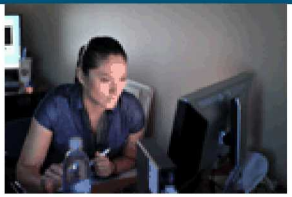
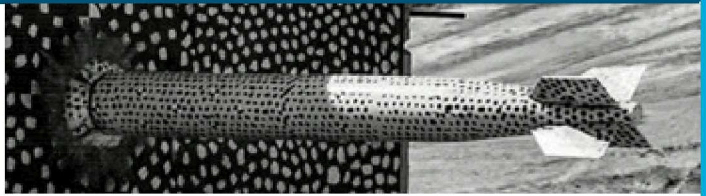
SAND2018-5763C

Abuse Testing to Understand High Energy Battery Failure





PRESENTED BY

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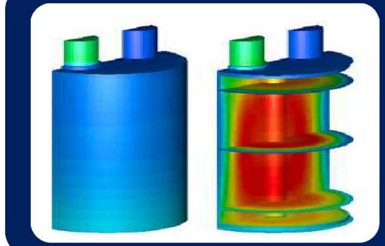
Science and Diagnostics of Battery Failure

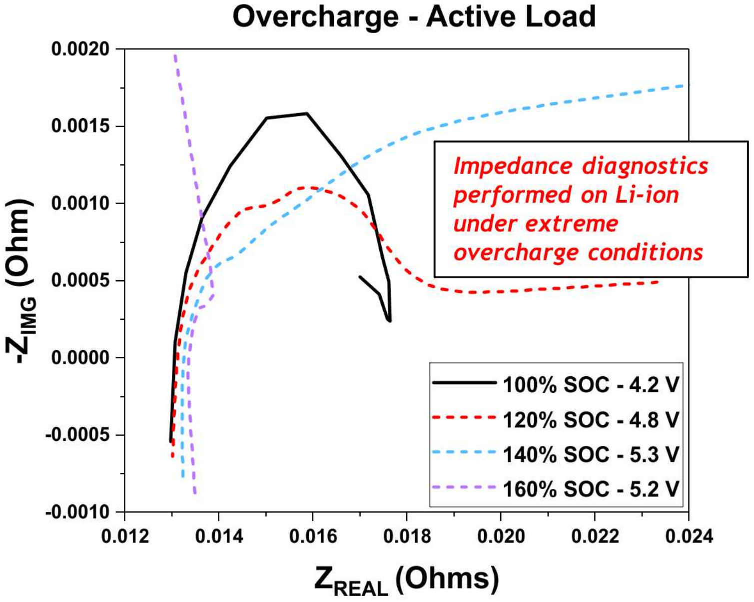
Materials R&D
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials
- Battery failure post mortem materials analysis

Testing
- Diagnostics during battery failure (pictured right)
- Gas analysis
- Battery calorimetry, including during failure
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Large scale thermal and fire testing (TTC)



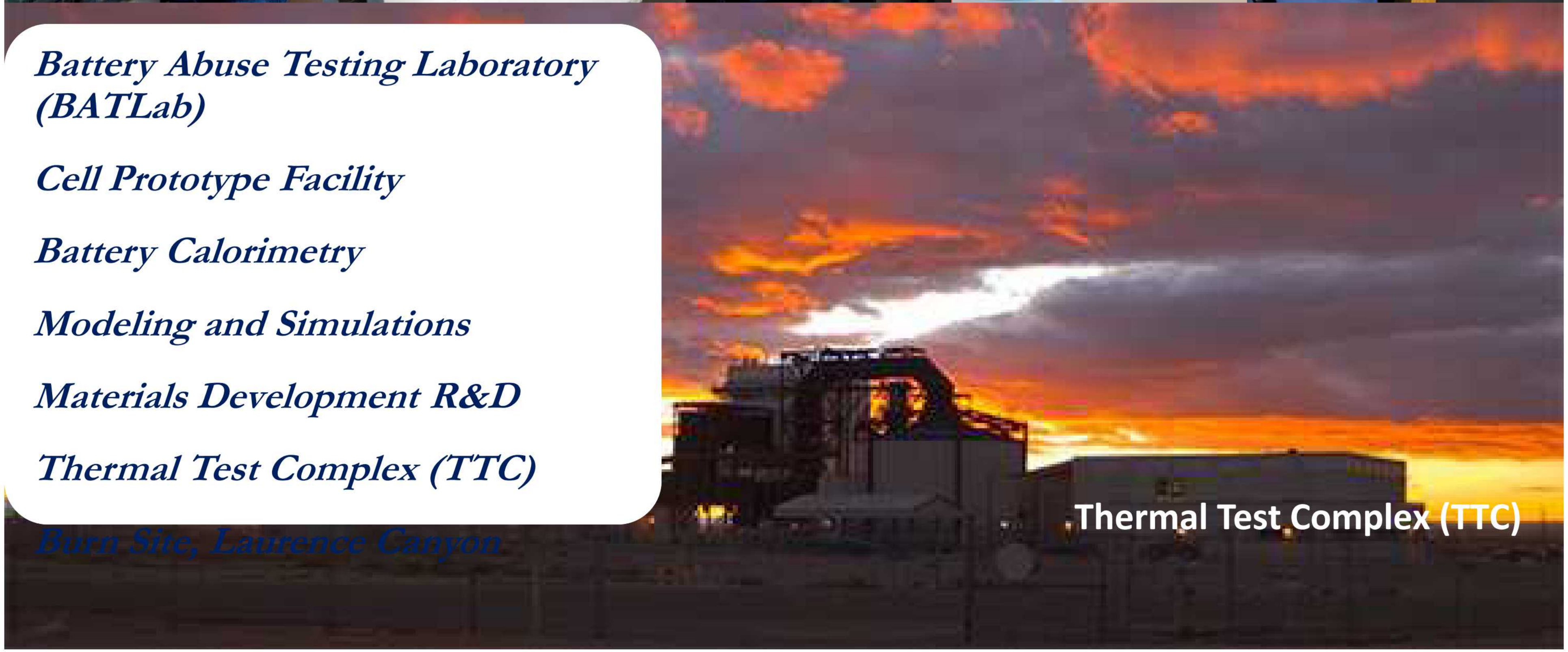
Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating vehicle crash and failure propagation models
- Fire Simulations to predict the size, scope, and consequences of battery fires

Procedure Development and Stakeholder Interface
- USABC Abuse Testing Manual (SAND 2005-3123)
- OE Energy Storage Safety Roadmap
- R&D programs with NHTSA/DOT to inform best practices, policies, and requirements
- Hosted International Battery Safety Workshops and Energy Storage Safety Workshop



- Sandia is uniquely positioned to study the entire life cycle of a technology, from science based development, to prototyping, to lifetime reliability and destructive testing
- New technologies present new risks. A high rigor environment at Sandia allows those risks to be adequately managed.
- Diagnostic tests can be performed under extreme failure conditions to understand the *how* and *why* of battery failure, as well as the consequences of energetic failures.

Capabilities and Infrastructure



Battery Abuse Testing Laboratory (BATLab)

Cell Prototype Facility

Battery Calorimetry

Modeling and Simulations

Materials Development R&D

Thermal Test Complex (TTC)

Burn Site, Laurence Canyon

Battery Abuse Testing Laboratory (BATLab)

Comprehensive abuse testing platforms for safety and reliability of cells, batteries and systems from mWh to kWh

Cell, module, and battery system hardware deliverables for testing

Mechanical abuse

- Penetration
- Crush
- Impact
- Immersion

Thermal abuse

- Over temperature
- Flammability measurements
- Thermal propagation
- Calorimetry

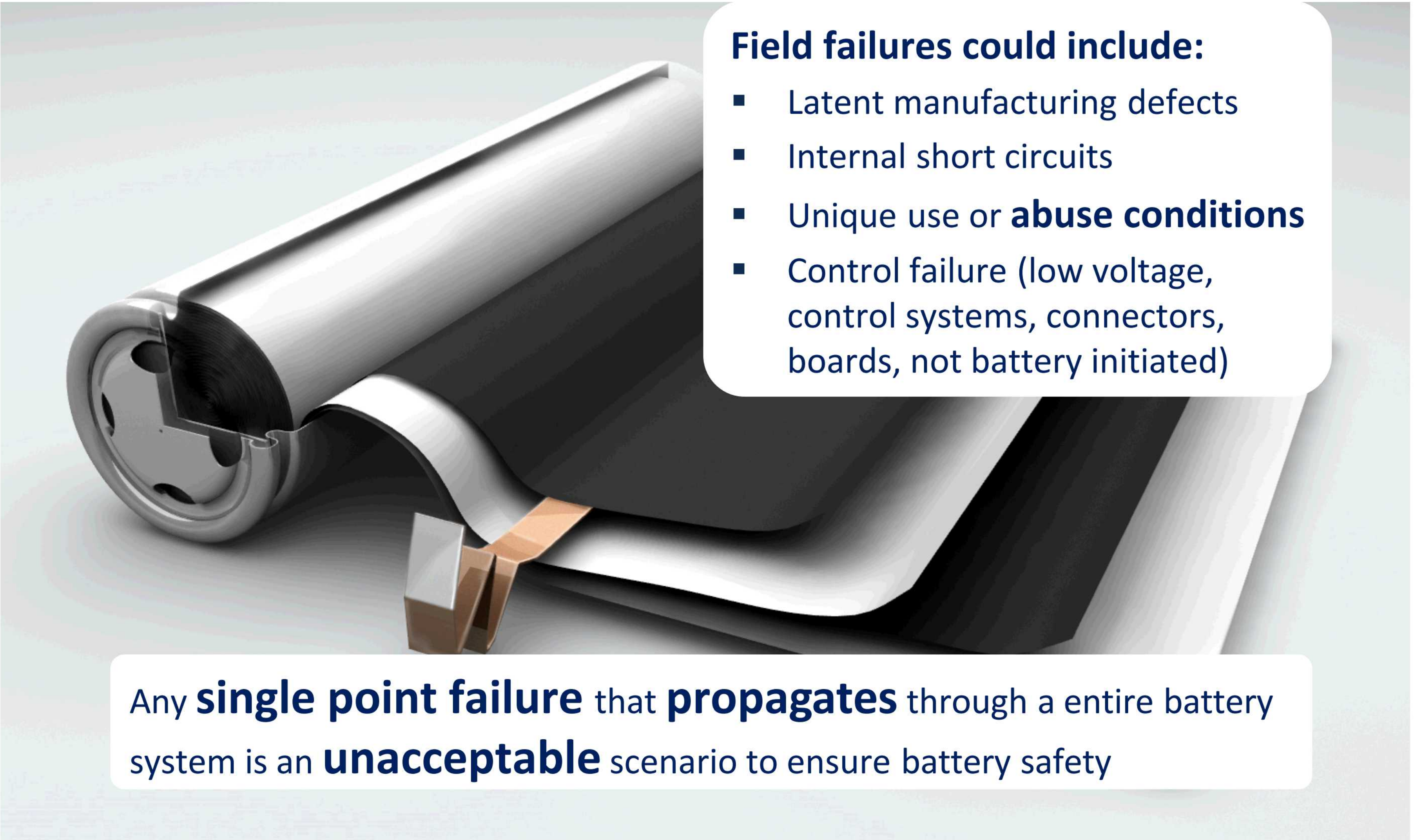
Electrical abuse

- Overvoltage/overcharge
- Short circuit
- Overdischarge/voltage reversal

Burn Site

Full Scale Battery Testing Facilities

Battery System Field Failures

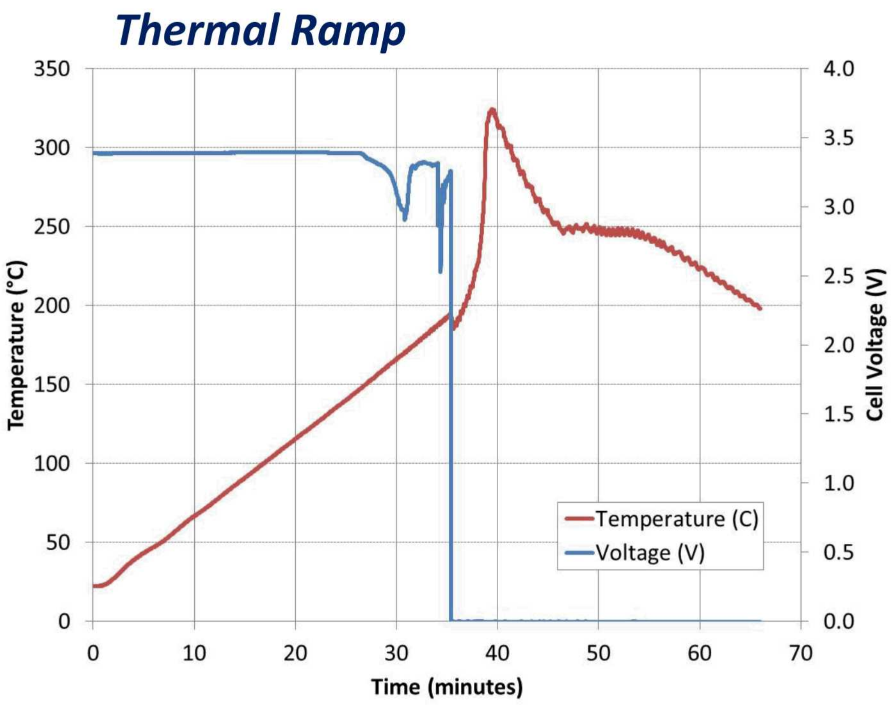


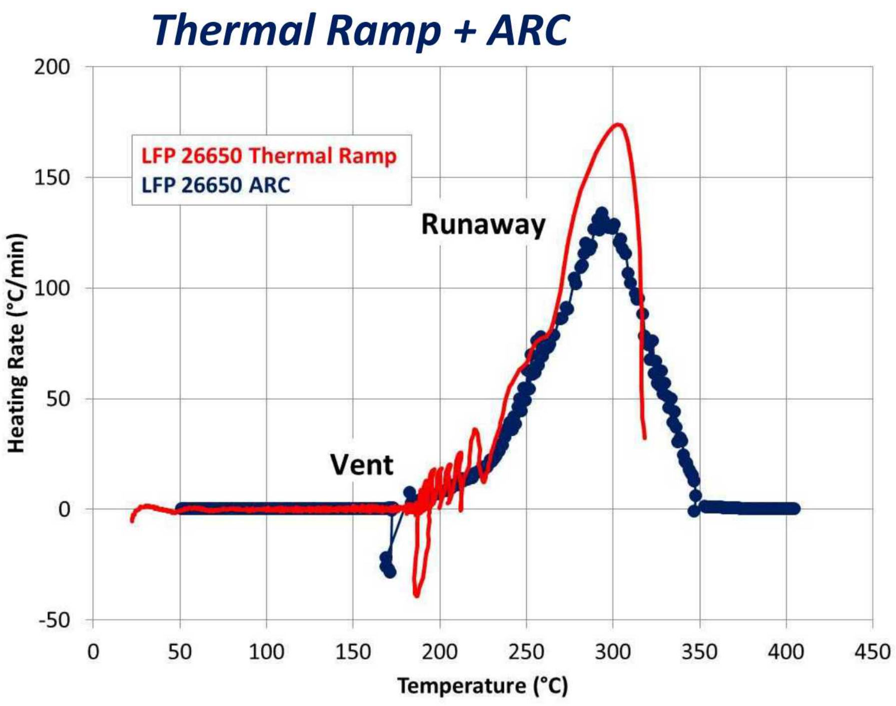
Field failures could include:

- Latent manufacturing defects
- Internal short circuits
- Unique use or **abuse conditions**
- Control failure (low voltage, control systems, connectors, boards, not battery initiated)

Any **single point failure** that **propagates** through a entire battery system is an **unacceptable** scenario to ensure battery safety

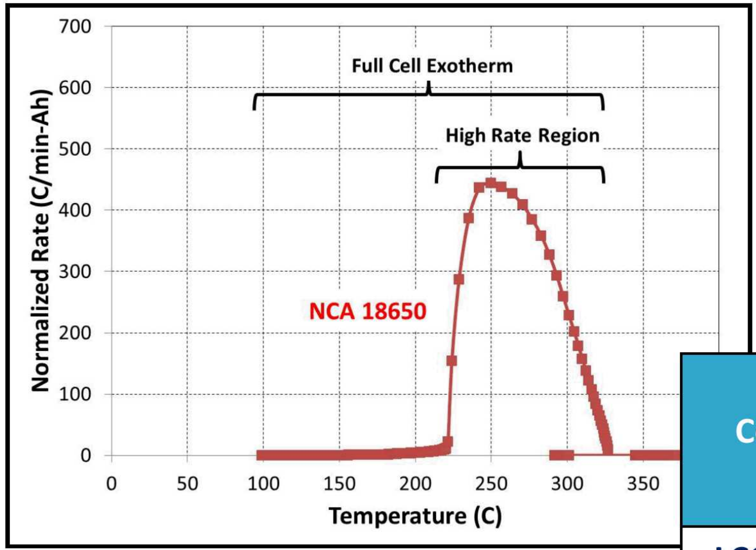
Characterizing Thermal Runaway





- ***Consistent cell behavior between thermal abuse and calorimetry experiments***
- ***Greater total temperature rise observed for the ARC experiment because it is in an adiabatic environment***
- ***May be able to use these data to compare results obtained between the two types of experiments***

Characterizing Thermal Runaway

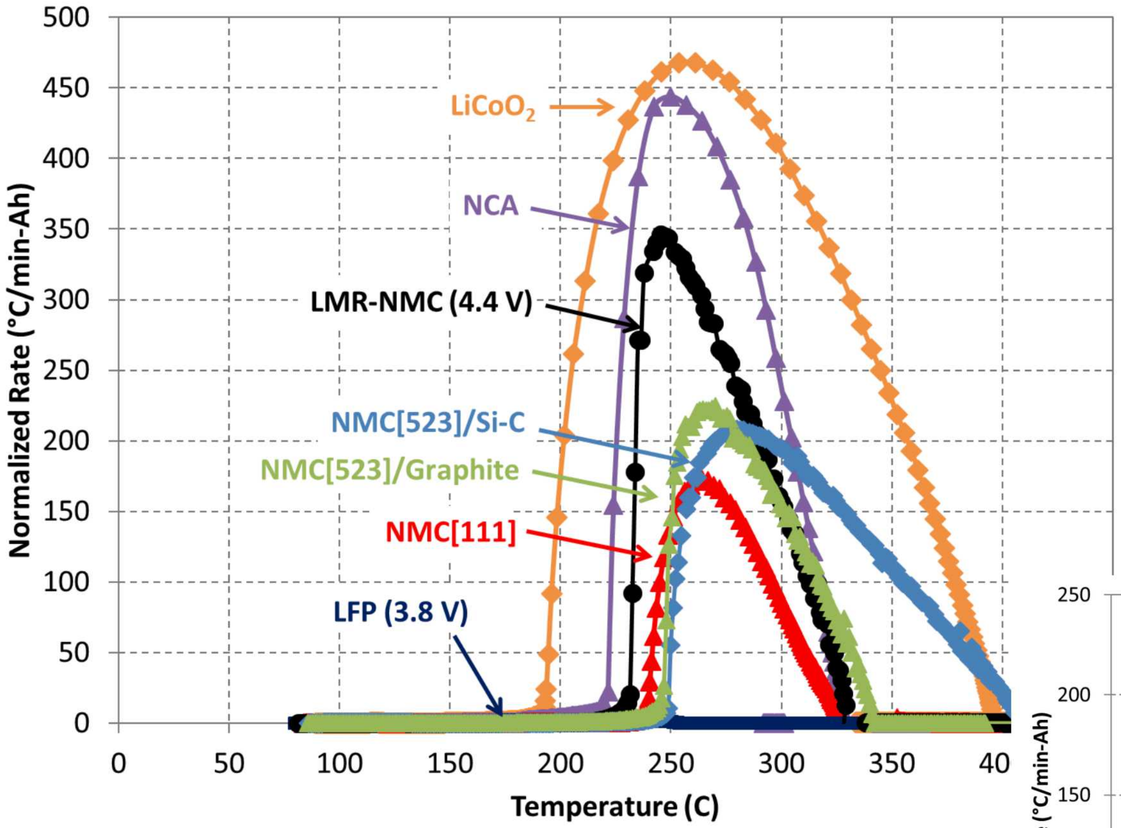


- ***Full cell runaway enthalpy shows a significant amount of heat generation from even an LFP 18650 cell***
- ***But that heat is generated at much different rates for the different cell types***

Cell Type	Capacity (Ah)	Runaway Enthalpy (kJ/Ah)		Peak Heating Rate (W/Ah)
		Full Cell	High Rate Region	
LCO 18650*	1.2	28.4	15.9	281
NCA 18650*	1.0	21.6	9.8	266
NMC 18650*	0.95	22.0	8.3	105
LFP 18650*	0.9	18.0	2.4	1
LFP 26650*	2.6	8.2	4.6	65
LFP 26650‡	2.6	8.0	4.5	65
*ΔH based on dT (exotherm) ‡ΔH based on dT/dt (exotherm)				

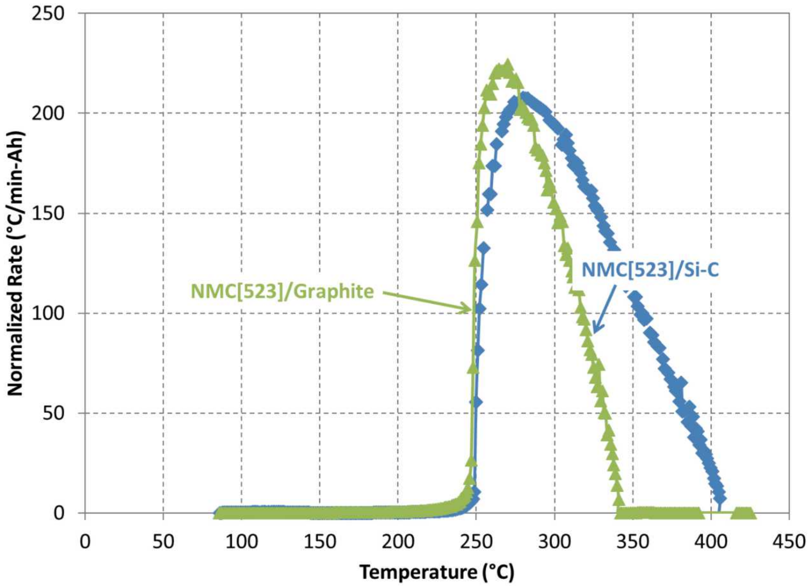
Data provide a quantitative measurement of the runaway enthalpy

Characterizing new materials



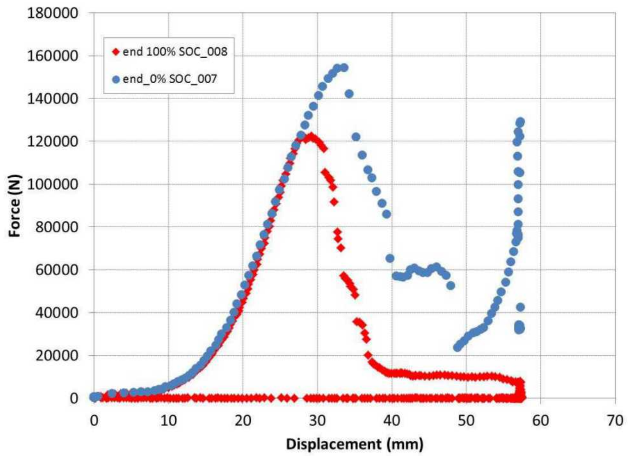
- *Accelerating rate calorimetry shows the behavior of various chemistries*
- *This gives information about peak heating rates and total energy of the thermal runaway*
- *Newer materials such as LFP provide significantly reduced thermal runaway intensities, but have limited energy density*

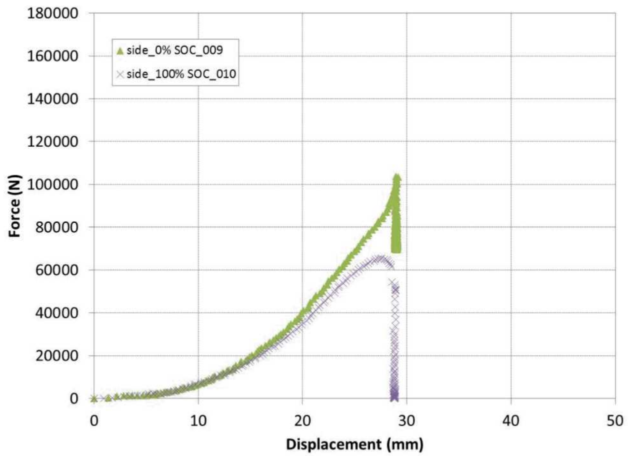
- *New materials can behave in different ways*
- *10-15% Si present in the anode leads to increased runaway energies for a similar cathode material.*



Mechanical Failure Testing

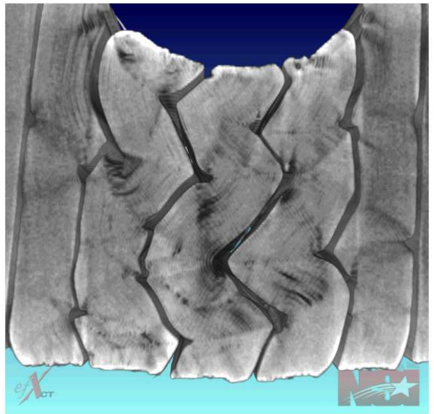
Mechanical behavior under compression

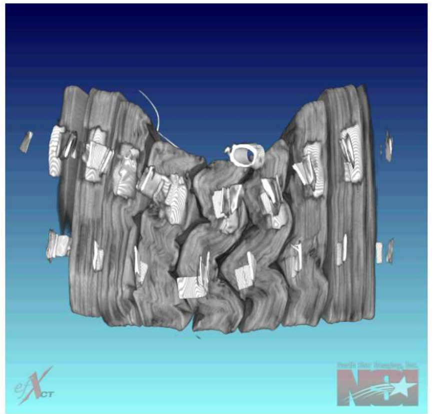




Analog "pole test" of a battery

CT analysis to study structural failure modes



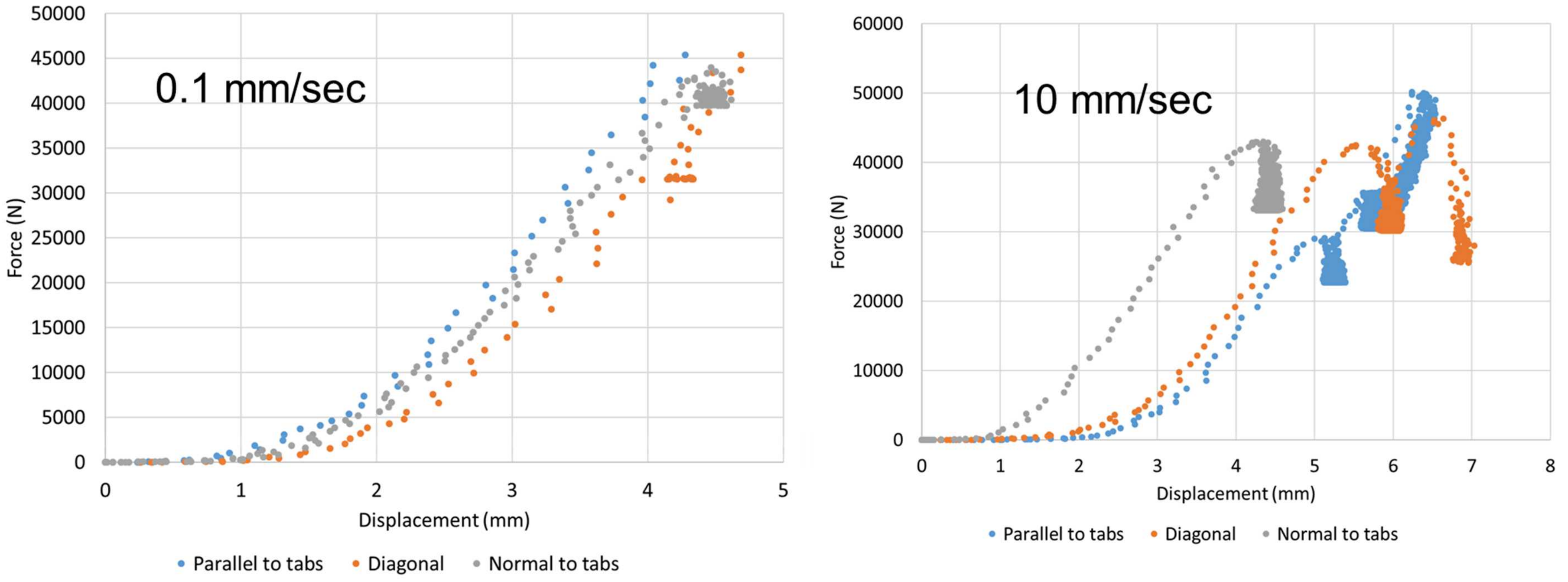


Determining baseline mechanical behavior of batteries during crush/impact testing
Testing support to validate mechanical models for batteries during a crash scenario

Mechanical property determination

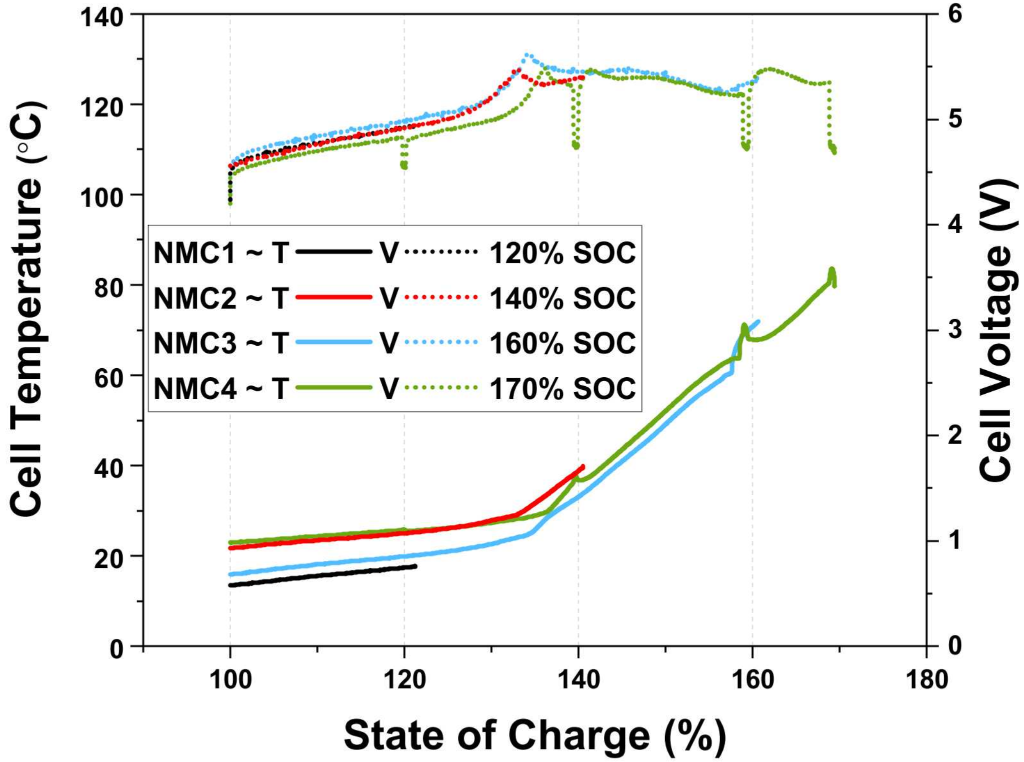
Crush testing and dynamic drop tower /impact tester development

Comparison of orientations



- Variation observed at higher rates – lower rates show little meaningful difference
- At higher rates some differences in both low rate data, some evidence of fracturing was observed in two of the three cases

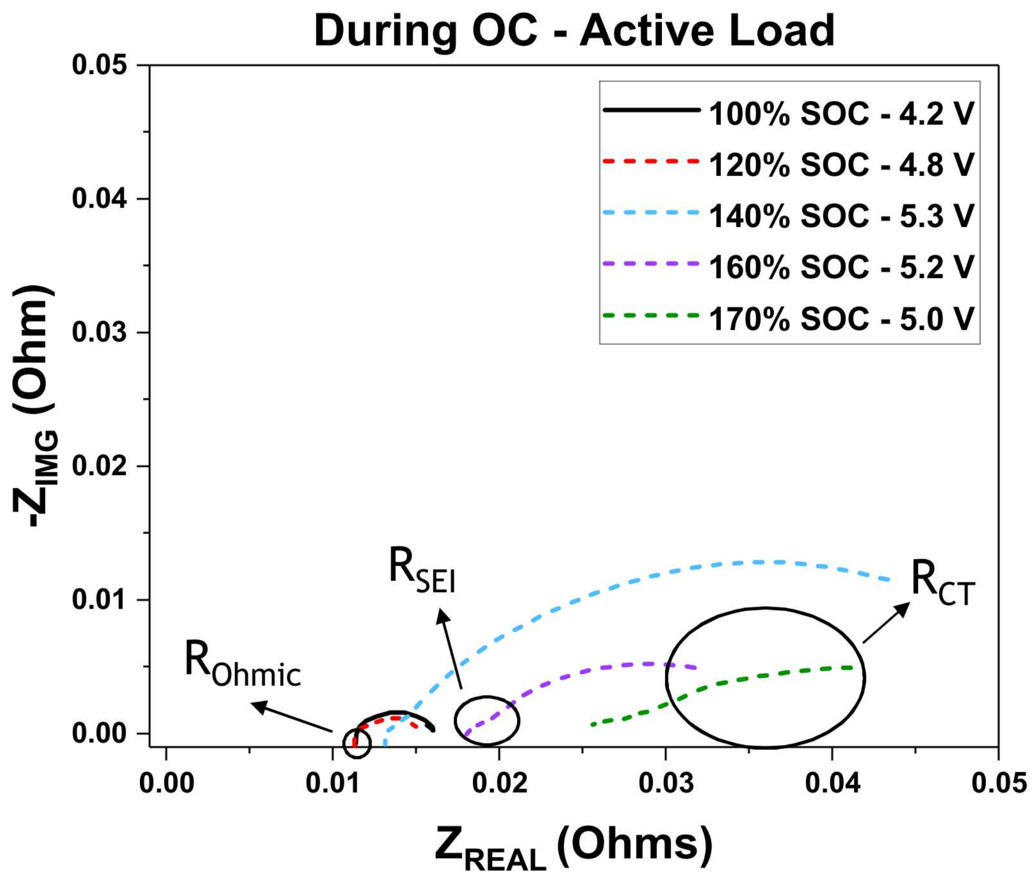
Overcharge Effects to Cell Temperature and Voltage

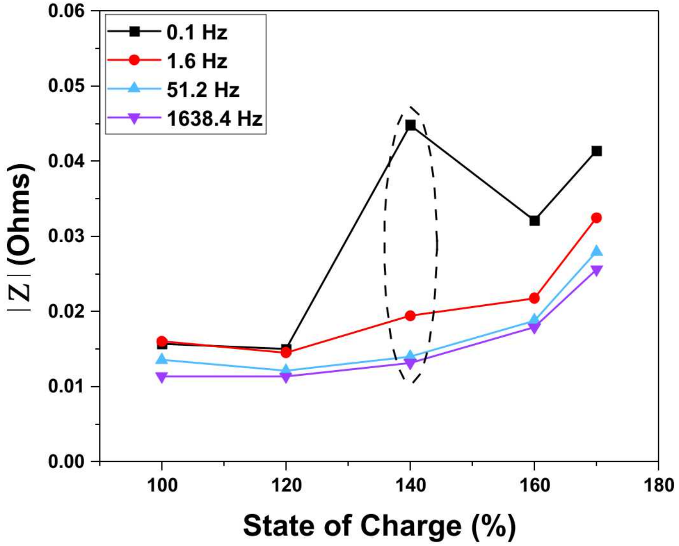


Four individual cells, NMC1, NMC2, NMC3 and NMC4, were overcharged to 120%, 140%, 160%, and 170% SOC, respectively.

	Initial T (°C)	Max. T (°C)	ΔT (°C)
NMC1-120%	13.5	17.7	4.2
NMC2-140%	21.7	39.8	18.1
NMC3-160%	15.9	71.9	56.0
NMC4-170%	23.0	83.5	60.5

Diagnostics – In-operando EIS of overcharged cell

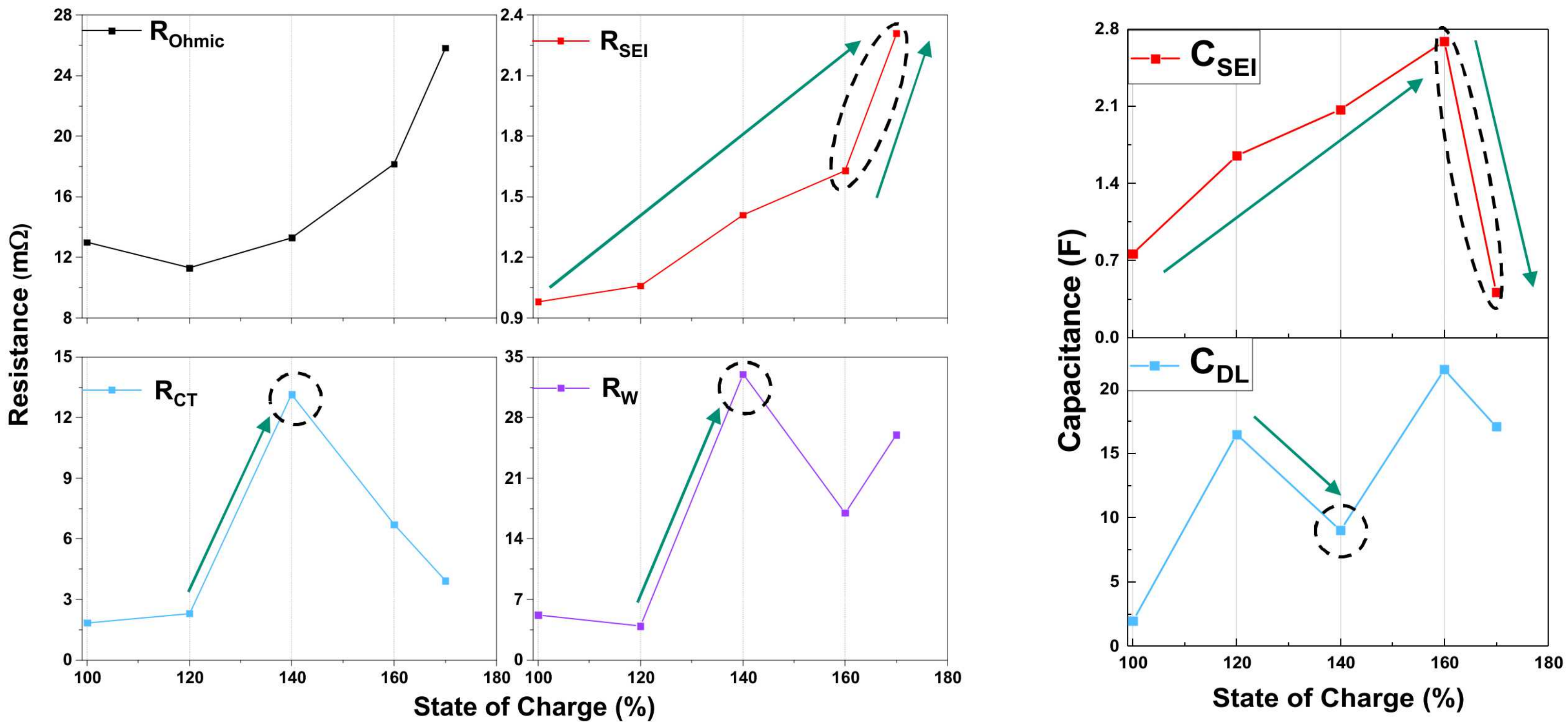


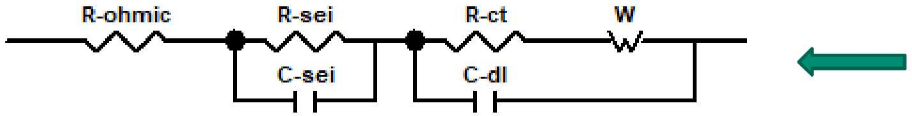


$$|Z| = \sqrt{Z_{REAL}^2 + Z_{IMG}^2}$$

- The R_{ohmic} increased for higher states of charge above 120% SOC. The change is associated with conductivity loss within the cell components.

Diagnostics – In-operando EIS of overcharged cell

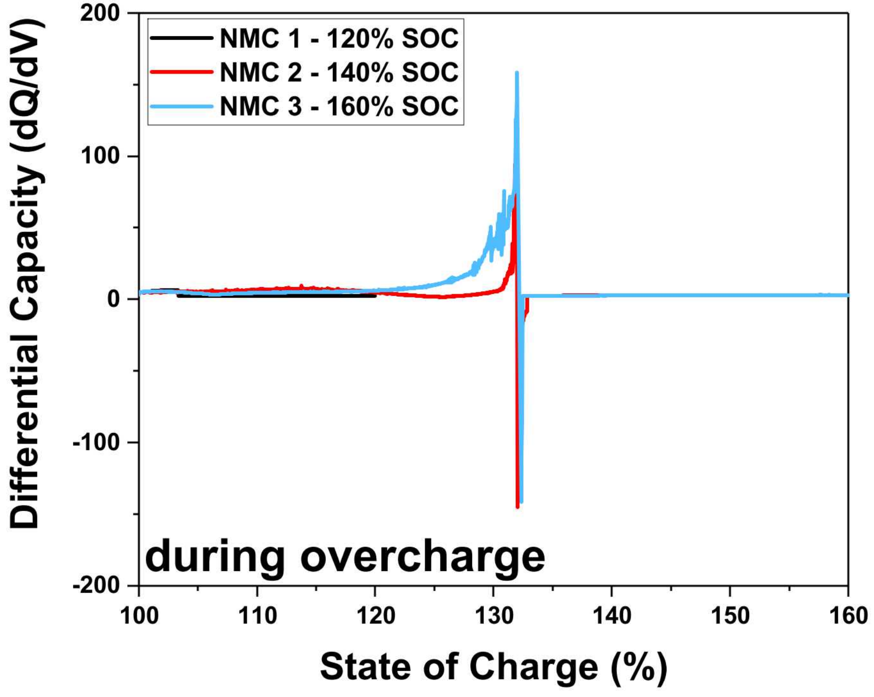


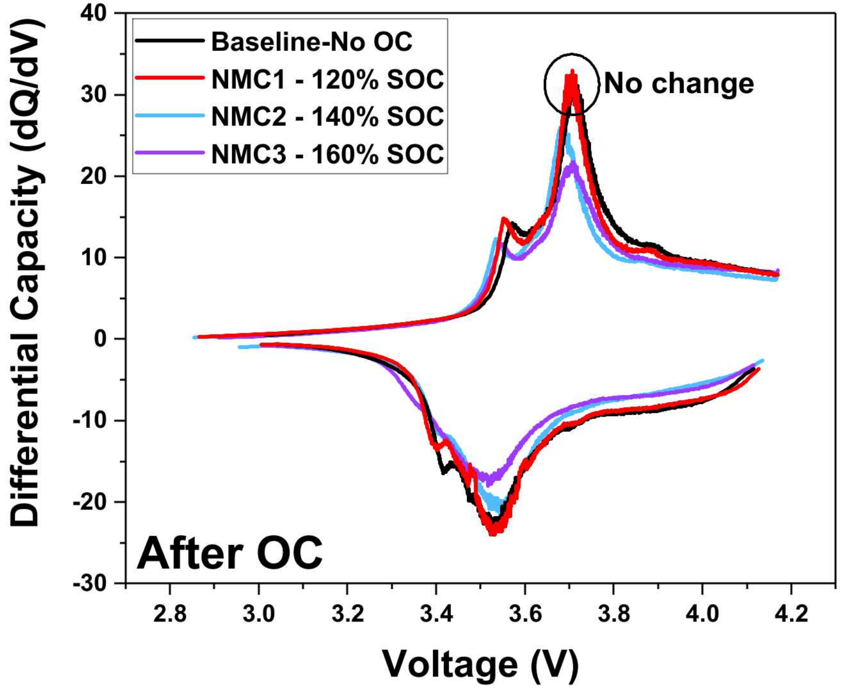


Equivalent Circuit

- The R_{SEI} slightly increased after each level of overcharge as well as the C_{SEI}, which could indicate a growth in the SEI layer.
- The R_{CT} significantly increased after 140% SOC and subsequently decreased for high SOC's.

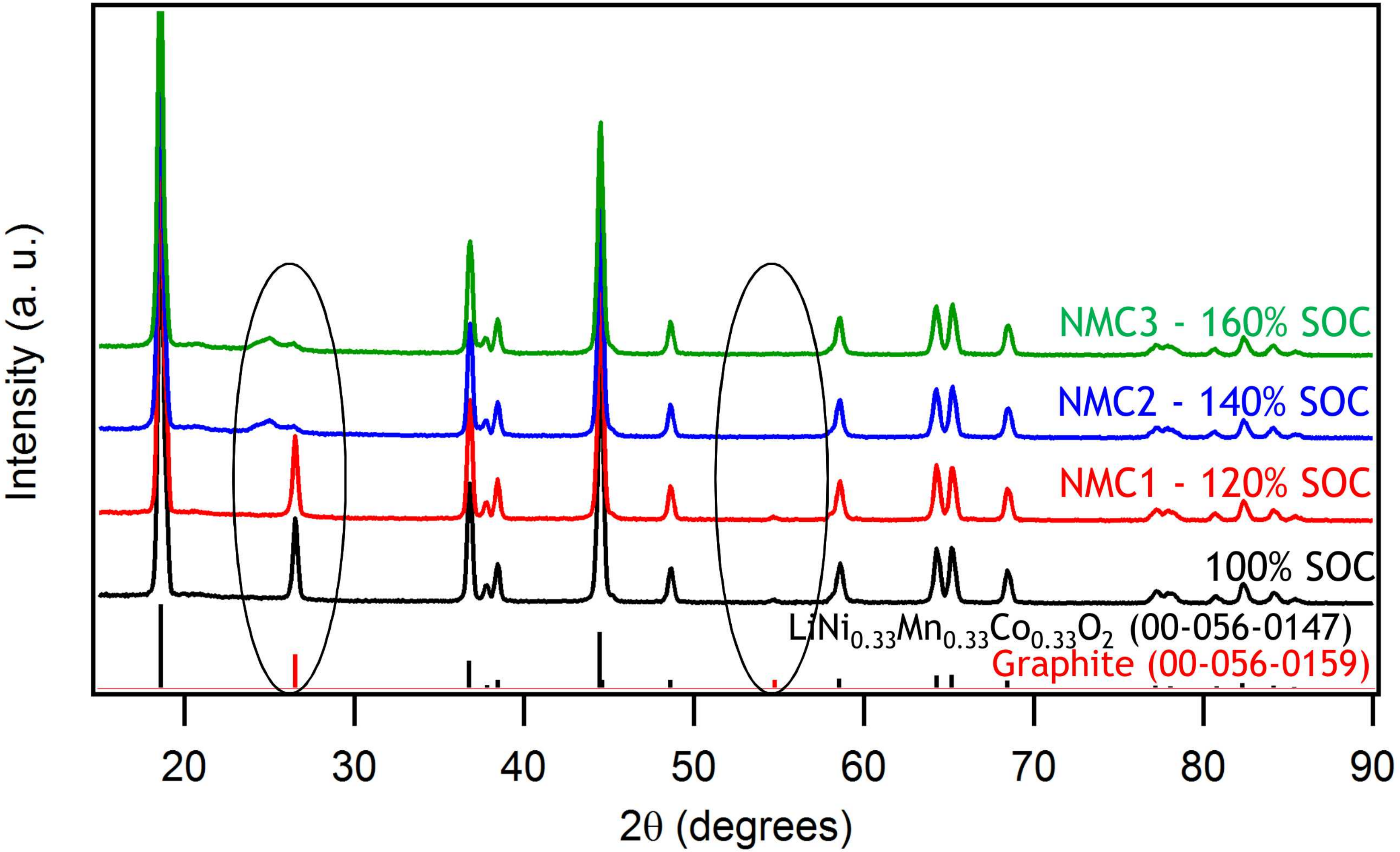
Differential Capacity





- The differential capacity calculated during the overcharge procedure identified a redox reaction between 130-135% SOC.
- The calculations after the abused conditions were applied indicated that 120% SOC caused little no effect to the redox processes.

XRD cathode

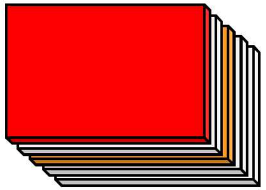


XRD diffractograms showed major changes after 120% SOC.

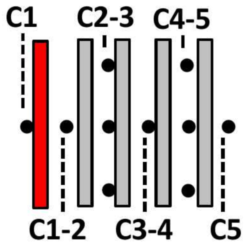
Failure Propagation Testing

Failures initiated by mechanical insult to edge cell of COTS $LiCoO_2$ packs (3Ah cells)

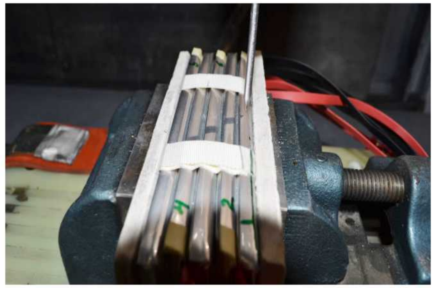
5 cell Battery

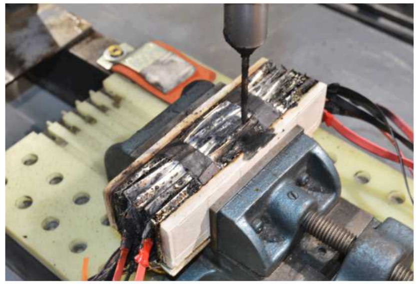


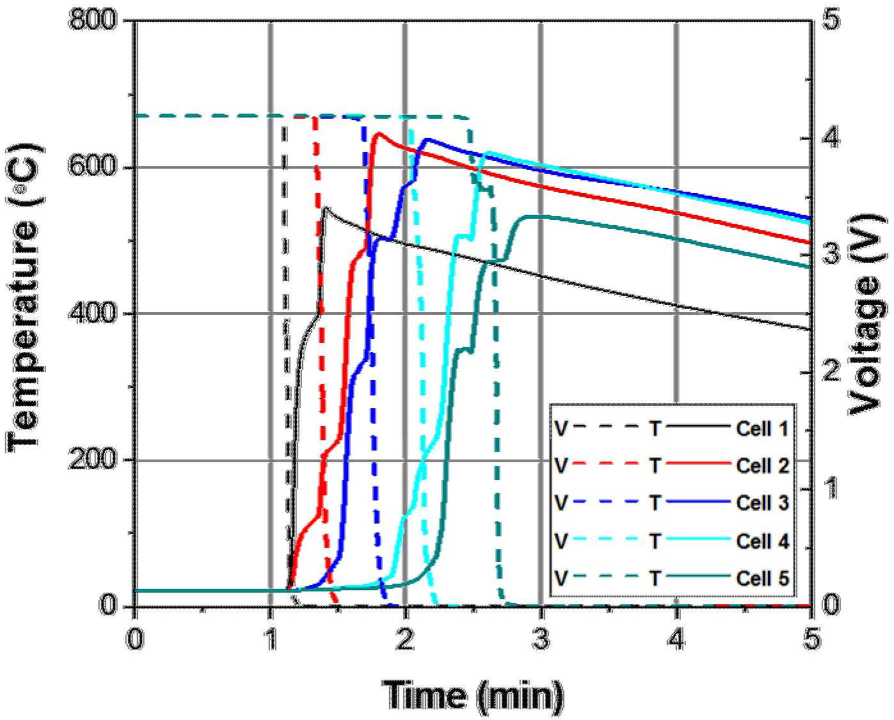
TC layout



- Successful initiation at Cell #1
- Propagation to adjacent cells
- Cascading failure to entire battery over 60 s



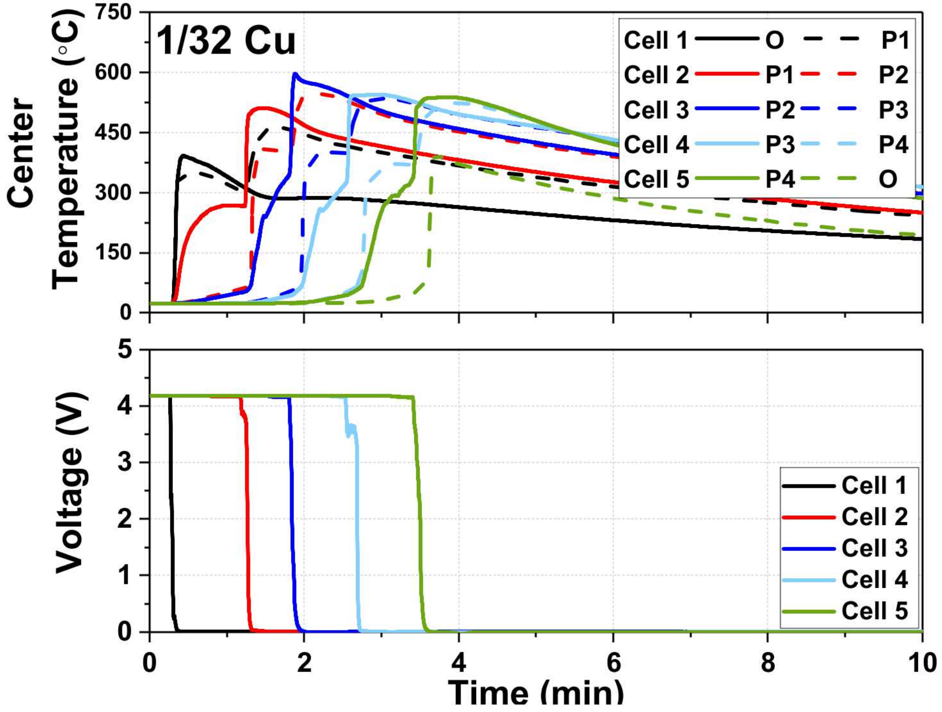


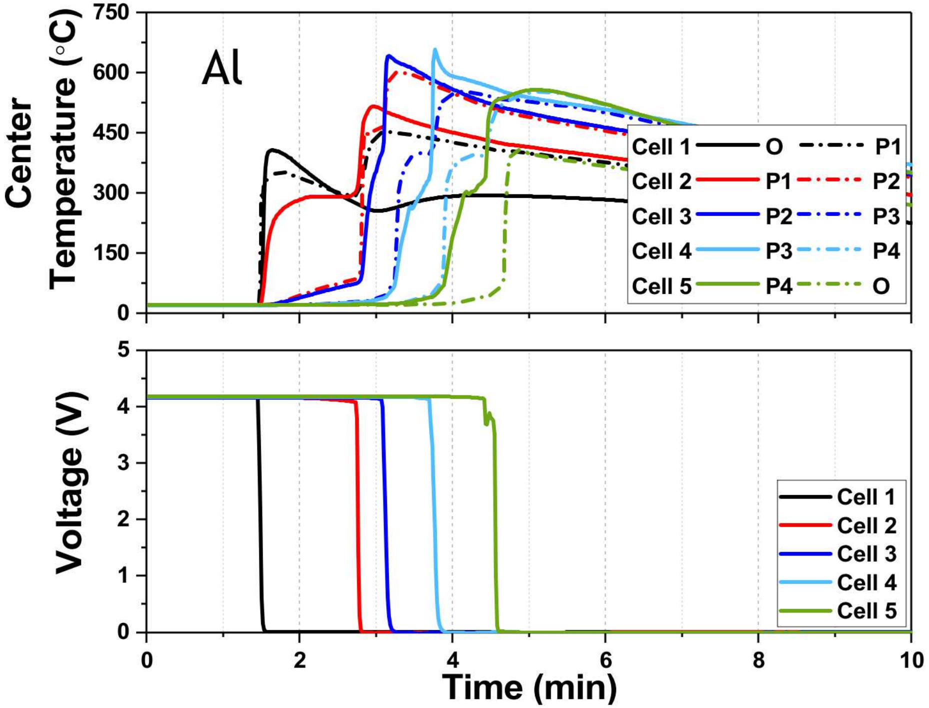


Observed complete propagation when cell are close packed with no thermal management

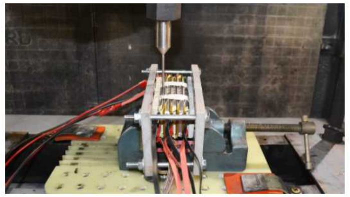
Failure propagation –passive mitigation

1/32" thick spacers



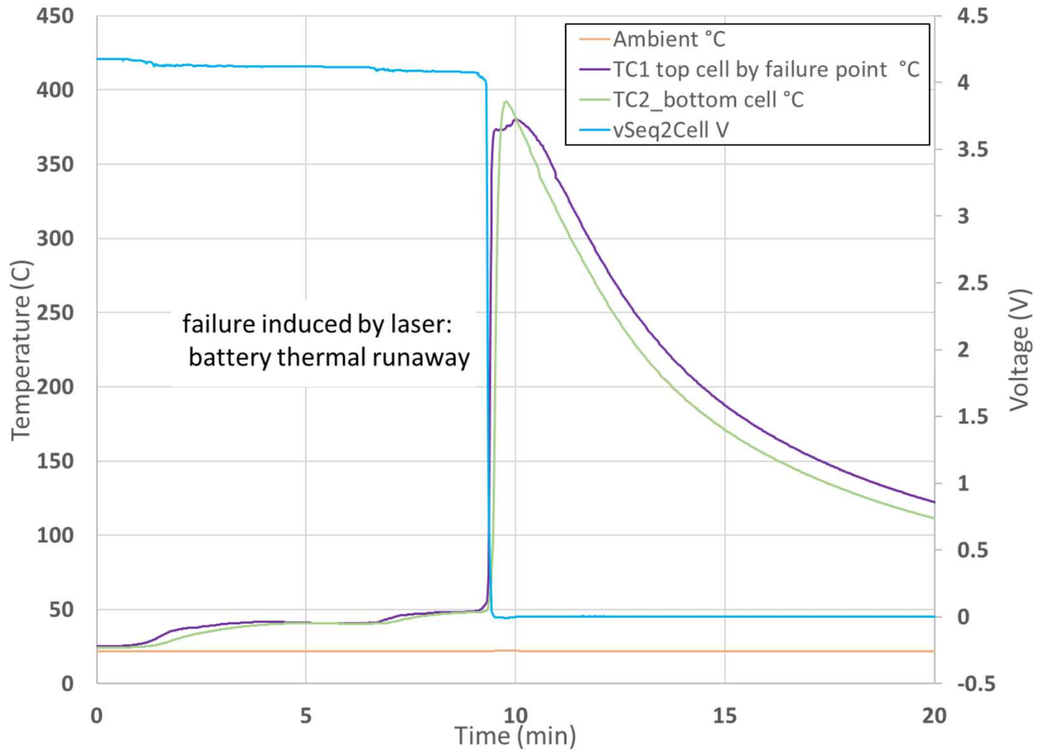


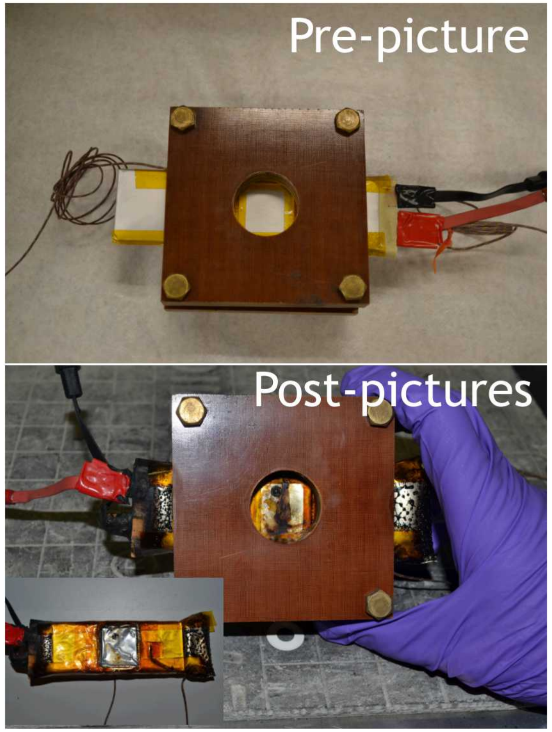
- *Spacers 1/32" thick*
- *Failure of Cell 1 observed initially*
- *Pulsing propagating failure behavior observed over the next several minutes*
- *Entire pack consumed ~4 minutes after initial cell failure*
- *Similar behavior when using both aluminum and copper spacers*



New Test Development

In hopes to reduce the oxygen exposure to hole being produced from laser, an IR transparent slide was used as barrier during testing





- Able to induce failure using laser through silica slide
- Final power setting of 350V, 20ms, 1Hz to induce thermal runaway
    - More energy needed to induce runaway through silica slide
- Maintained seal between silica and pouch cell until full runaway

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