Extreme Fast Charging — Status and Implications

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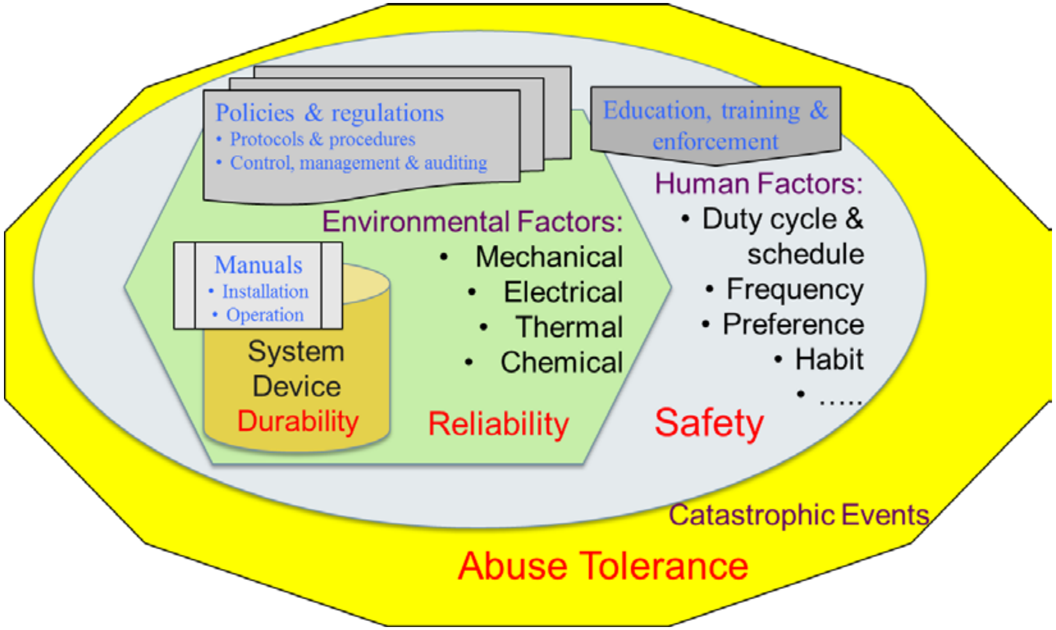
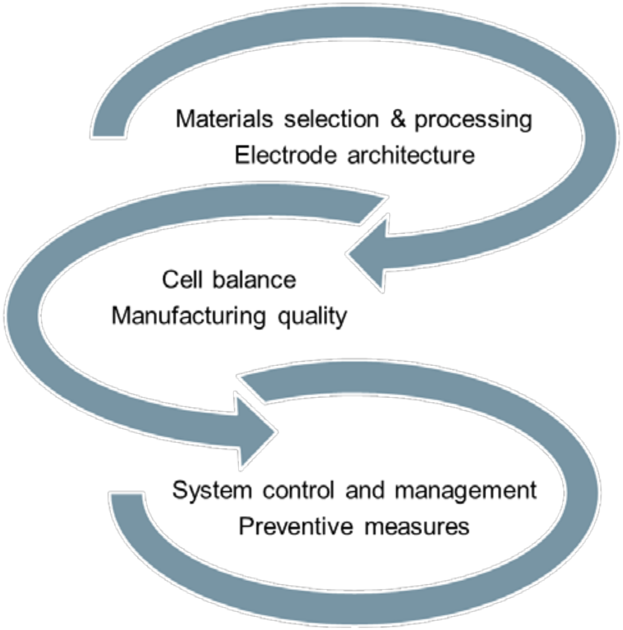
Energy Storage and Advanced Vehicles at INL

- Battery/energy storage technology
  - Energy material R&D
  - Extreme fast charging tech
  - Battery diagnostics & prognostics, failure mode & effect analysis
- Vehicle platform & charging infrastructure evaluation
- E-Mobility & impacts
- Grid integration, reliability & resilience
- Device/system vulnerability & cybersecurity

GAP IN TECHNOLOGY

- Integrated approach to address RISK, beyond COST

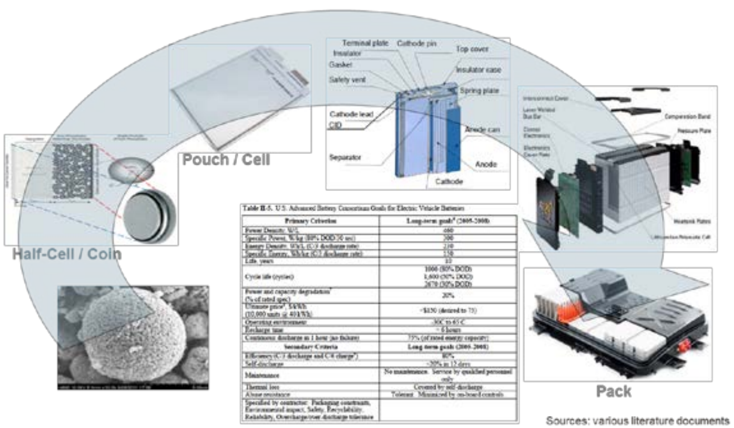


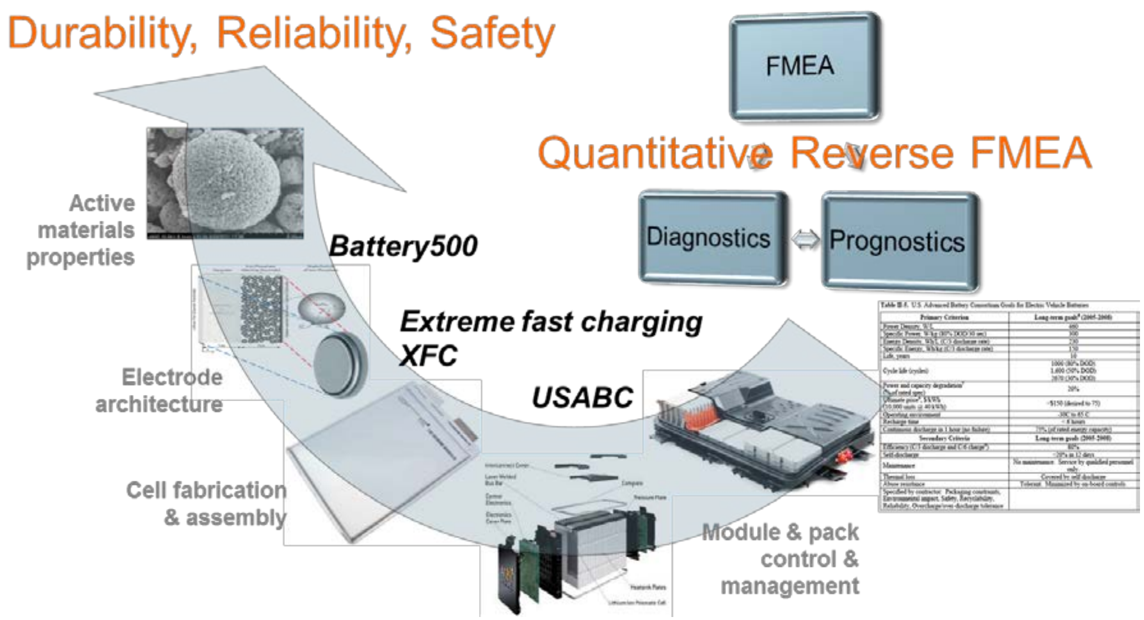


Liaw et al. *Safety of Lithium Batteries*, J. Garche and K. Brandt, eds. Chapter 8A.1, pp. 269–302. Elsevier, 2018.

GAP IN TECHNOLOGY

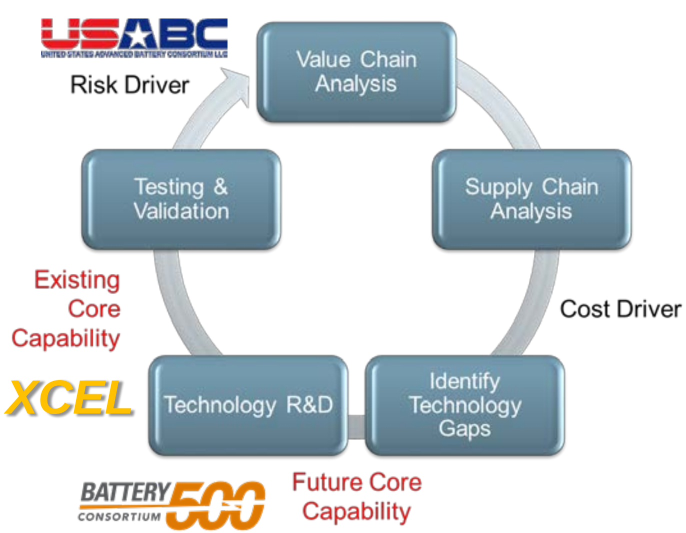
- Needs for system-based, integrated failure analysis (FA) + failure mode and effect analysis (FMEA) + diagnostic & prognostic tools

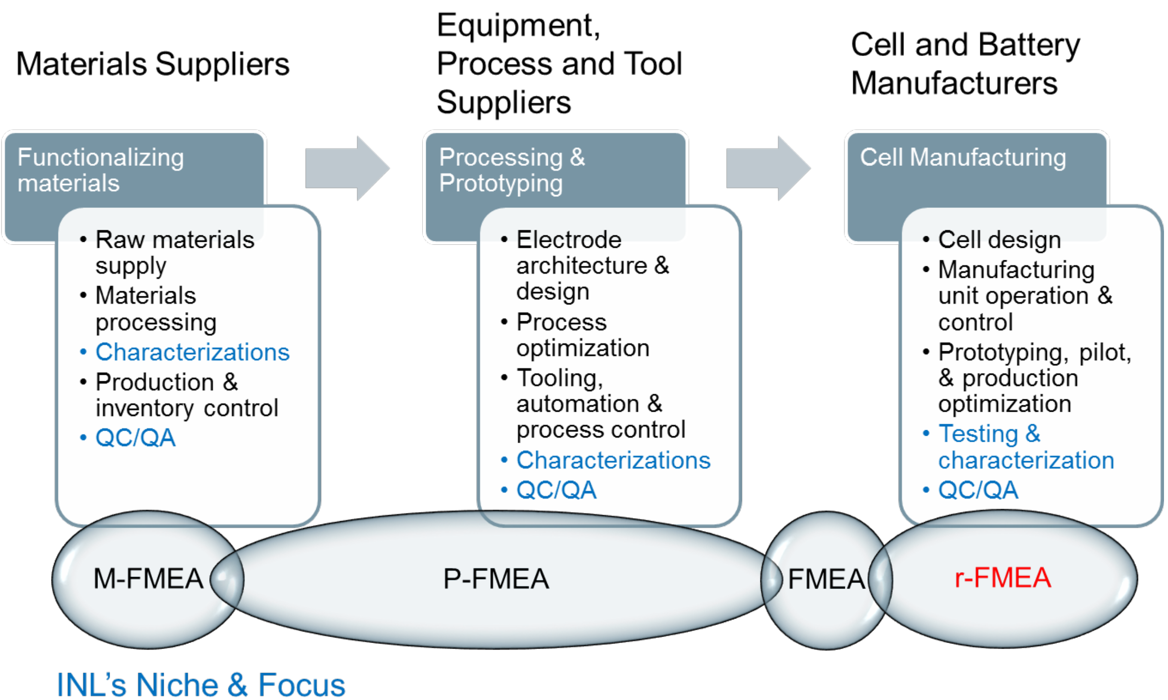




TECHNOLOGY OVERVIEW

- Holistic approach on entire supply chain

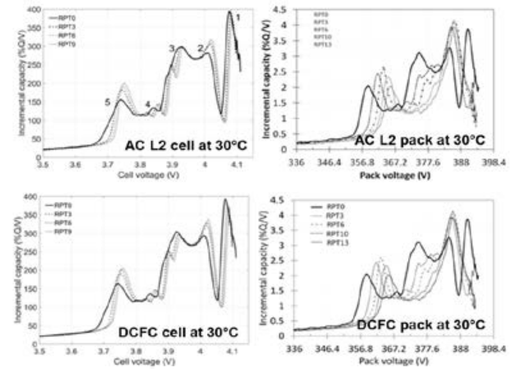




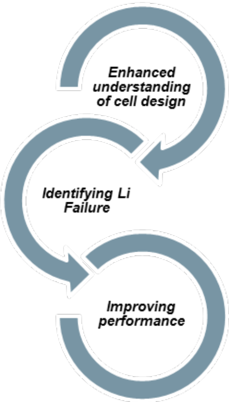
STATUS OF TECHNOLOGY

Battery/Cell Failure Mode and Effect Analysis (FMEA)

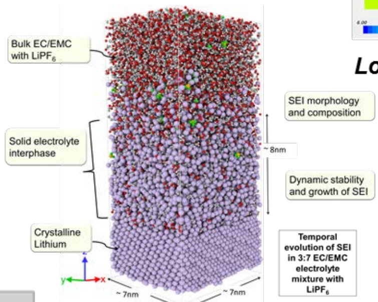
Journal of Power Sources 381 (2018) 56–65

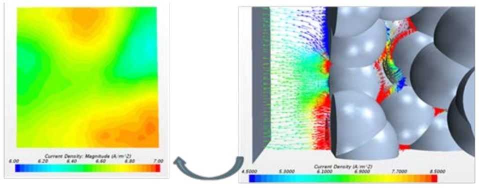


XCEL



BATTERY500 CONSORTIUM

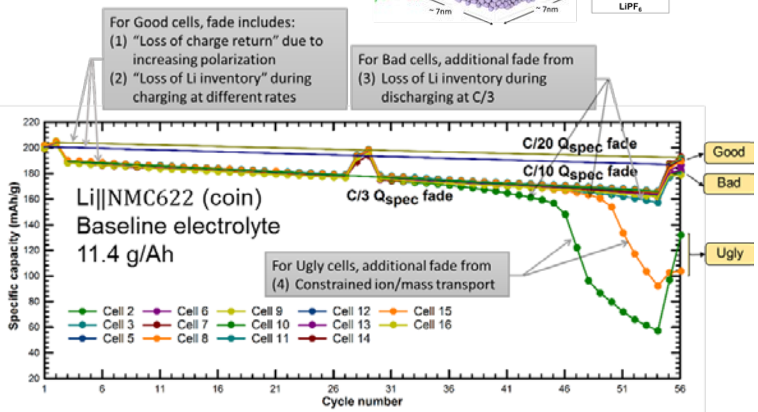




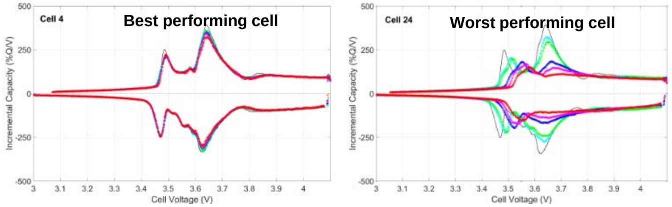
Local current density on Li metal electrode

Understand Variability

Non-destructive Battery Laboratory for Evaluation (NOBLE)



Battery/Cell Diagnostics & Prognostics (BCDP)



Extreme Fast Charging (XFC)

- Critical to support electrification in mobility, energy storage, and transportation
- Stress on charging infrastructure: distribution reliability and resilience
- Issues with scalability and affordability
- Impacts on power electronics and battery performance

Impacts on battery performance

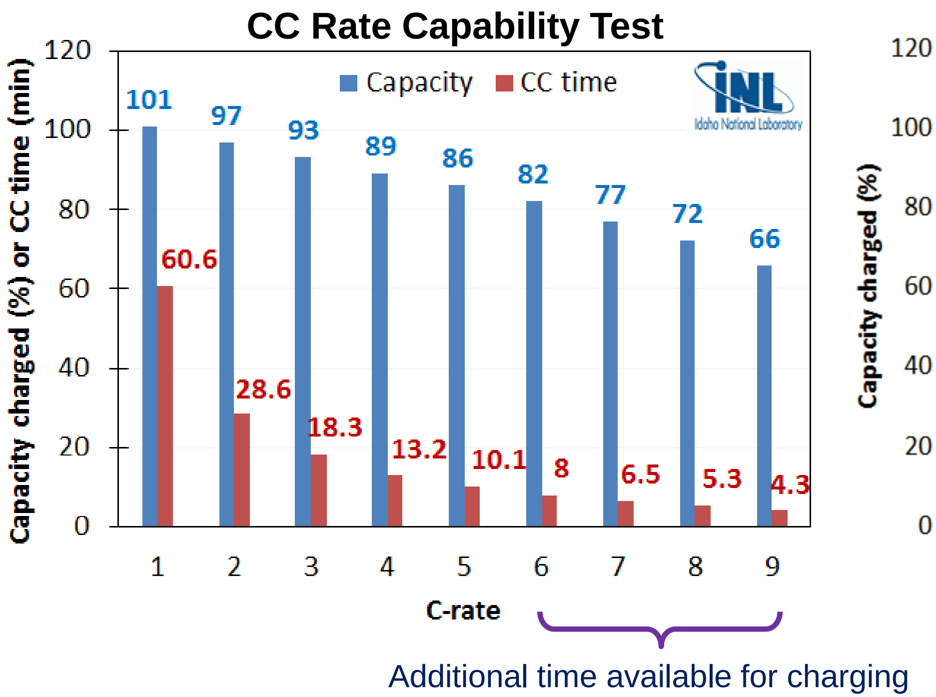
Subjects of Interest

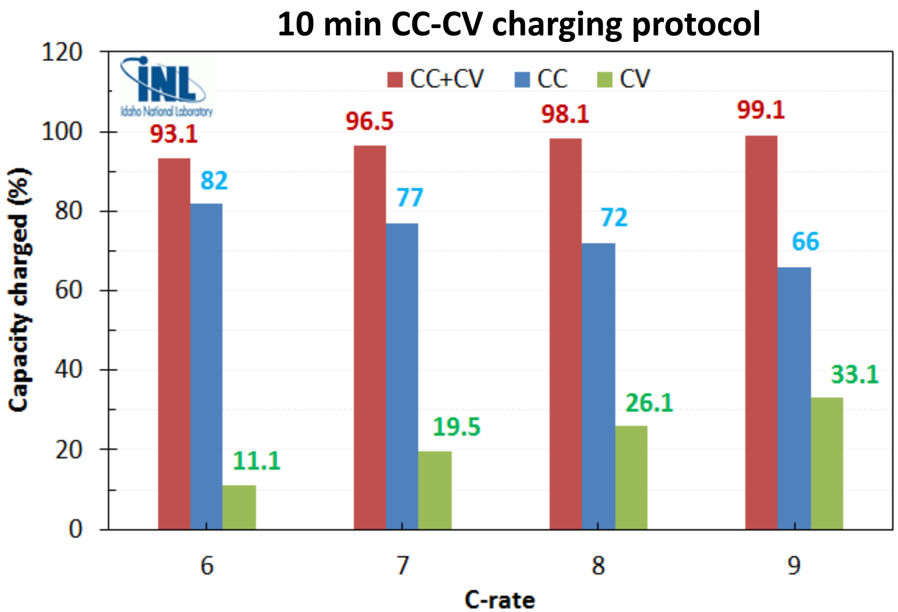
- Stress factors from XFC
- Sensitivity to charging algorithms / protocols
  - Focus on identifying factors that limit XFC and dynamics in ion transport issues
- Aging effects on
  - Cell balance
  - Kinetics / ion transport

Detecting Li plating and its impacts

Rate Capability Testing

- Rate capability by CC-CV charging protocols
- Charge return versus rate
- A 15-min rest to study components of overvoltage





Graphite / NMC532
V_{max}/V_{min}= 4.1V/3V

*CC: Constant Current, CV: Constant Voltage

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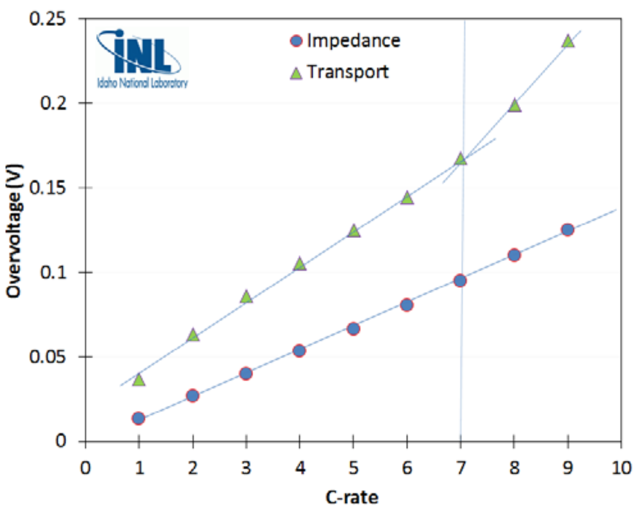
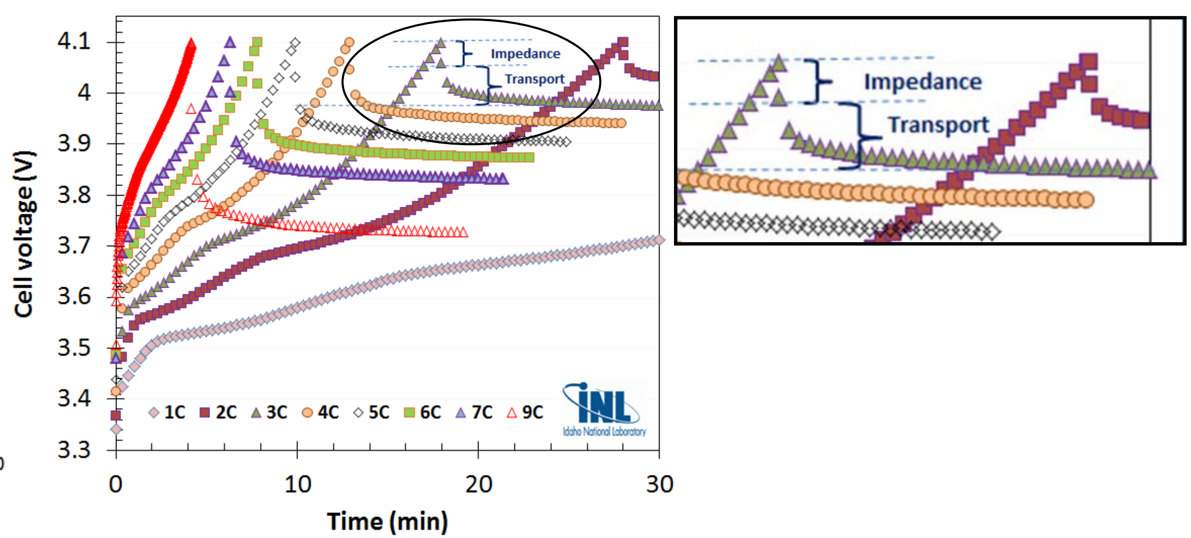
Rate Capability Testing

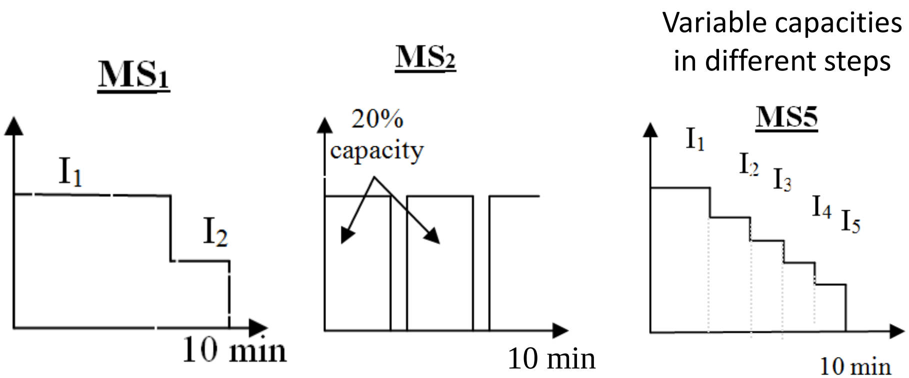
- Overvoltage due to *IR* (spontaneous relaxation) and ion transport (prolonged relaxation)
- *IR* (= *Ohmic* + *Rxn activation* polarizations) varies linearly w/ C-rate
- Noticeable ion transport limitation arises > 7C





Charging Protocols

- Charging protocols introduce rest time or current steps to minimize ion transport limitation
- Current levels defined based on ion transport change



Gr.	Cell count	10 min charging protocol
B	4 to 6	6.8C CCCV
C	8 to 10	6.8C MS1 (2-step current)
D	11 to 13	6.8C MS2 (pulsed current)
E	14, 16 and 17	9C CCCV
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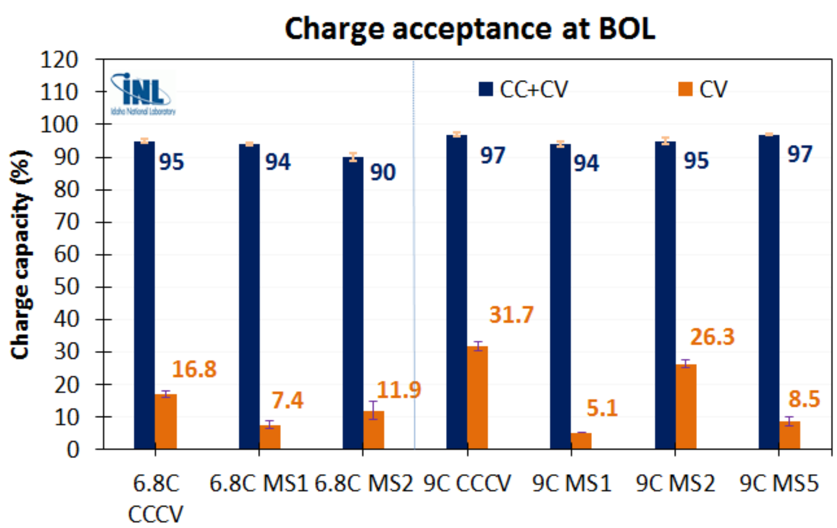
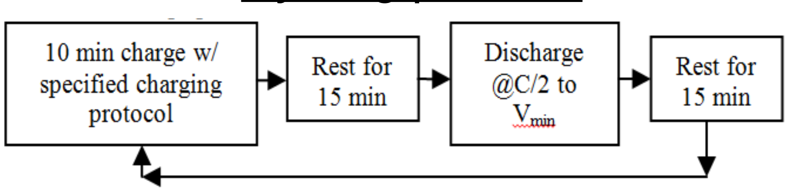
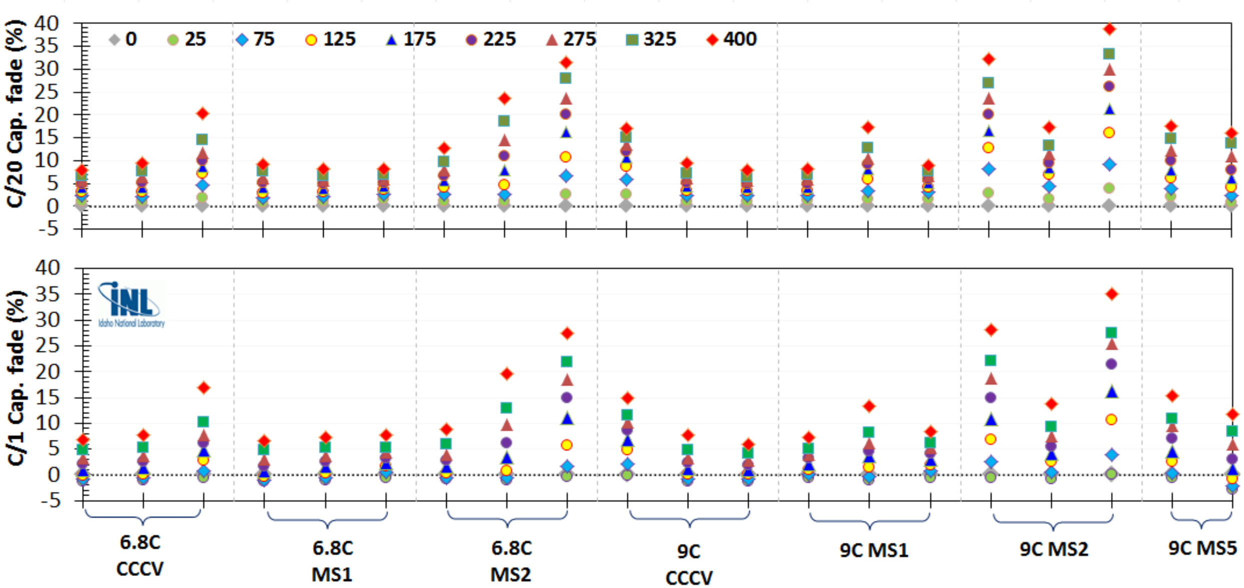


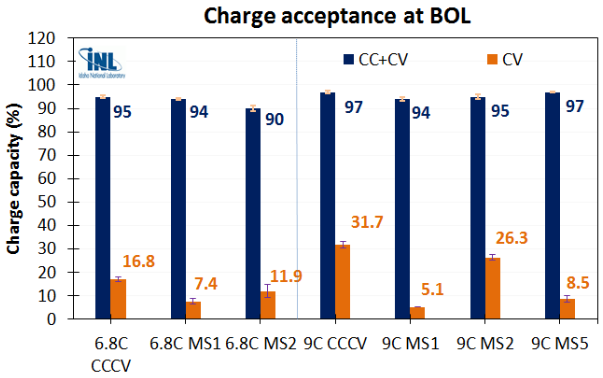
Cycling protocol



Cycling Result: Cell-to-cell variability

- 400 cycles completed
- Different rates of aging in different groups
- Significant variability in some groups (best: MS1 and worst: MS2).

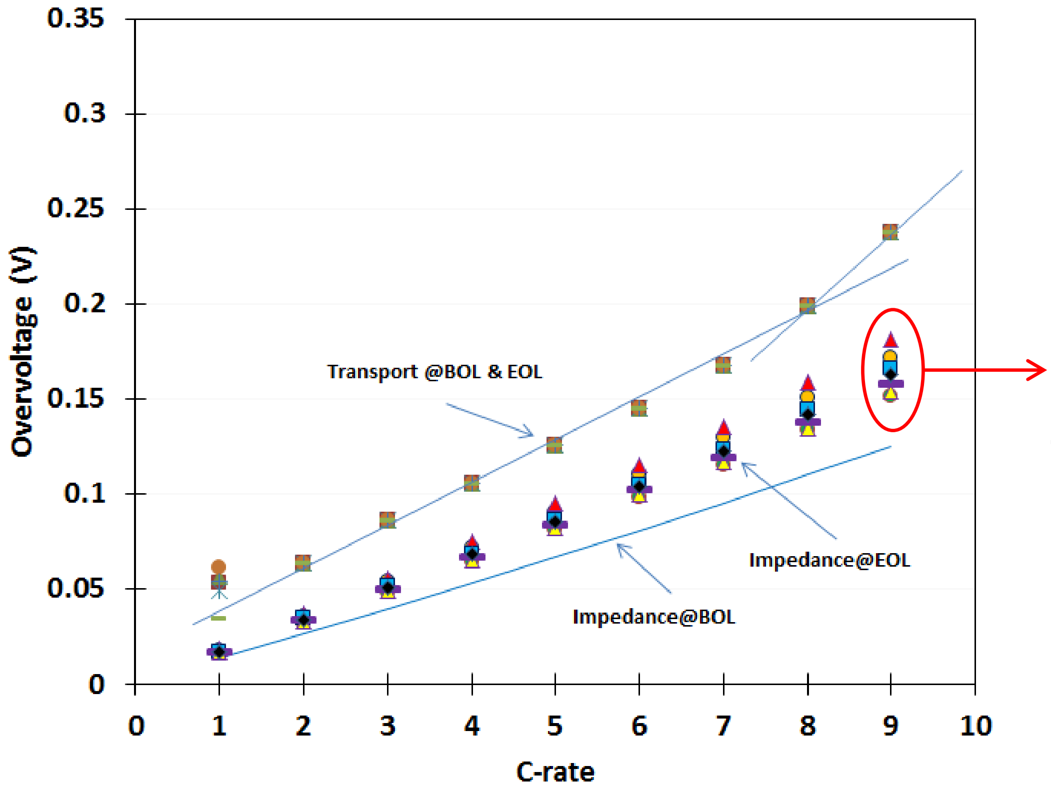


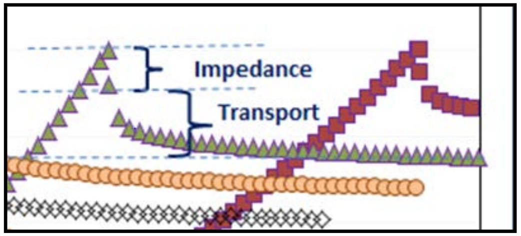


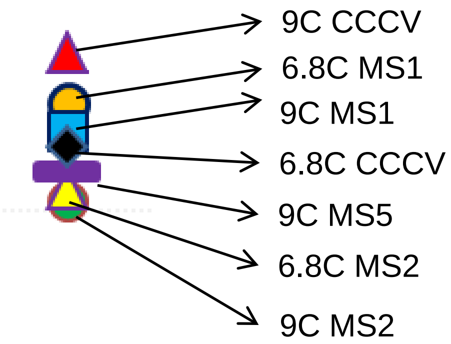
* Cell 24 died after the end of cycling

Cycling Result: Impedance and Transport

- Transport overpotential remains the same after 400 cycles.
- Overall *IR* (=*Ohmic*+*Rrxn*) increased significantly.



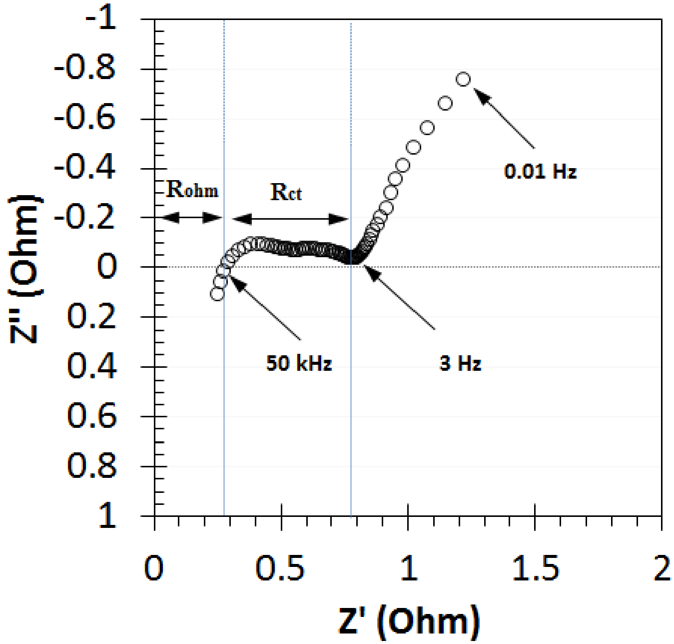


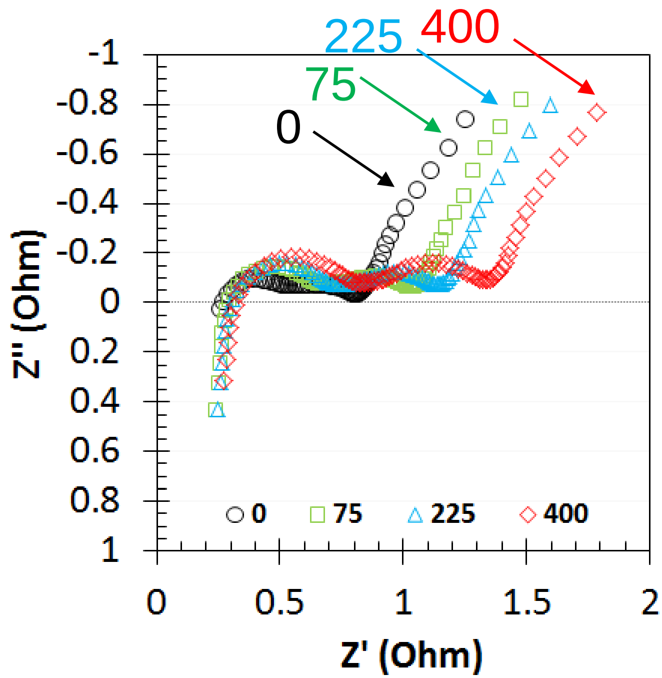


* Same effective C-rate for both cases

Cycling Result: Impedance and Transport

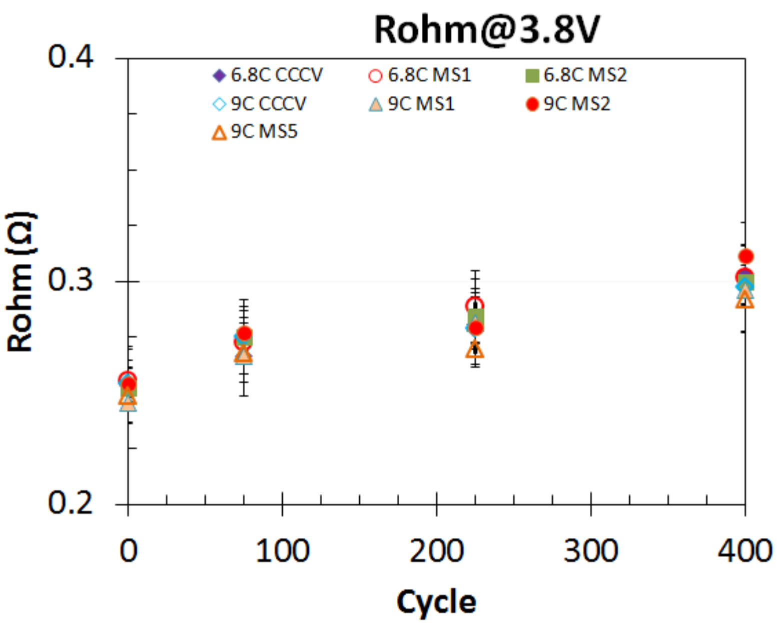
- EIS@3.8V performed at 0, 75 (RPT3), 225 (RPT6) and 400 (RPT9) cycles, 9C MS2
- Low frequency Warburg diffusion tail remains unchanged
- Slight increase in *Ohmic* resistance, R_{ohm}
- Visible changes in R_{ct}

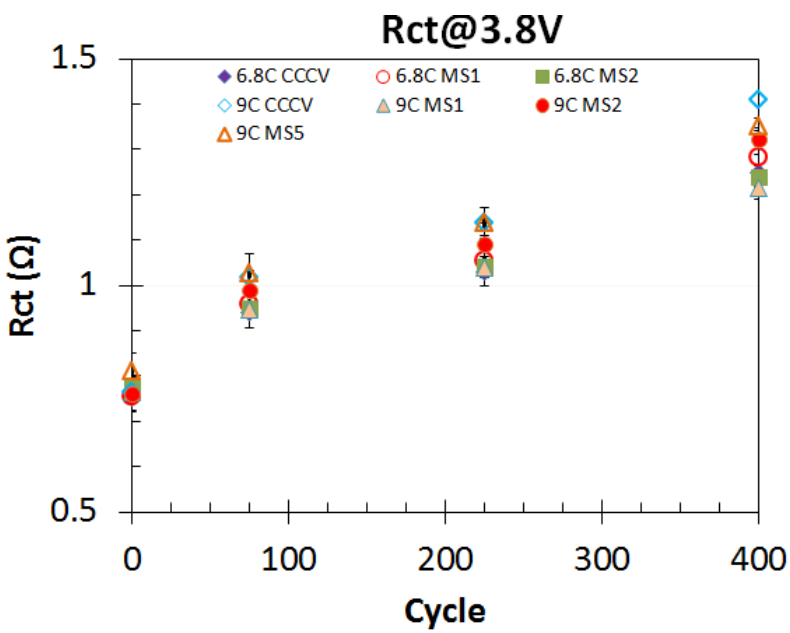




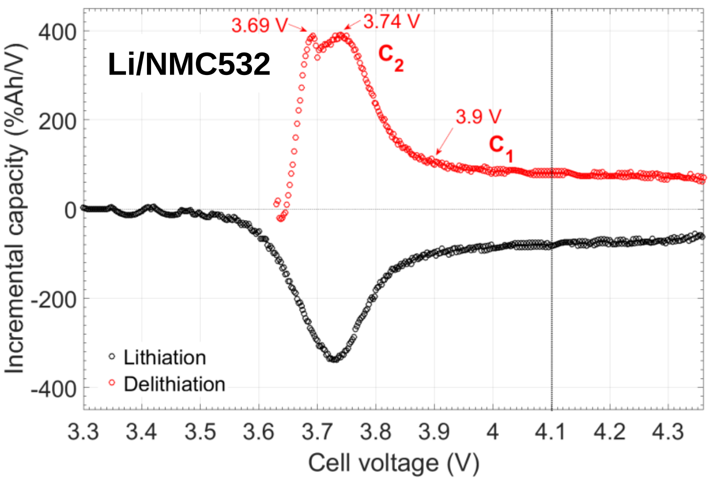
Cycling Result: Impedance and Transport

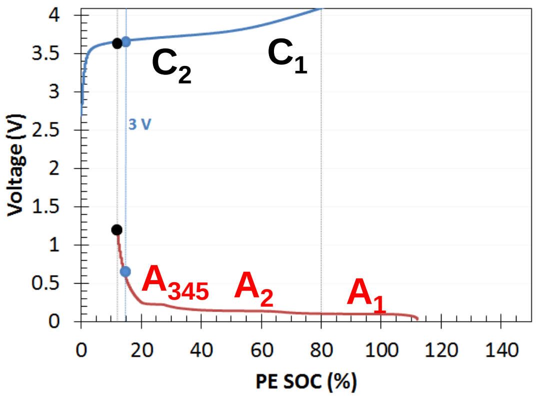
- *Ohmic* resistance constitutes about 20% of combined R_{ohm} and R_{ct}
- Significant change in R_{ct}

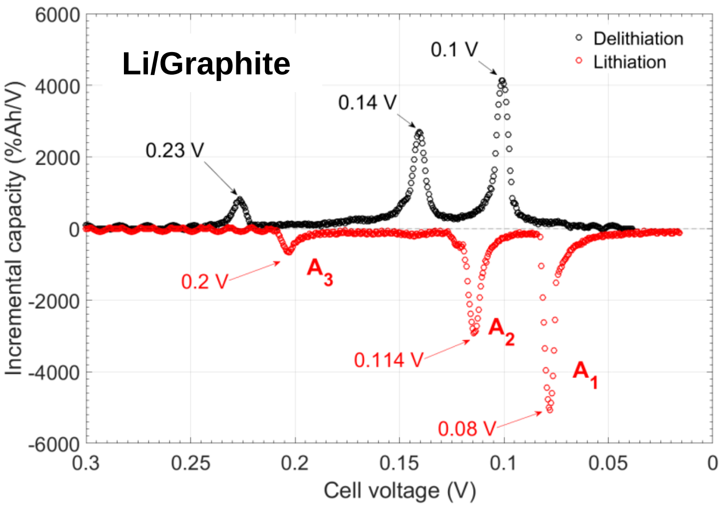


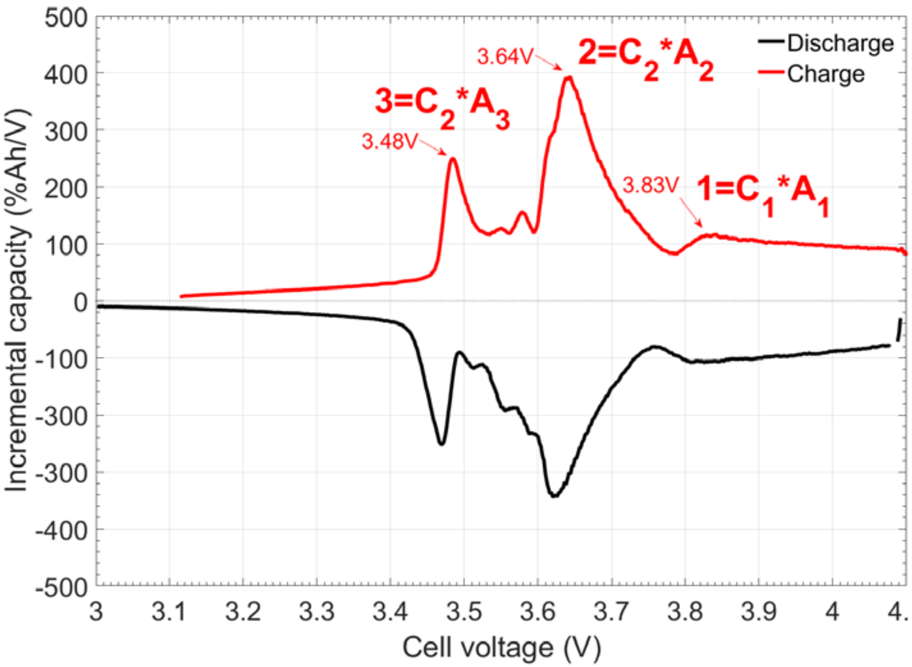


Cell Balance

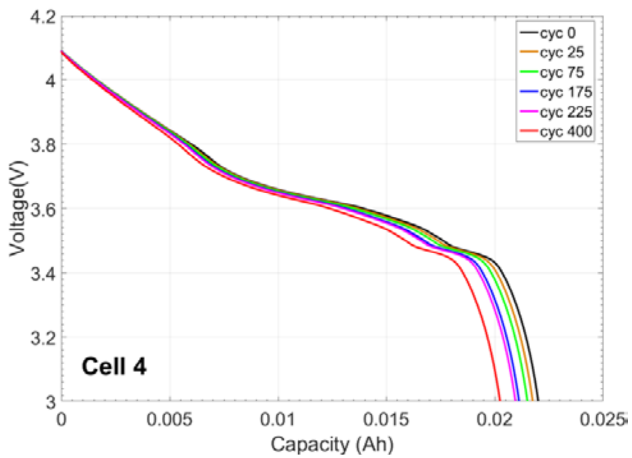


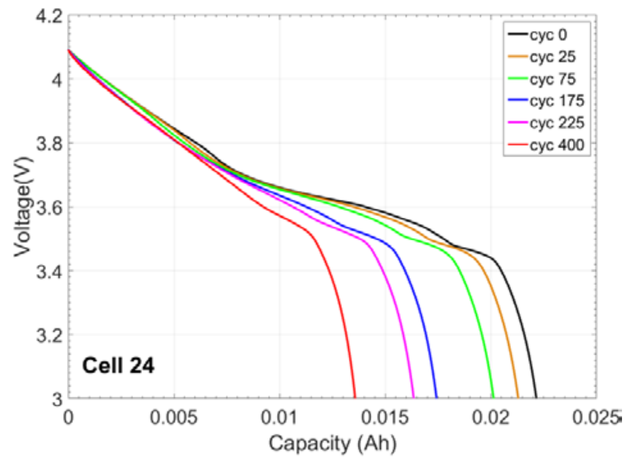


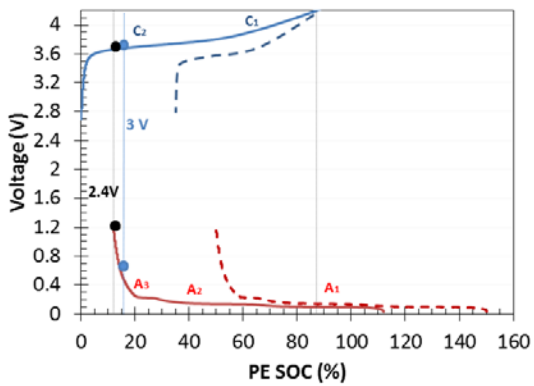


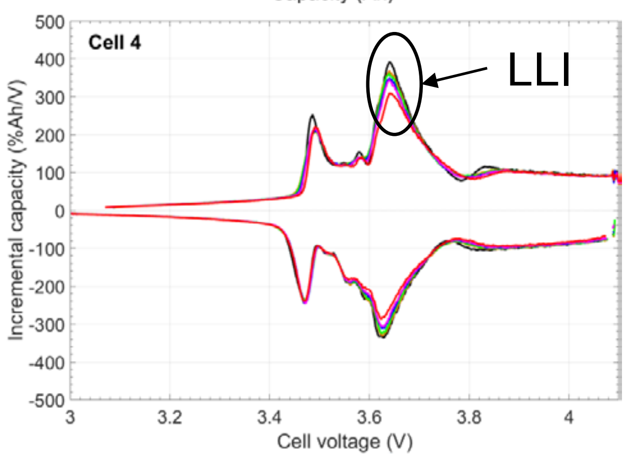


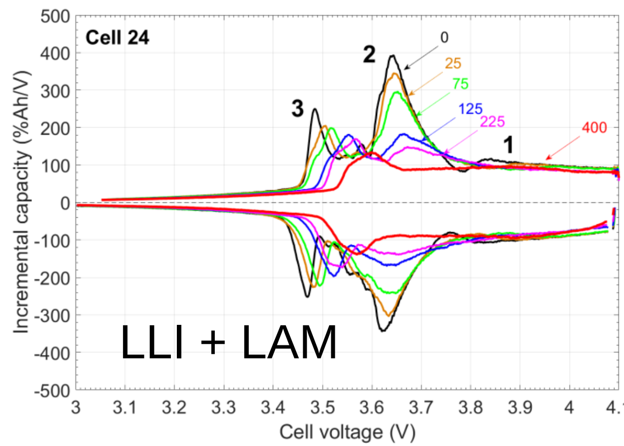
Cell Balance upon Cycle Aging











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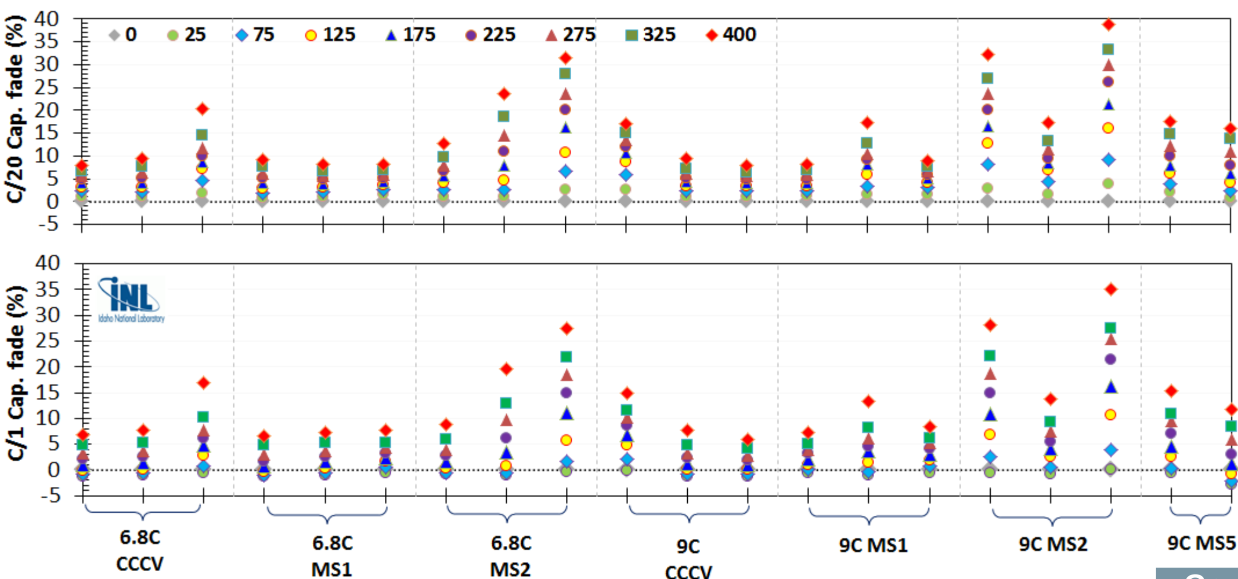

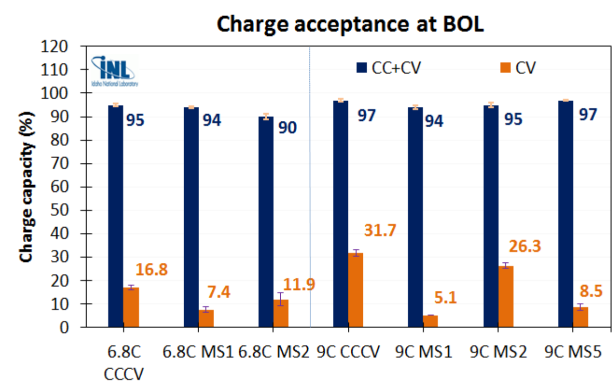

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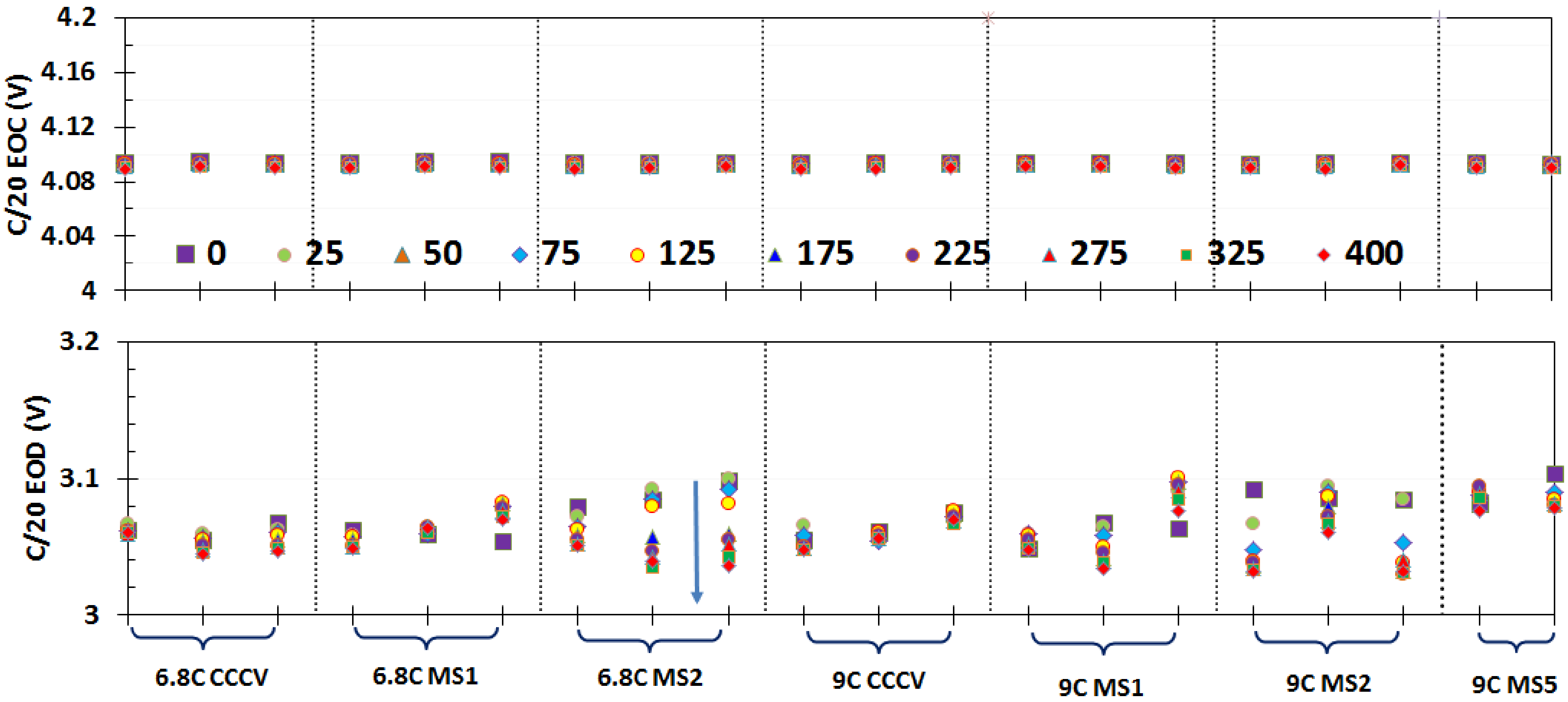
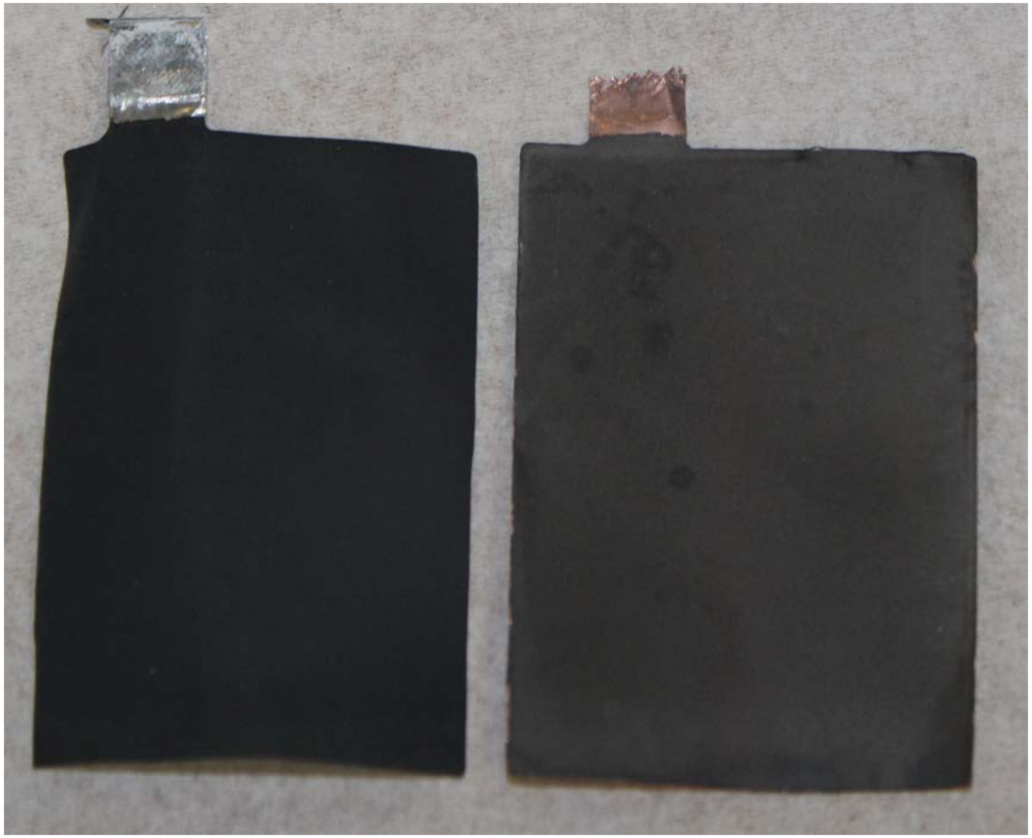
Aging mode analysis



- EOC rest voltage remain constant
- EOD rest voltage also decreases

XCEL Round 1 Best Performing cell



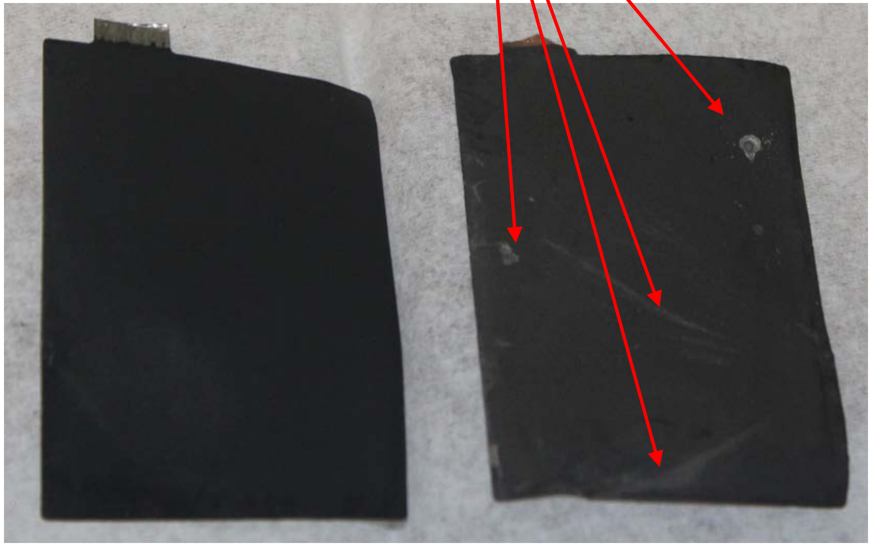
No visible sign of electrode damage or Li plating

- P452-Cell#17 (9C CCCV)
- 7.84% fade after 400 cycles (lowest aged cell)

XCEL Round 1 Worst Performing cell

Accumulation of metal like object at the edge of Anode.

Localized surface change probably due to plating



- P452-Cell#22 (9C MS2)
- 32.2% fade after 400 cycles (One of the highest aged cells)
- Cell#24 had highest aging (38.7%) after 400 cycles, but failed after completing the last RPT9

Conclusion

- Extreme fast charging – feasible with careful cell design & fabrication
- Aging mode analysis shows
  - Both loss of cathode (LAM_{dePE}) and Li inventory (LLI) were observed
  - Significant change in cell balance could be critical
  - Localized Li plating is problematic
  - Cell variability is pronounced – challenge for BMS