



# A Diagnostic and Prognostic Study of the Impact of Electric Utility Grid Operations on EV Batteries

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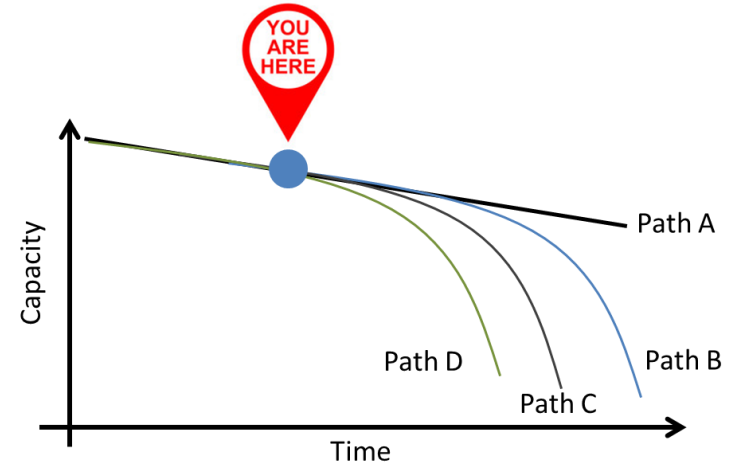
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# Motivation & Objective



Every battery is different and different paths will lead to different degradation

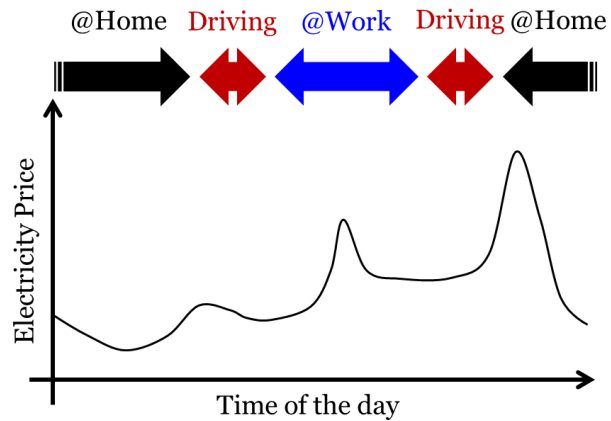


- ❖ Focus on the effect of different grid-vehicle interactions on the Li-ion battery degradation



# Test Scenarios

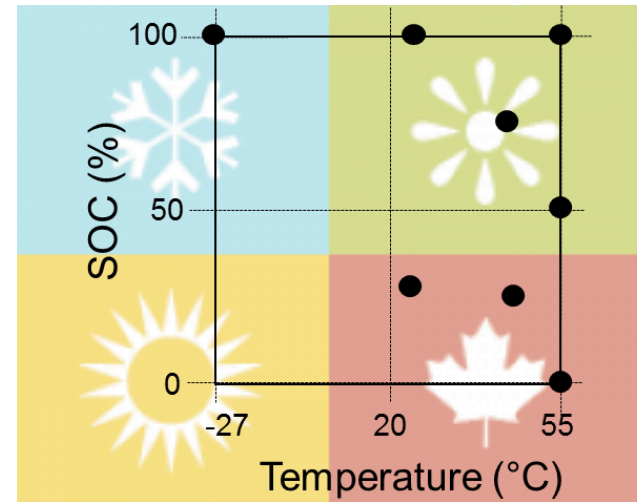
## 1: Vehicle-to-grid (V2G) and grid-to-vehicle (G2V)



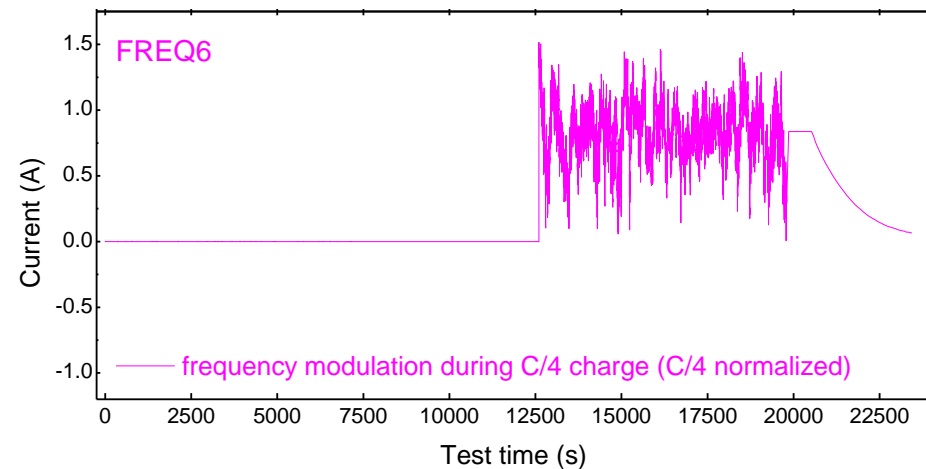
## 3: Driving cycles



## 2: Calendar aging

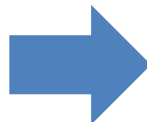


## 4: Frequency modulation

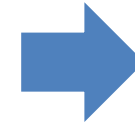
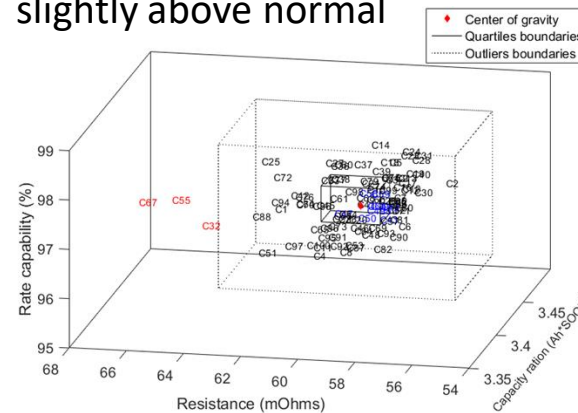


# Experimental approach

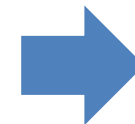
**100 cells were purchased**  
High quality Li-ion cells  
Similar to Tesla batteries



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

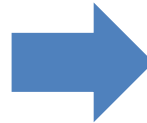
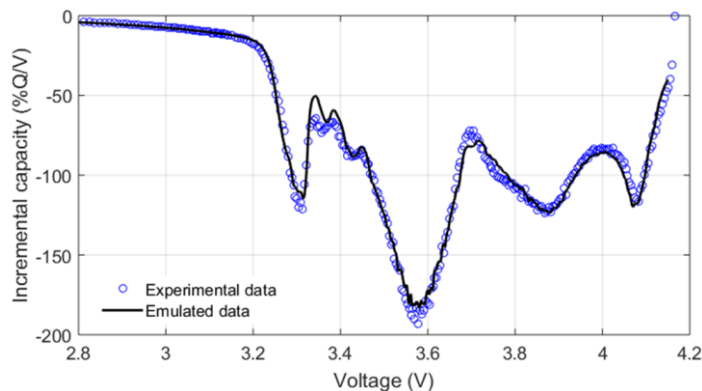


**36 cells selected for cycle aging experiment**  
Impact of V2G and G2V strategies

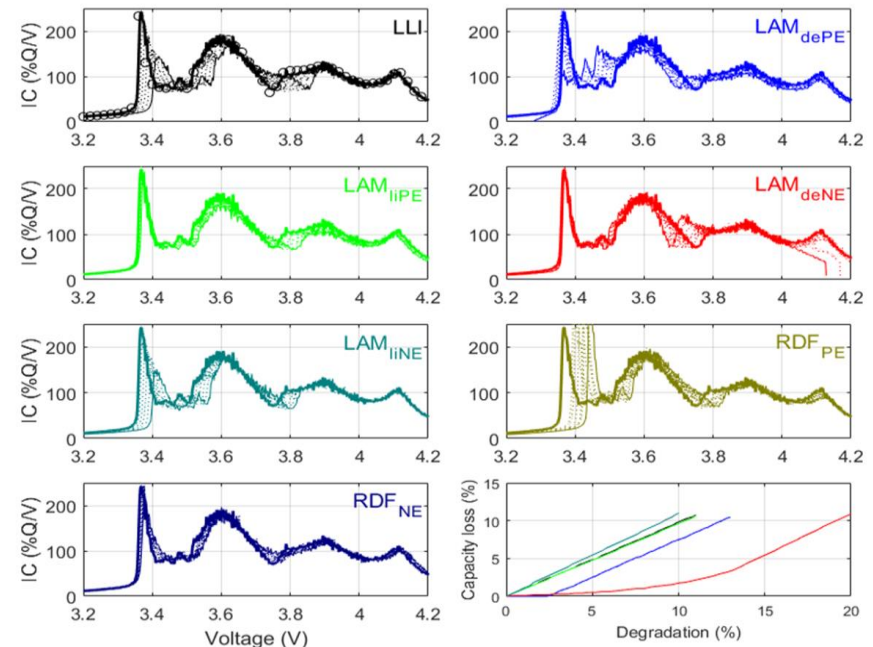


**16 cells selected for calendar aging experiment**  
Impact of time, state of charge and temperature

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



**Diagnosis model was compiled**



# Test Scenarios

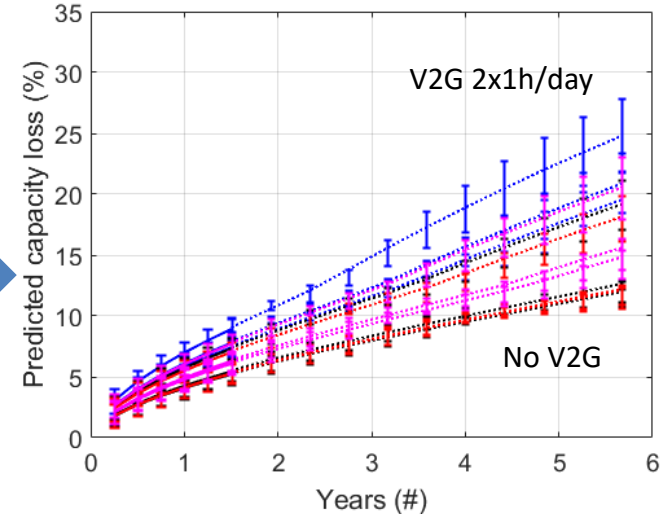
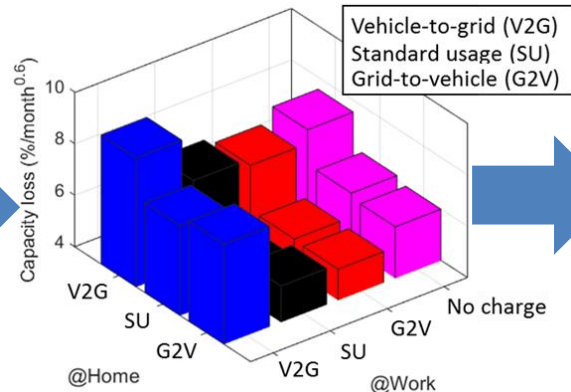
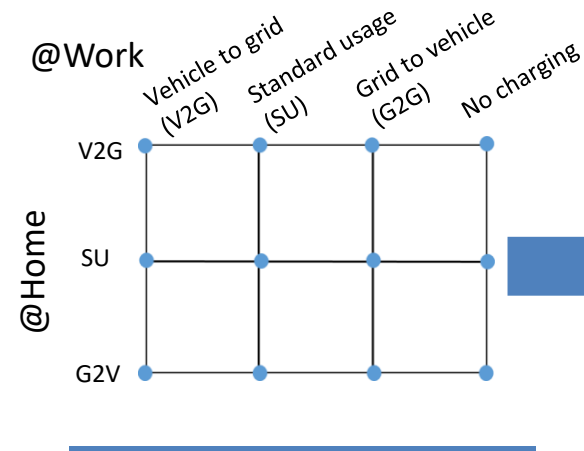
## 1: Vehicle-to-grid (V2G) and grid-to-vehicle (G2V)

### Results:

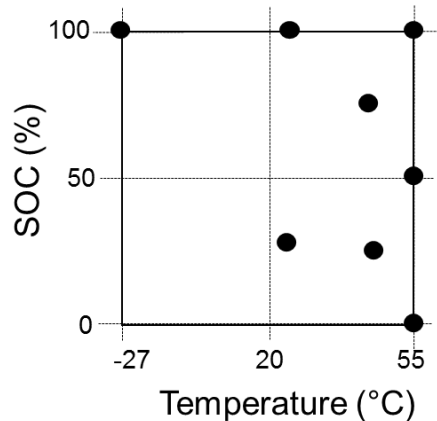
V2G 2x1h/day @ P/4 : +75% capacity loss  
 V2G 1h/day @ P/4 : +33% capacity loss  
 Charging 2x/day vs. 1x/ day: -5% capacity loss  
 SU vs. G2V : no significant effect

### Prognosis:

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

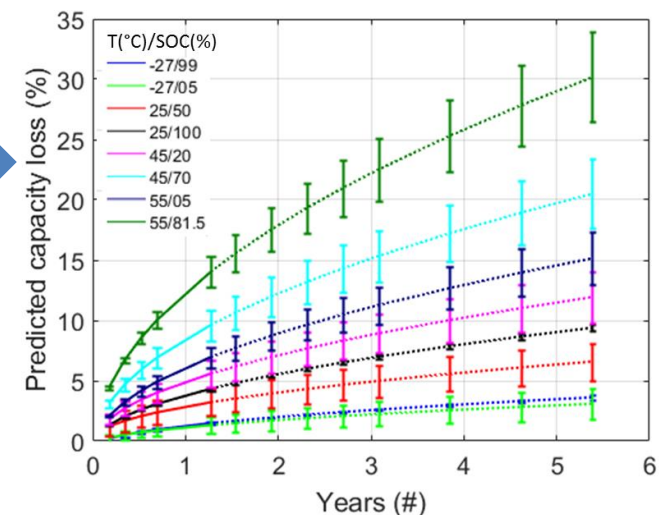


## 2: Calendar aging



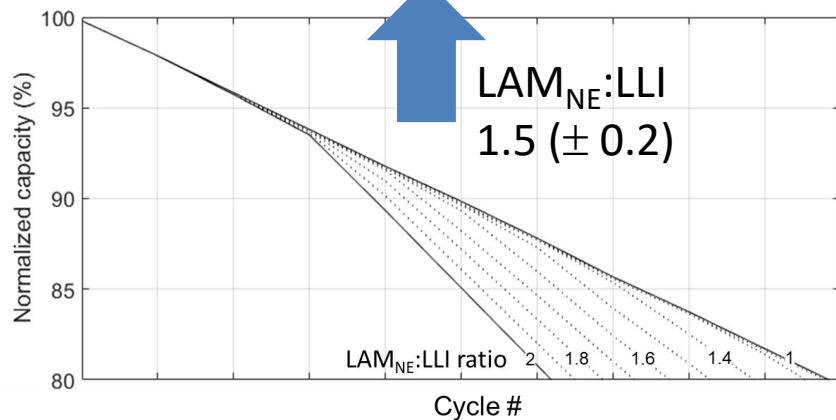
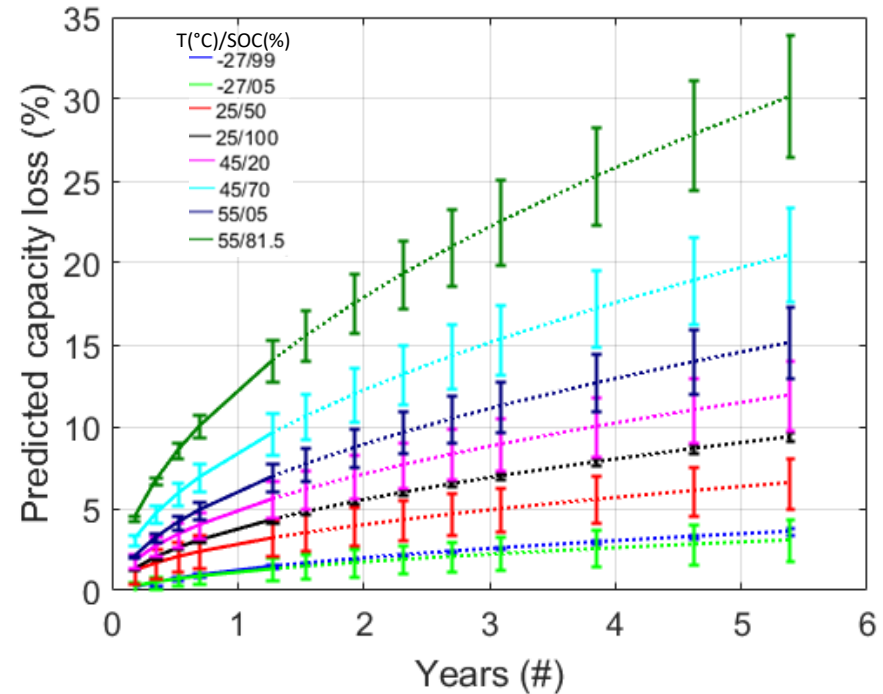
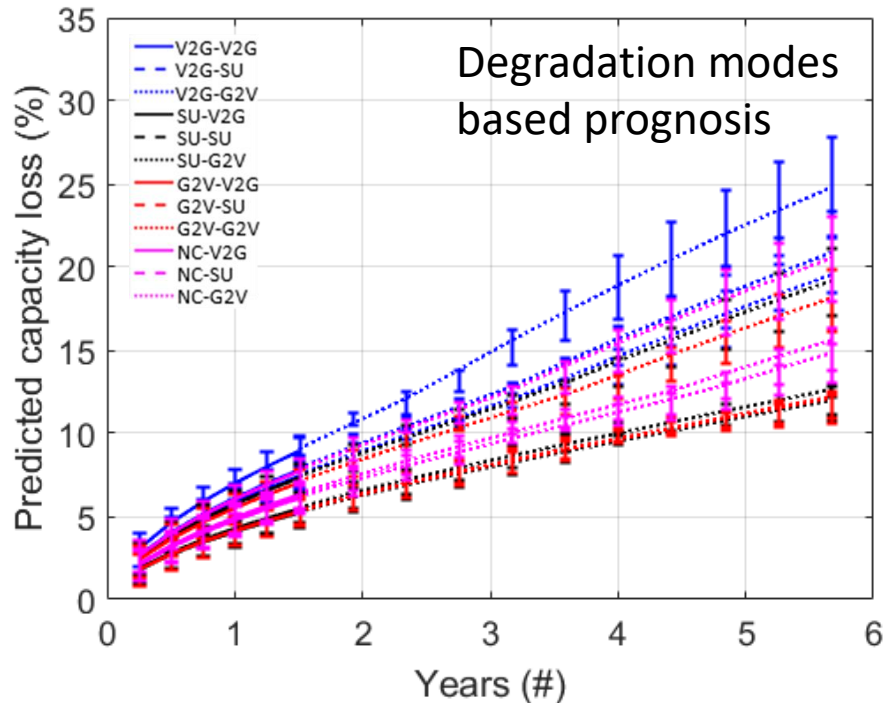
### Results:

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





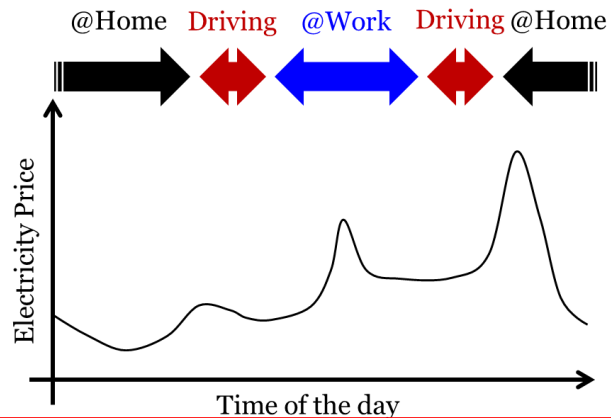
# Test Scenarios 1 & 2: Prognosis



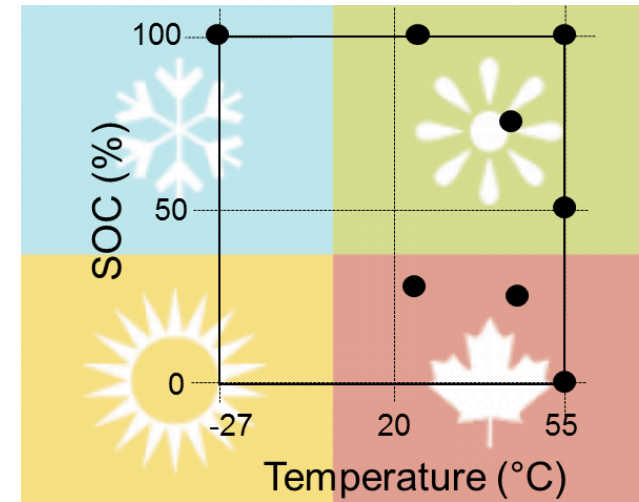
- Capacity based prognosis not valid for cycle aging experiment.
- Capacity loss accelerated by silent degradation mode.
- Cells might last < 4 years if V2G x2/day

# Test Scenarios

## 1: Vehicle-to-grid (V2G) and grid-to-vehicle (G2V)



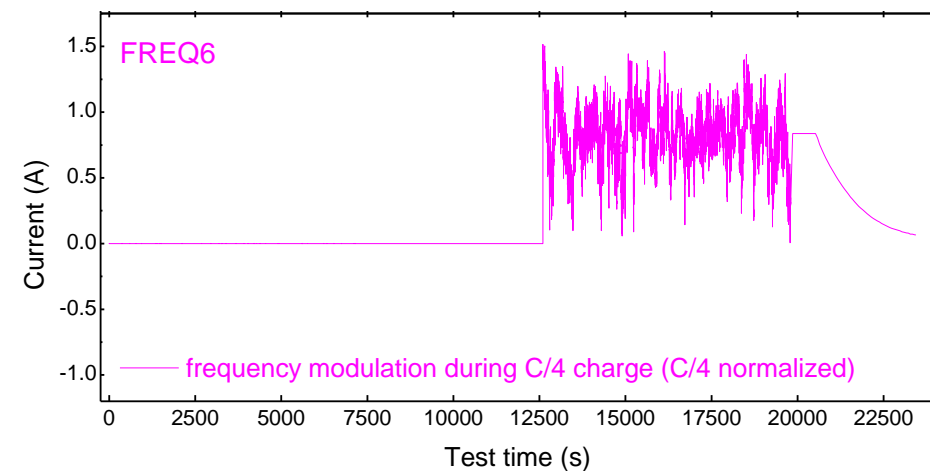
## 2: Calendar aging



## 3: Driving cycles

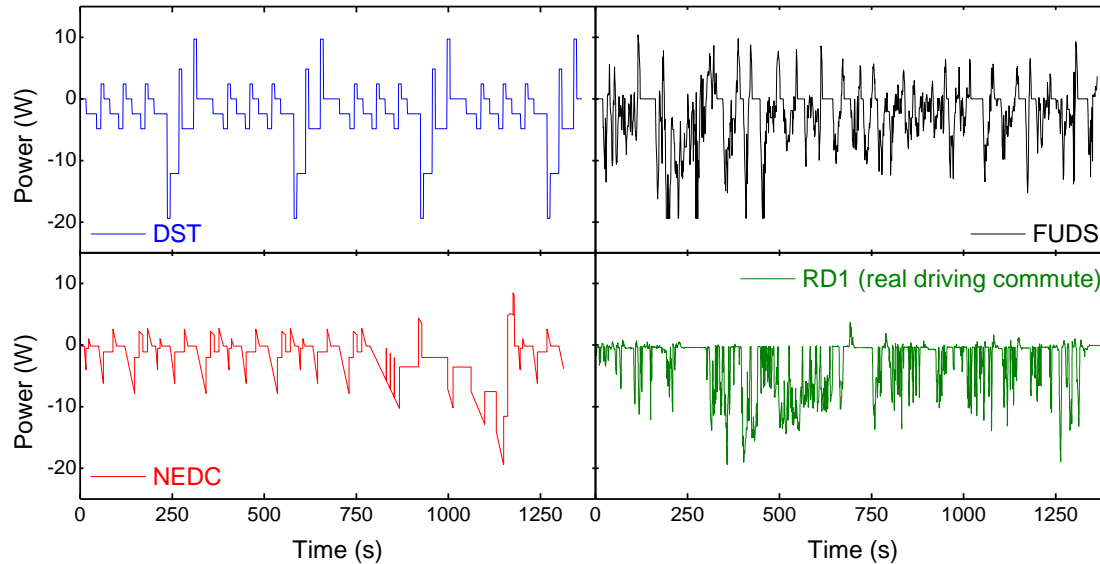


## 4: Frequency modulation



# Test Scenario 3: Driving cycles

## Experimental



- Actual discharge time lower than expected from the average current due to the dynamic applied current
- Driving data had no regenerative braking: simulated profiles have more charged capacity during driving

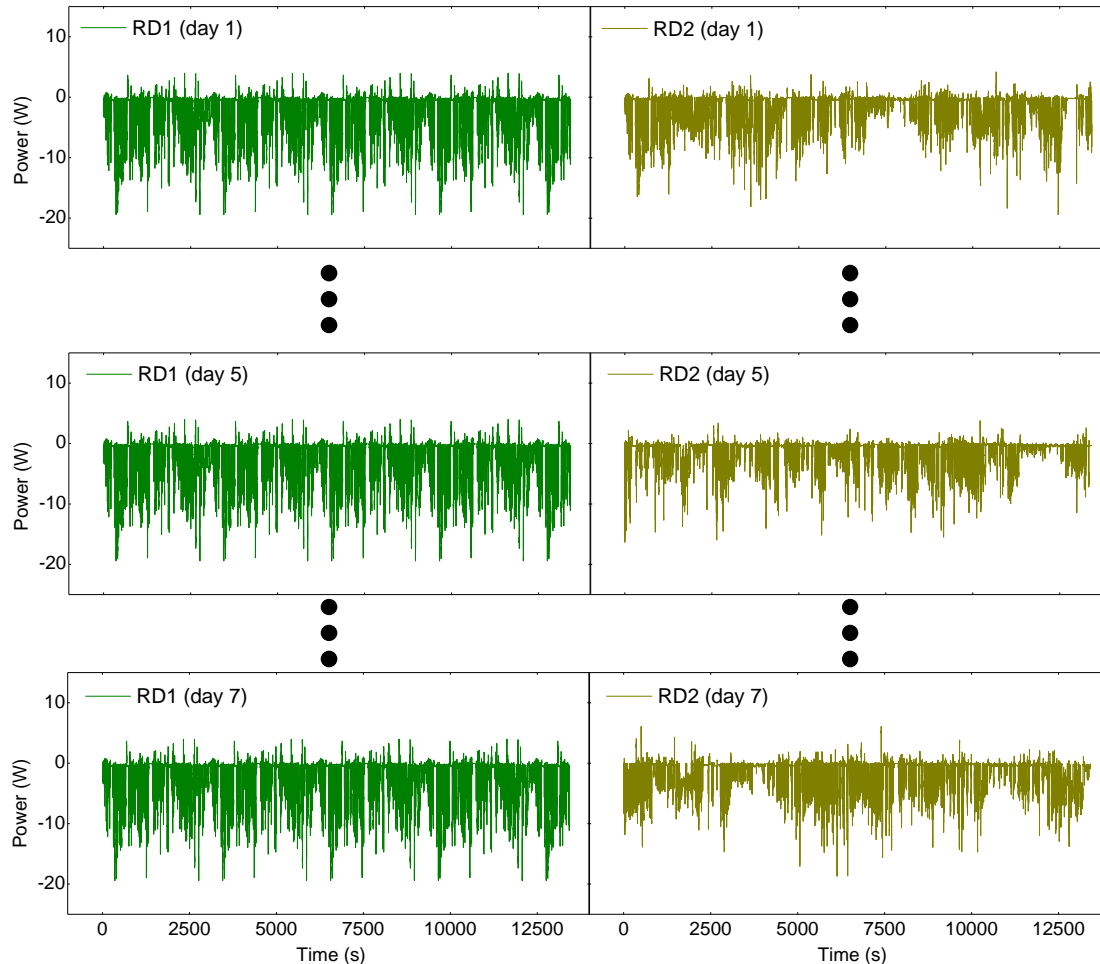
*During first discharge (3 cells tested per profile, 15 cells total)*

Driving profiles	Avg. Current (A)	C rate based on avg. current	Discharge time (hour)	Charge Capacity (Ah)	Discharge Capacity (Ah)
Dynamic Stress Test (DST)	-0.68	C/4.8	4.03	0.51	3.29
Federal Urban Driving Schedule (FUDS)	-0.70	C/4.6	3.74	0.56	3.20
New European Driving Cycle (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
RD2: real driving (complete dataset)	-0.45	C/7.3	6.73	0.04	3.01



# Driving cycles

## Experimental

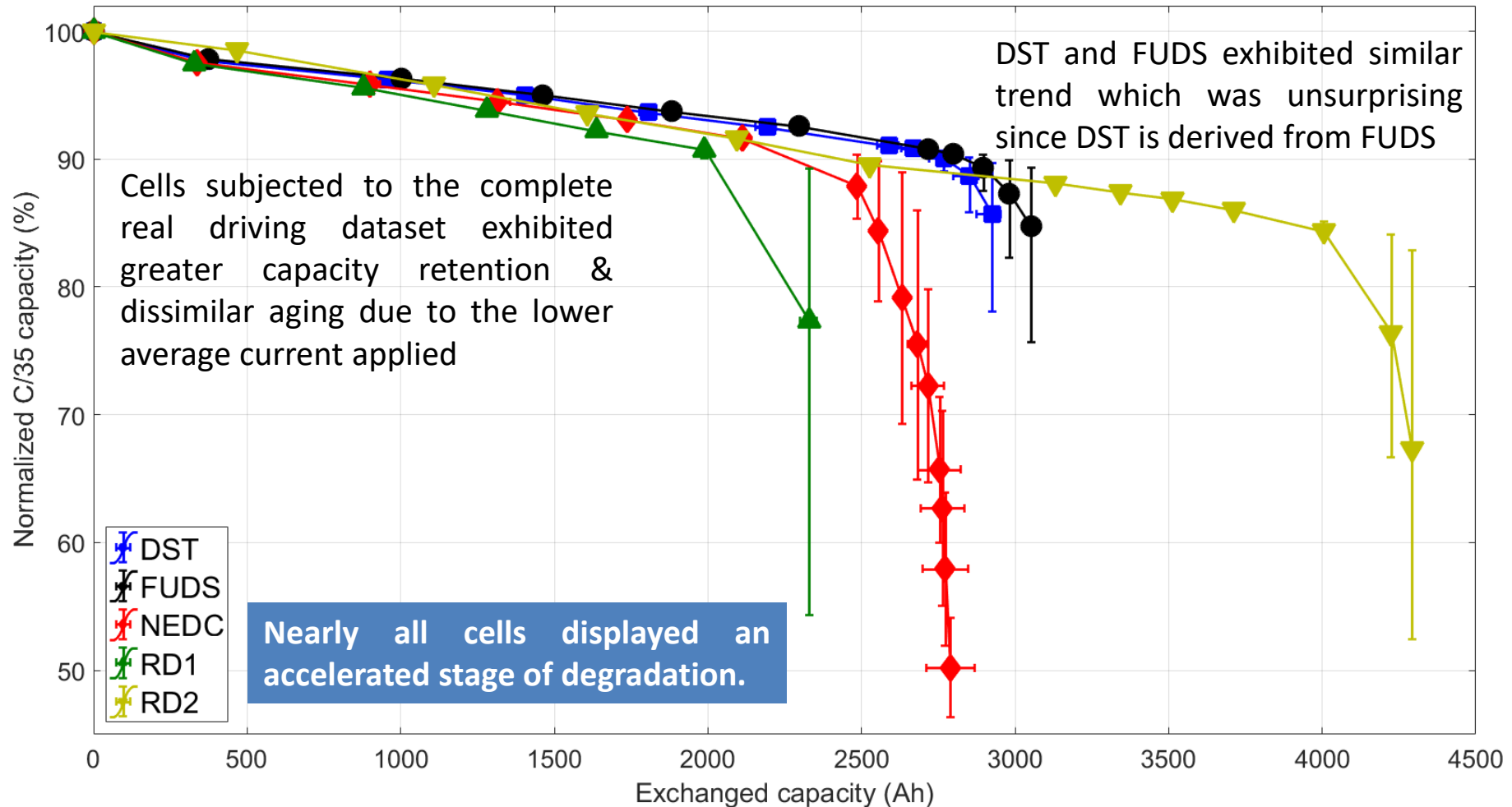


- Real driving data obtained from 2-year EV data collection program
- RD1 is 1 commute with an average discharge current comparable to the simulations
- RD2 is a set of 30 unique commutes

All driving profiles were repeated until the cell were fully discharged

# Driving cycles

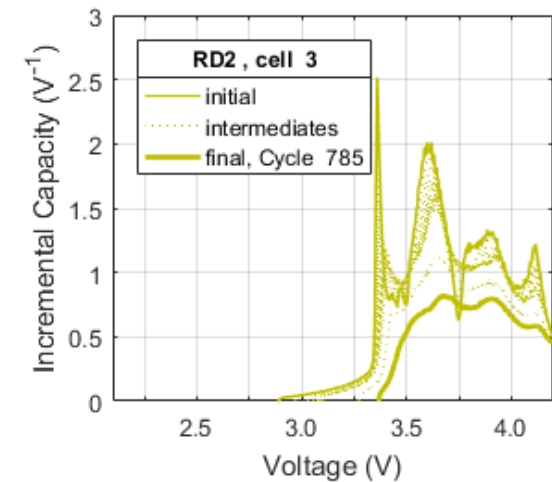
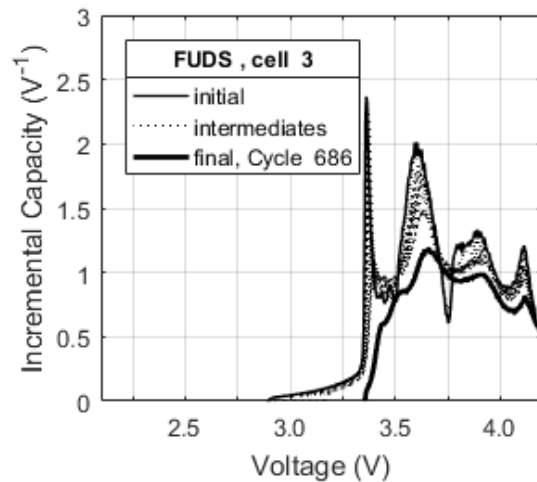
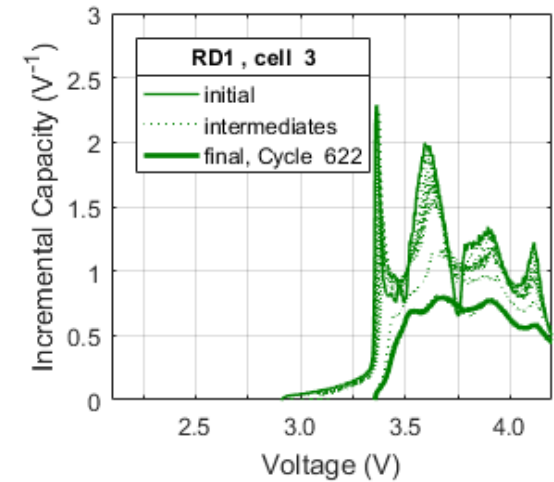
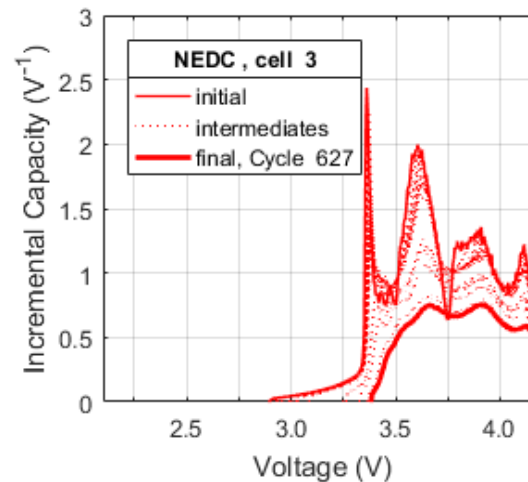
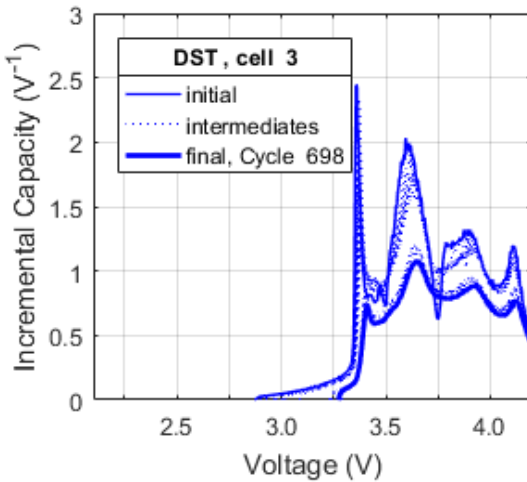
## Capacity loss



➤ At similar C-rates, low charge capacity during discharge led to lower cell lifetimes.

# Driving cycles

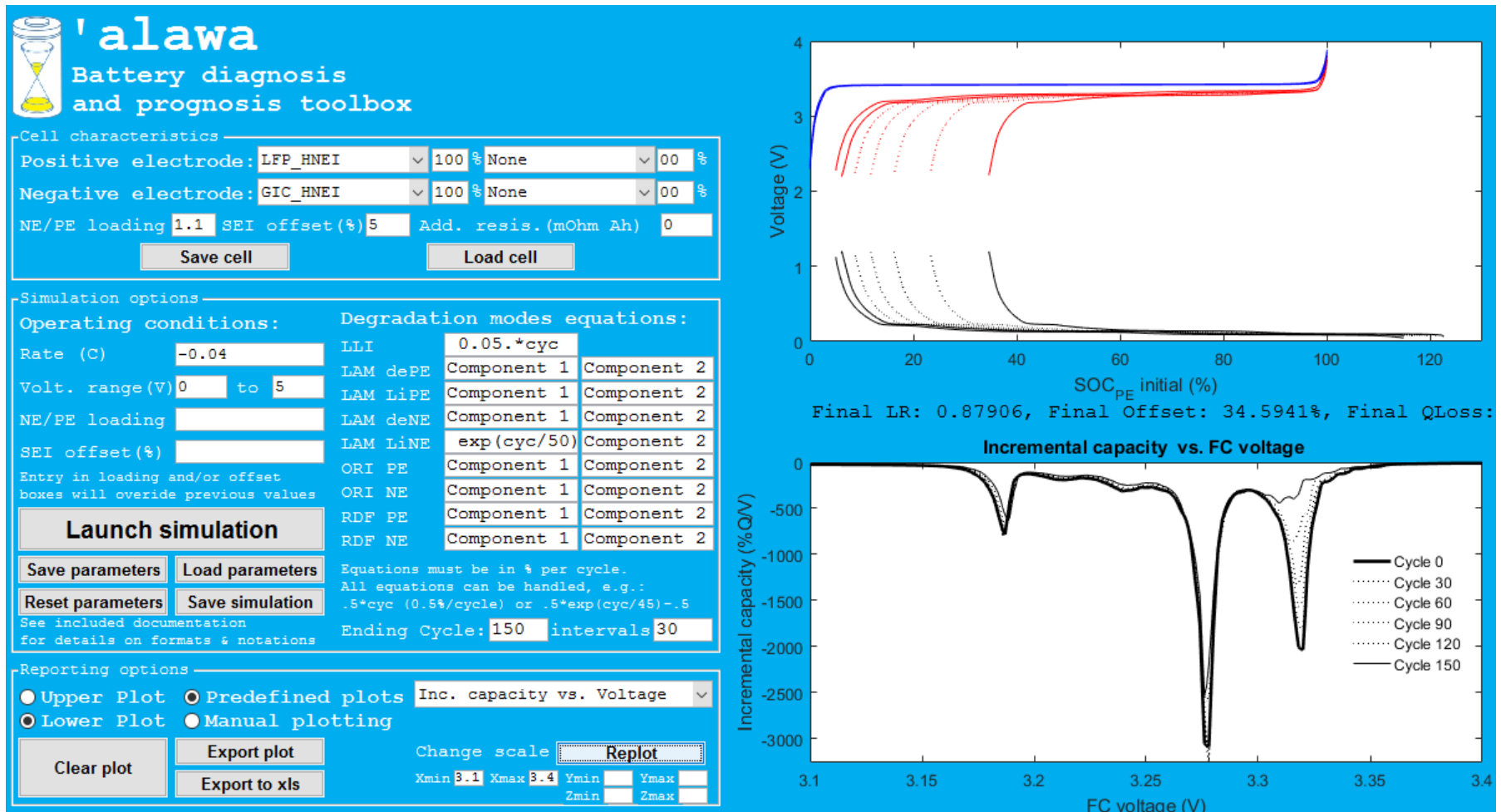
## Incremental capacity curve evolution with aging



- Evolution of the incremental capacity curves for all the cells tested were similar indicating a specific degradation process.

# Mechanistic diagnosis and prognosis

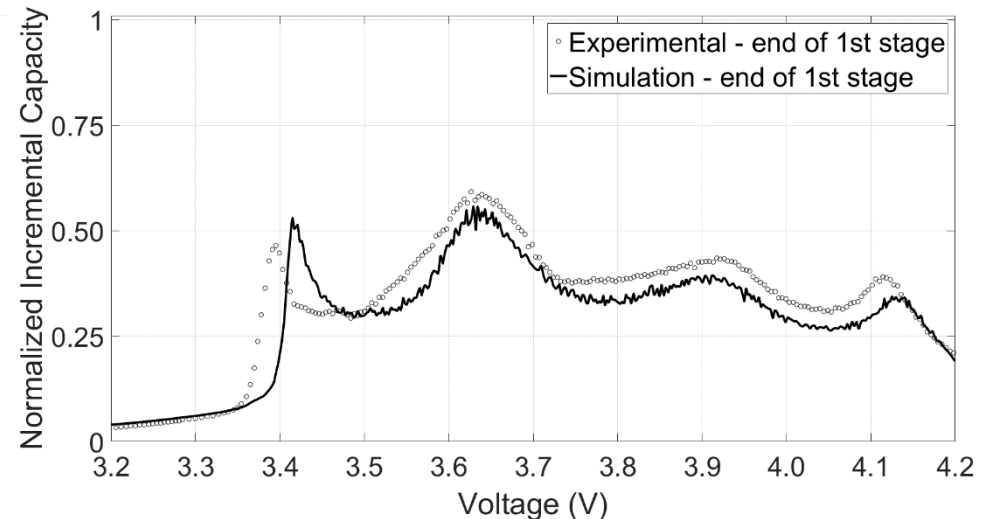
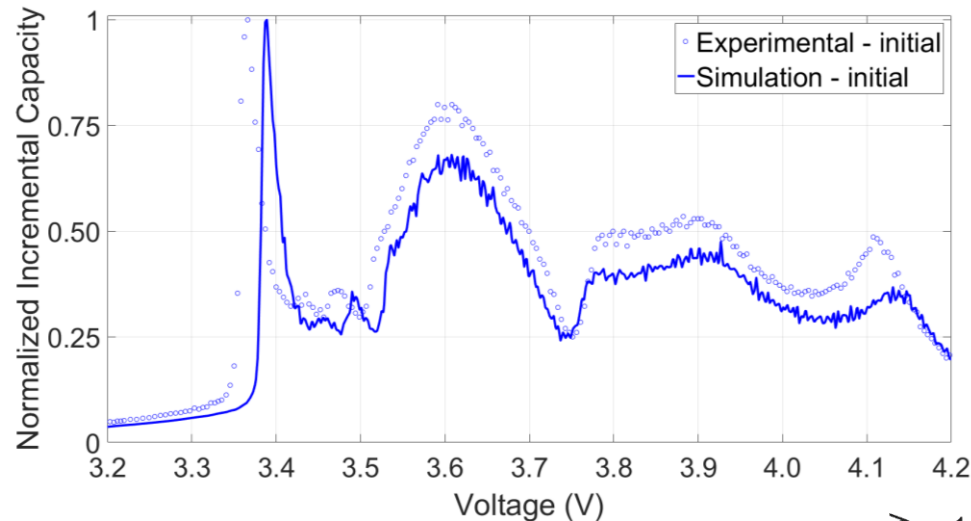
Simple, fast, powerful and accurate diagnosis and prognosis tool



Stand alone GUI available for license or collaboration

# Driving cycles

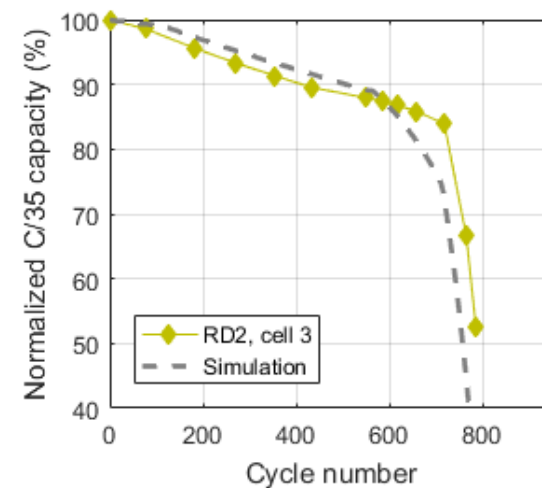
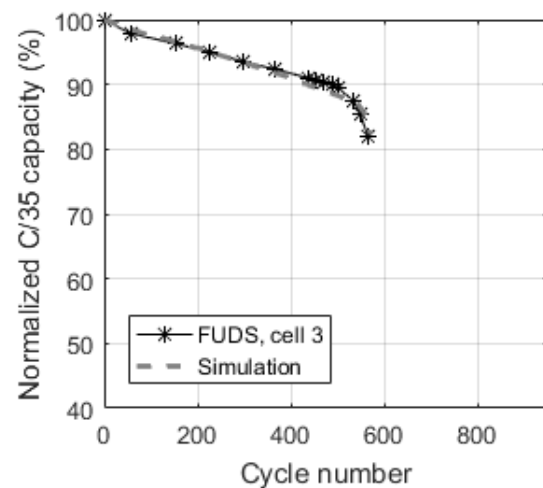
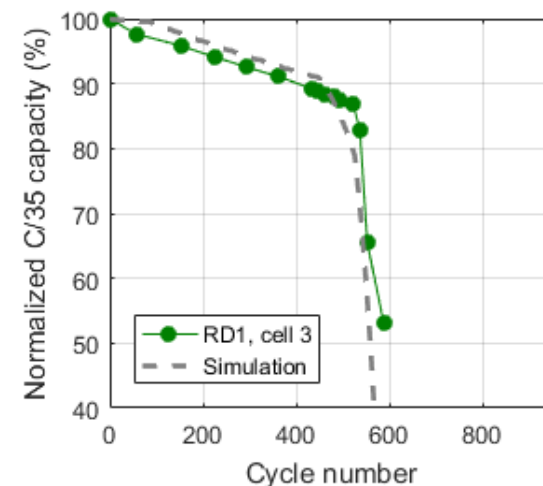
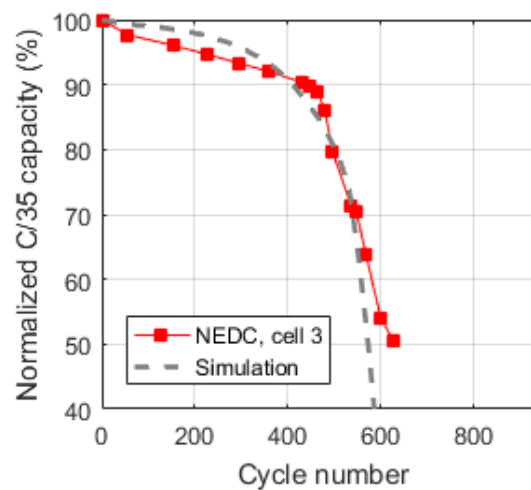
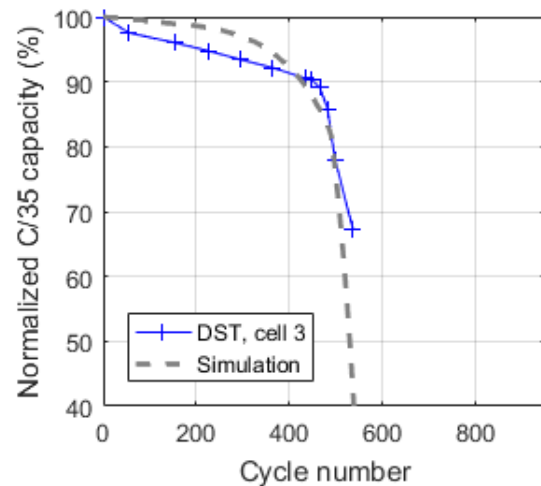
## Incremental capacity (IC) analysis



Experimental data fit to quantify the relative values of the degradation modes.

# Driving cycles

## Fitting





# Driving cycles

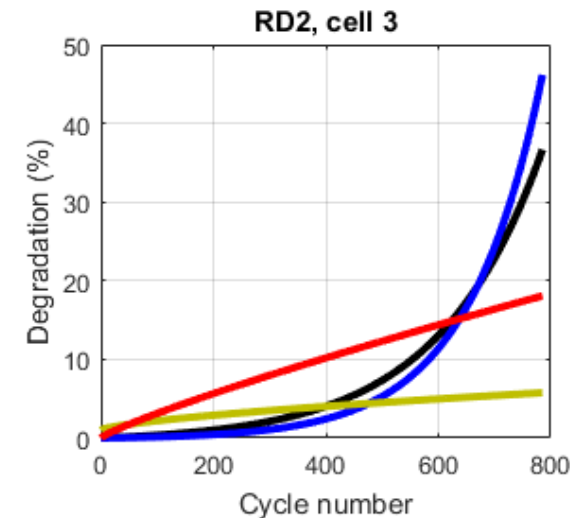
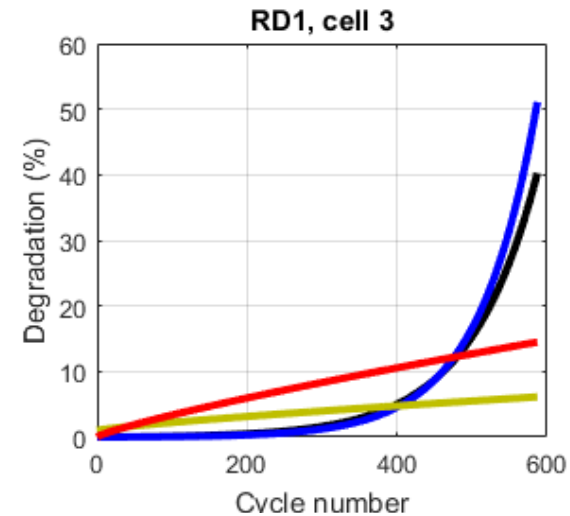
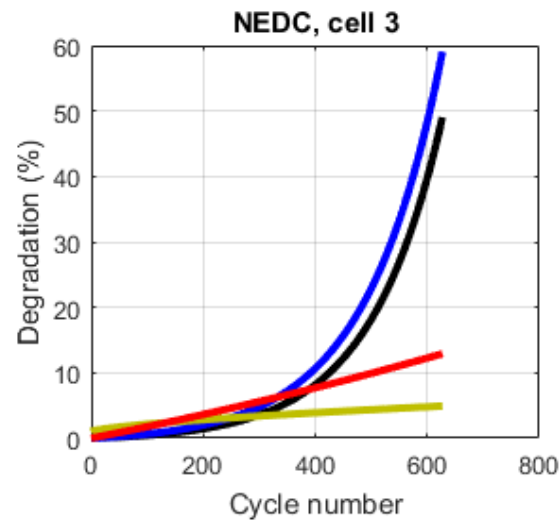
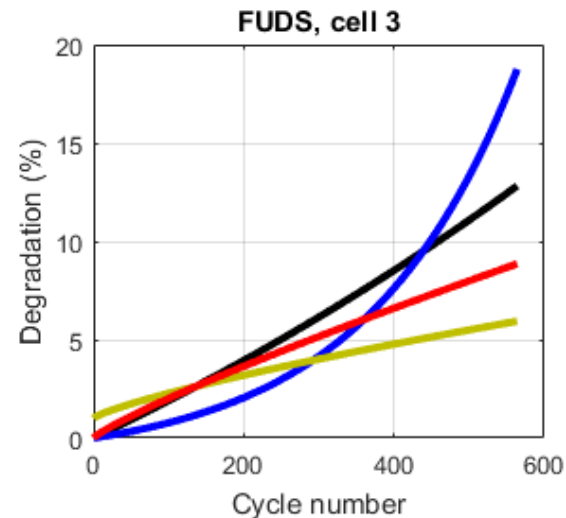
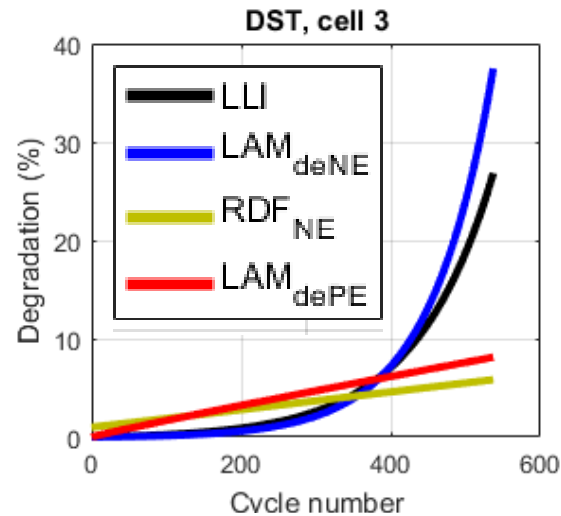
## Fitting

**LLI**: loss of lithium inventory

**LAM<sub>deNE</sub>**: loss of active material at the negative electrode

**RDF<sub>NE</sub>**: rate degradation factor at the negative electrode

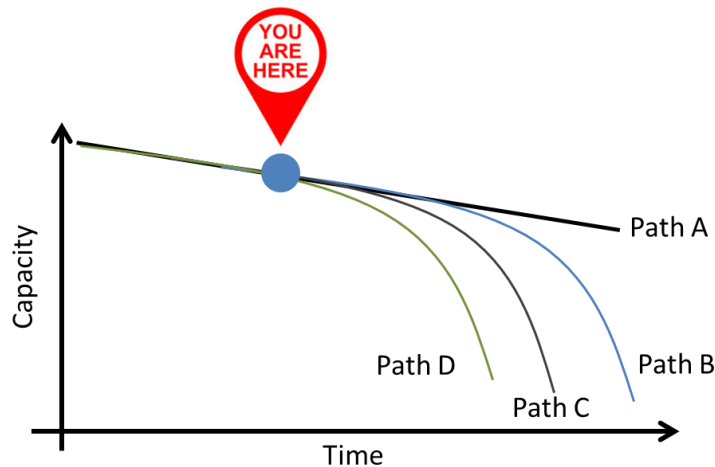
**LAM<sub>dePE</sub>**: loss of active material at the positive electrode



➤ Accelerated stage dominated by the loss of lithium and loss of active material at the negative.

# Conclusions

- ❖ An accelerated aging stage predicted and observed.
- ❖ Regenerative braking and dynamic charging may improve cell lifetimes.
- ❖ Features in incremental capacity curves change in a similar manner despite differences in aging.
- ❖ Analysis needs to be improved to be able to predict when a second accelerated aging stage will occur.



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<http://evtc.fsec.ucf.edu/research/>



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