

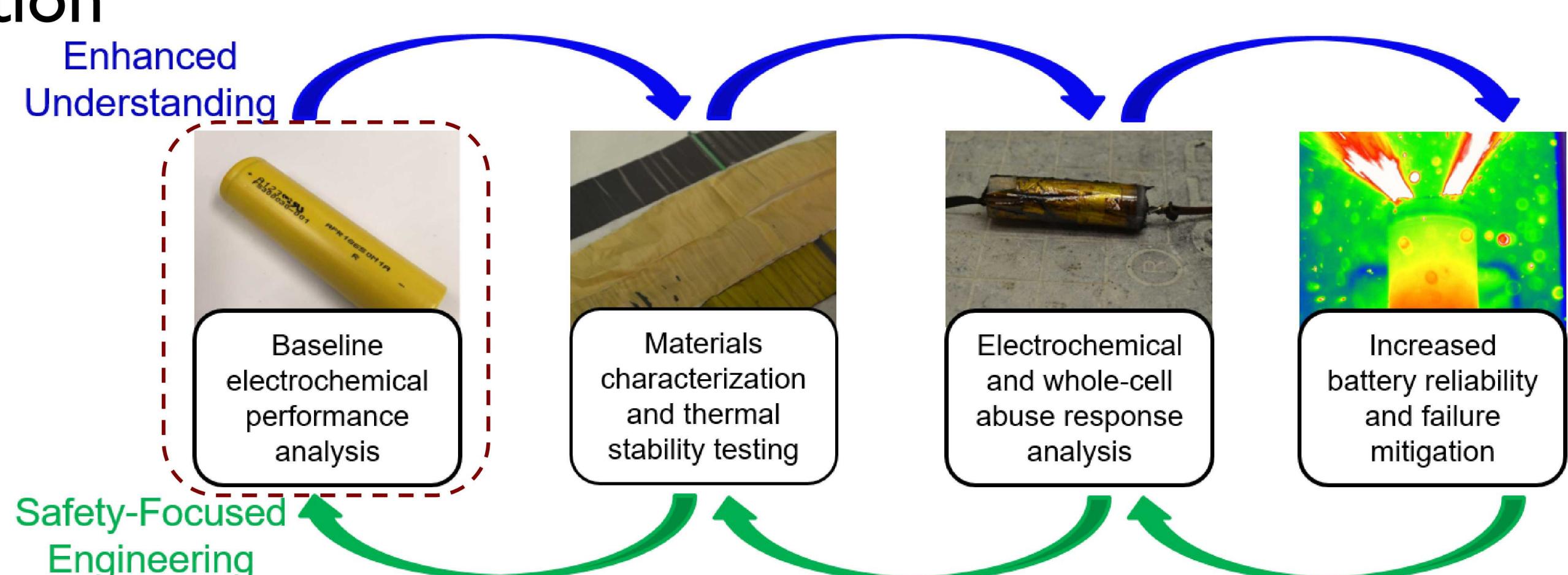


# Comprehensive Study of Commercial Lithium-Ion Cell Aging Behavior and Abuse Response

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## 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 <sub>4</sub> )	NCA (Ni <sub>x</sub> Co <sub>y</sub> Al <sub>1-x-y</sub> O <sub>2</sub> )	NMC (LiNi <sub>0.8</sub> Mn <sub>0.15</sub> Co <sub>0.05</sub> O <sub>2</sub> )	
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

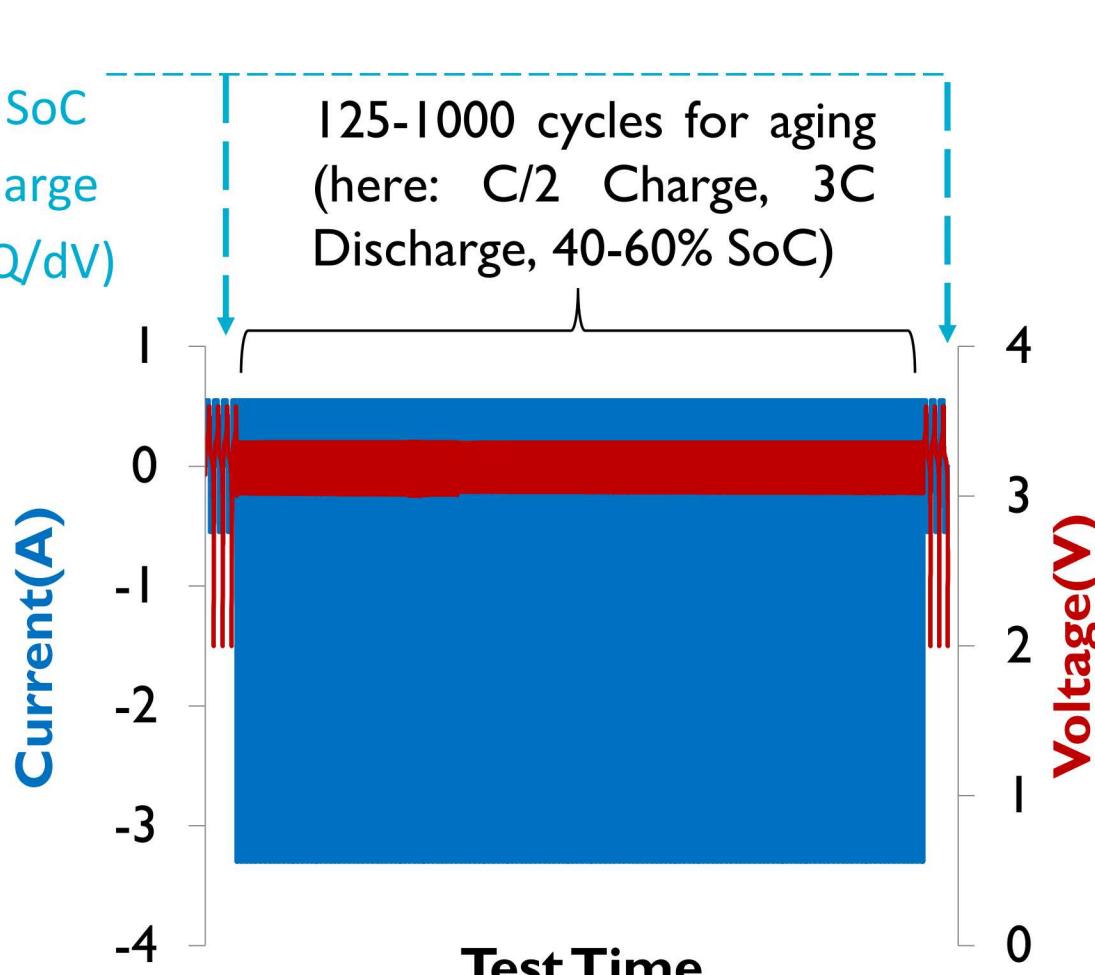
## Test Procedure

Electrochemistry of cell aging is monitored via:

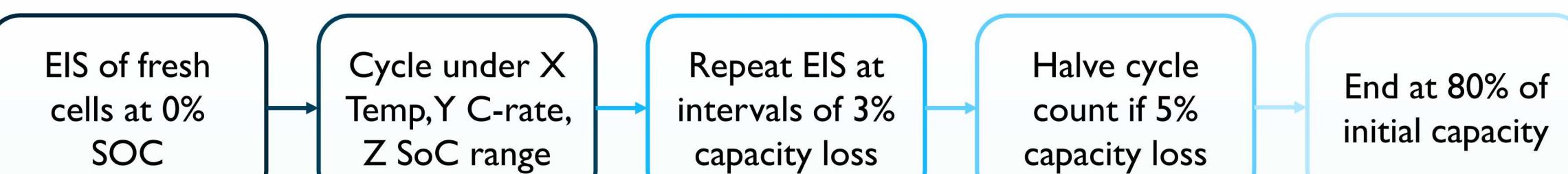
- capacity decline
- electrochemical impedance spectroscopy (EIS)
- differential capacity analysis (dQ/dV)

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



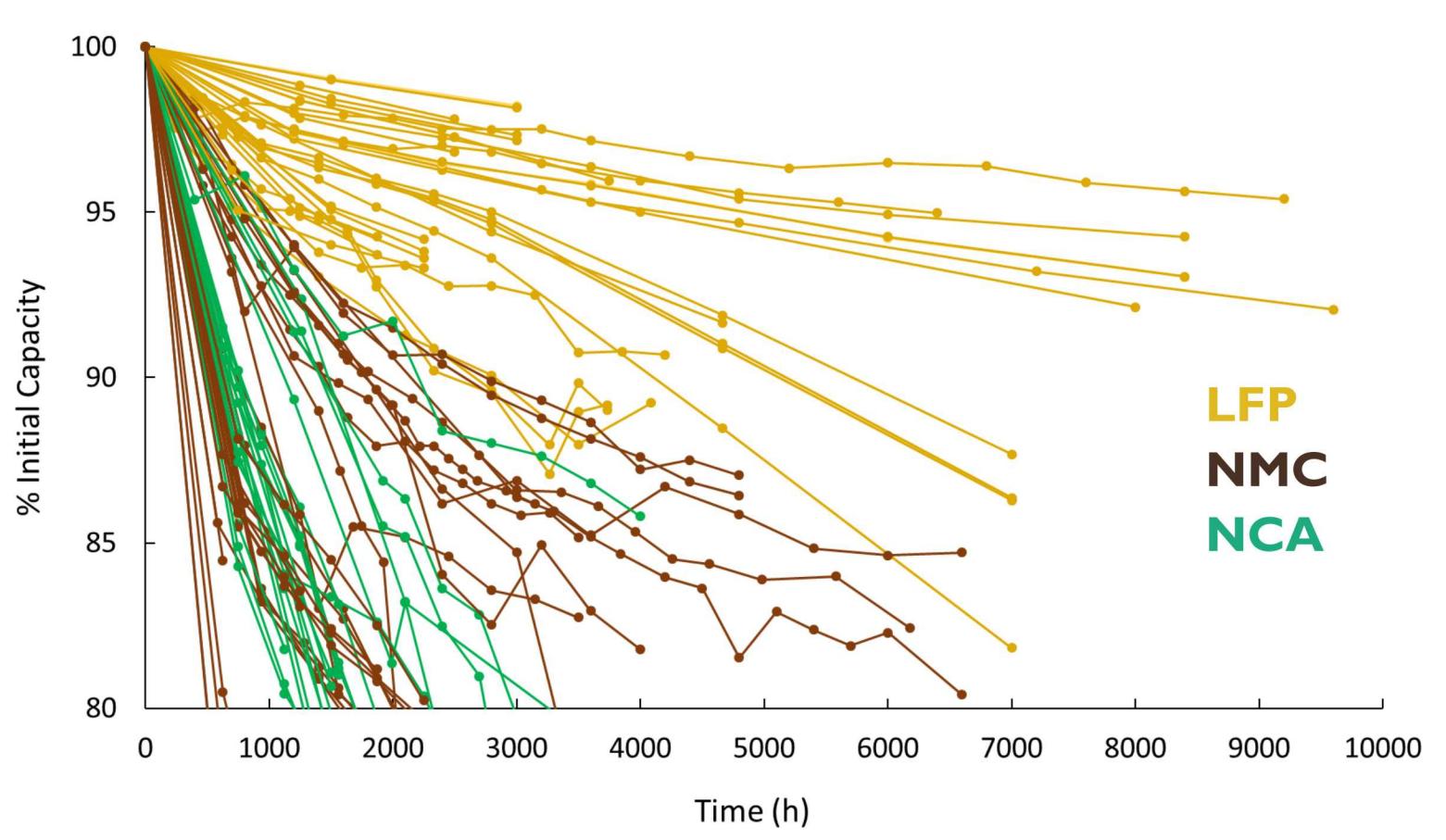
### Cell Cycling Sequence



## Acknowledgments

- Funded by Dr. Imre Gyuk through the U.S. Department of Energy; Office of Electricity

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

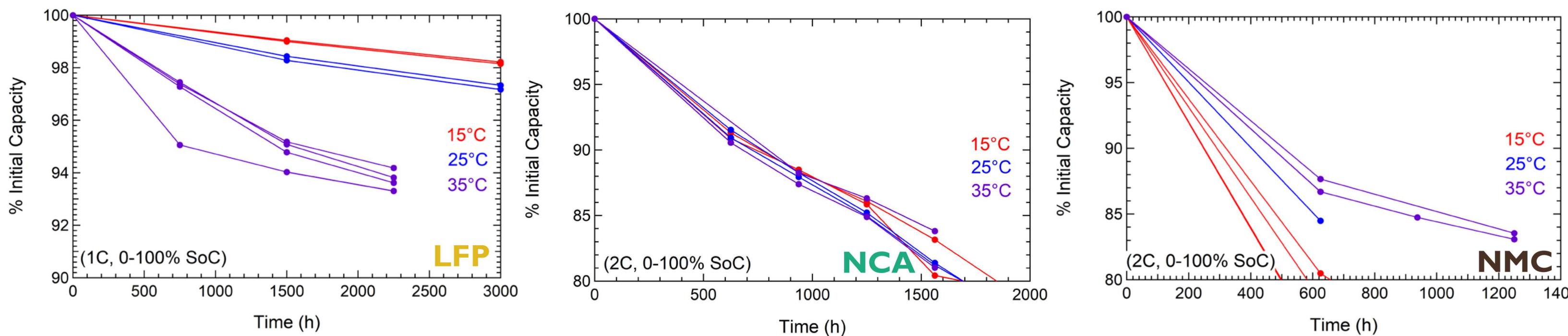


### Observations

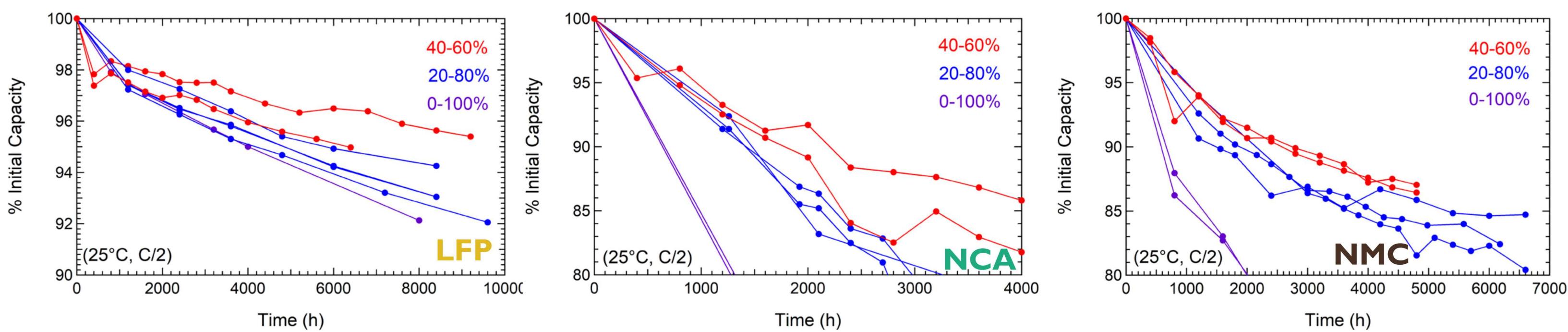
- LFP most stable, but still sensitive to cycling conditions
- Temperature dependence inverted for LFP and NMC; limited for NCA
- NCA and NMC particularly sensitive to full discharge

Next Step: analysis of variance and multifactor relationships

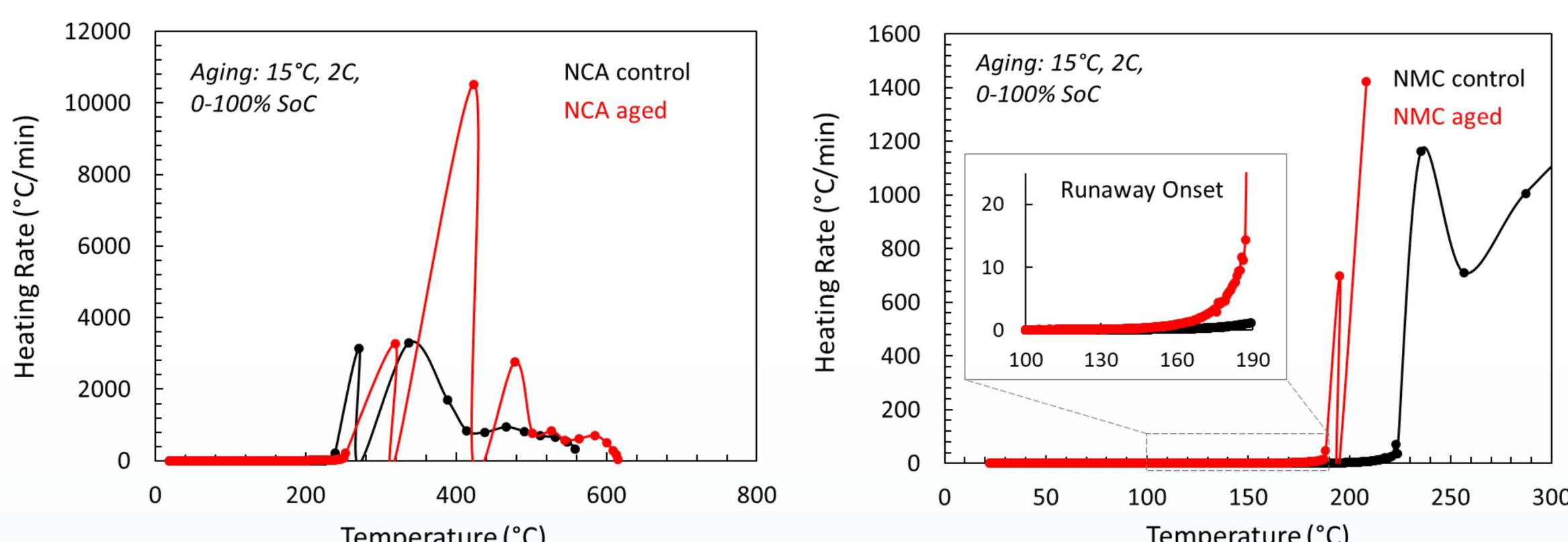
### Temperature Dependence of Aging



### SoC Dependence of Aging



### Accelerated Rate Calorimetry of Fresh and Aged Cells



Preliminary calorimetry shows greater heat release and lower onset temperatures for aged cells

## 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)
- Cell aging can reduce safety via lower runaway onset temperatures and greater heat release