SAND2021-2009C

CENTER 7500

CSEP

COMPONENT SCIENCE, ENGINEERING, & PRODUCTION





Mitigation of Failure Propagation: A Model-Based Experimental Design

PRESENTED BY

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Team members: Chris Grosso, Randy Shurtz, Andrew Kurzawski, Josh Lamb and John Hewson

March 9, 2021

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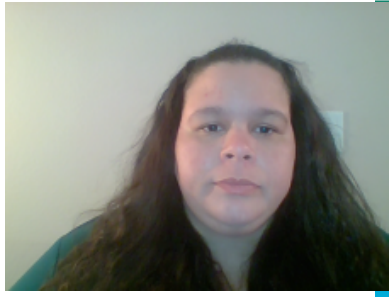
Capabilities and Infrastructure



Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)

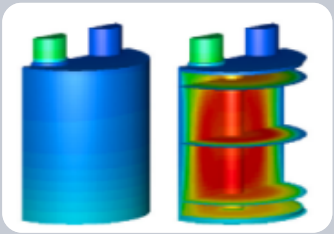
Battery Pack/System Testing
Thermal Test Complex (TTC) and Burnsite

Battery Calorimetry

Safety Science

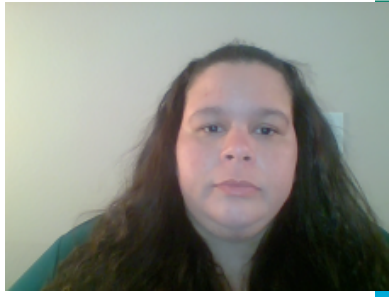
Materials R&D
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

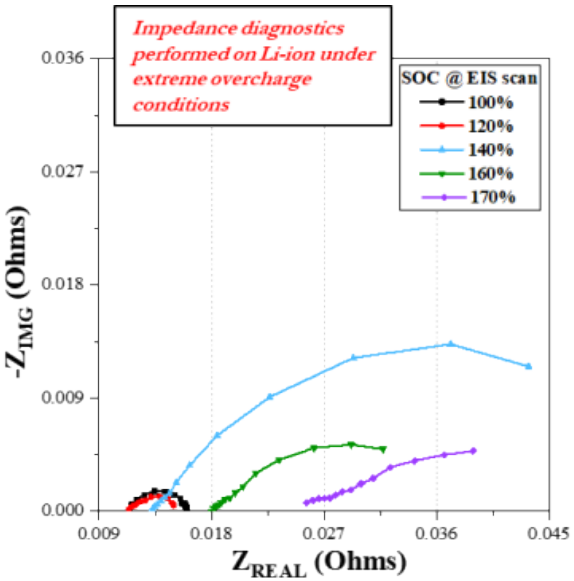
Testing
- Electrical, thermal, mechanical abuse testing
- Battery calorimetry
- Large scale thermal and fire testing (TTC)
- Failure propagation testing on batteries/systems
- Degradation and diagnostics during and post battery failure



Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating 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

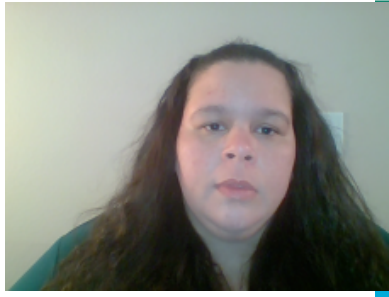




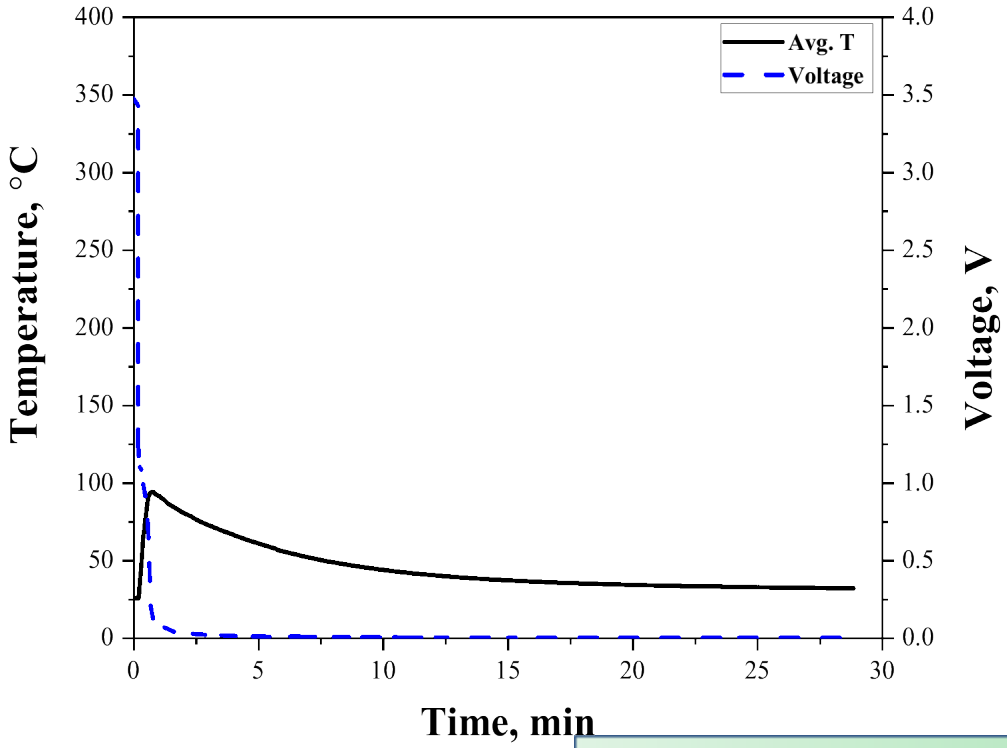
Sandia is uniquely positioned to study the entire life cycle of a technology.

New technologies present new risks. A high rigor environment at Sandia allows those risks to be adequately managed.

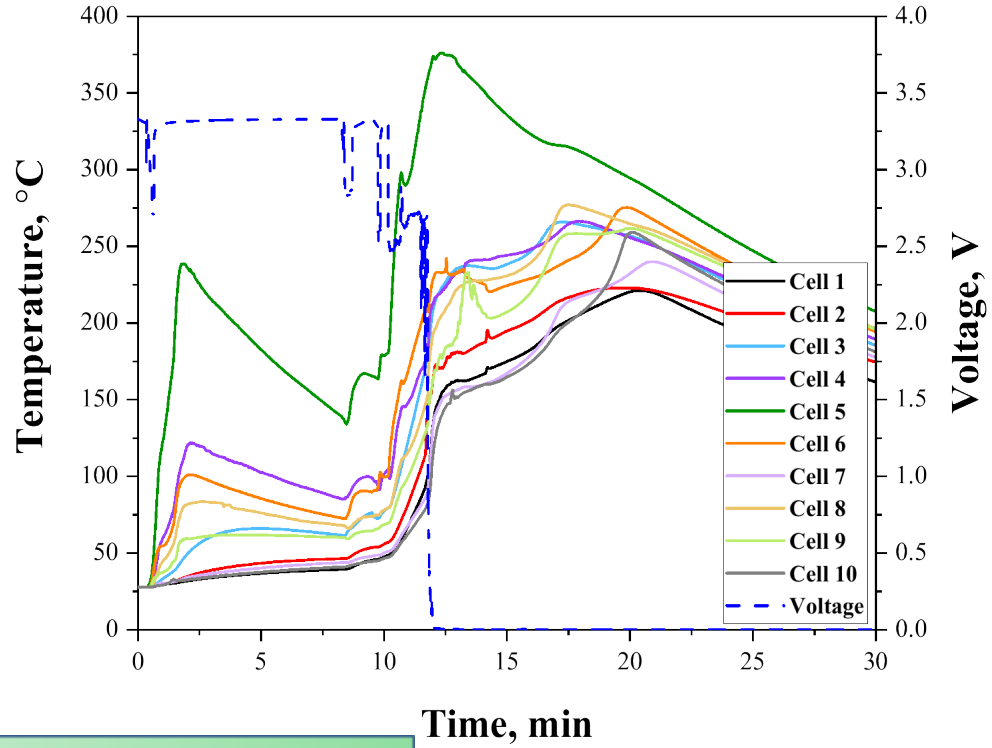
Motivation for Propagation Testing



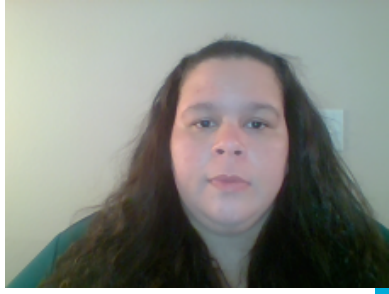
Single Cell Failure



How do these behaviors impact a larger, more complex system?



Strategies to Mitigate Failure Propagation



Passive Mitigation

- Heat dissipation (e.g., heat sink, phase change)
- Inter-cell/inter-module spacing (e.g., triangular configuration of cylindrical cells)
- Reduce available energy (e.g., limited state of charge)

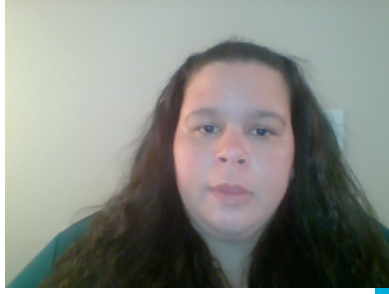
Active Mitigation (*external energy input required*)

- Air cooling
- Liquid cooling (e.g., water, ethylene glycol)

Objective

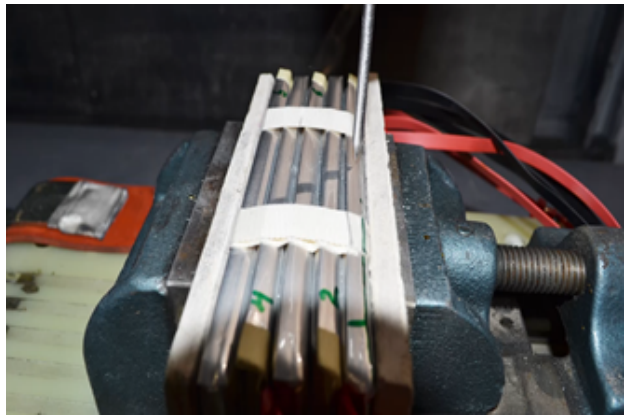
Reduce the risk of failure propagation with passive and active thermal management

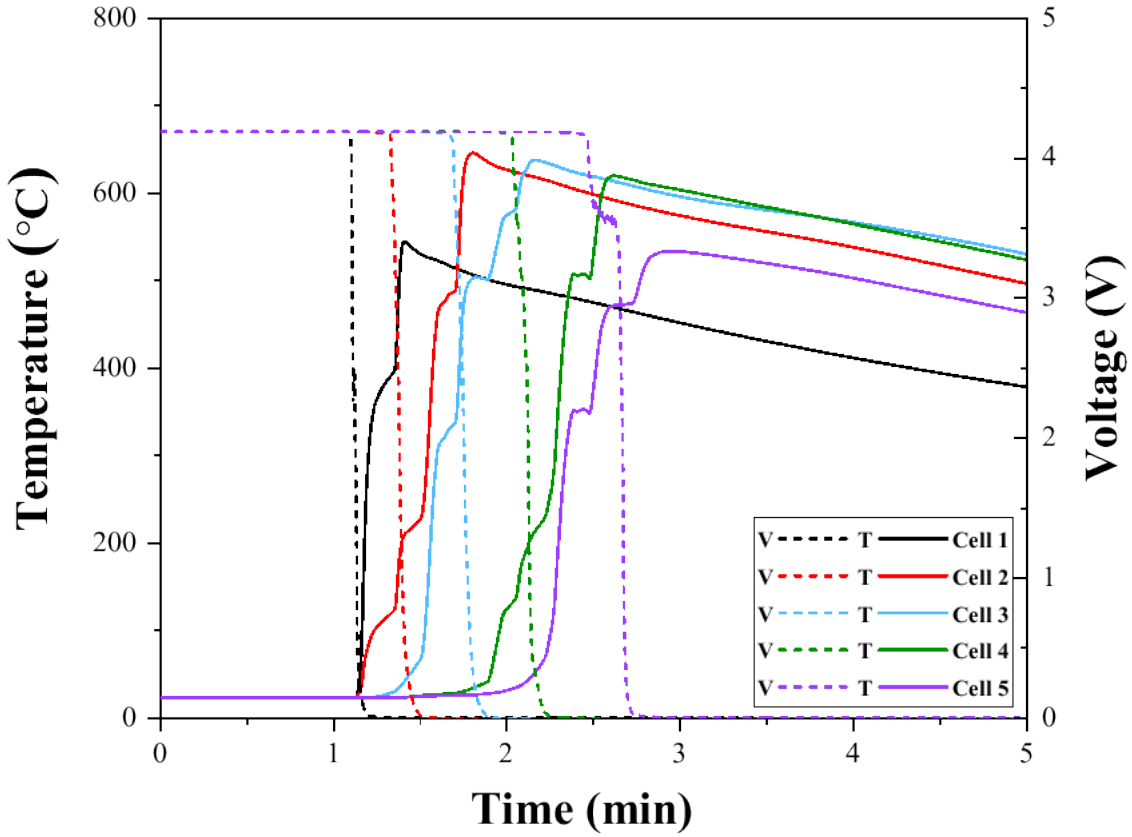
Unmitigated Failure Propagation



Test Details

- $LiCoO_2$ 3Ah pouch cells
- 5 closely packed cells
- Failure initiated by a mechanical nail penetration in the outer cell (cell 1)
- Thermocouples (TC) between cells





Torres-Castro, L. et al., (2020) J Electrochem. Soc., **167**(9): 090515
Kurzawski, A., et al. (2020). Proc. Combust. Instit. **38**.

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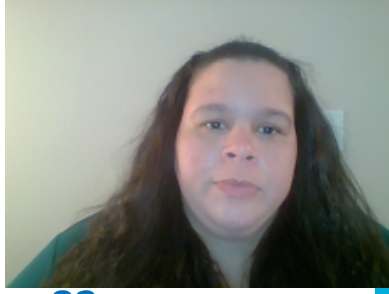

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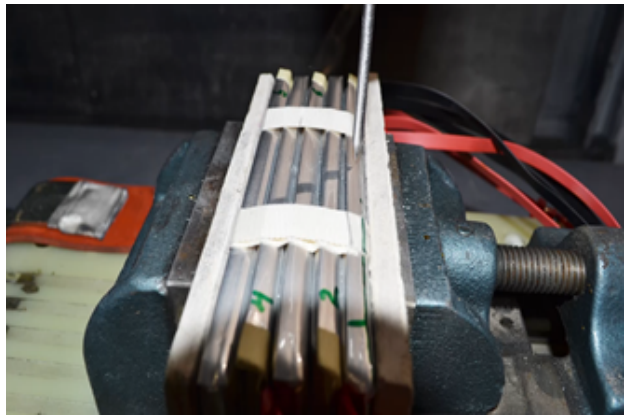
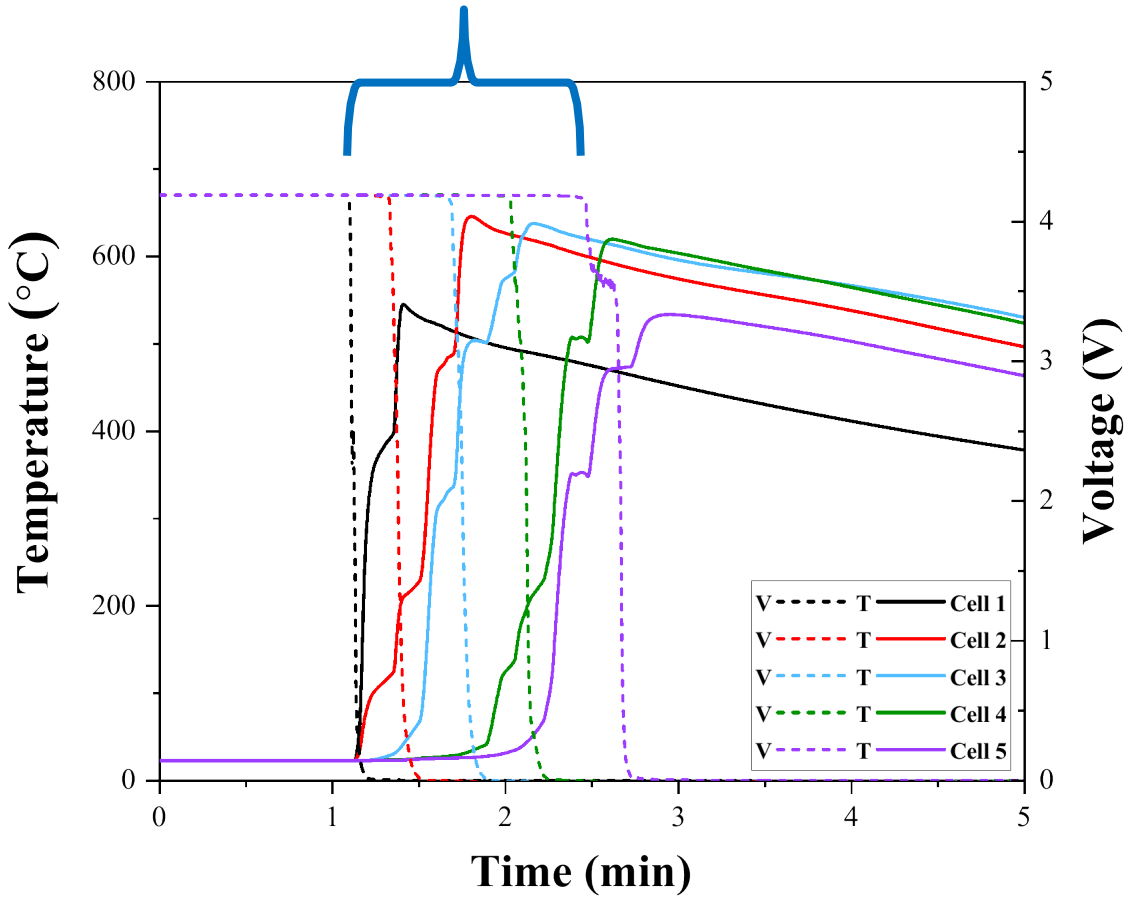


Cascading failure to entire battery over 82 s



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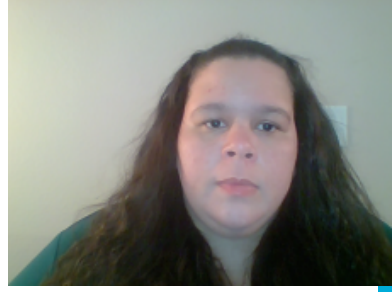
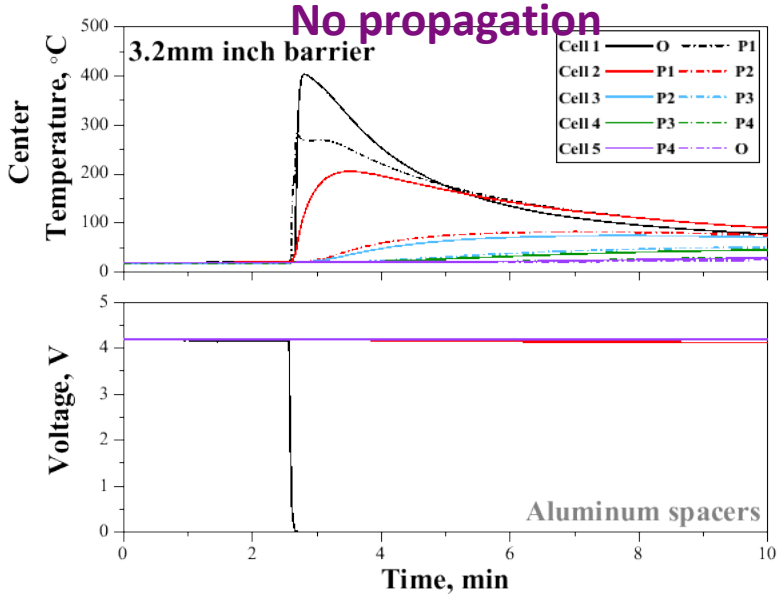
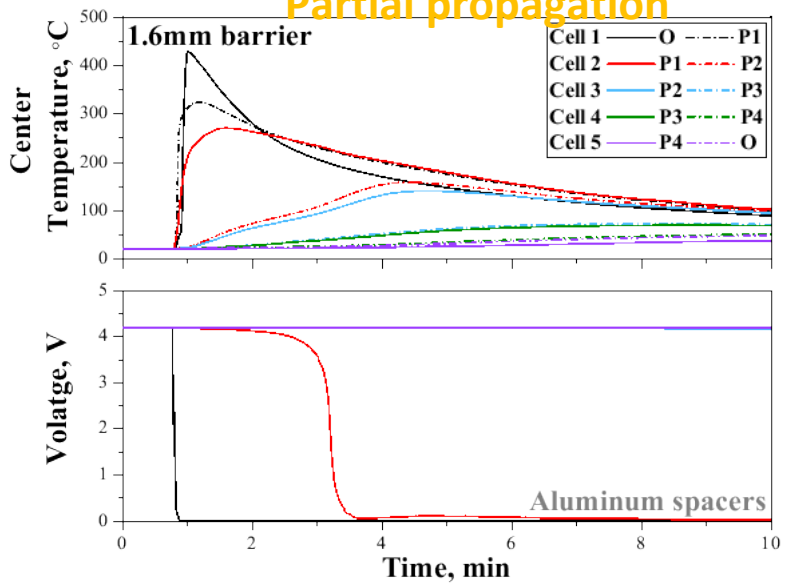
Failure Propagation with Passive Mitigation



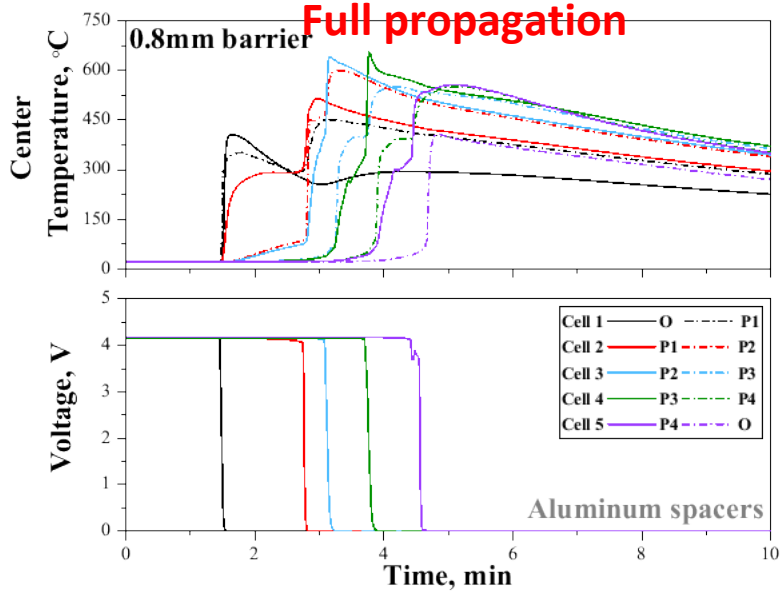
No propagation



Partial propagation



Full propagation



- The plates provided an additional thermal mass to dissipate heat release, hence reducing the risk of propagation
- Thinner plates did not prevent failure propagation, but they significantly reduced the overall heat release rate and propagation speed

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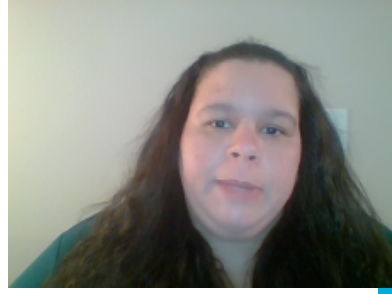
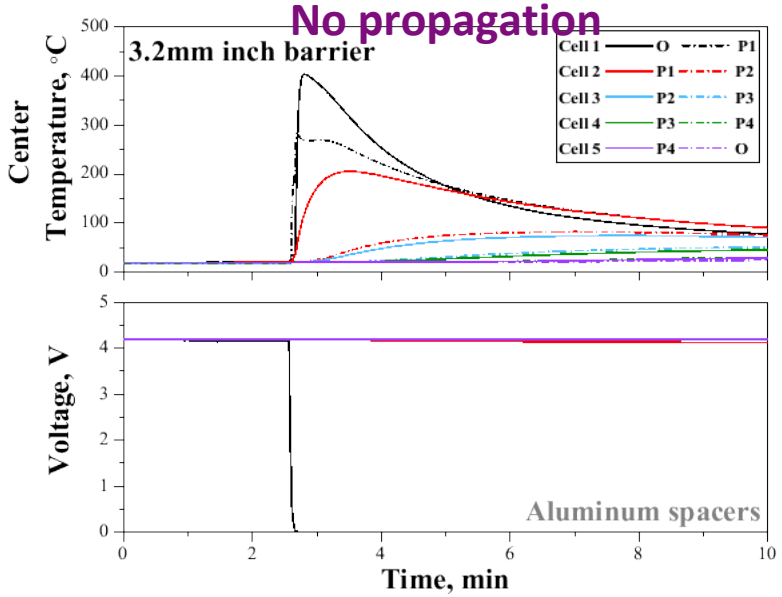
Failure Propagation with Passive Mitigation



Risk of Propagation

No propagation



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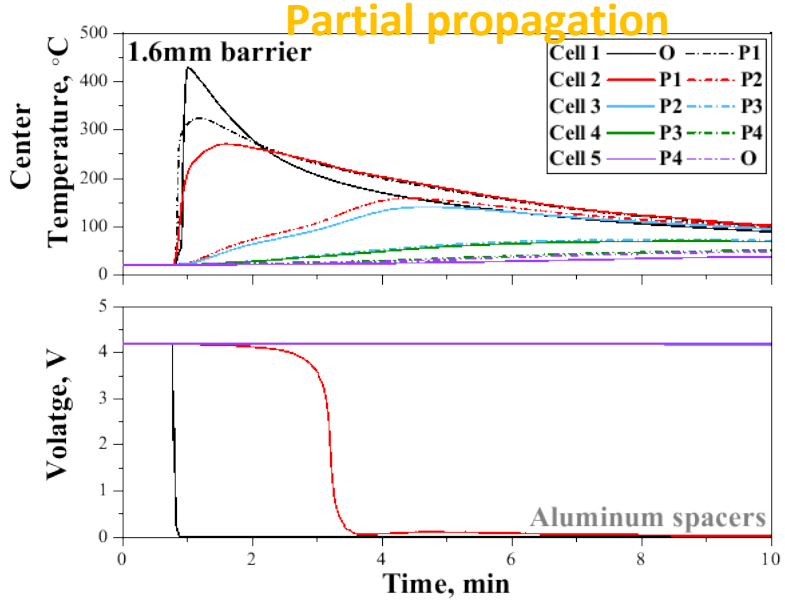
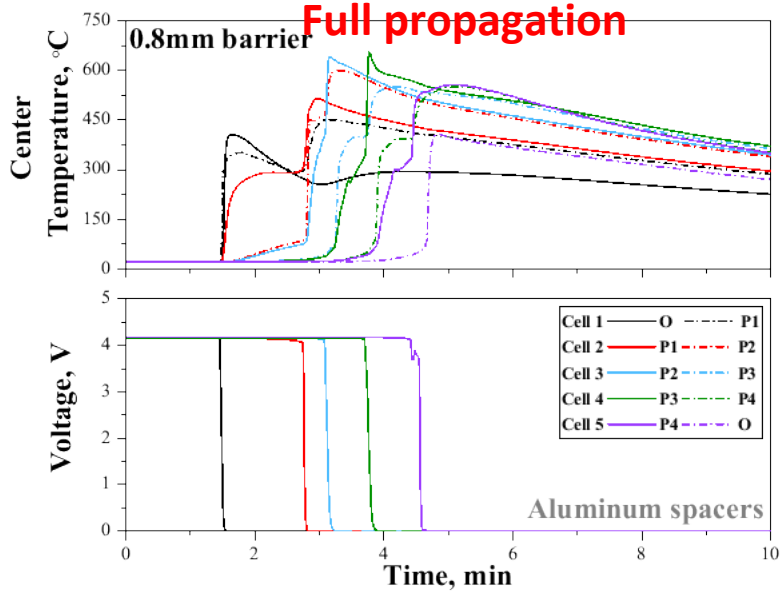


Full propagation



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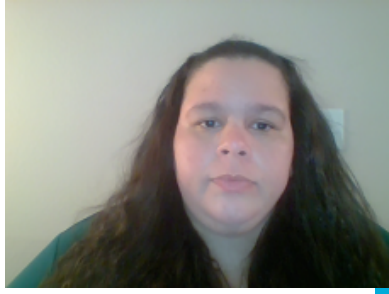
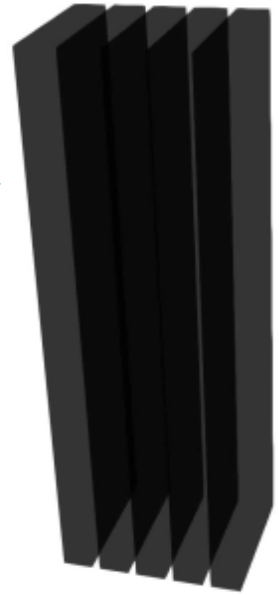
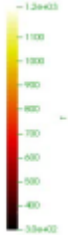
Predicting Thermal Runaway



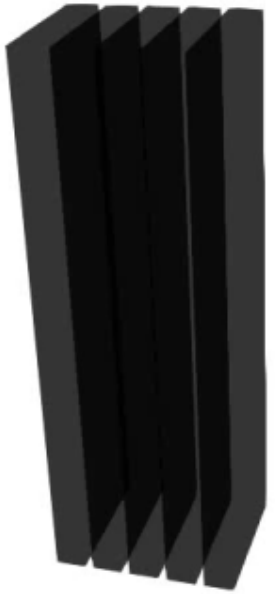
Large-scale testing is costly, and simulations allow exploration of the design space if well grounded in reality

Short circuit simulated in first cell acts as boundary condition

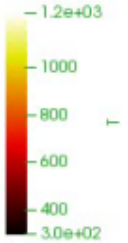




Baseline cell stack: Thermal runaway propagates



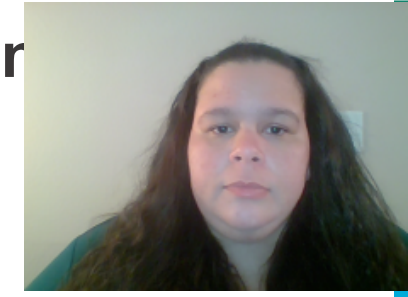
Thermal modifications (Reduced conductivity, increased contact resistance): **Propagation mitigated**

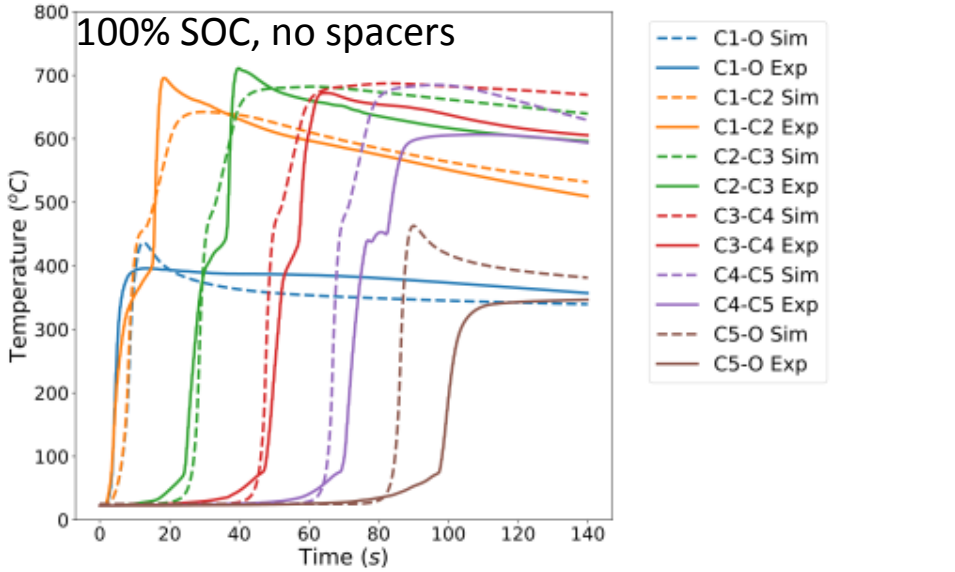


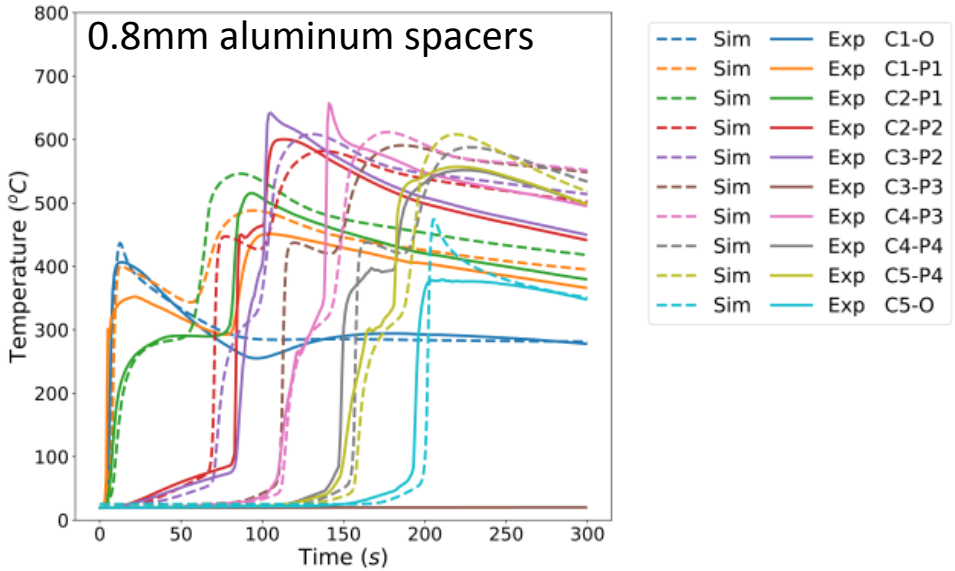
- Measurements are reality but simulations allows us to better understand the behavior changes
- Explore boundaries between mitigation and cascading failure

Lamb, J., et al. (2015). J. Power Sources **283**: 517-523.

Temperature-Time Propagation Measurements and Prediction
by Andrew Kurzawski



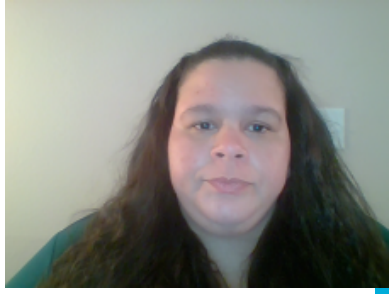




Metallic inserts

- Add heat capacity
- Increase time delay for cell runaway
- Prevent propagation for 30% increase in net heat capacity
- Reduced SOC results suggest homogeneous heat capacity changes of 25% sufficient

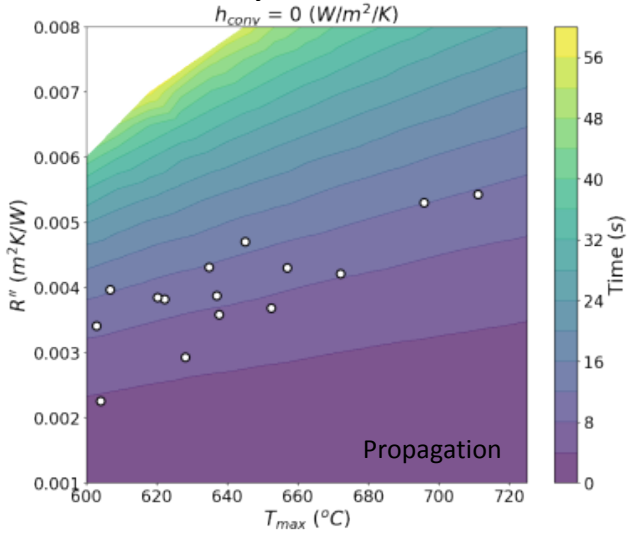
Limits of Failure Propagation
by Andrew Kurzawski



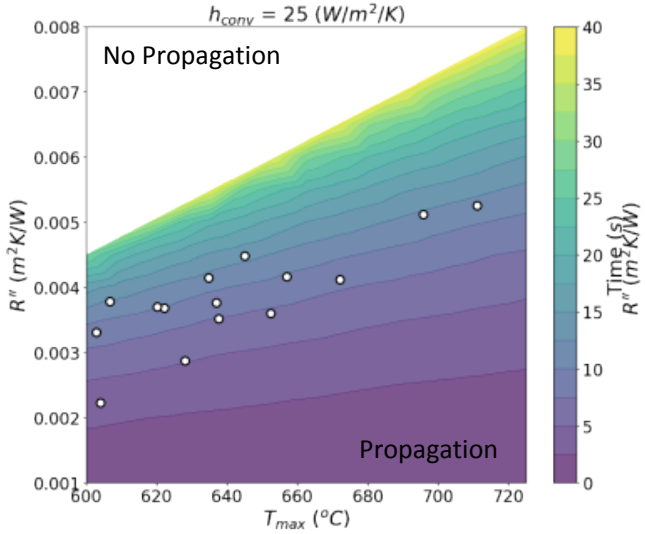
Energy per heat capacity, cooling and inter-cell resistance defines propagation limits

Model maps delay in propagation: yellow region is infinite delay—*failure to propagate*.

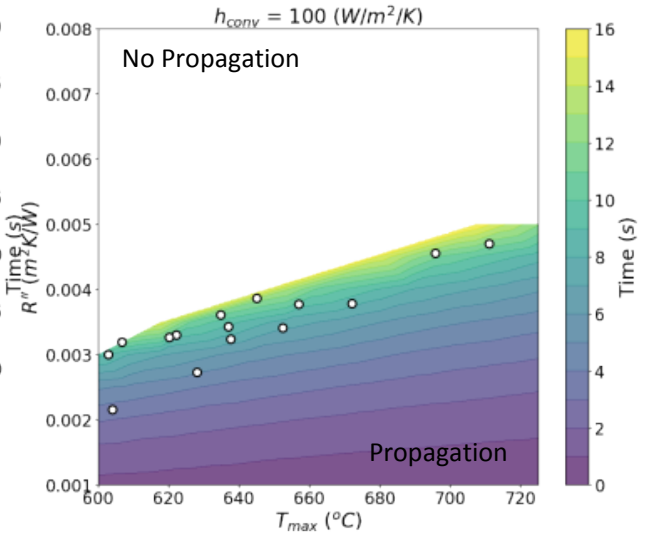
Fully insulated



Moderate cooling



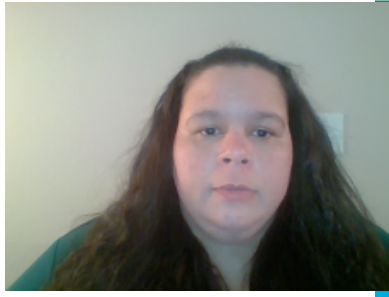
Strong air cooling

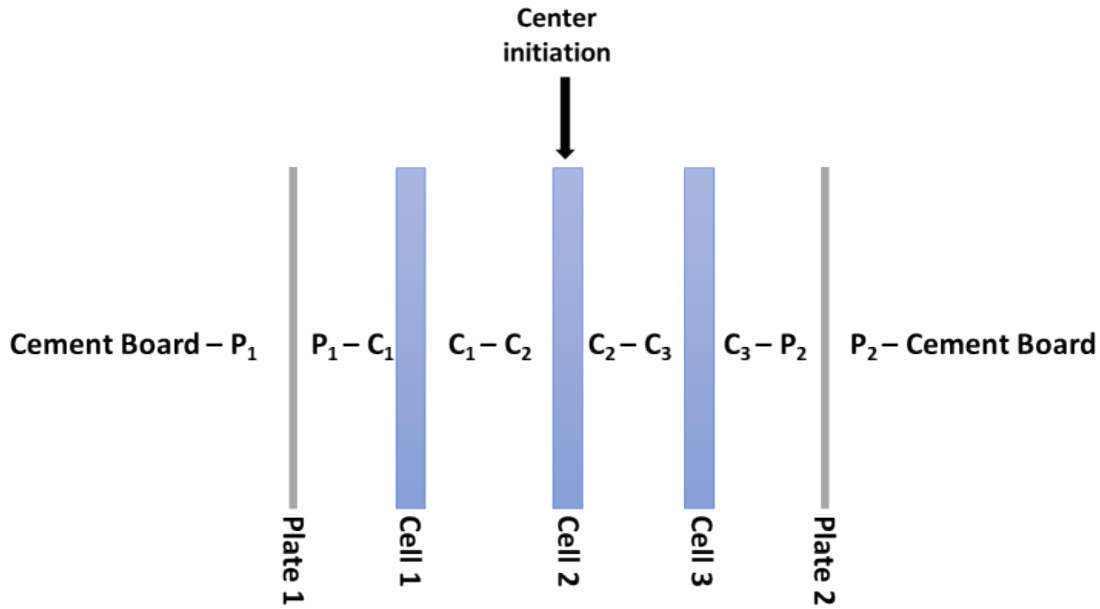


Convection cooling and conduction through stack results in failure to propagate for some scenarios.

Consider cost/design tradeoff : cooling versus thermal resistance.

Exploration of Mitigation Strategies Through Simulations





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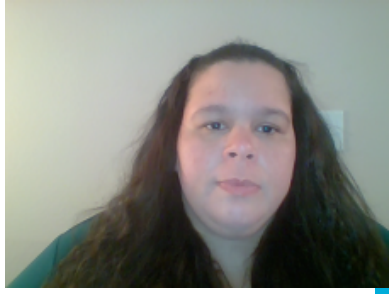
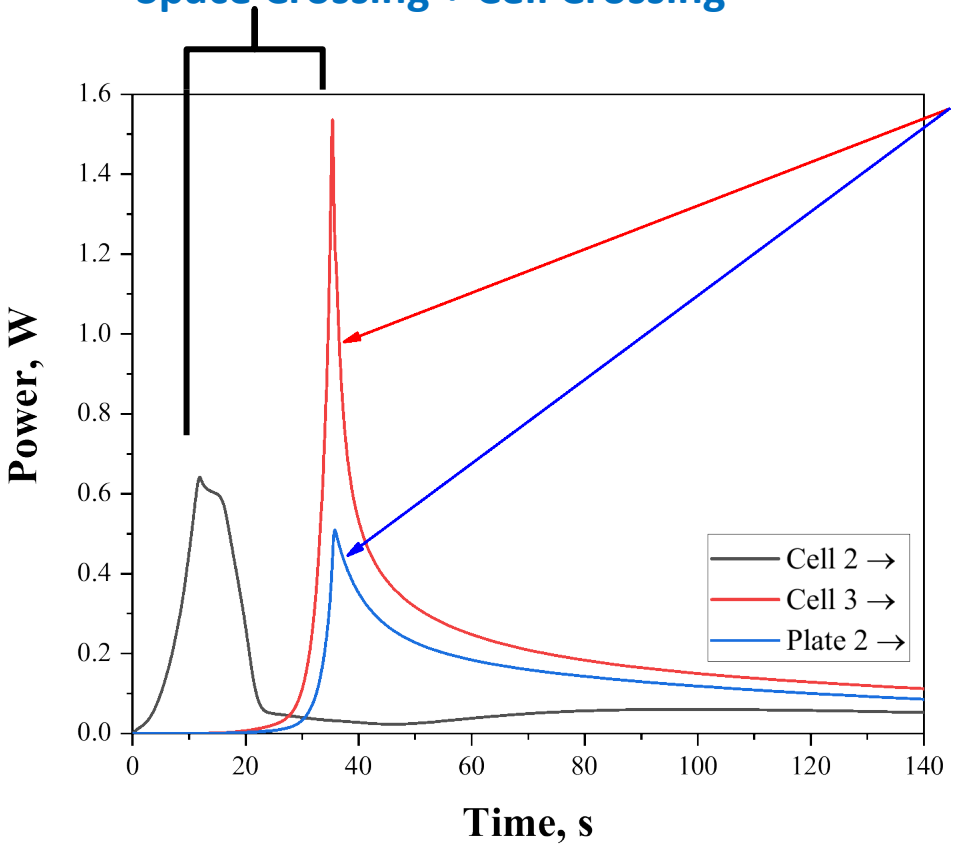
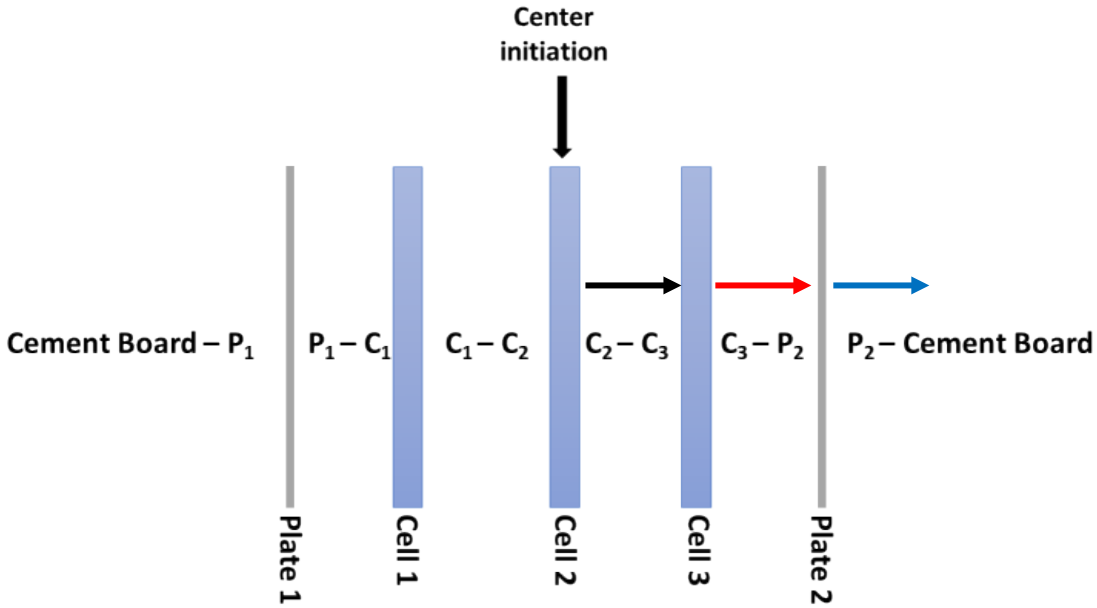


Space Crossing + Cell Crossing



Difference between heat out of last cell and heat out of plate



Exploration of Mitigation Strategies Through Simulations
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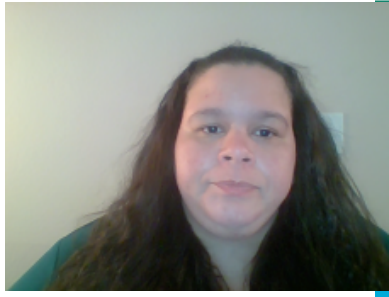
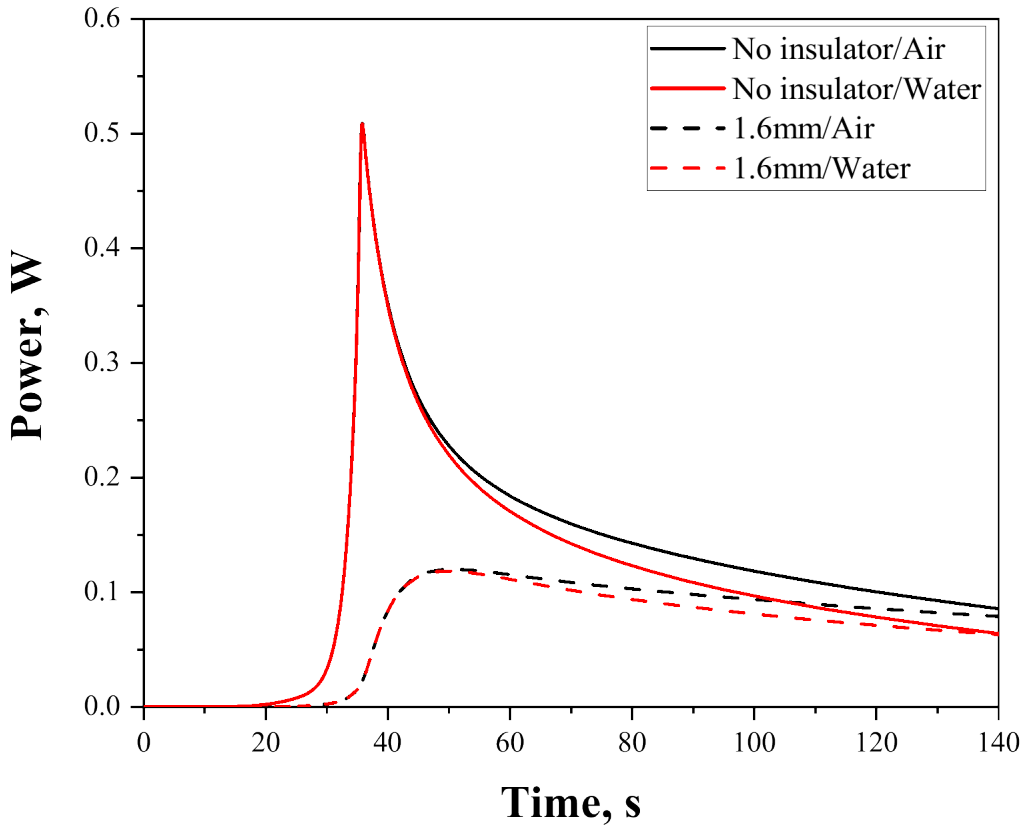
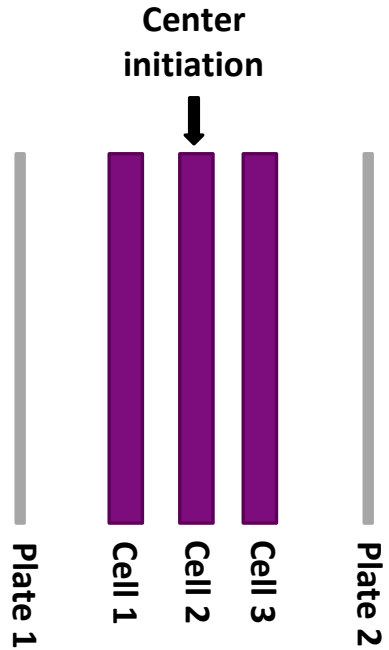


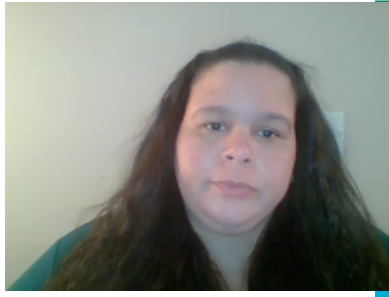
Effect of insulator thickness on the heat out of the battery pack



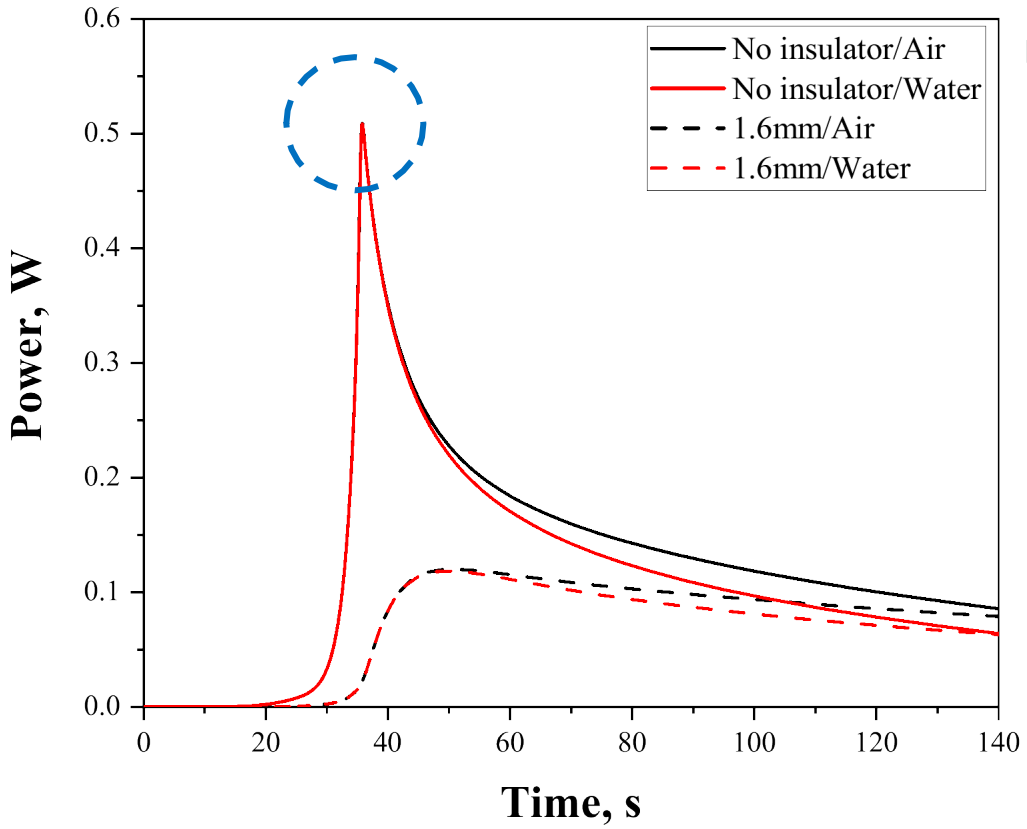


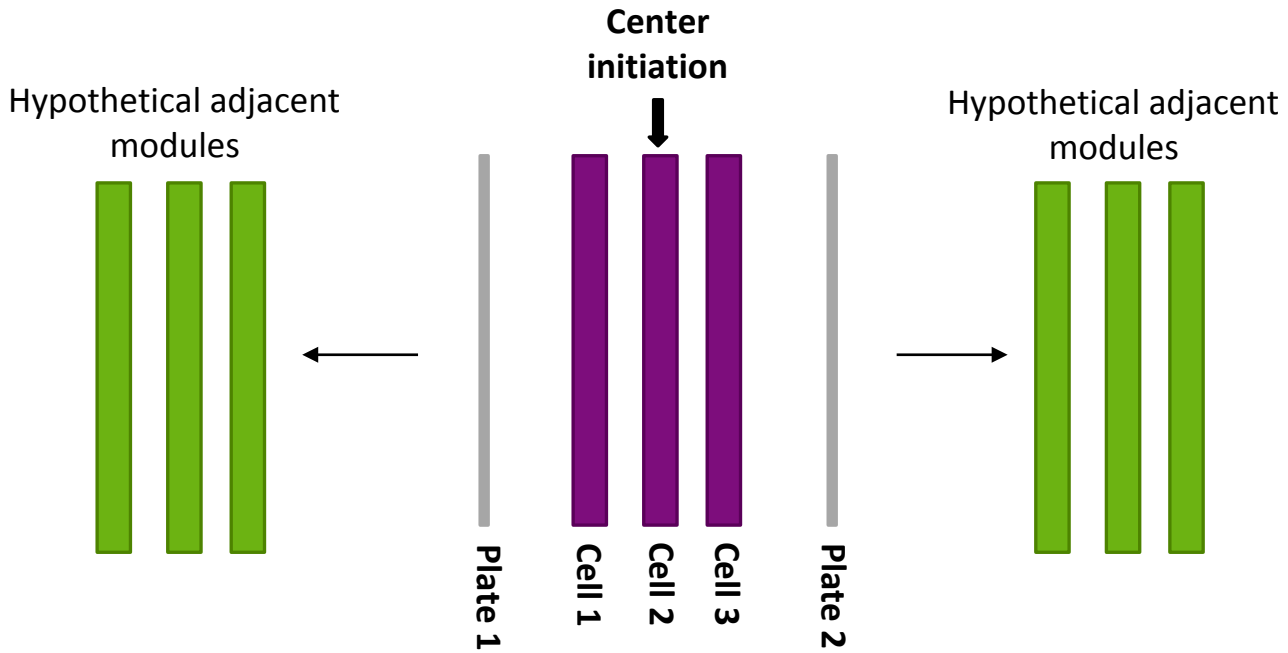
Water cooling increases decay rate of tails, indicating more heat transfer out of the stack

Exploration of Mitigation Strategies Through Simulations
by Randy Shurtz



Effect of insulator thickness on the heat out of the battery pack





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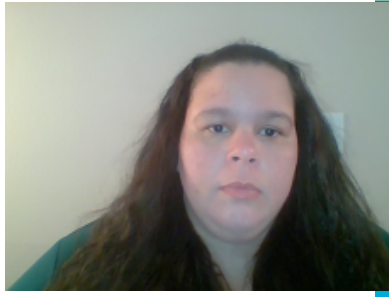

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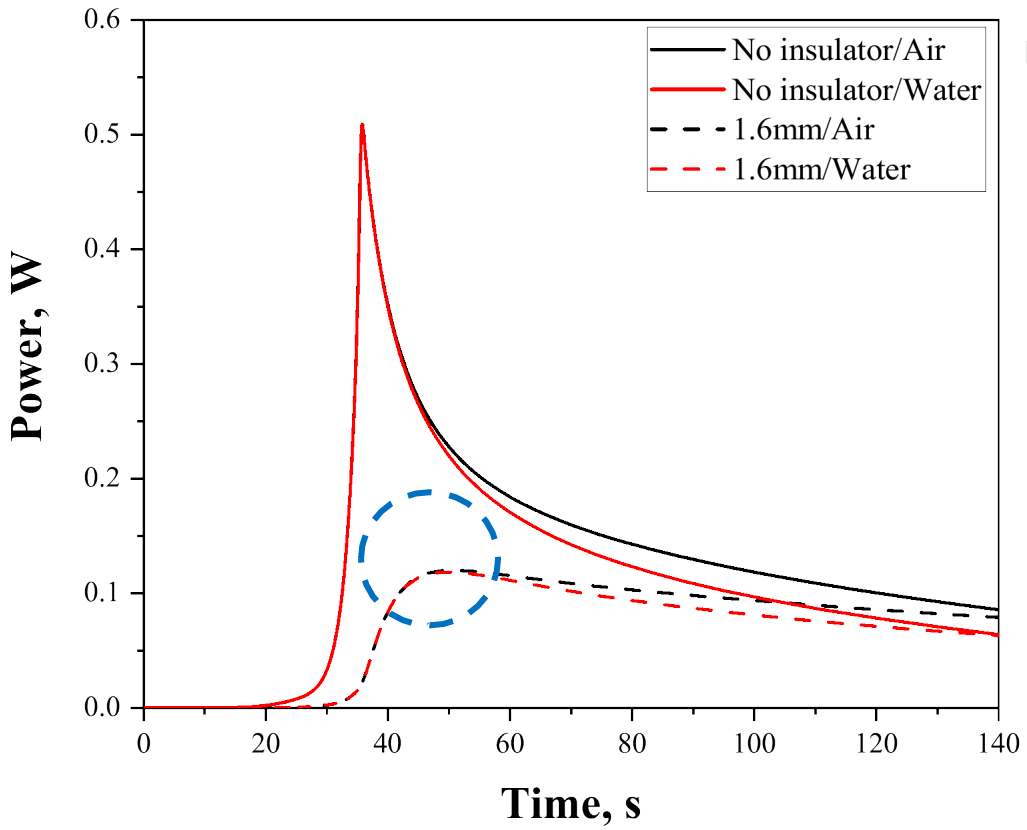
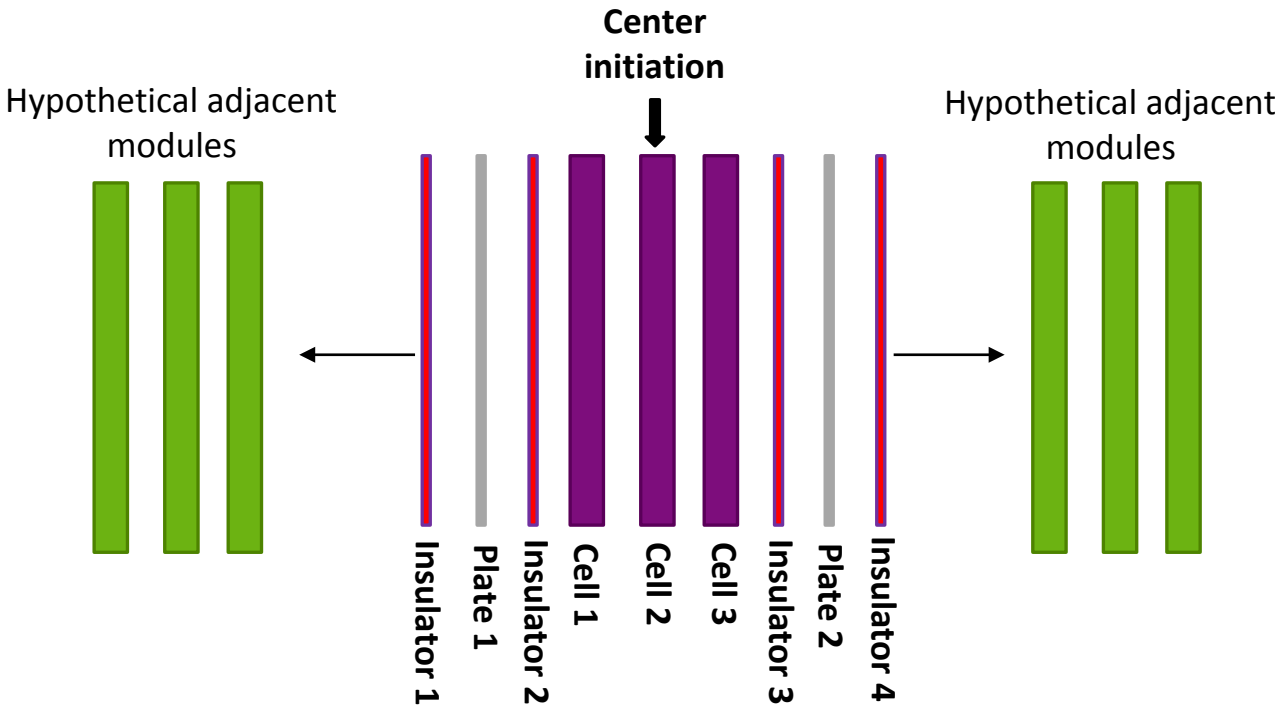
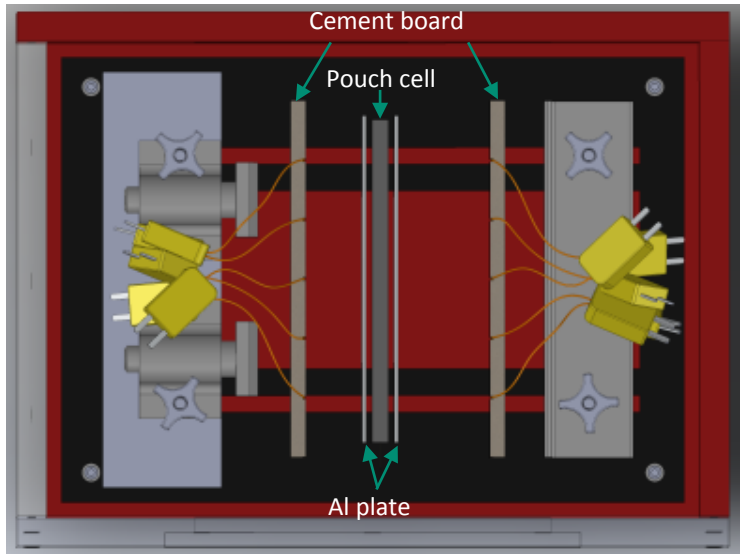
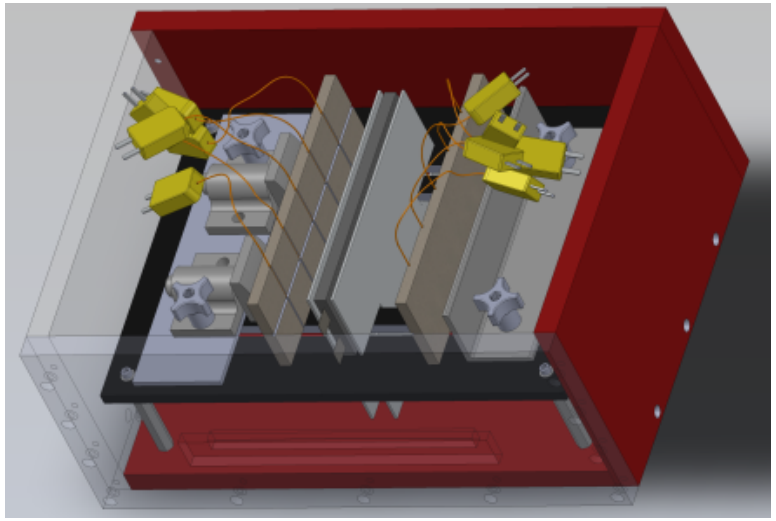




Insulation and structural materials delay heat transfer to adjacent cells/modules and allow for heat dissipation

Model Based Experimental Design

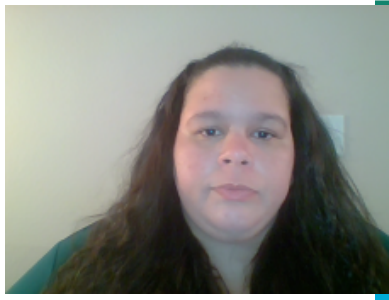




Test matrix

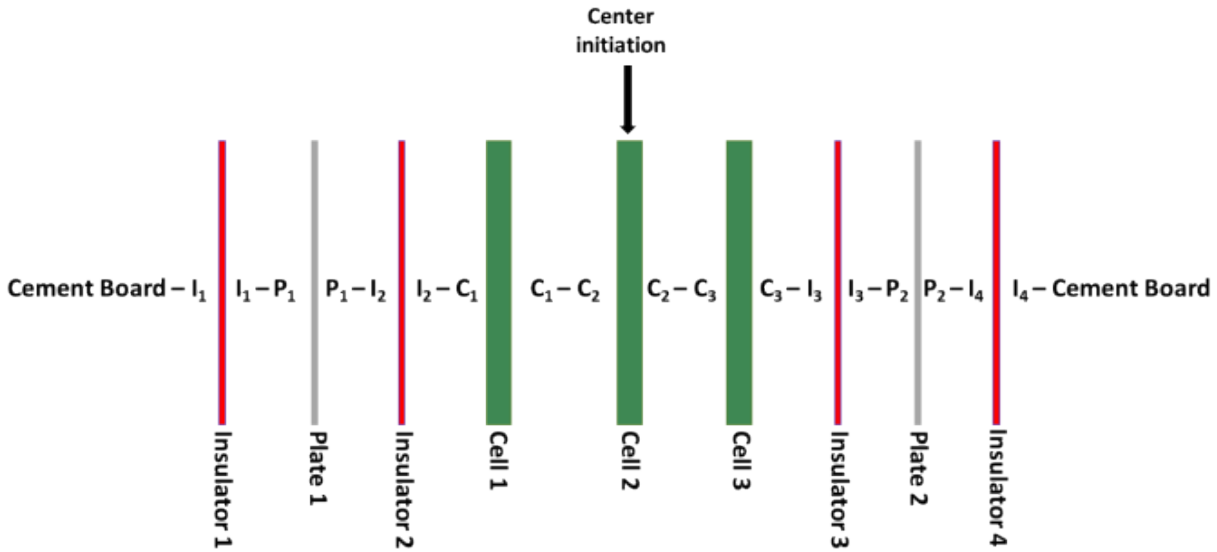
3x pouch cells

- Baseline
- Al Plate/Insulator
- Al Plate/Insulator/Water

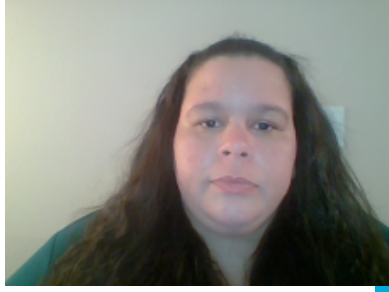


Al plate
0.8mm
G10 insulator
0.4mm or 1.6mm

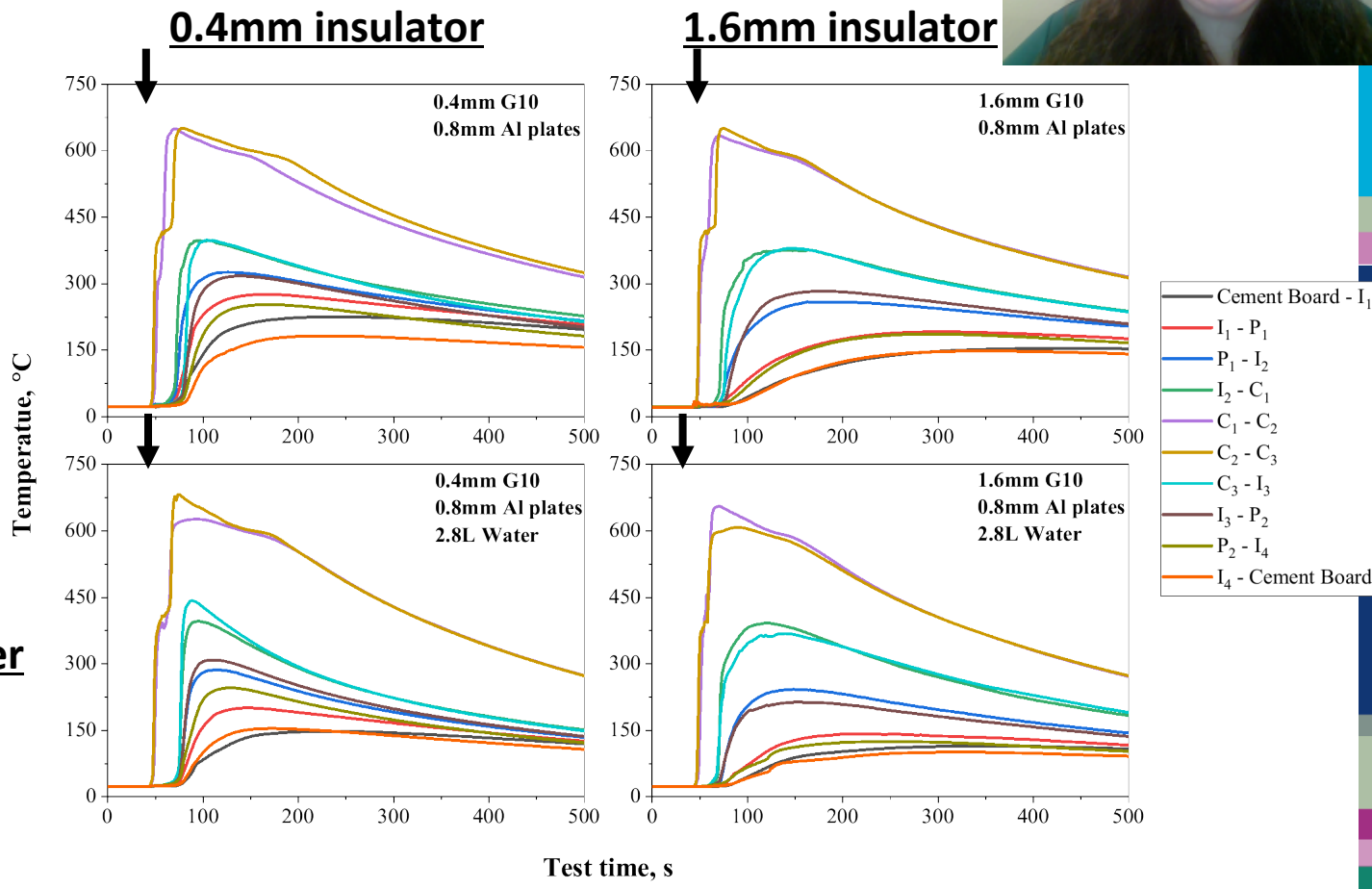
Thermocouple map



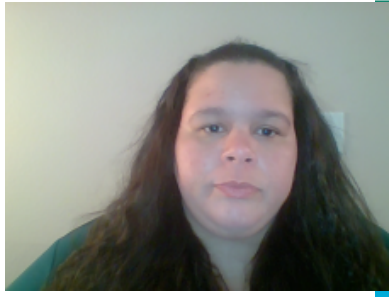
Temperature Profile



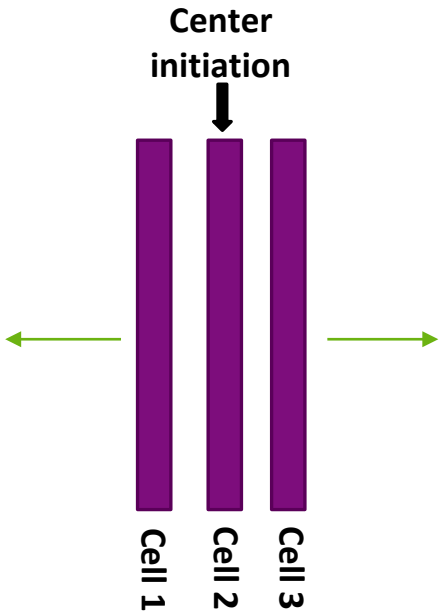
The maximum temperature of the failed cell remained in the same region independently of insulator thickness or level of cooling (air/water)



Temperature Profile



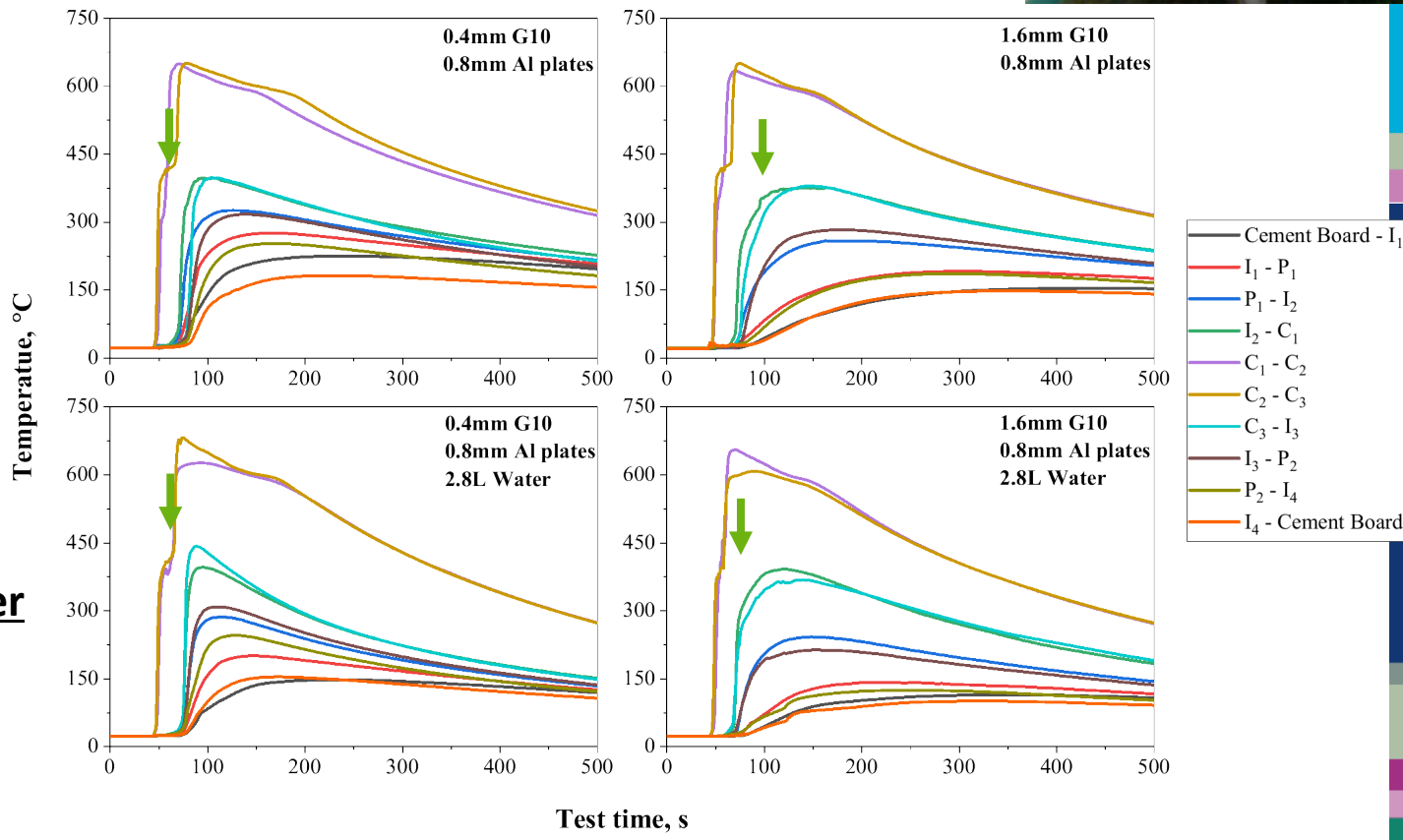
No mitigation = heat transfer from the edge cell to the adjacent module sufficient to trigger thermal runaway



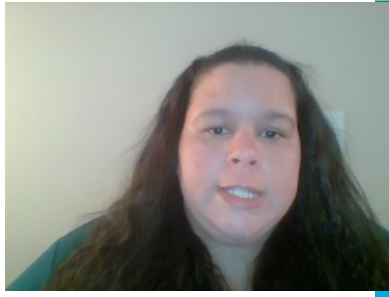
0.4mm insulator **1.6mm insulator**

Plate

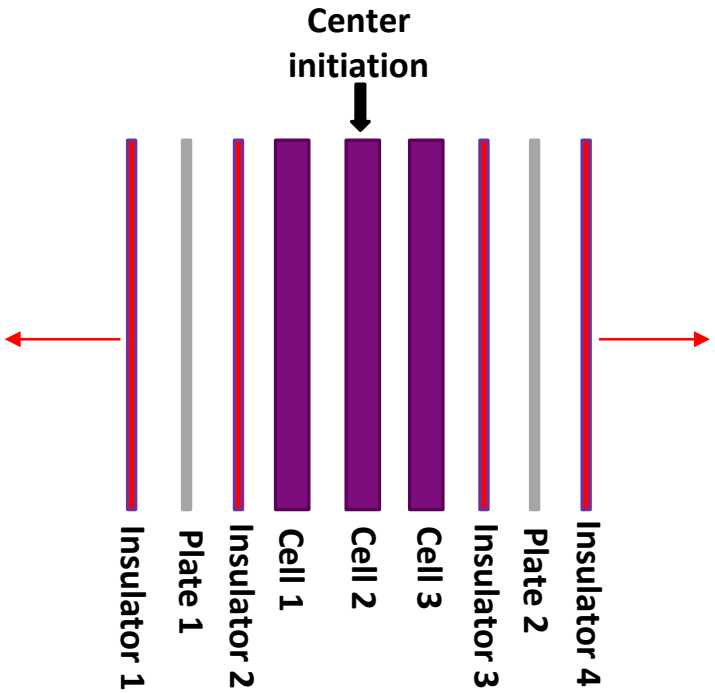
Plate/Water



Temperature Profile



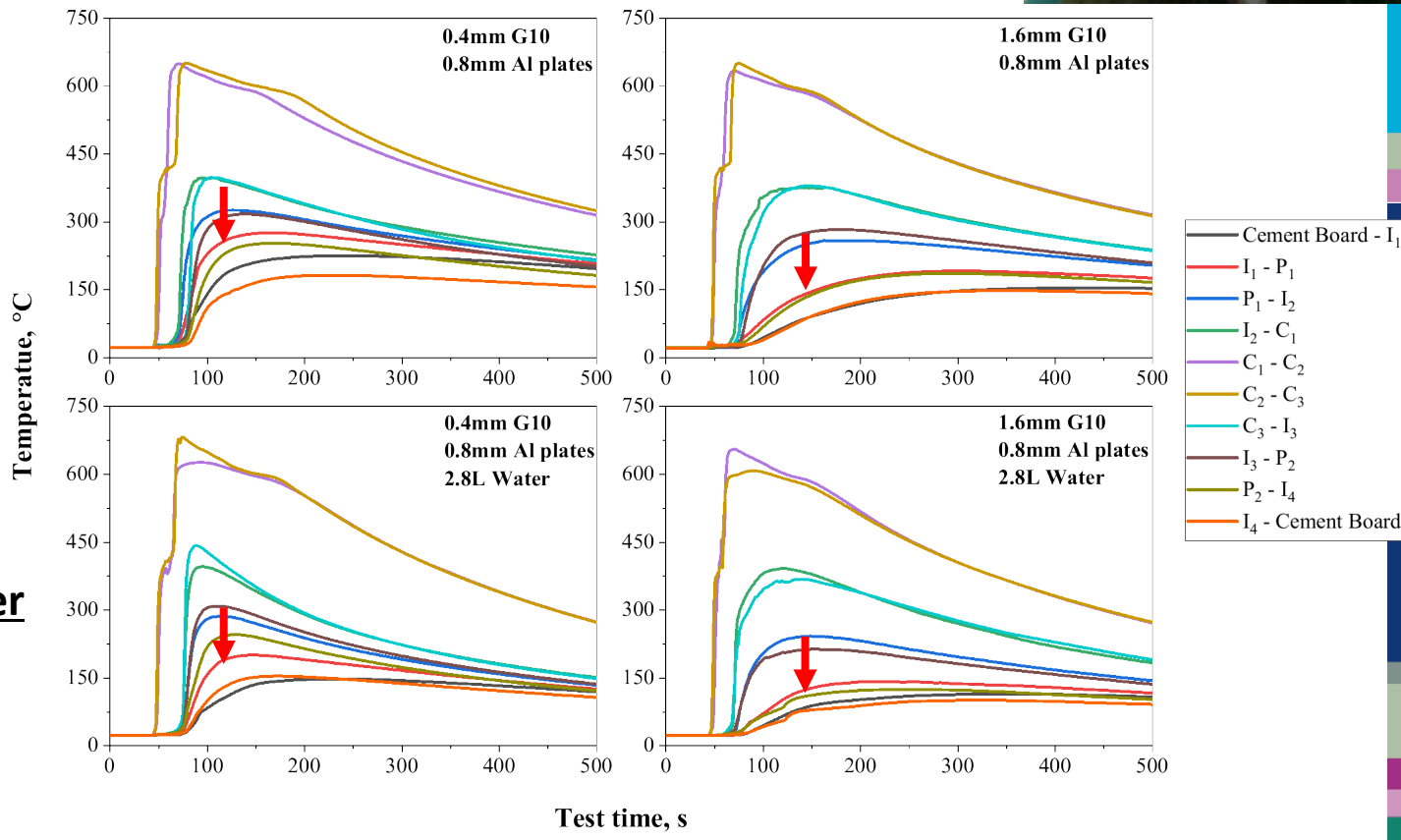
Mitigation = Adjacent module exposed to temperature between 100˚C-150˚C, reducing the risk of thermal propagation



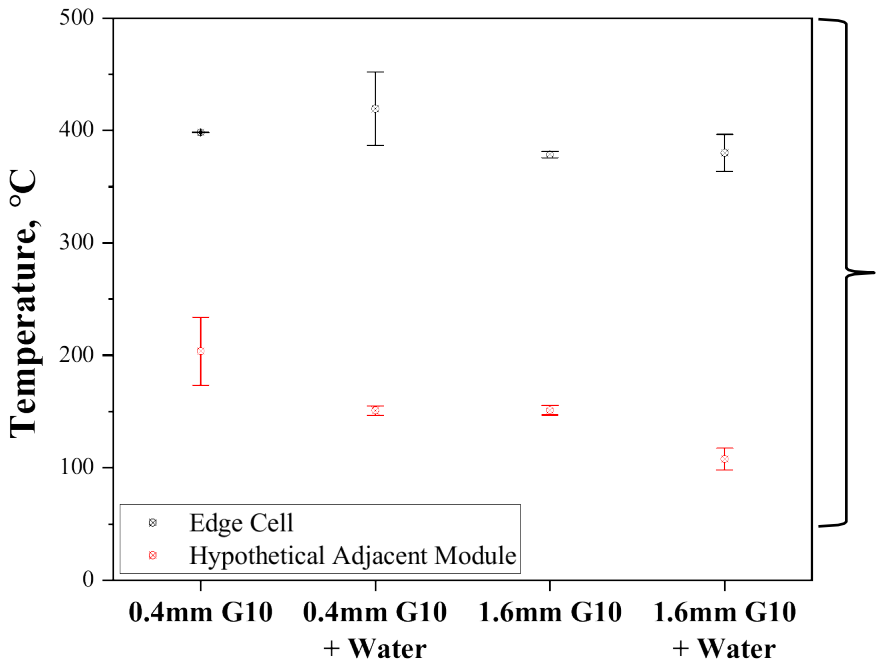
Plate

Plate/Water

0.4mm insulator **1.6mm insulator**

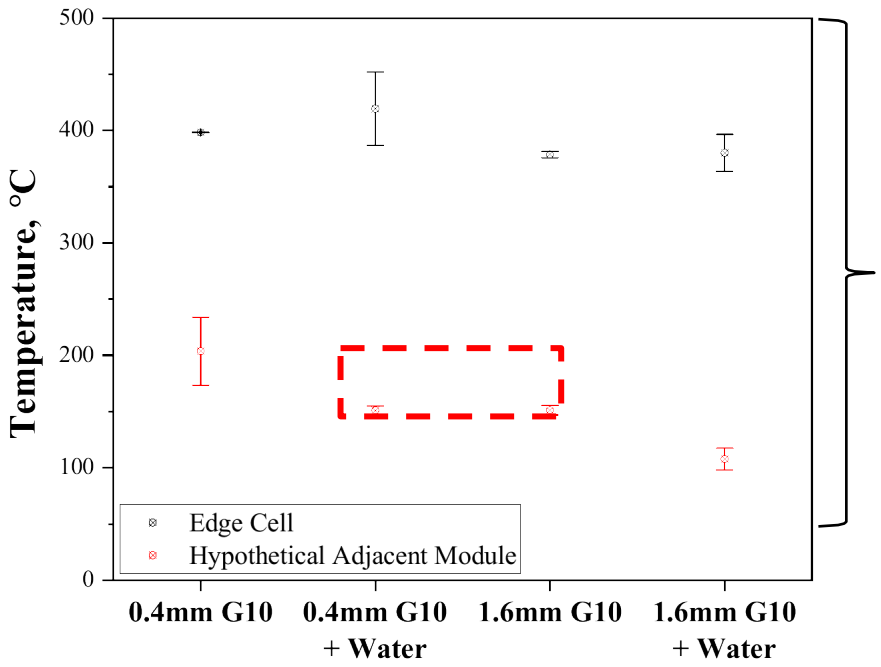


Hypothetical Adjacent Module Temperature Exposure



- The hypothetical adjacent module will be exposed to temperatures nearly identical when using 0.4mm G10 insulator with water-cooled plates or 1.6mm G10 insulator with no water
- Thicker insulators and the inclusion of water reduces the risk of failure propagation

Hypothetical Adjacent Module Temperature Exposure



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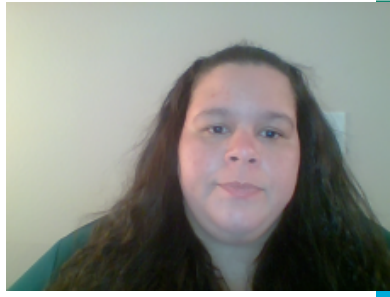
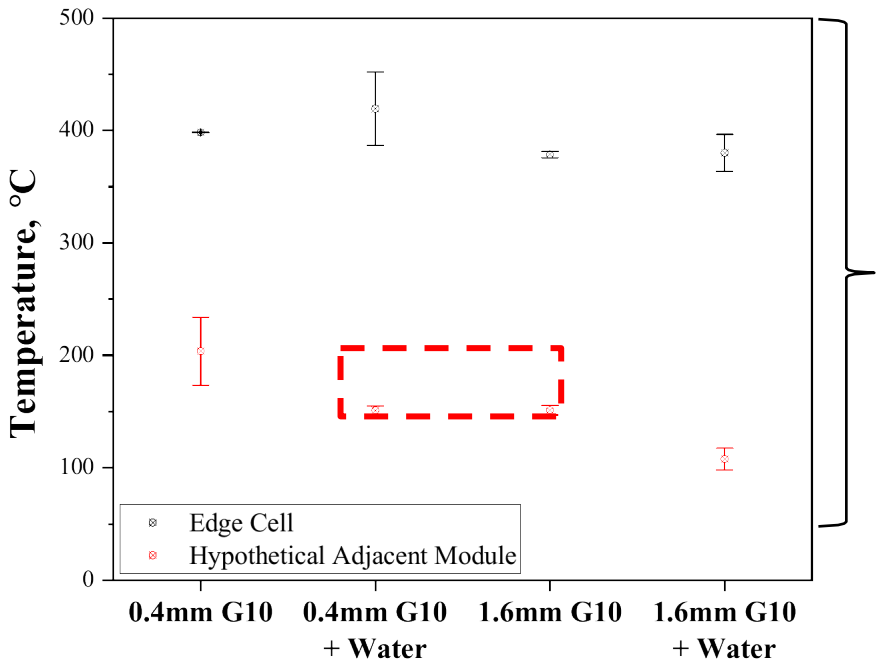
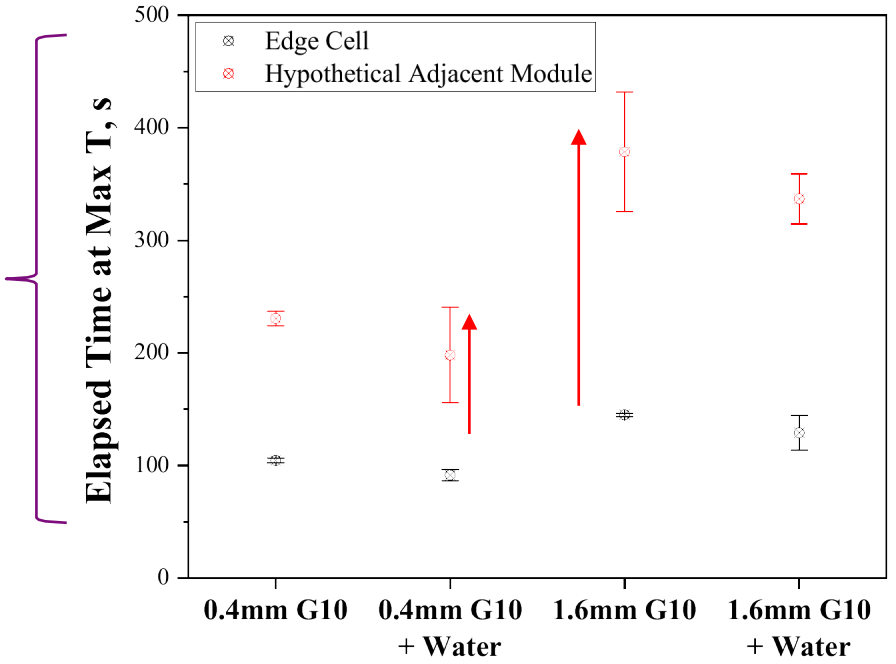
Hypothetical Adjacent Module Temperature Exposure



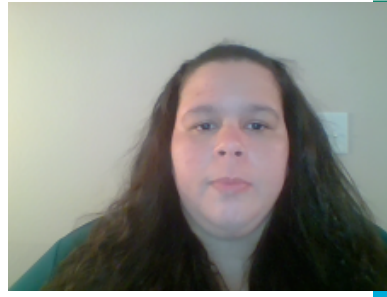


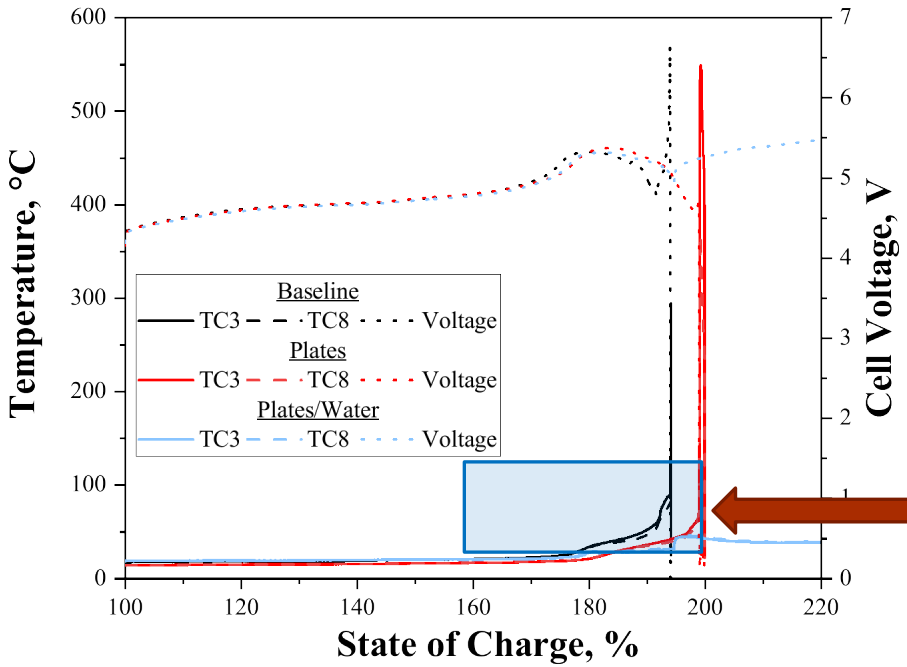
- The hypothetical adjacent module will be exposed to temperatures nearly identical when using 0.4mm G10 insulator with water-cooled plates or 1.6mm G10 insulator with no water
- Thicker insulators and the inclusion of water reduces the risk of failure propagation

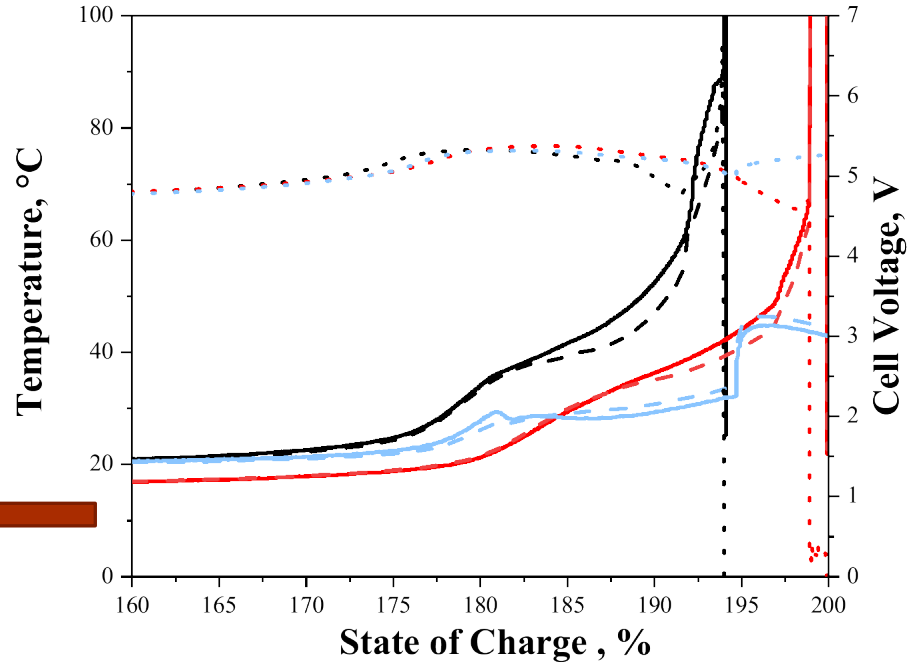
The elapsed time at the max. temperature further demonstrates that adding thermal mass slows down the heat transfer to the hypothetical adjacent module

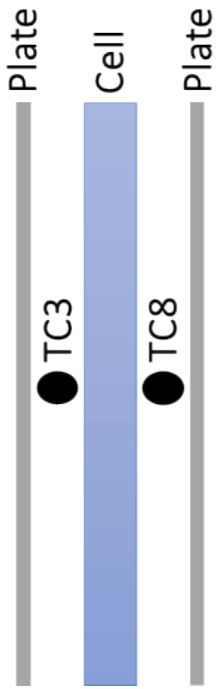


Overcharge Behavior with Air and Water Cooling



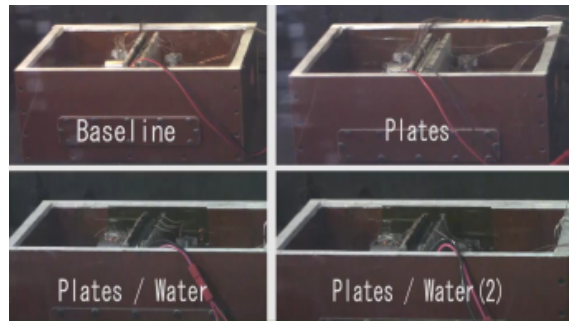




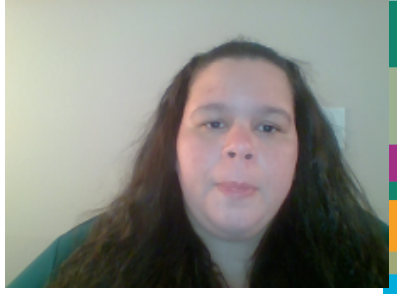


For SOCs >175%

- ✓ Baseline - faster self-heating and an earlier onset SOC to thermal runaway
- ✓ Plates - slower self-heating with maximum temperatures ~500°C
- ✓ Plates/Water - No thermal runaway

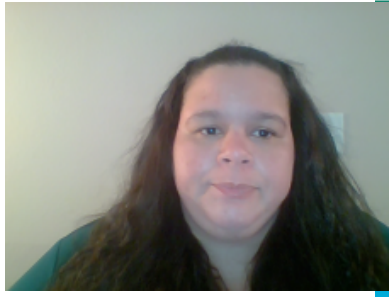


Summary



- A cell may exhibit a dramatically different failure response when in a string, module, or pack than during single -cell abuse testing
- Metallic plates are effective in small packs, but there is a trade-off between cost, weight, and volume
- Understanding of heat transfer is critical to incorporate the dynamics of heat transfer and make use of the system thermal mass
- Failure testing of large, complex systems is resources intensive. Model-based designs present a potential remedy to this, allowing us to infer a large amount of information from a relatively small number of tests.

Project Contacts



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