Sandia National Laboratories

Thermal runaway propagation models: from module scale to system scale

Andrew J. Kurzawski[1], Jacob Mueller[2], Yuliya Preger[3], John C. Hewson[1]

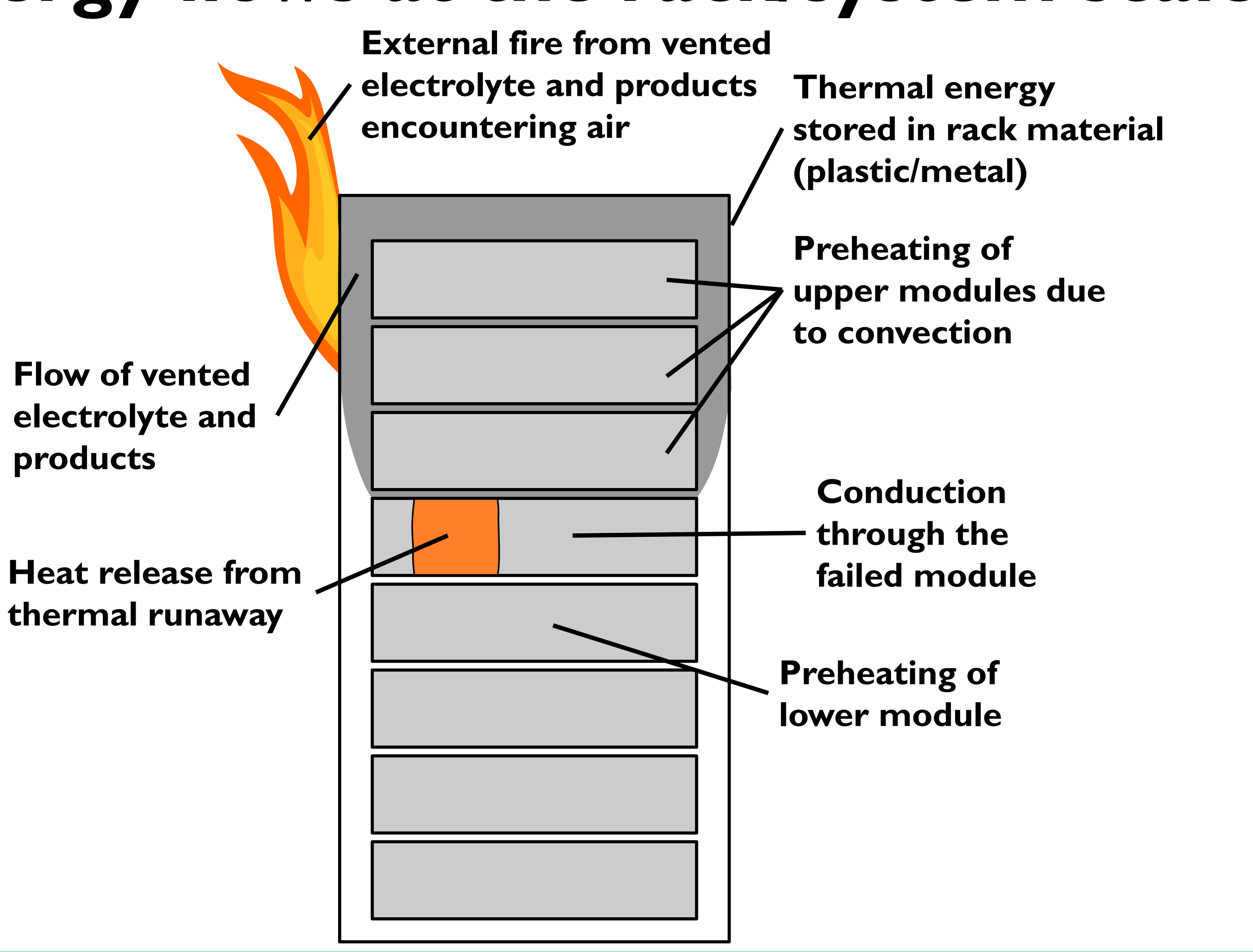
[1]Fire Science and Technology, [2]Power Electronics & Energy Conversion Systems, [3]Energy Storage Tech. and Systems

Sandia National Laboratories, Albuquerque, NM

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.
- Models enable knowledge to be applied to different scenarios and larger scales.
- A large body of work exists (both experiments and simulations) on propagating thermal runaway at the module scale.
- A small amount of experimental data is available in the literature at the system scale.
- Models are needed for safety predictions at the system scale, but several complexities are introduced when simulating large systems.
- To issue predictions that inform real-time intervention decisions, a balance must be struck between model fidelity and computational speed.
- A system scale thermal network model is proposed to capture bulk heat transfer processes.

Energy flows at the rack/system scale



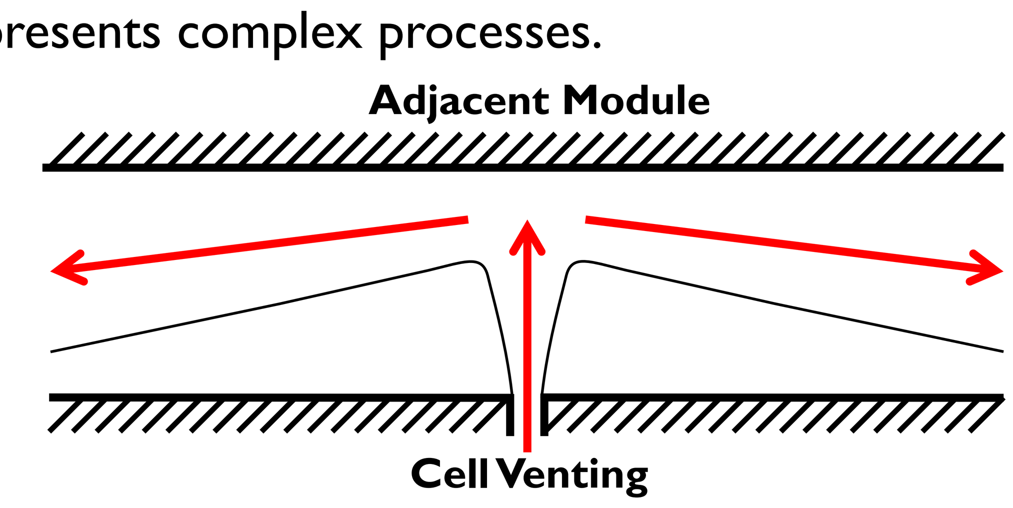
Thermal energy conservation module i in a network of N modules:

$$M_i c_{p,i} \frac{dT_i}{dt} = P_i(t) - \theta_{i,amb}(T_i - T_{amb}) - \sum_{j=1}^{N} \theta_{i,j}(T_i - T_j)$$

Stored Thermal Energy | Heat Generation | Ambient Heat Loss | Transfer Between Modules

Key sub-models: conductance and heat generation

- Conductance to ambient, $\theta_{i,amb}$, represents losses to the surroundings.
- Module-to-module conductance, $\theta_{i,j}$, represents complex processes.
  - Heat transfer from vented gases
  - Conduction through structural components
  - Ongoing collaboration with The University of Memphis to calculate convective contribution to $\theta_{i,j}$

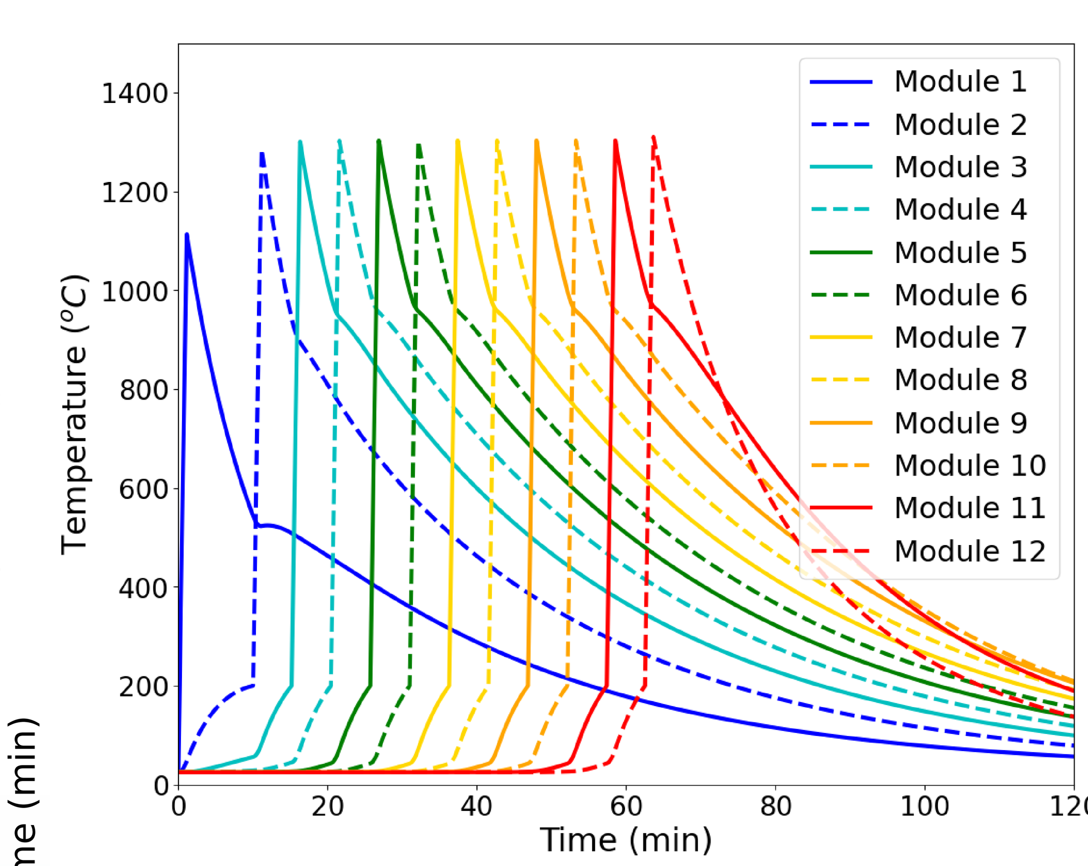


- At the cell level, heat generation is typically modeled with a series of Arrhenius reactions.
- This level of fidelity is computationally expensive at the rack scale so heat generation is simplified to a constant rate over time that depends on the state of charge (SOC).

$$P_i(t) = \frac{Q_i}{\tau_i}, Q_i = SOC_i \times Q_{max}$$

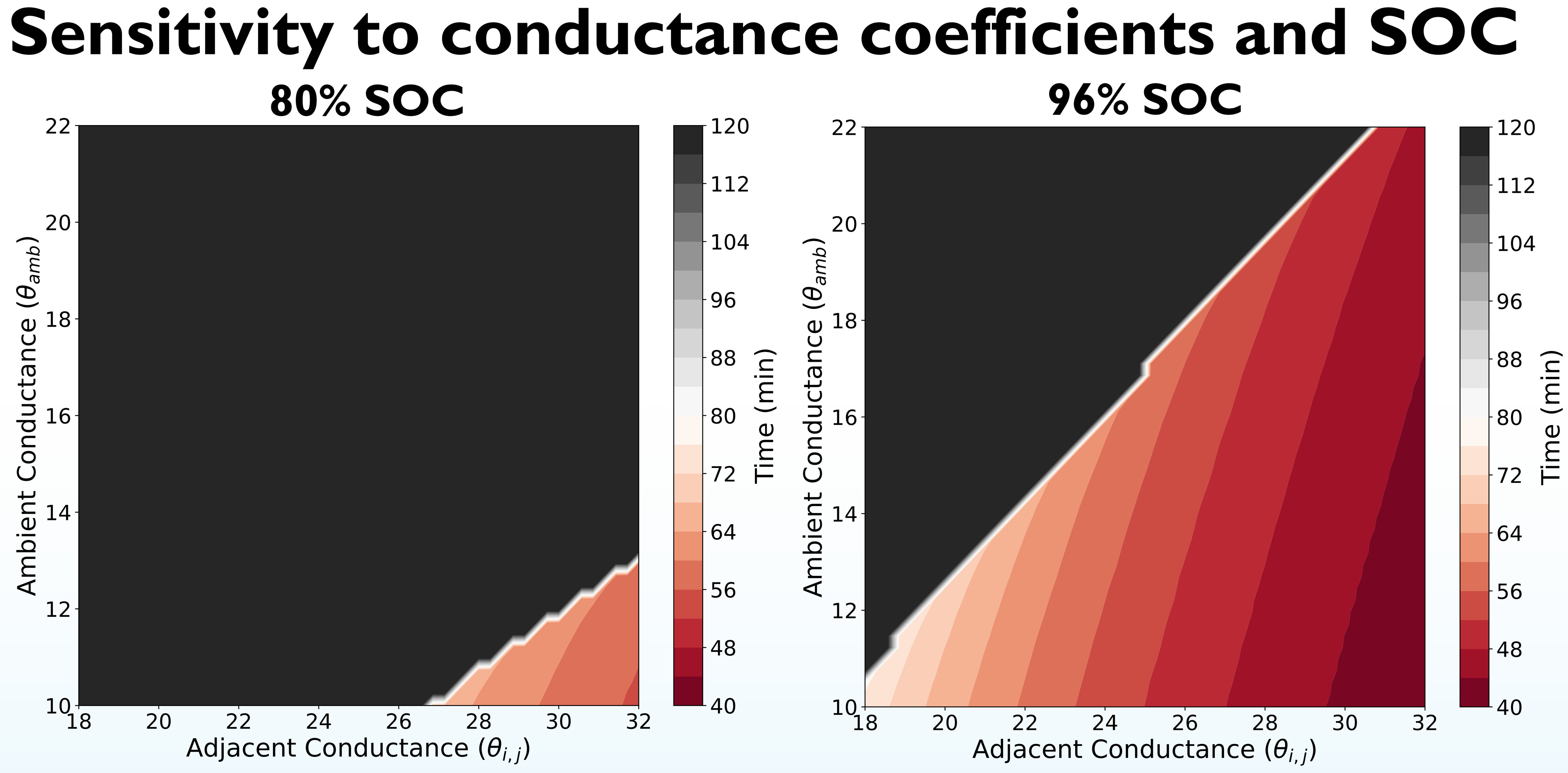
- The available energy and heat release duration are predicted using the SOC when the module reaches the critical thermal runaway temperature:

$$\frac{1}{\tau_i} = A_r \exp\left(\frac{-E_a}{R(T_a + Q_i/M_i c_{p,i})}\right)$$



- Example predictions from the network model shows propagation through a rack of modules.
- Thermal runaway begins in Module 1 and propagates sequentially.

Sensitivity to conductance coefficients and SOC



- Total propagation time for the example 12 module rack is plotted against a range of conductances.
- Dark gray regions represent conditions where thermal runaway does not consume the whole rack.
- Losses to ambient compete with conduction to adjacent modules.
- Reducing SOC greatly reduces severity.

Summary

- Predicting thermal runaway at the system scale requires models that balance the complexity of the heat transfer processes with computational efficiency.
- A network model was formulated as a framework for beginning to predict this behavior.
- The model requires system specifications and experimental data to be validated.
- The key outputs that impact safety decisions are the total energy released and the duration of thermal runaway.

Acknowledgements: Funded by Dr. Imre Gyuk through the U.S. Department of Energy; Office of Electricity