Exceptional service in the national interest

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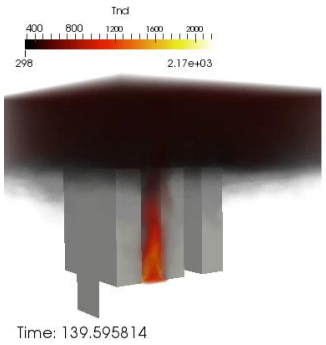

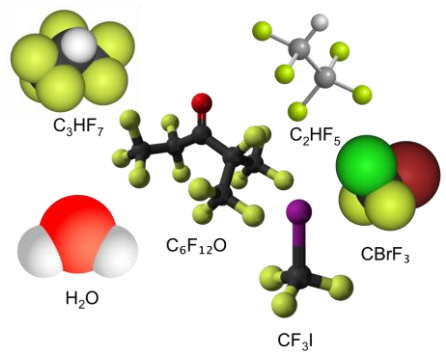

Energy Storage Technologies- Assessing Reliability and Safety

Summer Ferreira, Heather Barkholtz, Armando Fresquez

Peer Review Meeting
September 27, 2016

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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SNL Energy Storage System Analysis Laboratory

Sandia National Laboratories

Mission:

Assess the performance, reliability and safety of energy storage technologies to advance the adoption of stationary storage solutions.

Problem:

- Analysis differs across the industry resulting in “apples to oranges” data
- Life of storage technologies critical to validating economics
- Safety is uncertain as well, while measures to address safety aren’t based on rigorous science or empirical results.

Approach:

Develop advances through:

- Test protocols, using direct research and standards activities
  - *Measuring and Expressing ESS Performance*
- Consensus building among stakeholders in safety efforts
  - ESS Safety Working Groups
  - ESS Safety Forum 2017
- **R&D assessing top challenges to ESS Safety and reliability:**
  - **Cell to string assessment of performance, reliability, and failure**
  - **Correlate to modeling efforts**

Participation in Standards Activities

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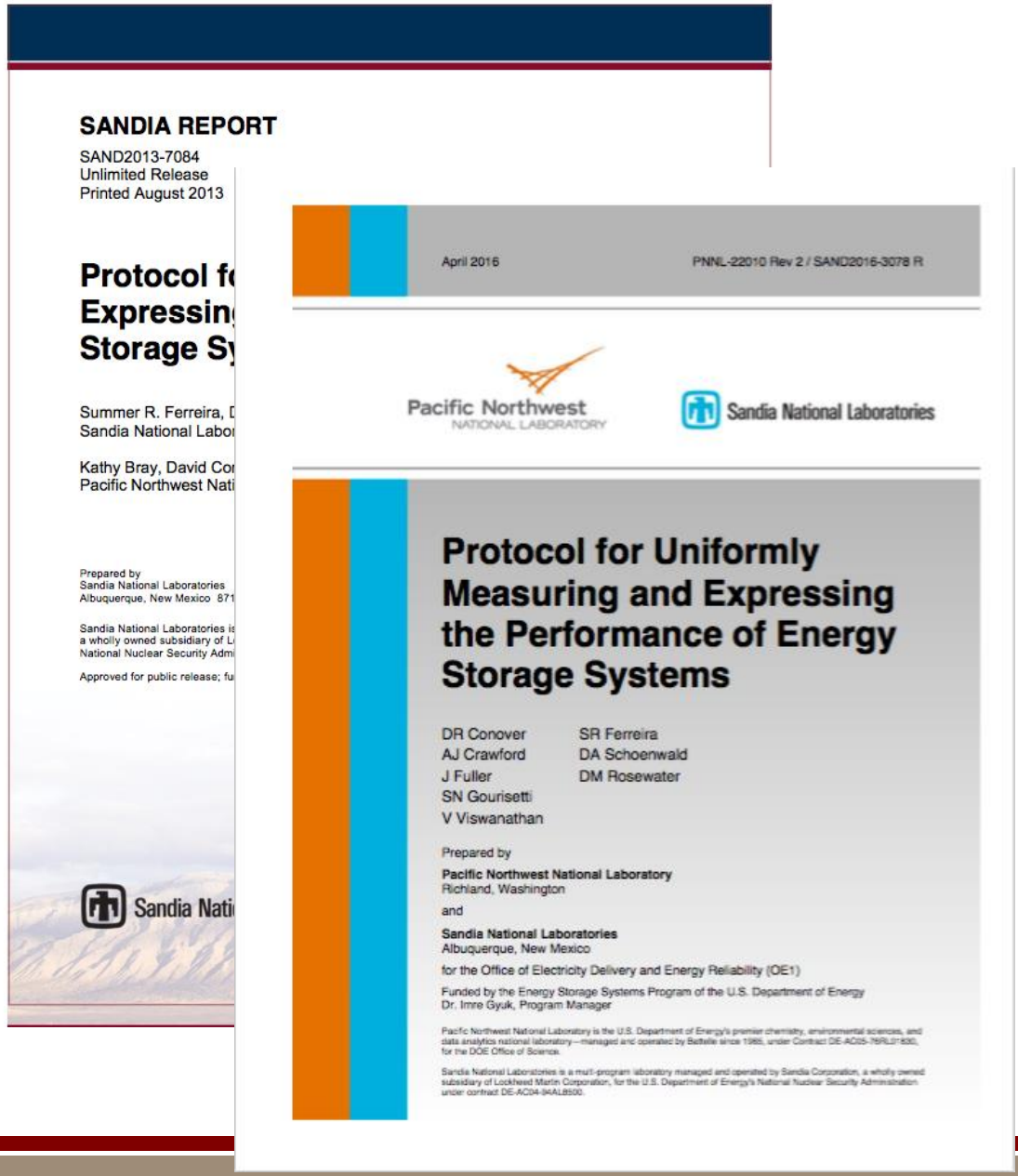
DOE Performance Protocol

- Included broad input from utility and manufacturing side.
- Testing and comments are welcome.

Third iteration of the DOE protocol *Measuring and Expressing ESS Performance*



ESS Safety FORUM 2017
MEETING THE CHALLENGE

Sandia National Laboratories

Feb. 22-24, 2017 at the LaFonda Hotel in Santa Fe, NM

Visit: https://share.sandia.gov/ess/ess-safety-forum-2017/

ESS Safety WORKING GROUP

Email: EnergyStorage@sandia.gov

- Short term priorities identified:
  - **Fire Suppression testing** and analysis
  - **Thermal runaway** research
  - **System scale burn test**
  - **Commodity classification** development
  - **Fire and vent gas modeling** and analysis

SNL Energy Storage System Analysis Laboratory

Sandia National Laboratories

Testing Capabilities Include:

Cell, Battery and Module Testing

- 14 channels from 36 V, 25 A to 72 V, 1000 A for battery to module-scale tests
- Over 125 channels; 0 V to 10 V, 3 A to 100+ A for cell tests

72 V 1000 A Bitrode (2 Channels)

High Power High Precision Analysis

- 200A, 5V testers with 40 ppm accuracy on round trip coulombic efficiency
- 2 single channel testers

System Testing

- Up to 1 MW, 480 VAC, 3 phase
- 1 MW/1 MVAR load bank

Energy Storage Test Pad (ESTP)

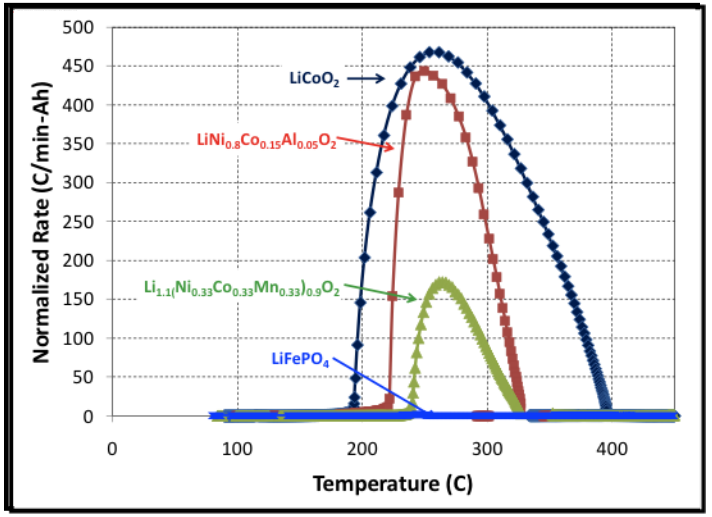
SNL Battery Abuse Testing Laboratory

Sandia National Laboratories

Battery testing, cell measurements, and materials development to support the development of inherently safe lithium-ion chemistries

- Safety and abuse tolerance evaluation of energy storage devices from cells to kWh batteries:
  - Mechanical abuse
  - Thermal abuse
  - Electrical abuse
- Understanding degradation mechanisms that lead to cell failure
- Provide experimental data to support abuse and thermal modeling
- Cell prototyping facility for materials development

Understanding abuse tolerance



50 Wh failure event

5 Wh failure event

Impact and Consequence of Scale on Safety

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The Lack of Safety:

Endangers Life
Loss of Property
Damages Reputation
Decreases Confidence in Storage

Consumer Cells (0.5-5 Ah) → Large Format Cells (10-200 Ah) → Transportation Batteries (1-50 kWh) → Utility Batteries (MWh)

www.ford.com www.samsung.com www.saftbatteries.com

Safety issues carry greater weight with increasing battery size

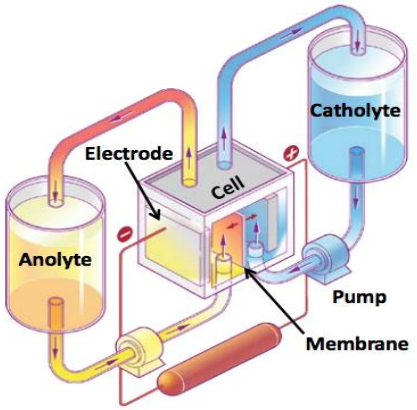
The Grid Energy Storage Safety Challenge

Sandia National Laboratories

Our R&D program in ESS Safety is building on past efforts within Sandia for electric vehicle battery safety funded through the Office of Vehicle Technology

- ***Variety of technologies***
- ***Proximity to population***
- ***Use conditions***
- ***Scale and size***
- ***Design considerations***
- ***System complexity***

Subway regen system, SEPTA



Redox Flow Battery

SAFT 10 MWh storage system

US Marine Corps FOB, Afghanistan

Key Challenges:

Utility safety incidents have highlighted the **need for a focused effort** in safety

Examples of Recent Issues with Energy Storage Safety

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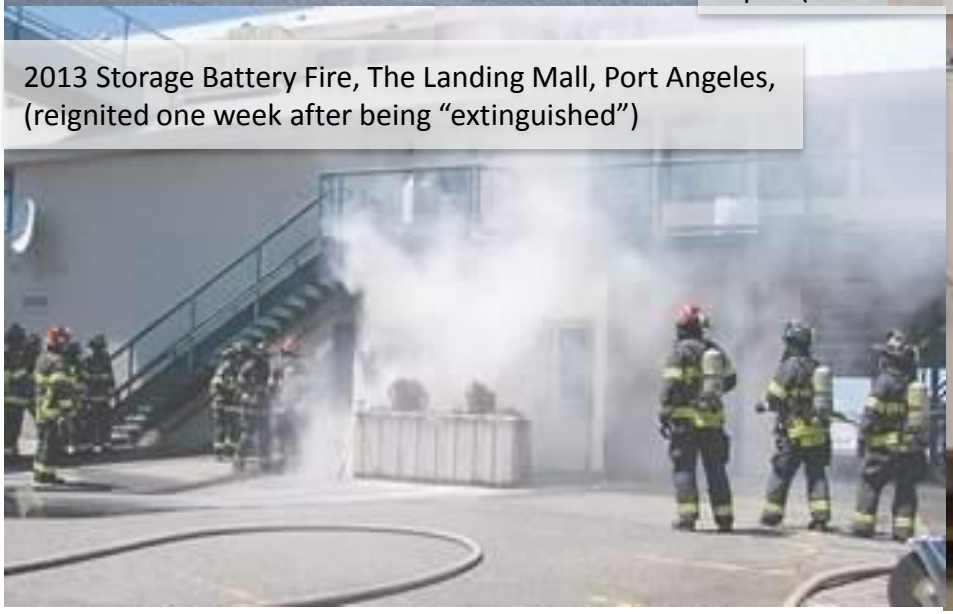
2011 Beacon Power Flywheel Failure

2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm

2011 NGK Na/S Battery Explosion, Japan (two weeks to extinguish blaze)



2013 Storage Battery Fire, The Landing Mall, Port Angeles, (reignited one week after being “extinguished”)

2012 GM Test Facility Explosion, Warren, MI

Improving battery safety

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Development of Inherently Safe Cells

- Safer cell chemistries
- Non-flammable electrolytes
- Shutdown separators
- Non-toxic battery materials
- Inherent overcharge protection

Safety Devices and Systems

- Cell-based safety devices
  - current interrupt devices
  - positive T coefficient
  - Protection circuit module
- Battery management system
- Charging systems designed

Effective Response to Off-Normal Events

- Suppressants
- Containment
- Advanced monitoring and controls

Battery Safety – Stationary Storage

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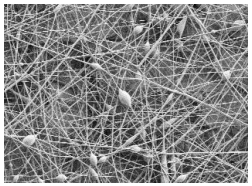
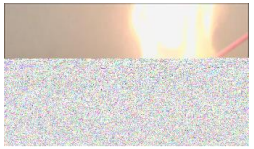
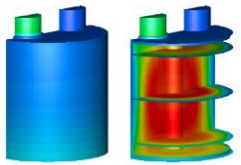


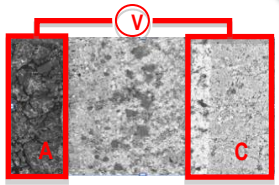


Materials R&D to date:
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

Materials R&D needs:
- Viable flow batteries
- Aqueous electrolyte batteries
- High specific heat suppressants
- Vent gas composition

Testing
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Suppressants and delivery with systems and environments
- Large scale thermal and fire testing (TTC)





Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating failure propagation models
- Fire Dynamic Simulations (FDS) to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation
- UL 1973-13 Batteries for Use in Stationary Applications
- ANSI/UL 9540-P (ESS Safety)
- UL 1974 (Repurposing)
- IEEE 1635-12 (Ventilation and thermal management)

Safety of 18650 Li-Ion Cells

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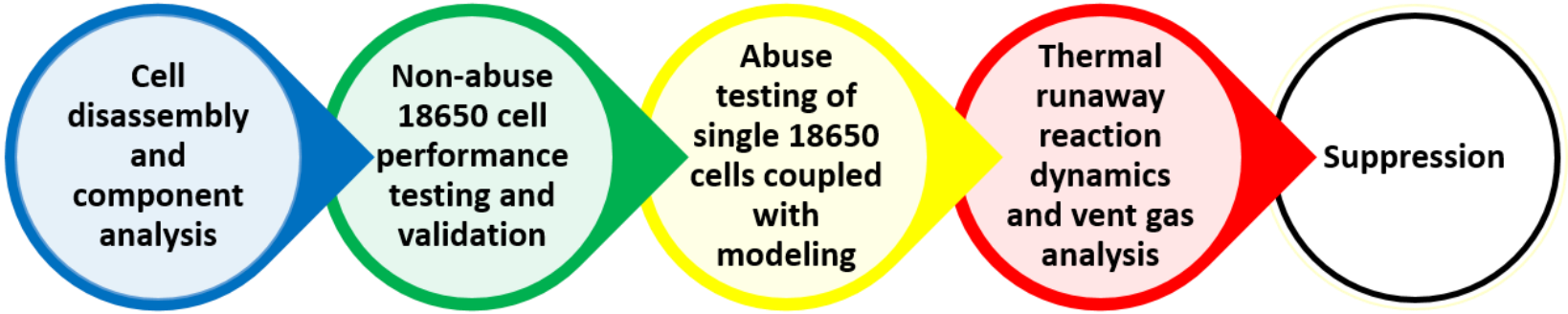
Cathode Chemistry	Nominal Capacity (mAh)	Nominal Voltage (V)	Δ T (°C)	Max Discharge Current (A)
LFP $LiFePO_4$	1100	3.3	-30 to 60	30
NMC $LiNi_{1-x-y}Mn_xCo_yO_2$	3000	3.6	-5 to 50	20
LCO $LiCoO_2$	2500	3.6	0 to 50	20
NCA $LiNi_{0.80}Co_{0.15}Al_{0.05}O_2$	2900	3.6	0 to 45	6

Suppressant analysis

Fire suppression testing is the top priority to the community.

Building from a fundamental understanding of failure from empirical and modeling we are assessing suppression.



Cell Disassembly and Component Analysis

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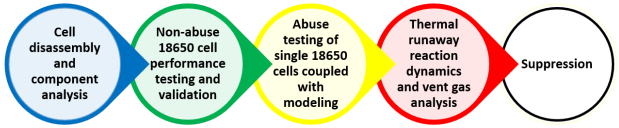
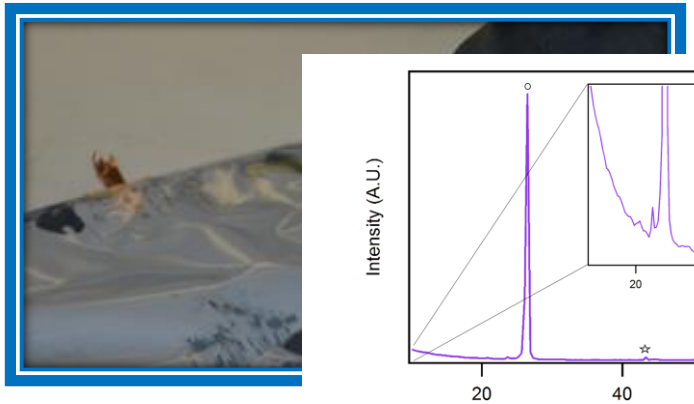
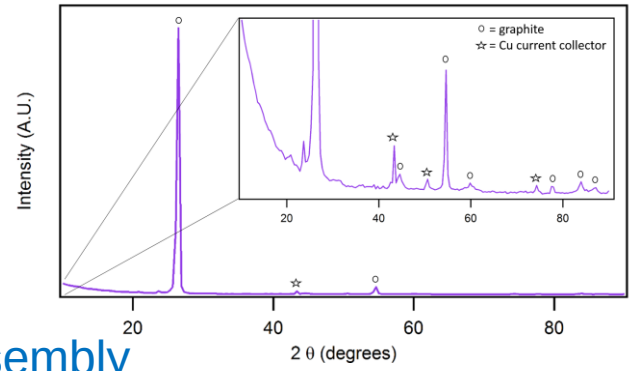
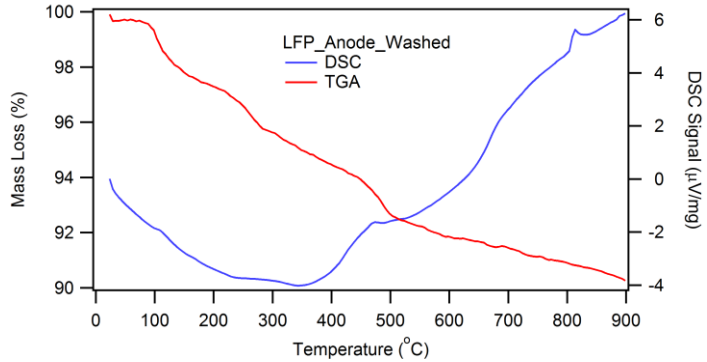


Graphite anode

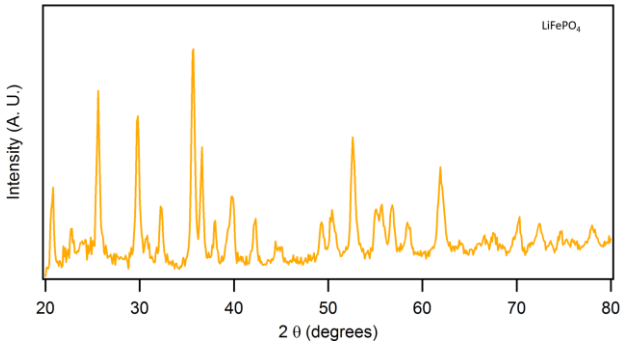


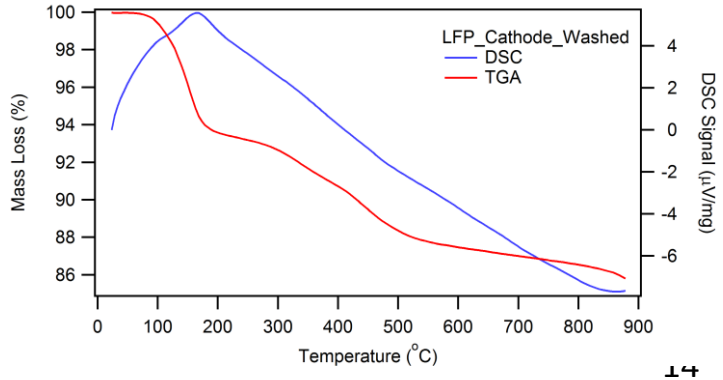
Disassembly





$LiFePO_4$ cathode





Non-Abuse 18650 Cell Performance Testing

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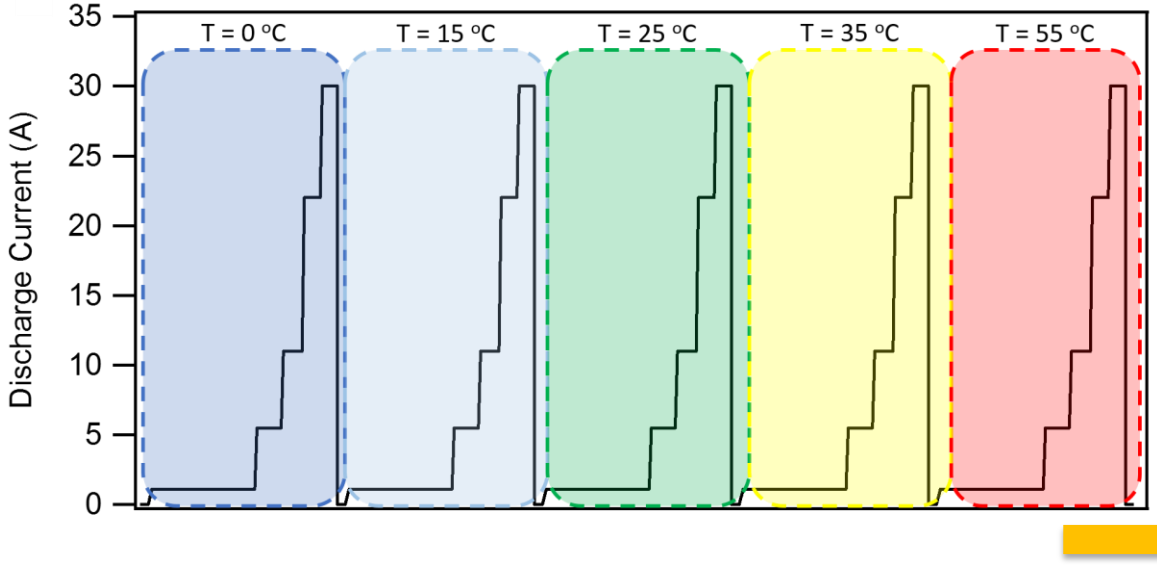

Continue into 'abuse'

Plan: Complete testing as far as possible in 'non-abuse' conditions for other chemistries and chamber temperatures.

Abuse 18650 Cell Performance Testing:

Repeat test plan allowing 'abuse' temperatures – how do cells respond? Do they fail? What is the impact on performance?

Thermal Runaway and Suppression

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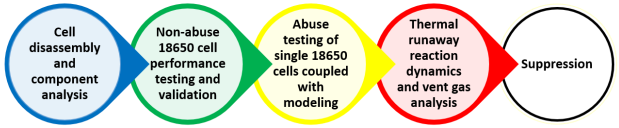

Thermal Runaway Plan:

- Couple material instability data with cell failure to understand electrode decomposition mechanisms.
- Estimate vent gas composition per decomposition mechanism.
- Understand how cell chemistry affects cell failure.
- Feed this information into models of cell failure and propagation.

Suppression Plan:

- Use modeling results to plan suppression testing.
- Build a gas/flame model system representing thermal runaway to test suppressants more reliably.
- Test available suppressants on thermal runaway of 18650 cells.

Summary

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- Provide metrics for evaluation performance, reliability and safety of ESS
- Assess performance, reliability and safety of ESS
- Testing failure propagation to understanding vulnerabilities
- Integrated R&D will assess failure behavior and consequences using **experimental** and **modeling** efforts across scale.
- Research informed by materials understanding is critical to
  - **Containment** of storage across scales and chemistries
  - Effective **suppressants** identification and use

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