Understanding Battery Degradation for Grid Energy Storage Systems

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Project Profile

- **Topic Area:** Grid Resilience & Reliability | **Vertical:** Safety & Reliability
- **Strategic Pathway:** Optimize
- **Project start and finish:** FY24-FY26

Problem Statement

- Current battery models are based on uniform, factory-new cells tested under simplified conditions which fail to predict the behavior of mixed-history, unevenly degraded, or second-life battery packs under real grid duty cycles
- This leads to over-engineering, underutilization, premature retirement, and uncertain safety margins
- New qualification methods are needed to enable reliable deployment of second-life batteries for grid storage

Approach

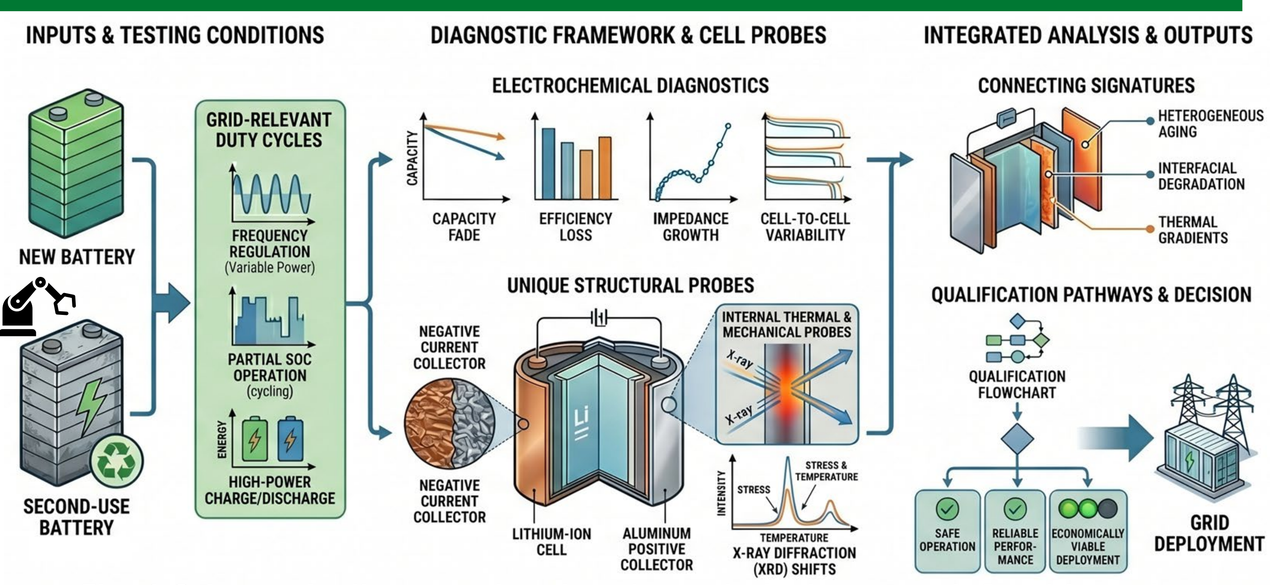
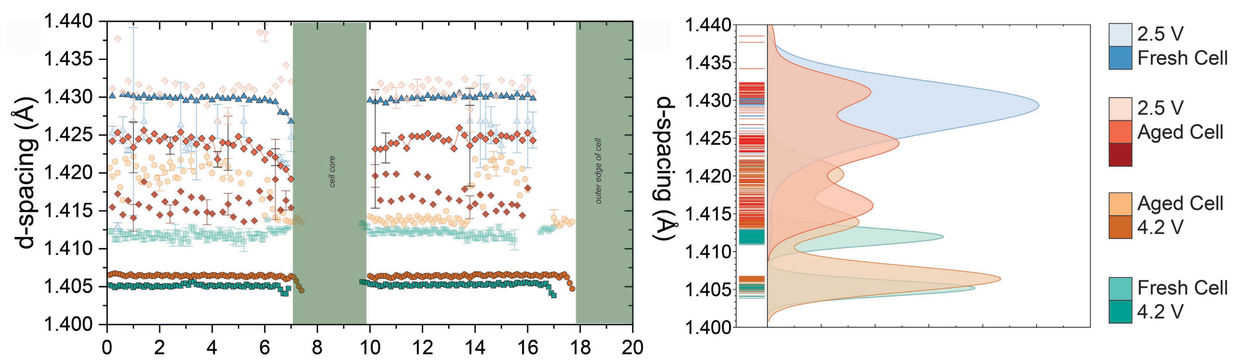
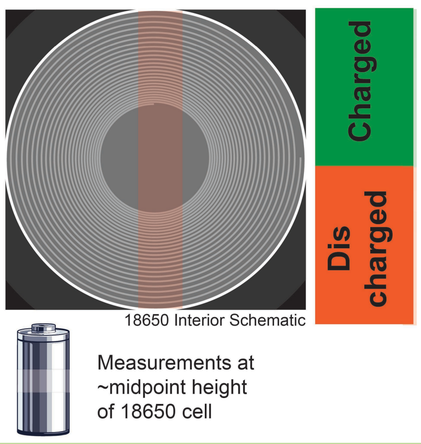


Fig. 1.Schematic diagram showing the technical approach for this project

- Developing robotic disassembly, sorting, and diagnostic workflows to safely identify reusable cells and modules from end-of-life packs.
- Combining electrochemical diagnostics with advanced operando characterization to track thermal gradients, heterogeneous aging, interfacial degradation, and cell imbalance under realistic grid duty cycles.
- Leveraging ORNL GRID-C capabilities to build from cell- and module-level qualification toward grid systems hardware validation for second-use battery deployment.

Study 1: Elucidating inhomogeneous electrochemical and structural response: Implications to thermal behavior





Chemistry: Fresh NCA / Graphite+Si
Configuration: Cylindrical Cell
Individual Cell Capacity: 3.4 Ah

Fig. 2. (113) peak position in fresh and aged cell measured at charged and discharged states. **In the aged cell, some cathode regions show d-spacing values like the charged state, even after full discharge.**

- Likely causes include electrically isolated regions or transport-limited domains
- These trapped delithiated domains may create thermally distinct regions within the electrode
- As a result, aged cells may retain higher-risk thermal behavior even when the cell appears discharged by voltage measurements

Study 2: Qualification of Second-Life Cells and Module Build Considerations[2,3]

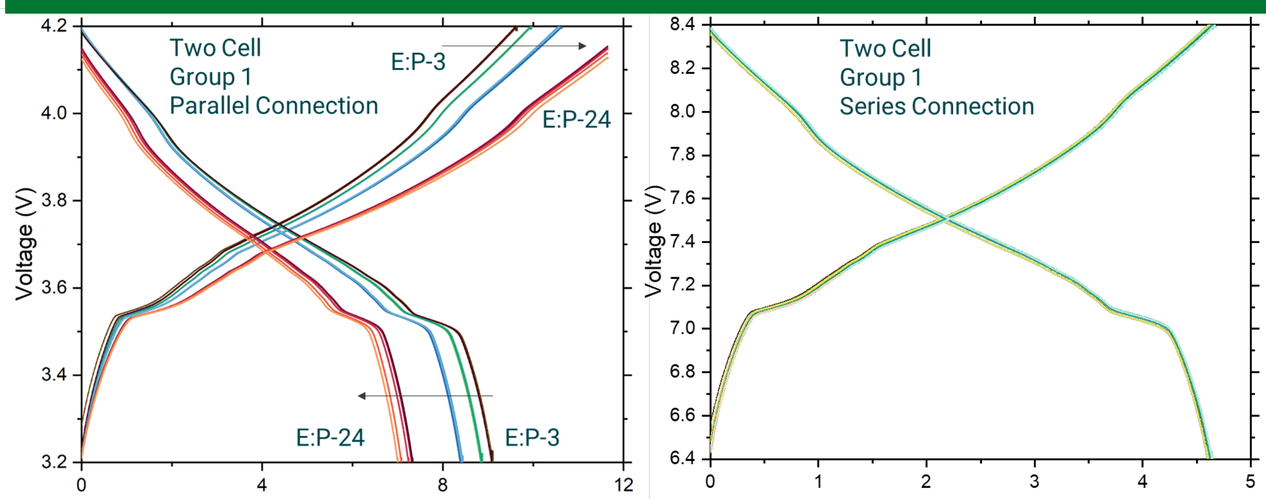


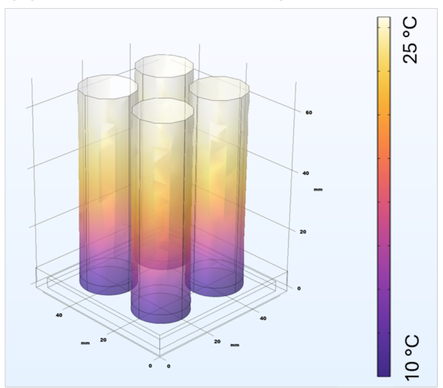
Fig. 3. Experimental evaluation of two-cell stacks built in parallel and series configuration. **Parallel configuration of aged cells introduces internal current loops potentially arising from anode slippage which is absent in serial configurations.**

- Pack configurations for "second-life" systems will need to be carefully tuned to account for nuanced electrochemical variations

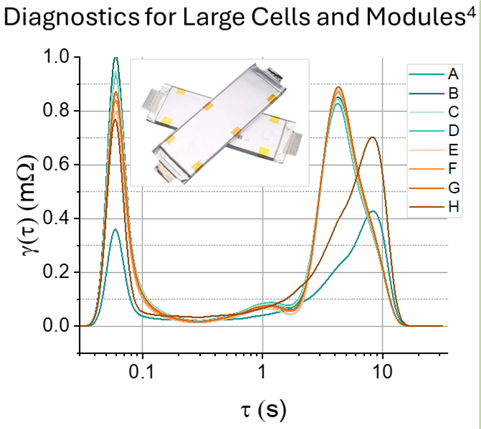
Chemistry: Second-Use NMC/Graphite
Configuration: Prismatic
Individual Cell Capacity: 5 Ah

Ongoing Work

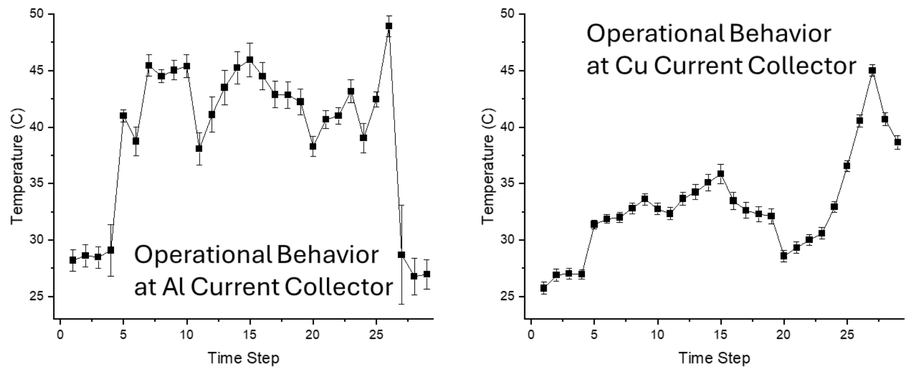
(a) Thermal Gradient Experiments



(b) Diagnostics for Large Cells and Modules[4]



(c) Operando Assessment of Thermal Behavior using Synchrotron Diffraction



(a)
Chemistry: Fresh LFP/Graphite
Configuration: Cylindrical
Individual Cell Capacity: 1.5 Ah
(b)
Chemistry: Second-use NMC/Graphite
Configuration: Pouch
Individual Cell Capacity: 70 Ah
(c)
Chemistry: Fresh NCA /Graphite+Si
Configuration: Cylindrical Cell
Individual Cell Capacity: 3.4 Ah

Fig. 4. (a) Simulated thermal gradient of a bottom cooled cylindrical cell configuration. This work is informed by EDF Power Solutions North America. *(b) Distribution of relaxation time results of a set of second-life cells for qualification. (c) Preliminary data analysis from operando diffraction data-sets from commercial cells probing thermal behavior.* **Experimental campaigns and data analysis are actively ongoing for these aspects.**

Conclusions, Impact, and Future Directions

- Second-use/EOL cells can remain useful, but performance depends on aging history, variability, and module configuration.
- Aged cells show heterogeneous domains that may remain locally delithiated even when the cell appears discharged, affecting safety and reliability.
- Assess real-life scenarios (thermal gradients, grid loads) for new and second-life battery systems using the coupled electrochemical diagnostics and advanced characterization approach to deliver data-driven insights

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References

1. *Combining Calorimetric, Thermodynamic, and Crystallographic Measurements to Characterize the Degradation of Li-ion 18650s after Long-Term Cycling.* Submitted.
2. *Considerations for Qualification of Second-Life Batteries for Grid Applications. Part I: Disassembly and Cell Diagnostics.* In Preparation.
3. *Considerations for Qualification of Second-Life Batteries for Grid Applications. Part II: Sub-system Assembly and Repurposed Module Diagnostics.* In Preparation.
4. *Lessons from Impedance Spectroscopy Studies of Battery Sub-systems for Fault Identification.* In Preparation