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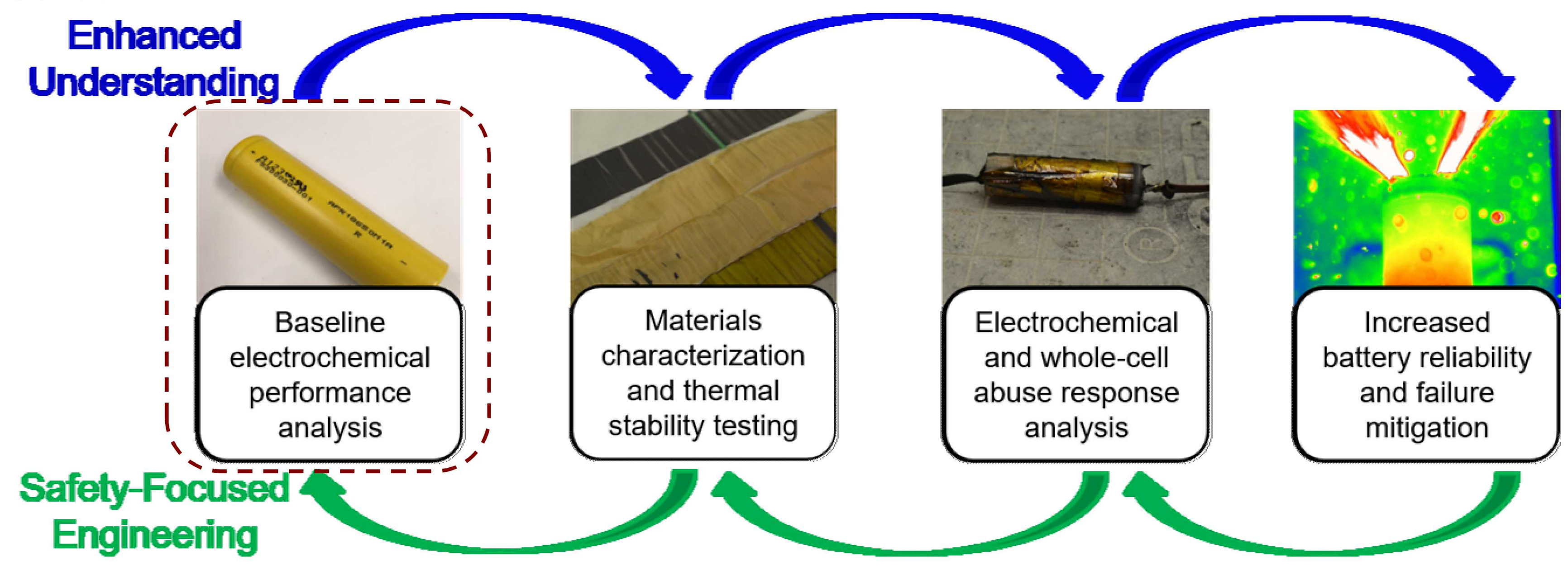
Aging Behavior and Abuse Response of Commercial Lithium-Ion Cells as a Function of Chemistry and Cycling Conditions

Yuliya Preger, Heather Barkholtz, Armando Fresquez, Frank Austin Mier, Babu Chalamala, and Summer Ferreira

Motivation

- Stationary energy storage systems (ESS) are increasingly deployed to maintain a robust and resilient grid
- As system size increases, safety becomes a critical concern
- Holistic approach: study of electrochemistry, materials, and whole-cell abuse will fill knowledge gaps for failure mitigation
- Comprehensive studies comparing application specific aging behavior of popular commercial batteries have been limited
- Safety of aged cells and influence of aging pathway on cell safety is unclear

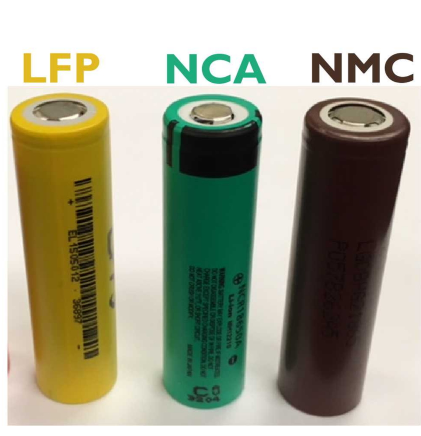


Study Design

Design of experiment approach with two cells at each set of conditions, all within manufacturer specifications (88 cells total)

Variable				
Chemistry	LFP ($LiFePO_4$)	NCA ($Ni_xCo_yAl_{1-x-y}O_2$)	NMC ($LiNi_{0.8}Mn_{0.15}Co_{0.05}O_2$)	
Discharge Rate*	C/2	1C	2C	3C
State of Charge Range	40-60%	20-80%	0-100%	
Environment Temperature	15°C	25°C	35°C	

*Charge rate always C/2



Commercial cell specifications

Battery	LFP (A123)	NCA (Panasonic)	NMC (LG Chem)
Capacity	1.1 Ah	3.2 Ah	3.0 Ah
Voltage	3.3 V	3.6 V	3.6 V
Max Discharge Current	30 A	6 A	20 A
Operating T	-30 to 60°C	0 to 45°C	0 to 50°C

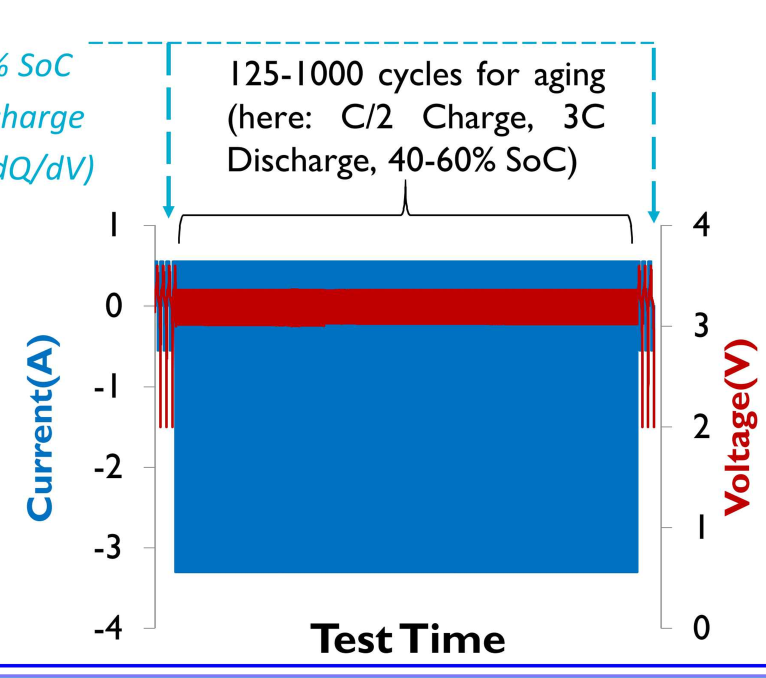
Test Procedure

Electrochemistry of cell aging is monitored via:

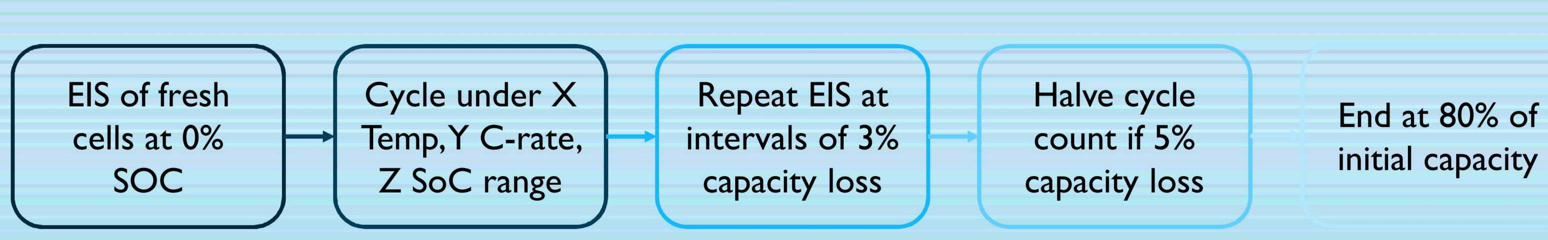
a) *capacity decline*
b) *electrochemical impedance spectroscopy (EIS)*
c) *differential capacity analysis (dQ/dV)*

Upon reaching 80% capacity, cells will be disassembled and subject to abuse tests to determine how aging has modified their materials composition and influenced safety.

Typical Round of Cycling

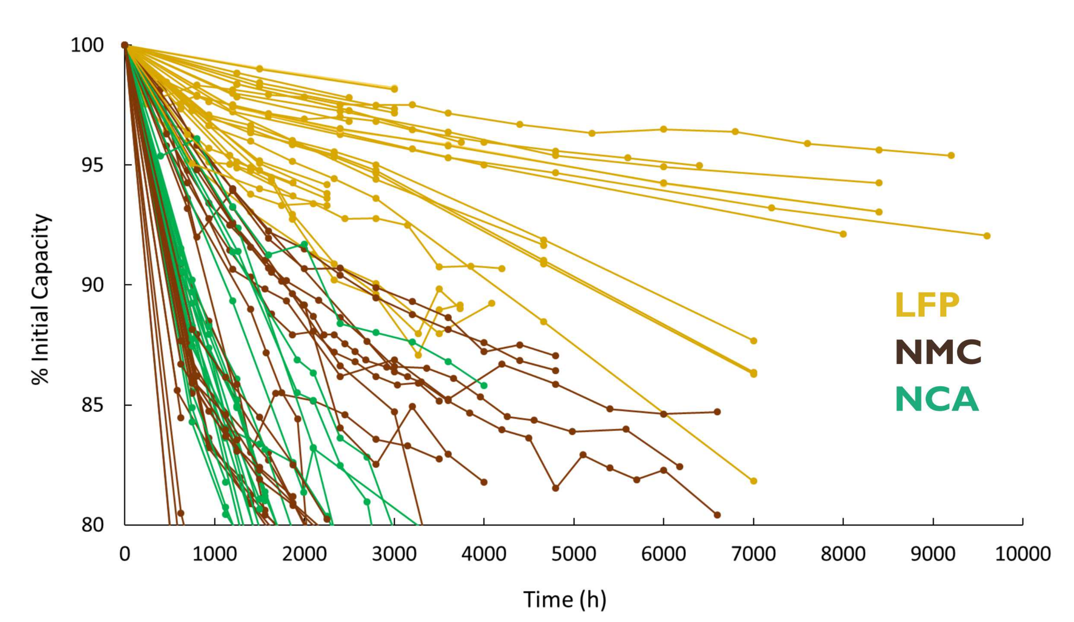


Cell Cycling Sequence



Performance

Even within manufacturer specifications, cycling conditions have a profound effect on cell degradation, with each chemistry exhibiting differing sensitivities to each variable.

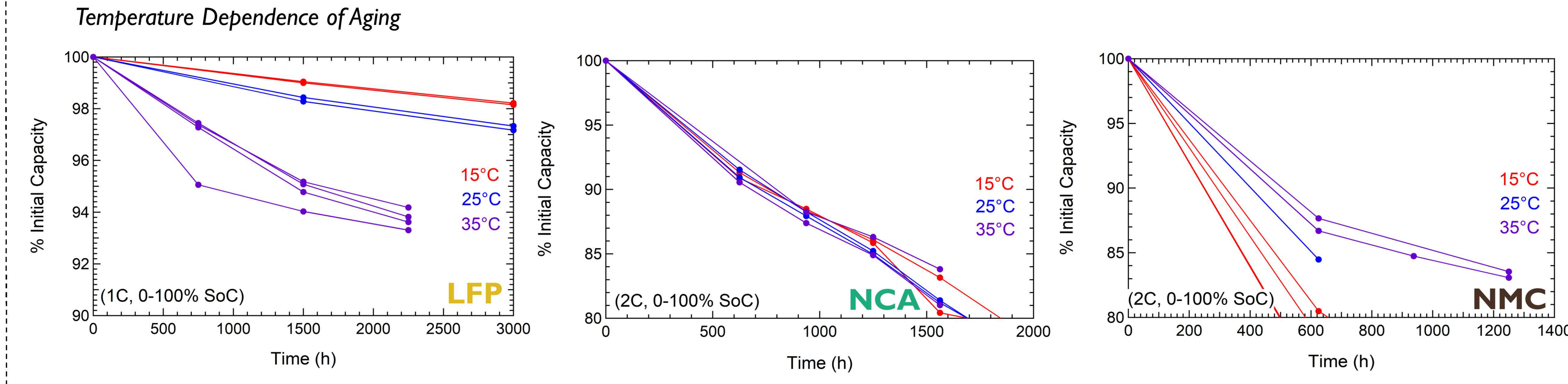


Observations

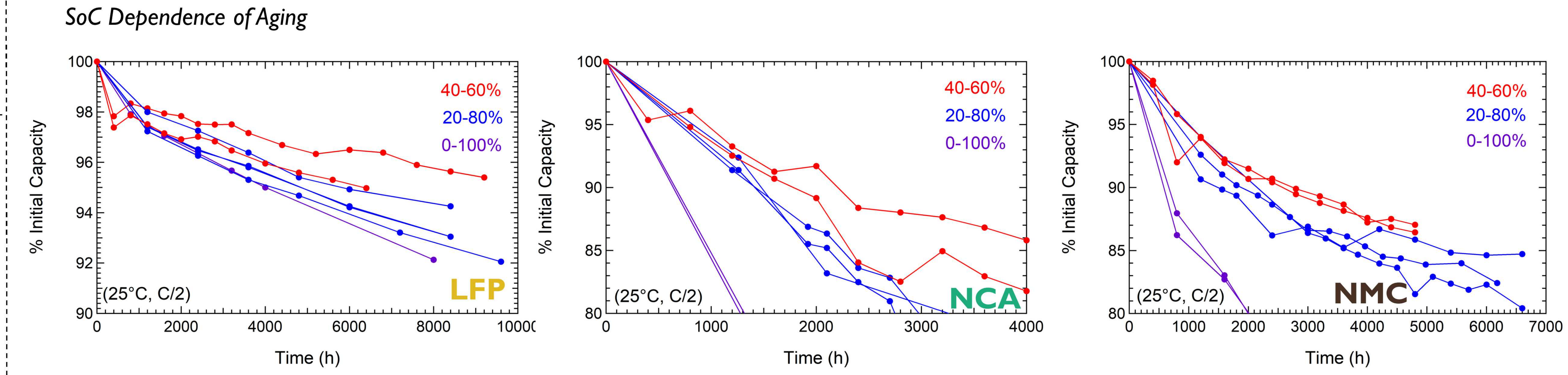
1) *LFP most stable, but still sensitive to cycling conditions*
2) *Temperature dependence inverted for LFP and NMC; limited for NCA*
3) *NCA and NMC particularly sensitive to full discharge*

Next Step: analysis of variance and multifactor relationships

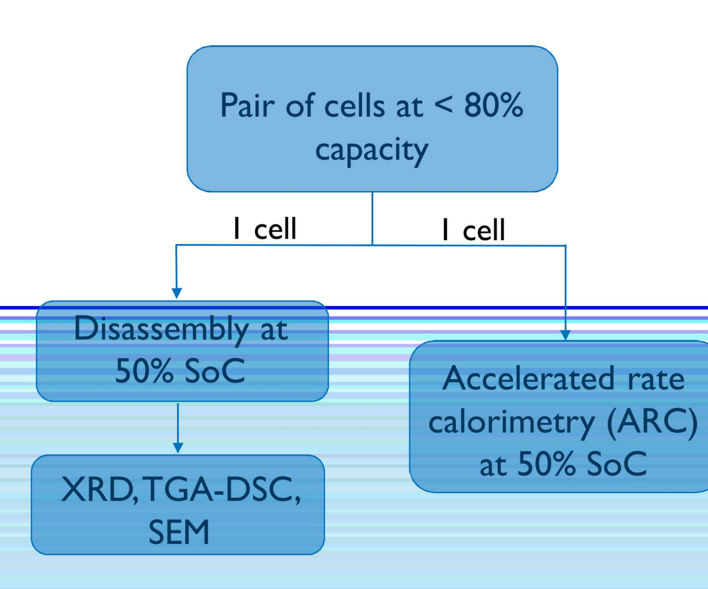
Temperature Dependence of Aging

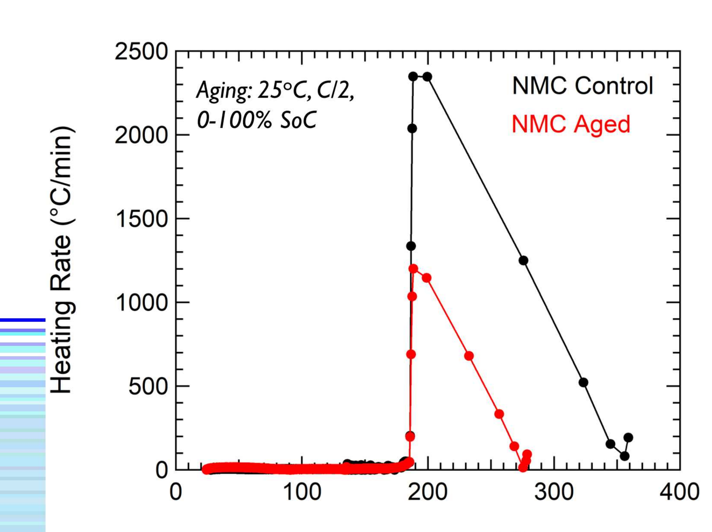


SoC Dependence of Aging



The influence of cell age and aging pathway on abuse response is poorly understood. Does aging make cells more safe (via capacity loss), less safe (via long-term materials degradation), or only minimally affect abuse response? Various cells from the aging study will undergo abuse testing and component materials characterization to relate materials changes to changes in safety.





Preliminary thermal ramp shows little change in onset, proceed with more sensitive ARC approach.

Conclusions

- LFP most stable chemistry, but stability still profoundly influenced by cycling conditions (especially temperature)
- Application requirements must be considered: different chemistries can exhibit opposite responses to a variable (particularly temperature)
- Influence of aging pathway on cell safety best explored via calorimetry

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