A05-0443
Sunday October 13

A05 Diagnostic and Characterization of Li-ion Electrodes, Separators and Cells - 1

Synthetic vs. Real Driving Cycles: A Comparison of EV Battery Degradation

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The complexity of battery diagnosis

Path dependence of the degradation

Traffic

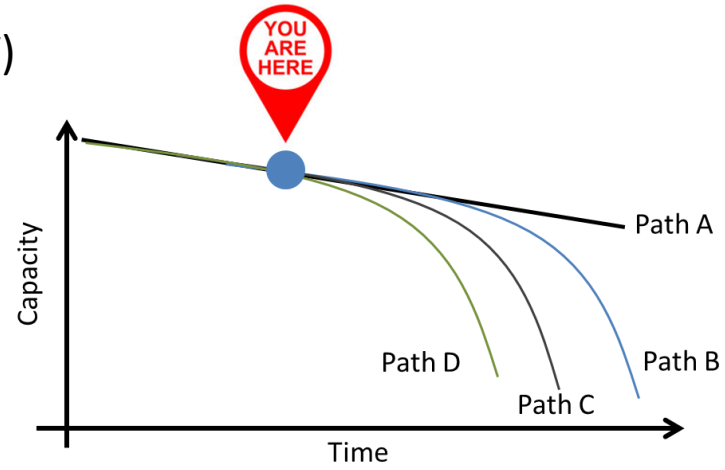

Road type


Driving habits


Charging habits


Temperature


Grid ties (V2G / G2V)



Different paths will lead to different degradation

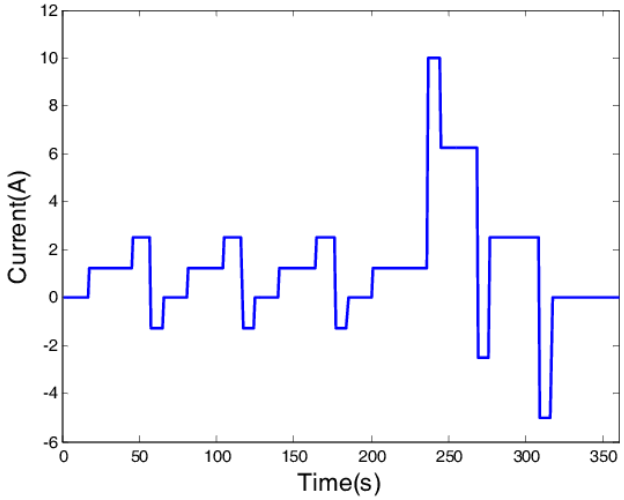
Every battery is different

Synthetic vs. Real Driving Cycles: A Comparison of EV Battery Degradation

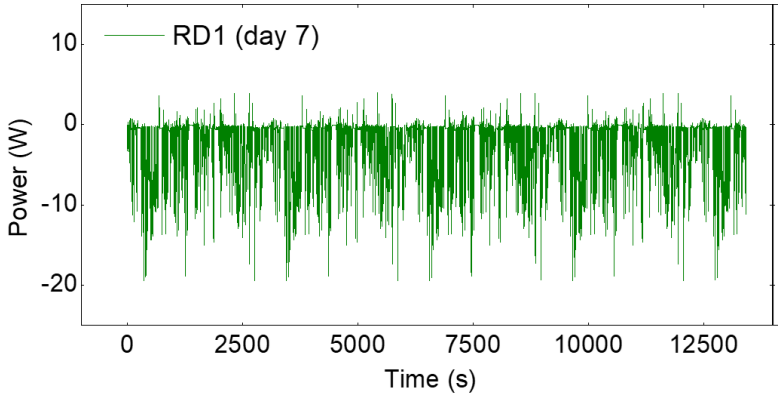
Objective & Motivations

Synthetic driving cycles and accelerated aging protocols are essential to accumulate data on electric vehicle (EV) battery lifetimes.

Battery deterioration is path-dependent and this work focused on the representability of synthetic driving cycle in terms of mimicking actual EV battery degradation.



VS.



Batteries 2019, 5, 42; doi:10.3390/batteries5020042

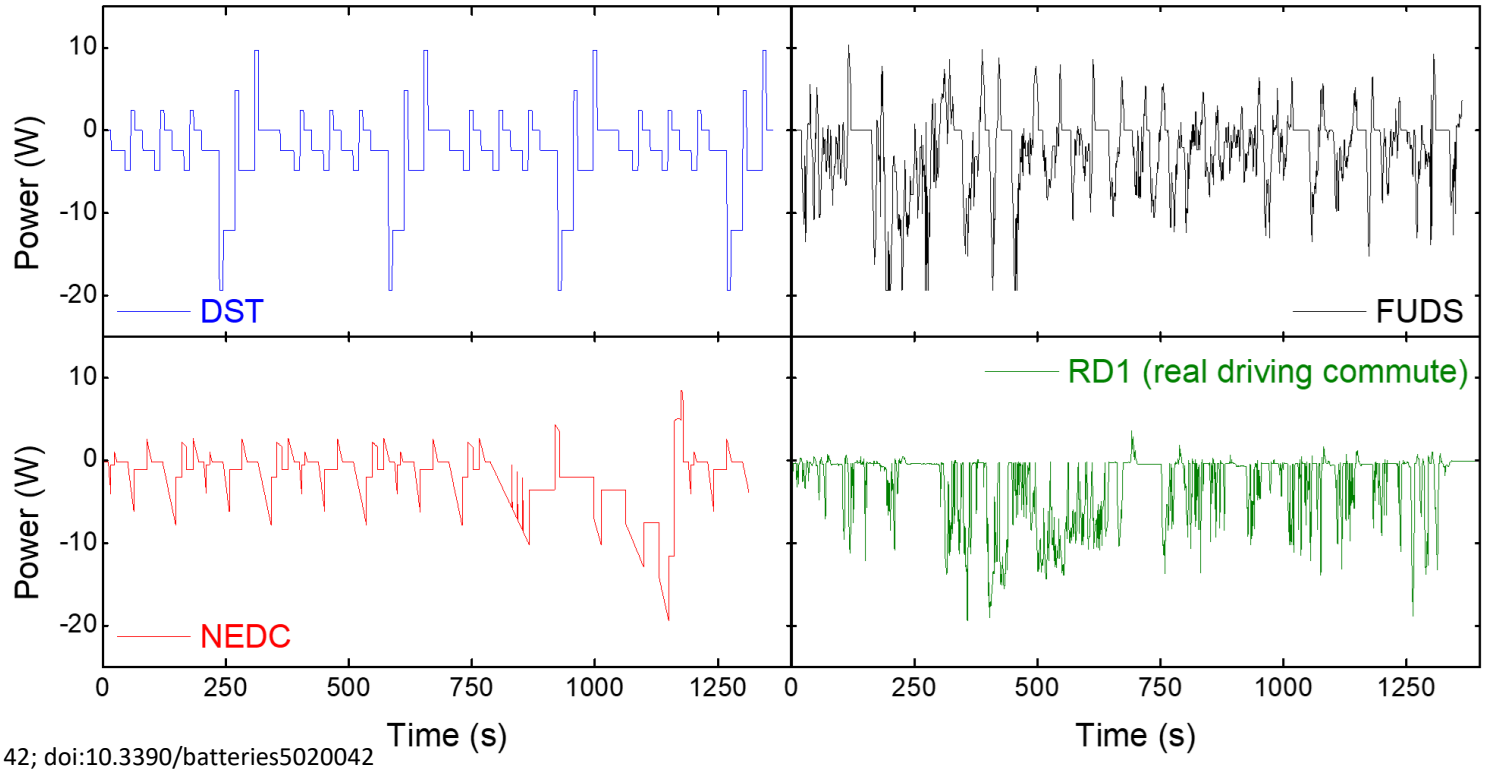
Experimental approach

3 synthetic driving profiles on Panasonic 3350 mAh NCR 18650B cells

Dynamic Stress Test (DST), Federal Urban Driving Schedule (FUDS), and New European Driving Cycle (NEDC),

Real driving data obtained from HNEI 2-year EV data collection program

20 EVs for 2 years, more than 100,000 km collected,



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20 EVs for 2 years, more than 100,000 km collected,

Scaled so average power is similar

Main difference is that our driving cycle has limited regenerative braking

During first discharge (3 cells tested per profile, 15 cells total)					
Driving profiles	**Avg. Current (A)**	**C rate based on avg. current**	**Discharge time (hour)**	**Charge Capacity (Ah)**	**Discharge Capacity (Ah)**
DST	-0.68	C/4.8	4.03	0.51	3.29
FUDS	-0.70	C/4.6	3.74	0.56	3.20
NEDC	-0.66	C/4.9	4.25	0.30	3.13
RD1: real driving (commute comparable to simulations)	-0.73	C/4.5	4.12	0.03	3.03

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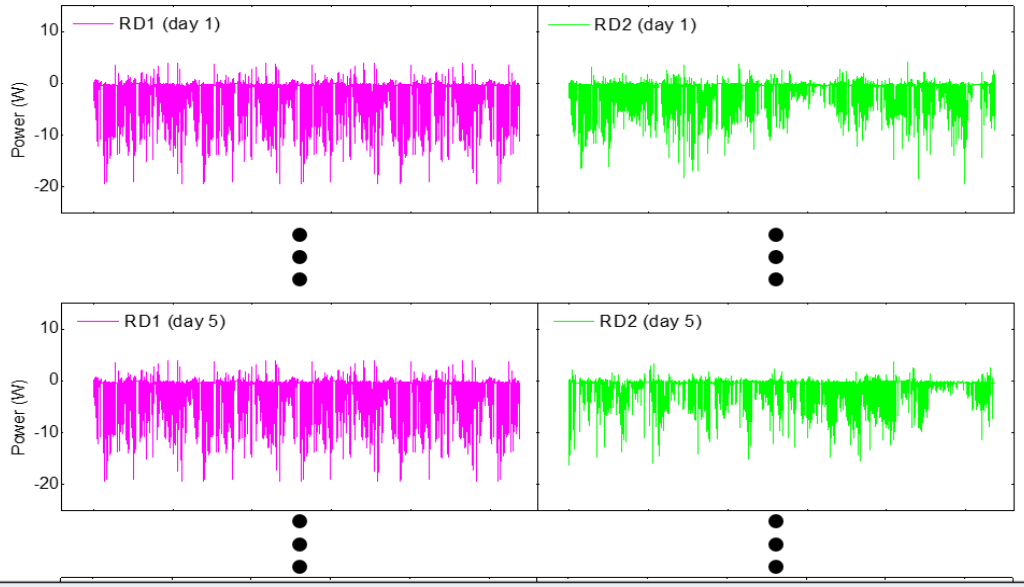
Experimental approach

Real driving data obtained from HNEI 2-year EV data collection program

- Impact of traffic was also investigated
- Representative commute vs. 30 unique commutes in a loop



During first discharge (3 cells tested per profile, 15 cells total)					
Driving profiles	**Avg. Current (A)**	**C rate based on avg. current**	**Discharge time (hour)**	**Charge Capacity (Ah)**	**Discharge Capacity (Ah)**
RD1: real driving (commute comparable to simulations)	-0.73	C/4.5	4.12	0.03	3.03
RD2: real driving (complete dataset)	-0.45	C/7.3	6.73	0.04	3.01

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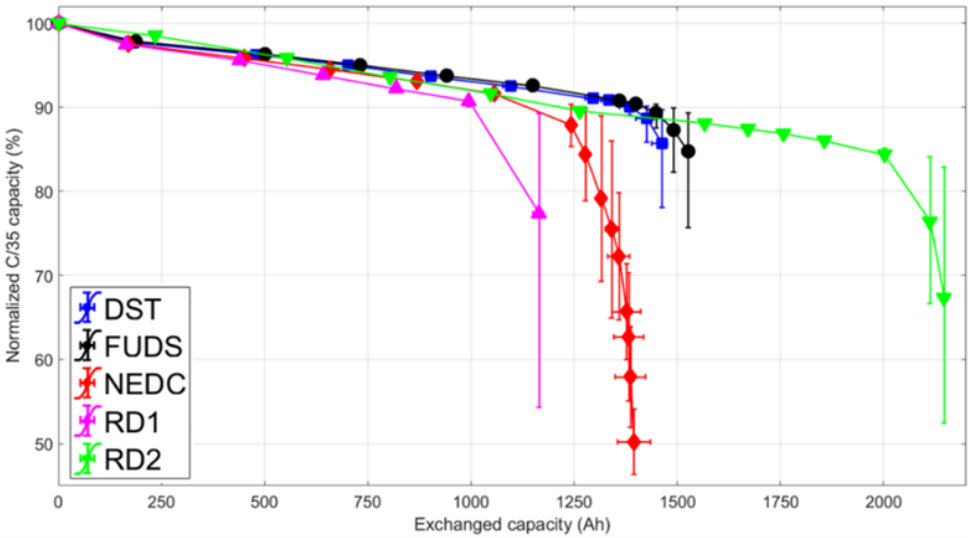
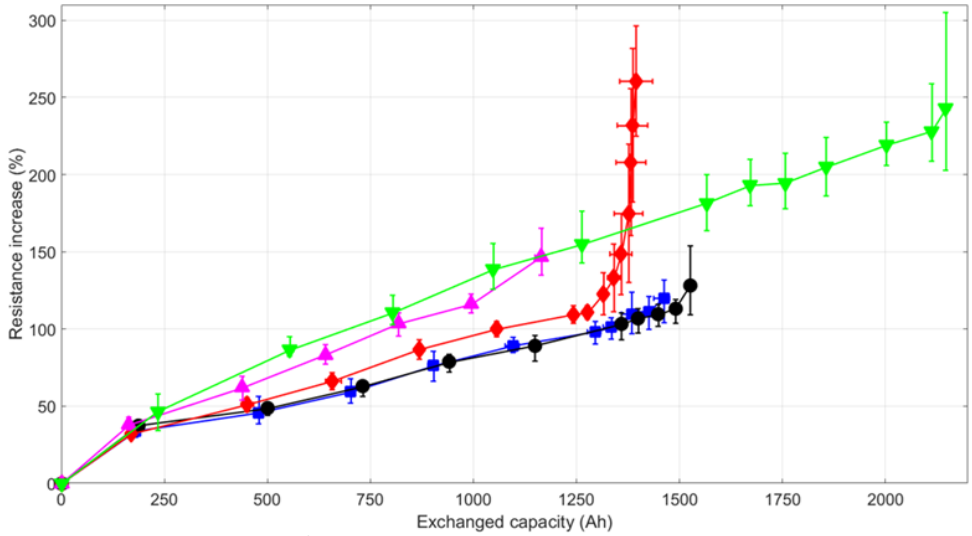
Capacity loss and resistance increase

Significant differences between duty cycles





All cells displayed an accelerated stage of degradation after similar linear fading.

2nd stage starting after 350 to 800 cycles.

DST and FUDS exhibited similar trend which was unsurprising since DST is derived from FUDS.

At equal power usage, duty cycles that charged the least failed first

Resistance increase accelerates only after 2nd stage started.

Clear impact of duty cycle
Different pace or different degradation?

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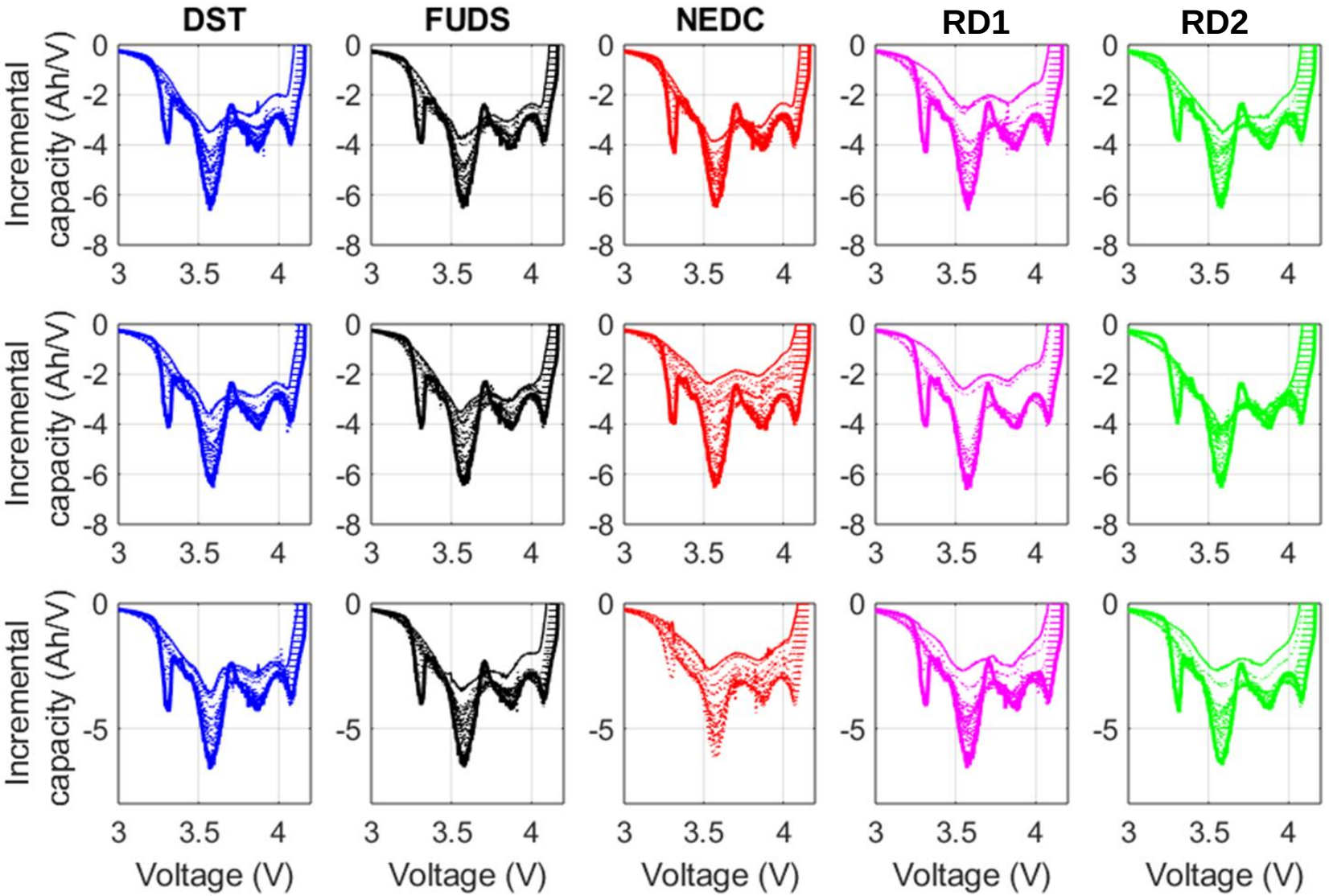
Incremental capacity

All cells have a similar response



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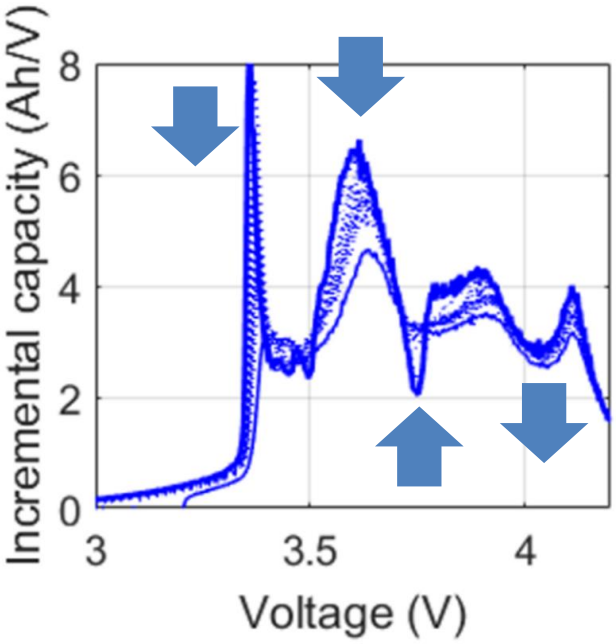
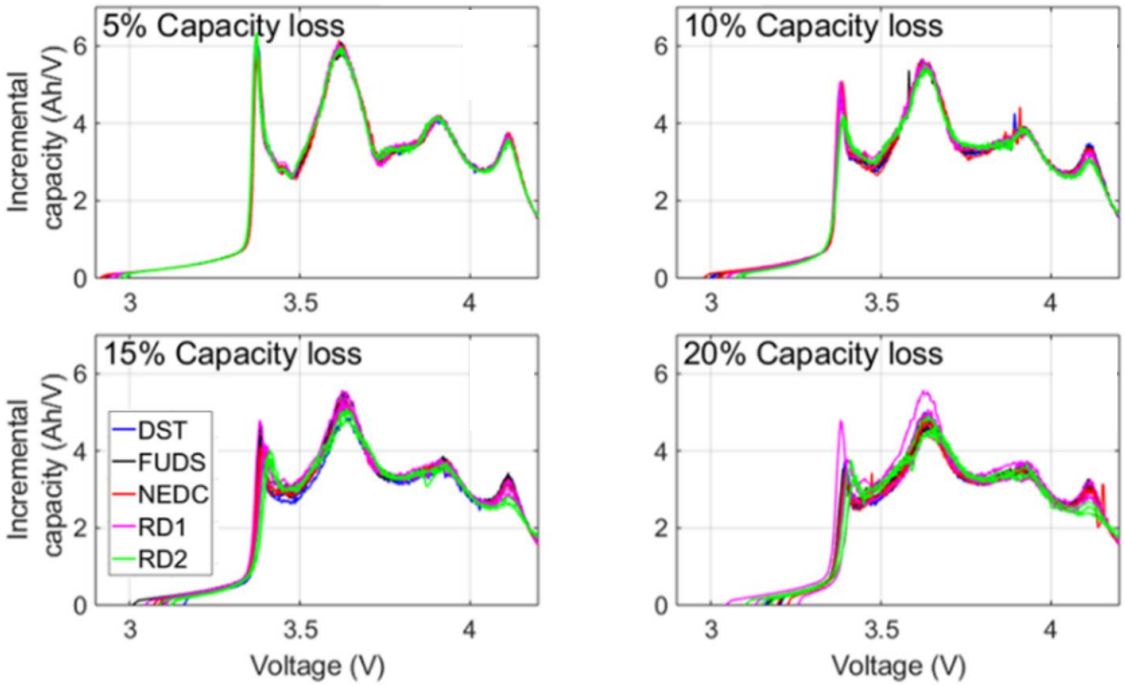
Incremental capacity

All cells have a similar response

But small difference when compared closely, especially for capacity loss > 15%





Features of interest (FOI):
All peak intensity decreased.
Local minimum at 3.7V increased
Local minimum at 4V decreased

Lot of changes on IC curves
Need to perform sensibility analysis to link changes to actual degradation modes

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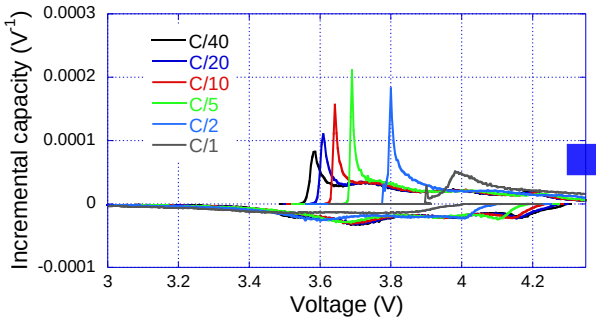
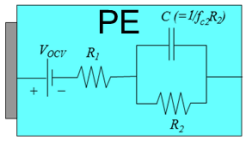
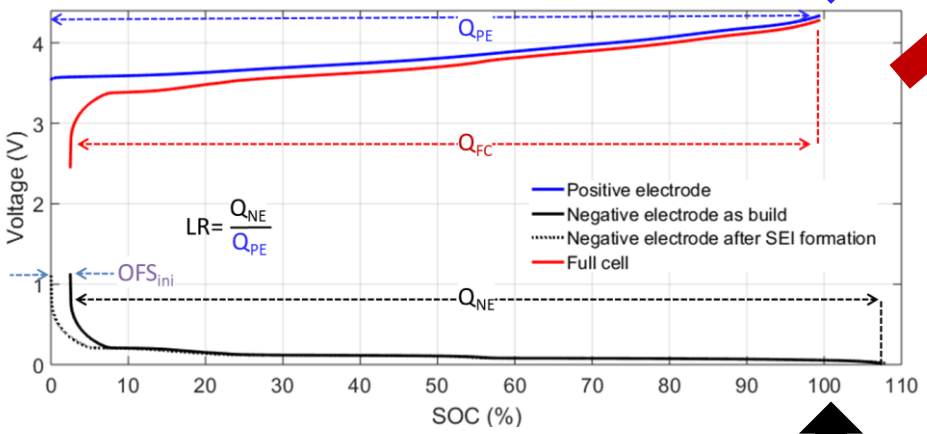
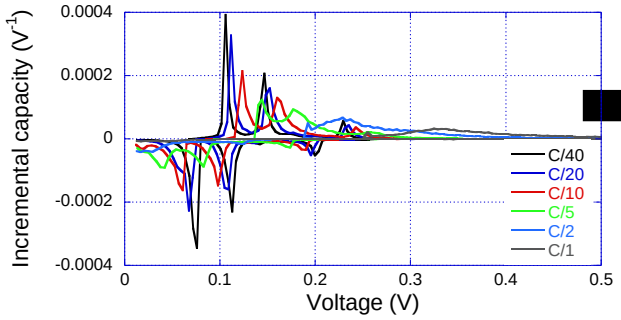
Cell emulation

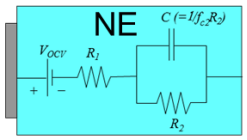
Mechanistic modeling

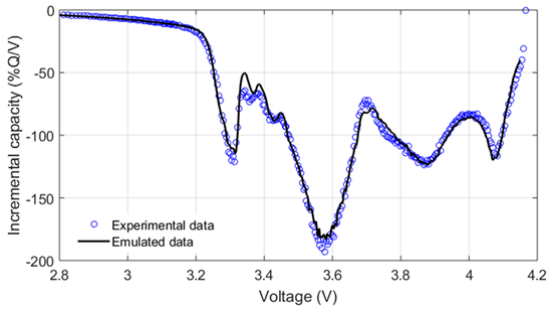


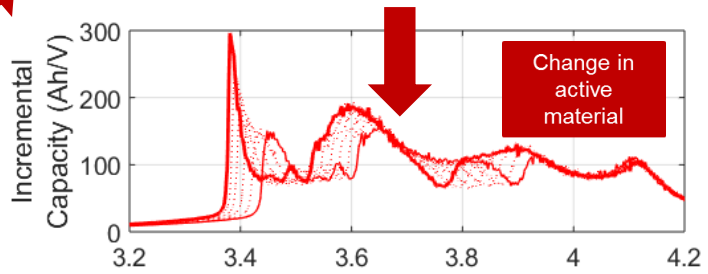


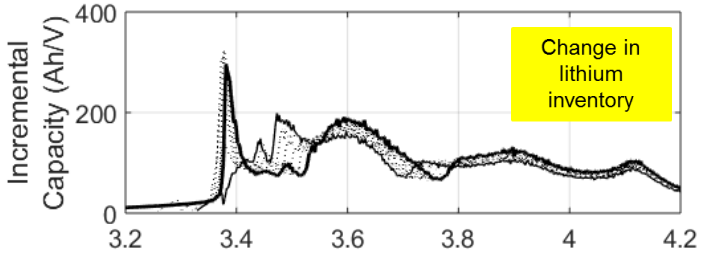


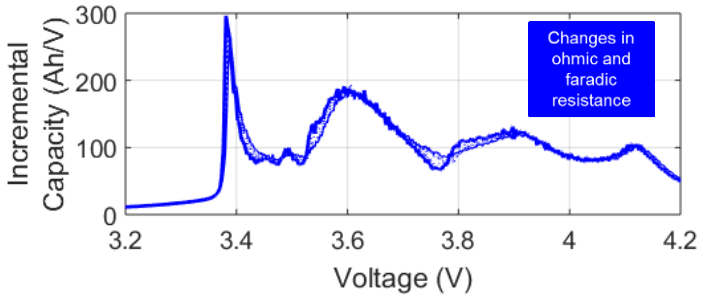




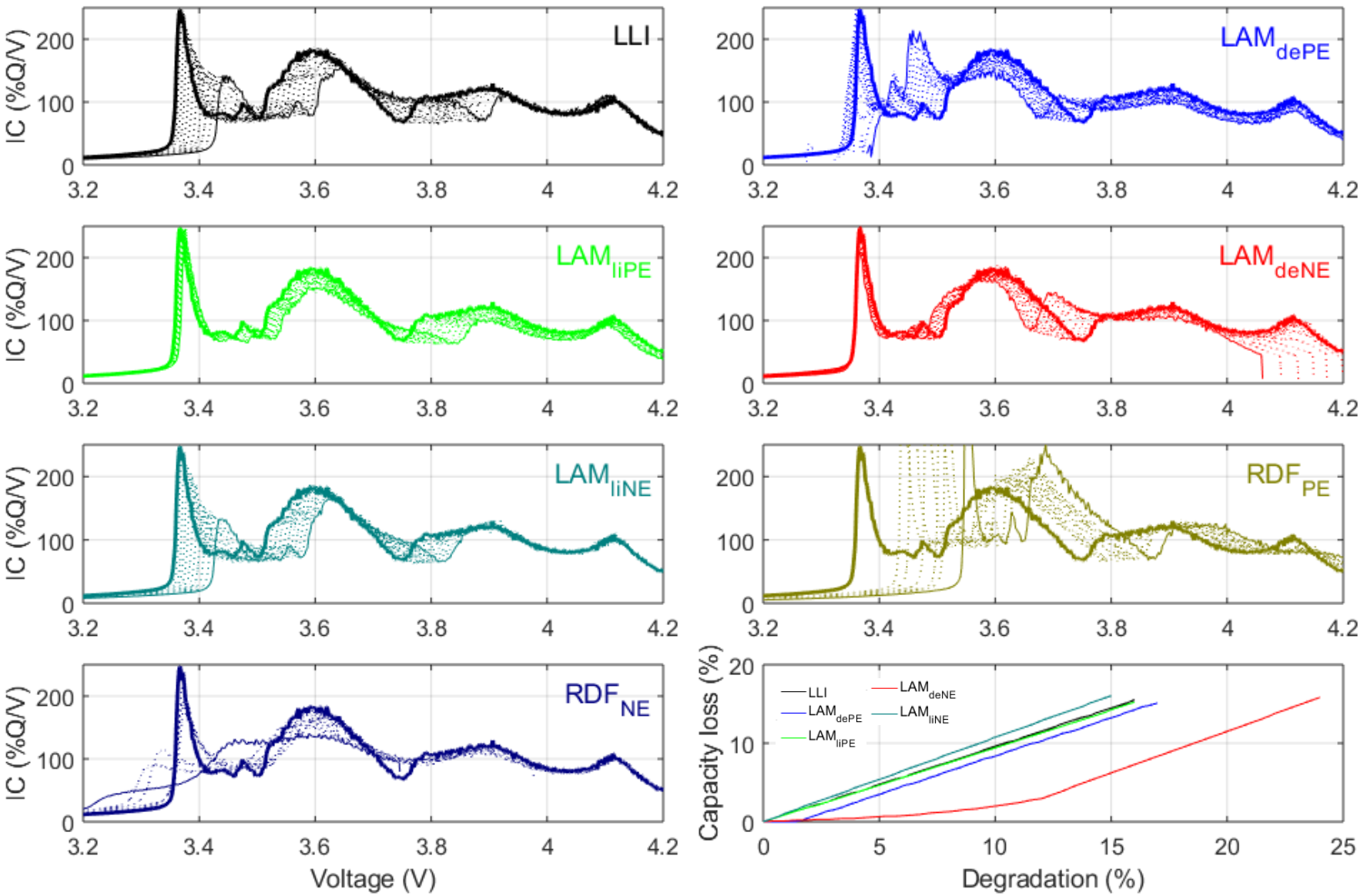








Degradation map



LLI, loss of lithium inventory; **LAM_{deNE}**, loss of active material at the negative electrode; **LAM_{dePE}**, loss of active material at the positive electrode

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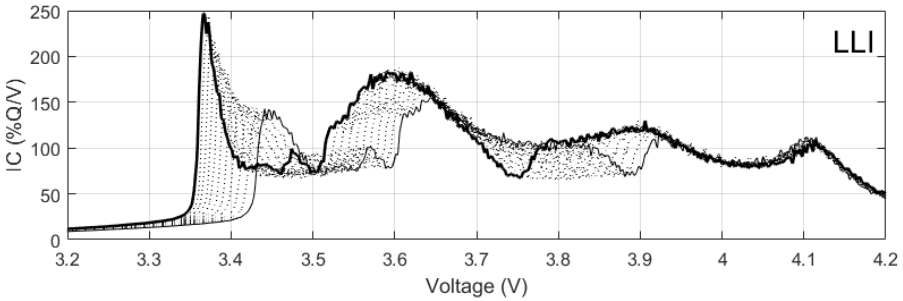
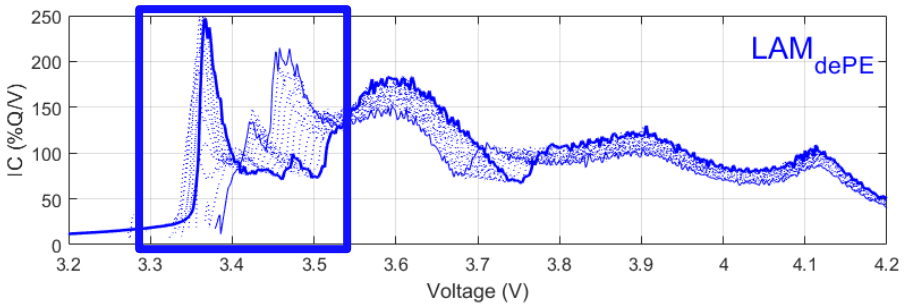
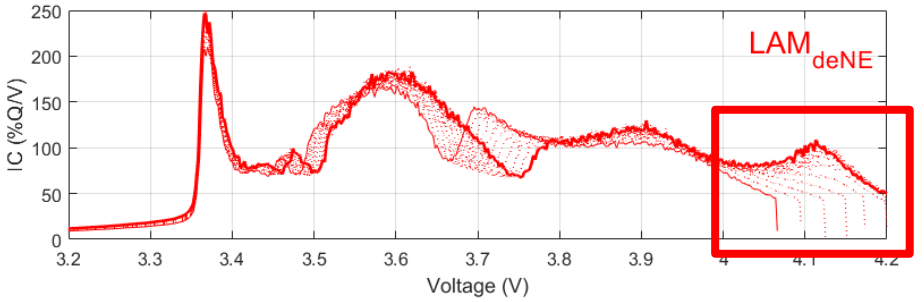
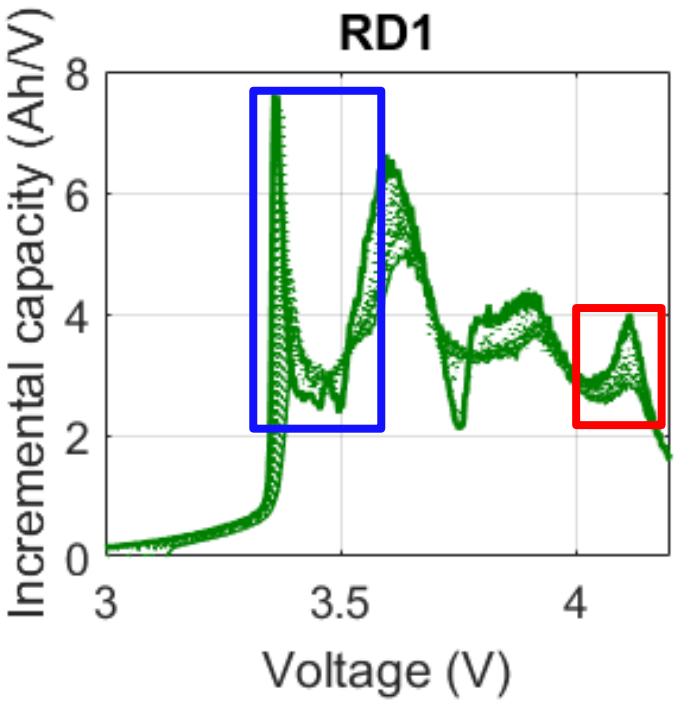
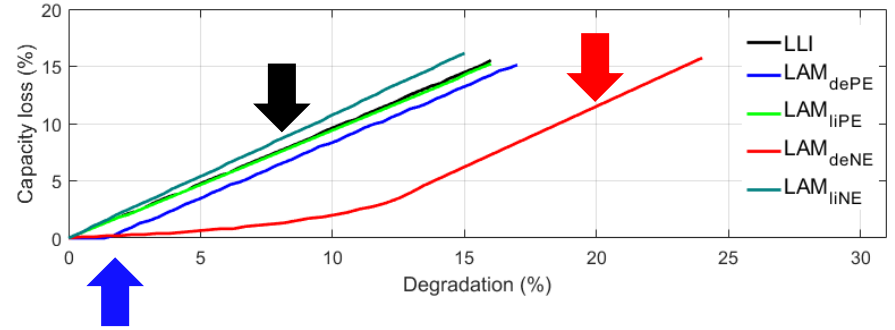
Sensibility analysis











From experimental data:

Capacity loss not from PE or NE→ Had to be from LLI

LLI induces the capacity loss, 1:1 relationship

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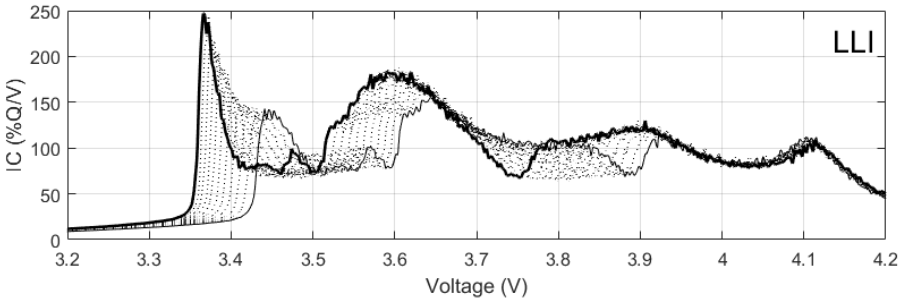
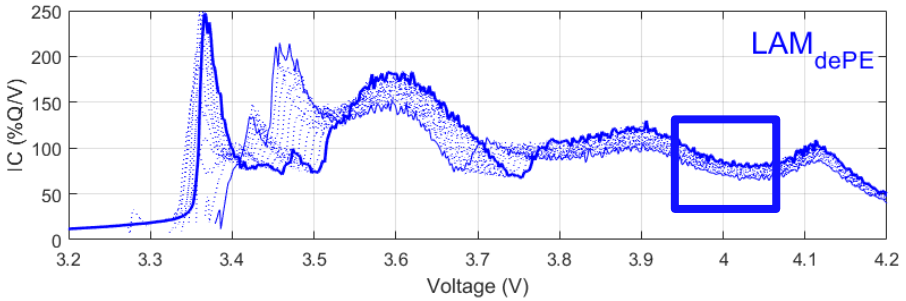
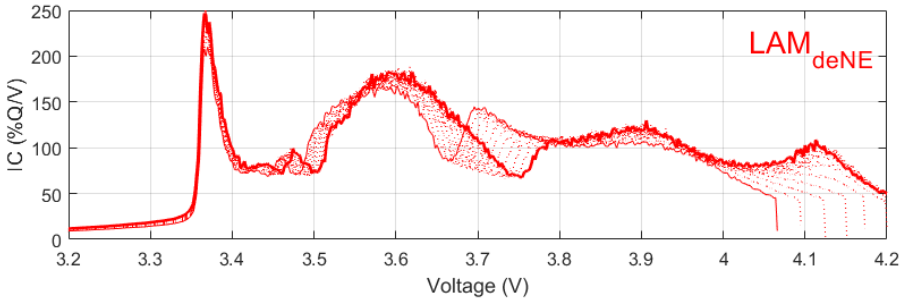
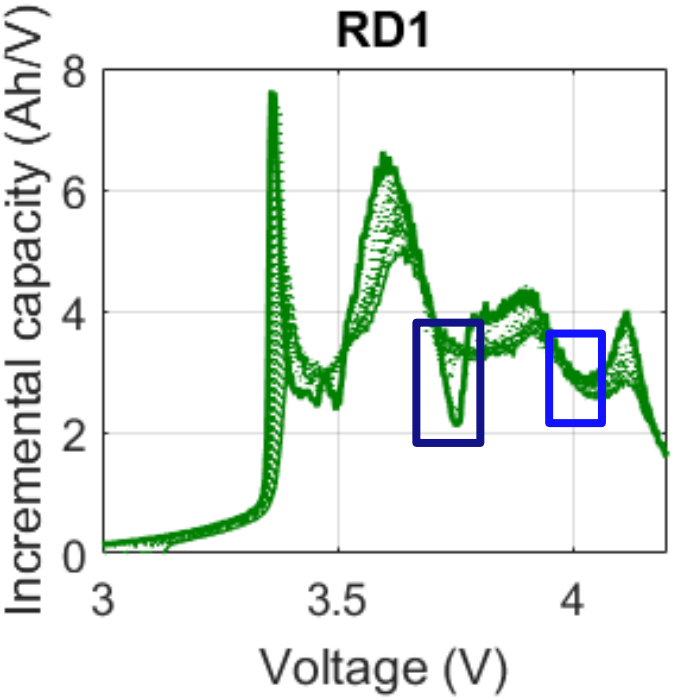
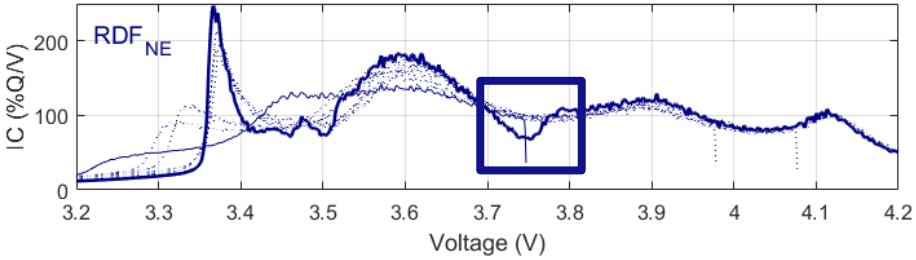
Sensibility analysis











RDF_{NE}: rate degradation factor at the negative electrode

Sensibility analysis: direct estimation possible for LAM_{dePE} and RDF_{NE} quantification

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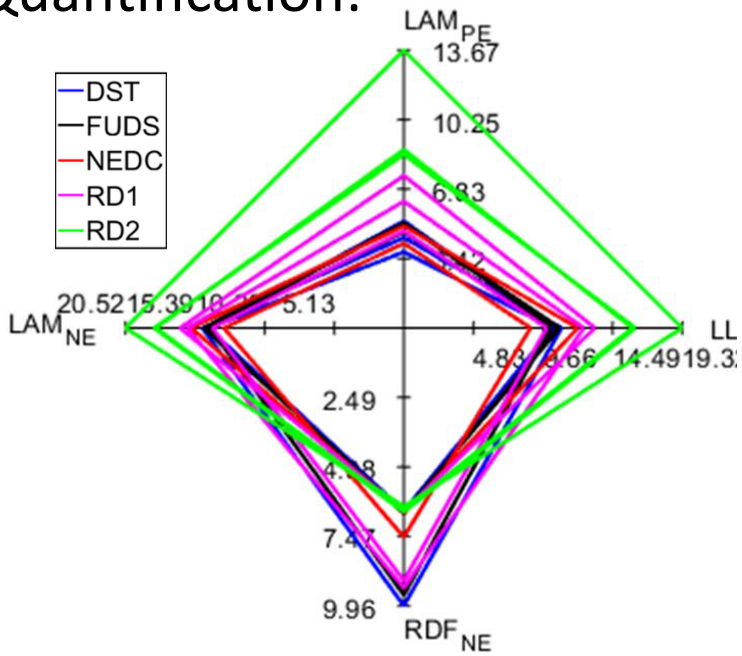
LAM_{NE} estimation & Overall diagnosis at stage 2 onset

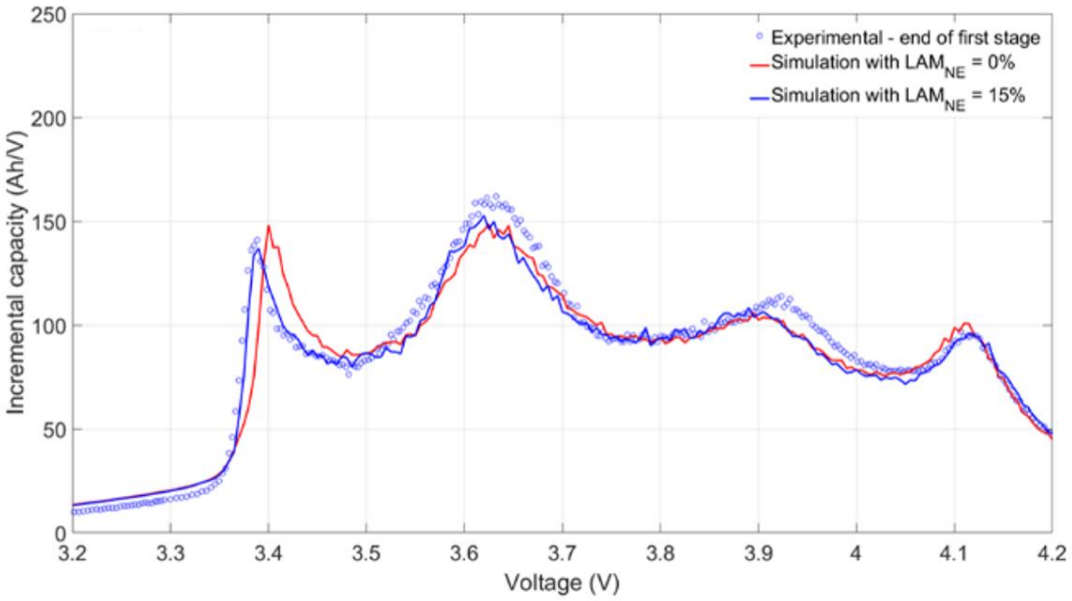
LAM_{NE} can be obtained by Fitting the full curve

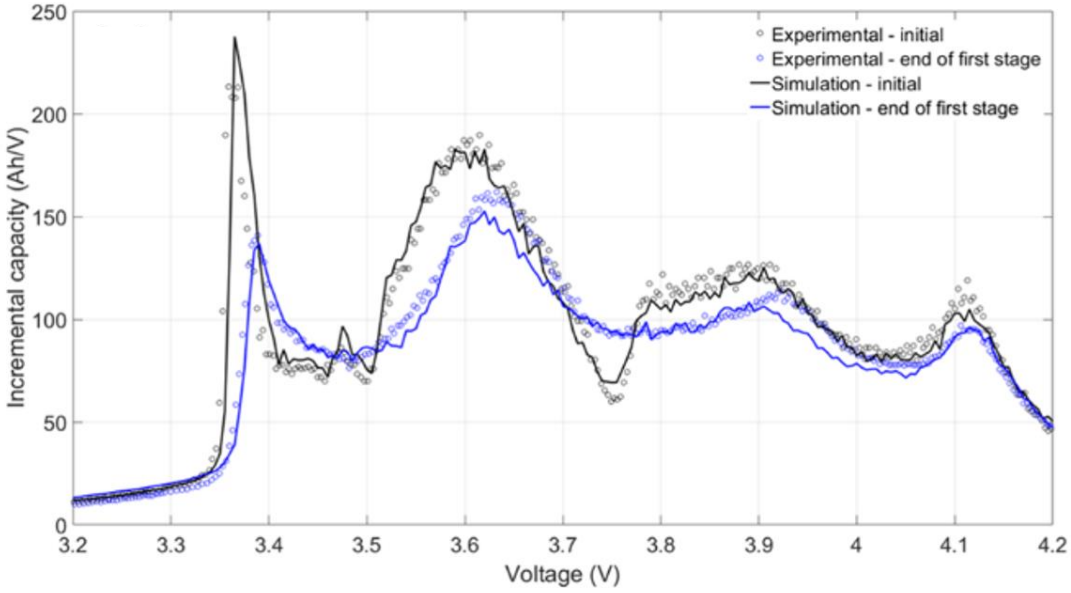
Enables complete degradation Quantification:



@Last point before degradation stage 2

Although close, all duty cycles have different degradation patterns





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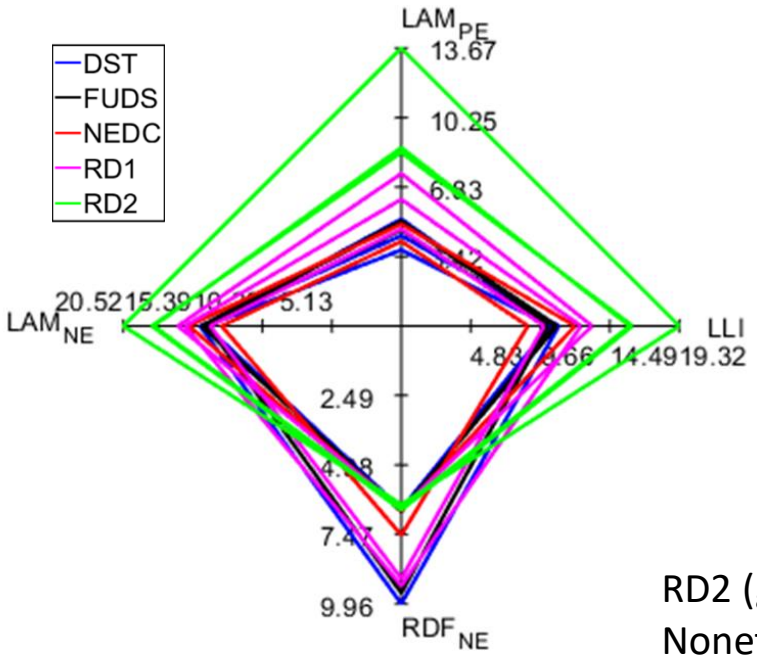
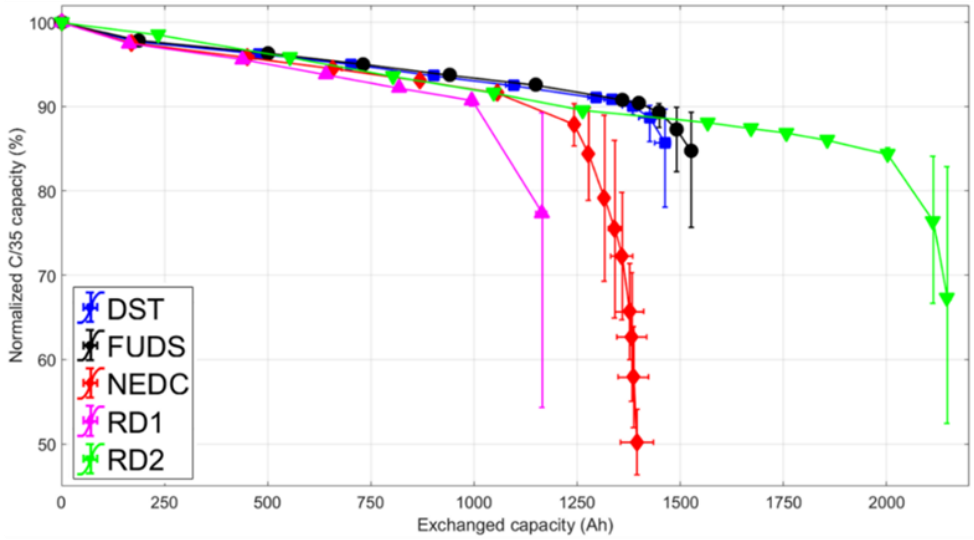
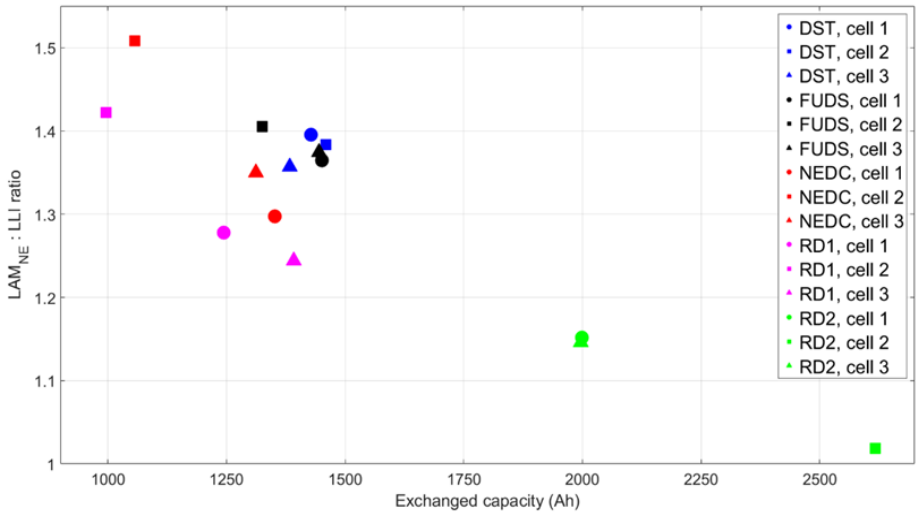
Understanding the 2nd stage onset





RD2 (green) is more degraded because second stage appears later.
Nonetheless, it also has less RDF_{NE} and more LLI.

The ratio of the LAM_{NE} to the LLI may be a decisive parameter in predicting the relative lifetimes of these cells.
Second stage began sooner for the cells that exhibited a higher ratio.
Cells with ratios lower than 1 will never experience second stage.



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Conclusions

Synthetic duty cycles seem to replicate real usage quite closely if power usage are similar,

- Real driving has more LAM_{PE} but less regenerative braking
- Would be important to also match

Battery durability not limited by normal aging but by apparition of second stage,

- Ratio LAM_{NE} vs. LLI might be important metric,
- Ratio < 1 : no second stage induced by LAM_{NE},
- Higher the ratio, faster second stage will happen,

Traffic could have a big impact on battery durability,

- Same commute with 30 days instead of repeating 1 doubled the life,
- Might want to modify testing to account for that effect.

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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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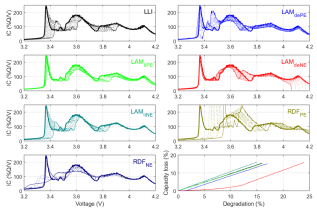
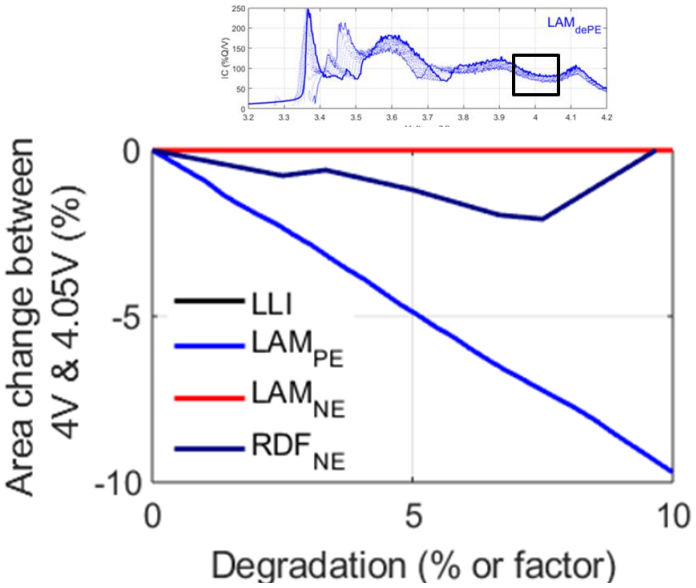
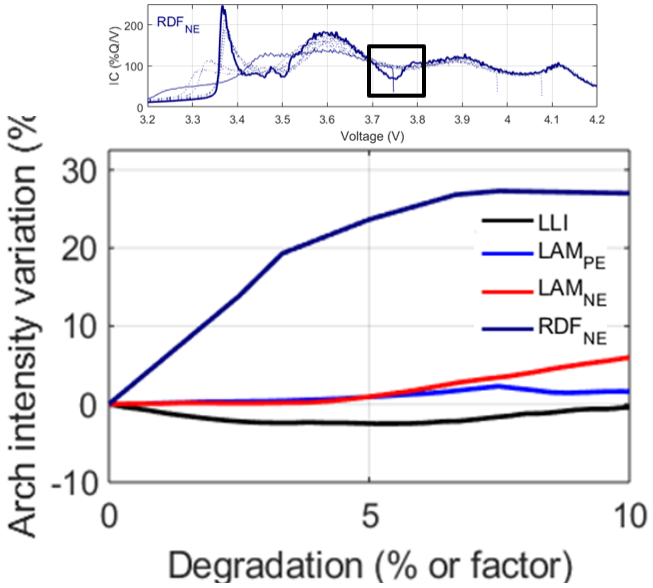
Sensibility analysis

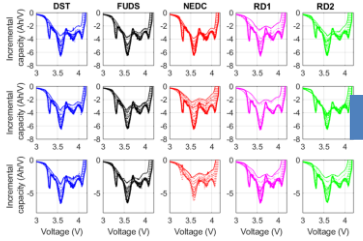
Mechanistic model

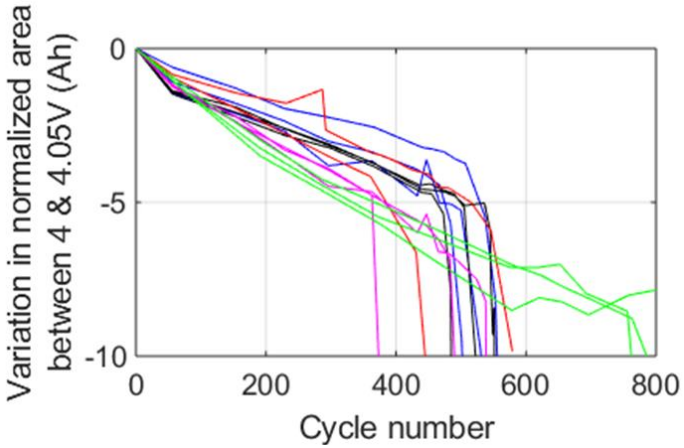


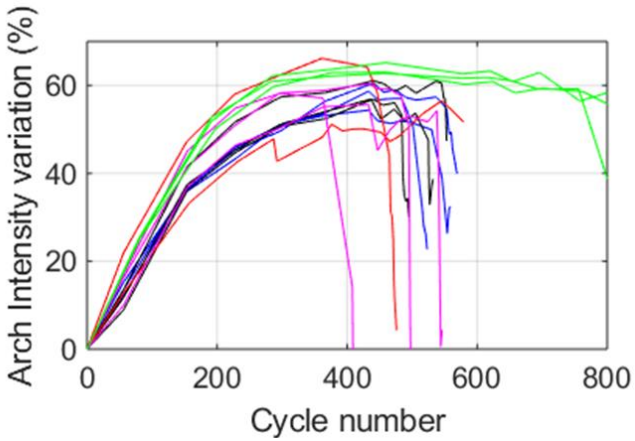




Experimental







LLI, LAM_{PE} and some RDF_{NE} **can be deciphered directly**.