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Li-ion Battery Chemistries under Grid Duty Cycles

Daiwon Choi, Alasdair J. Crawford, Vilayanur V. Viswanathan, Mark Engelhard, Vijayakumar Murugesan, David M. Reed, Vincent L. Sprenkle

Pacific Northwest National Laboratory

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Outline

- Standard grid service test procedures
- Cell performance and degradation analyses
  - 6 months (180 days) of continuous test results
  - Cylindrical cell (18650 & 26650) from 4 different vendors
  - 3 different battery chemistries

  LFP : $LiFePO_4$, NMC : $LiNi_xMn_yCo_zO_2$, NCA : $LiNi_{0.85}Co_{0.1}Al_{0.05}O_2$
- Post-mortem cell characterization (XPS)
- Conclusion
- Future work

Battery Test Method

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❑ Variables

- **Time :** 24h grid cycle (1day)
- **State-of-Charge (SOC) :** 20~80%
- **Depth of Discharge (DOD or ΔSOC) :** 20, 40, 60%
- **Power (C-rate):** within cell specifications (voltage window)
- **Temperature :** 25°C
- **Number of cells:** 3 under same test condition (total: 156 cells)

❑ Schedules (# of conditions)

- **BS : Baseline (3) –** holding (aging) at different SOC levels
- **FR : Frequency Regulation (4)**
- **PS : Peak Shaving (3)**
- **EV : Electric Vehicle (3)**

Testing Methods

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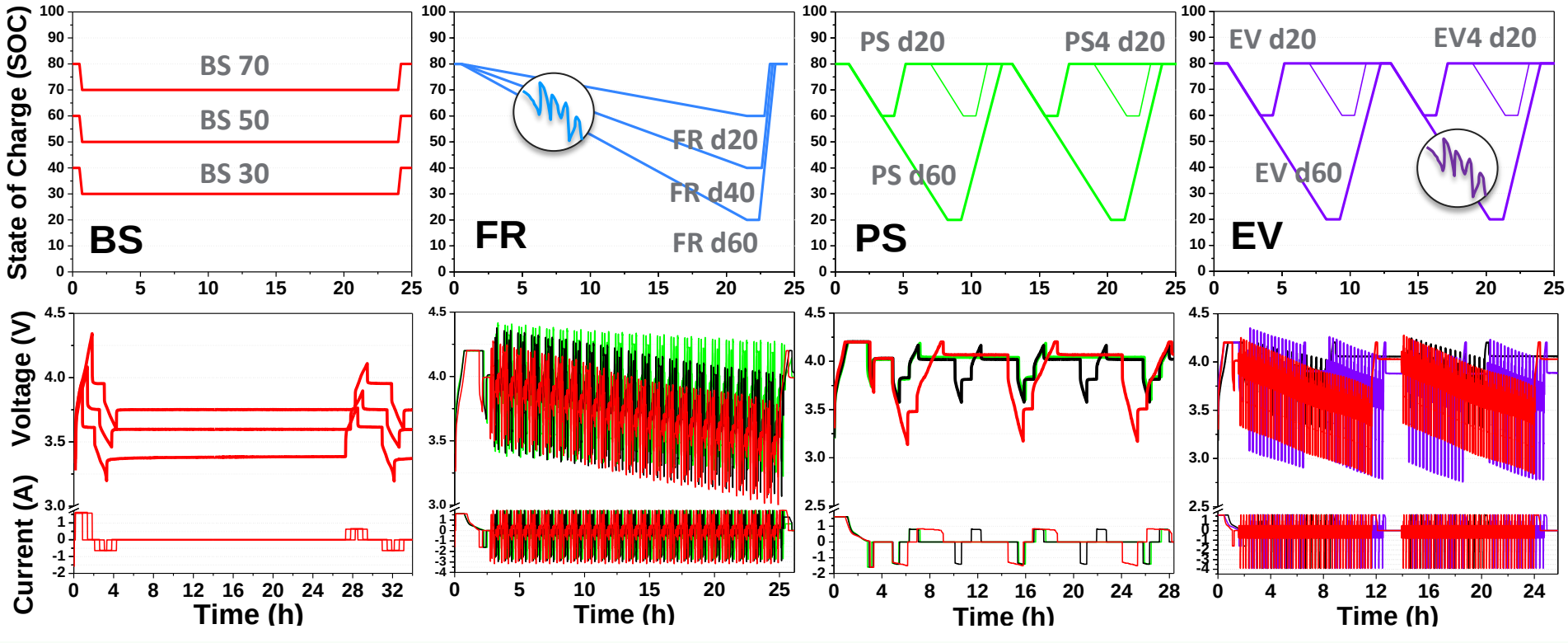

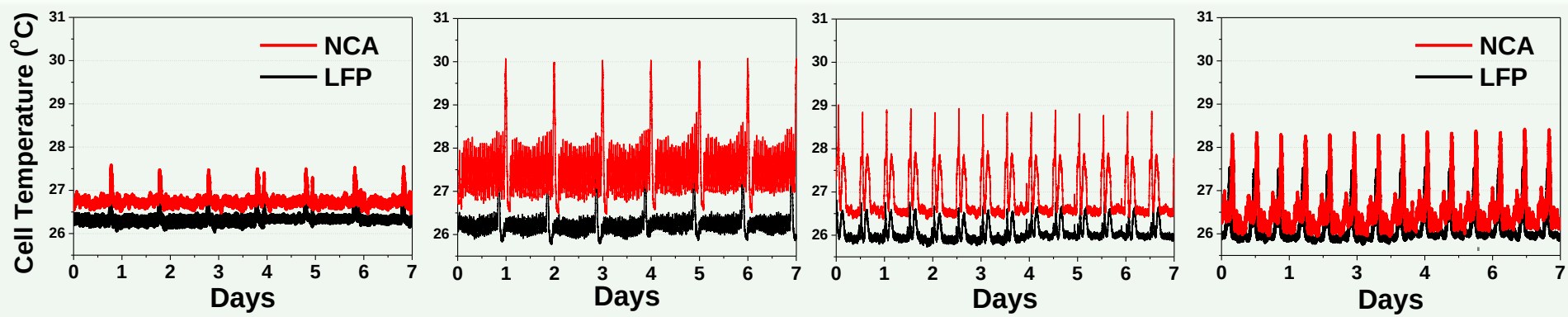

Degradation Trends

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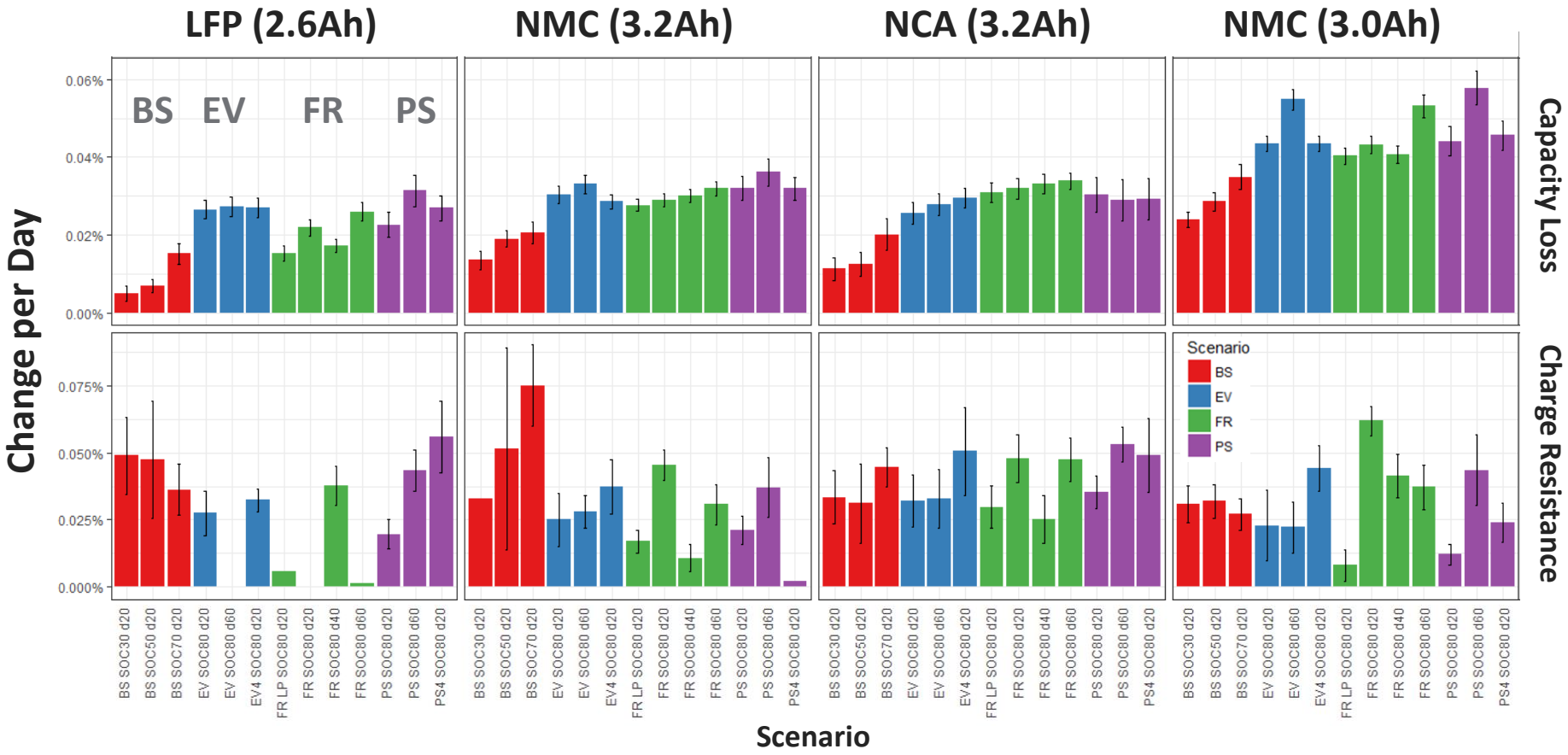
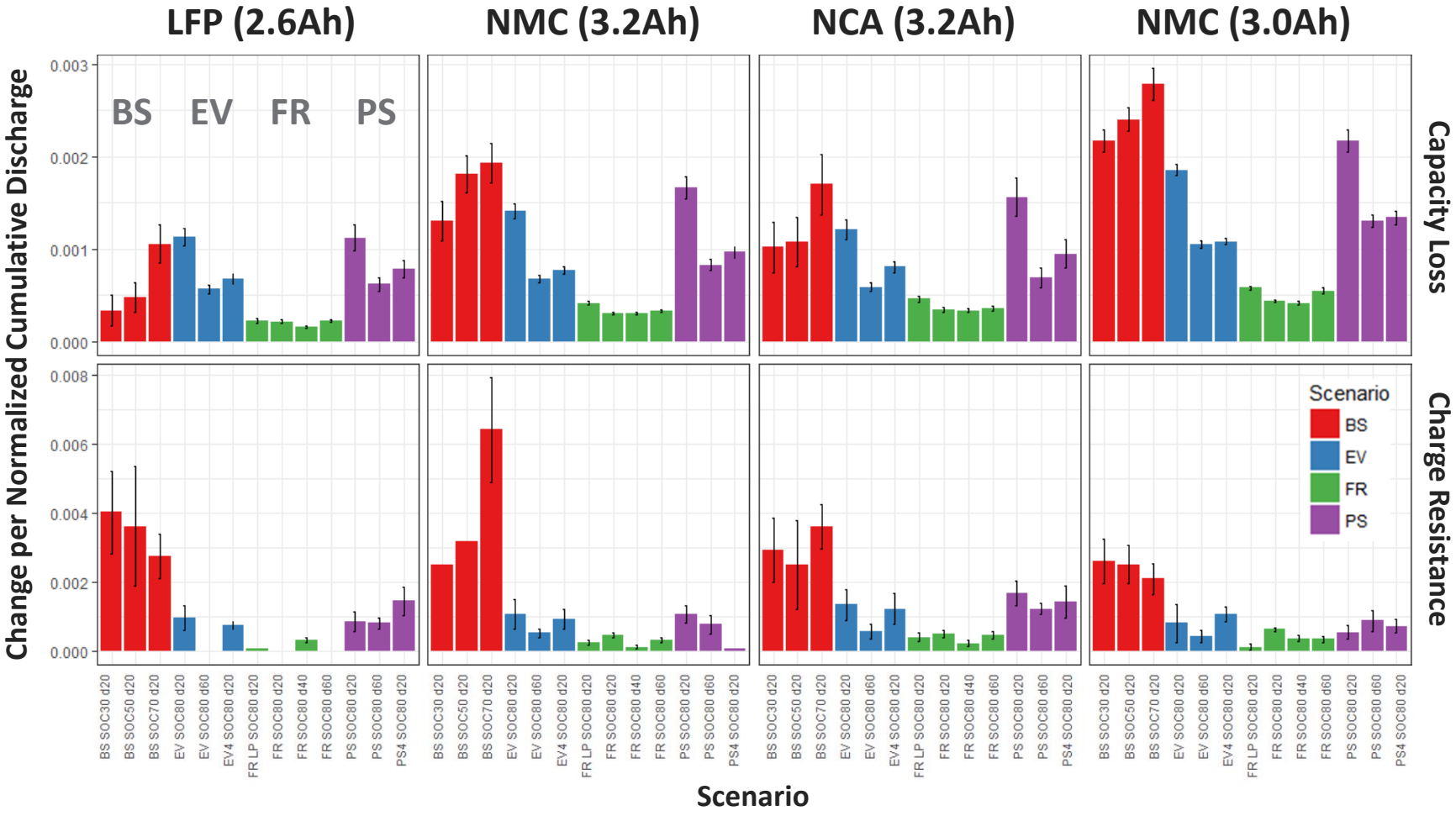


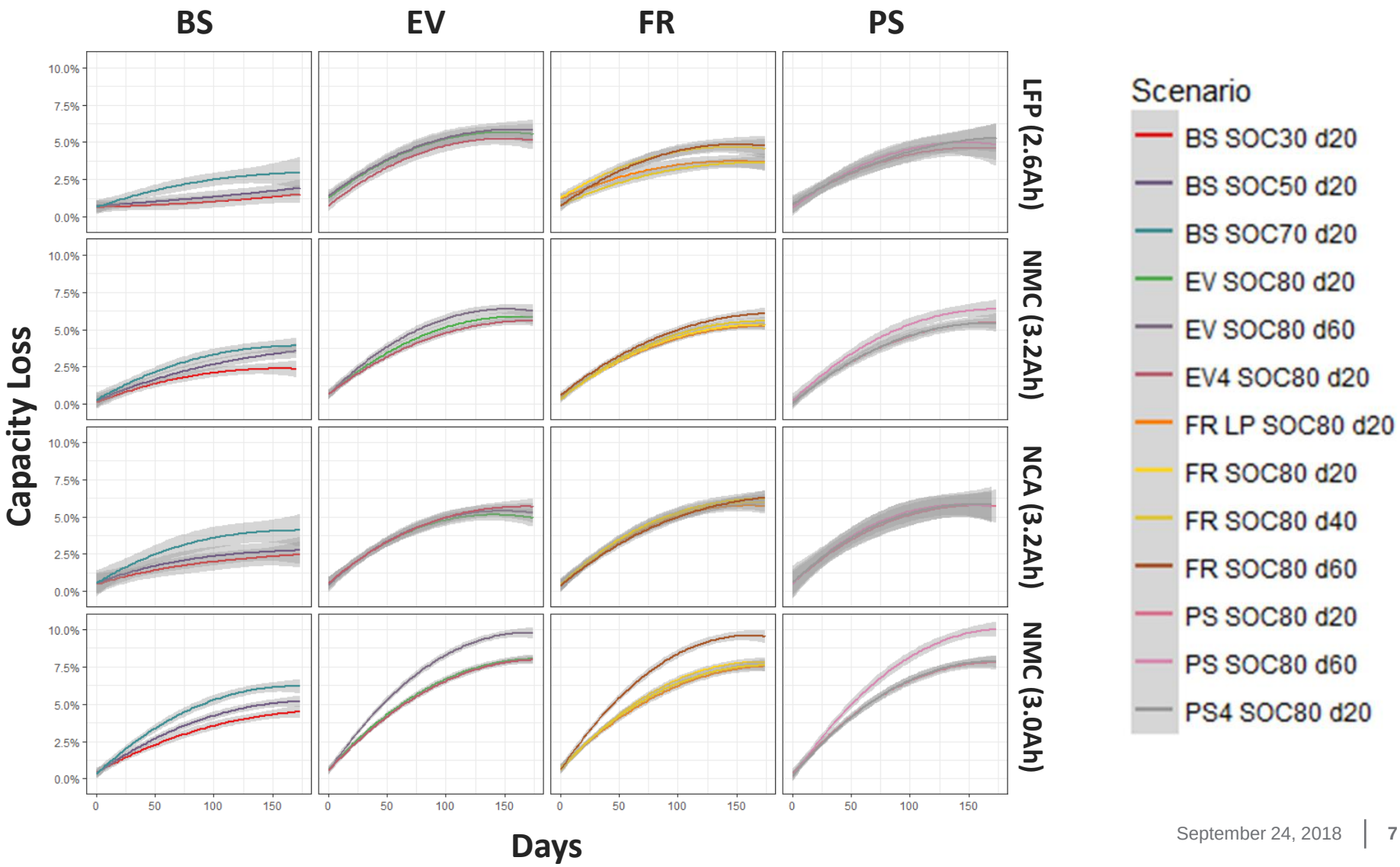
- Capacity degrades with higher SOC level aging
- LFP aging degradation is the lowest
- FR, PS and EV show similar degradation rate
- NMC (3.2 and 3.0Ah) cell show different degradation behavior

Energy Utilizations



- **FR service utilizes more energy per degradation rate**

Capacity Loss Trends



dV/dQ Analyses

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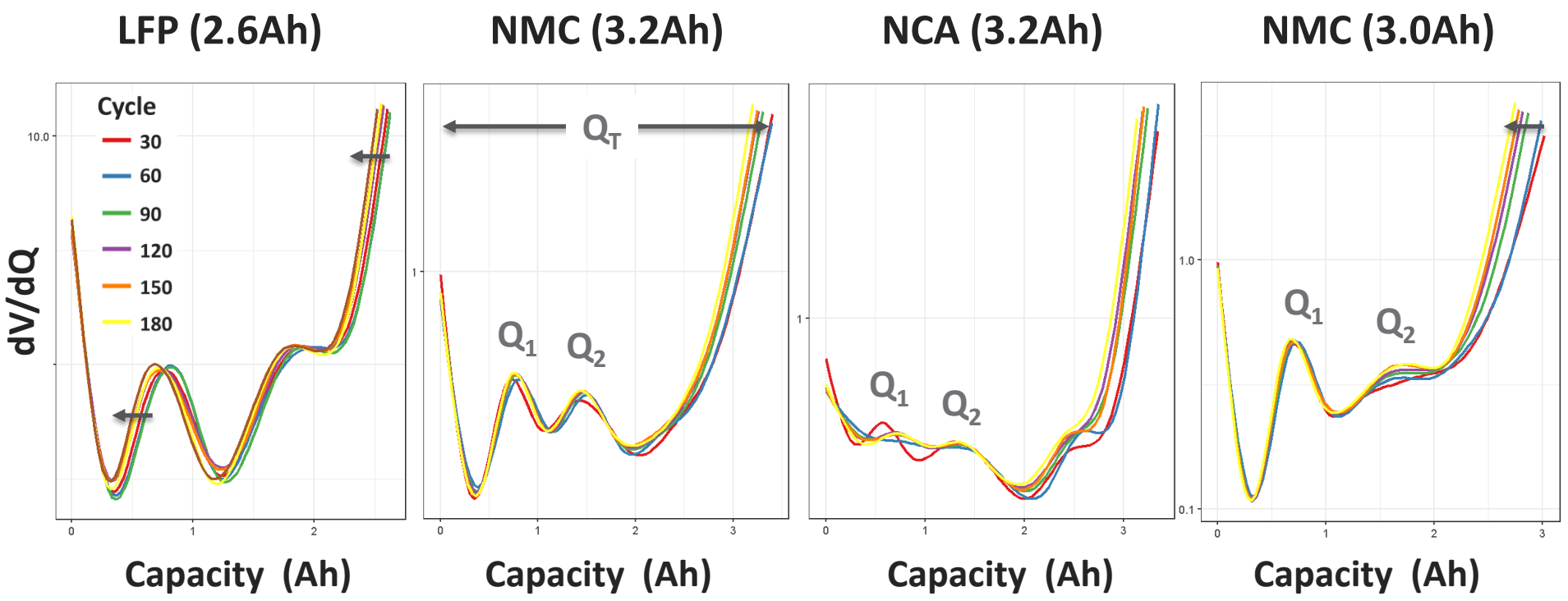

- 180days of continuous frequency regulation service cycles ΔSOC 60%.
- NMC & NCA: the cathode degrades faster than the graphite anode.
- LFP : Lithium loss.

Performance Analyses

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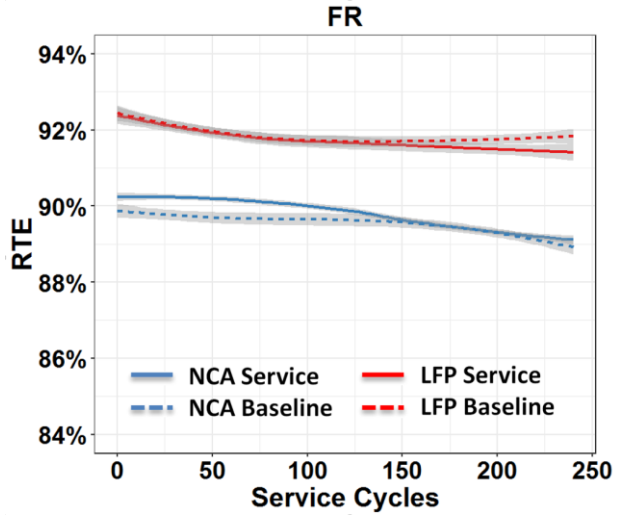

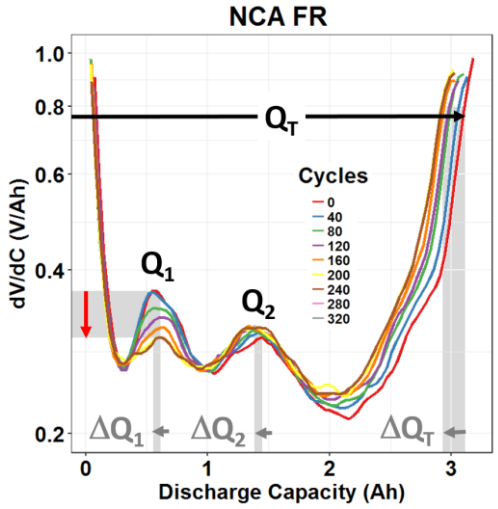

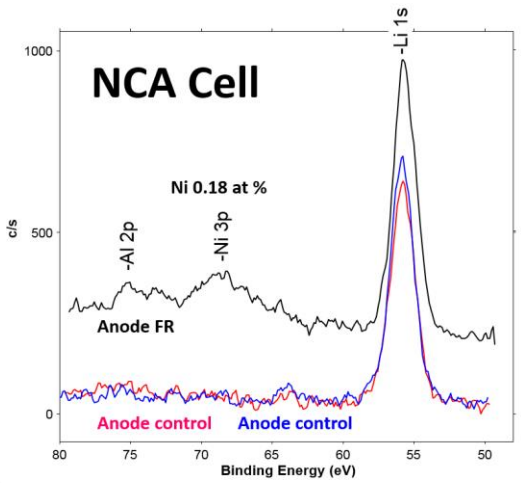

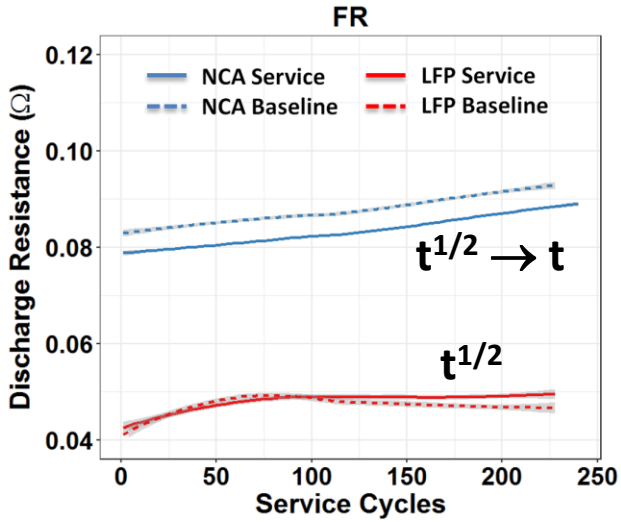

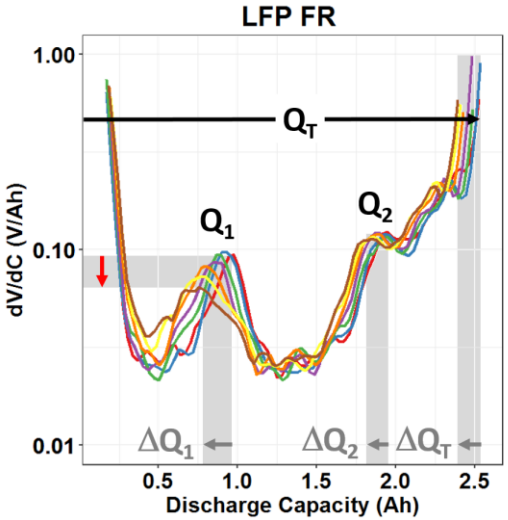

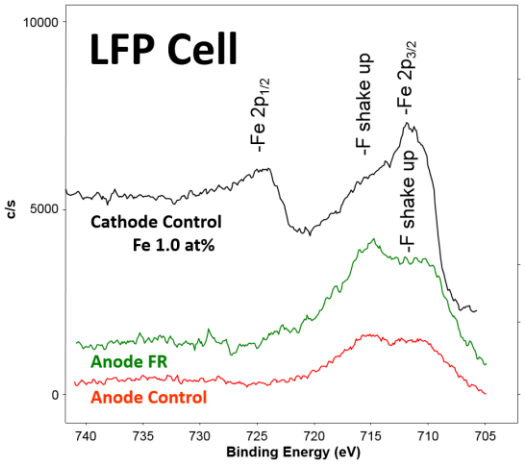

Ref) A.J. Crawford *et al.* , "**Lifecycle comparison of selected Li-ion battery chemistries under grid and electric vehicle duty cycle combinations**", *J. Power Sources* 380 (2018) 185–193

Conclusions

- LFP cells have better aging, capacity, and energy retention.
- Frequency regulation degrades the least per energy utilized.
- Even with a same battery chemistry, cycling stability varies with cell engineering.
- dV/dQ analyses can be used for *in-situ* battery health monitoring
- Higher SOC level degrades the battery the most.
- Cathode dissolution occurs for NCA and NMC cells

Future Work

- Test methods developed here will be applied to larger energy storage modules and systems including Li-ion, lead acid, high temperature sodium and flow batteries.
- For better understanding the dV/dQ analyses, three-electrode setup for cylindrical cell will be implemented to separate cathode and anode voltage profiles and capacities using Li metal as a references.
- Additional 192 test channels will be installed with temperature and impedance monitoring.
- Post-mortem cell characterization will conducted using advanced techniques.

Acknowledgements

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