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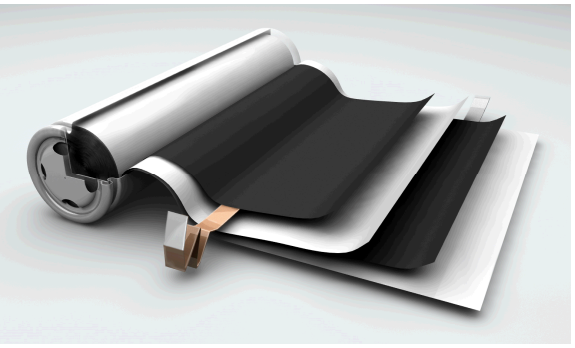
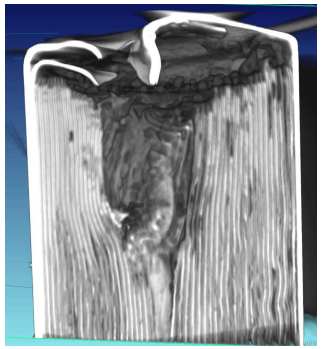

Electrochemical Abuse Testing

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Sandia National Laboratories

Energy Storage Peer Review

San Diego, CA, October 11-12, 2017

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Approach and Capabilities

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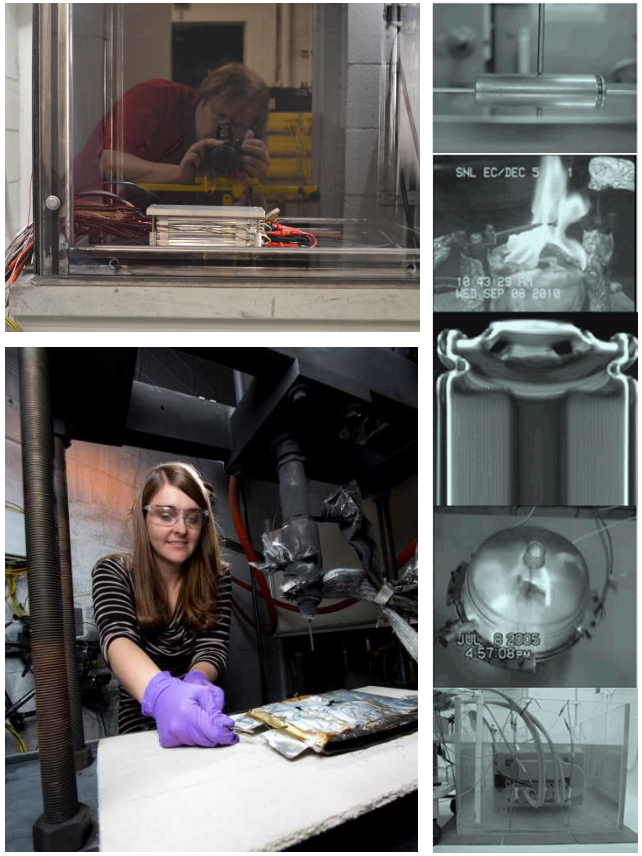
Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)



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

Battery Calorimetry

Understanding Battery Safety

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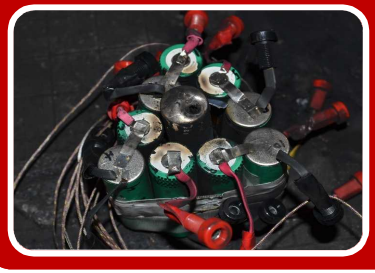
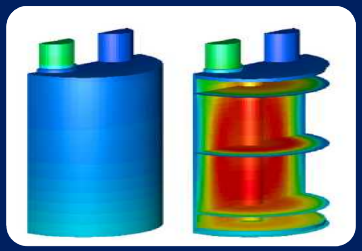
Materials R&D

- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials



Testing

- Electrical, thermal, mechanical abuse testing
- Large scale thermal and fire testing (TTC)
- Failure propagation testing on batteries/systems
- Diagnostic techniques for battery state of stability
- Development for DOE Vehicle Technologies and USABC



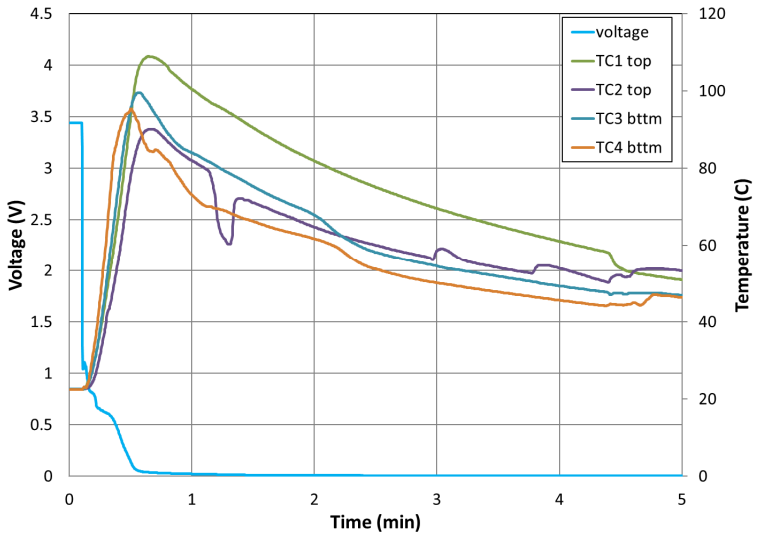
Simulations and Modeling

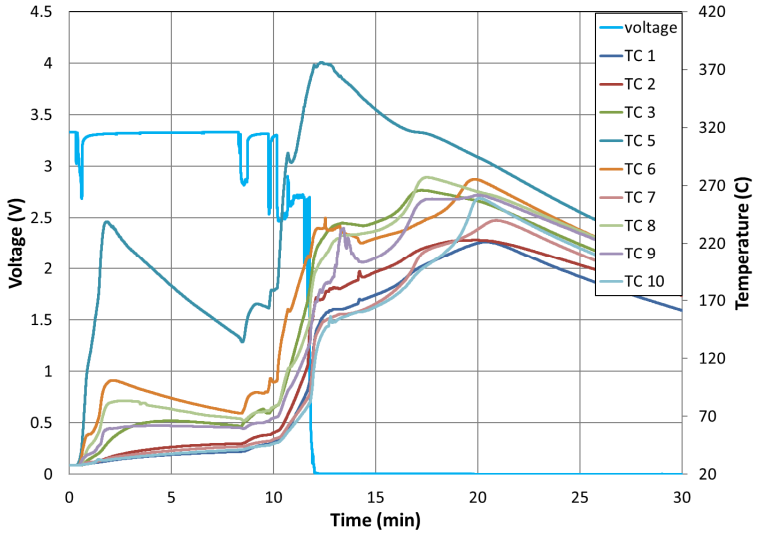
- Multi-scale models for understanding thermal runaway
- Validating vehicle crash and failure propagation models
- Fire Simulations to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation

- USABC Abuse Testing Manual (SAND 2005-3123)
- SAE J2464/UL 1642 procedures and standards
- R&D programs with NHTSA/DOT to inform best practices, policies, and requirements

Motivation for propagation testing

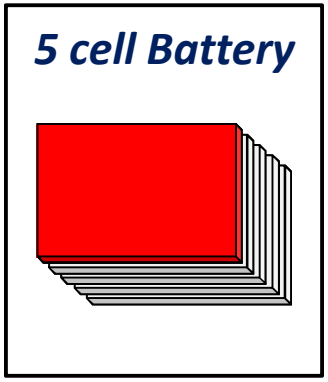


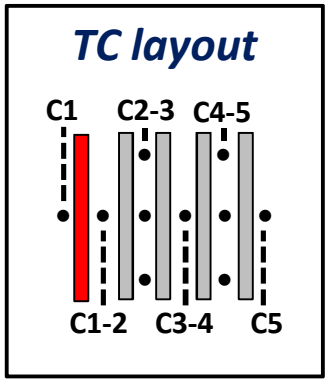


- ***Results of single cell nail penetration and 1S10P propagation test***
- ***26650 LFP cell***
- ***Single cell has relatively minor failure***
- ***Significant increase in intensity with a 10 cell pack***

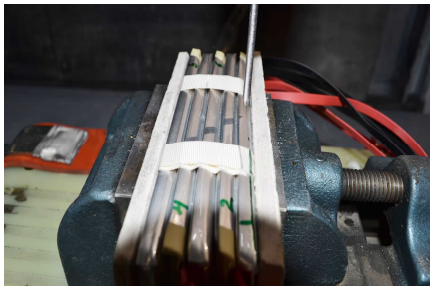
Failure Propagation: No Thermal Management

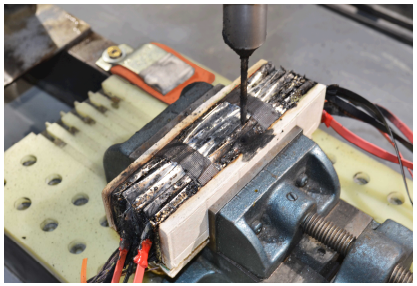
Failures initiated by mechanical insult to edge cell of COTS $LiCoO_2$ packs (3Ah cells)

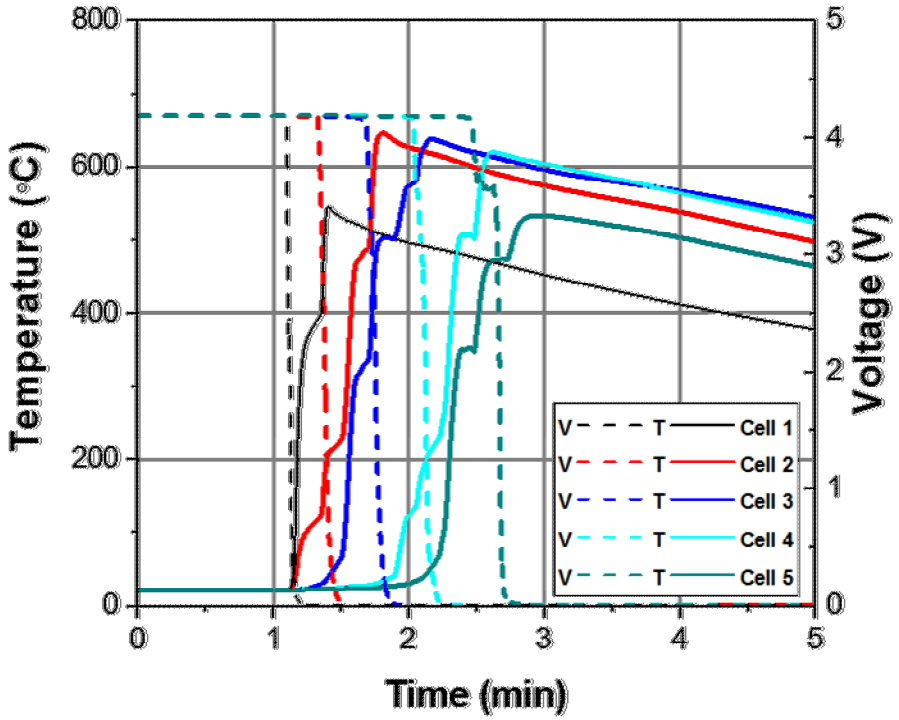




- Successful initiation at Cell #1
- Propagation to adjacent cells
- Cascading failure to entire battery over 60 s

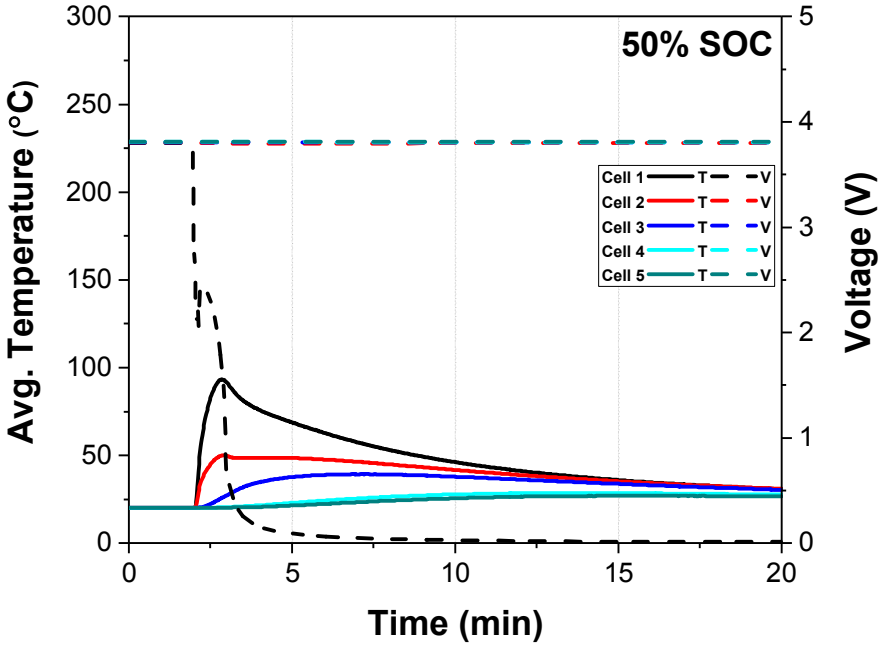


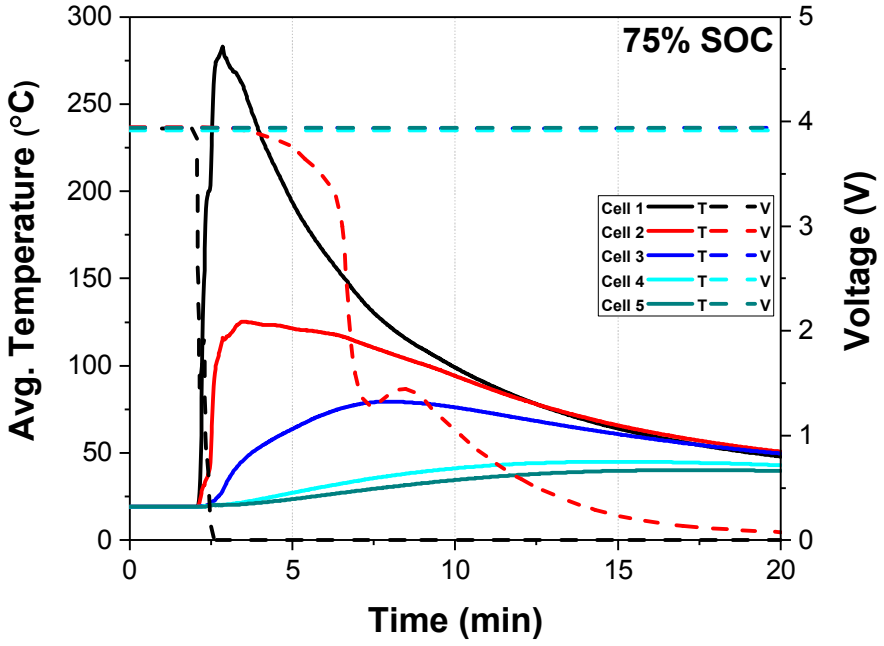




- ***Observed complete propagation when cell are close packed with no thermal management***

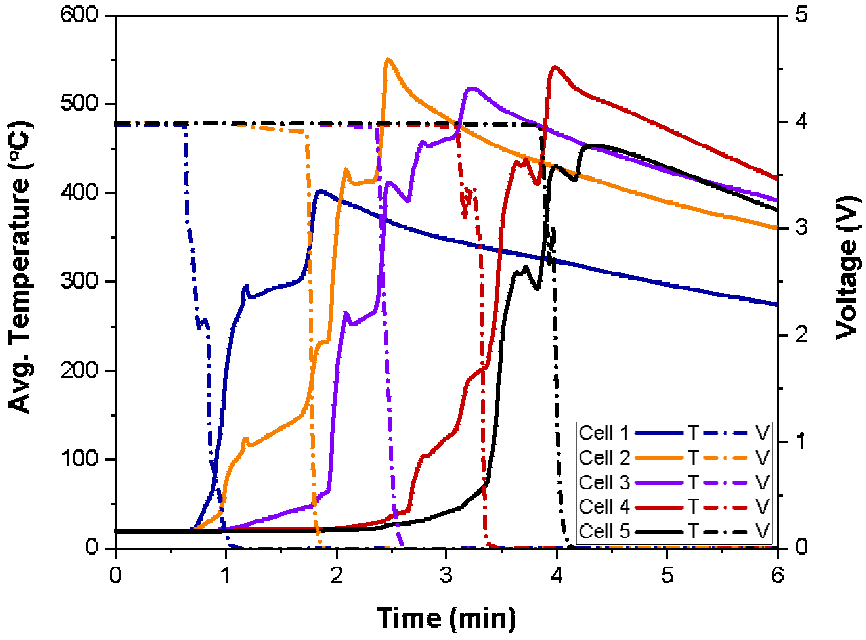
Mitigation through de-rating cells

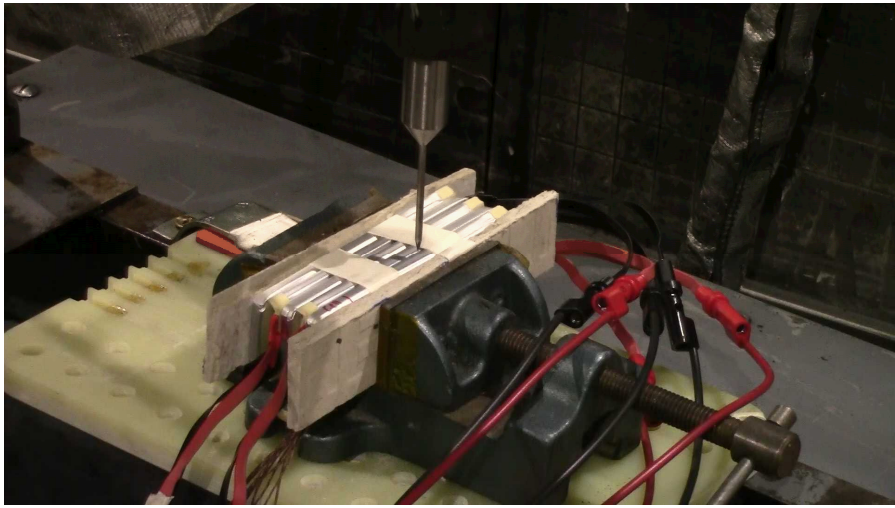




- *50% SOC no cell to cell propagation observed*
  - *Thermal runaway of initial cell failure also fairly minimal*
- *Limited propagation at 75%*
  - *Cell 2 went into thermal runaway following the failure of cell 1*
  - *Some other cell damage was observed but no high rate thermal runaway events seen inn cells 3-5*

Limits to cell de-rating





- ***Full failure of pack observed starting at 80% SOC***
- ***Compared to unmitigated baseline, peak temperatures observed were only marginally lower (550 °C vs 620 °C)***
- ***Total pack propagation observed after ~4 minutes vs ~80 seconds at 100% SOC***

Failure Propagation Testing: Inclusion of Thermal Management

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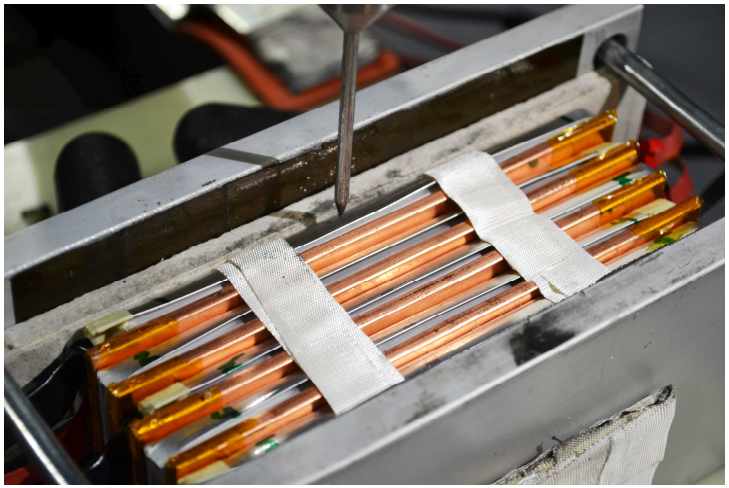
Methodology:

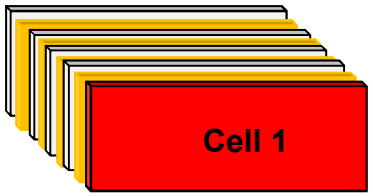
- Experimentally determine a reproducible thermal runaway initiator for each cell type
- Use this initiator to trigger a single cell thermal runaway failure in a battery
- Evaluate the propagation of that failure event

Experiment

- COTS $LiCoO_2$ 3Ah pouch cells
- 5 cells closely packed
- Failure initiated by a mechanical nail penetration along longitudinal axis of edge cell (cell 1)
- **The current effort is focused on understanding extent of propagation with inclusion of passive thermal management in the form of heat sinks between pouch cells (aluminum and copper)**



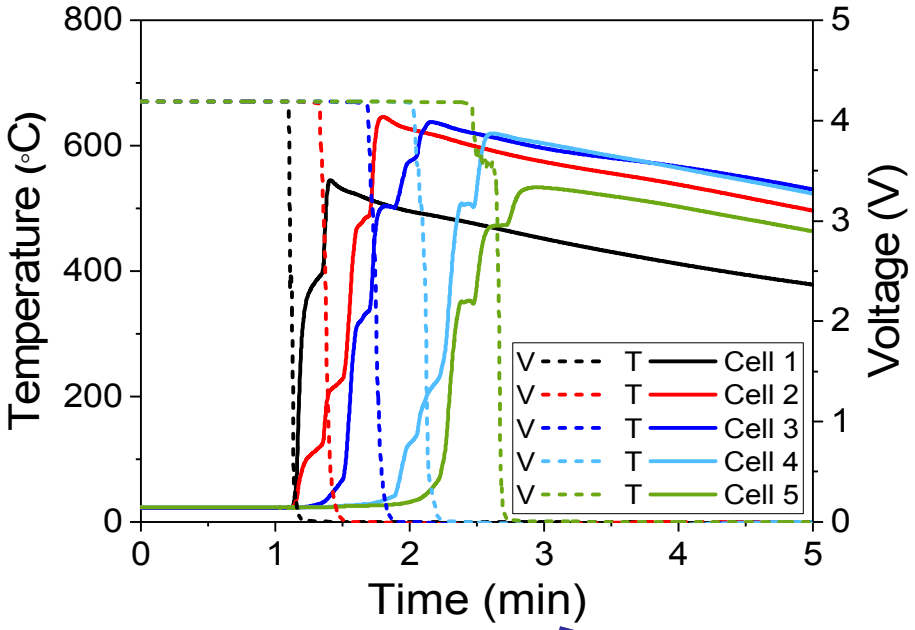
5 cell pack with aluminum or copper spacers between cells

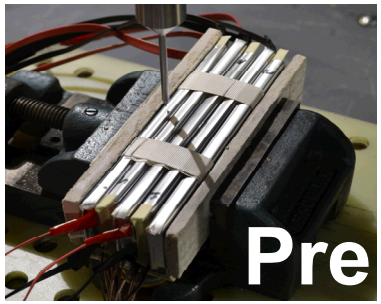


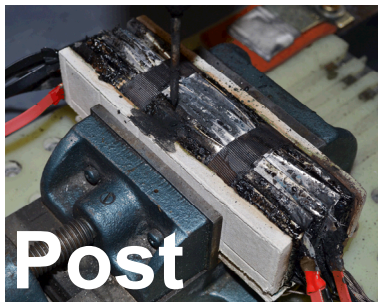
For more detail on these results please see poster titled "Mitigation techniques for failure propagation" presented by Dr. Loraine Torres-Castro

J. Lamb et al. J. Power Sources 283 (2015), 517-523 and C. J. Orendorff et al. SAND2014-17053

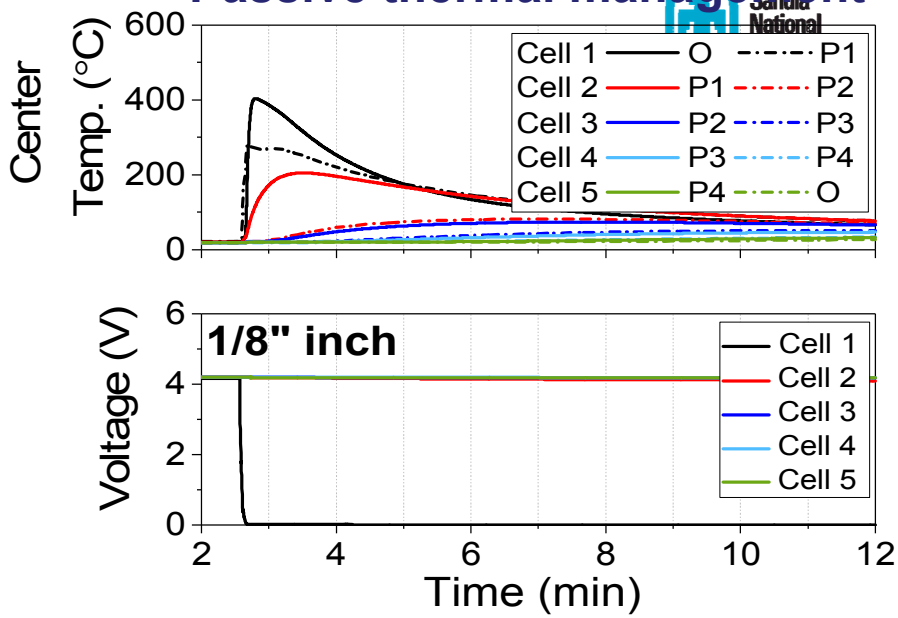
Baseline







Passive thermal management



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Discussion

- A cell may exhibit dramatically different failure response when in a string, module or pack than during single cell abuse testing
- Limiting the SOC can have a meaningful impact in propagating failure, however this comes at a significant cost to total energy storage
- Propagation can be mitigated through system engineering, however the results can be unpredictable. Further, electrical design will play a role in susceptibility to failure testing.
- Failure testing of large, complex systems is fairly resource intensive. Model based design presents a potential remedy to this, allowing us to infer a large amount of information from a relatively small number of tests.

Acknowledgements

- Imre Gyuk – US Department of Energy Office of Electricity

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