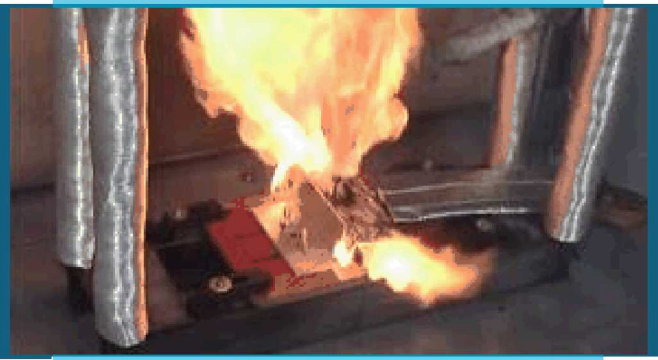
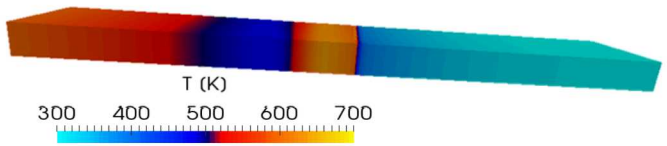
SAND2020-10222C

Thermal Analysis to Mitigate Cascading Propagation of Lithium-Ion Cell Stacks





PRESENTED BY

John Hewson, Andrew Kurzawski, Randy Shurtz,

Loraine Torres-Castro, Yuliya Preger, Joshua Lamb

Office of Electricity Peer Review, September 30, 2020

SAND2019-11411 C

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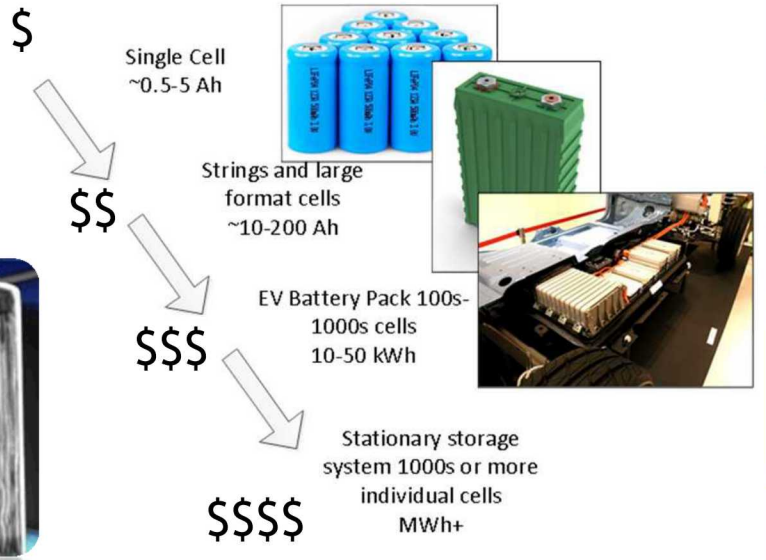
BACKGROUND OVERVIEW
Predicting and Mitigating Thermal Runaway

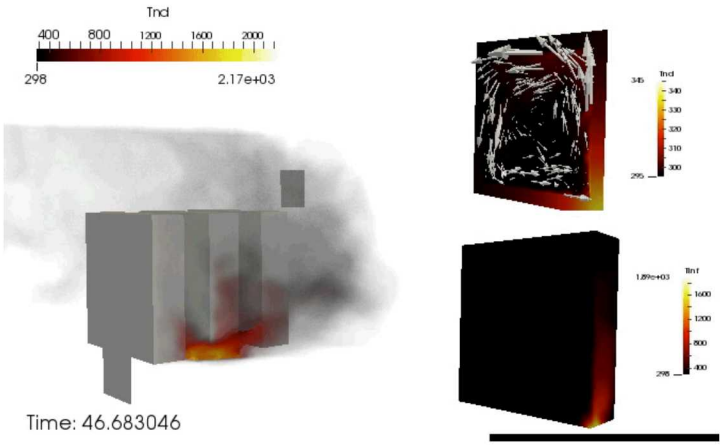
Validated safety and reliability is one of the critical challenges identified in 2013 Grid Energy Storage Strategic Plan

Safety incidents are rare but possible, including external causes.

How can we reduce facility investment risk?

- Prevent single point failure from cascading to large-scale system risk.
- Current approach is test to safety.





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

- Link source terms to material science – morning talk by Randy Shurtz.

www.cnn.com www.nissan.com
www.samsung.com www.saft.com
www.internationalbattery.com

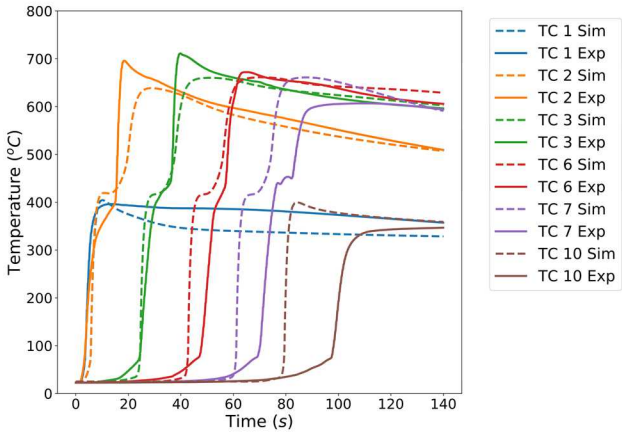
OBJECTIVES

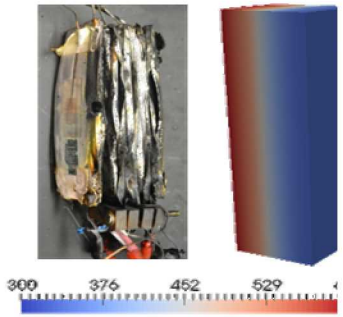
Provide robust system scale safety and reliability

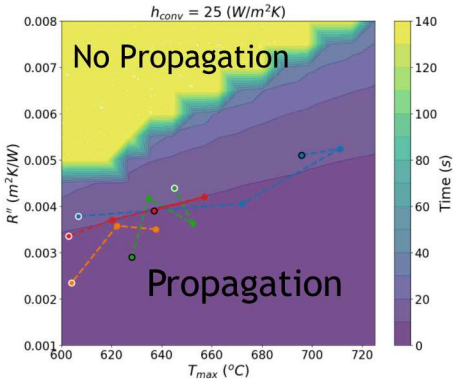
Validated safety and reliability is one of the critical challenges identified in 2013 Grid Energy Storage Strategic Plan

Develop methods to mitigate any point failures by avoiding propagation

1. ***Develop validated predictive models of cell-to-cell*** then module-to-module propagation.
   - Concurrent ***experimental program*** for validation (Loraine Torres-Castro)
   - Other tasks link predictive heat release to material science (Randy Shurtz)
2. Identify ***boundaries of propagation versus mitigatio***
   - ***Thermal aspects of system design***
   - Electrical aspects of system design
   - Battery chemistry and material science
   - Algorithms for active control strategies.
3. Develop capabilities to evaluate design tradeoffs.
4. Promote a broader acceptance of quality approaches to energy storage safety.





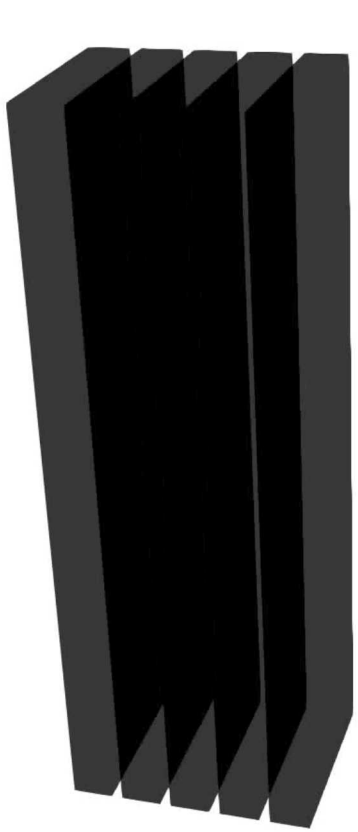


OVERVIEW
Predicting and Mitigating Thermal Runaway

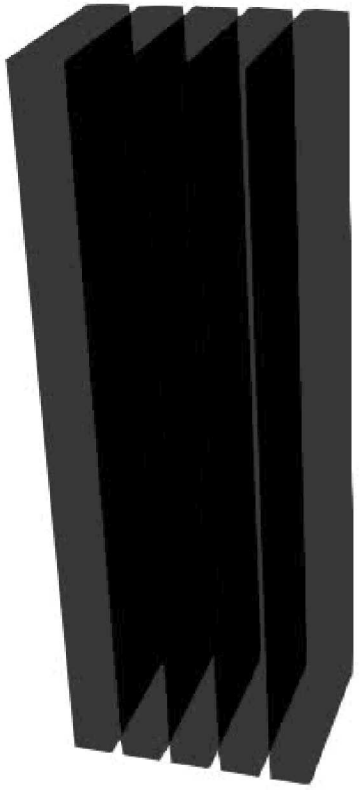
How can we reduce facility investment risk?

- Identify boundaries between mitigation and cascading failure

Short circuit simulated in first cell acts as boundary condition →



Baseline cell stack: Thermal runaway propagates

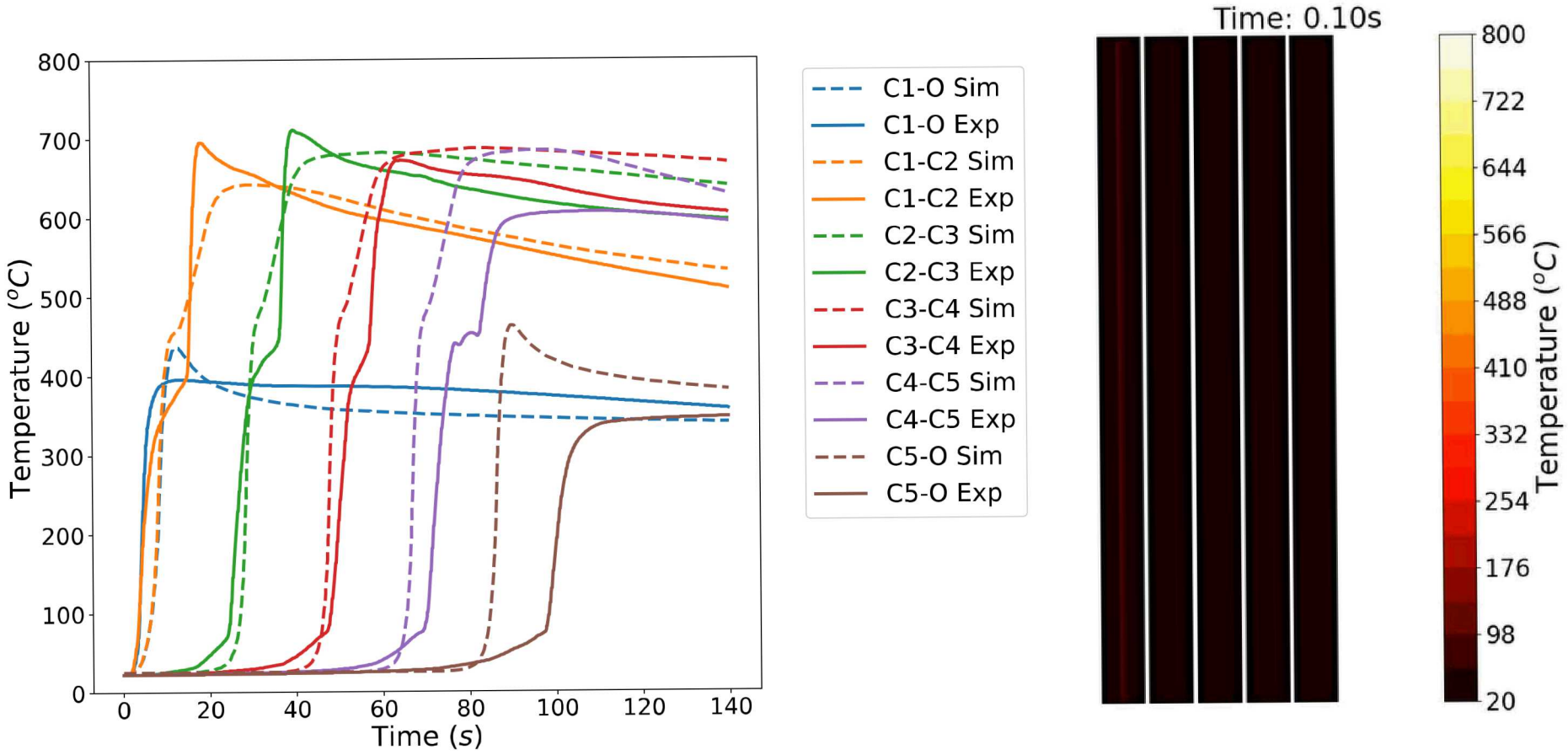


Thermal modifications (Reduced conductivity, increased contact resistance): **Propagation mitigated.**

Torres-Castro, L. et al., (2020) J Electrochem. Soc., **167**(9): 090515

RESULTS - Predicting Thermal Runaway

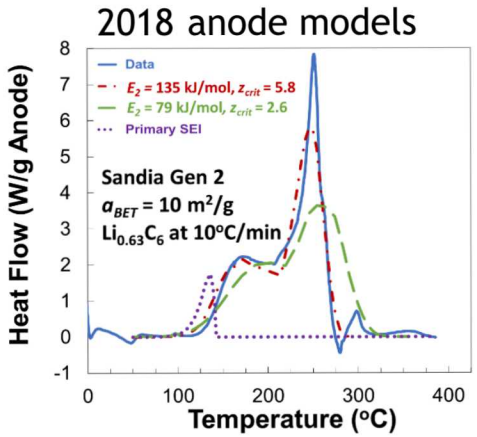
Simulation and measurements: 5 x 3 Ah LCO cells, 100% SOC, no plates

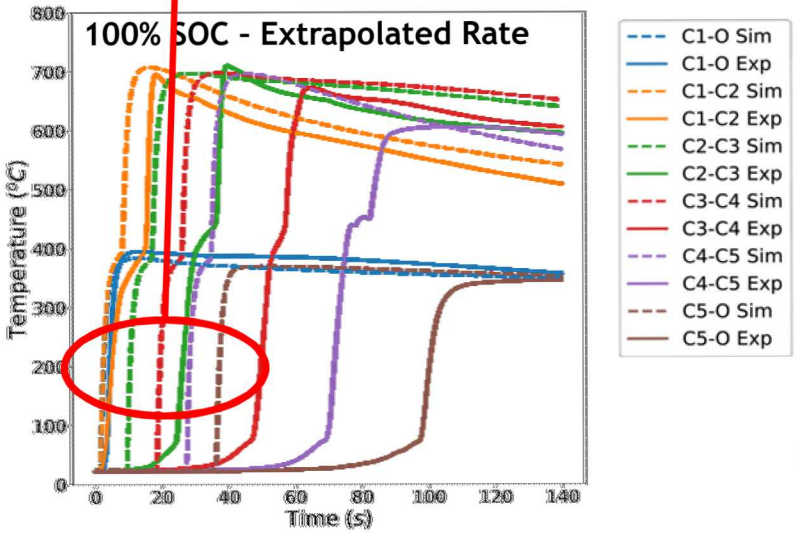


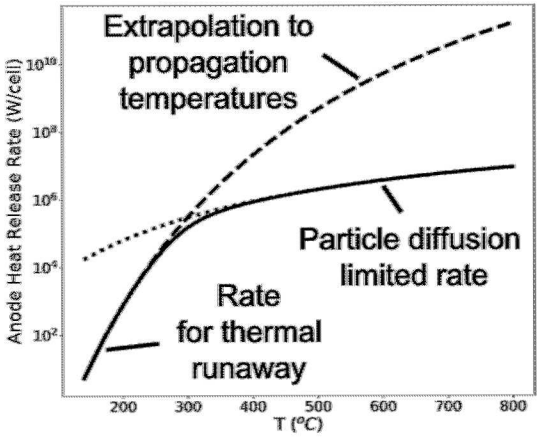
RESULTS - Predicting Thermal Runaway

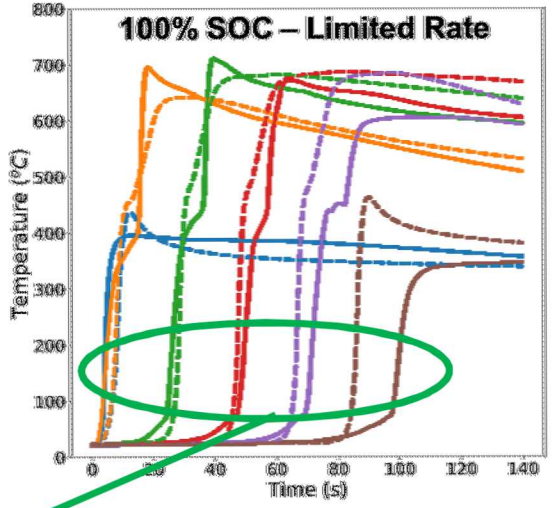
Challenge: Calorimetry measurements only at lower temperatures.

- Extrapolating thermal runaway models to cascading failure predicts too-fast propagation.
- Lack higher-temp measurements to predict cascading failure.







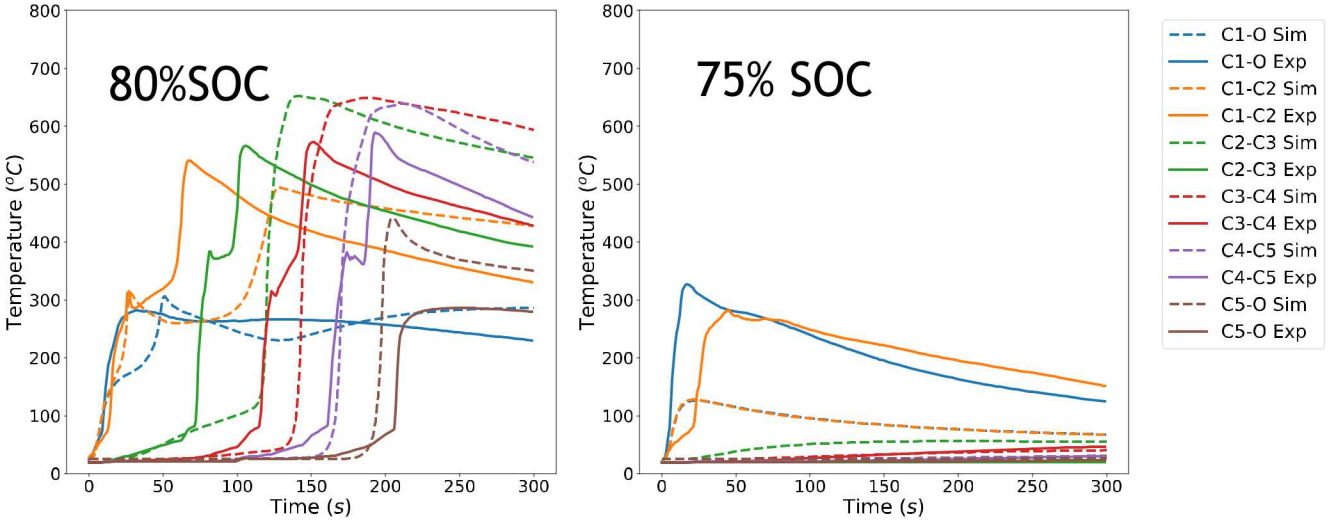


- Identified particle diffusion limit at cell propagation temperatures.
- *Enables prediction over range of propagation/mitigation*.

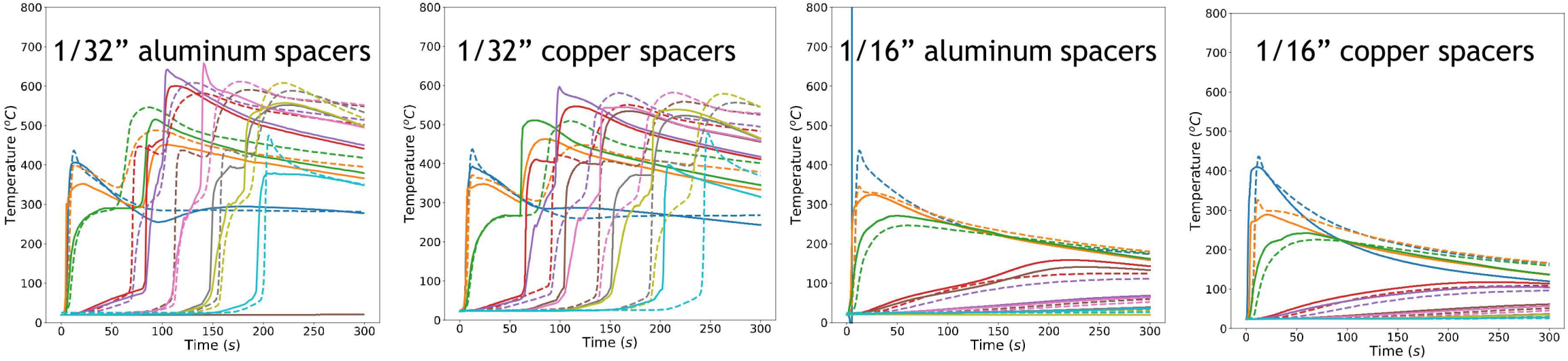
Kurzawski, A., et al. (accepted 2020). "Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion cell stacks." Proc. Combust. Instit. **38**.

RESULTS - Predicting Thermal Runaway Propagation/Mitigation

Temperature-time propagation measurements and predictions



- Successful prediction over a range of reduced SOC and metallic inserts.
- Collectively add heat capacity & increase time delay for cell runaway.
- Prevent propagation for 30% increase in net heat capacity.



Kurzawski, A., et al. (accepted 2020). "Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion cell stacks." Proc. Combust. Instit. **38**.

RESULTS - Predicting Thermal Runaway Propagation/Mitigation

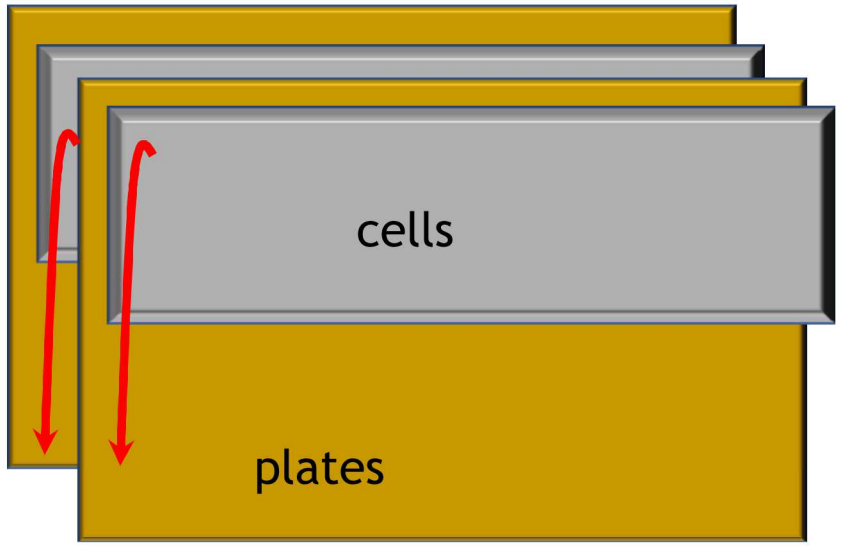
Heat capacity/plates and SOC propagation/mitigation summary

State of Charge	Experiment	Simulation
100% SOC	Propagation	Propagation
80% SOC	50/50 Propagation	Propagation
75% SOC	No Propagation	No Propagation
50% SOC	No Propagation	No Propagation

Effective Heat Capacity	Experiment	Simulation
778 J/kg/K (no spacers)	Propagation	Propagation
893 J/kg/K (1/32” Al)	Propagation	Propagation
941 J/kg/K (1/32” Cu)	Propagation	Propagation
1009 J/kg/K (1/16” Al)	No Propagation	No Propagation
1103 J/kg/K (1/16” Cu)	No Propagation	No Propagation

Quantified: Increased heat capacity per stored energy can inhibit cascading propagation.

Can we use thin plates to dissipate heat to the rest of the structure/cooling system?



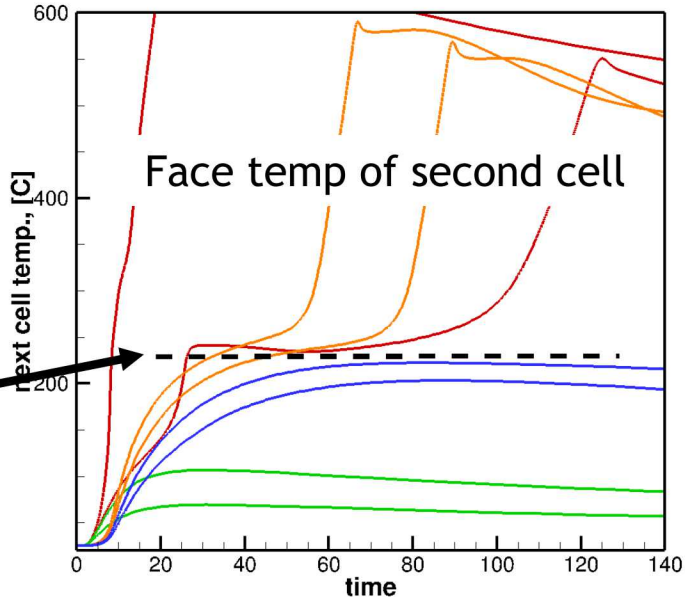
Torres-Castro, L. et al., (2020) J Electrochem. Soc., **167**(9): 090515
Kurzawski, A., et al. (accepted 2020). Proc. Combust. Instit. **38**.

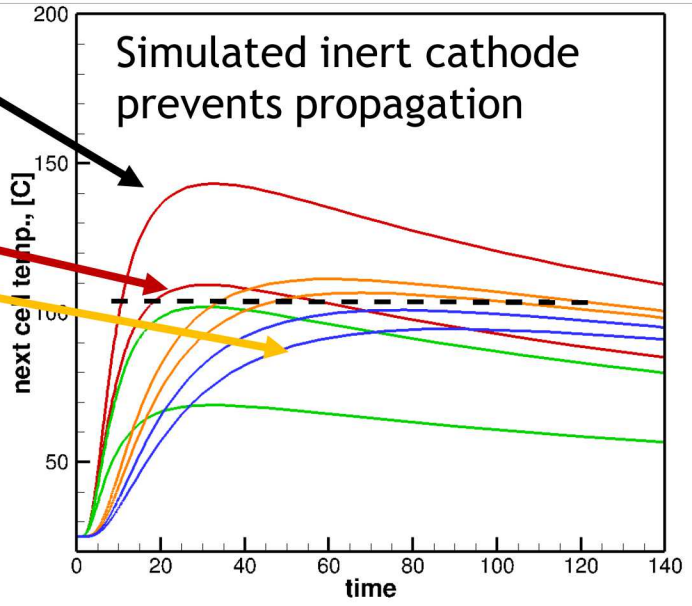
RESULTS – Opportunities with Predictive Simulations

Demonstrated predictive capabilities allow us to ask design questions about previous cases:

- What next-cell temperature must be avoided to prevent propagation?
  - Next-cell face temperature shows limiting value.
  - Cleaner separation if we simulate inert cathode.
- Also note time delay with plates versus no plates.

- Time delays are opportunities to dissipate heat.
- *But time to conduct heat through plate is long: (20-30 s)*

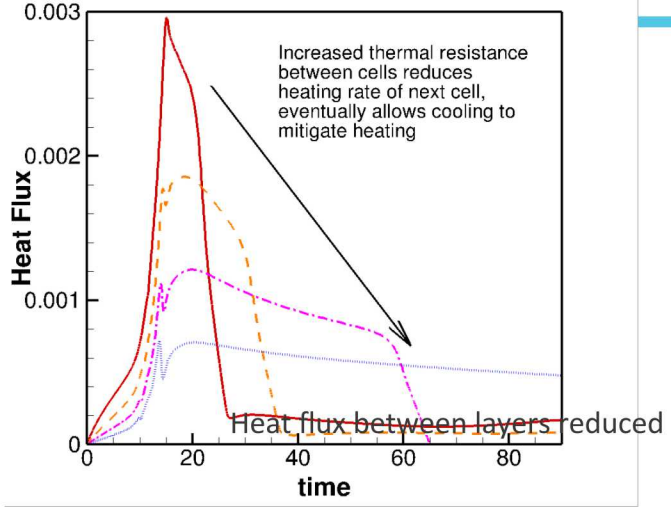


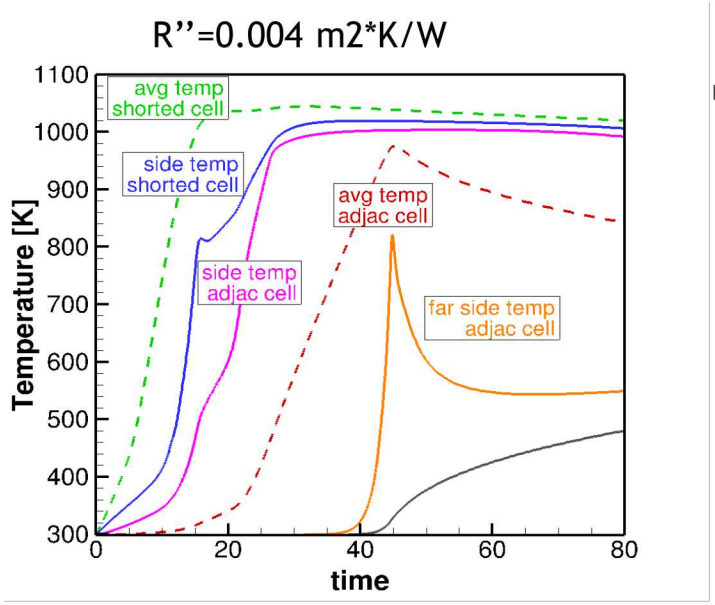


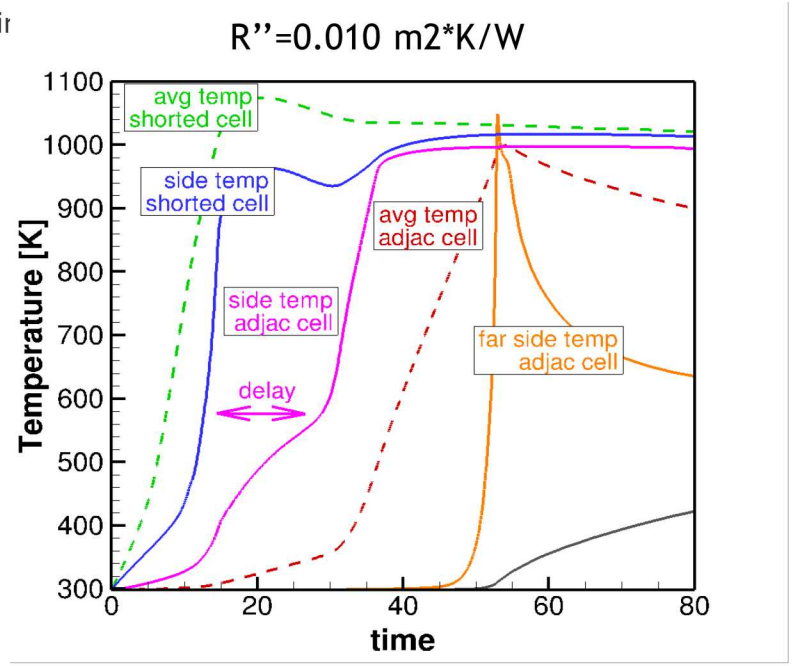
RESULTS – Opportunities with Predictive Simulations

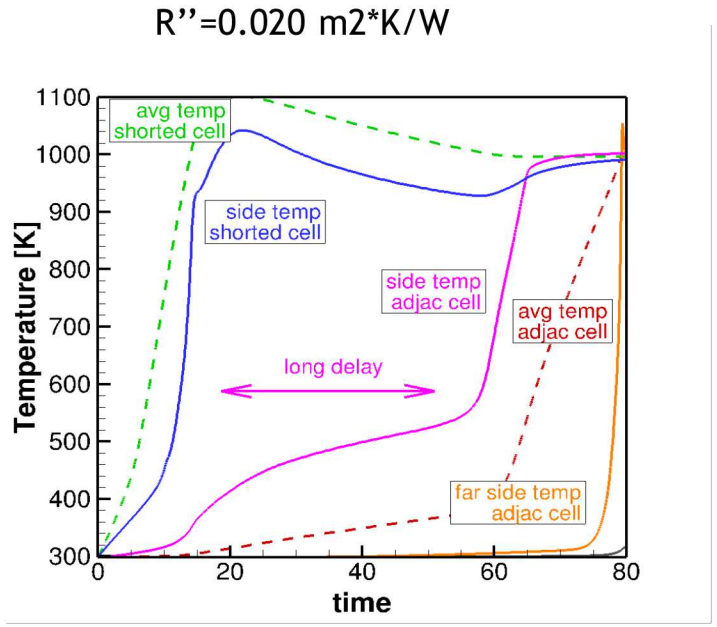
Thermal resistance between cells reduces the max heat flux between cells.

- Cell-to-cell contact resistances on the order 0.002 to 0.004 m2*K/W.
- Thermal resistance of a few mm of insulating plastic, ceramic, etc. can increase this by 10x or more.





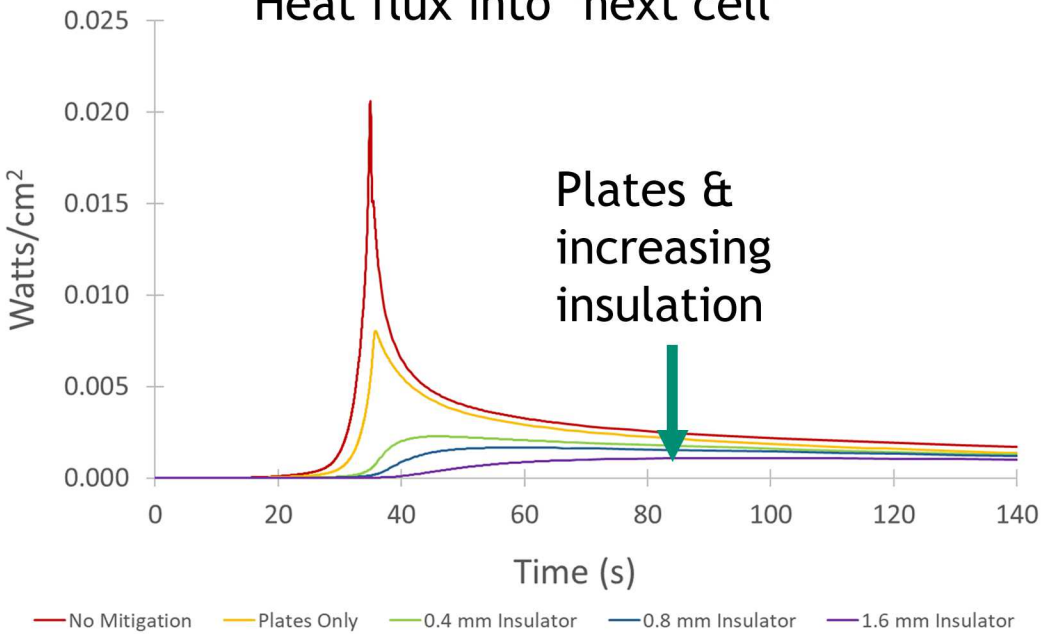




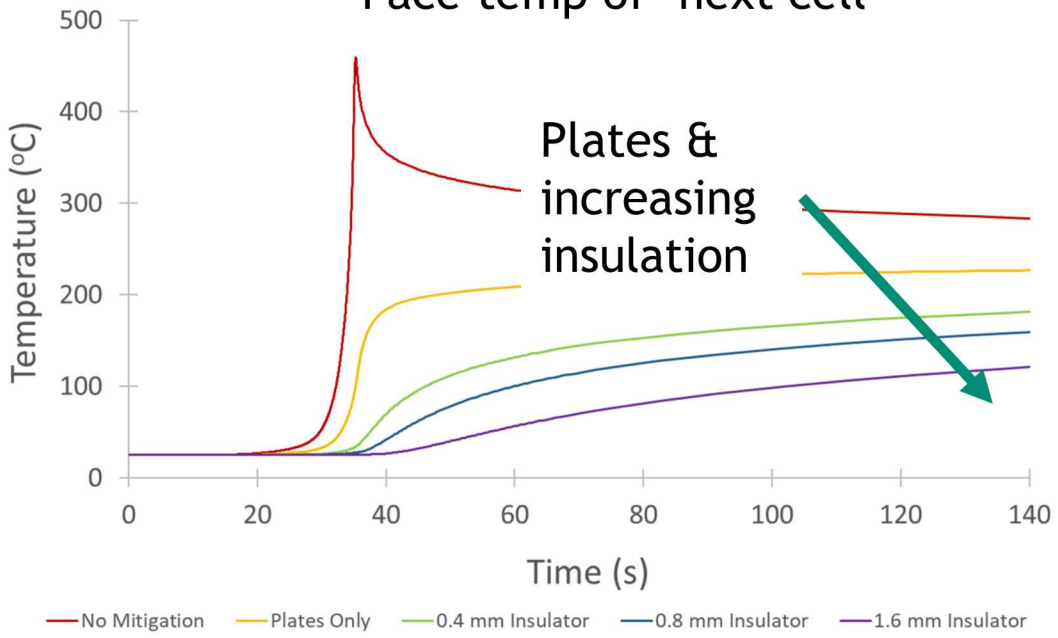
Heat transfer time scales associated with active cooling project
next presentation with Loraine Torres-Castro

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

Heat flux into ‘next cell’



Face temp of ‘next cell’

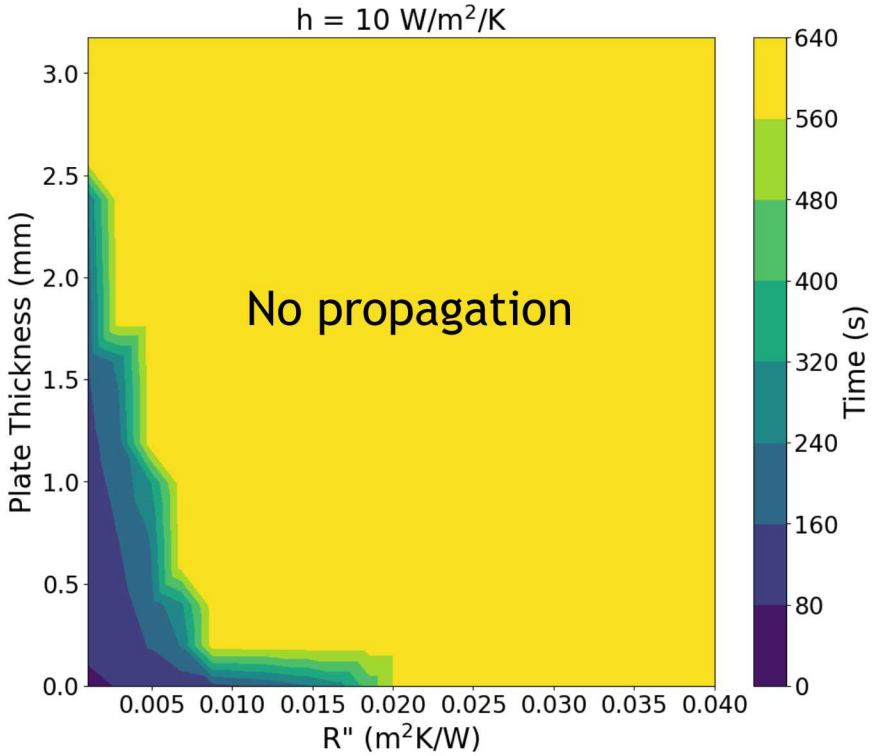


Look forward to our forthcoming manuscript with analytic expressions for system design criteria

RESULTS - Predicting and Mitigating Thermal Runaway

Limits of cascading thermal runaway

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



Result here is for 3 Ah LCO cells.

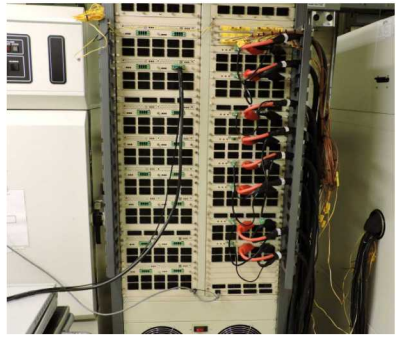
Other results can be obtained through model parameter sweeps.

Developing LIM1TR: open source code (**L**ithium-**I**on **Mi**tigation for **1**-D **T**hermal **R**unaway)

Provides design tool for system design community.

TEAM Predicting and Mitigating Thermal Runaway

Sandia Battery Test Facilities



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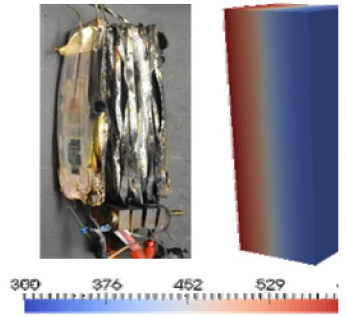
Loraine Torres-Castro
Joshua Lamb
Jill Langendorf

Sandia Fire Sciences



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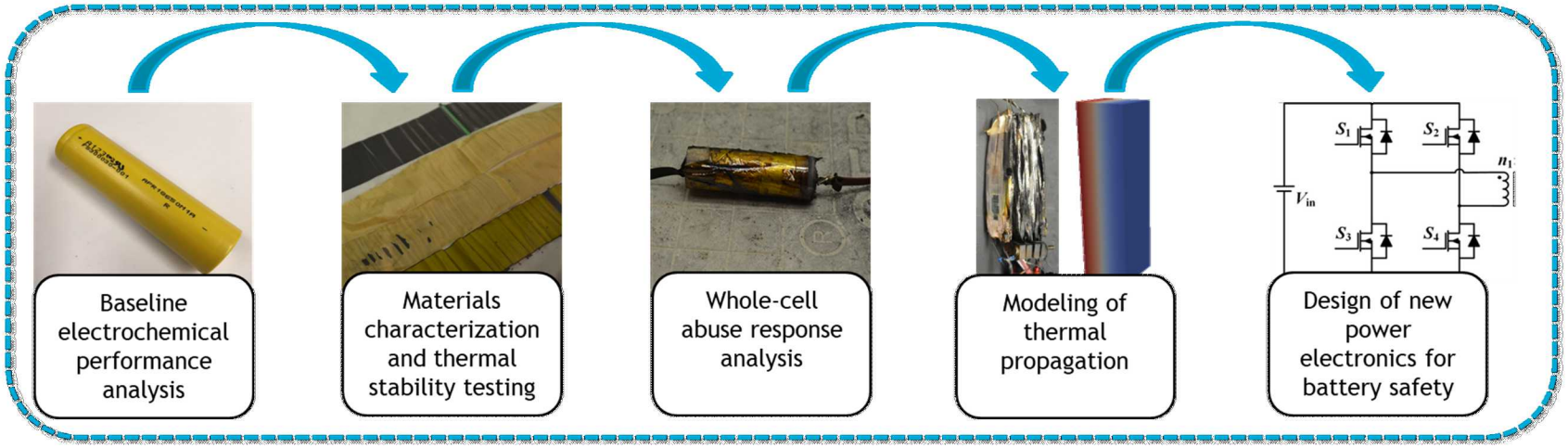

PUBLICATIONS

Peer-reviewed publications

- L. Torres-Castro, A. Kurzawski, J. Hewson, J. Lamb, "Passive mitigation of cascading propagation in multi-cell lithium ion batteries," *Journal of the Electrochemical Society*, vol. 167, 2020

- A Kurzawski, L. Torres-Castro, R. Shurtz, J. Lamb, and John Hewson, "Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion stacks," *Proceedings of the Combustion Institute* (2020) https://doi.org/10.1016/j.proci.2020.06.270

- R. C. Shurtz and J. C. Hewson, "Materials Science Predictions of Thermal Runaway in Layered Metal-Oxide Cathodes: A Review of Thermodynamics," *J. Electrochem. Soc.,* 167, 090543 (2020) https://dx.doi.org/10.1149/1945-7111/ab8fd9.

SUMMARY
Predicting and Mitigating Thermal Runaway

- Relate material models to experimental measurements at multi-cell level.

  - Implement new high-temperature chemistry.
  - Identified particle diffusion as potential high-temp physics limit.
  - Provides ***comprehensive predictions of propagation and mitigation over range of conditions***.

- Address safety modeling associated with thermal modifications. Determine limits of cascading failure.

  - Mitigate propagation with
    - increased heat capacity per stored energy.
    - thermal resistance between cells.
  - Mapped out limits.
  - Provide experimental design.
  - ***Quantified relative effectiveness*** experimentally and through predictions.

CONTACTS

Thank you

- Funded by the U.S. Department of Energy, Office of Electricity, Energy Storage program under the guidance of Dr. Imre Gyuk, Program Director.

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