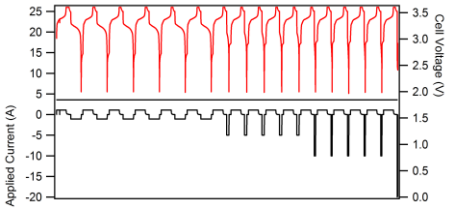
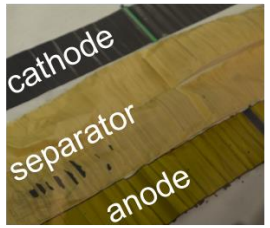
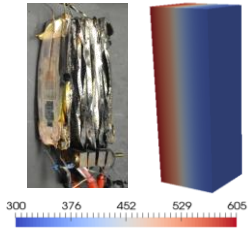
Long-term Performance and Safety of Li-ion Cells







PRESENTED BY

Yuliya Preger

DOE OE Peer Review 2020

September 30, 2020

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND #: SAND2020-9624 C

PROJECT OVERVIEW

SUMMARY: Experimentally quantify commercial Li-ion battery failure at the cell and materials level at varying operating conditions

SIGNIFICANCE:

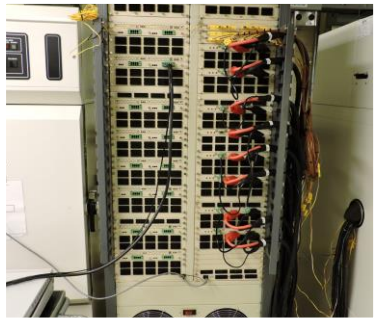
- Li-ion battery energy storage system selection is fraught with uncertainty
  - Limited performance and safety data is publicly available, making it difficult to quantify risk at various operating conditions
- Broader understanding of degradation and failure can inform new technologies for intervention

ALIGNMENT WITH CORE MISSION OF DOE OE:

- Energy storage systems contribute to resilience, reliability, and flexibility of energy infrastructure
- Dissemination of ‘apples to apples’ safety and performance data can accelerate risk assessment, selection, and adoption of energy storage technologies

PROJECT TEAM

Sandia Battery Test Facilities

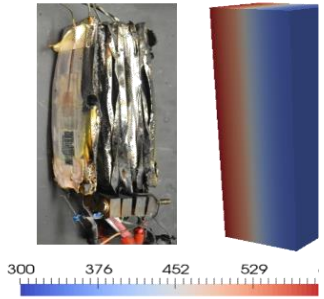


Yuliya Preger
Reed Wittman
Armando Fresquez

Sandia Battery Abuse Lab

Loraine Torres-Castro
Joshua Lamb
Jill Langendorf
Chris Grosso
Lucas Gray

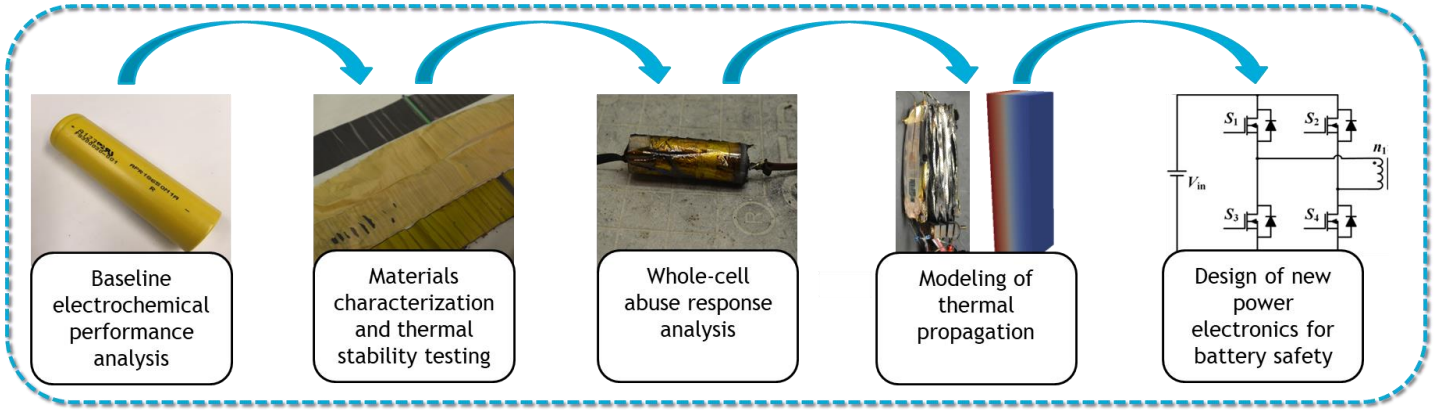
Sandia Fire Sciences



John Hewson
Randy Shurtz
Andrew Kurzawski

Center for Integrated Nanotechnologies

Sergei Ivanov



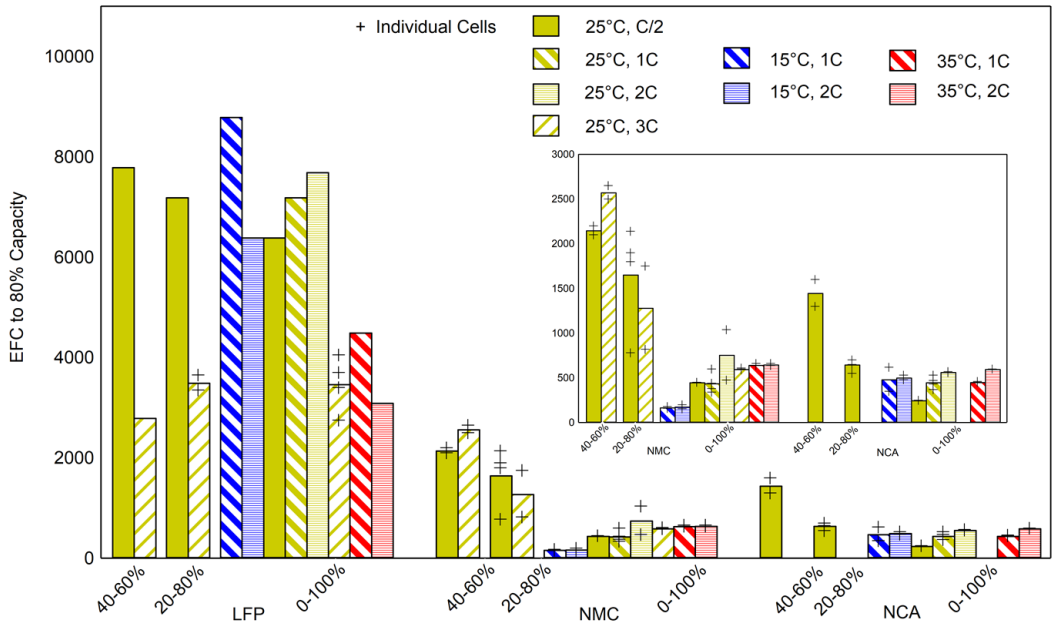
PROJECT OBJECTIVES

- Understand difference in aging behavior as a function of chemistry, environment, and use case for popular commercial Li-ion chemistries
- Relate fading performance to changes in electrochemical and materials properties
- Understand impact of cell age and aging protocol on abuse response
- Develop public resources for sharing and analyzing battery data

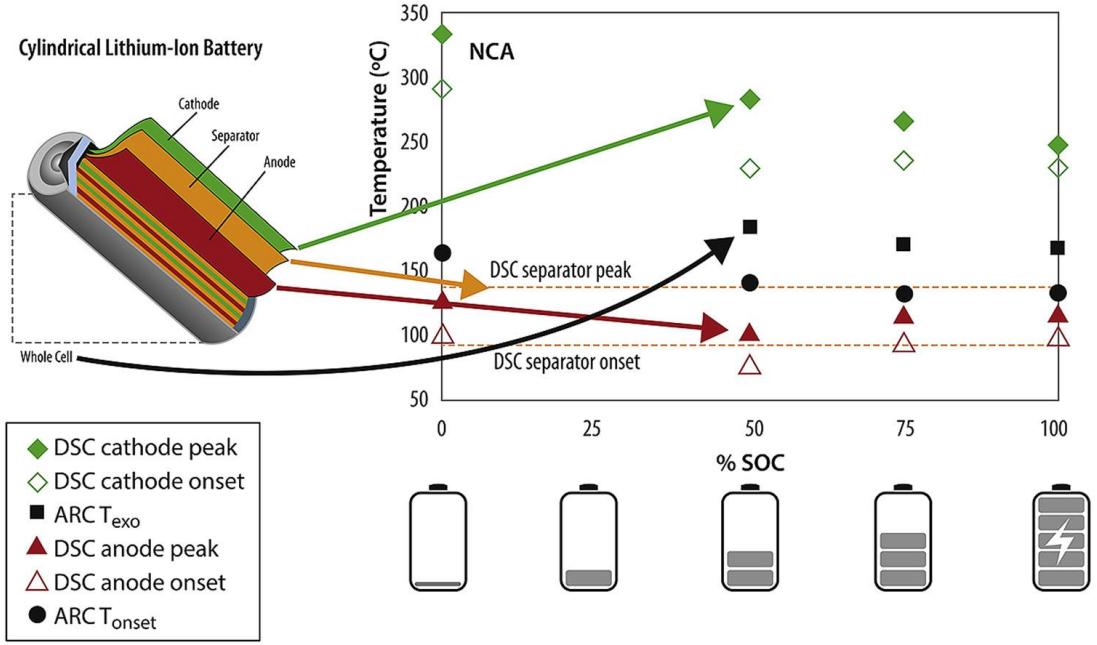
PROJECT PREVIOUS WORK

- Multi-year cycling study of commercial NMC, NCA, and LFP cells to 80% capacity, varying discharge rate, depth of discharge, and temperature
- Analysis of cycling condition impact on capacity/energy retention and round-trip efficiency
- Comparison to previous studies to identify universal trends and provide standard deviation for performance

- Thermal runaway measurements for fresh commercial Li-ion batteries at 0-100% SOC
- Component-level degradation mapped to whole fresh cell thermal runaway



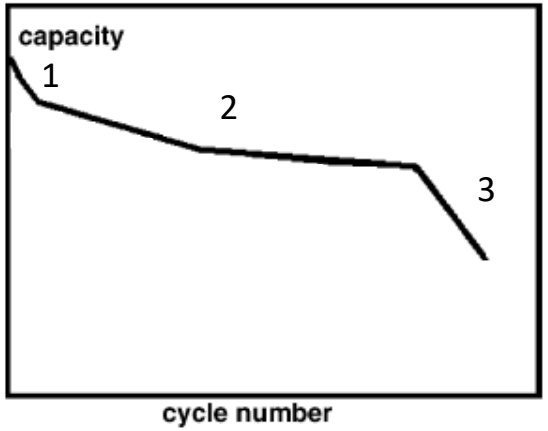
Preger et al. *J. Electrochem. Soc.* **2020**, *167*, 120532.



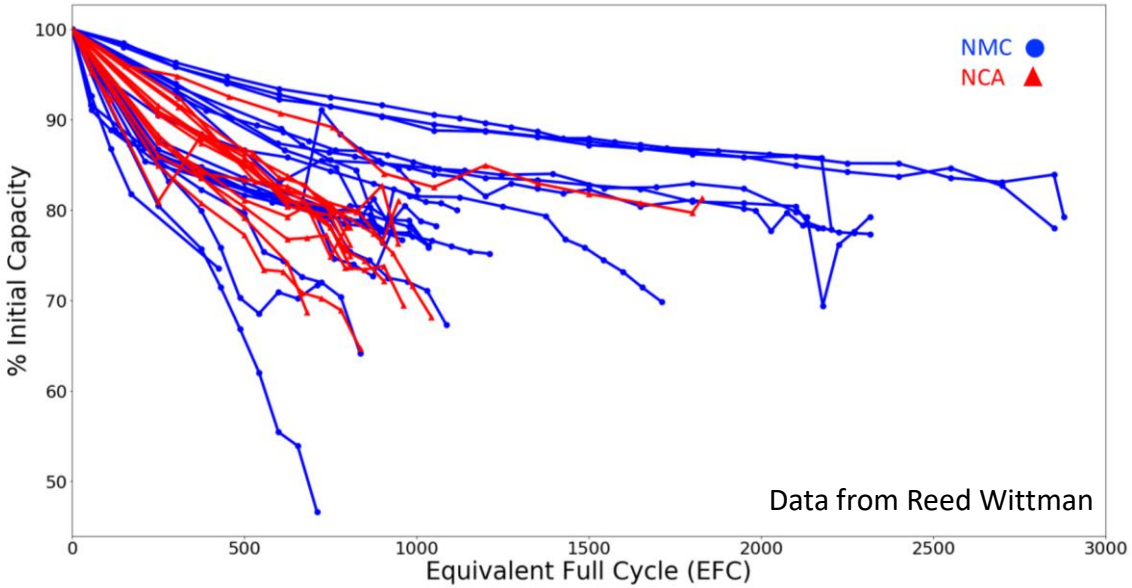
Barkholtz et al. *J. Power Sources* **2019**, *435*, 226777.

PROJECT RESULTS – Performance Beyond 80% Capacity

- Spec sheets and cycling studies typically report degradation to 80% capacity (holdover from EVs)
  - Beyond 80% relevant for grid + 2nd life applications
- Typical model of Li-ion battery degradation assumes transition from linear behavior (Zone 3)
  - No definitive answer on when or why
- Currently, we are cycling NMC and NCA cells from earlier study to 'knee point'
- Completing electrochemical (EIS, differential capacity analysis) and materials characterization (CT scans, XRD, calorimetry, SEM) for fresh, 80%, and post-knee cells
  - Electrochemical analysis, CT scans, and XRD done for fresh and 80% cells



Spotnitz et al. *J. Power Sources* **2003**, *113*, 72.



Innovation: first broad study of degradation beyond 80% capacity with comprehensive materials and electrochemical correlation

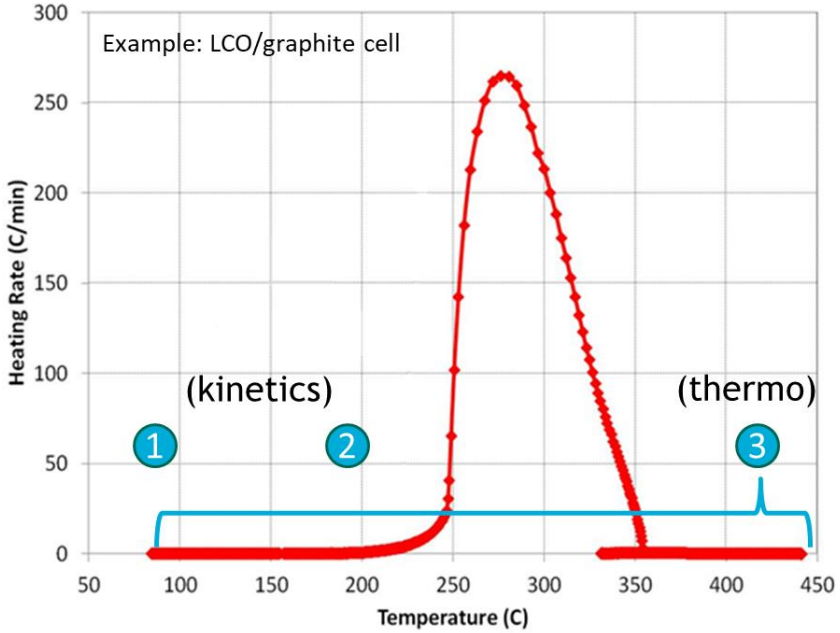
PROJECT RESULTS – Safety Beyond 80% Capacity

- Standard abuse testing is reported only for fresh cells; influence of cell age on safety is unclear
  - More safe (due to capacity loss)?
  - Less safe (due to materials instability)?
  - Little difference?

- Thermal runaway of fresh and aged cells compared via accelerated rate calorimetry (ARC)

- Analyzed all previous reports + dozens of experiments at Sandia on ARC of aged cells
  - Abuse response most strongly influenced by aging temperature
  - Lower self-heating onset at lower temperature, likely due to appearance of plated Li
  - Heat release generally the same or lower as cell ages
  - Need more data on non-thermal abuse (e.g. long-term stability of protective devices for overcharge and short circuit)

Representative ARC analysis



1. Self-heating onset temperature
2. Thermal runaway onset temperature
3. Total heat release (ΔT)

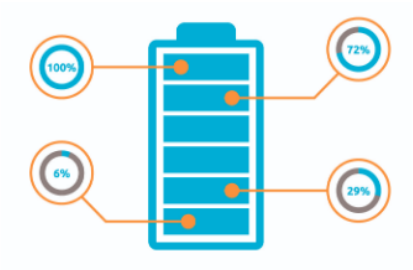
Innovation: first comprehensive evaluation of influence of battery age and aging protocol on abuse response

PROJECT RESULTS – Battery Cycling Database

BatteryArchive.org

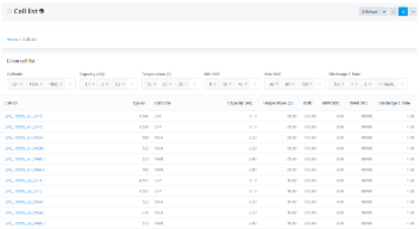
A repository for easy visualization, analysis, and comparison of battery data across institutions

View Data



Features

1 Filter battery data



Query and filter for specific experimental conditions.

2 Visualize and compare data

Display battery data, including voltage curves and capacity fade.

3 Compare data with models

Apply performance and degradation models to battery data.

Motivation

- Battery data not reported and shared systematically
- Difficult to compare results from different groups
- Metadata not indexed for easy searching/reuse

Site Development

- Dr. Valerio de Angelis (CUNY): site architecture
- Sam Roberts-Baca (SNL): front end
- Mark Spoonamore (SNL): database guidance
- Prof. Venkat Subramanian (UT-Austin): models

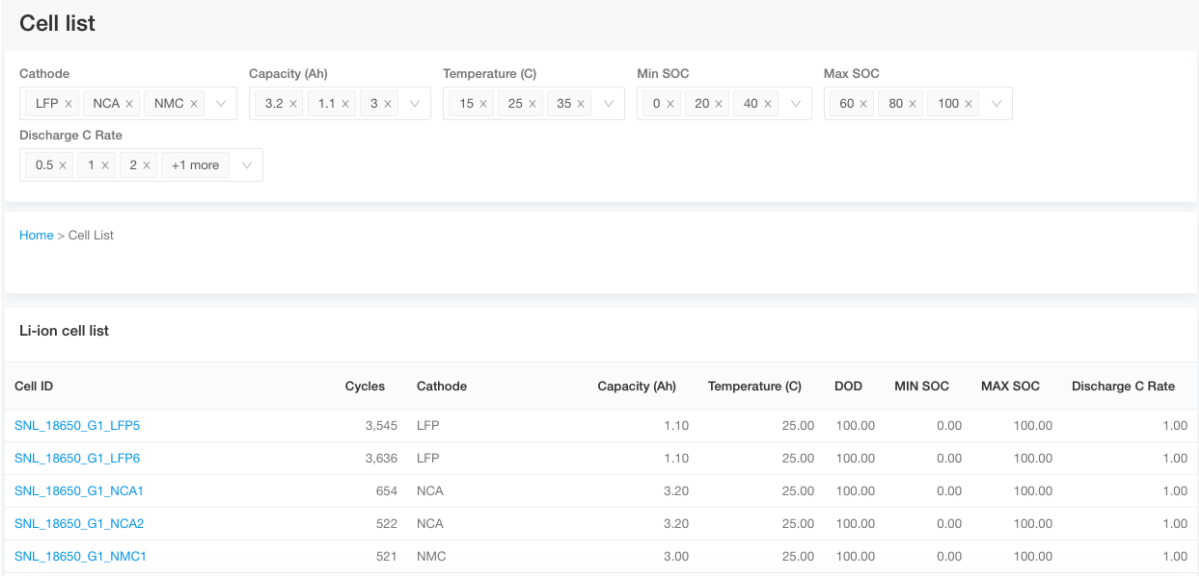
Critical Feedback & Data Contributions

- PNNL
- Hawaii Natural Energy Institute
- Jet Propulsion Lab
- NRC Canada
- RWTH Aachen University

Innovation: first public repository for easy visualization, analysis, and comparison of battery data across institutions

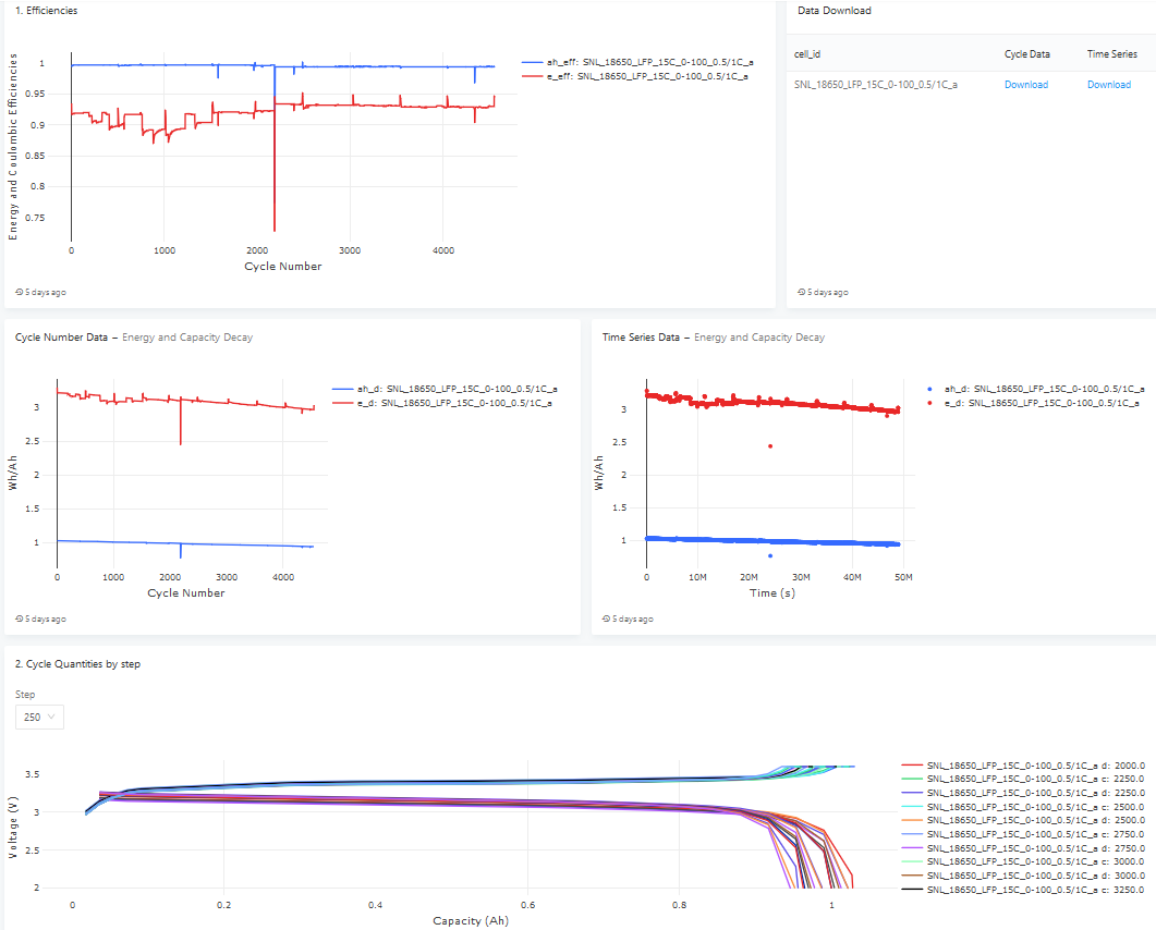
PROJECT RESULTS – Battery Cycling Database

Search by metadata related to cell + cycling conditions



Cell ID	Cycles	Cathode	Capacity (Ah)	Temperature (C)	DOD	MIN SOC	MAX SOC	Discharge C Rate
SNL_18650_G1_LFP5	3,545	LFP	1.10	25.00	100.00	0.00	100.00	1.00
SNL_18650_G1_LFP6	3,636	LFP	1.10	25.00	100.00	0.00	100.00	1.00
SNL_18650_G1_NCA1	654	NCA	3.20	25.00	100.00	0.00	100.00	1.00
SNL_18650_G1_NCA2	522	NCA	3.20	25.00	100.00	0.00	100.00	1.00
SNL_18650_G1_NMC1	521	NMC	3.00	25.00	100.00	0.00	100.00	1.00

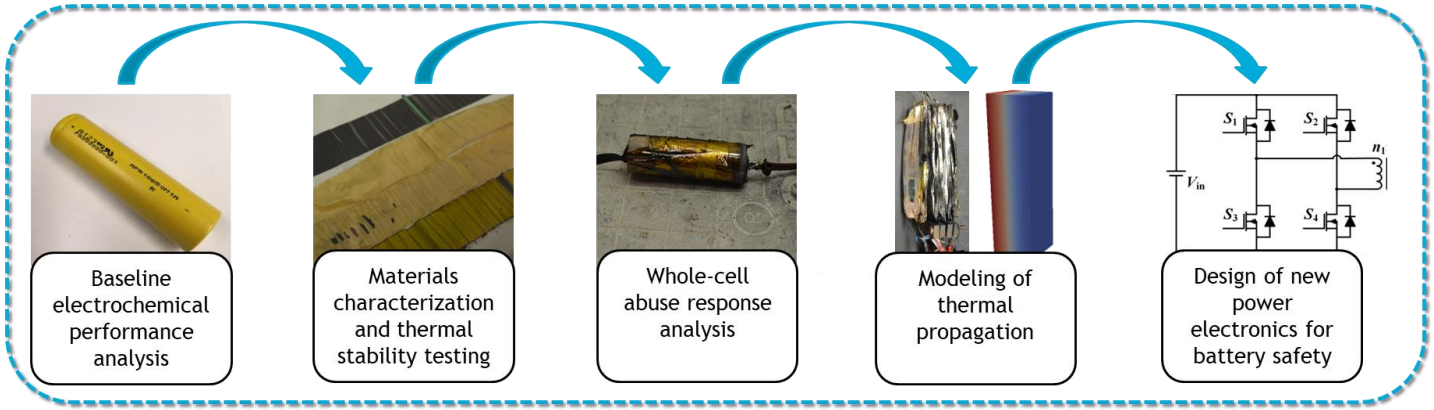
Efficiencies, capacity and energy decay, and voltage curves automatically plotted for selected cells



Site launched in August 2020: so far, over a hundred visitors from a dozen countries have logged multiple sessions

Core of site is complete, but many modifications still in progress (e.g. more and different kinds of battery data)

LOOKING FORWARD



- **Li-ion Cell Performance and Safety**
  - Continuing electrochemical and materials characterization of Li-ion cells cycled beyond 80% capacity
  - Expansion of batteryarchive.org
  - Extending applications of battery data in technoeconomic analysis and monitoring of anomalous behavior for predictive maintenance and cybersecurity

- **Power Electronics & Battery Safety**
  - Influence of module configuration and power electronics topology on degradation
  - Possible interventions in imminent battery failure scenarios

ACCOMPLISHMENTS SUMMARY

Presentations

- **Degradation of Commercial Lithium-ion Cells Beyond 80% Capacity**; 236th ECS Meeting, Atlanta, GA; October 2019.

- **Rigorous Approaches to Quantifying Cell Failure to Enable Large-Scale Failure Modeling – Materials, Mechanics, and Electrochemistry**; 10th Annual Battery Safety Summit, Alexandria, VA; October 2019.
  With interview in: Battery Power Online *"Modeling Goes a Long Way to Prevent Lithium-ion Battery Safety Failure"*

- **Degradation of Commercial Lithium-ion Cells Beyond 80% Capacity**; Battery Safety Council Forum 8, Washington D.C.; November 2019.

- **Safety and Performance of Commercial Li-ion Cells**; Batteries Gordon Research Conference, Ventura, CA; February 2020.

- **Battery Reliability R&D, Life Beyond 80%;** Energy Storage Systems Safety and Reliability Forum, Richland, WA; March 2020.

Tutorials

- IEEE Power and Energy Society Tutorial on "Energy Storage System Safety and Reliability"; July and September 2020.

Publications

- Y. Preger, H. M. Barkholtz, A. Fresquez, D. L. Campbell, B. W. Juba, J. Roman-Kustas, S. R. Ferreira, B. R. Chalamala, "**Degradation of Commercial Lithium-ion Cells as a Function of Chemistry and Cycling Conditions**" *Journal of the Electrochemical Society*, 2020, *167*, 120532.

- R. Fioravanti, K. Kumar, S. Nakata, B. R. Chalamala, Y. Preger, "**Predictive Maintenance Practices – For Operational Safety of Battery Energy Storage Systems.**" *IEEE Power and Energy Magazine,* 2020.

- Y. Preger, L. Torres-Castro, J. Langendorf, J. Lamb, C. Orendorff, B. R. Chalamala, "**Review of the Safety of Aged Lithium-ion Batteries as a Function of Aging Protocol and Abuse Method**" (in preparation)

- J. Lamb, L. Torres-Castro, J. Hewson, R. Shurtz, Y. Preger, C. Orendorff, "**The Role of Energy Density in Lithium-ion Battery Thermal Runaway**" (in preparation)

- J. Obert, L. Torres-Castro, Y. Preger, R. D. Trevizan, "**Ensemble Learning, Prediction and Li-ion Cell Charging Cycle Divergence**" (in preparation)

Other

- Launched Batteryarchive.org: first public, multi-institution searchable database of battery cycling results

- Organizing Symposium at the Fall 2020 MRS Meeting: Advancement of Lithium-Based High-Energy Density Batteries at Multiple Scales, Factoring in Safety

- Organizing Session at Resilience Week 2020: Enabling Safe Operation of Energy Storage Systems for Enhanced Resilience

PROJECT CONTACTS

- Funded by the U.S. Department of Energy, Office of Electricity, Energy Storage program. Dr. Imre Gyuk, Program Director.
- Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.
- This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science by Los Alamos National Laboratory (Contract DE-AC52-06NA25396) and Sandia National Laboratories (Contract DE-AC04-94AL85000).

For questions about this presentation: ypreger@sandia.gov

For further details on experimental work, see the following posters:

- Long-term Performance and Safety of Commercial Li-ion Cells (Yuliya Preger)
- Electrochemical and Materials Characterization of Li-ion Cells During Long-Term Cycling (Reed Wittman)