Sandia National Laboratories
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Predicting and Preventing Cascading Thermal Runaway

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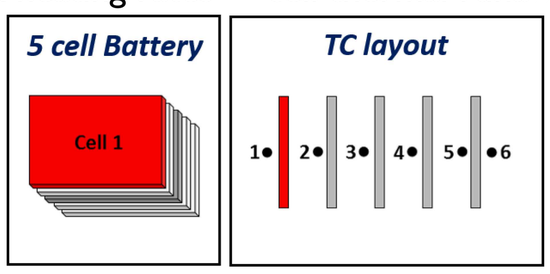
Motivation

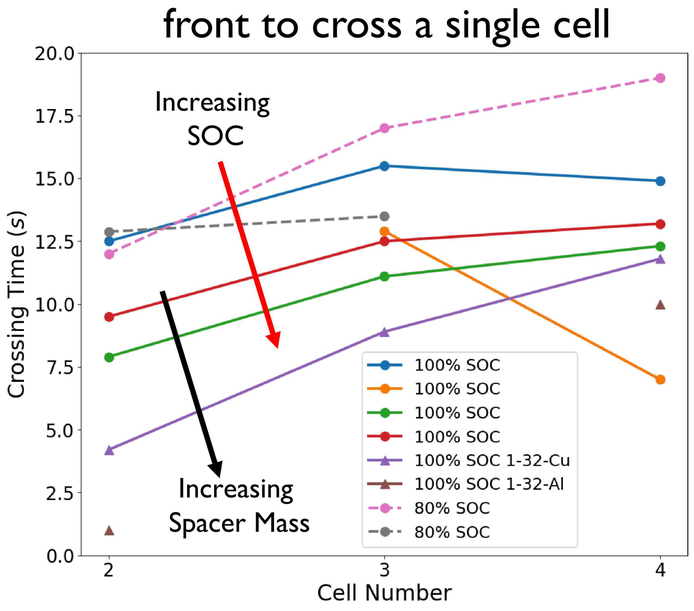
- Stationary energy storage systems (ESS) are increasingly deployed to maintain a robust and resilient grid.
- As system size increases, financial and safety issues become important topics.
- Holistic approach: electrochemistry, materials, and whole-cell abuse will fill knowledge gaps.
- Understand design space for mitigation strategies.
- Understand and predict limits of cascading failure given thermal runaway of a cell.
- Heat losses/cooling can prevent thermal runaway given enough time.
- Heat loss time strongly dependent on thermal mass, conductivity and contact resistance.
- Predict the full parameter space.

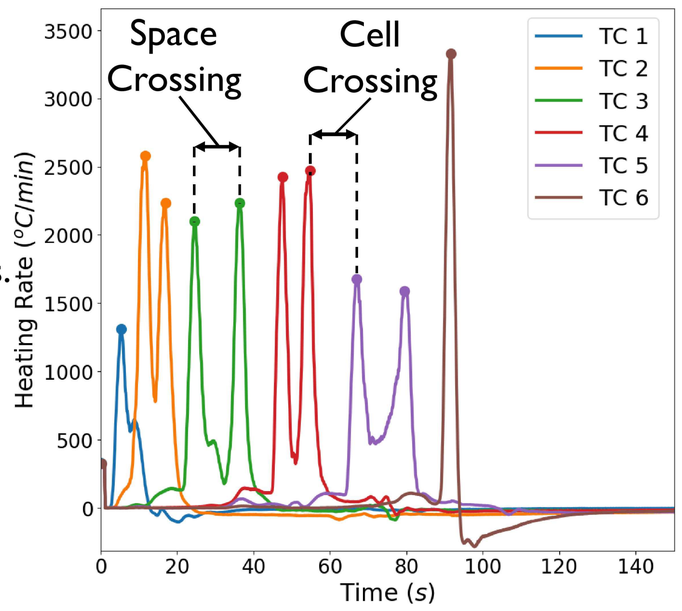
Understanding Times in Cascading Failures

- Propagation data from Sandia (Lamb, et al. (2015) and Torres-Castro) for 5 x cells.
- Extracted heating rate from thermocouples.
- Peak heating rates → cell thermal runaway

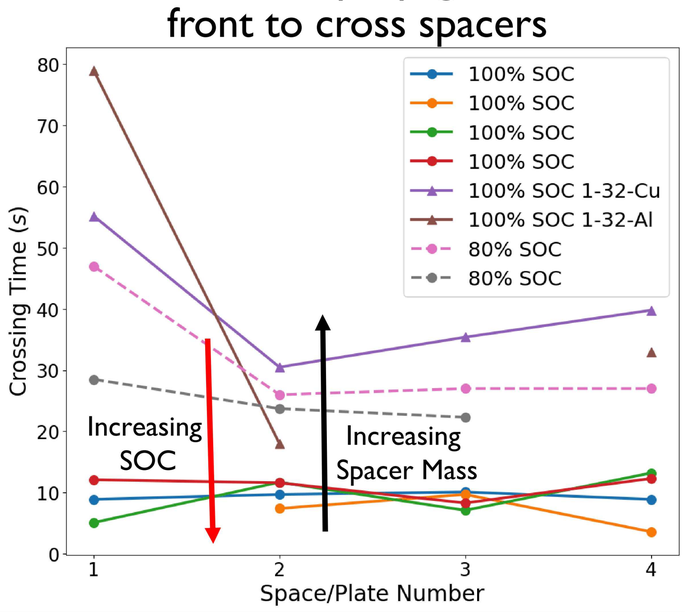


Time for propagation front to cross a single cell



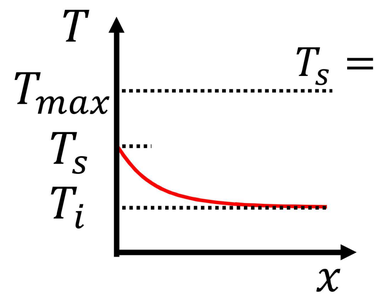


Time for propagation front to cross spacers



Estimating Thermal Delays in Propagation: Contact Resistance

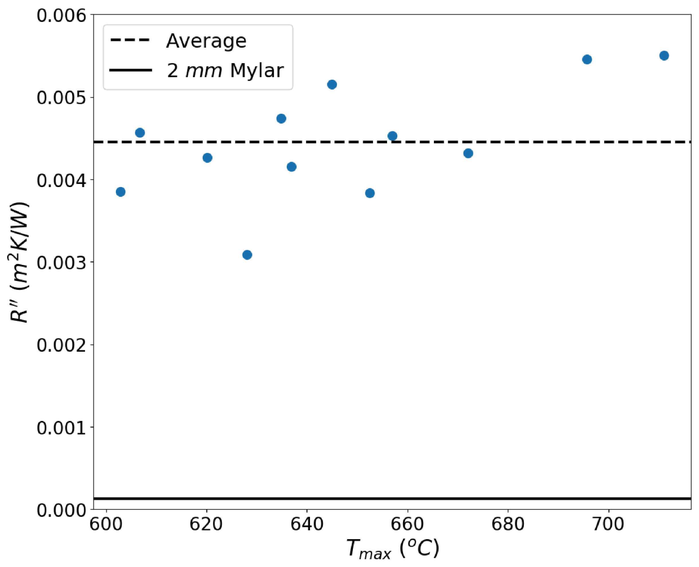
- Intercell contact resistance is significant, esp. with added spacer.
- Time delay from contact resistance is important in limiting cascading propagation (see below).
- Analytical contact resistance: first order estimate.
- A semi-infinite solid with a convective boundary condition is solved.



$$T_s = T_i + (T_{max} - T_i)[1 - \exp(\eta^2)\,\mathrm{erfc}(\eta)]$$

Where: $\eta = \frac{h\sqrt{\alpha t}}{k}$ and $R'' = \frac{1}{h}$

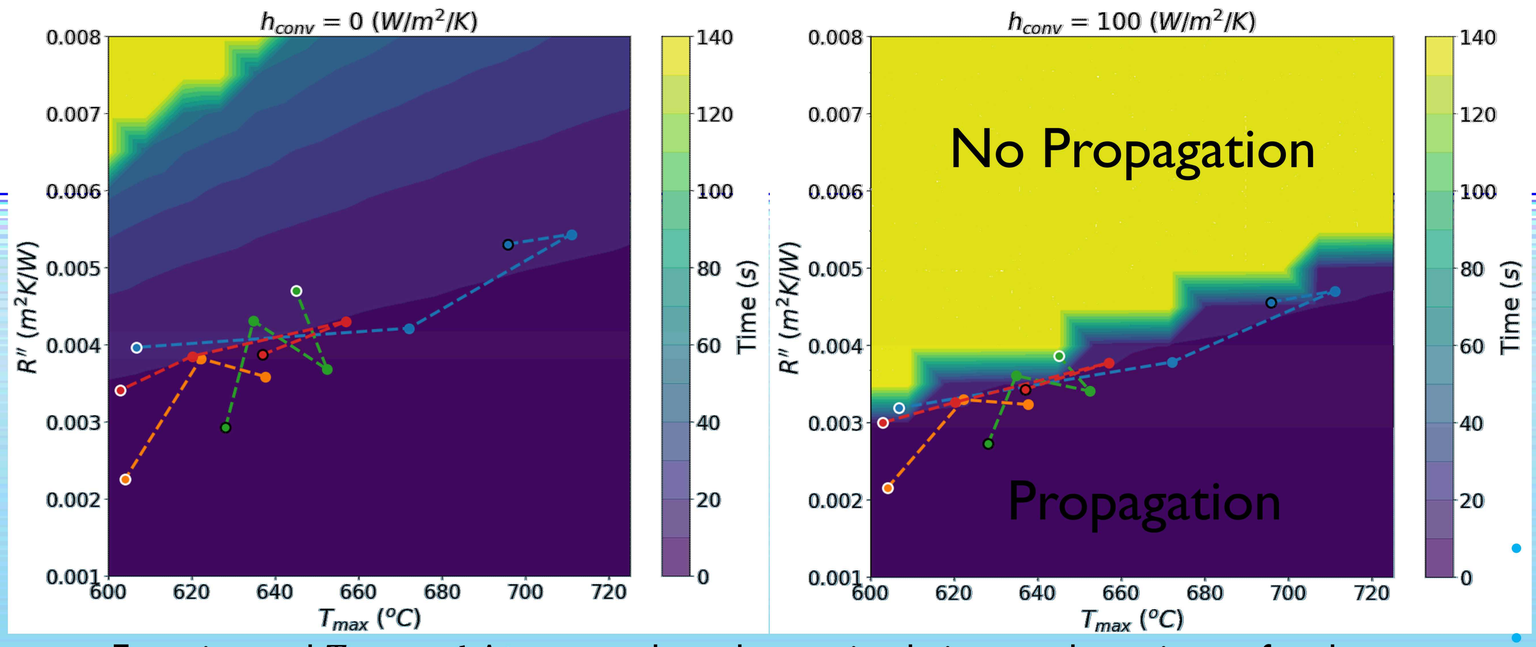
- Inverted for contact resistance (R'') using experimental T_{max} and Δt_{lag}.
- Estimate for contact resistance: 0.0045 m^2K/W.
- For reference, the thermal resistance of 0.2 mm of Mylar is approximately 1.3e-4 m^2K/W.



Limits of Cascading Thermal Runaway

Including Cooling Defines Propagation Limits: Finite Element Heat Transfer Model

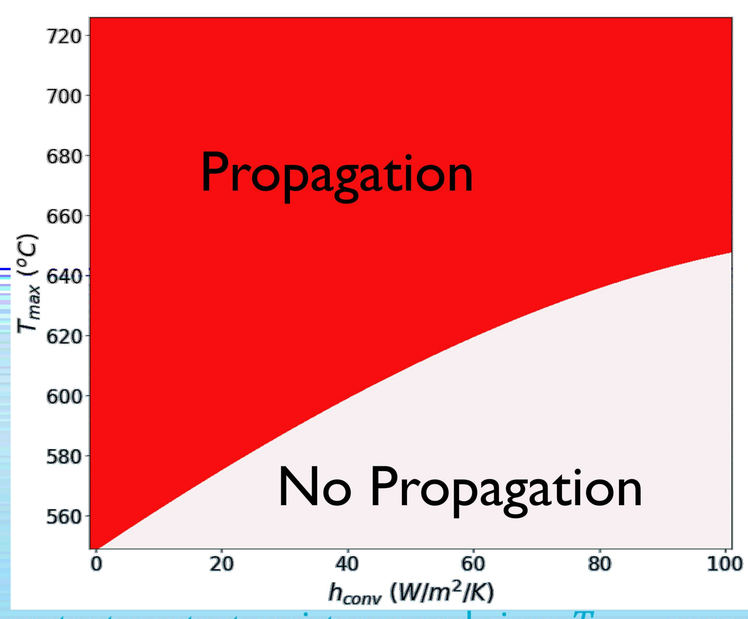
- Including full heat transfer leads to correction in contact resistance.
- Convection cooling and conduction through stack results in failure to propagate for some scenarios.



- Experimental T_{max} and Δt_{lag} are plotted over simulation results to invert for the contact resistance for two heat transfer coefficients (above left and right).

Propagation Limits of Varied Heat Release Rates and Losses

- T_{max} is related to SOC, thermal mass and cooling rates.
- Heat release rates and propagation also depend on contact resistance and preheating from compromised cells.



- For constant contact resistance and given T_{max}, propagation can be prevented by increased cooling rate (h_{conv}).
- This provides boundaries of cascading failure in terms of design variables.

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J. Lamb, C. J. Orendorff, L. A. M. Steele and S. W. Spangler, *J. Power Sources*, **283**, 517 (2015).