UPDATE ON AN EIGHT-YEAR PERFORMANCE, MATERIALS, AND SAFETY STUDY OF COMMERCIAL LI-ION CELLS

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PROJECT PROFILE

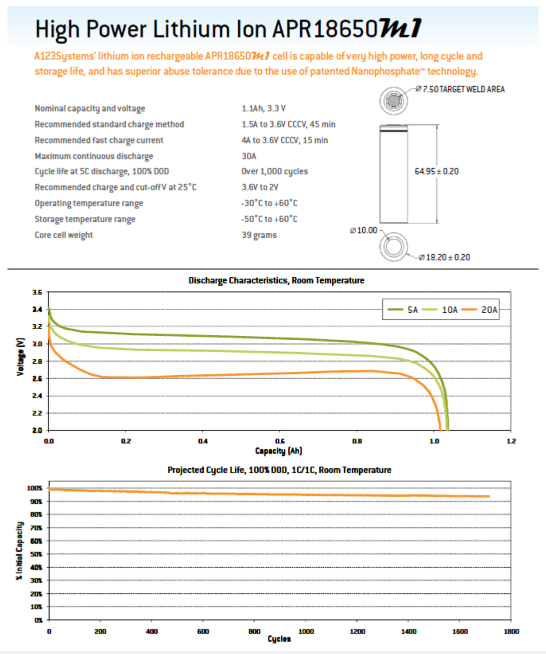
Topic: Safety & Reliability | Vertical: Safety & Reliability

Strategic Pathway: Stabilize

Project start and finish: FY20-FY27

PROBLEM

The long-term performance of Li-ion batteries is not well understood due to a lack of comprehensive public studies, especially beyond 80% capacity (a historical threshold from other applications). Identifying operating conditions under which their degradation changes will increase the reliability, safety, and value extracted from existing Li-ion ESS that support the grid.



Limits of existing approaches:

- Manufacturer spec sheets only show operating limits, not cycle life under different conditions
- Accelerated aging experiments with machine learning for lifetime prediction do not extrapolate to new degradation modes

APPROACH

We cycled commercial LFP, NMC811, and NCA cells at a variety of temperatures, discharge rates, and SOC ranges. Cells underwent materials characterization and abuse tests in uncycled and aged states to link performance and safety outcomes to specific degradation mechanisms.

Cycling

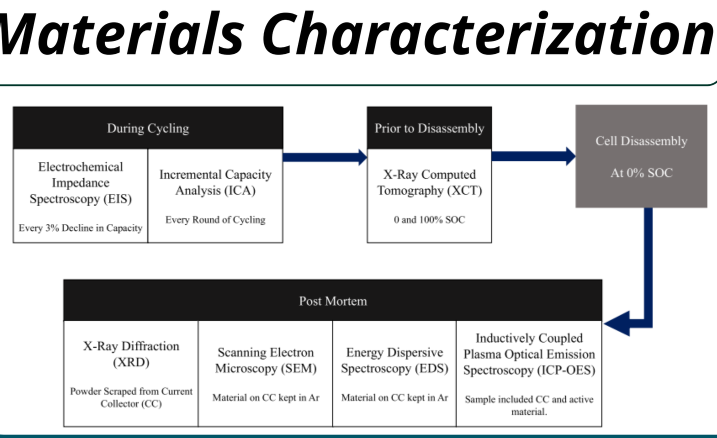
Tested 2-4 cells per condition

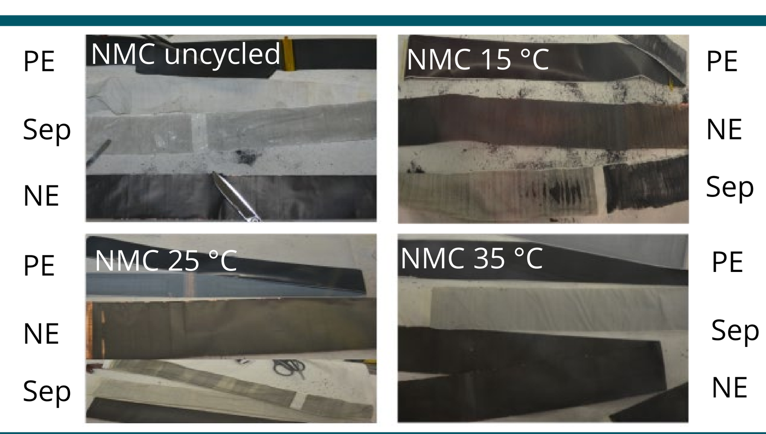
SOC, Temperature, Discharge Rate	
40%–60%, 25 °C, 0.5C	0%–100%, 15 °C, 1C
20%–80%, 25 °C, 0.5C	0%–100%, 25 °C, 1C
0%–100%, 25 °C, 0.5C	0%–100%, 35 °C, 1C
0%–100%, 15 °C, 2C	40%–60%, 25 °C, 3C
0%–100%, 25 °C, 2C	20%–80%, 25 °C, 3C
0%–100%, 35 °C, 2C	0%–100%, 25 °C, 3C

Current status of all cells

Outcome	NCA	NMC	LFP
Total Started	31	32	33
Still Cycling	9	18	28
Above 80% capacity	0	0	9
Below 80% capacity	9	18	19
Not cycling	22	14	5
Materials characterization	12	6	3
Reached 40% capacity	6	5	0
Experienced cell failure	4	3	2

Materials Characterization



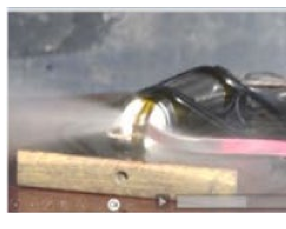


Safety

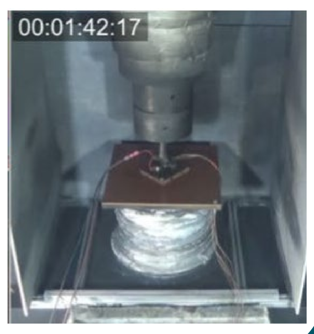
Cell name	OC	ODC	ARC	Nail	Crush
NCA-uncycled	3	3	2	3	
NCA-aged-80	3	3	2	3	
NMC-uncycled	1	1	1		1
NMC-aged-70%	1	1	1		2
NMC-aged-40%	1				1
LFP-uncycled	1	1	1		2
LFP-aged-80%	1	1	1		2

Calorimetry (ARC)

Overcharge



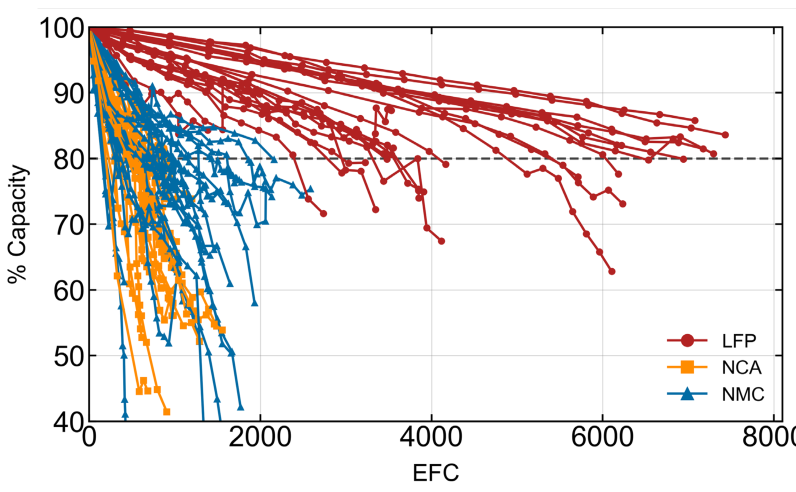
Crush

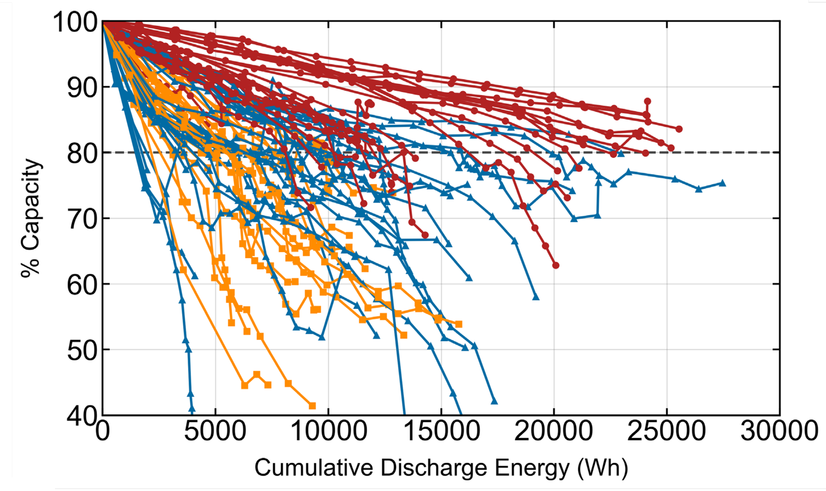


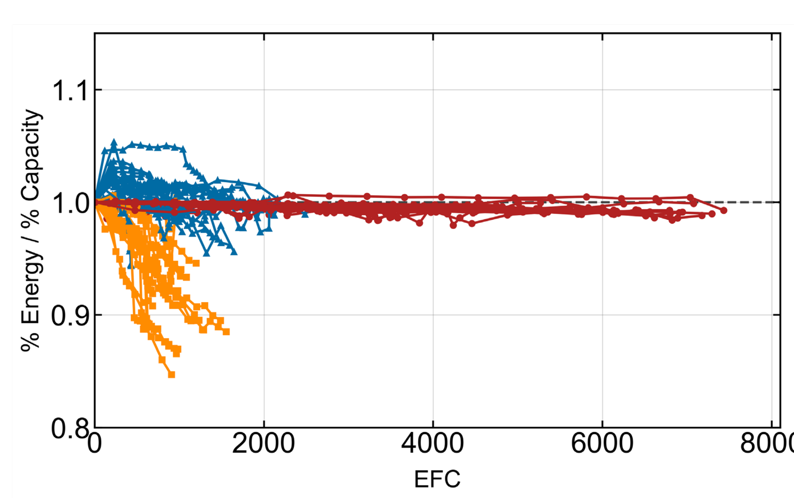
LATEST RESULTS

Long-term cycling and exploring different metrics for aging reporting

All cells showed nearly 400 EFC beyond 80% capacity, and many exhibited ~linear degradation to 40% capacity. Energy decayed faster or slower than capacity depending on the chemistry and cycling conditions.

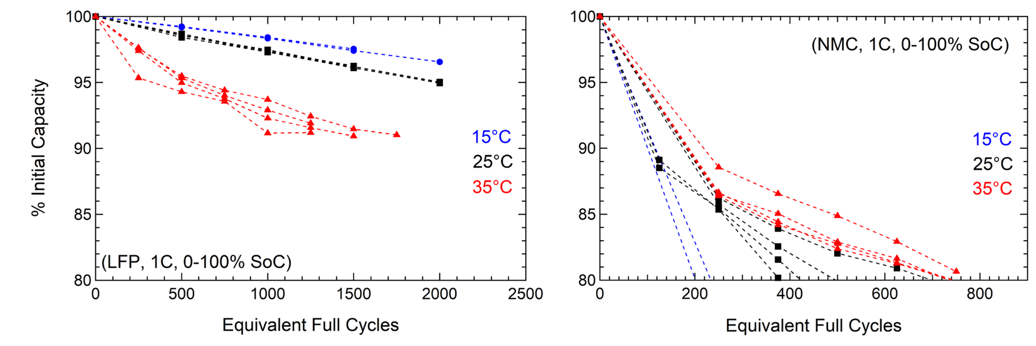




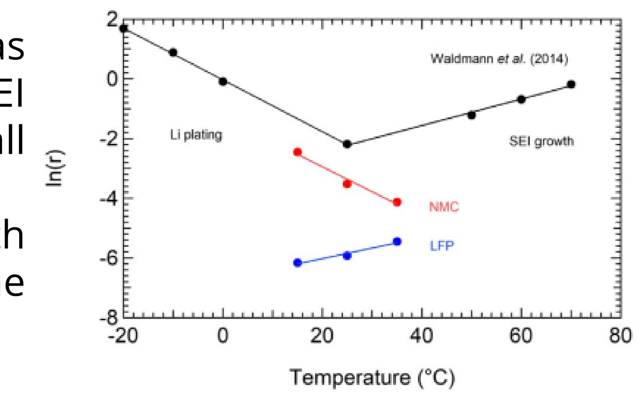


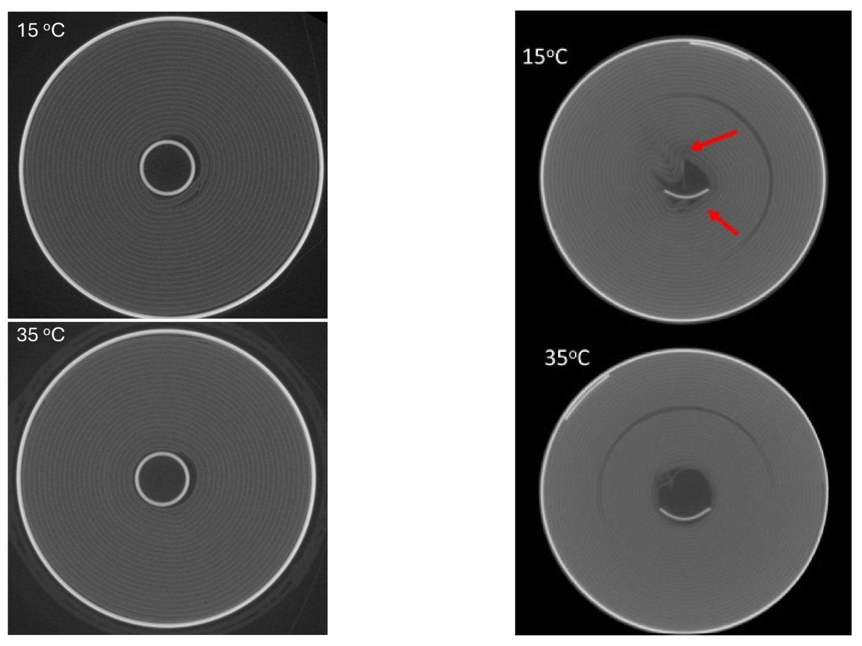
LFP vs NMC materials characterization: impact of aging temperature

LFP and NMC cells exhibited an inverse dependence on temperature during cycling.



LFP aging was dominated by SEI formation across all conditions (increasing with temperature). The NMC cells shifted from Li plating to SEI formation. Li plating also caused cell deformation and loss of active material.





CONCLUSIONS & IMPACT

This data represents the broadest, long-term public study of Li-ion cell performance and safety. It has been leveraged by hundreds of companies to (1) understand the impact of different operating conditions on degradation, (2) perform technoeconomic analysis, (3) serve as a benchmark for emerging non-Li technologies, and (4) assess viability of 2nd-life batteries for more affordable deployments.

Example feedback in the last year

- Energy VC: "recently came across your publication and think it is an excellent benchmark"

- Utility: "your work on aged LiB played a significant role in shaping our research and evaluation for this application"

- Battery user: "sheer duration and cycle count is wonderful; you continue cycling well below 80% and thousands of cycles"

FUTURE DIRECTIONS

Leverage collected data to:

- Deconvolute contributions of calendar/cycle aging to inform more economical operation of LFP (most common ESS chemistry)
- Inform safety standards for battery end-of-life management

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