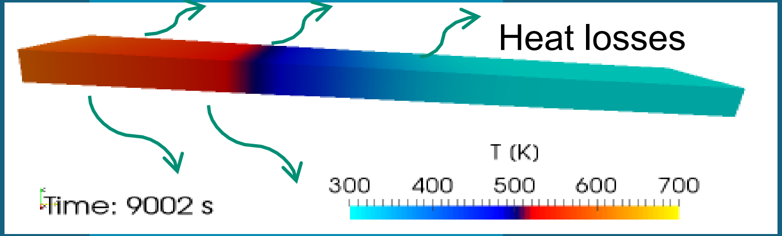
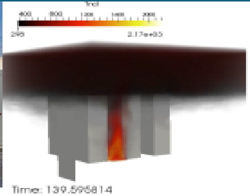
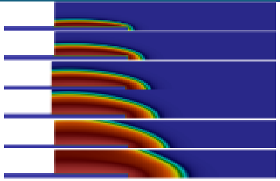
SAND2022-16103C

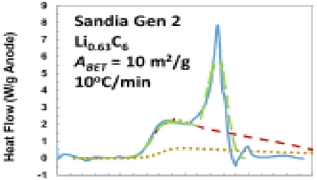
Sandia National Laboratories

Battery safety research at Sandia: Moving toward designs that mitigate cascading failure









Presented by

John Hewson, with Andrew Kurzawski

Randy Shurtz, Loraine Torres-Castro

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

Battery Safety Council

Nov. 16, 2022

SAND2021-4856 C

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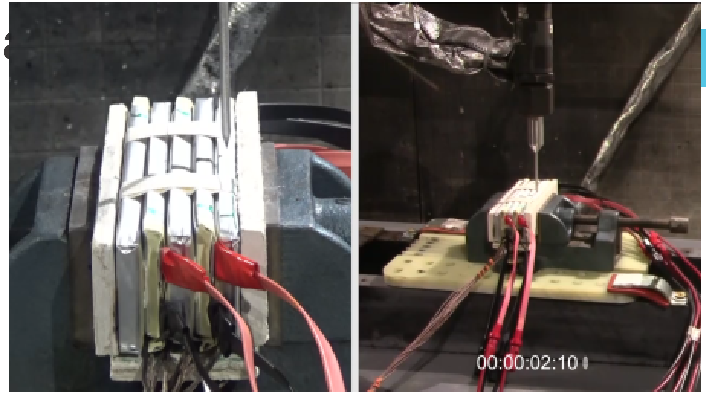
Utility-Scale Storage System Failures

EPRI BESS Failure Database
https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

Predicting and Mitigating Thermal Runawa



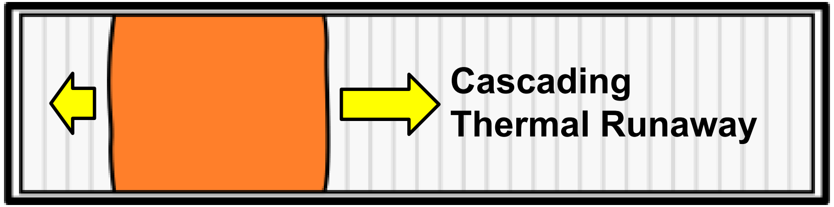
Validated safety and reliability is one of the critical challenges in deploying large-scale or mission-essential energy storage

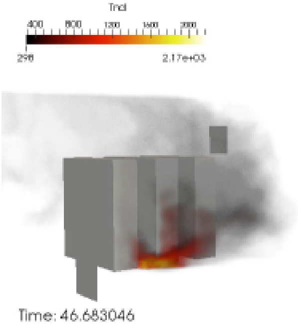
Safety incidents are rare but possible, incl. external causes.

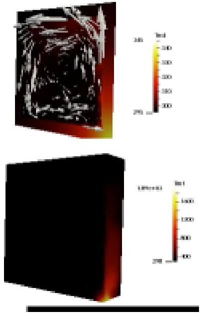
How can we reduce risk?

- Prevent single-point failure from cascading to large-scale system risk.
- Design inherently safer systems that are resistant to cascading failure.

Module







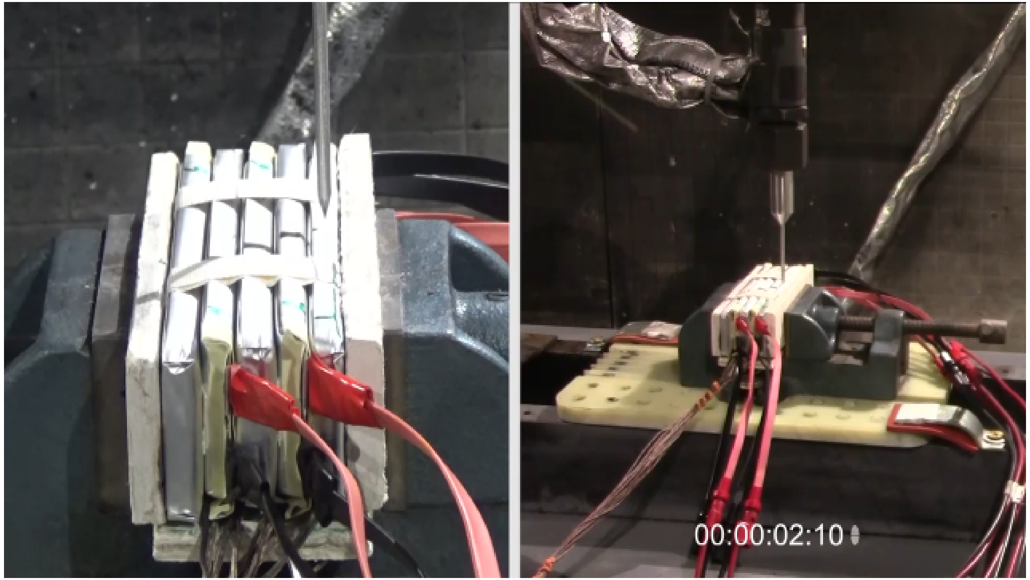
Simulations allow exploration of the design space if well grounded in reality.

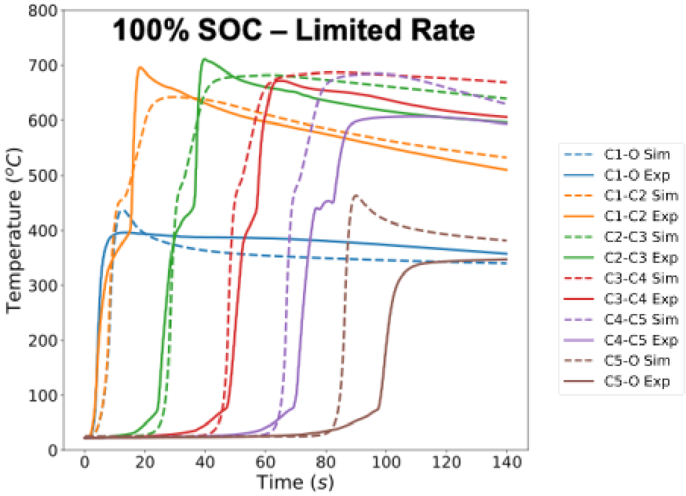
A parameter space analysis can provide general safety-focused design guidelines

www.internationalbattery.com

Nail penetration of pouch cell in stack

Venting removes electrolyte, changes the energy available. Calibrate on max temp.

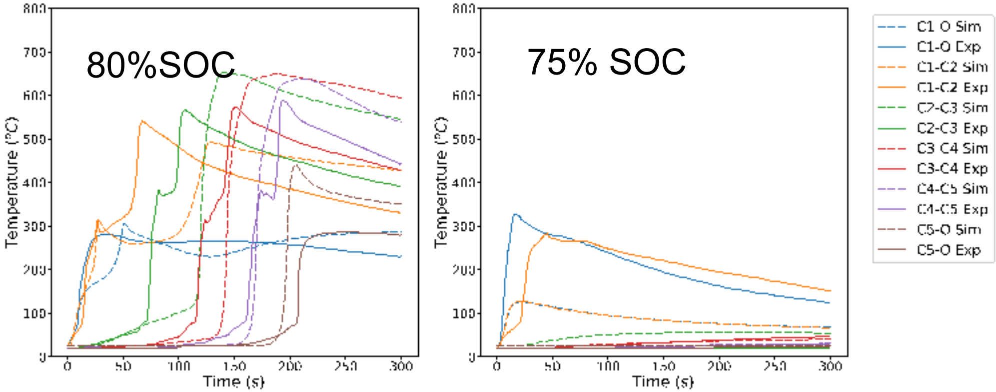




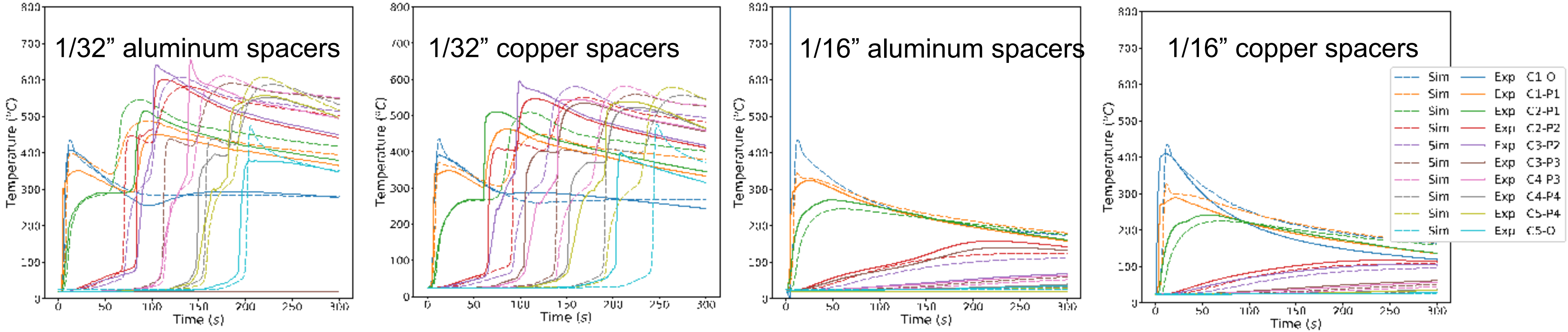
Kurzawski, A., et al. (2020). "Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion cell stacks." <u>Proc. Combust. Instit.</u> **38**.

New chemistry models successfully predict full range of scenarios

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. (2020). "Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion cell stacks." Proc. Combust. Instit. **38**.

Simplified scenario and reduced parameter set for propagation mitigation

Cells have a characteristic thermal runaway temperature.

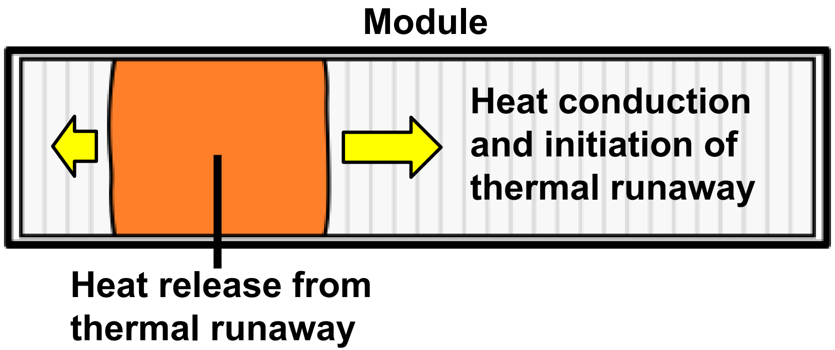
- Propagation mitigated if the next cell temperature is less than this.
- Dissipate heat to avoid propagation.

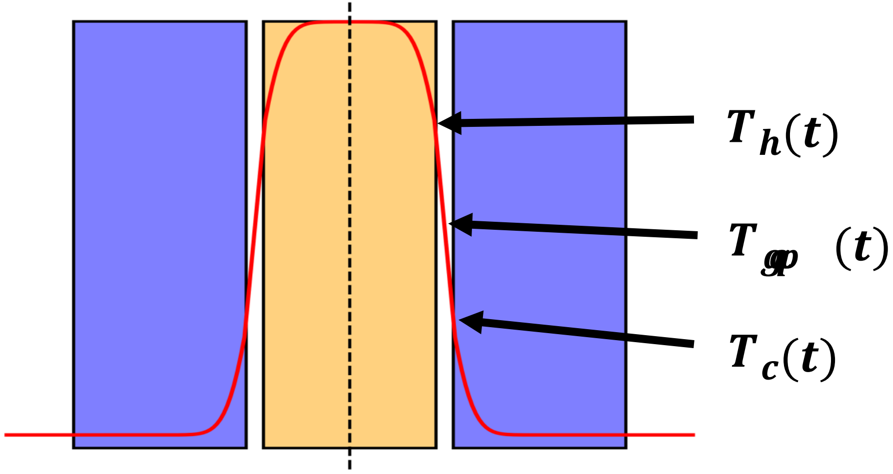
Where can the heat from a failed cell go?

- Along a cell stack and to the surroundings.

Parameters affecting next-cell temperature:

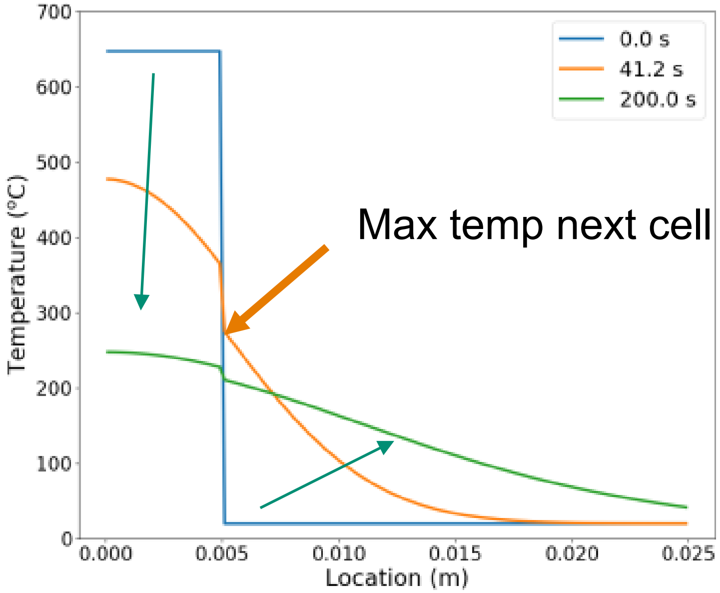
- Thermal resistance along the stack.
- Ability to dissipate heat.
- Heat sinks (structure/cooling system).

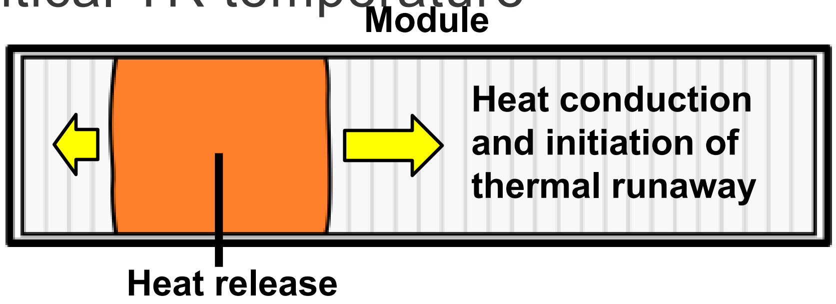




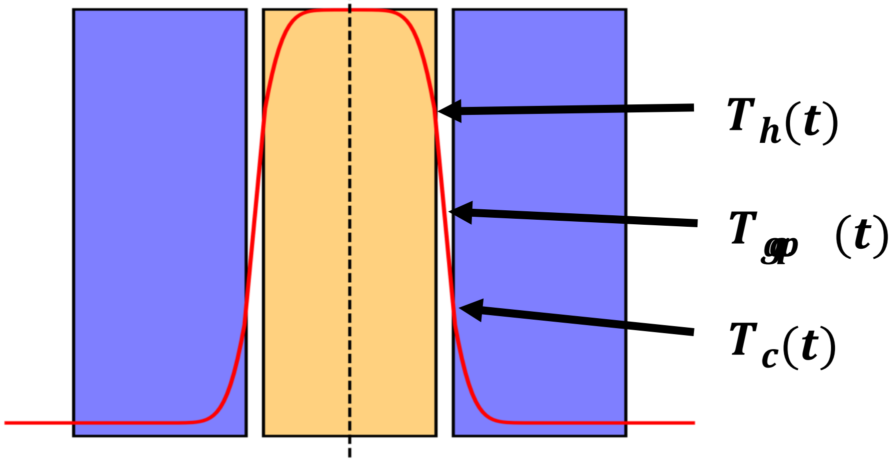
Heat transfer along adiabatic stack with thermal resistance, *R*” Chemistry turned off to look for critical TR temperature

Adiabatic module scenario at first

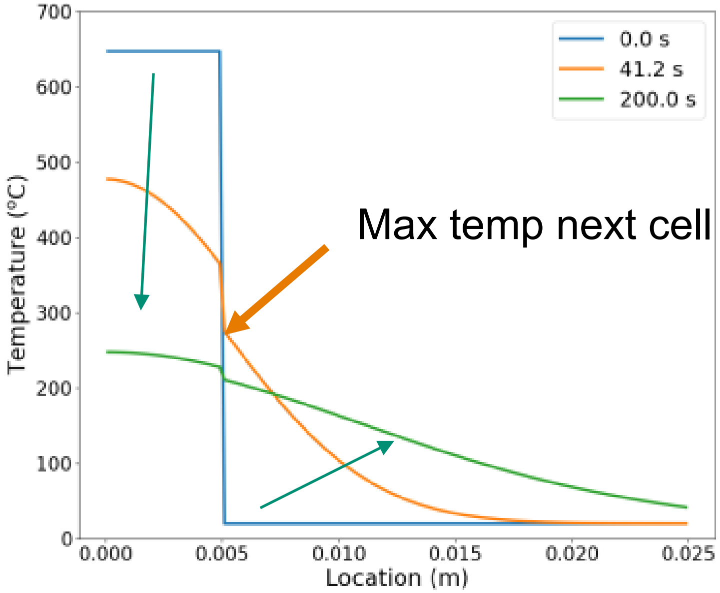


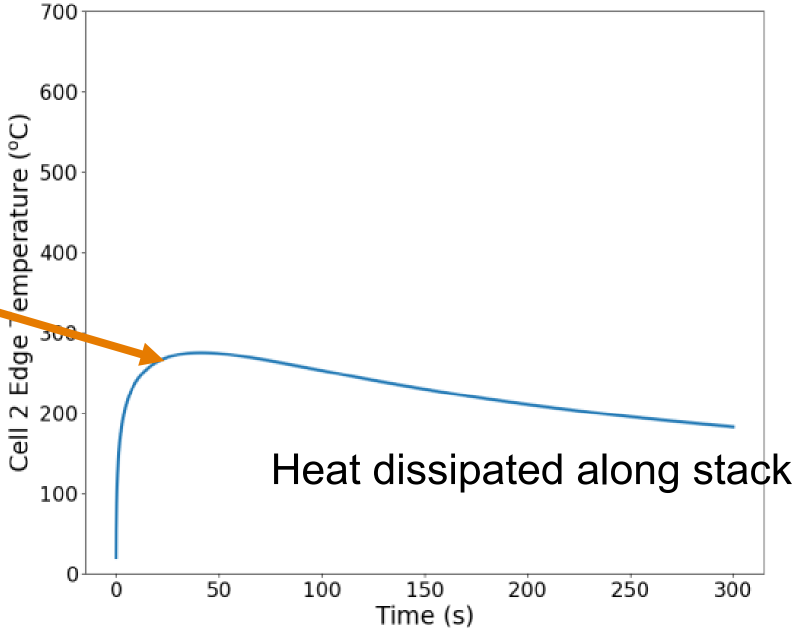


TR in cell affects surrounding cells



Heat transfer along adiabatic stack with thermal resistance, *R*”
Chemistry turned off to look for critical TR temperature



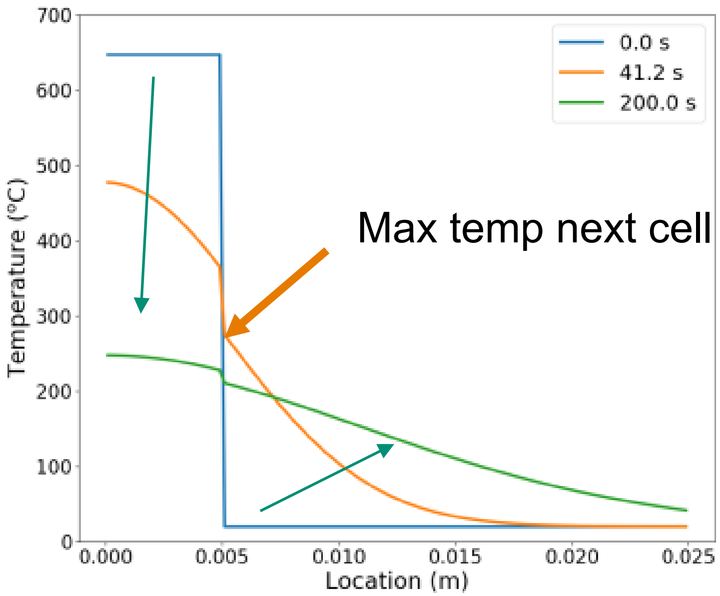


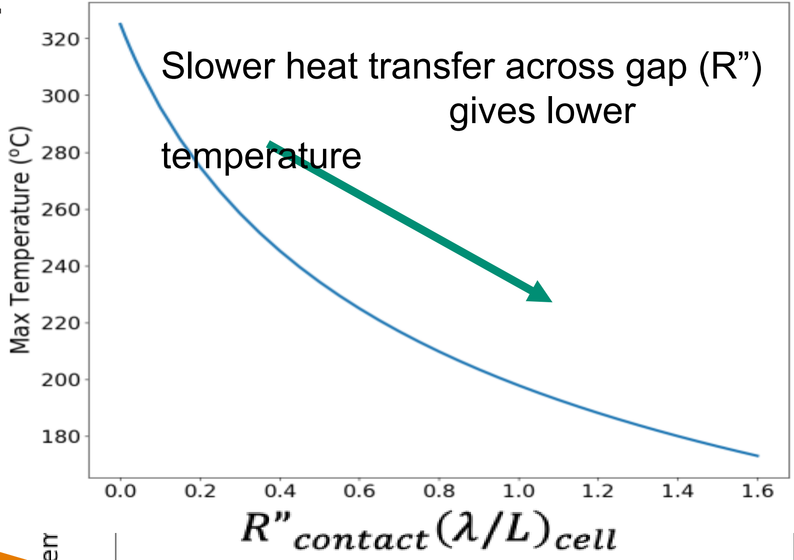
Heat transfer along adiabatic stack with thermal resistance, *R*”

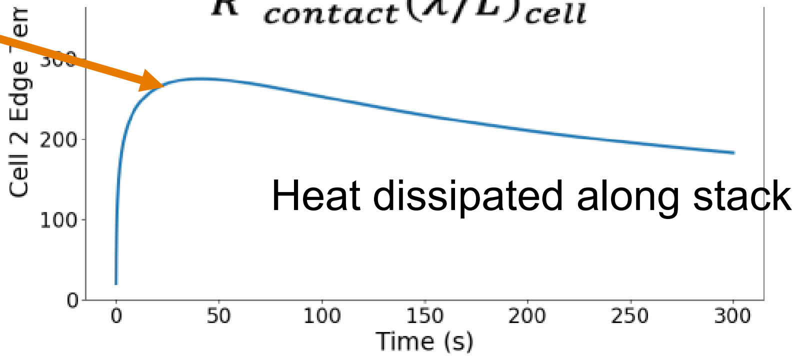
Chemistry turned off to look for

Max temp of next cell depends on

$$\frac{1}{Bi} = \frac{R''_{contact}}{(L/\lambda)_{cell}} = \frac{R''_{contact}}{R''_{cell}}$$







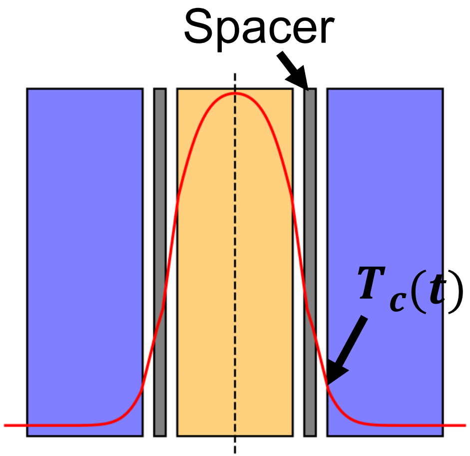
Conduction with thermal dilution

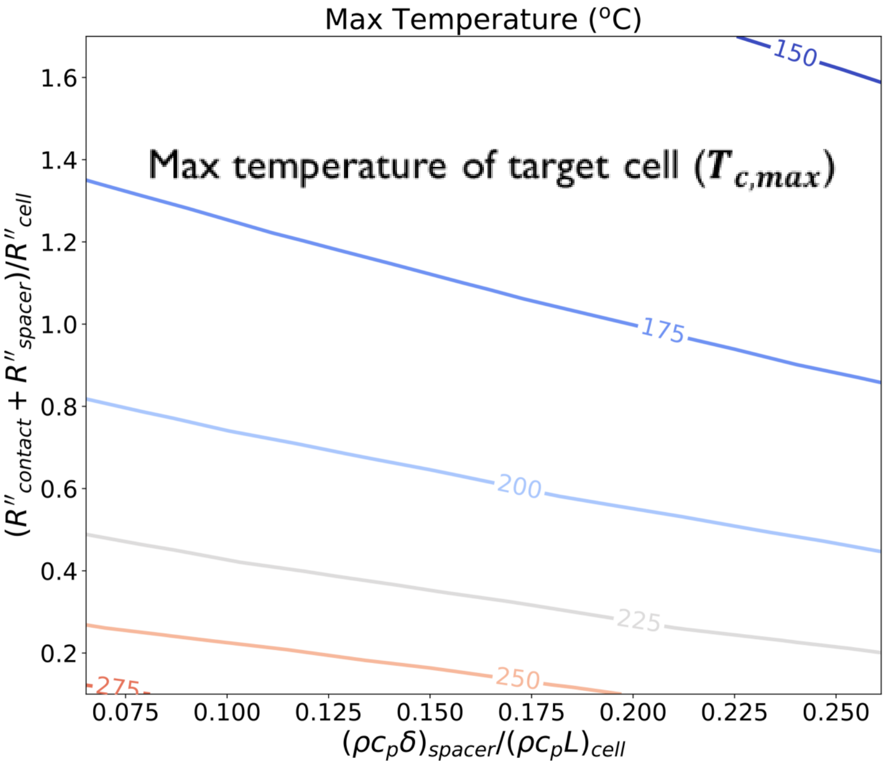
Additional temperature reduction can be achieved by adding inert material (ex: structure, casing, spacers).

$$\frac{1}{Bi} = \frac{R''_{contact} + (\delta/\lambda)_{spacer}}{(L/\lambda)_{cell}}$$

The heat capacity ratio of inert spacer material to cells is:

$$\phi_{capacity} = \frac{(\rho c_p \delta)_{spacer}}{(\rho c_p L)_{cell}}$$





Thermal runaway temperature leading to propagation versus max cell temperature

Previous results determine max target cell temperature. Relate this to thermal runaway/propagation temperature.

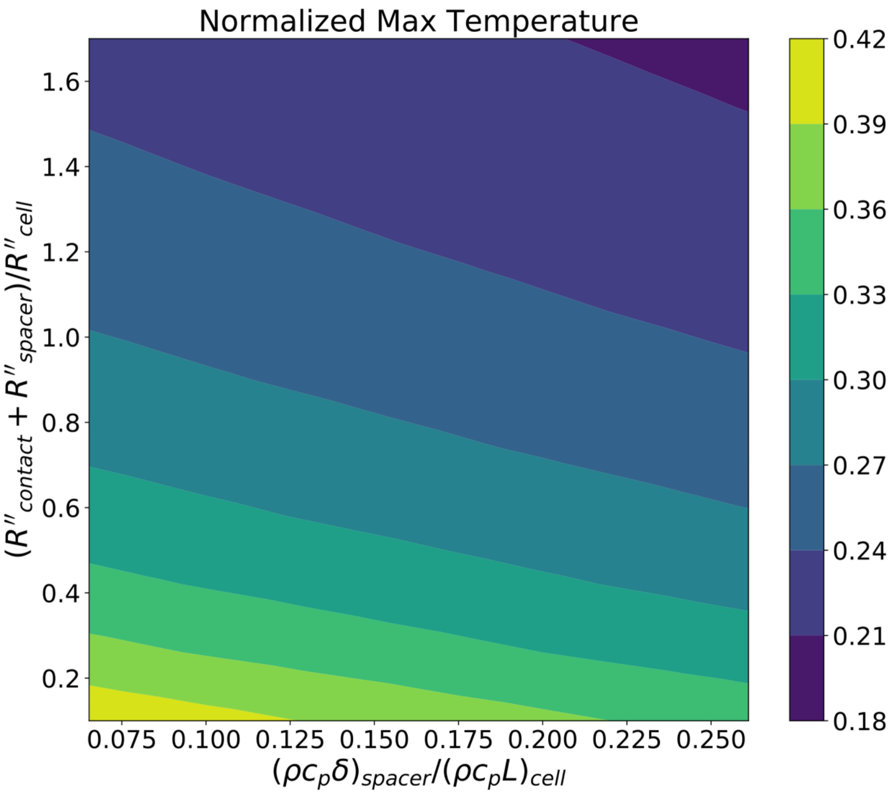
Ratio of temperature rise to get thermal runaway, ΔT_{TR}, to the temperature rise of initiating cell, $T_{h,0} - T_{c,0}$.

$$\theta_{TR} = \frac{\Delta T_{TR}}{T_{h,0} - T_{c,0}}$$

Normalize max temperature of target cell similarly:

$$\theta_{max} = \frac{T_{c,max} - T_{c,0}}{T_{h,0} - T_{c,0}}$$

No propagation if: $\theta_{max} < \theta_{TR}$



Summary: Cell-to-cell failure mitigation

Non-dimensional parameters can be used to describe heat flows.

- Thermal conduction:

$$\frac{1}{Bi} = \frac{R''_{contact}}{(L/\lambda)_{cell}}$$

- Heat capacity:

$$\phi_{struct} = \frac{(\rho c_p \delta)_{struct}}{(\rho c_p L)_{cell}}$$

- TR temp over heat release:

$$\theta_{TR} = \frac{\Delta T_{TR}}{T_{h,0} - T_{c,0}}$$

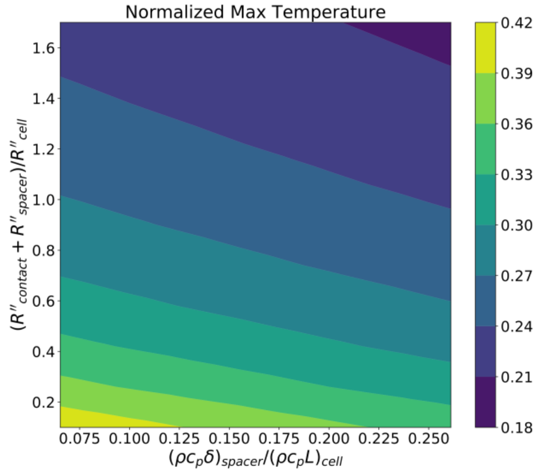
- Propagation criteria

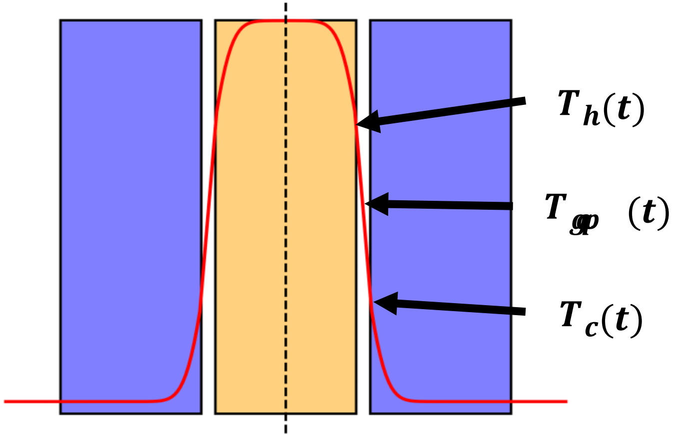
$$\theta_{max}(Bi, \phi_{struct}, T_{h,0} - T_{c,0}) < \theta_{TR}$$

Heat must be removed before the onset of thermal runaway 150~200°C.

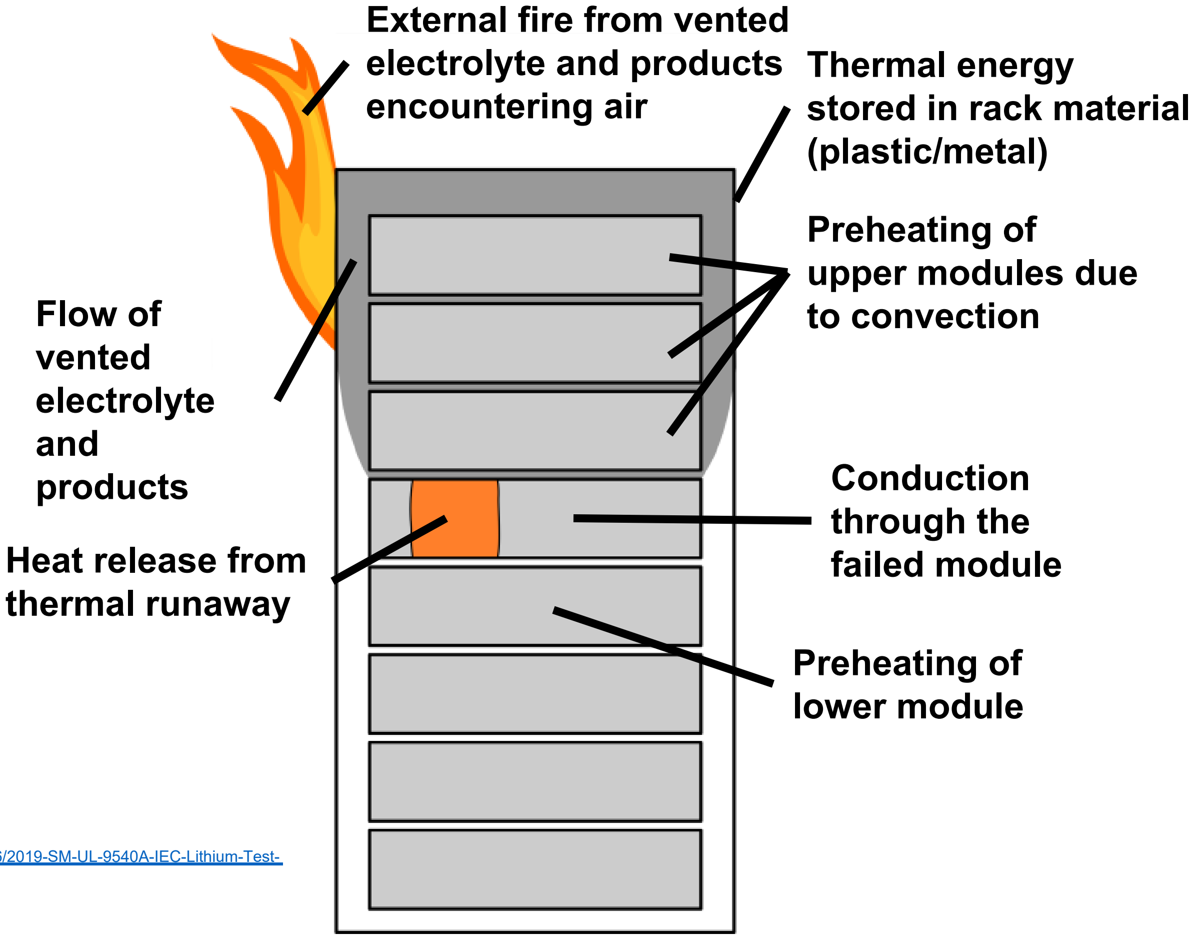
Relative time scales of heat flows determine the propagation rate.

Understanding of heat transfer scales is critical for system design.



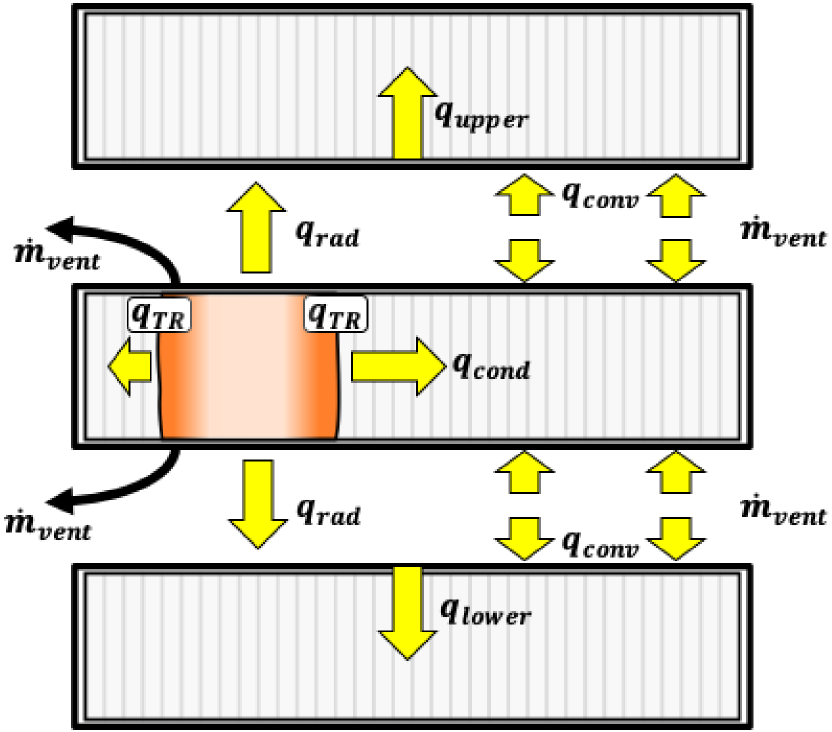


Energy flows at the rack/system scale



Source: (top) https://cmte.ieee.org/pes-essb/wp-content/uploads/sites/43/2019/06/2019-SM-UL-9540A-IEC-Lithium-Test-Summary.pdf
(bottom) https://www.lgessbattery.com/eu/grid/product-info.lg

Need a reduced parameter set to span failure scenarios.



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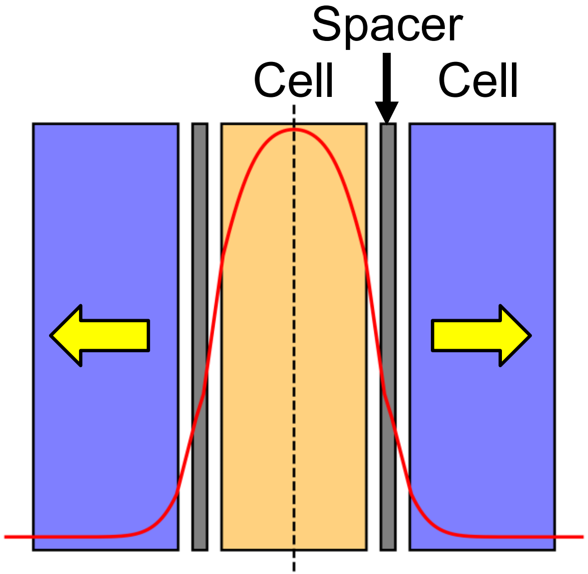
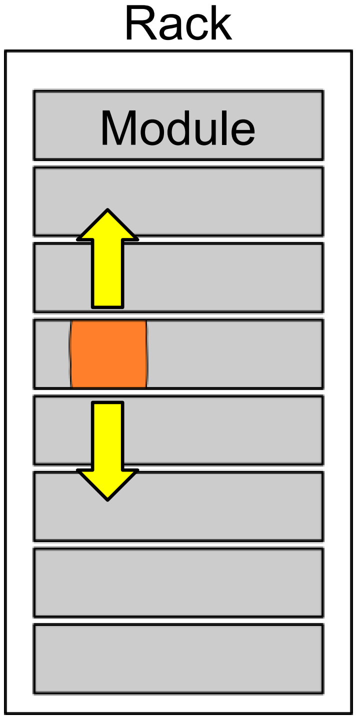
(bottom) https://www.lgessbattery.com/eu/grid/product-info.lg

Extending heat transfer concepts from module to rack scale





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Extending heat transfer concepts from module to rack scale

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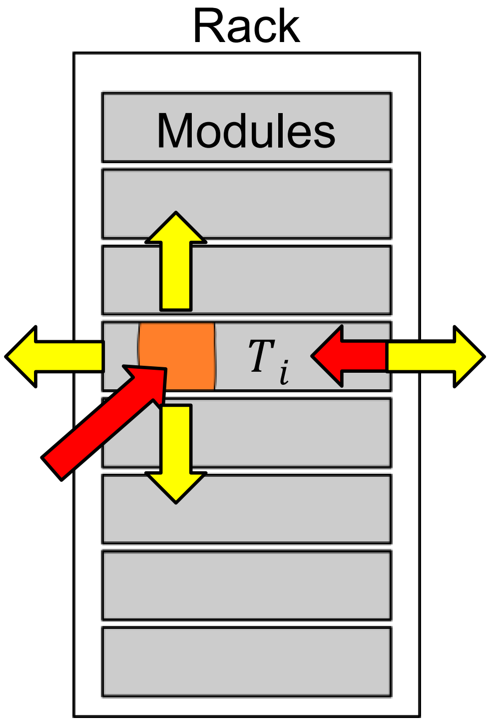
Stored Thermal Energy

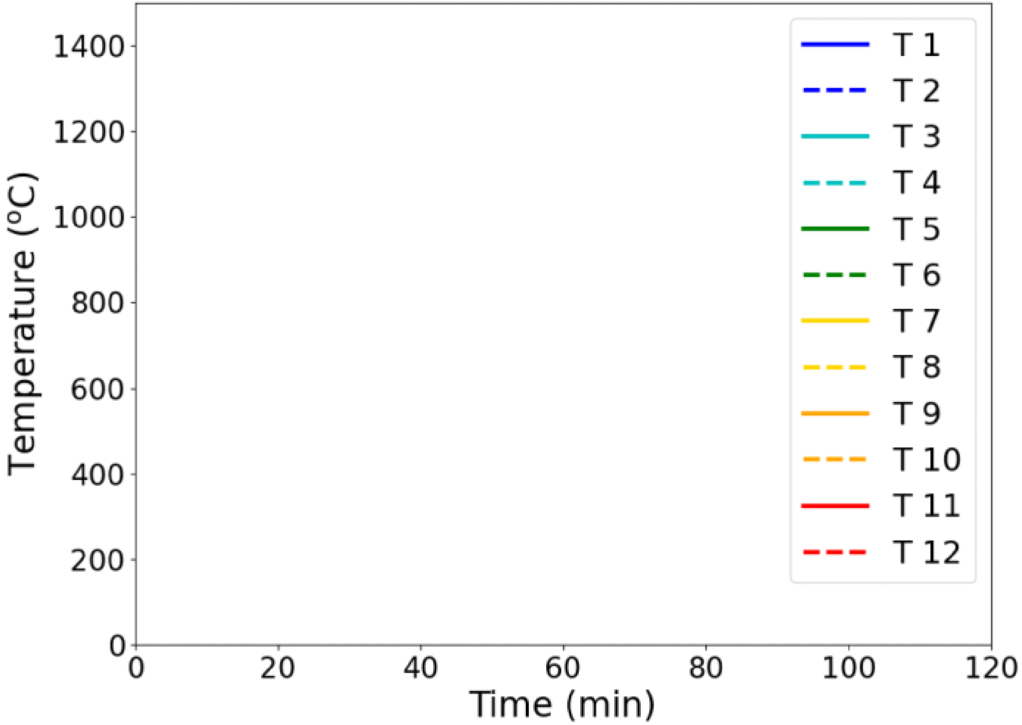
Heat Generation

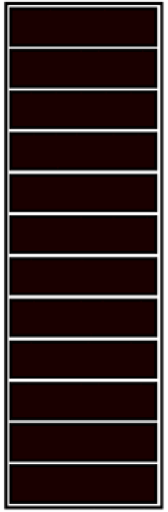
Ambient Heat Loss

Transfer Between Modules



Example scenario: thermal runaway in a rack of 12 modules



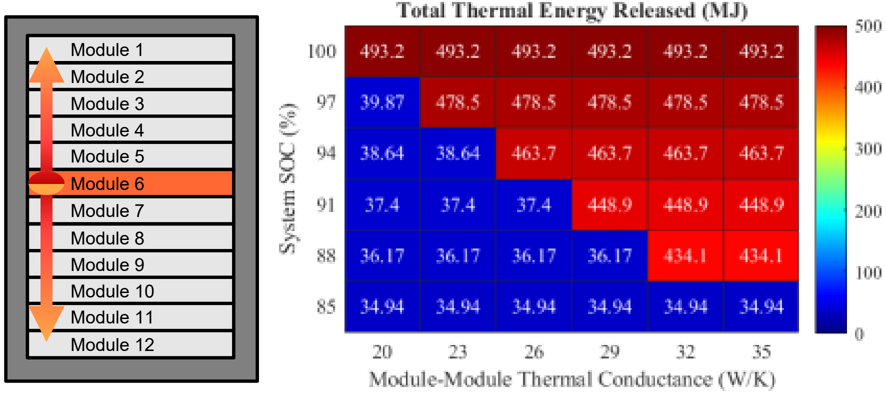


Nominal case consisting of 12 modules at 96% state of charge.

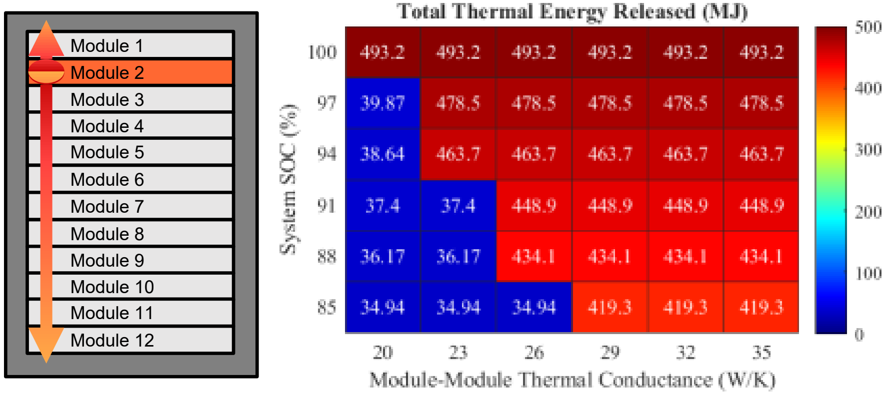
Thermal runaway spreads through the system in about 1 hour.

Total Energy Release vs SOC, Thermal Conductance

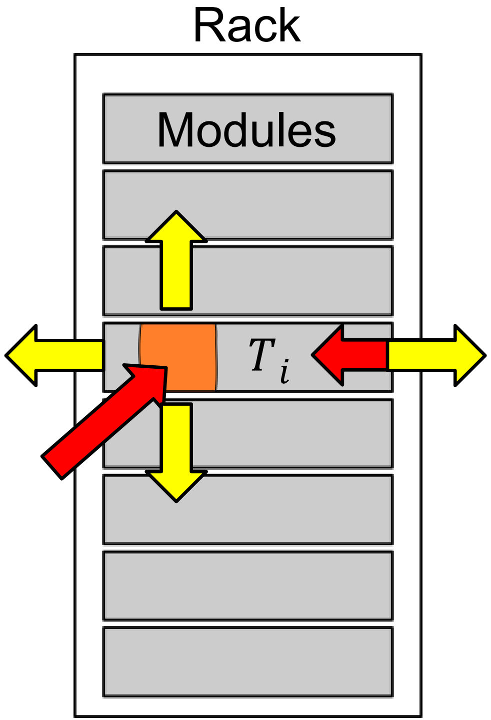
Module 6 Failure without Intervention



Module 2 Failure without Intervention



Crude network models allow preliminary simulation of module-to-module propagation



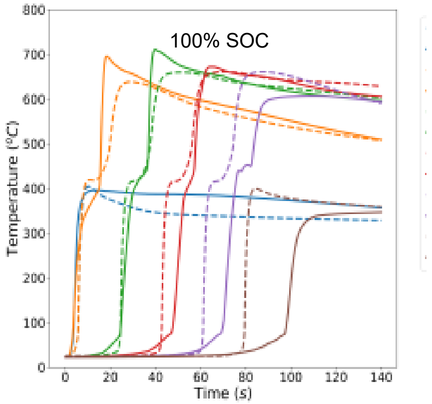
Summary: Propagation/Mitigation

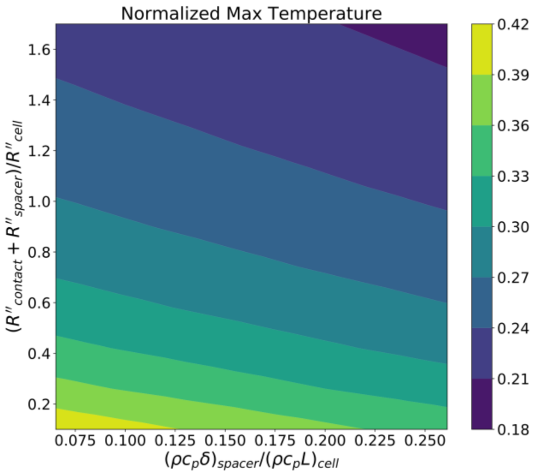
Finite element model with chemical source terms tested against range of propagation/mitigation experimental data

- Models capture propagation trends including mitigation using plates and insulation between cells.

- Models improve understanding of mitigation:
- Heat capacity to absorb energy.
- Thermal resistance to allow heat dissipation along stack and cooling to surroundings.

- Parameter space maps out limits of propagation for above parameters and cell runaway temperature.
  - Moving toward more universal parameter space maps.

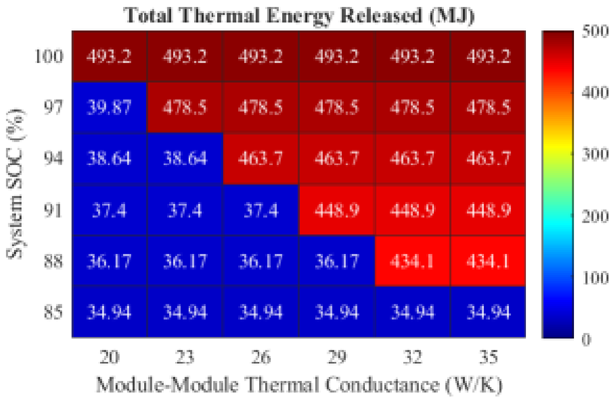


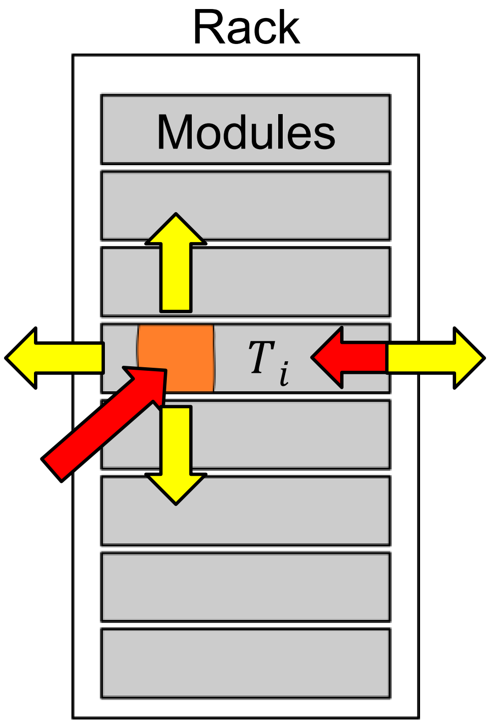


Summary: Moving toward module-to-module mitigation

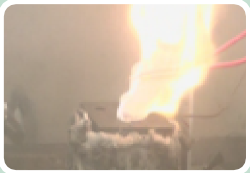
- Crude network models allow preliminary simulation of module-to-module propagation

Understanding mitigation boundaries is important for designing safe energy storage systems.



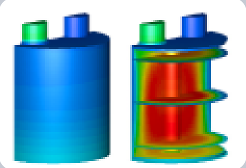


Battery Safety Science



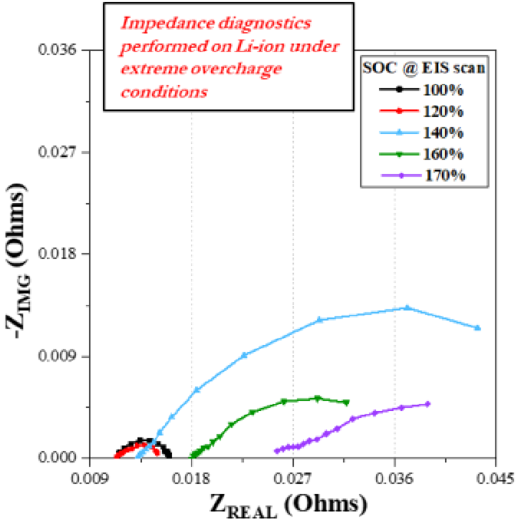
Materials R&D
- Non-flammable electrolytes and electrolyte salts
- Coated active materials
- Thermally stable materials
- Battery calorimetry

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.

Capabilities and Infrastructure

Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)

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

Battery Calorimetry

Thank you

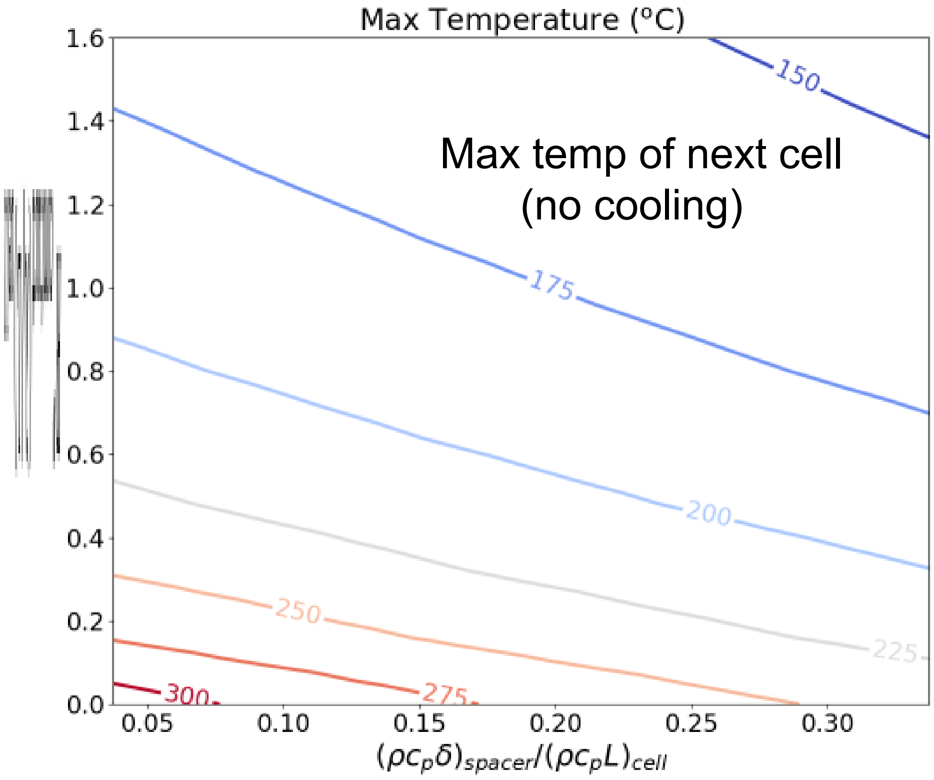
- Funded by the U.S. Department of Energy, Office of Electricity, Energy Storage program under the guidance of Dr. Imre Gyuk, Program Director.

- Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

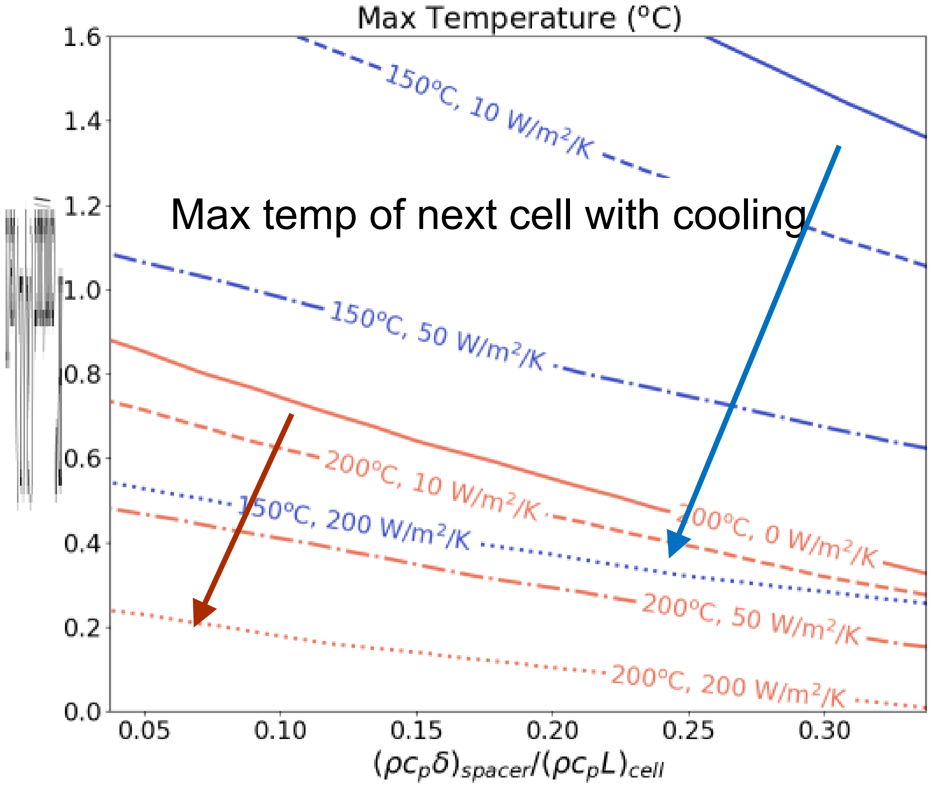
- For further information: John Hewson - jchewso@sandia.gov

Backup materials

Map of limiting temperature versus thermal resistance, heat capacity and cooling

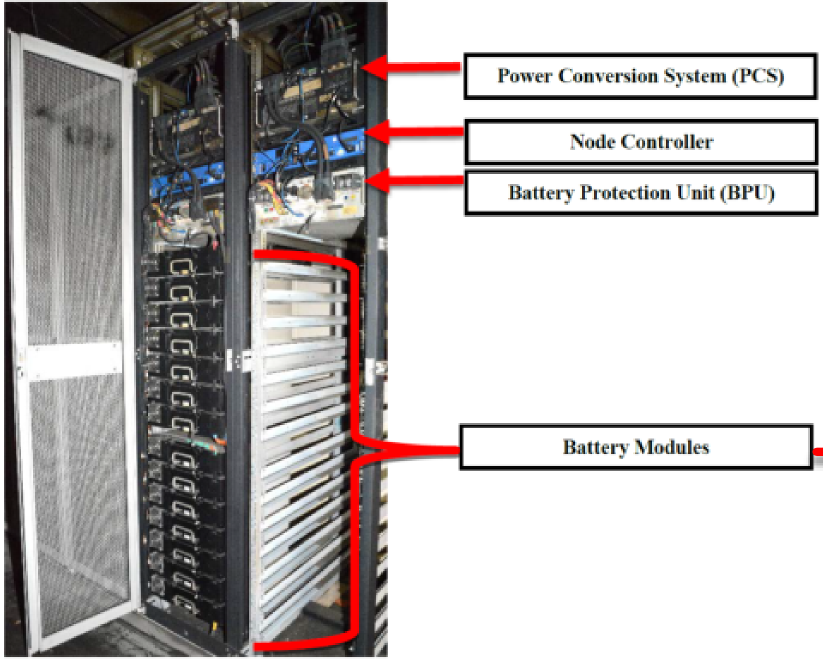


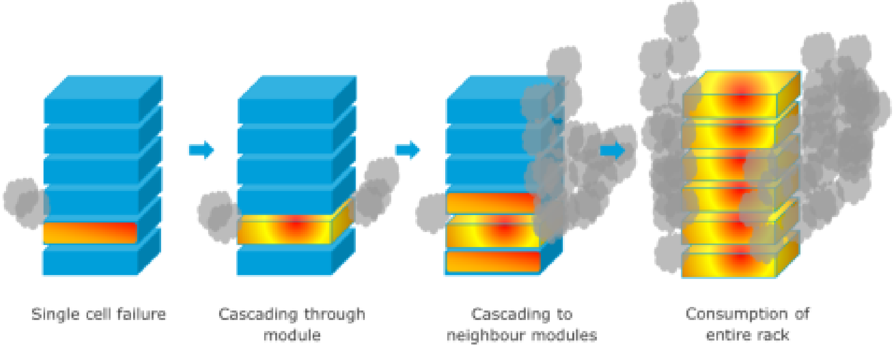
Heat capacity ratio

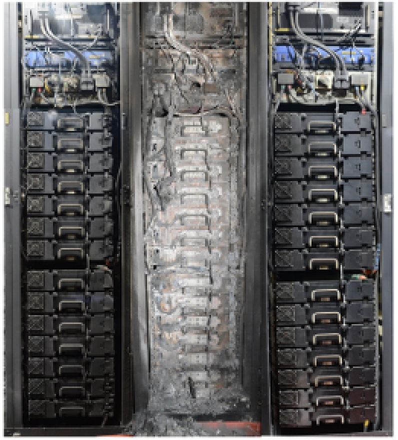


Heat capacity ratio

Propagating Thermal Runaway







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