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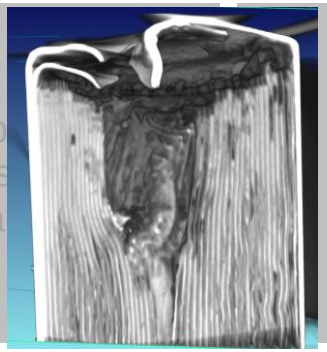

Total Stored Energy and its Impact on Thermal Runaway

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

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Approach and Capabilities

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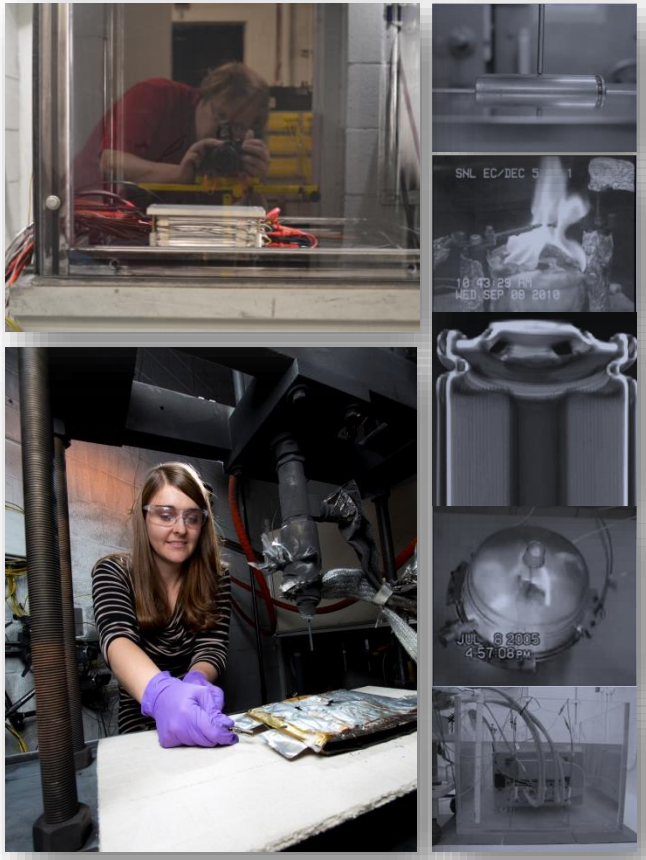
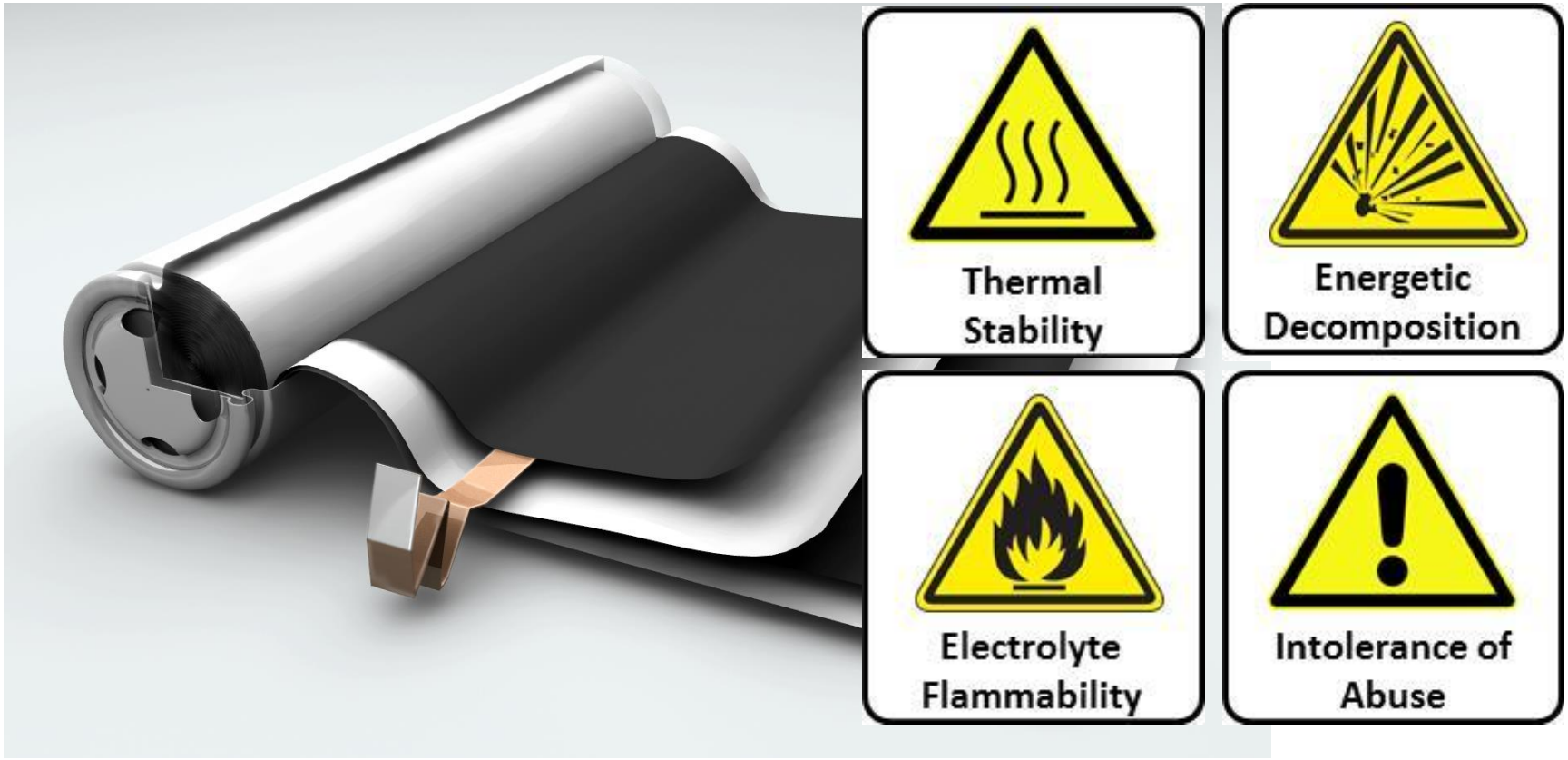
Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)



Battery Pack/System Testing
Thermal Test Complex (TTC) and Burnsite

Battery Calorimetry

Lithium-ion Safety Issues



Testing program aimed at understanding and improving abuse tolerance of energy storage systems

Calorimetry of Lithium-ion Cells

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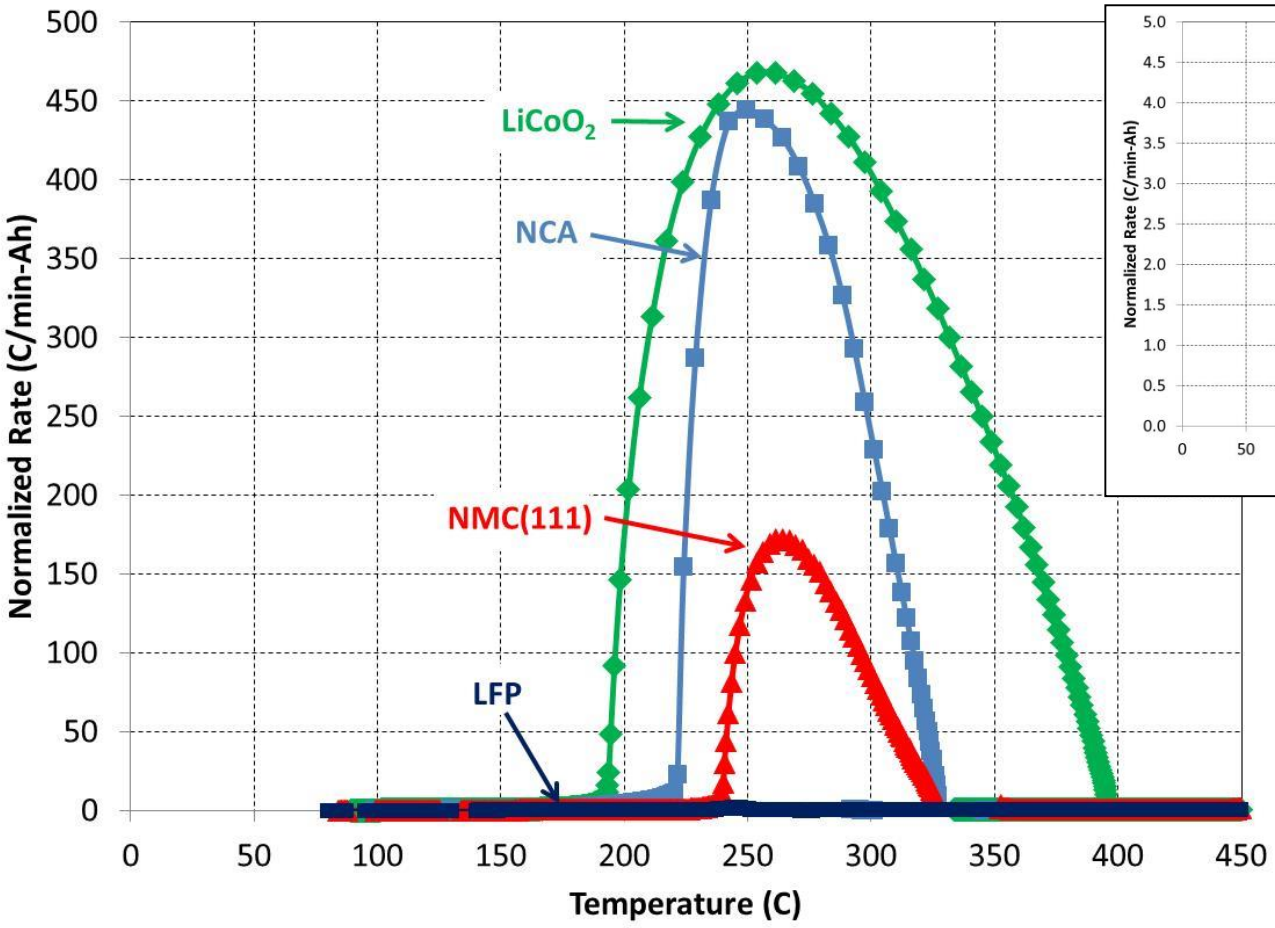
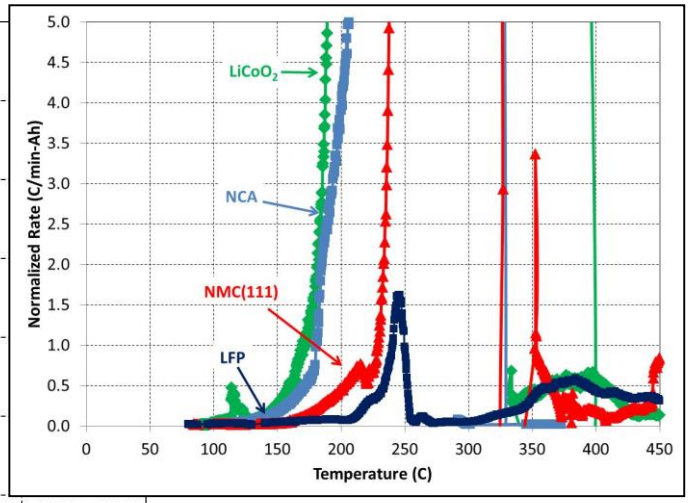
Accelerating rate calorimetry (ARC) of 18650 cells with different cathode materials

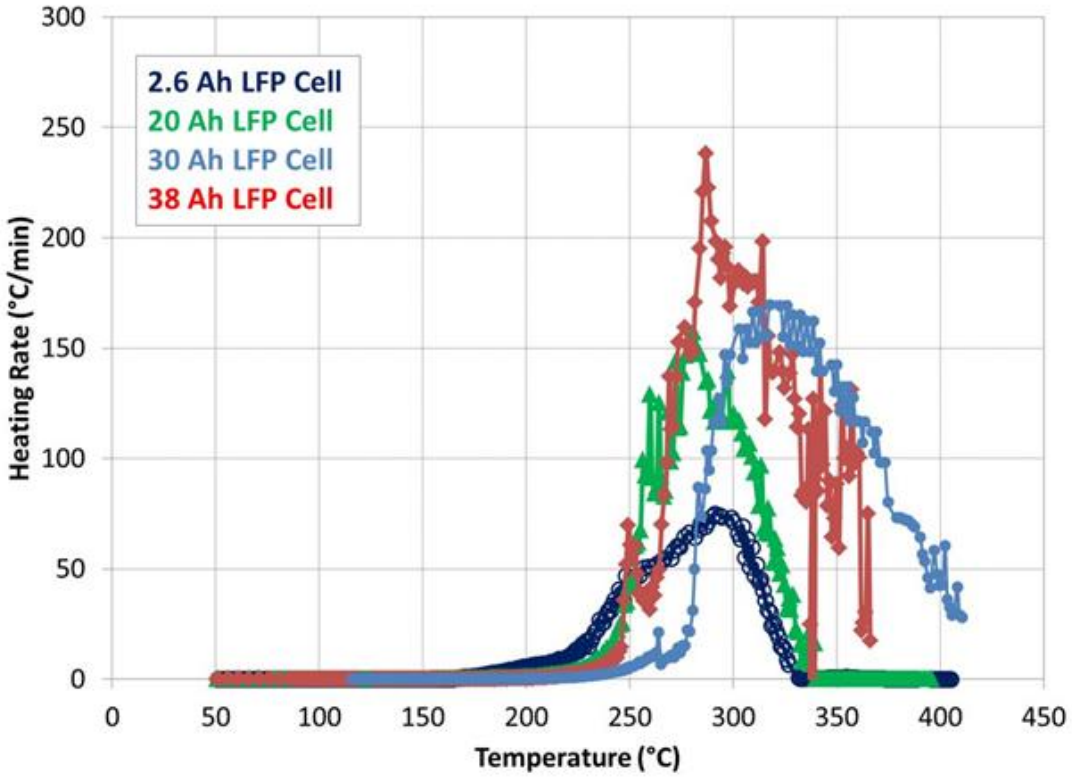




High Rate Runaway	
Cathode	$\Delta H_{runaway}$ (kJ/Ah)
$LiCoO_2$	15.9
NCA	9.8
NMC111	8.3
LFP	2.4

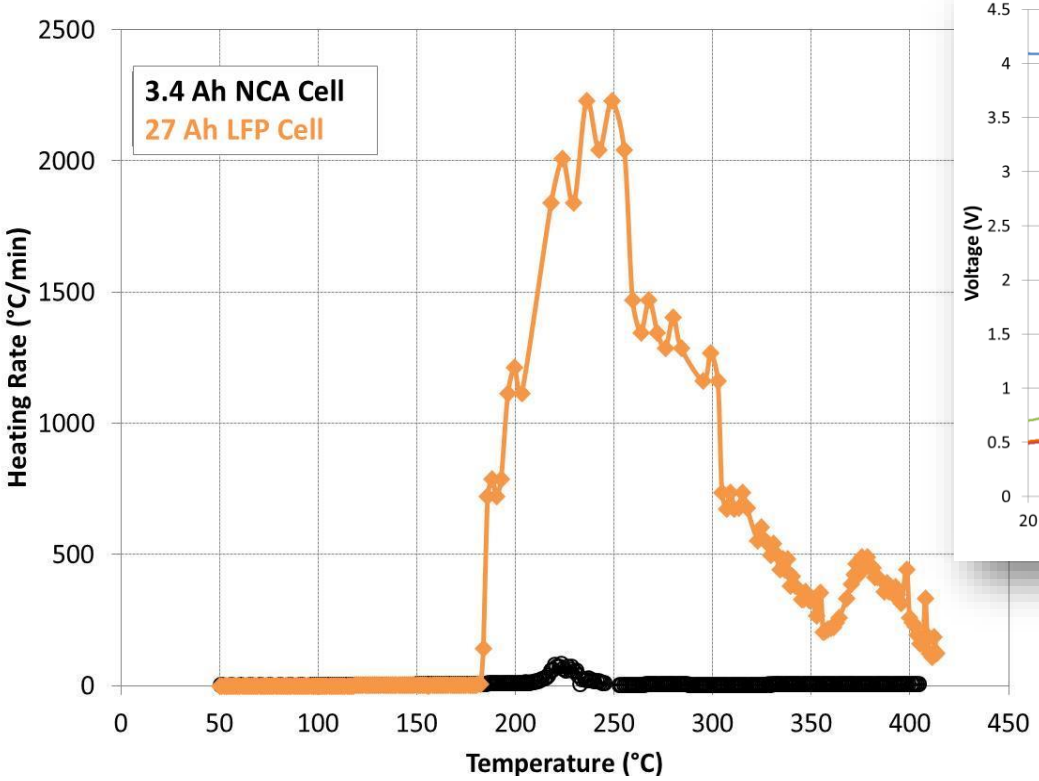
- Develop an understanding of how the runaway response scales with cell size.
- Traditionally testing performed at 100% SOC; how does this change at lower SOC?

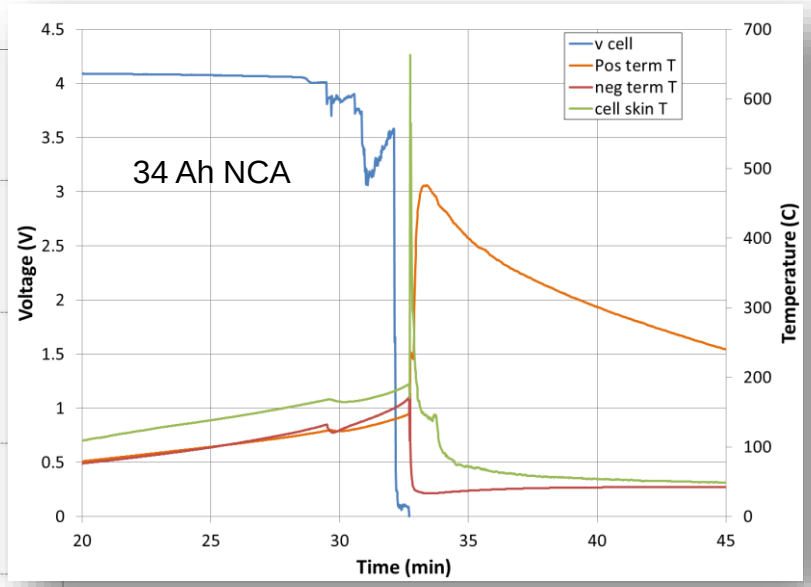
Impact of capacity - LFP



- ARC testing on LFP cells ranging from 2.6 to 38 Ah
- Rates increase somewhat with cell size
- Largest increase in peak heating rates observed when going from 2.6 to 20 Ah; Little change observed when increasing from 30 to 38 Ah

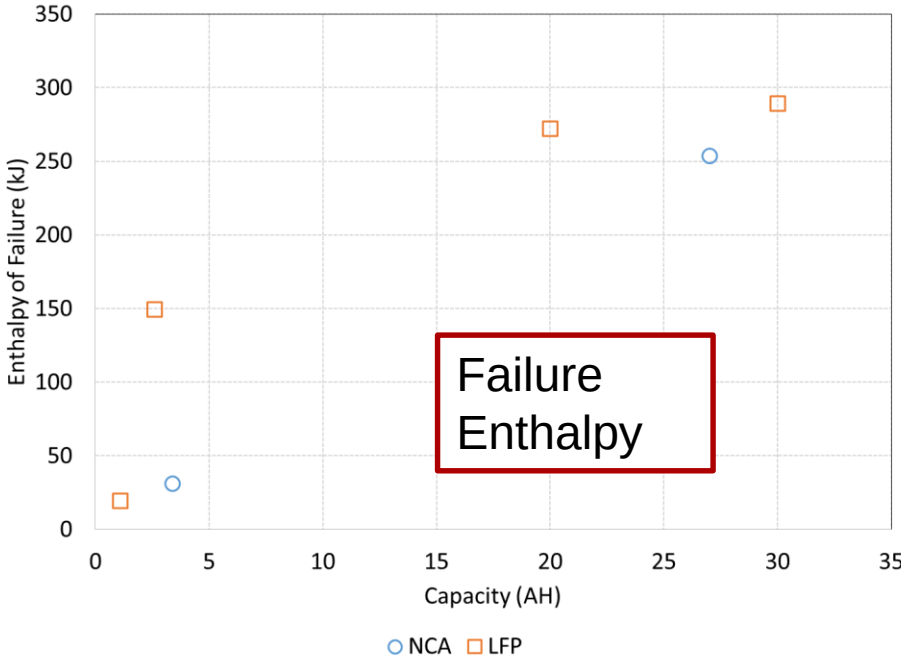
Impact of capacity - NCA

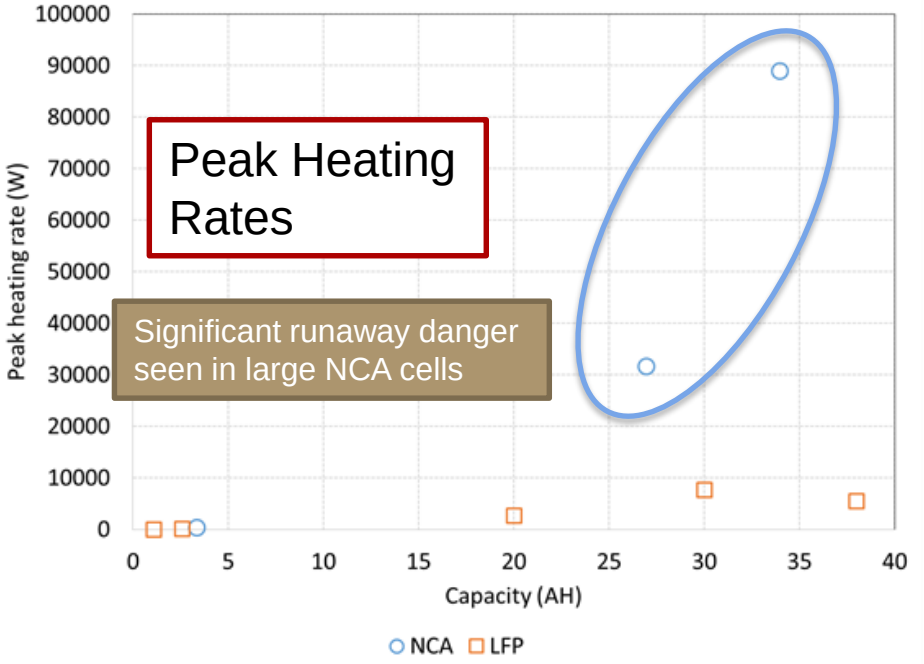




- **ARC Testing on 3.4 and 27 Ah NCA cells; larger capacity NCA cells not tested in ARC due to very high peak heating rates. 34 Ah heating rates estimated from thermal ramp test shown on right**
- **Very high peak heating rates are observed in the larger two cells**

Comparison of Chemistry and Size

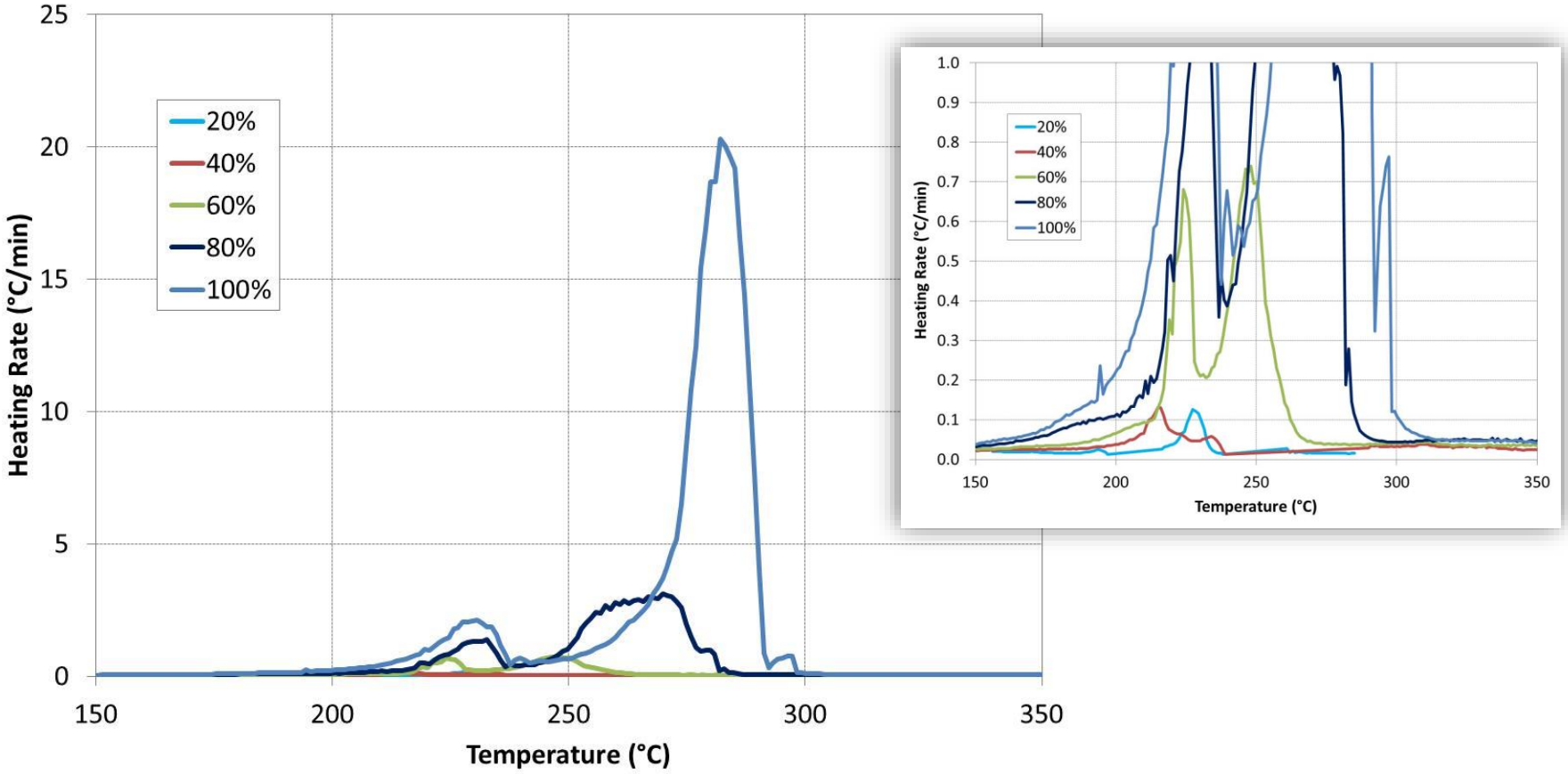




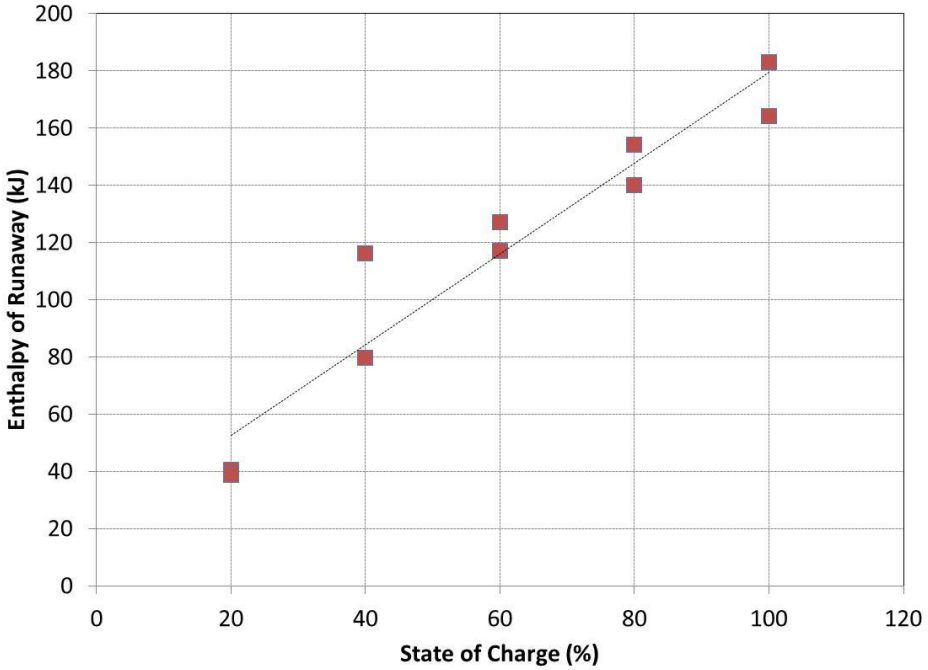
- **Enthalpy scales generally linearly with size, and is similar for both chemistries – This data suggests that failure enthalpy is largely tied to the available stored energy**
- **Peak heating rates significantly higher for large NCA cells**
- **High peak heating rates are generally thought to carry a higher thermal runaway risk, but what is the impact when significant energy is available in numerous smaller cells?**

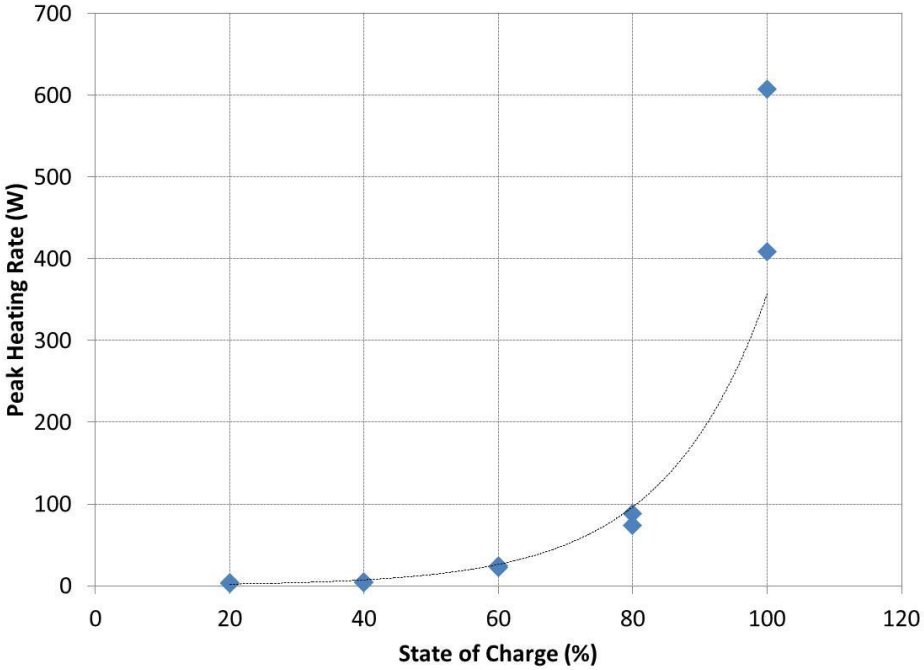
SOC and Thermal Runaway

- **16 Ah automotive (PHEV) pouch cells (mixed $LiMn_2O_4$ spinel)**
- **Significant impact can be easily observed above 60% SOC, very low rate self heating below that**



Impact of SOC on Runaway

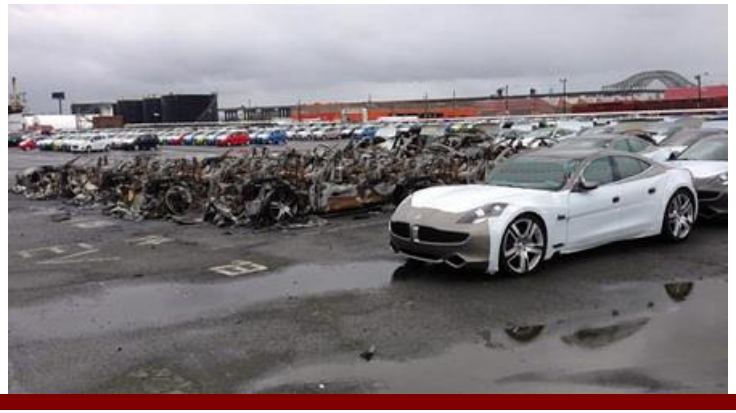


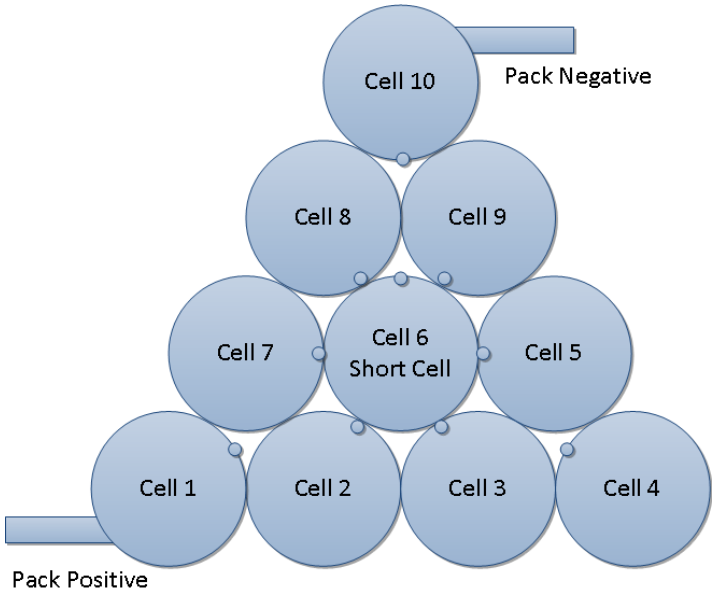


- **Results show a nearly linear relationship between total heat release (kJ) and cell SOC – similar to data for cell size this suggests that failure enthalpy is based largely on the stored energy available**
- **Heat release rates (e.g. runaway reaction kinetics) follow an almost exponential relationship with cell SOC – again this is traditionally thought to cause a greater risk of thermal runaway**
- **Could a runaway still occur with large numbers of low SOC cells or cells in well insulated conditions?**

Configuration based scaling - Battery Failure Propagation

- Simply, the propensity of the energetic failure of a single cell to cause widespread thermal runaway within a battery
- Most large battery systems are designed to withstand the loss of several cells from a performance standpoint
- A point failure becomes more serious if it can send nearby cells into thermal runaway
- Recent events (Fisker, Boeing) have had battery runaway events that engulfed the entire pack
- Provide previously collected data as well as new data to developers of battery propagation models





- Diagram showing cell and thermocouple locations
- Series and parallel constructions used, series pack wired in order from Cell 1 to cell 10
- Simple compared to a large battery system to understand general driving forces

Detailed procedure described in SAND2014-17053 “Propagation Testing Multi Cell Batteries” Available from Sandia

Battery Failure Propagation

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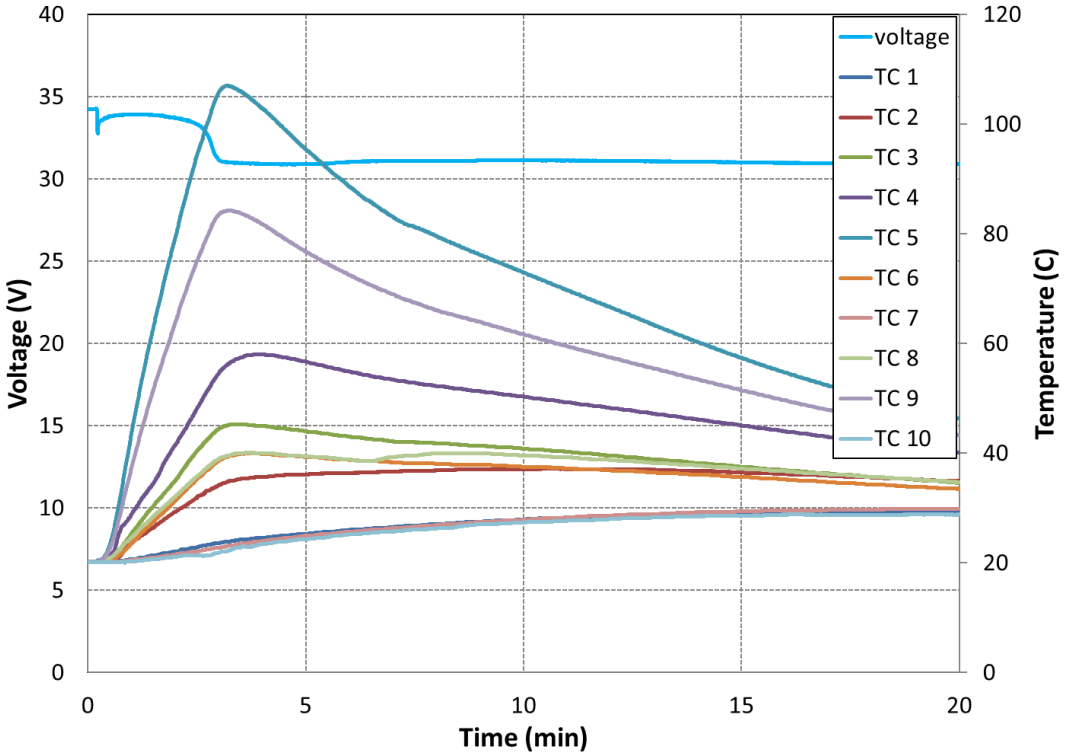
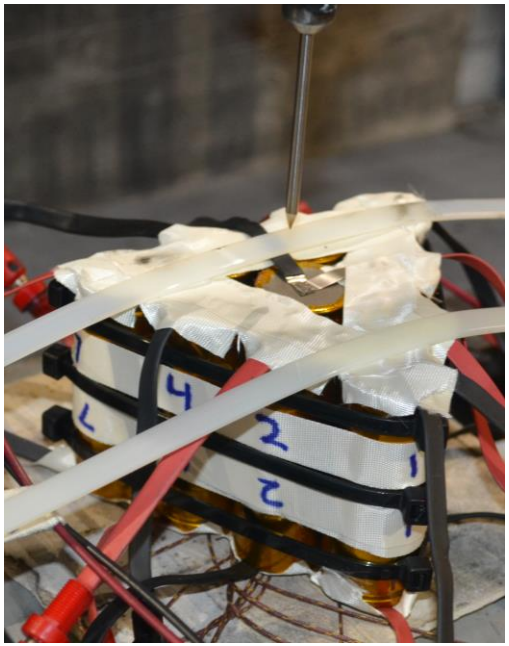
LFP 26650 cells – 10S1P





- Pack constructed from 2.6 Ah LFP cells, failure initiated with nail penetration to central cell
- No cell to cell failure observed
- Heating rates observed similar to that for single cell

Battery Failure Propagation

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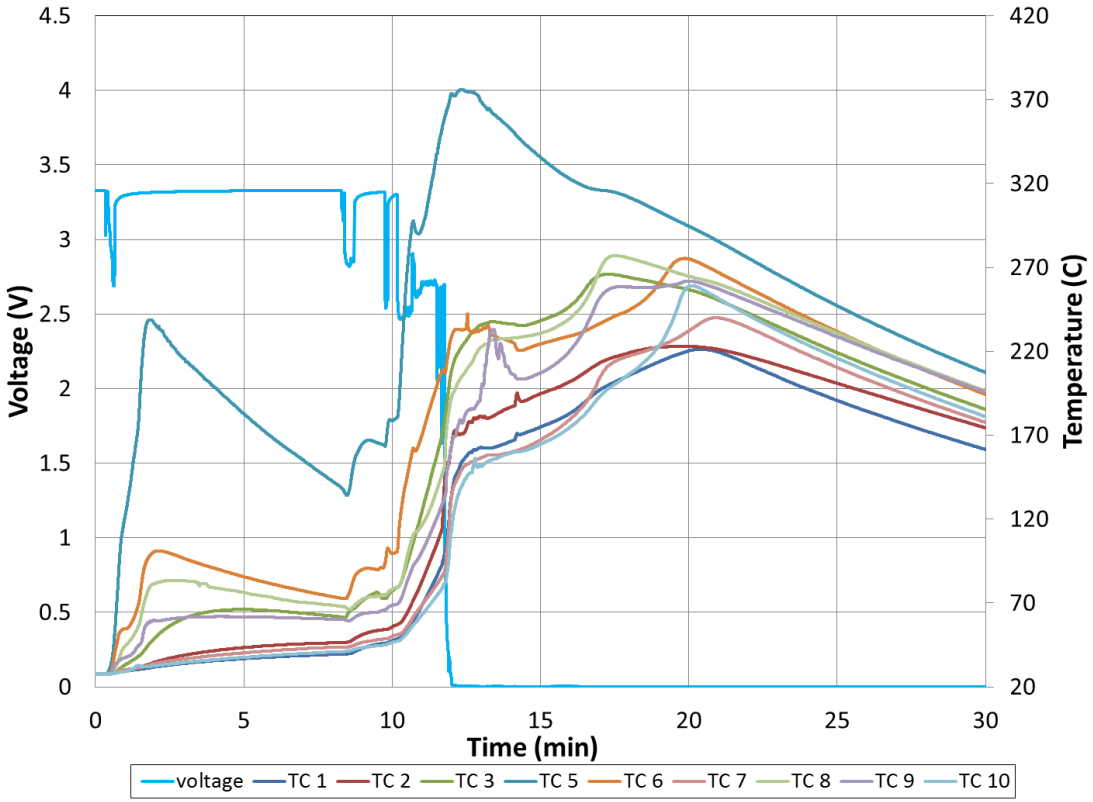
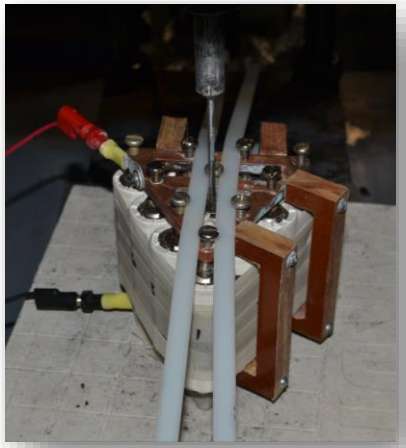
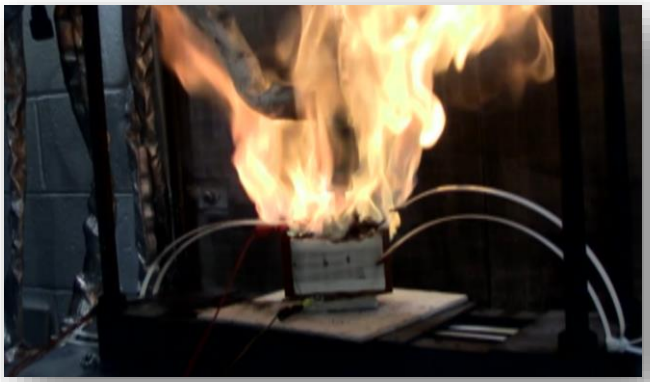
How a cell with low peak heating rates can have a catastrophic failure

LFP 26650 cells - 1S10P



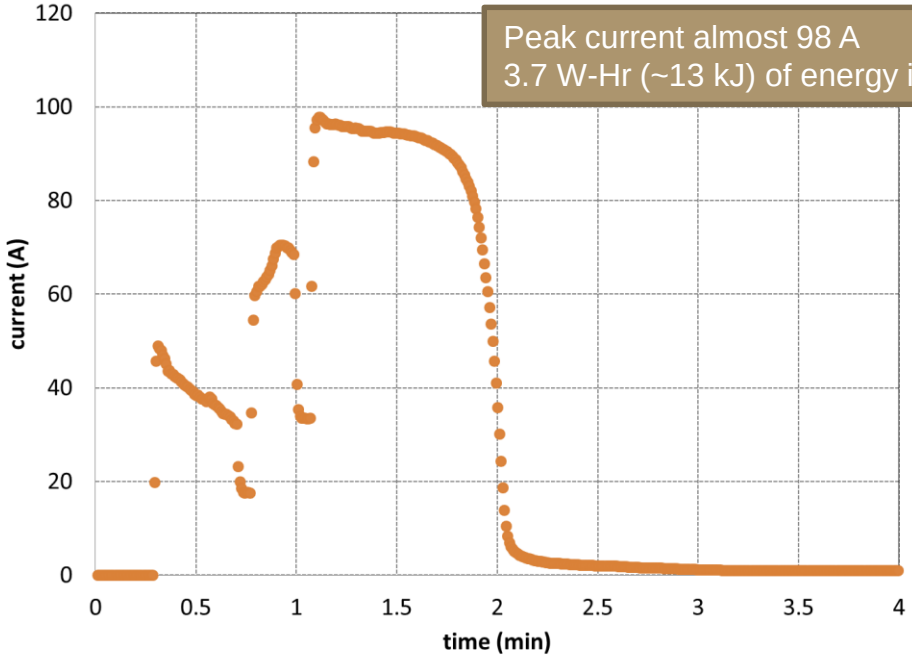


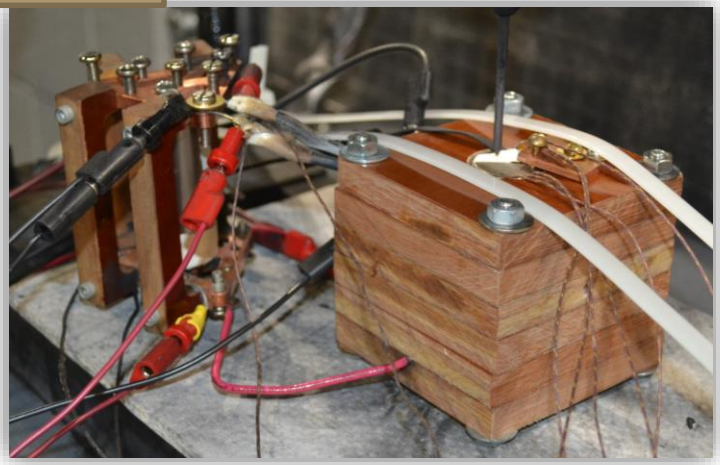


- **Pack constructed from 2.6 Ah LFP cells, failure initiated with nail penetration to central cell**
- **Complete propagation failure in LFP-26650 1S10P pack**
- **Significant increase in the severity of failure from a single cell – Single cell peak heating rates of ~105 W**

Internal shorts in parallel

Two cell parallel module – single cell short created with nail penetration
Short circuit current measured across constantan bridge wire of known resistance





- **A single cell delivered a peak of ~98A and 13 kJ of energy into the shorted cell in ~2 minutes**
- **This shows how the presence of stored energy within a system increases the potential for failure**
- **Could a runaway still occur with large numbers of low SOC cells or cells in well insulated conditions?**

Summary

- Data collected so far suggests that while the intensity of a single cell failure is highly dependent on cell size, chemistry and state of charge, the total energy of a failure is largely only dependent on the stored energy
- This distinction is of greater consequence as more energy is made available, demonstrated here by adding multiple cells to a single system
- Future questions include how do equivalent energies but different numbers of cells compare (i.e. one 50 Ah cell vs. 5 10 Ah cells) and how large amounts of stored energy might impact a system even at low states of charge

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