Sandia National Laboratories

Exceptional service in the national interest

UNDERSTANDING BESS FIRE HAZARDS AT THE SYSTEM LEVEL WITH EXPERIMENTS AND MODELING

Andrew Kurzawski, Michael Meehan, Randy Shurtz, John Hewson, Alex Bates, Loraine Torres-Castro

Sandia National Laboratories

DOE OE Energy Storage Peer Review

8/6/2025

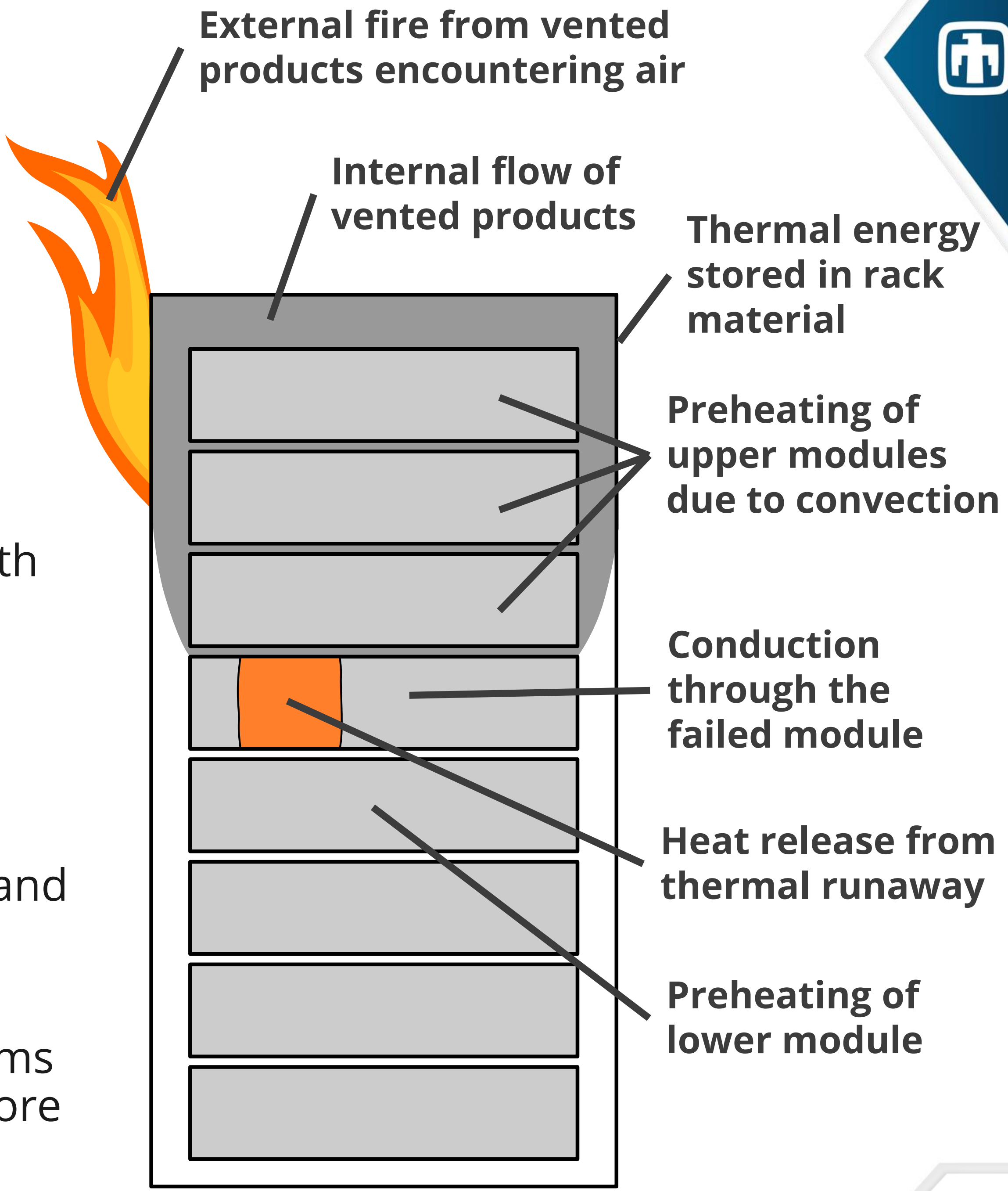
U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

Sandia National Laboratories is a multimission 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-NA0003525.

SAND2025-05809C

PROJECT OVERVIEW

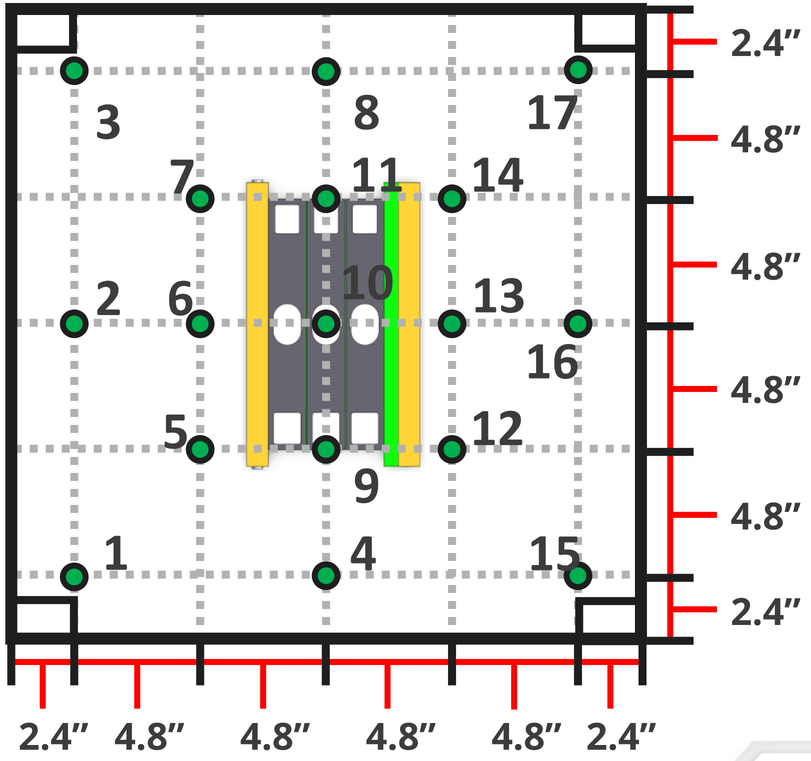
- **Project Goal:** Use experiments and simulations to understand thermal runaway for energy storage systems.
- **Current Practice:** Mainly lab-scale experiments, with little data on full systems in the open literature.
- **Why Sandia?**
  - Synergy and communication between experimentalists and computational modelers with years of experience studying battery safety.
  - Facilities for conducting and instrumenting large thermal runaway experiments.
  - Drive to share learnings with the public.
- **Impact:** ESS designers, integrators, first responders, and standards developers can better understand thermal runaway behavior at the system scale.
- **Alignment:** Improving safety of energy storage systems strengthens the nation's power grid by providing a more reliable and secure service.



MODULE-TO-MODULE HEAT TRANSFER FROM VENTING

- Collaboration with NITE NLab in Japan on inter-lab experimental variability to inform safety standards testing.
- A plate instrumented with 17 thermocouples was used to measure heating during the module propagation experiments. Two plate heights: 20 cm and 5 cm.

Thermocouple Layout (Top View)



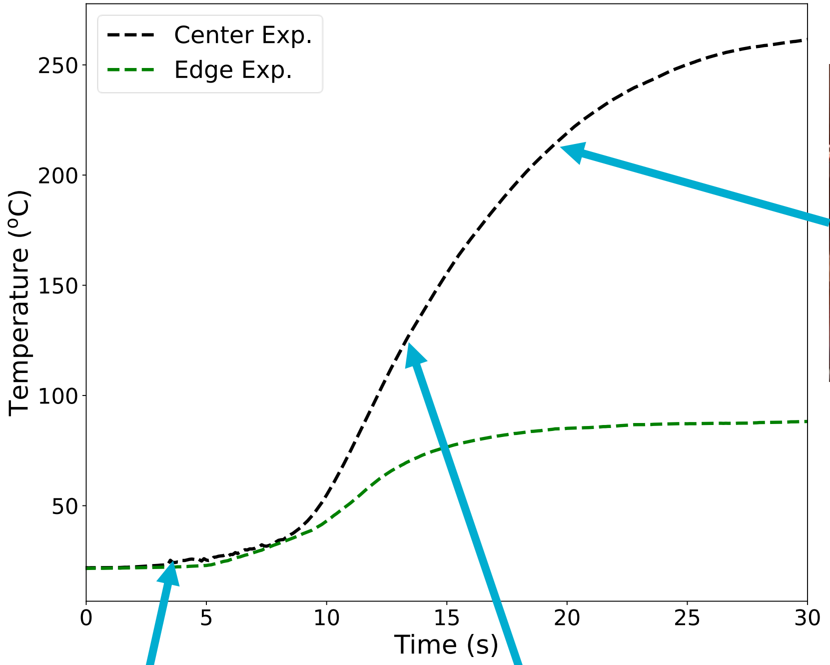
HOW TO ESTIMATE HEAT FLUX

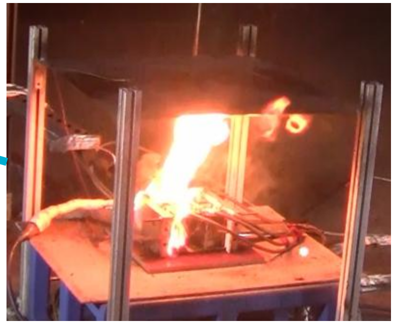
- Thermocouple measurements show the response of the plate to the jet from three cells venting.
- We use inverse methods to get heat flux from temperature measurements.

Heat Fluxes → **Forward Model** → **Temperature Predictions**

Heat Fluxes ← **Inverse Model** ← **Temperature Data**

Plate Temperature: Cell 1 Venting

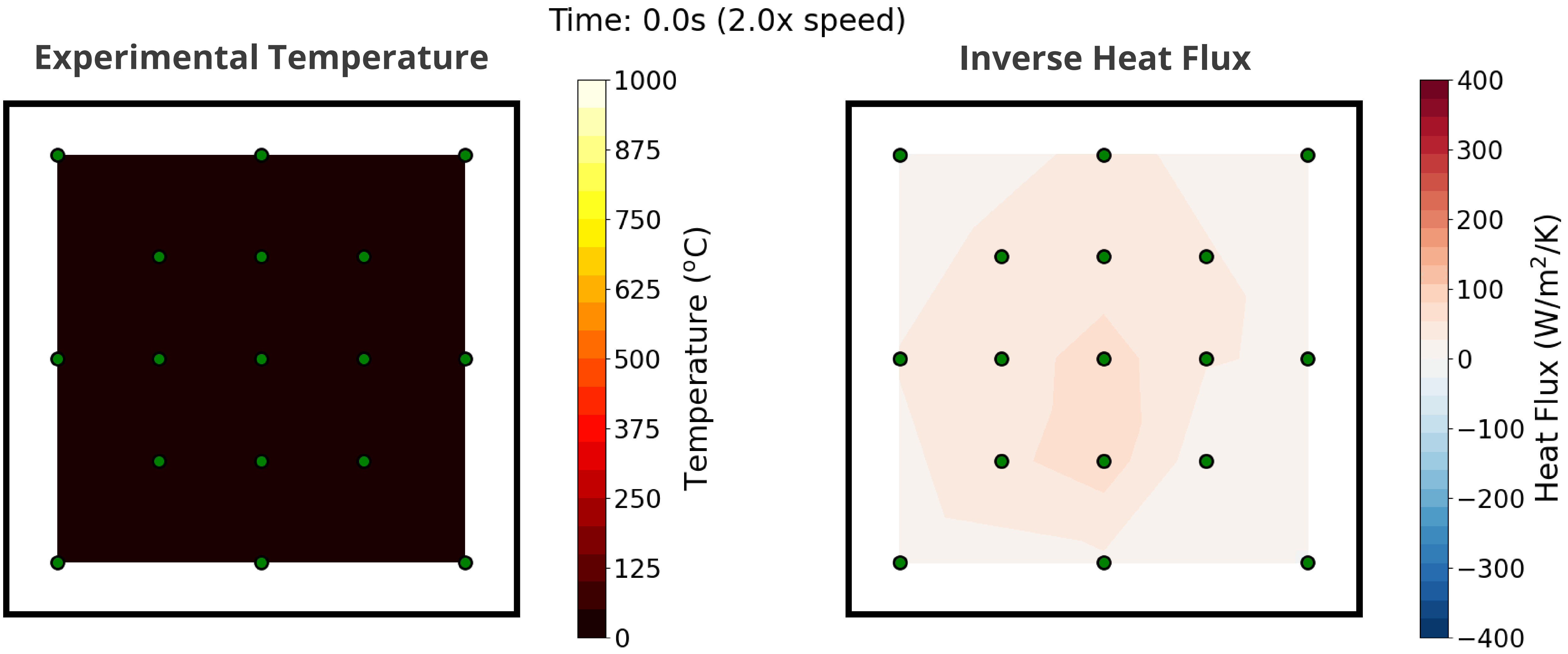




Venting progression:
- Unburned gas and hot particles
- Fast flaming
- Slow flaming

EXPERIMENTAL TEMPERATURES AND INVERSE HEAT FLUX

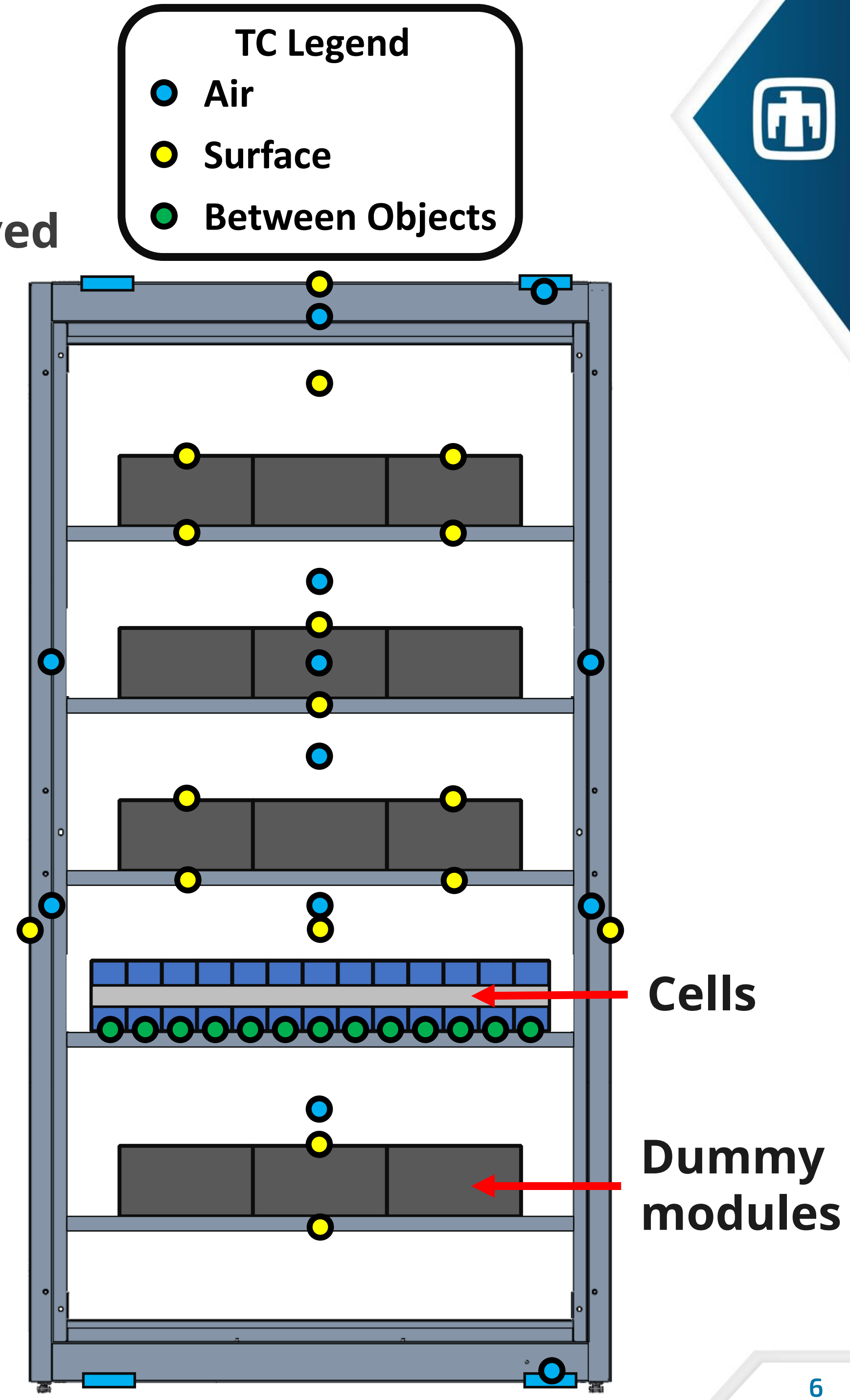
20 cm Plate Height: Cell 1 Venting



25 KWH RACK-SCALE EXPERIMENT

- **Goal:** test capabilities to conduct a rack-scale experiment and collect rare rack-scale data.
- 25 kW hour system
  - 200 Ah NMC prismatic
  - 1 shelf: 26 cells in two 13s1p rows
  - 4 shelves: sand-filled aluminum dummy modules
- 60 thermocouples (not all pictured)
- Thermal runaway initiated with a patch heater between two cells.

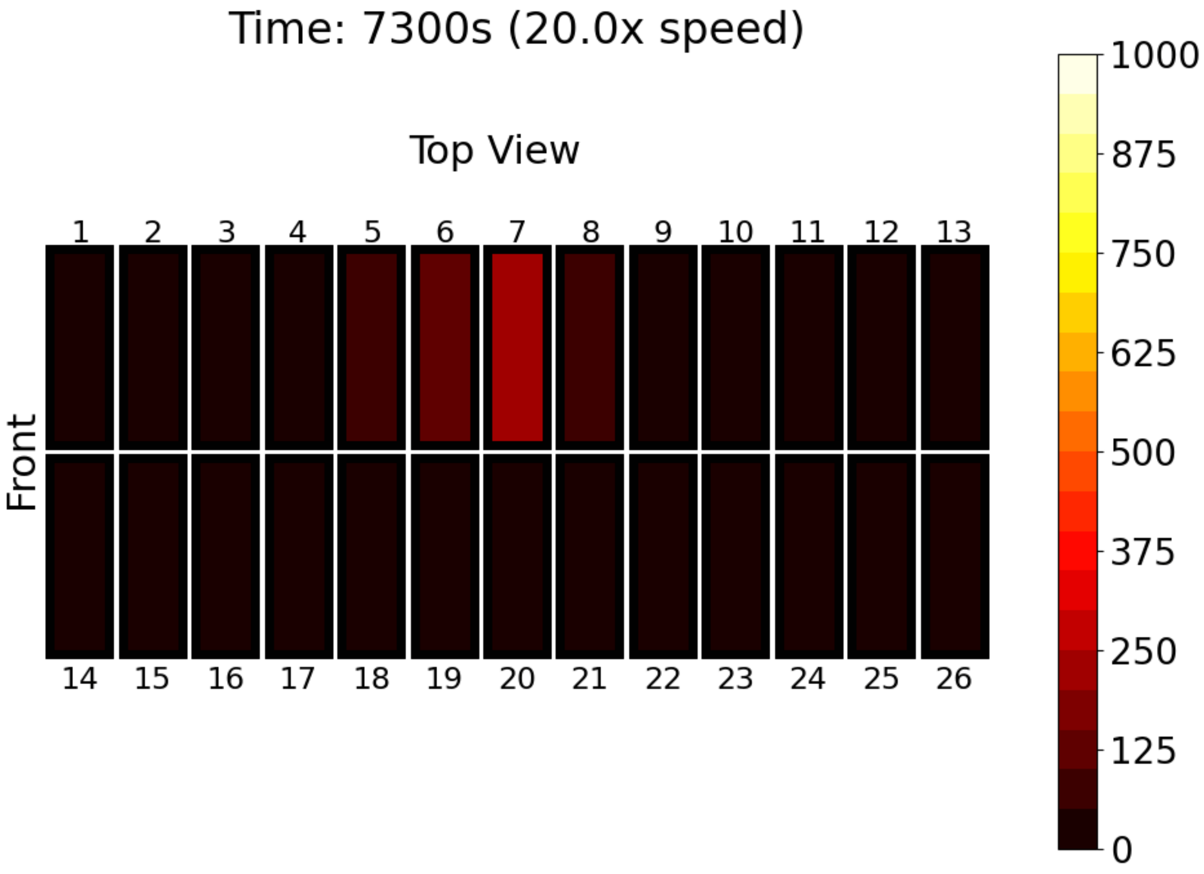
Pre-test side view with walls removed

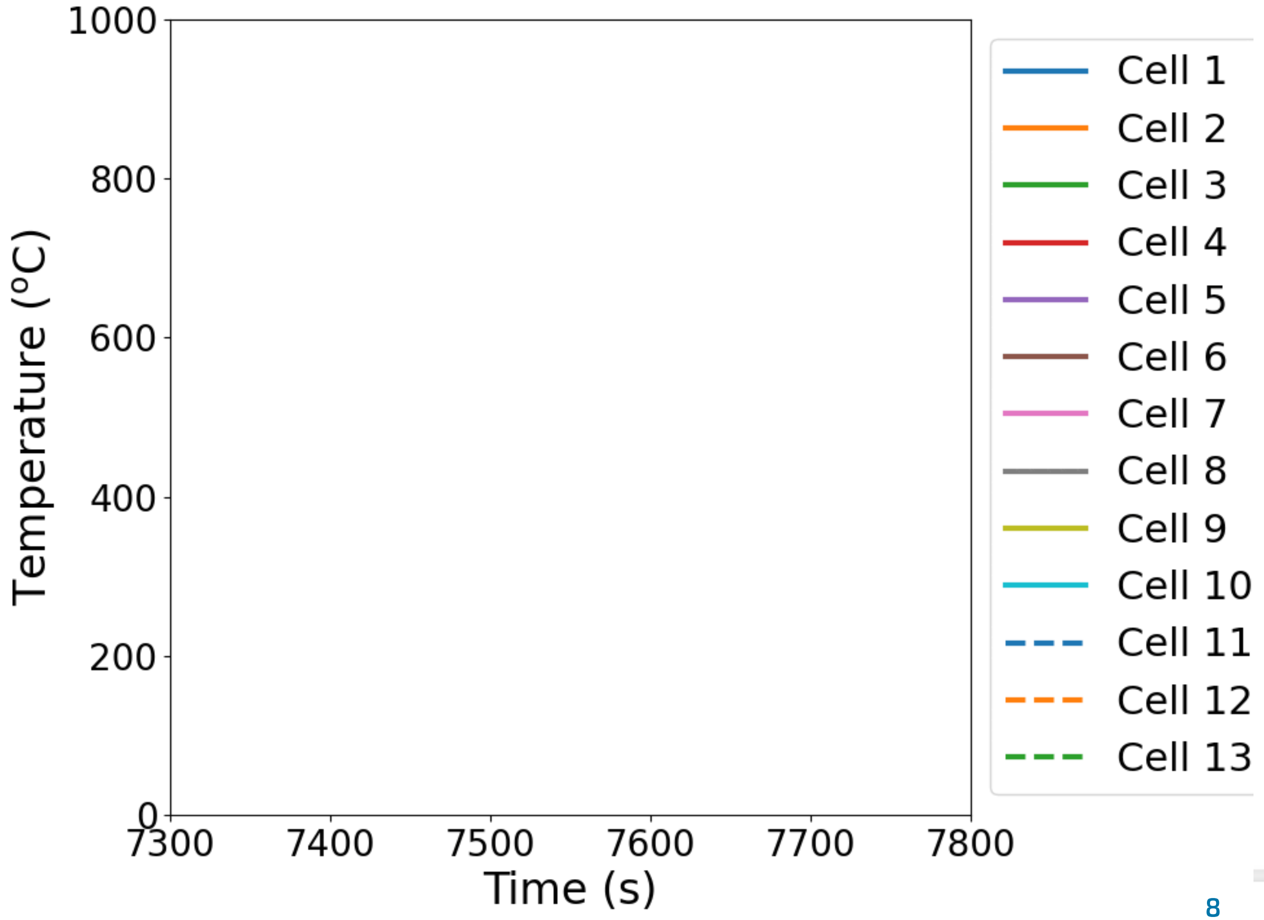


25 KWH RACK SCALE EXPERIMENT

25 KWH RACK SCALE EXPERIMENT

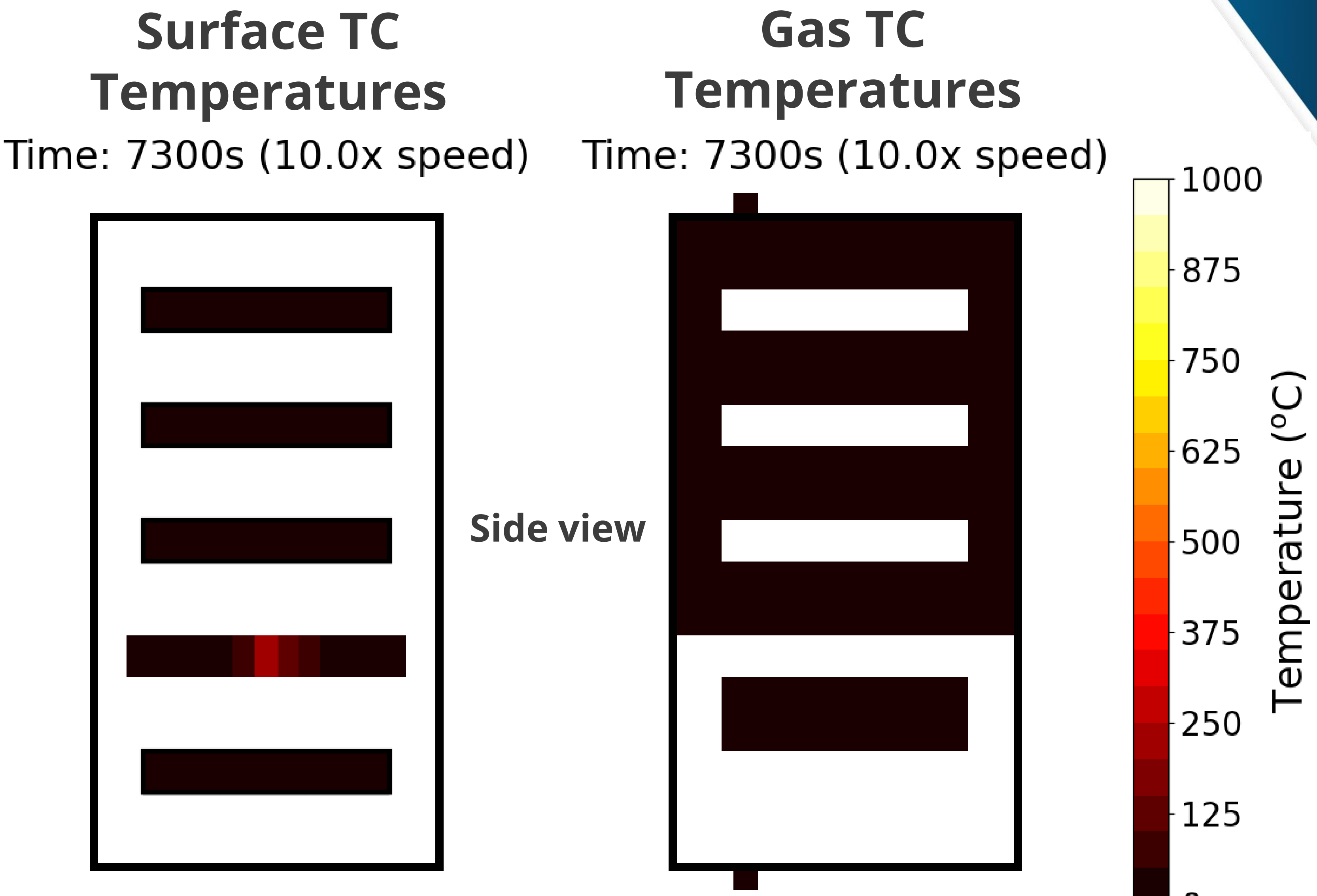
- The heater between cells 6 and 7 was attached to cell 7.
- TCs are embedded in shelf plastic below cells.
- End cells 1 and 13 were exposed to additional heating from the fire.





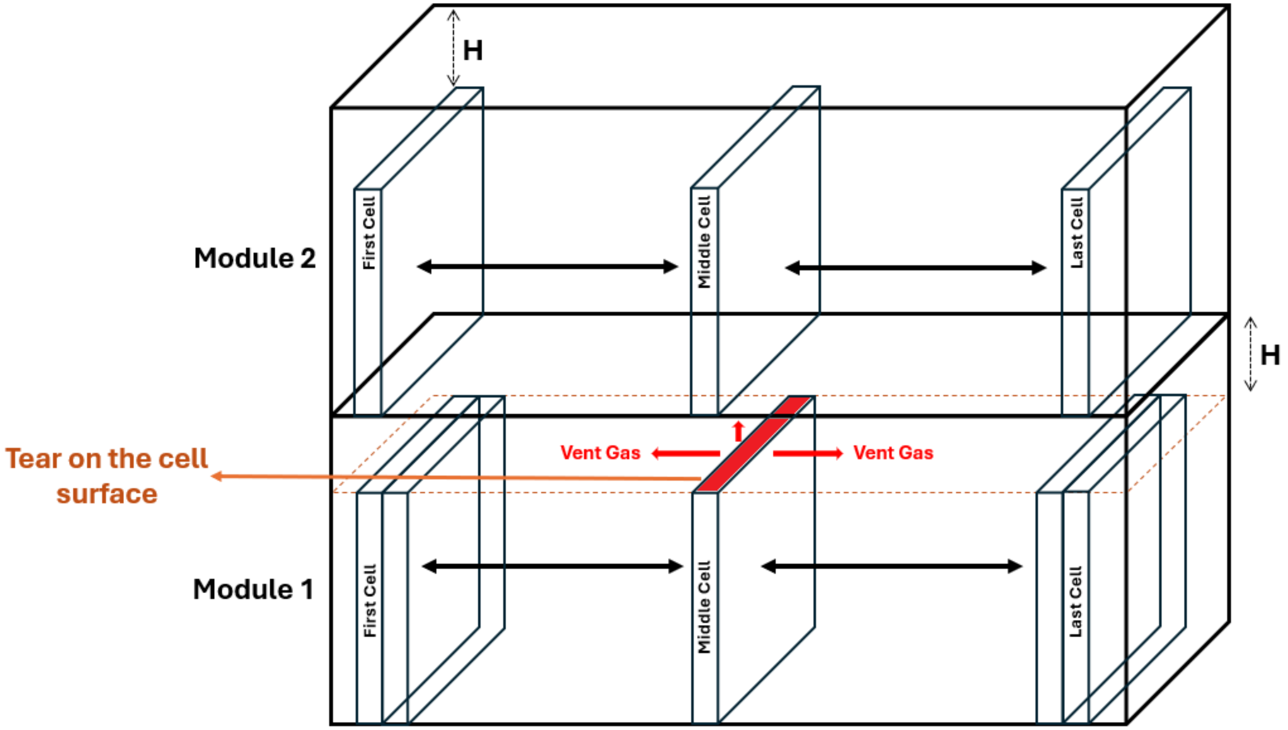
25 KWH RACK SCALE EXPERIMENT

- Dummy module had TCs on top of the modules and below the shelves.
- The under side of the two dummy modules above the cell modules saw the most heating.
- The top dummy module received more heat from the gas in the top of the rack than the gas below the shelf.
- The bottom dummy module does not see significant heating until several minutes after thermal runaway began.

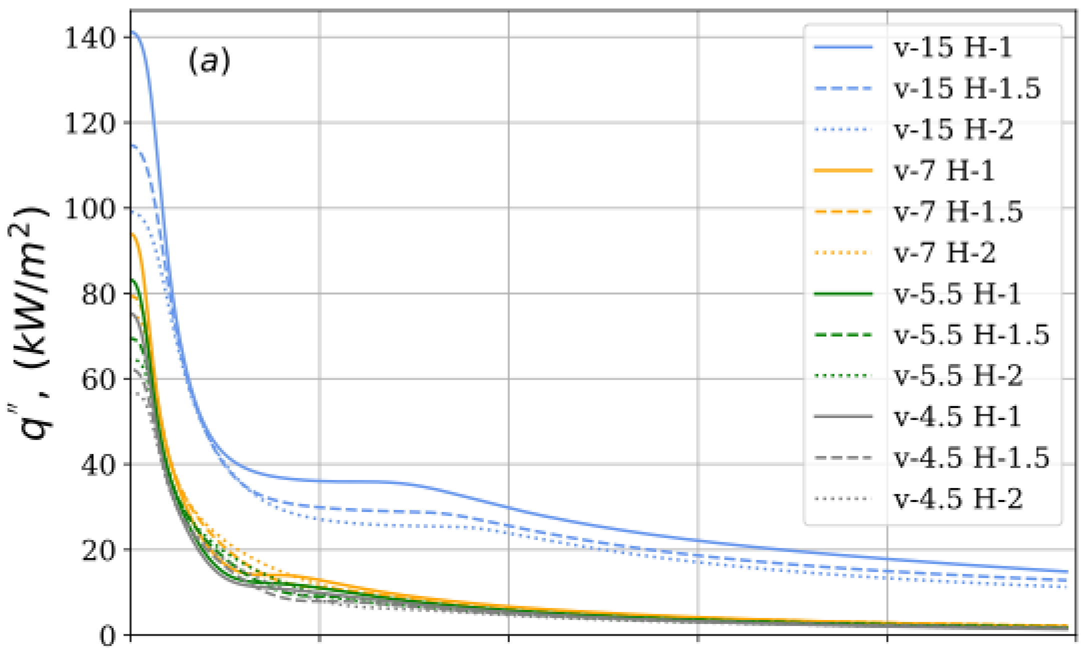


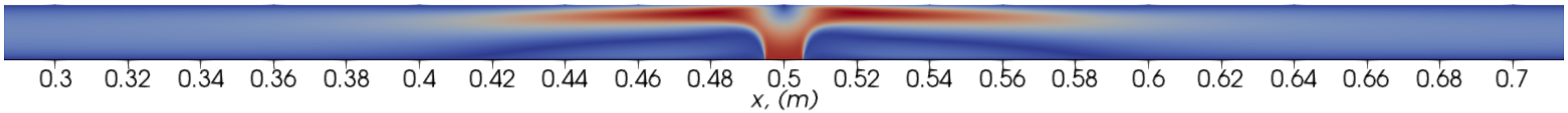
UNDERSTANDING VENTING HEAT TRANSFER TO ADJACENT MODULES

- Consider cells venting with hot gases impinging on a module of cells above.



Heat flux from hot gases



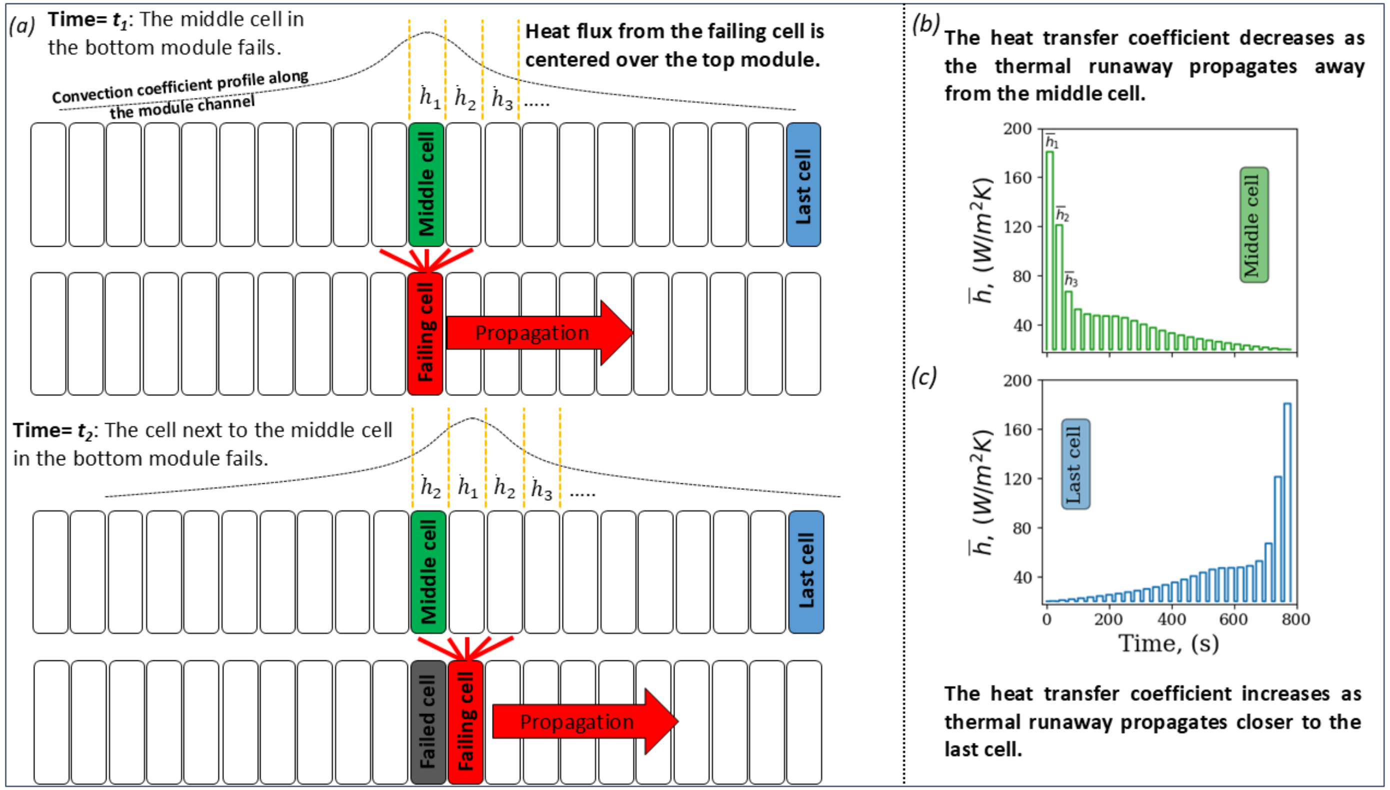


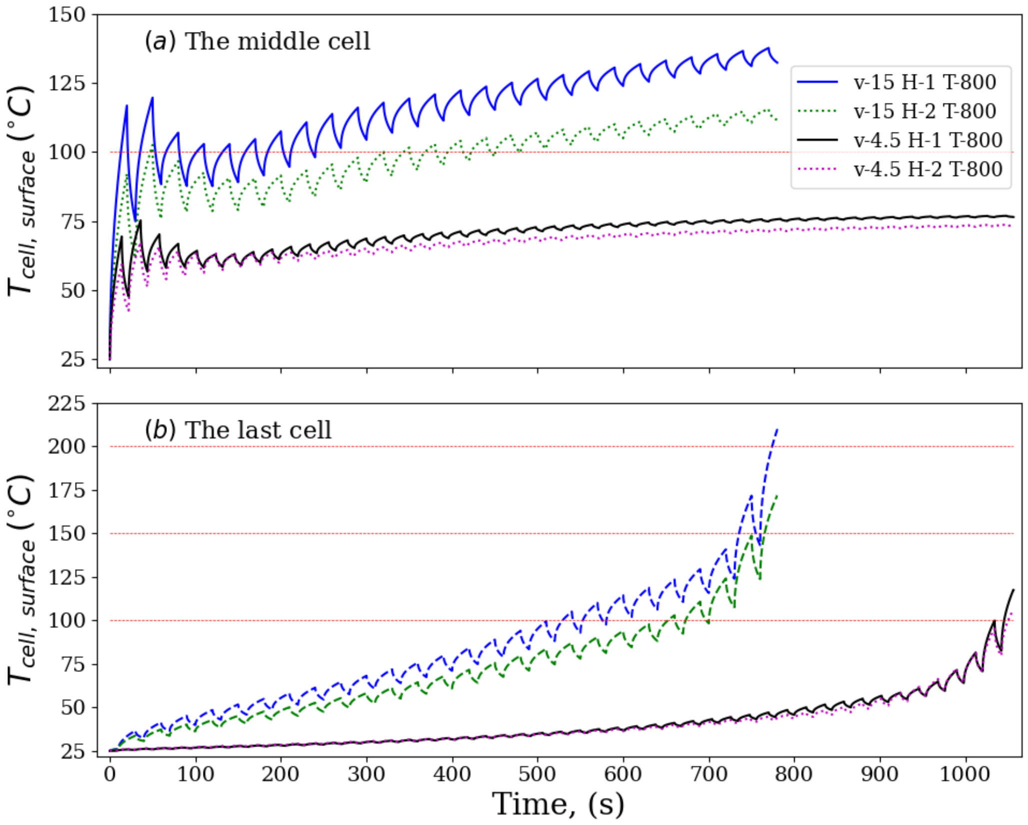
Venting Flow

Simulations from A. Qatramez, D. Foti, and A. Headley at The University of Memphis

UNDERSTANDING VENTING HEAT TRANSFER TO ADJACENT MODULES

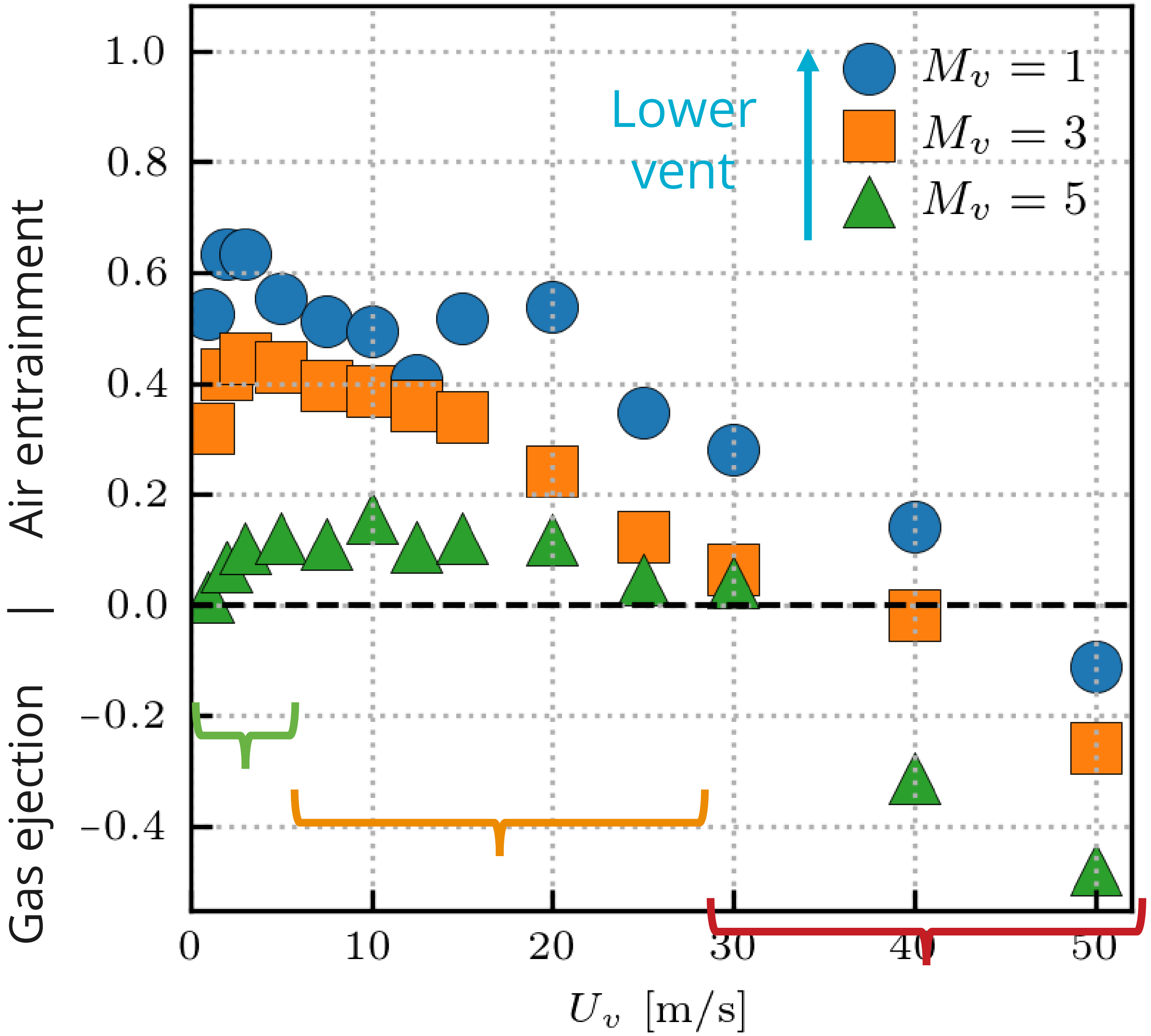
- Now consider cell-to-cell propagation and its effect on venting heat transfer.
- Venting has a greater effect when propagation starts far and moves closer: increasing heating rates are more dangerous.

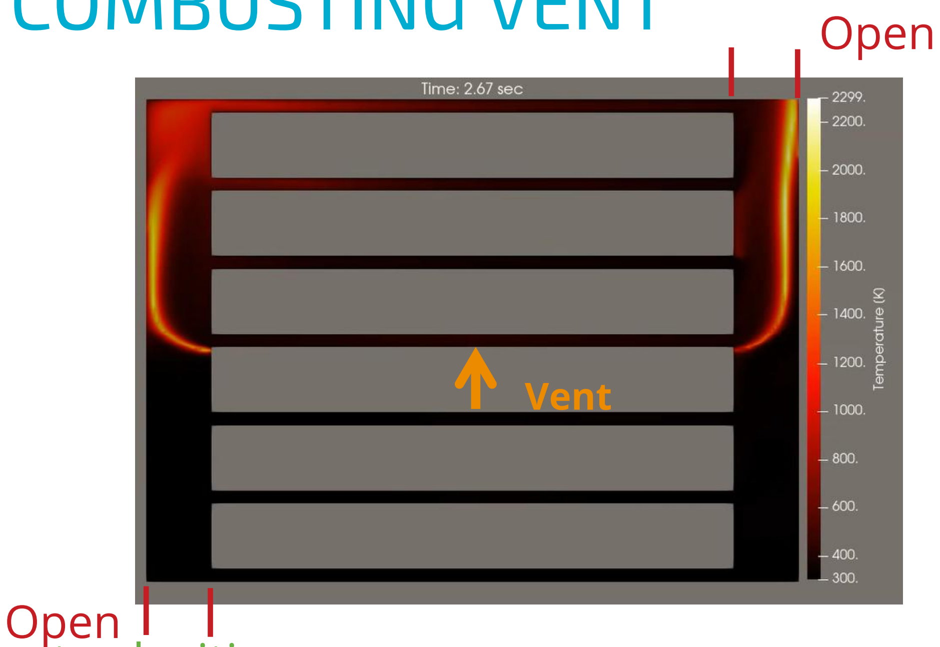




Simulations from A. Qatramez, D. Foti, and A. Headley at The University of Memphis

PROJECT RESULTS: ENTRAINMENT FOR COMBUSTING VENT GAS





See Poster: M. Meehan et al. "Toward algebraic modeling of natural convection inside simplified energy storage systems"

Low vent velocities:

- Mass entrainment *increases* due to increase in buoyancy provided by the vent gas and flames.

Moderate vent velocities:

- Mass entrainment *decreases or remains constant* due to increase in inertia relative to buoyancy

High vent velocities:

- Inertial forces are strong enough to overcome buoyancy and push vent gases out of the bottom of the rack.

SUMMARY

- Sandia is conducting multiple projects all centered around the same goal: improving the safety of energy storage systems with collaborative experiments and modeling.
- Propagation experiments and inverse simulations with collaborators at NITE allow for the calculation of venting heat fluxes.
- Rack-scale experiments capture energy flows during thermal runaway.
- Simulations with collaborators at the University of Memphis predict heat transfer into adjacent modules.
- Rack-scale simulations allow for exploration of the design space with coupled flow and heat transfer.

ACKNOWLEDGEMENTS

- Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & 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-NA0003525. SAND#0000-XXXXX
- This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division.
- Additional thanks to all of Sandia's safety thrust team, the Batlab technicians, and our collaborators at NITE Japan and The University of Memphis.