G profiles on batteries.

The goal of this research was to assess such impact.

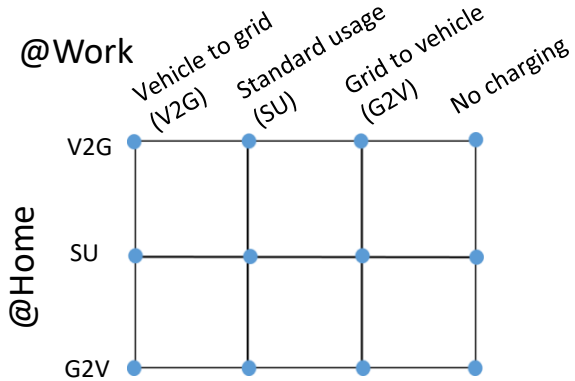
- Compare capacity loss / resistance changes
- Analyze degradation mechanisms

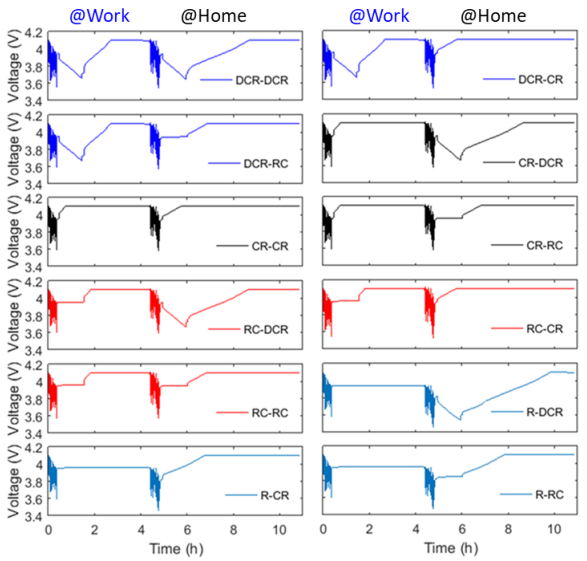
Experimental approach

Design of experiment methodology: cycle and calendar aging

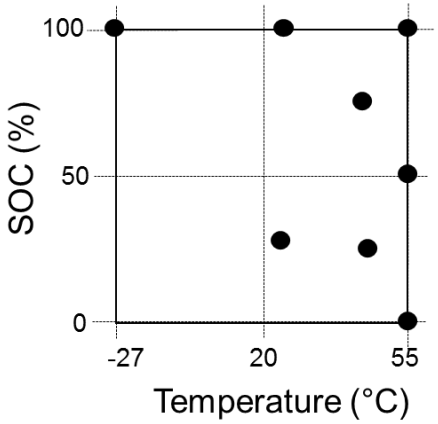


Cycle aging experiment





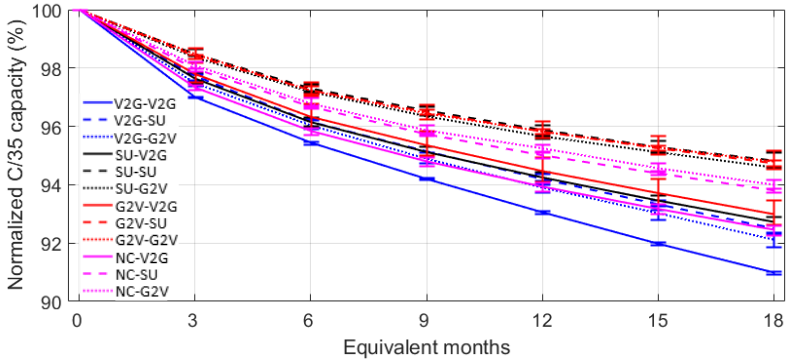
Calendar aging experiment

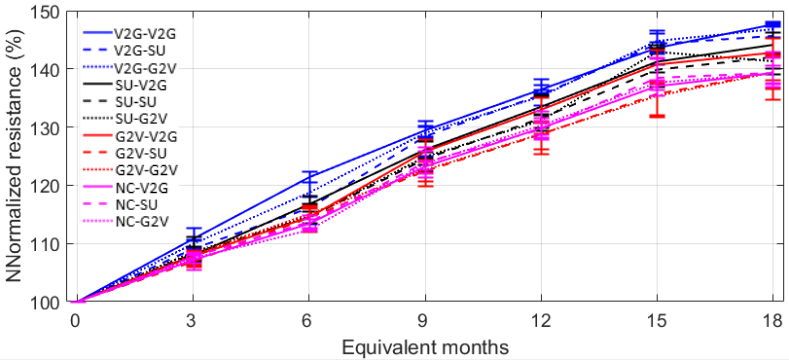


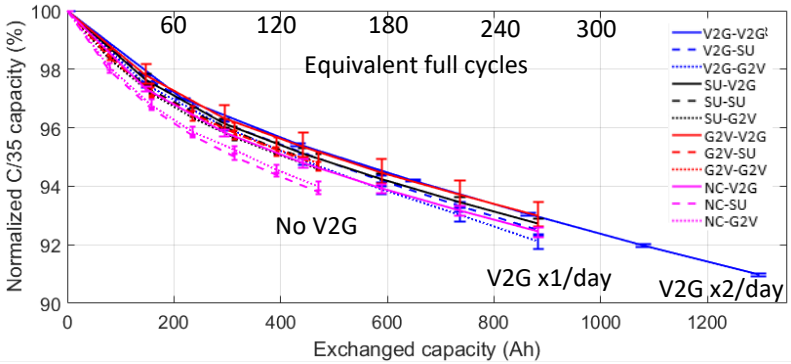
Dubarry et al., J. Power Sources 358 (2017) 39-49

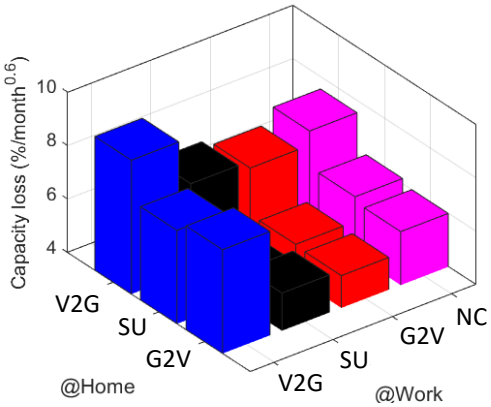
EV Cell Degradation under Electric Utility Grid Operations

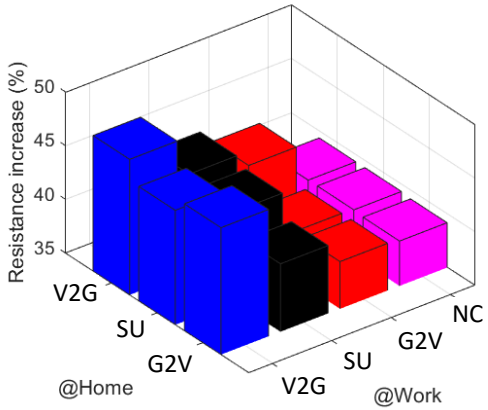
Cycle aging experiment

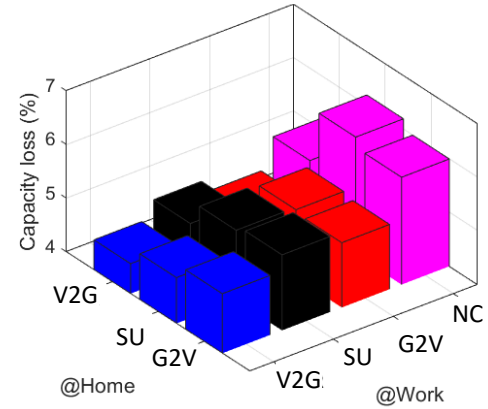












V2G 2x/day:
+ 75% capacity loss
+ 10% resistance
V2G 1x/day
+ 33% capacity loss
+ 5% resistance

Charging 2x/day
- 5% capacity loss

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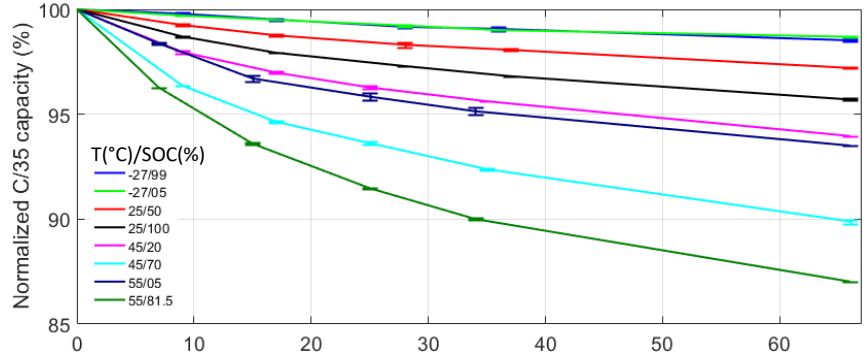
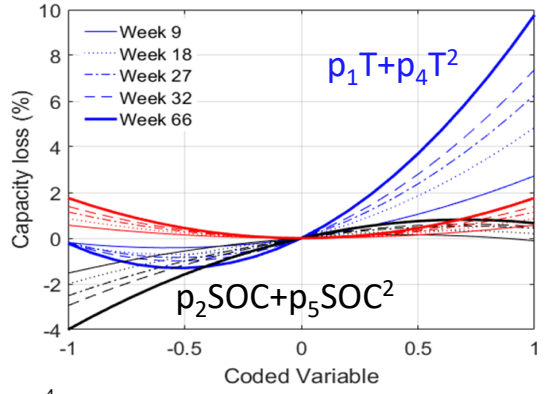
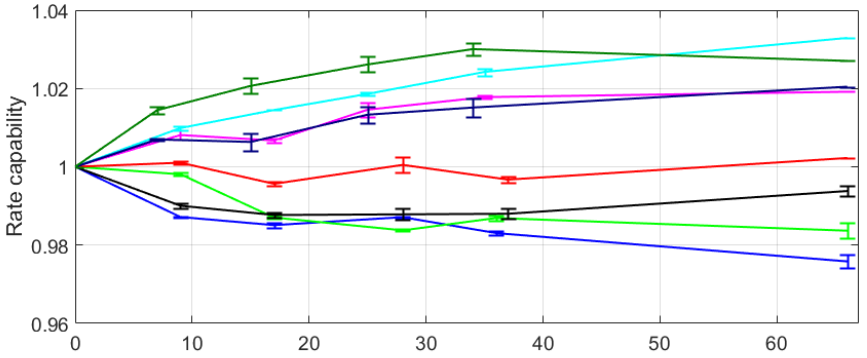
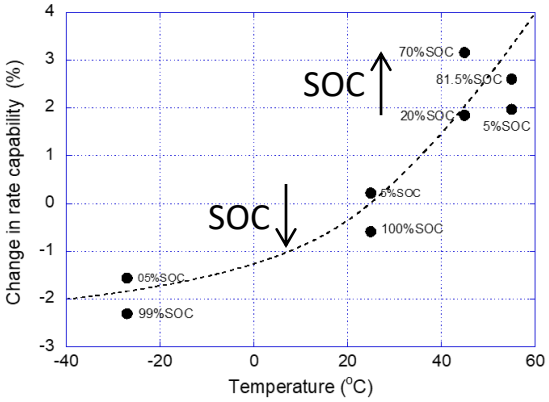
Calendar aging experiment

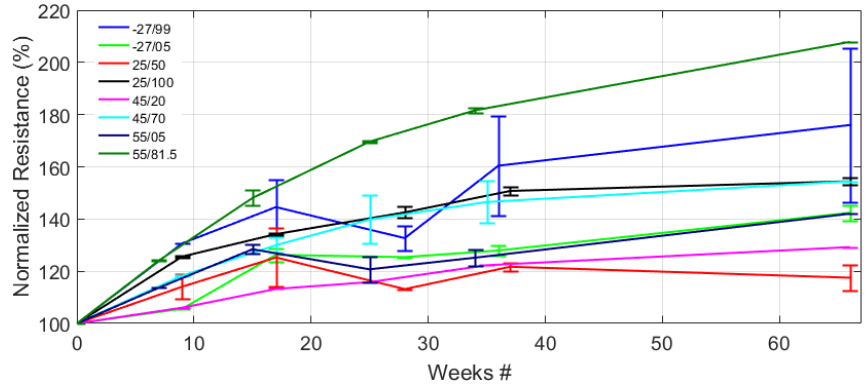


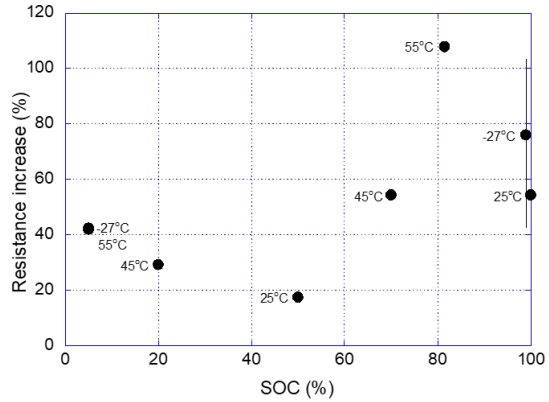


Capacity loss modeled with a double-quadratic equation. Impact: temperature > SOC.









Calendar aging impact limited at RT, important for higher temperatures

Rate capability mostly sensitive to temperature

Resistance mostly sensitive to SOC

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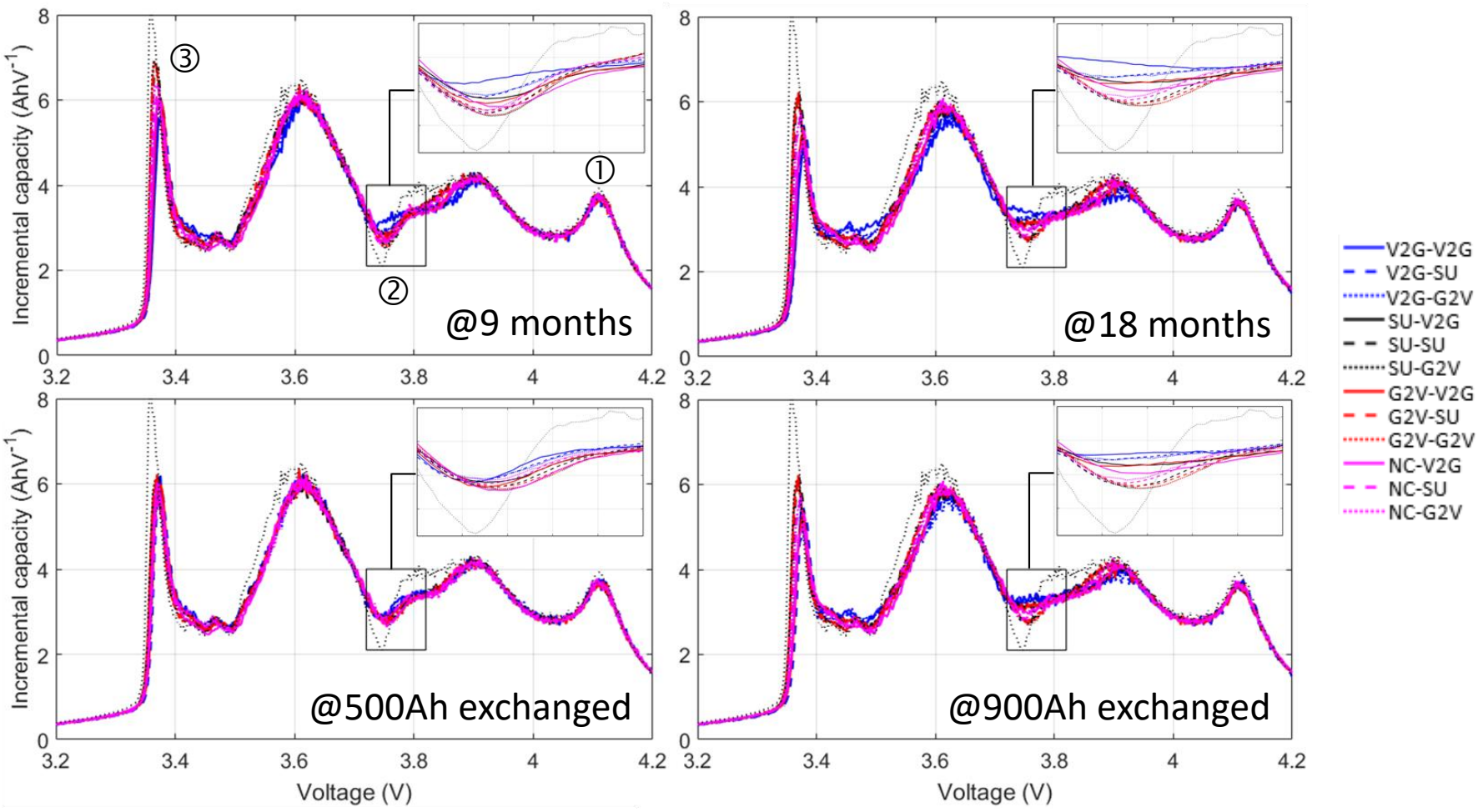
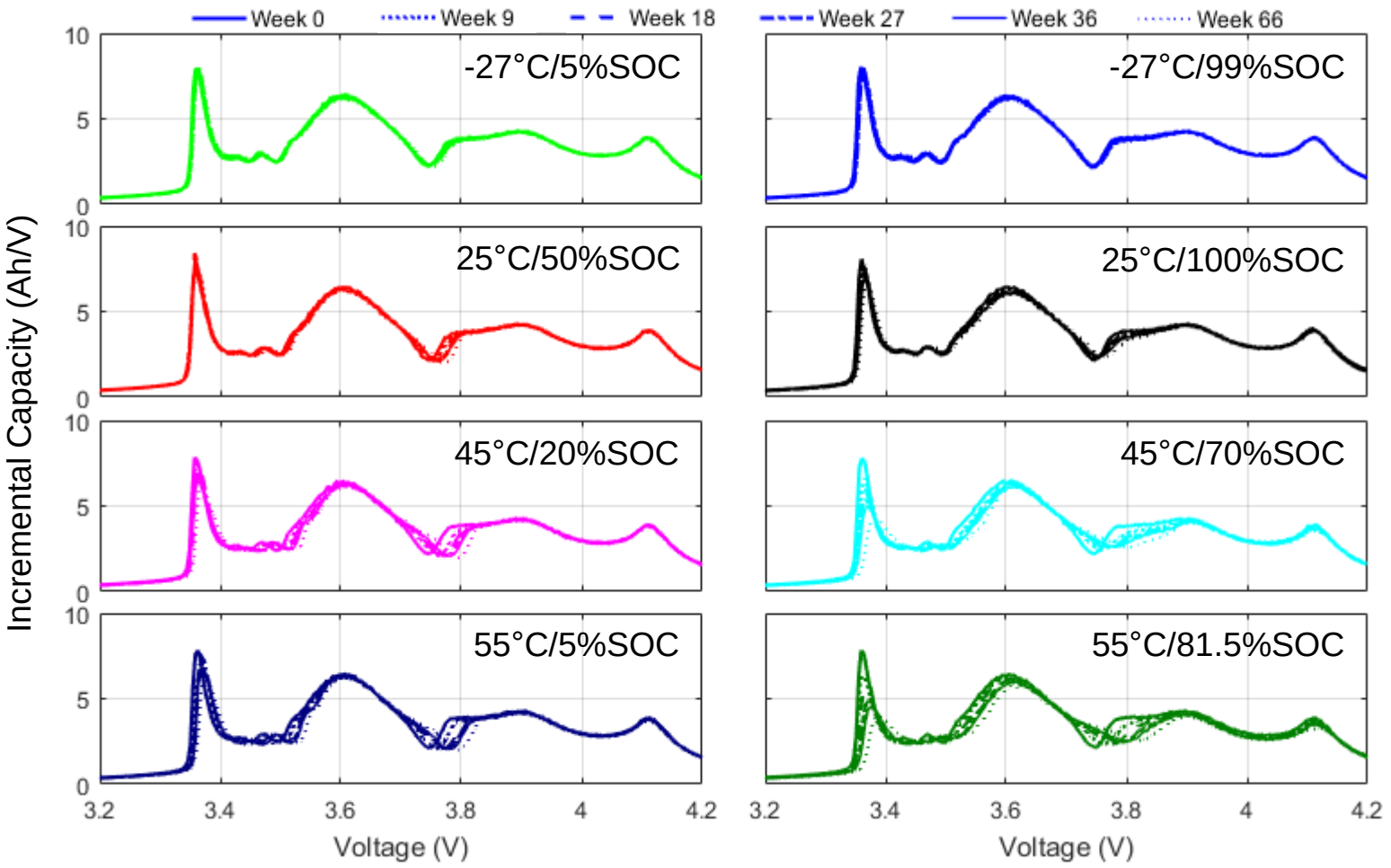
Cycle aging experiment – Incremental capacity



All cycle aging signatures are close but there are slight differences

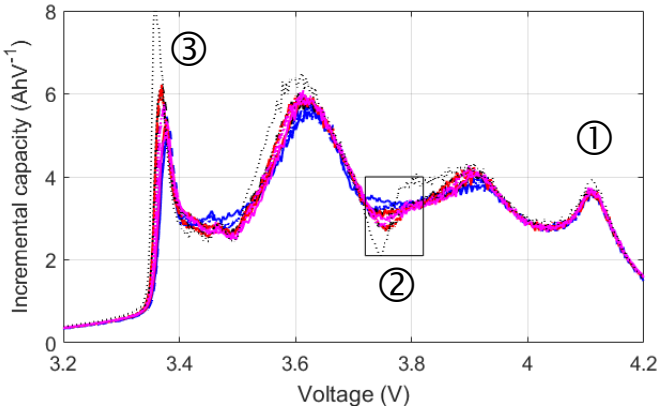
Calendar aging experiment – Incremental capacity

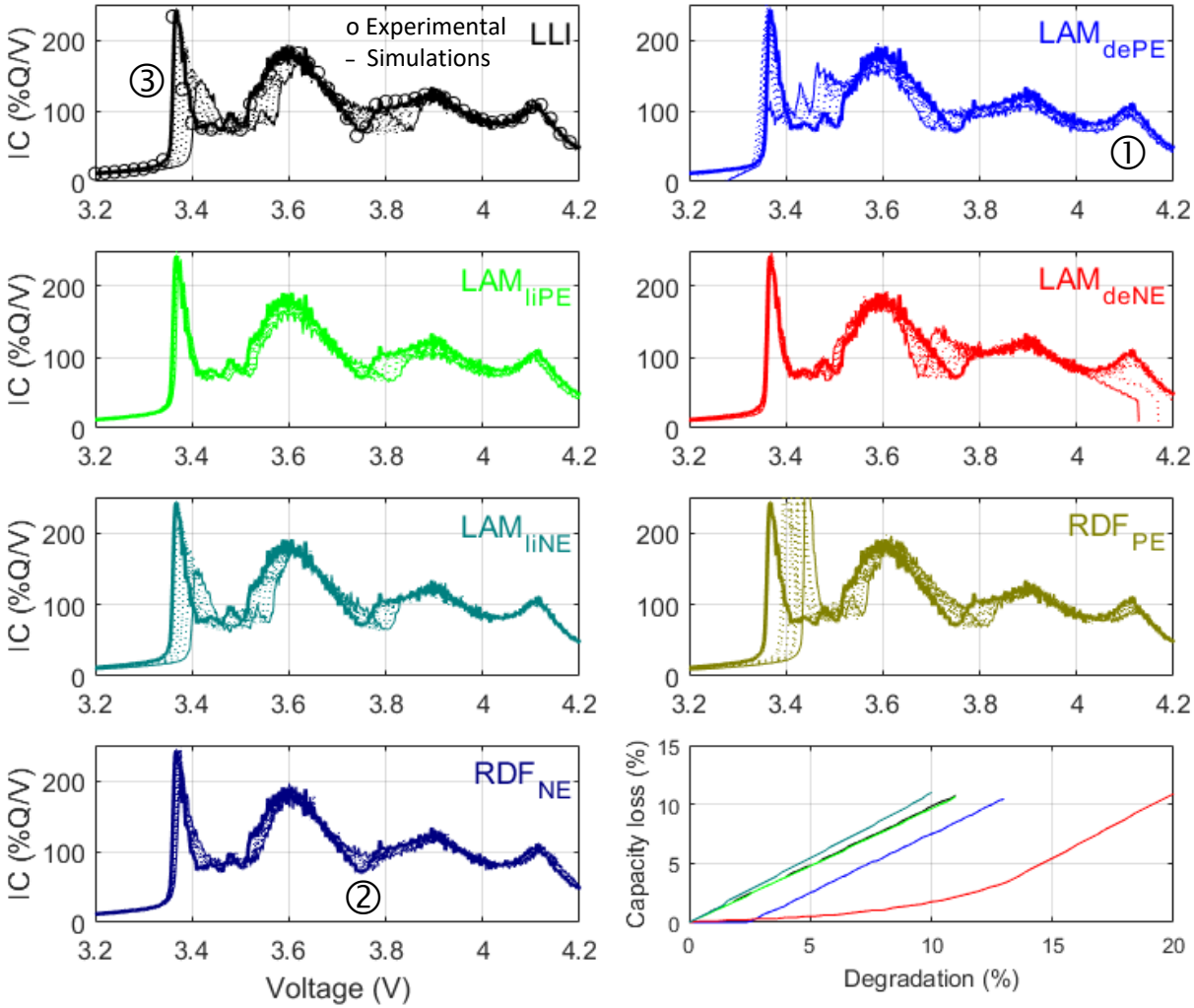


Clear difference between low SOC aging / high SOC aging

Degradation modes emulation

Compare experimental variations to the signature of individual degradation modes

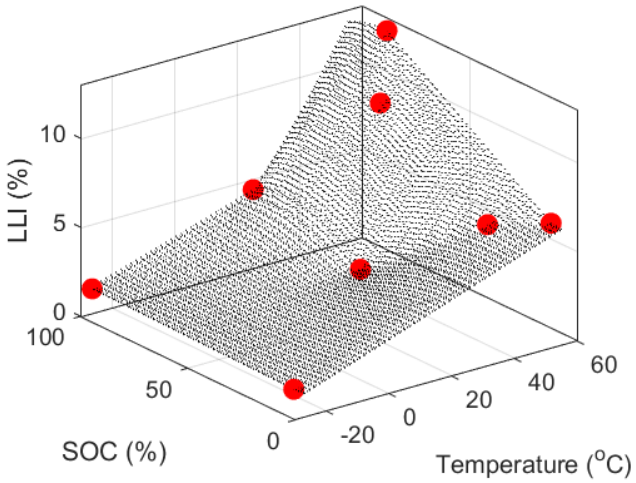


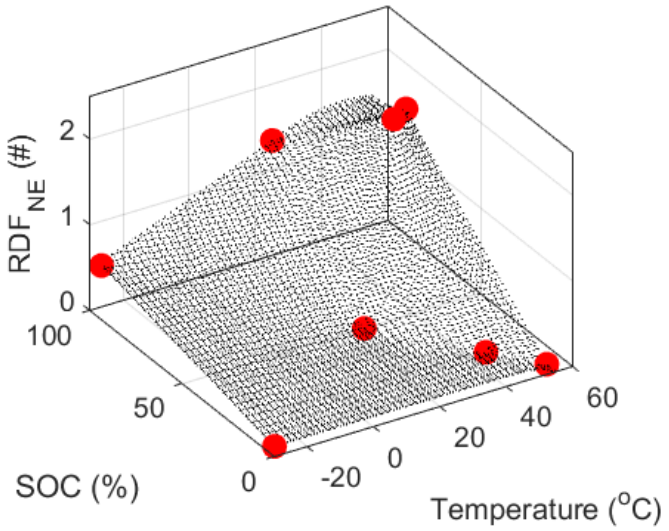


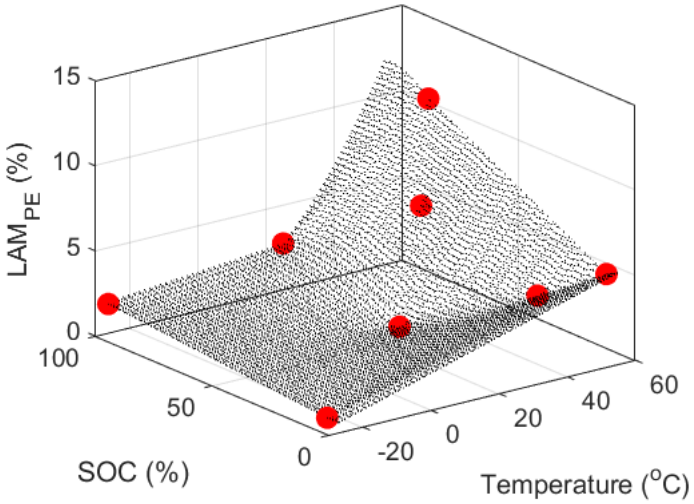
Degradation likely involves loss of lithium inventory, loss of active positive electrode and degradation of the negative kinetics.

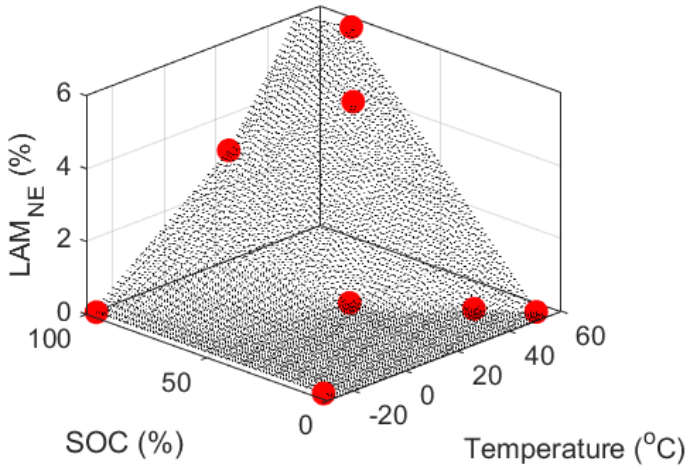
Degradation modes emulation quantification

Calendar aging experiment









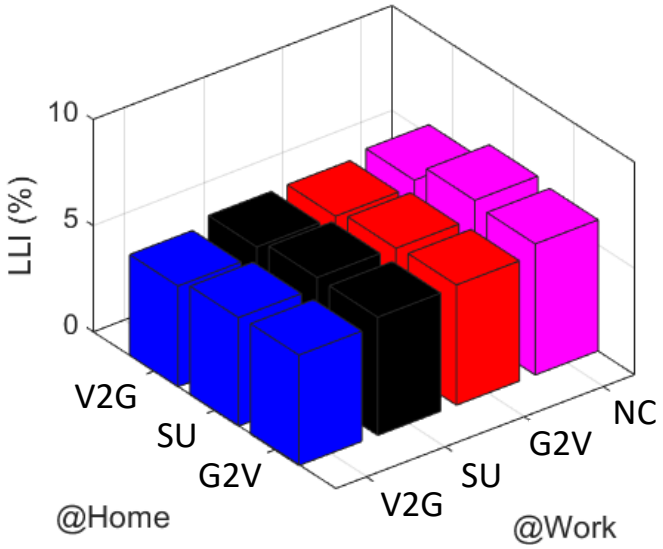
Capacity loss solely induced by LLI

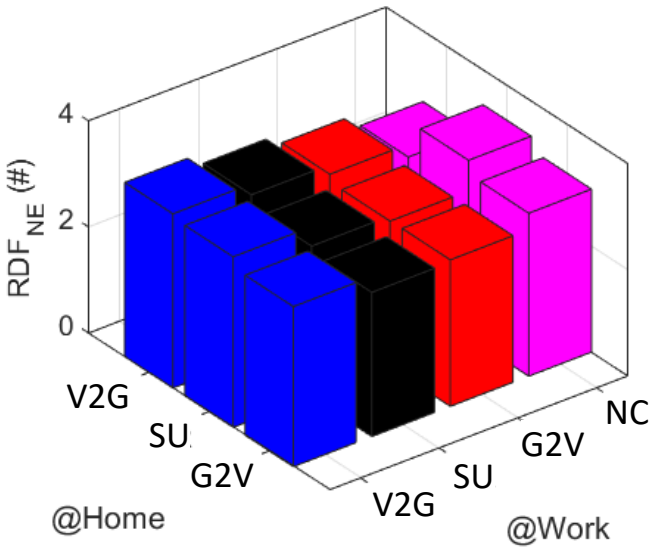
Temperature induces LAM_{PE} and LLI

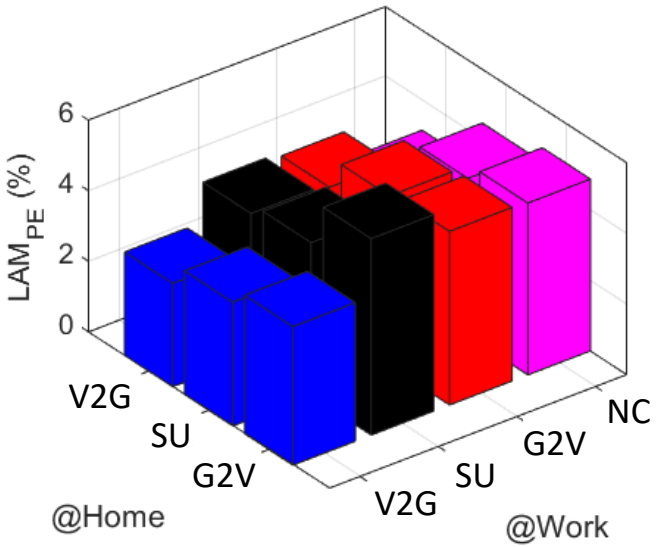
High SOC induces LAM_{NE} and NE kinetic degradation

Degradation modes emulation quantification

Cycle aging experiment - after 500Ah exchanged





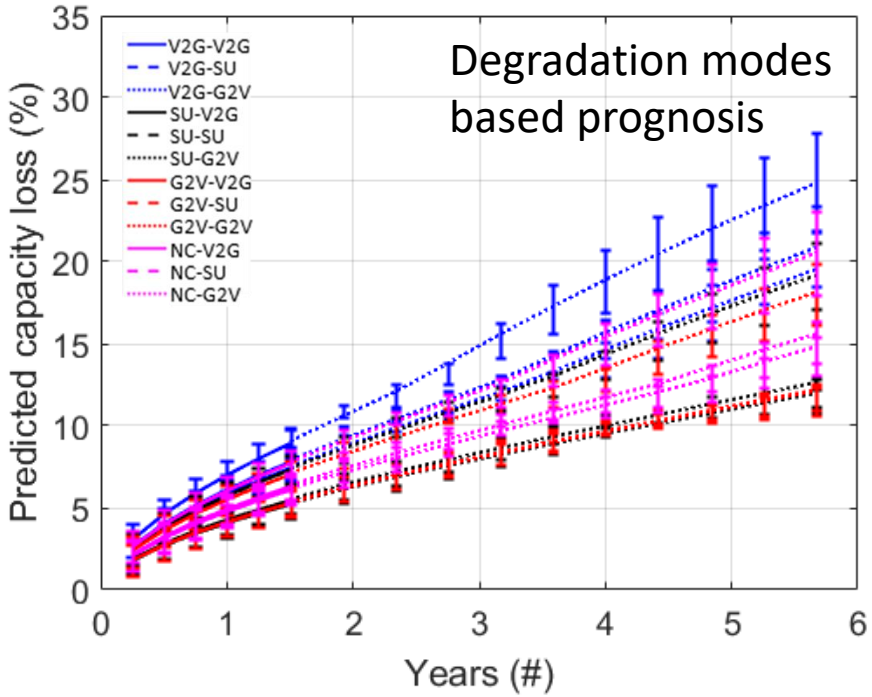


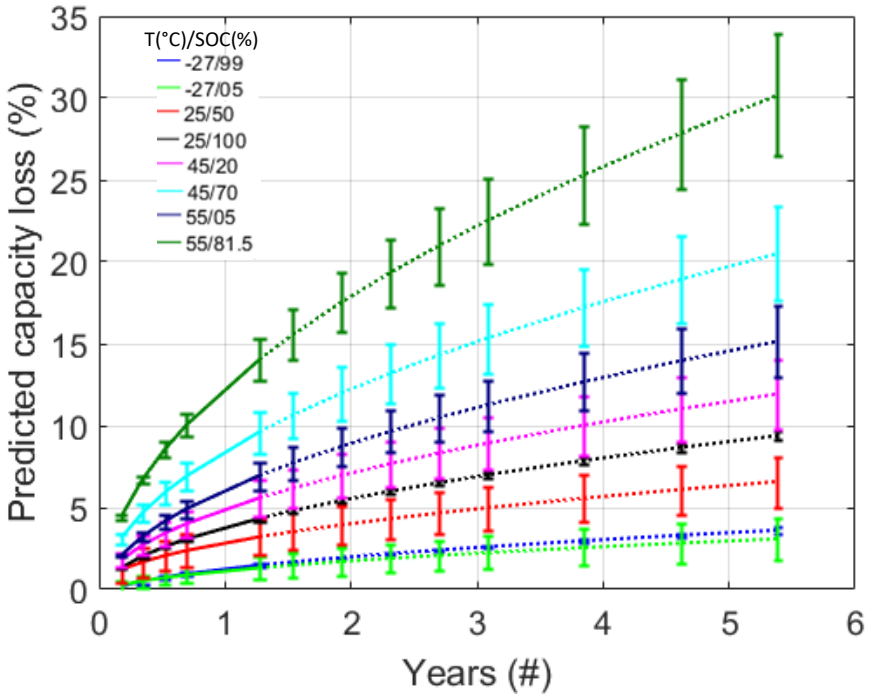
LAM_{NE}
No accurate quantification
Estimated between 5-8%

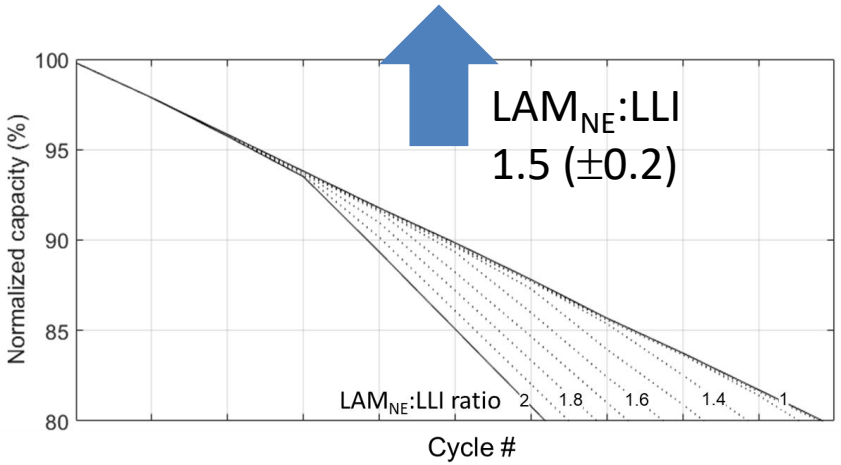
- LLI larger for 1 charge/day
- RDFNE larger for V2G
- LAMPE larger for no V2G
- LAM_{NE}:LLI ratio likely > 1

EV Cell Degradation under Electric Utility Grid Operations

Prognosis







Capacity based prognosis not valid for cycle aging experiment.
Capacity loss accelerated by silent degradation mode.

Cells might last < 4 years if V2G x2/day

Conclusions

Bidirectional Charging Impact Analysis

"Blind" V2G is shortening cells durability (+75% capacity loss if 2x/day)

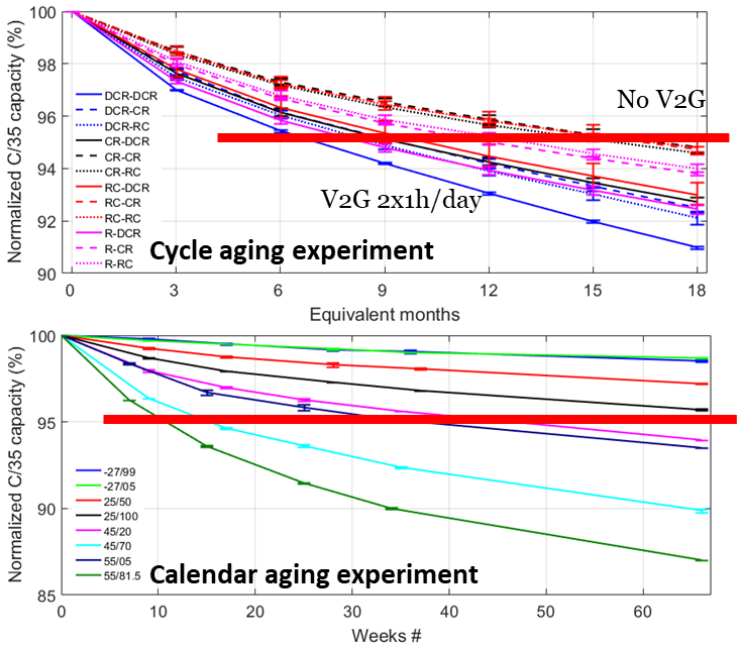
G2V might be beneficial in warm climates

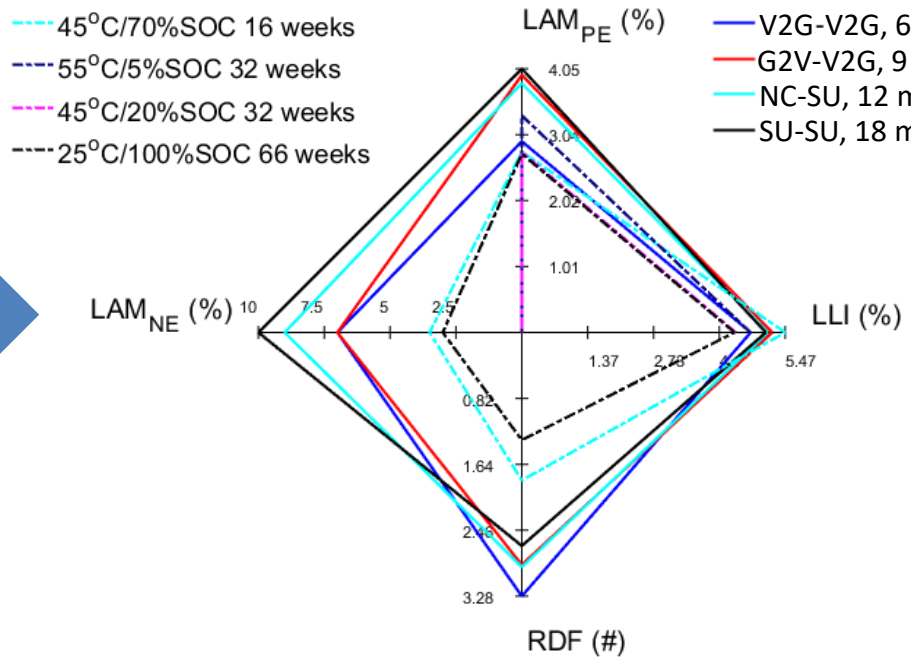
Intelligent V2G/G2V might be a good option

V2G only to get the cell to a safer SOC for calendar aging (cf. Uddin, Marongiu)

Uddin et al., Energy 133 (2017) 710-722, Marongiu et al., Applied Energy 137 (2015) 899–912

Path dependence of degradation





Acknowledgments

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Hawaiian Electric

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Thank you for your attention! Questions ?

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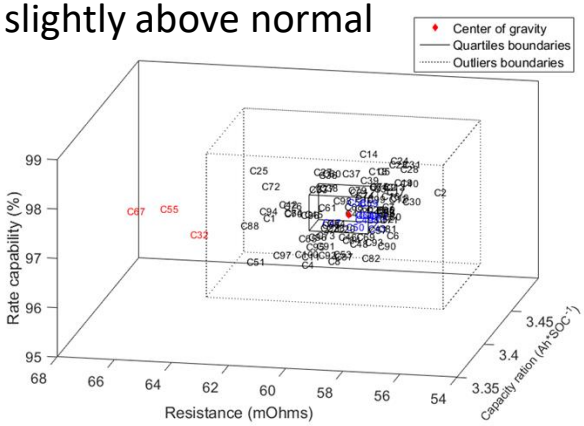
Experimental approach

Preliminary testing

100 cells were purchased
High quality Li-ion cells
Similar to Tesla batteries

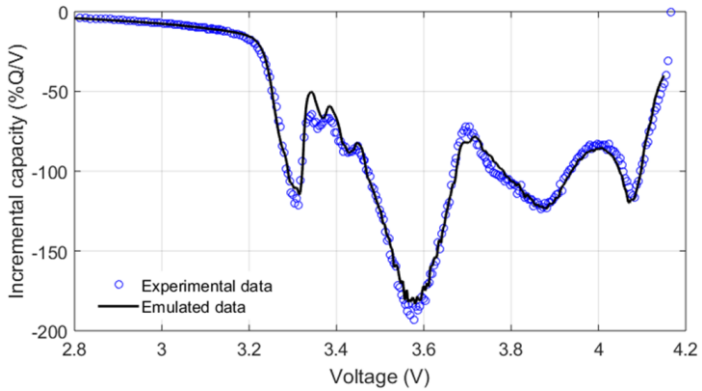
All checked for initial quality
Only 3 outliers with resistance slightly above normal



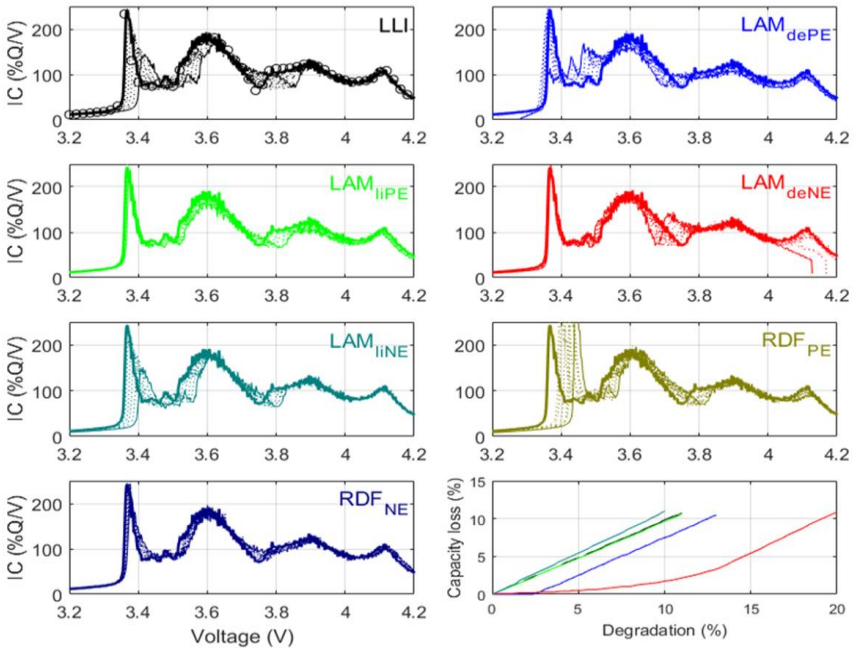
36 cells selected for cycle aging experiment
Impact of V2G and G2V strategies

16 cells selected for calendar aging experiment
Impact of time, state of charge and temperature

Cell was emulated
Model built from individual electrode data: helps diagnosis



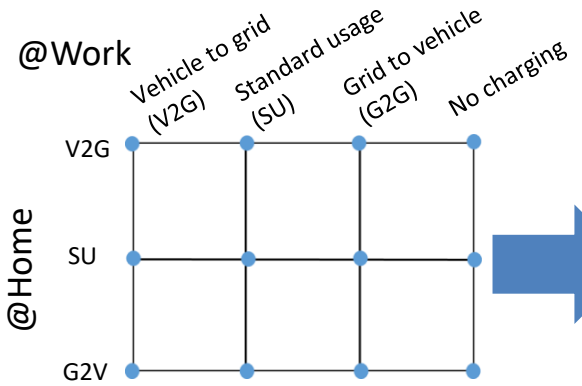
Diagnosis model was compiled



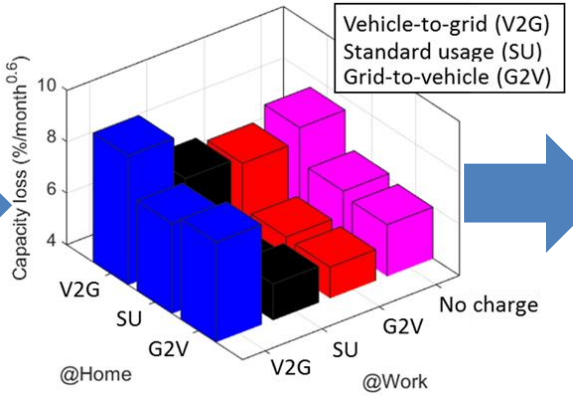
Dubarry et al., Batteries **2016**, 2, 28

Conclusions - Bidirectional Charging Impact

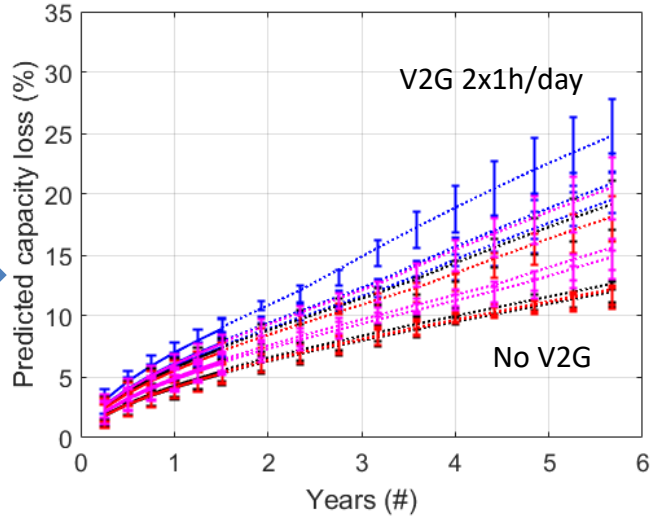
Cycle aging experiment



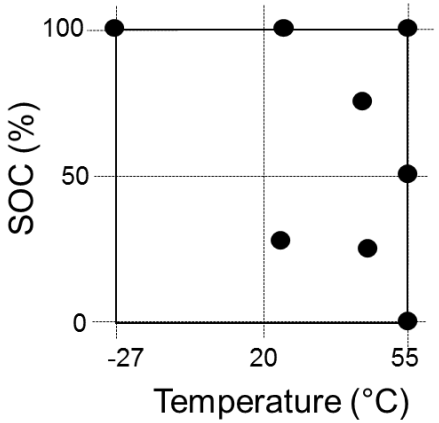
Results:
V2G 2x1h/day @ P/4 : +75% capacity loss
V2G 1h/day @ P/4 : +33% capacity loss
Charging 2x/day vs. 1x/ day: -5% capacity loss
SU vs. G2V : no significant effect

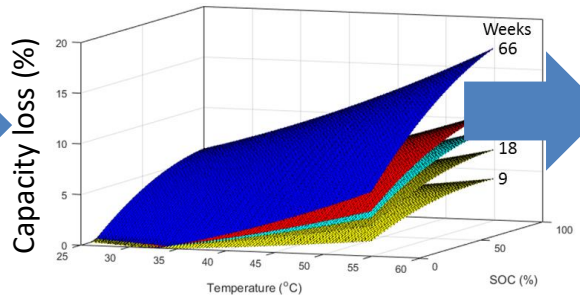


Prognosis:
V2G strategy drastically reduces durability
G2V might be beneficial in warm climates



Calendar aging experiment





Results:
Significant effect of time, temperature and SOC.
Temperature effect > SOC effect at high values