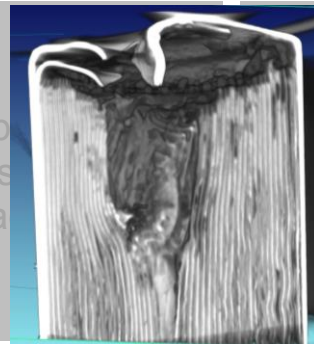


Exceptional service in the national interest



Battery Safety and Abuse Testing at Sandia National Laboratory

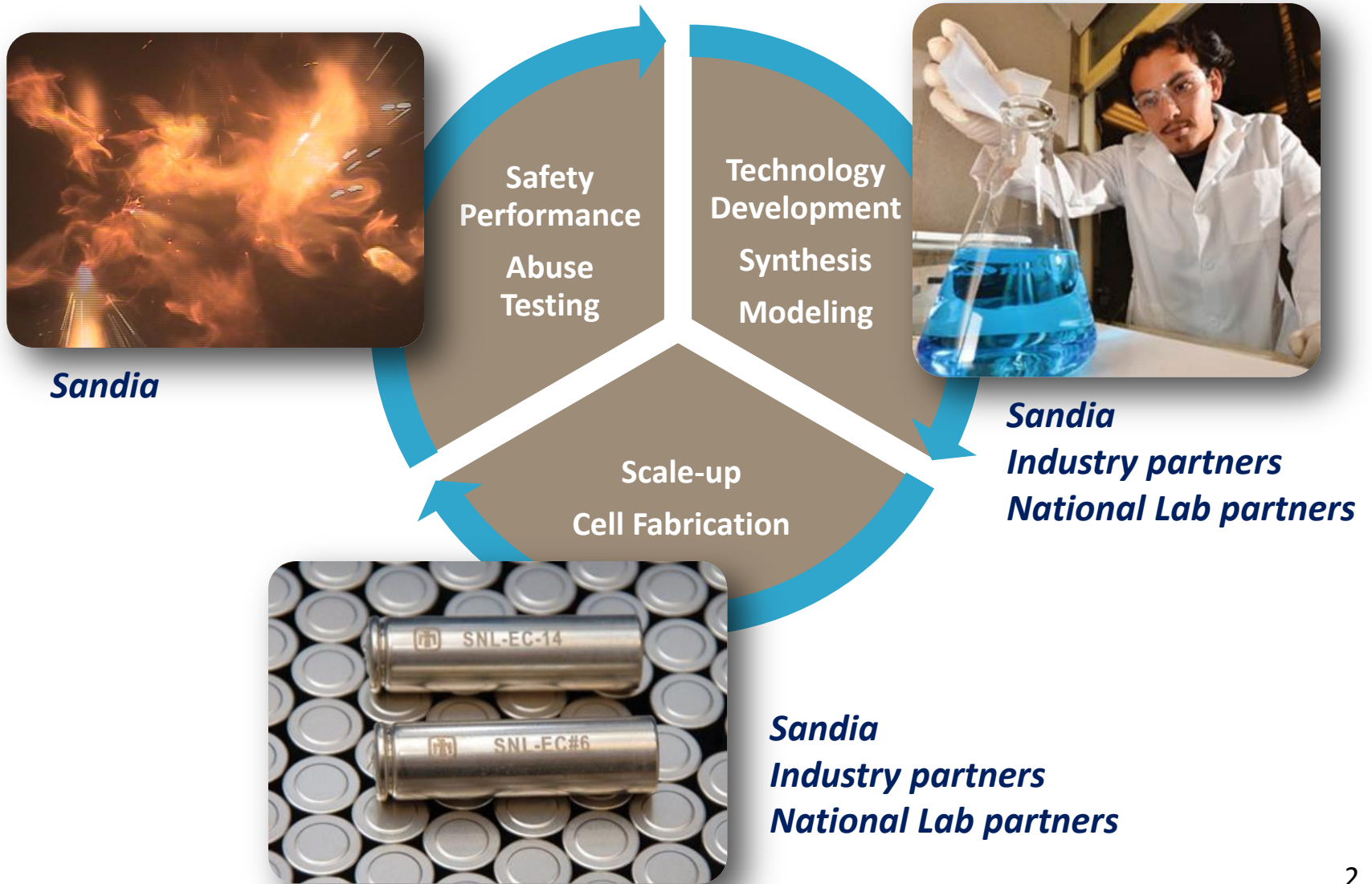
Joshua Lamb

US-China Electric Vehicle and Battery Technology Workshop

August 19, 2014

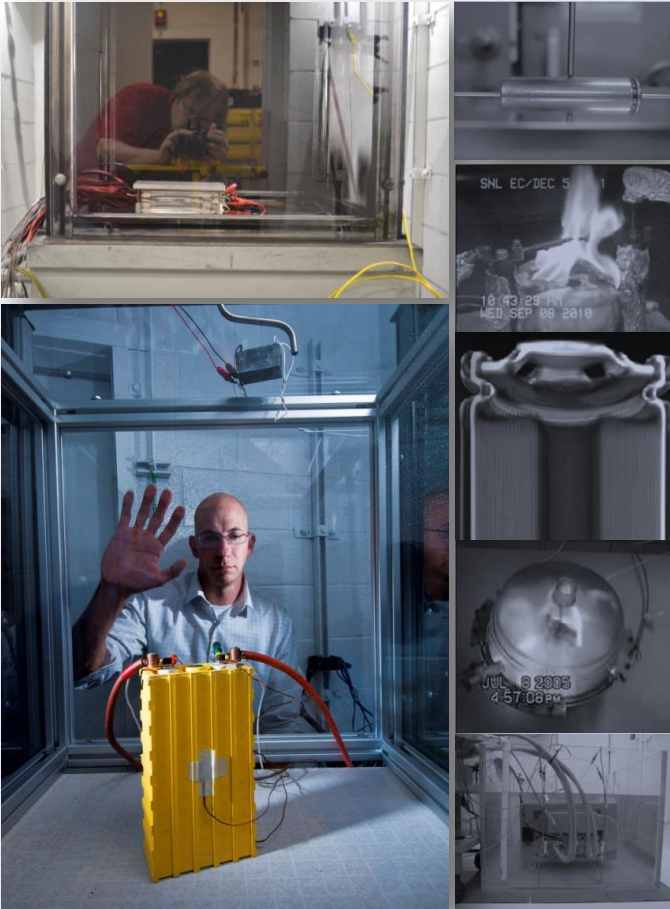


Approach



Capabilities

Cell and Module Testing Battery Abuse Testing Laboratory (BATLab)



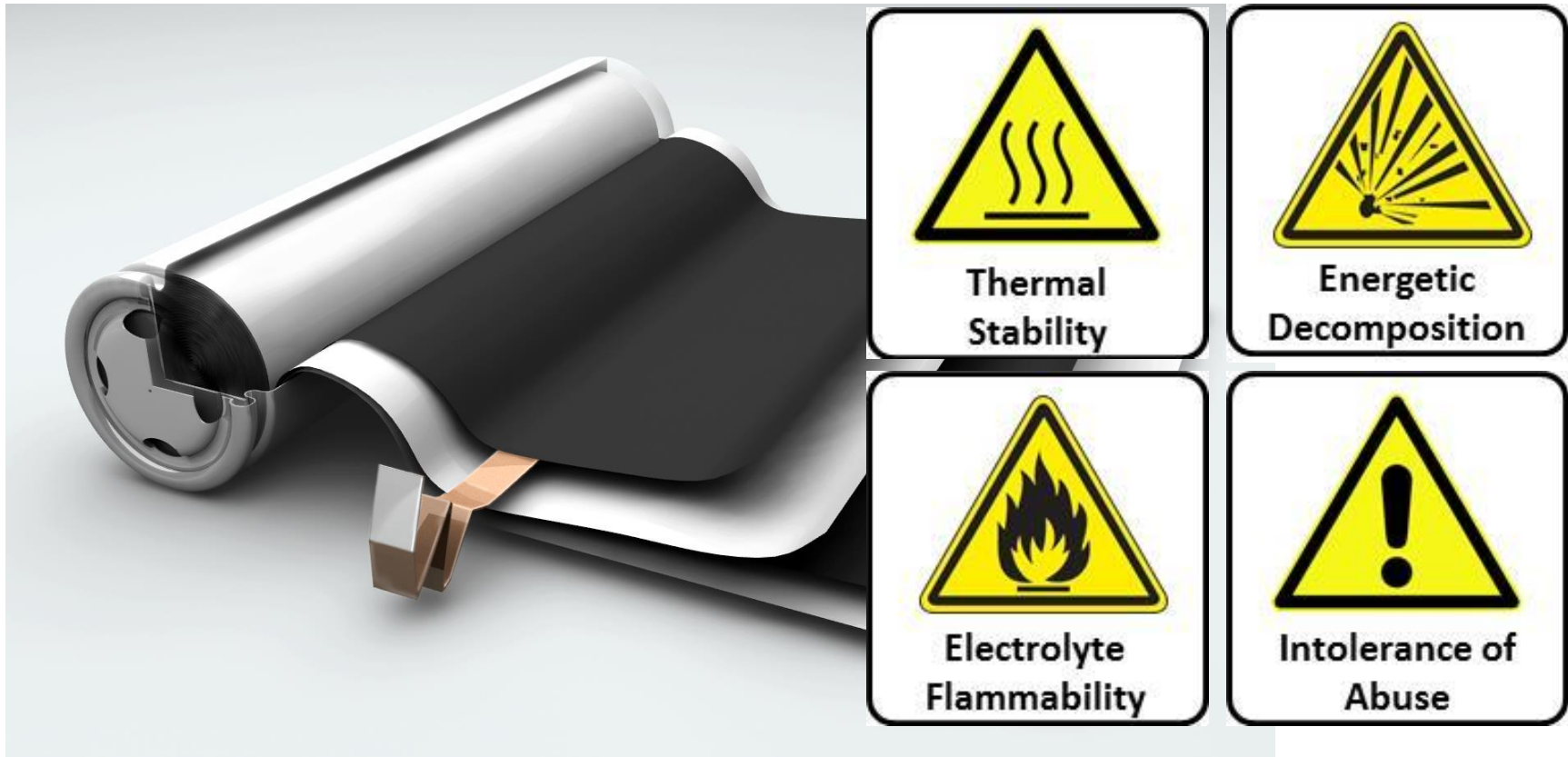
Battery Pack/System Testing Thermal Test Complex (TTC)



Battery Calorimetry



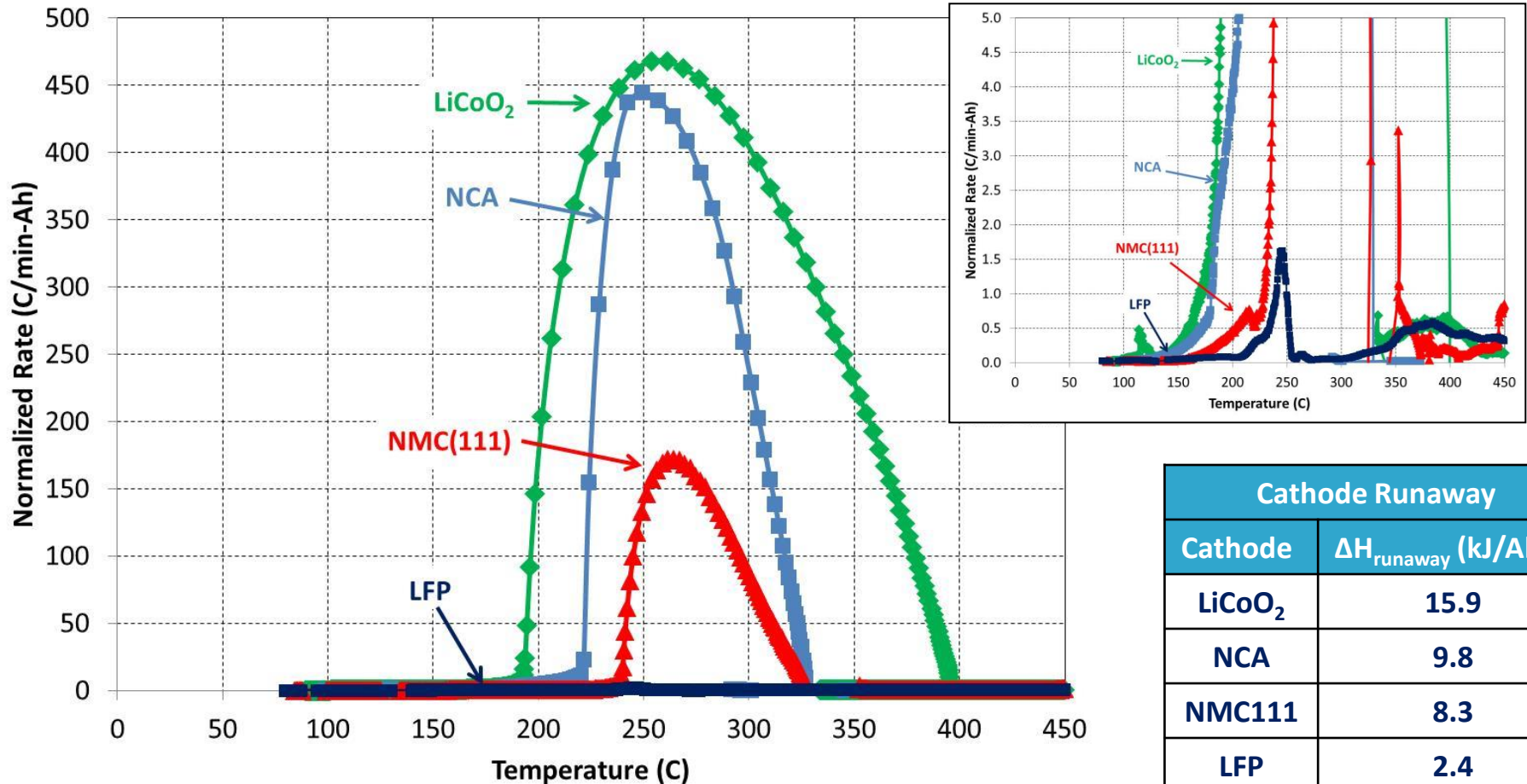
Challenges with Inherent Cell Safety Sandia National Laboratories



Need to address these issues at the cell materials level in order to field the most inherently safe energy storage products

Calorimetry of Lithium-ion Cells

Understanding the thermal runaway response of materials in cells

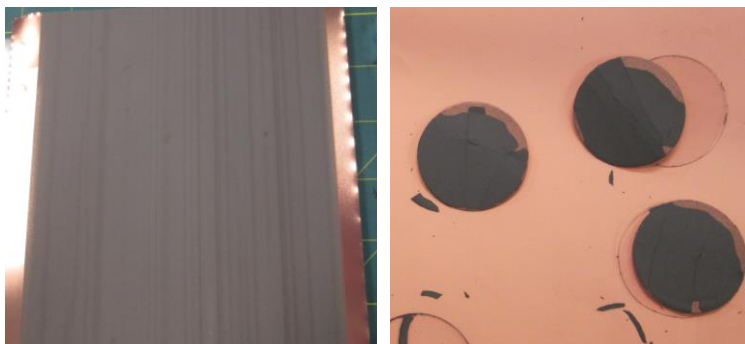


*Can high energy cathodes behave like LFP during thermal runaway?
Where do high capacity Si/C anodes fit on this plot?*

Si/C Anode Abuse Tolerance

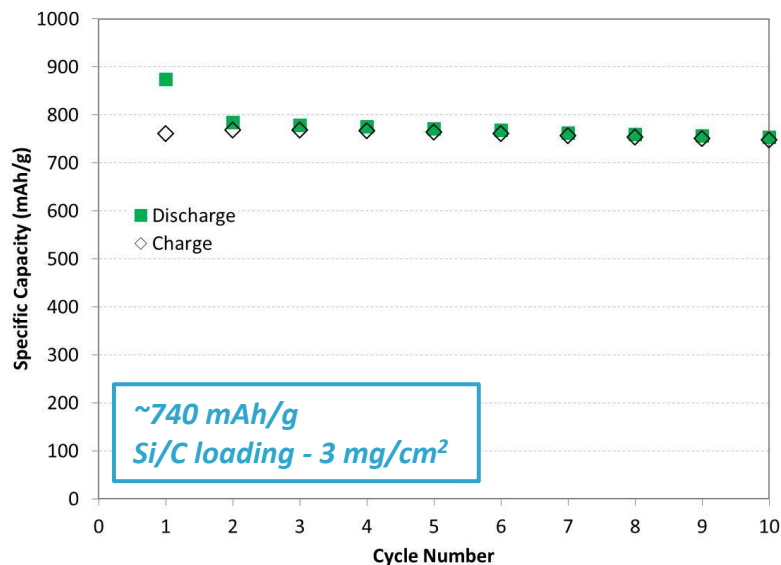
Understanding safety issues with Si materials in lithium-ion cells

Electrode processing issues

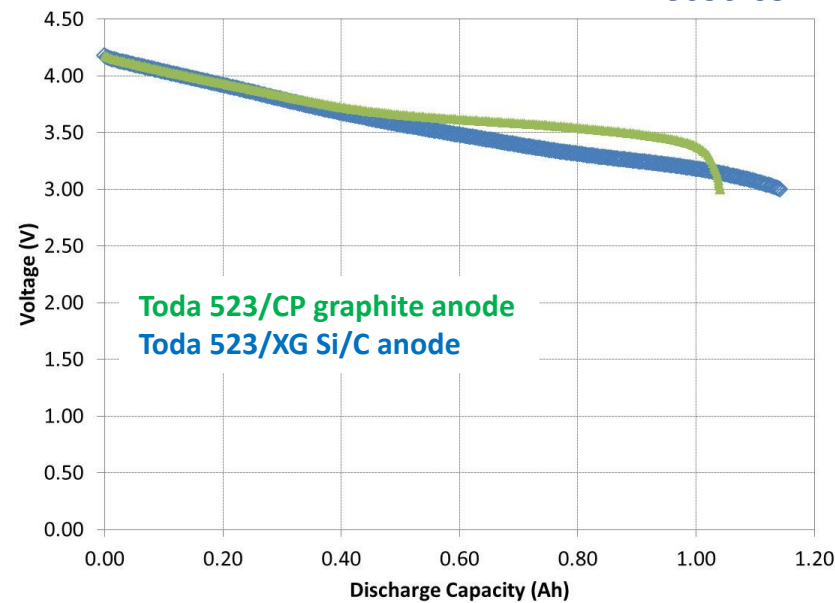


Slurry heterogeneity

Cracking > 4 mg/cm²



18650 Cell

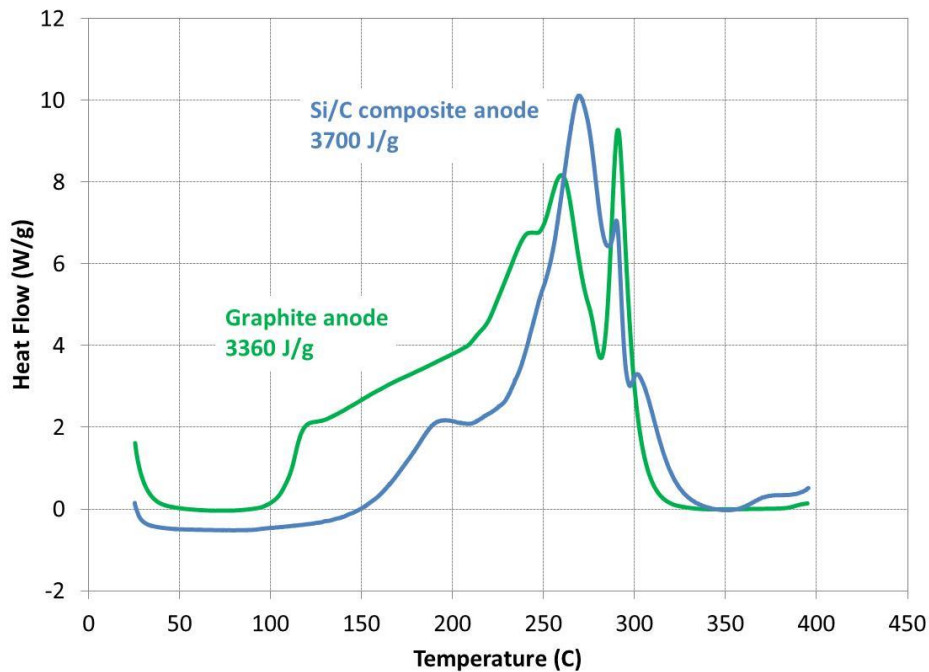


- Cell parameters:
 - 1.2 M LiPF₆ in EC:EMC (3:7)
 - No additives
 - N:P = 1.3
- ~10% more capacity in the Si/C cell compared to the graphite anode cell

Note: initial experiments done with EC.

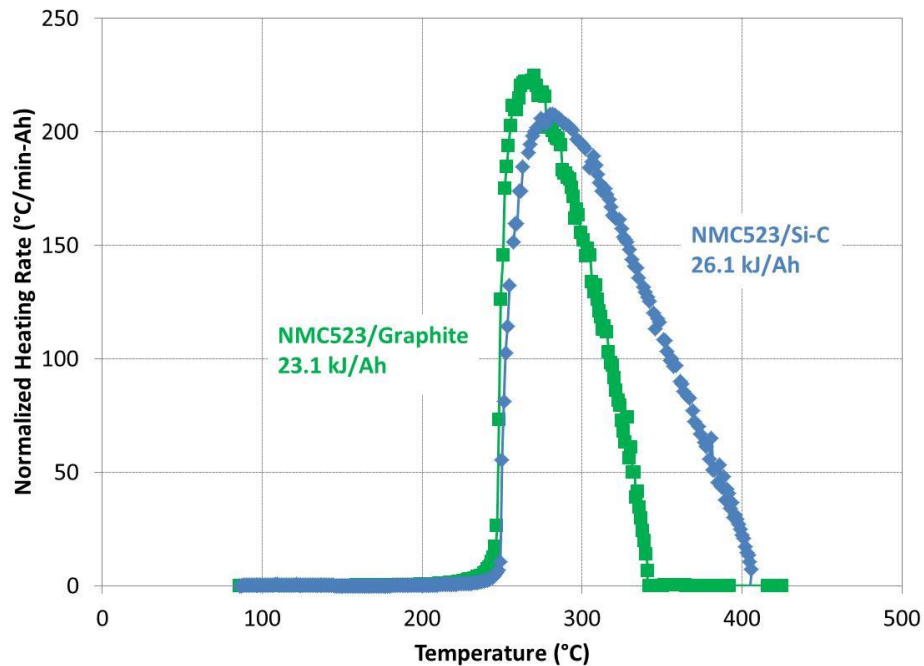
Si/C Anode Abuse Tolerance

Calorimetry on Si/C materials



~10% increase in heat generation over graphite

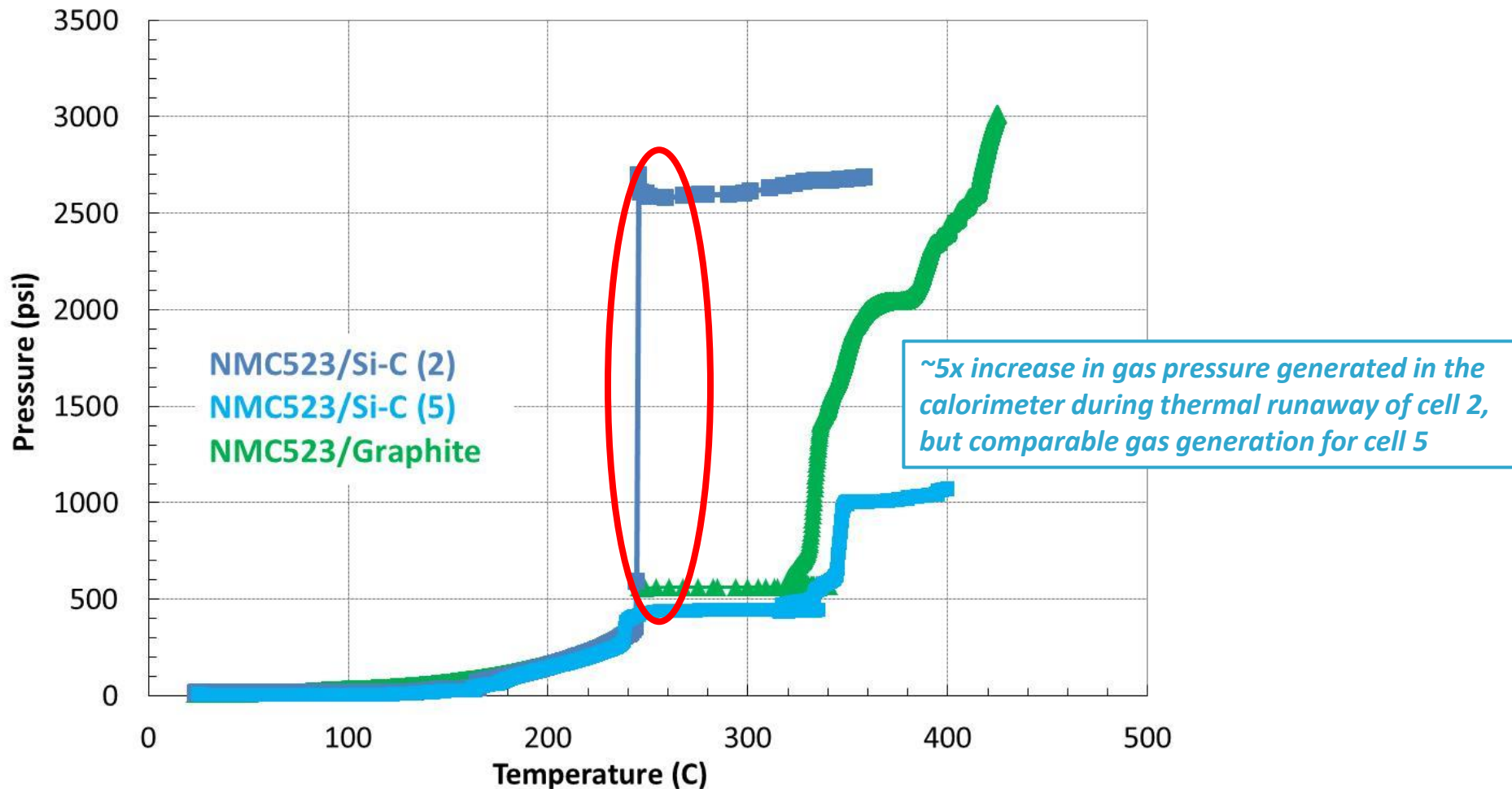
Calorimetry on Si/C in 18650 cells



~10% increase in heat generation in cells

Thermal runaway enthalpy of Si/C-NMC cells is ~10% greater than Graphite-NMC cells

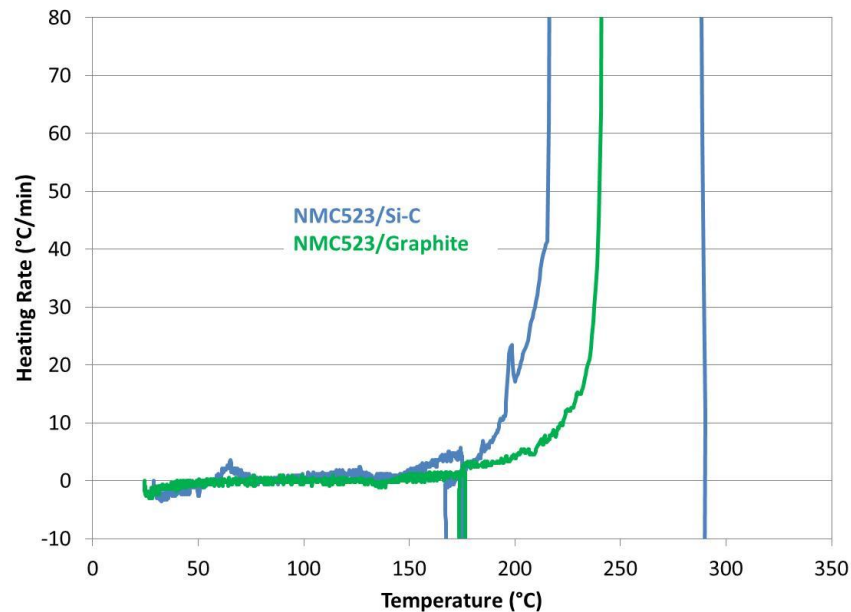
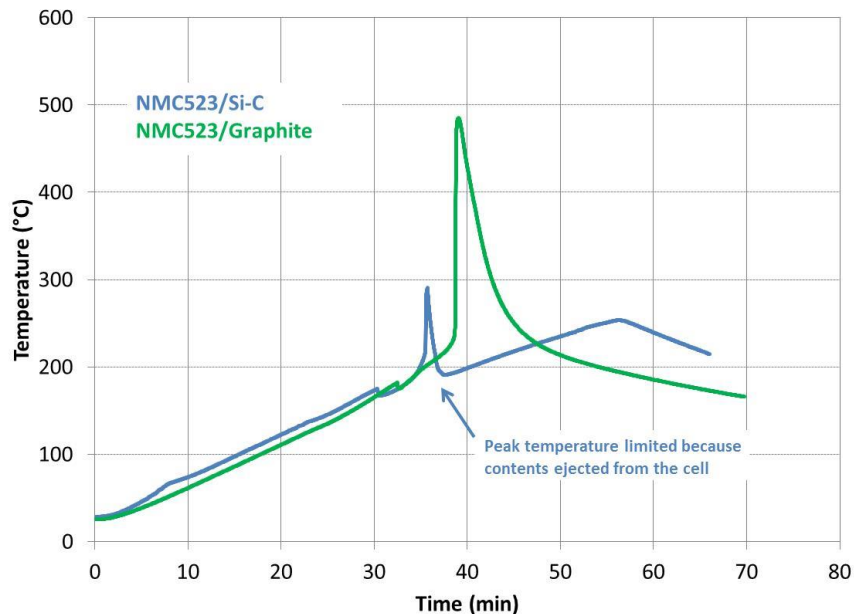
Si/C Anode Abuse Tolerance



Quantitative gas analysis pending to better understand this issue and its implications on Si/C abuse tolerance

Si/C Anode Abuse Tolerance

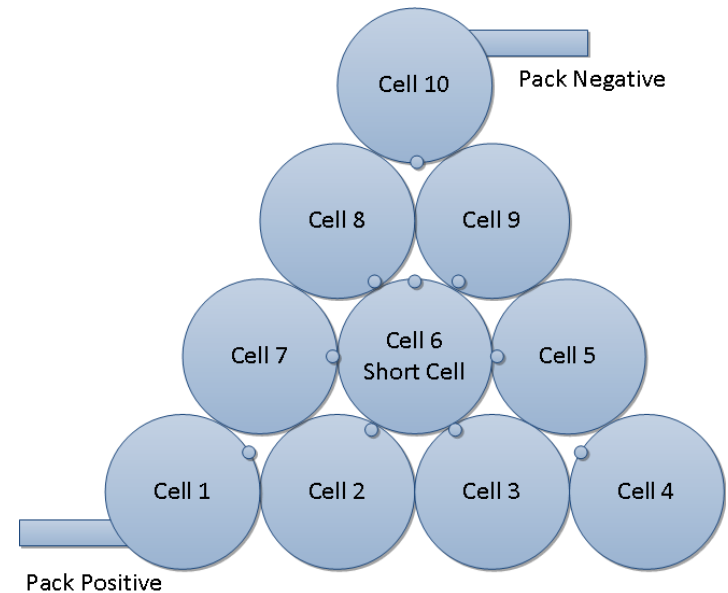
Thermal Abuse Testing



Comparable performance between the Si-C and Graphite cells, but self-ignition observed with the Si-C cell

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

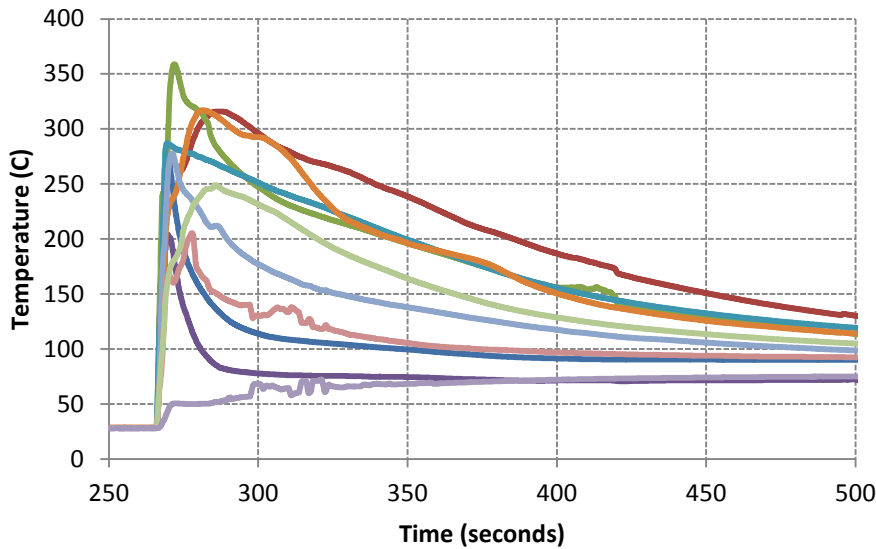


- Diagram showing cell and thermocouple locations
- Series and parallel constructions used, series pack wired in order from Cell 1 to cell 10



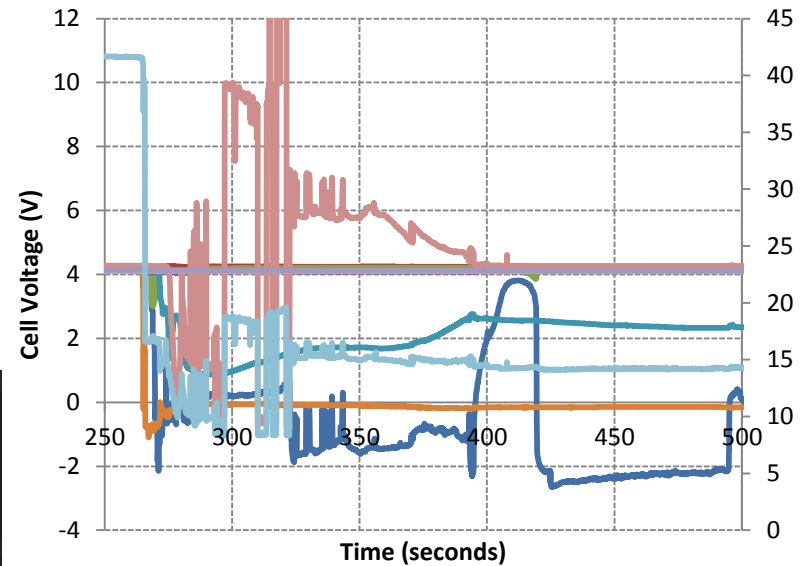
Cells:
Panasonic
Model CGR18650CG
2250 mAh nominal capacity
Avg wt. 44g

Propagation Testing (10S1P)

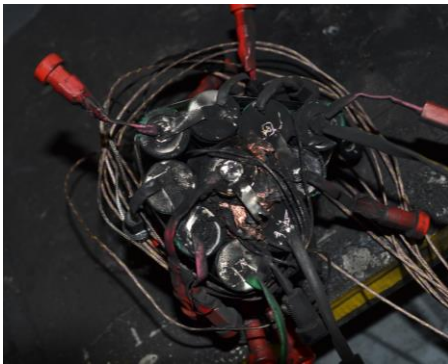


Cell 1 Cell 2 Cell 3 Cell 4 Cell 5
Cell 6 Cell 7 Cell 8 Cell 9 Cell 10

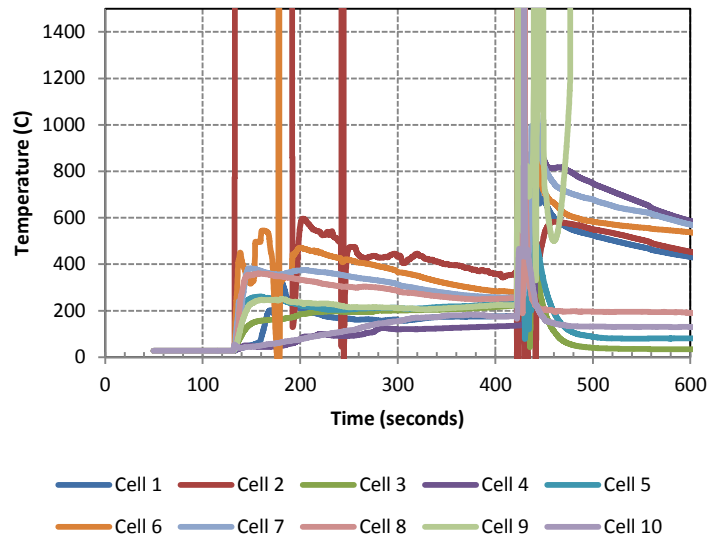
- Successful initiation at Cell #6
- Initial thermal runaway occurs in first 30 seconds
- Failure of some cells observed, but failure does not propagate through entire pack



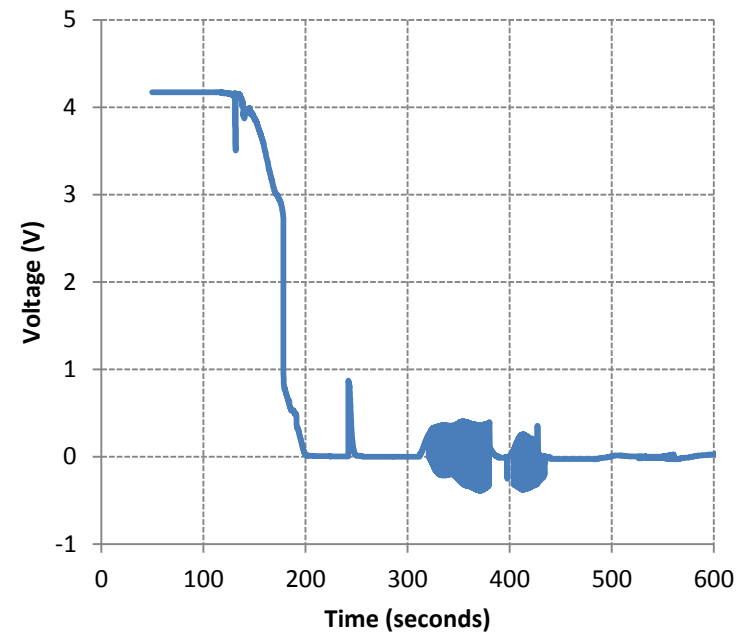
Cell 1 Cell 2 Cell 3
Cell 4 Cell 5 Cell 6
Cell 7 Cell 8 Cell 9
Cell 10 Pack voltage



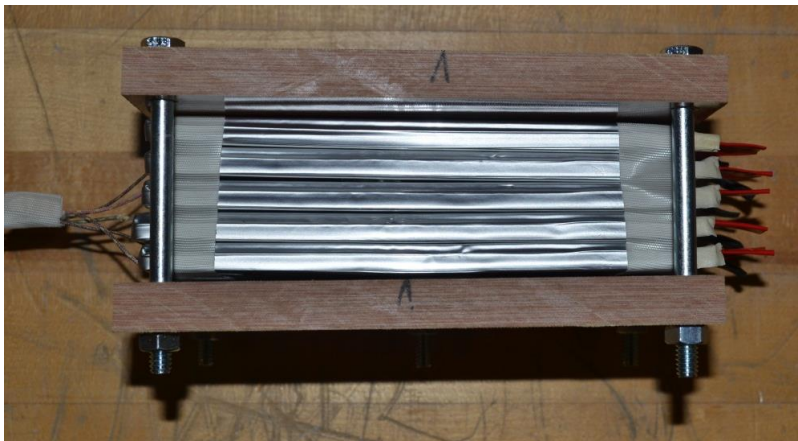
Propagation Testing (1S10P)



- Successful initiation at Cell #6
- Propagation to adjacent cells first, followed by outlying cells
- Cascading failure to entire battery over 450s
- Some thermocouples (K-type) saturated during test



Propagation pack test and cell details Sandia National Laboratories



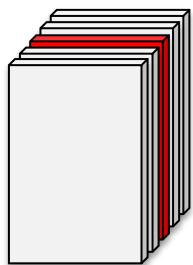
Cells:

AA Portable Power Corp

Model PL-7035130-10C (www.batteryspace.com)

3000 mAh nominal capacity

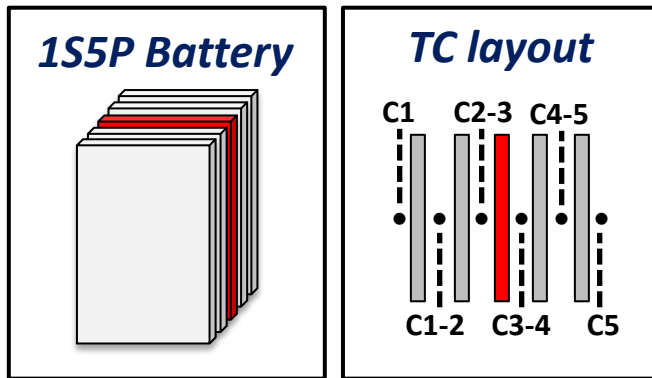
66.26 g measured cell mass



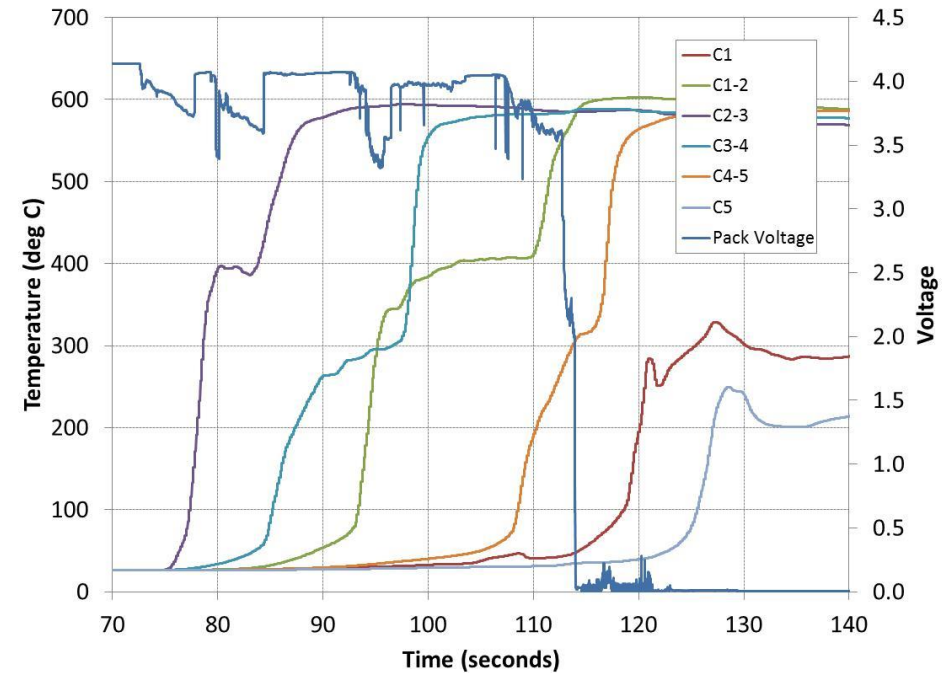
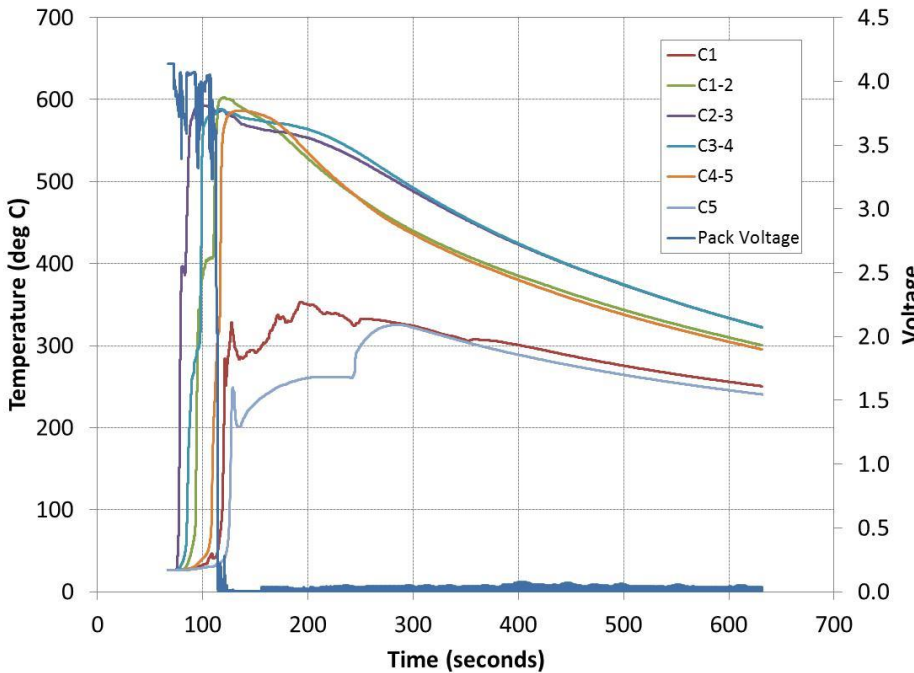
- **Experiment:**
- *1s5P and 5s1p modules built and constrained in phenolic*
- *Central cell failure initiated (labeled in data as cell 3)*
- *Thermocouple measurements taken between each cell*

Constituent	wt %	Mass
LiCoO2	50	33.13
Carbon(graphite)	10	6.626
PP	5	3.313
PVDF	2	1.325
PE	5	3.313
CMC	0.5	0.3313
LiPF6	5	3.313
EC	5	3.313
DMC	5	3.313
Ni	2.5	1.656
Cu	5	3.313
Al	5	3.313

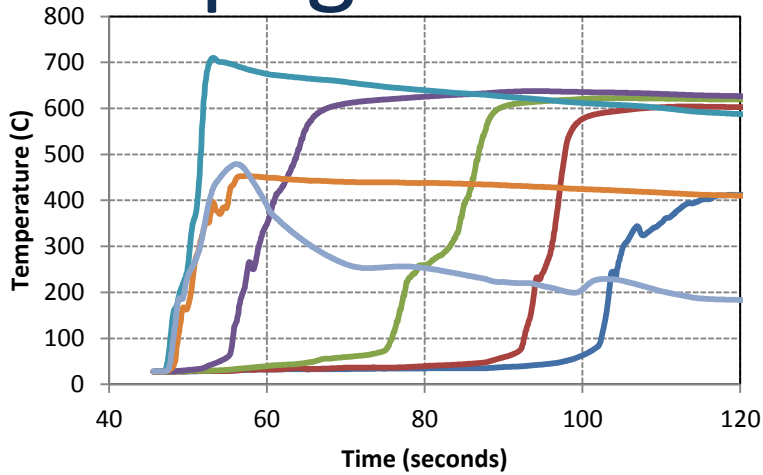
Propagation Testing (1S5P)



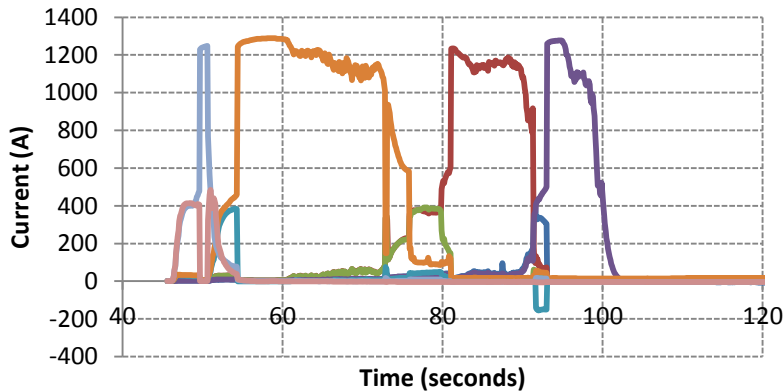
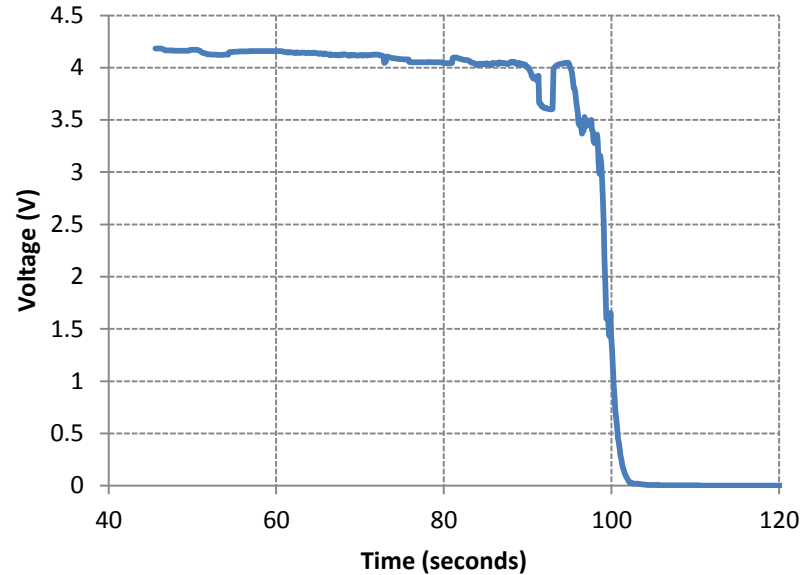
*Failure and runaway initiated at Cell #3
Propagation to adjacent cells
Cascading failure to entire battery over 50 s*



Propagation Testing (1S5P)



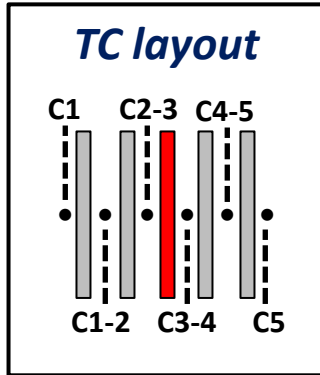
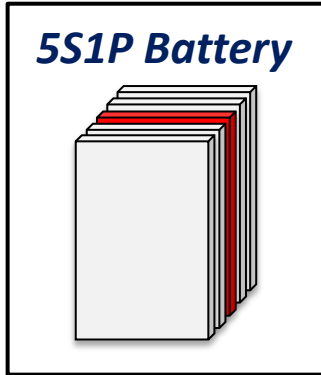
— Cell 1 — Cell 1-2 — Cell 2-3 — Cell 3-4
— Cell 4-5 — Cell 5 — Bridge 4+



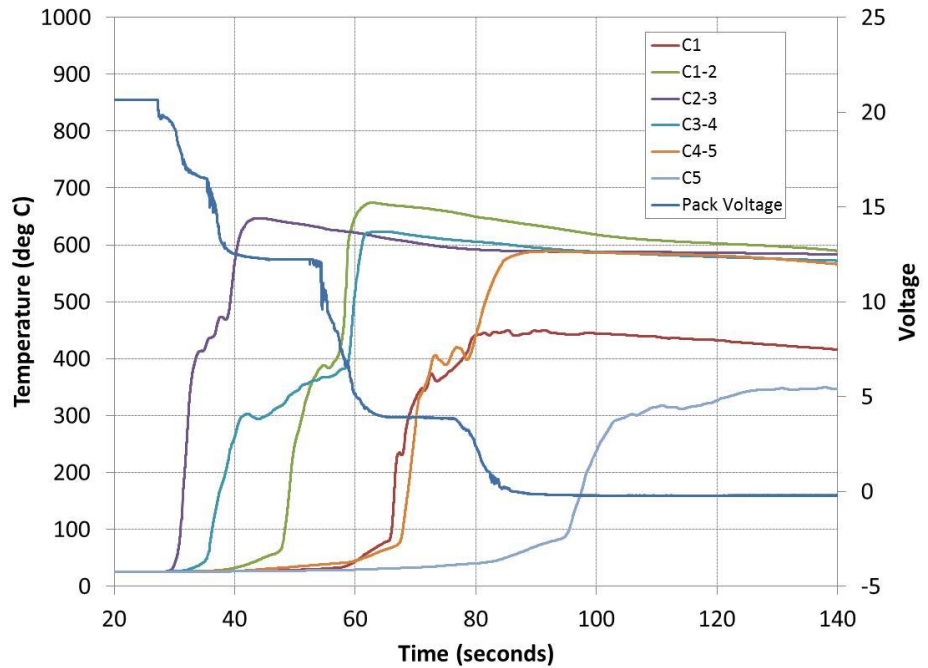
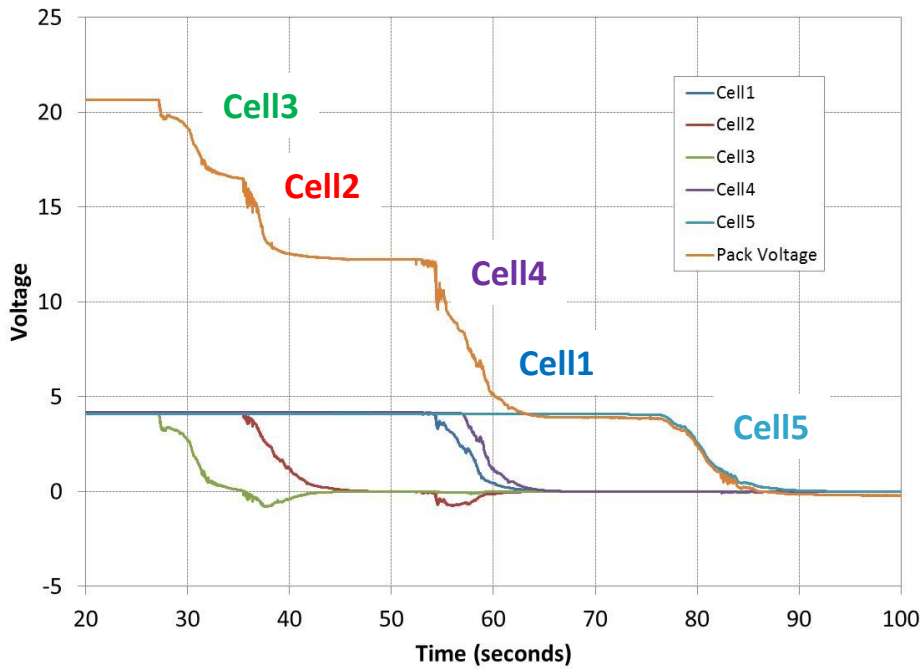
— Bridge 1+ — Bridge 2+ — Bridge 3+ — Bridge 4+
— Bridge 1- — Bridge 2- — Bridge 3- — Bridge 4-

- Failure and runaway initiated at Cell #5
- Temperature corrected short circuit current is on the order of ~200 A through the central cell load point in the battery

Propagation Testing (5S1P)

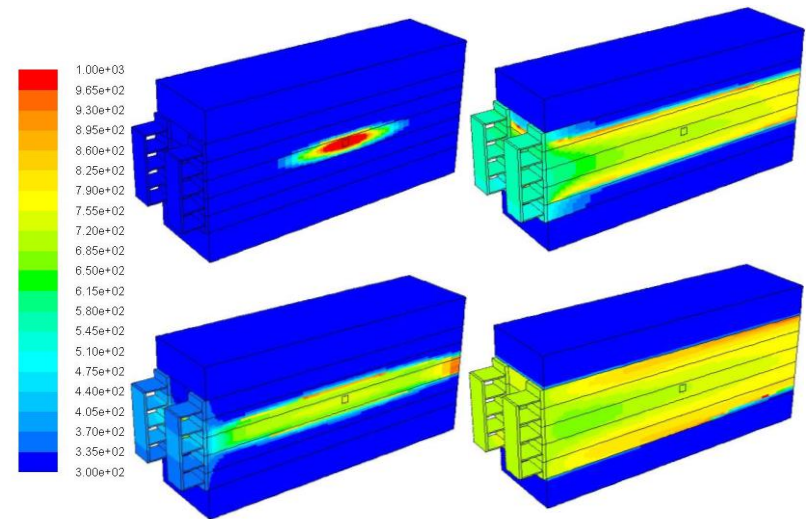


- Successful initiation at Cell #3
- Propagation to adjacent cells
- Cascading failure to entire battery over 60 s



Summary

- Prismatic pouch cells show little difference between series and parallel configurations
 - In both cases thermal runaway cascaded through the entire pack within ~50-60 seconds
 - The large area of direct contact between cells likely contributes to this. The rate of heat transfer between neighboring cells is high enough to overwhelm any effects of electrical configuration



Modelling performed by collaborators at NREL showing temperature profiles after initiation

- 18650 cell packs meanwhile showed significant difference between configurations
 - Not all cells went into runaway in series configuration, while in parallel the runaway was more severe and eventually encompassed all cells
 - A smaller area of contact exists between cells limiting the heat transfer during thermal runaway. In parallel configuration
- Si/C anode performance evaluated in comparison to NMC cathode material

Acknowledgements

- Tom Wunsch
 - Christopher Orendorff
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 - Brian Cunningham