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Predicting Thermal Responses for Actively Cooled Designs Following Thermal Runaway

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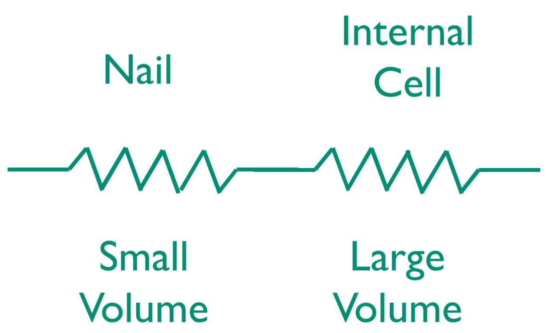
Introduction

- 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.
- Models enable knowledge to be applied to different scenarios and larger scales.
- When thermal runaway models include enough realistic physics, they can be used to:
  - Identify experimentally accessible parameters that strongly influence cascading propagation of thermal runaway through modules of cells.
  - Predict trends in heat transfer and cascading propagation behavior.
  - Identify regions of parameter space of greatest interest for experiments.
  - Evaluate mitigation strategies and explain novel experimental observations.

Modeling Short Circuit Ignition

- Adjust resistances in model to match surface temperature rise for single cells.
- Series resistances specify rate and heat release distribution from short circuit.
  - Fraction of total resistance specifies heat release in nail versus cell.
  - Concentrating heat release in small nail volume yields faster ignition.
  - Internal resistance grows and limits rate as solvent is depleted.
- Voltage correlated to limiting reactive electrode material.

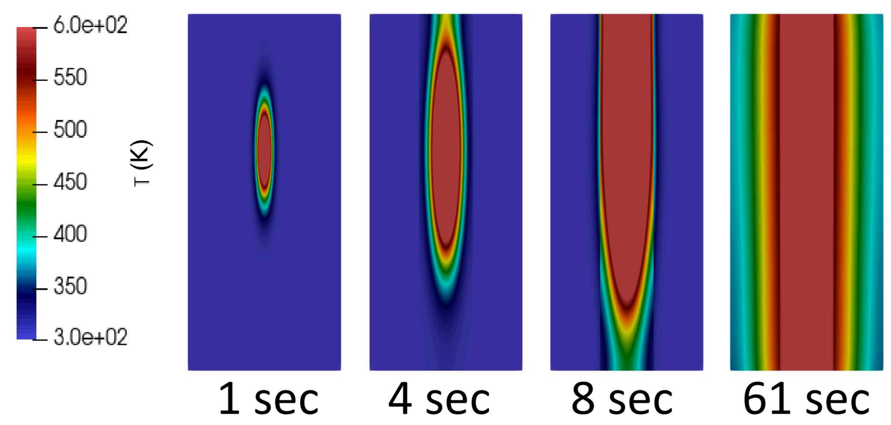


$I = V/R_{tot}$

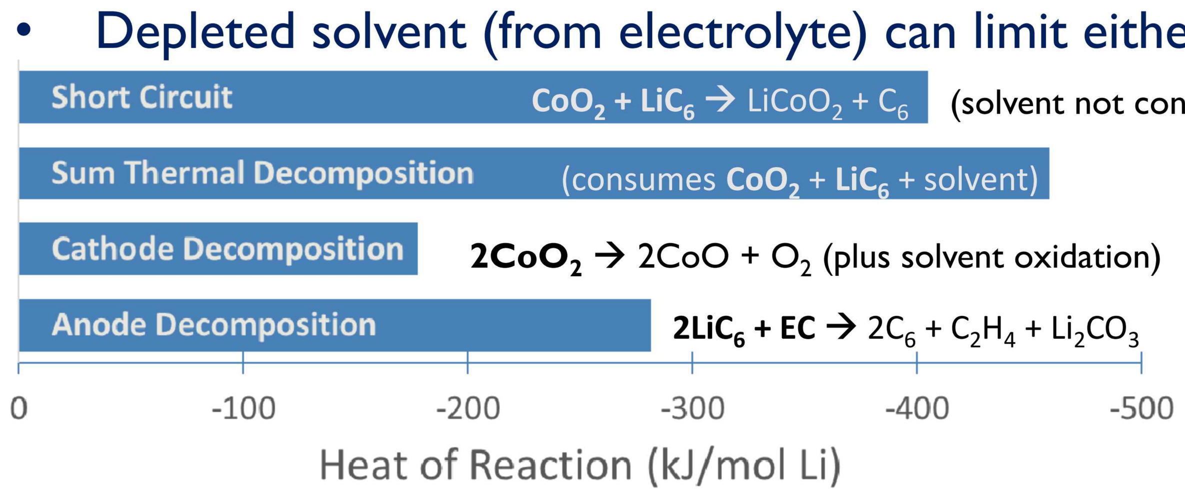
$P_{tot} = V^2/R_{tot}$

$P_N = R_N(V/R_{tot})^2$

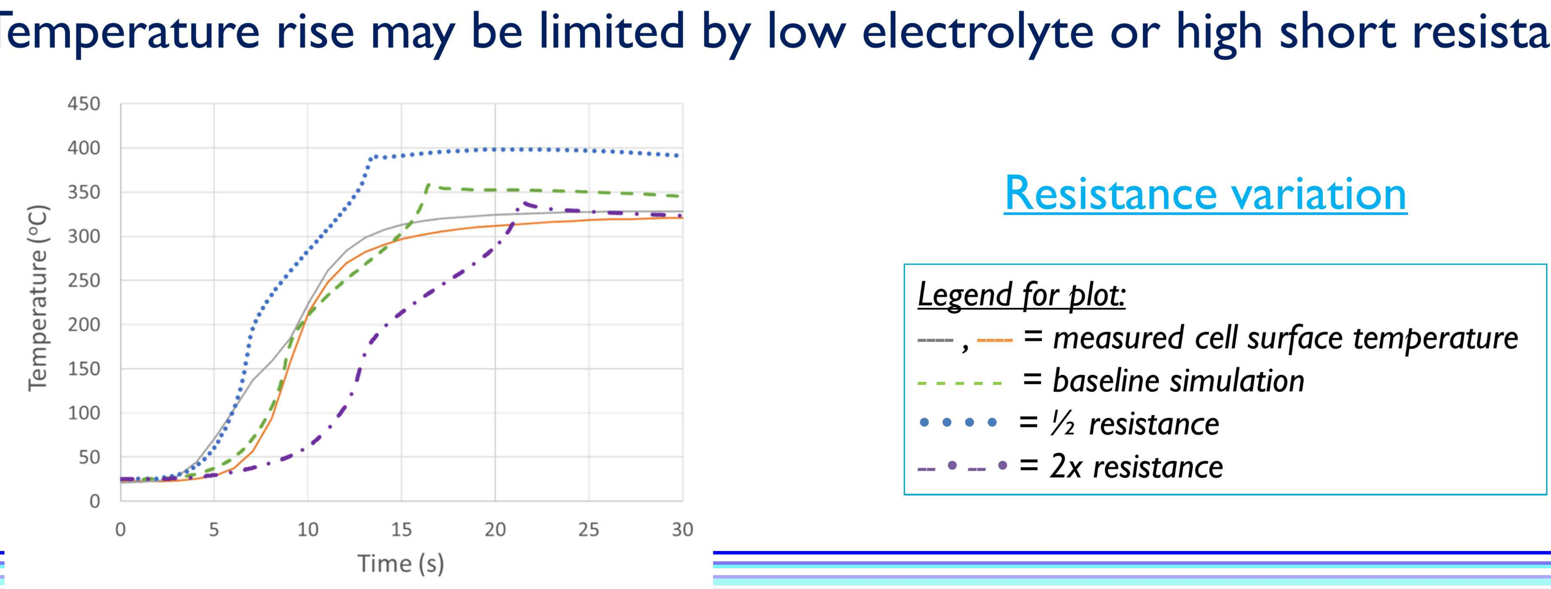
$P_{IC} = R_{IC}(V/R_{tot})^2$



- Short circuits and thermal decomposition compete for the same reactants.
  - Thermal decomposition can be more energetic.
  - Thermal decomposition is typically faster once ignited.
  - Depleted solvent (from electrolyte) can limit either process.

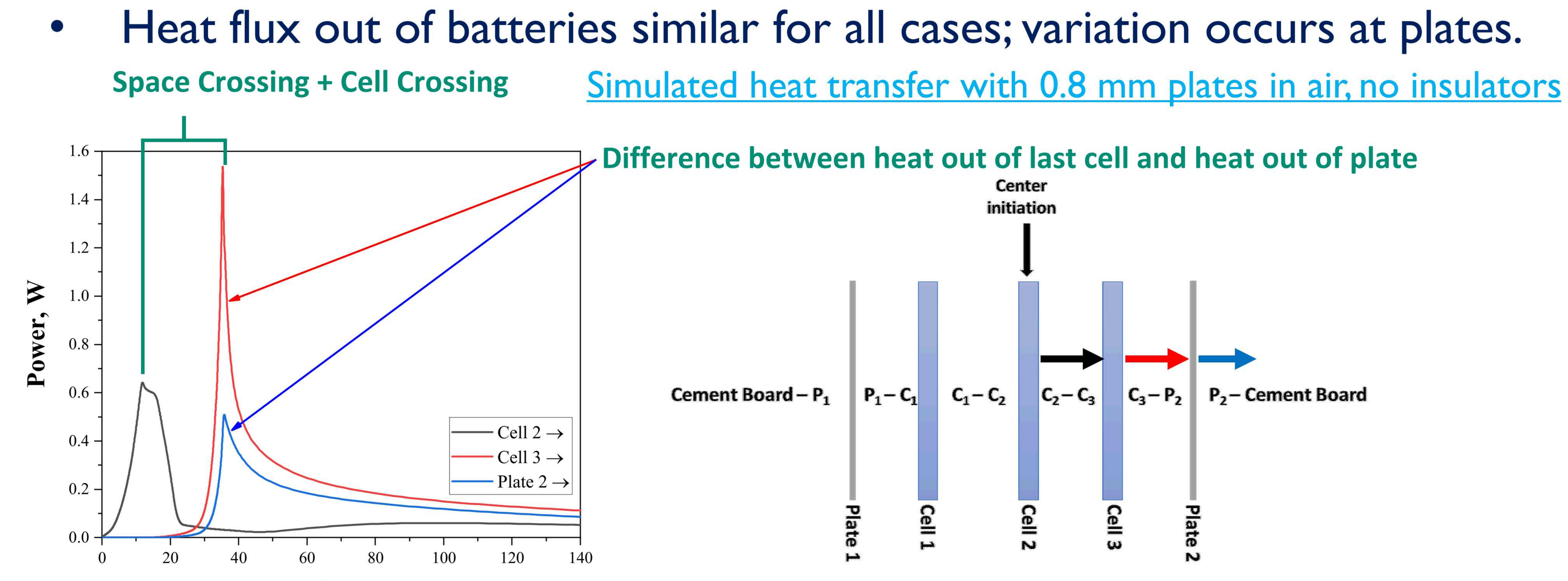


- Effects of short circuit geometry and location:
  - Central heat release yields sharp peak in cell surface temperature.
  - Off-center heat release slows rise to final temperature
    - Makes internal propagation limiting
- Temperature rise may be limited by low electrolyte or high short resistance.

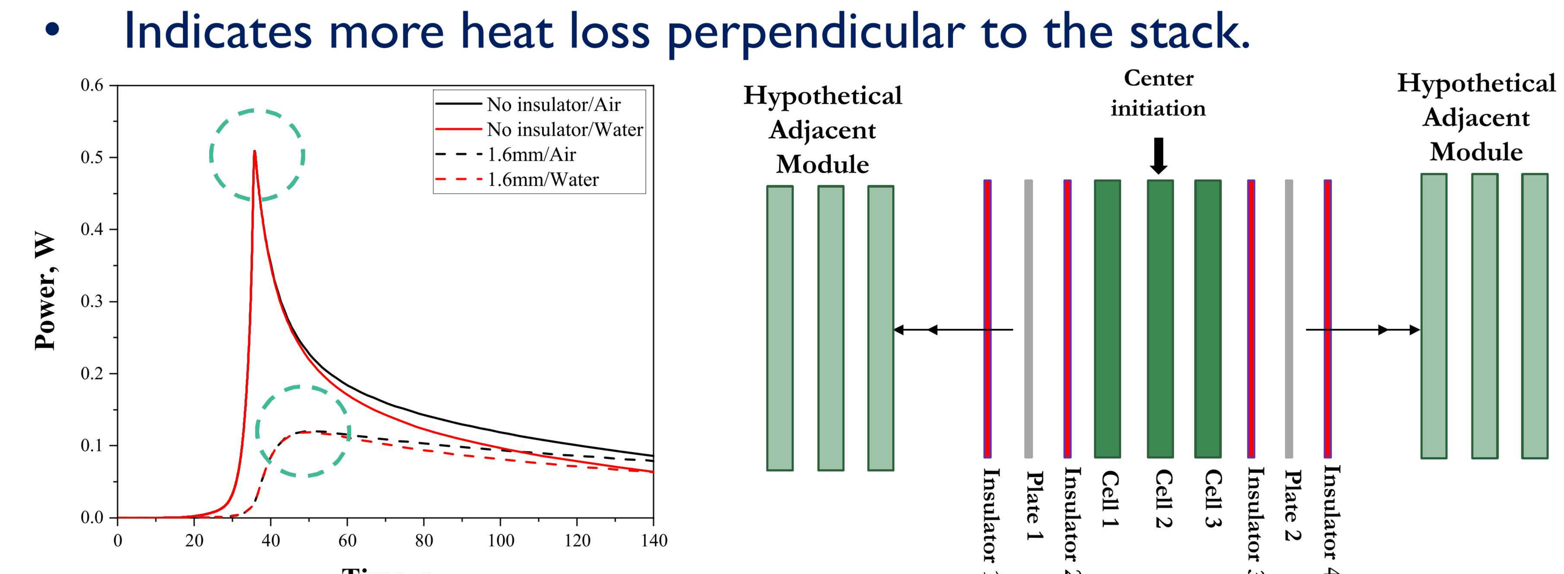


Predicted Effectiveness of Active Cooling

- Aim is to reduce heat available to a hypothetical adjacent module.
  - Measurements are reality, but simulations enable better understanding.
- Simulations of 3-cell stack (4 Ah each) with plates used to examine heat transfer.
  - Scoping simulations to down-select parameter space for experiments.
  - Heat flux out of batteries similar for all cases; variation occurs at plates.

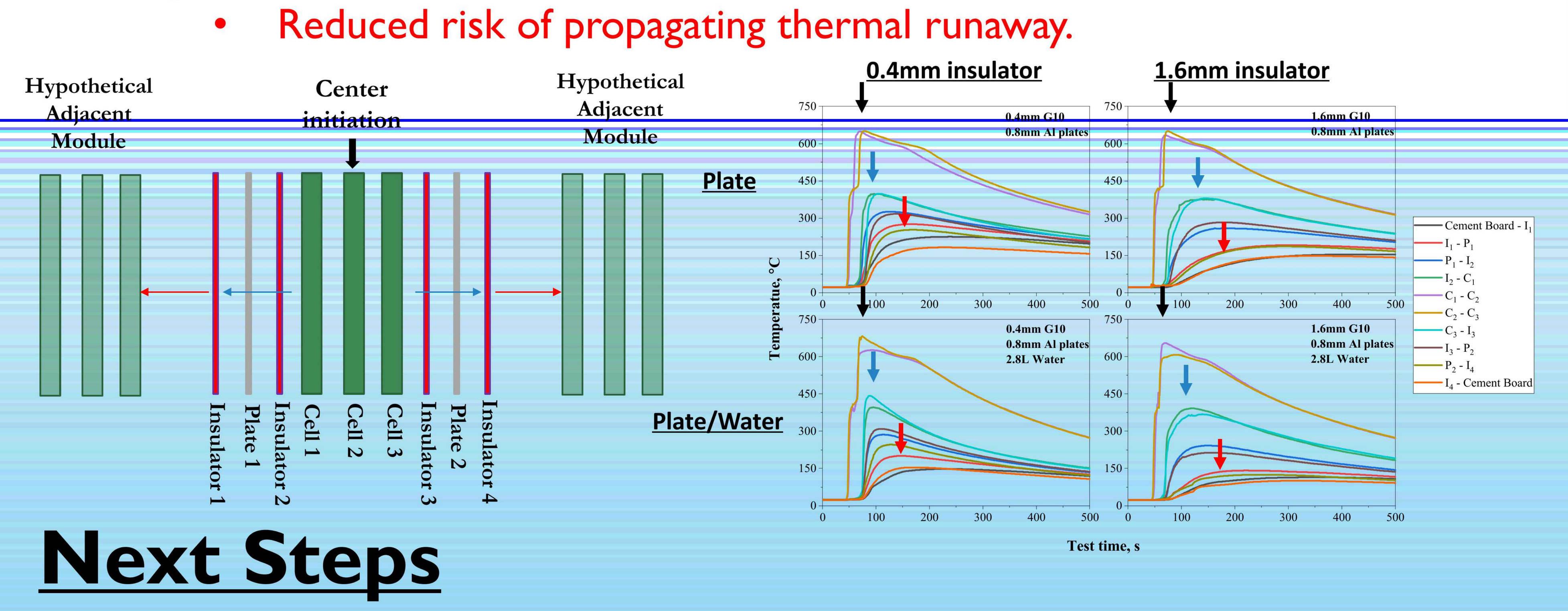


- Insulators decrease heat transfer from batteries through plates.
  - More time available for heat losses perpendicular to the stack.
- Faster decay of heat transfer in the stack direction with water cooling.
  - Indicates more heat loss perpendicular to the stack.



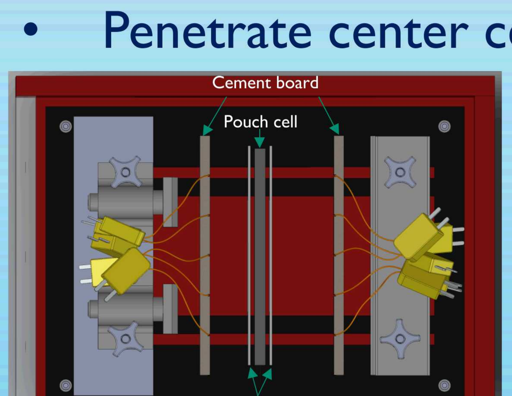
Experiments Verify Simulated Trends

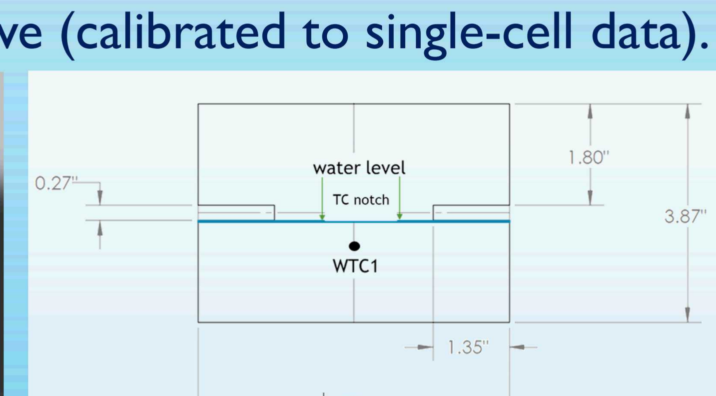
- Maximum temperature adjacent to failed cells was nearly constant.
- Without insulator mitigation, temperature and heat transfer available to hypothetical adjacent module sufficient to trigger thermal runaway (>350°C).
- With insulator mitigation, hypothetical adjacent module is exposed to temperatures between 100°C and 150°C.
  - Reduced risk of propagating thermal runaway.



Multi-Cell Active Cooling Configuration

- Three cells between aluminum plates and cement boards (two each).
  - Option to insert plates into a water bath, plate thickness can vary.
  - Optional insulators on each side of the plates, thickness can vary.
- Penetrate center cell, model as described above (calibrated to single-cell data).





Next Steps

- Use new experimental data to refine assumptions in model and parameters.
- Extract more learning from simulations and publish results.
- Identify more active cooling scenarios of interest for simulations and experiments.

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