2023 June 6-8, Santa Fe, New Mexico
ENERGY STORAGE SYSTEMS
SAFETY & RELIABILITY FORUM

Li-ion Battery Fire Hazard Evaluation -- Testing, Modeling and Scaleup

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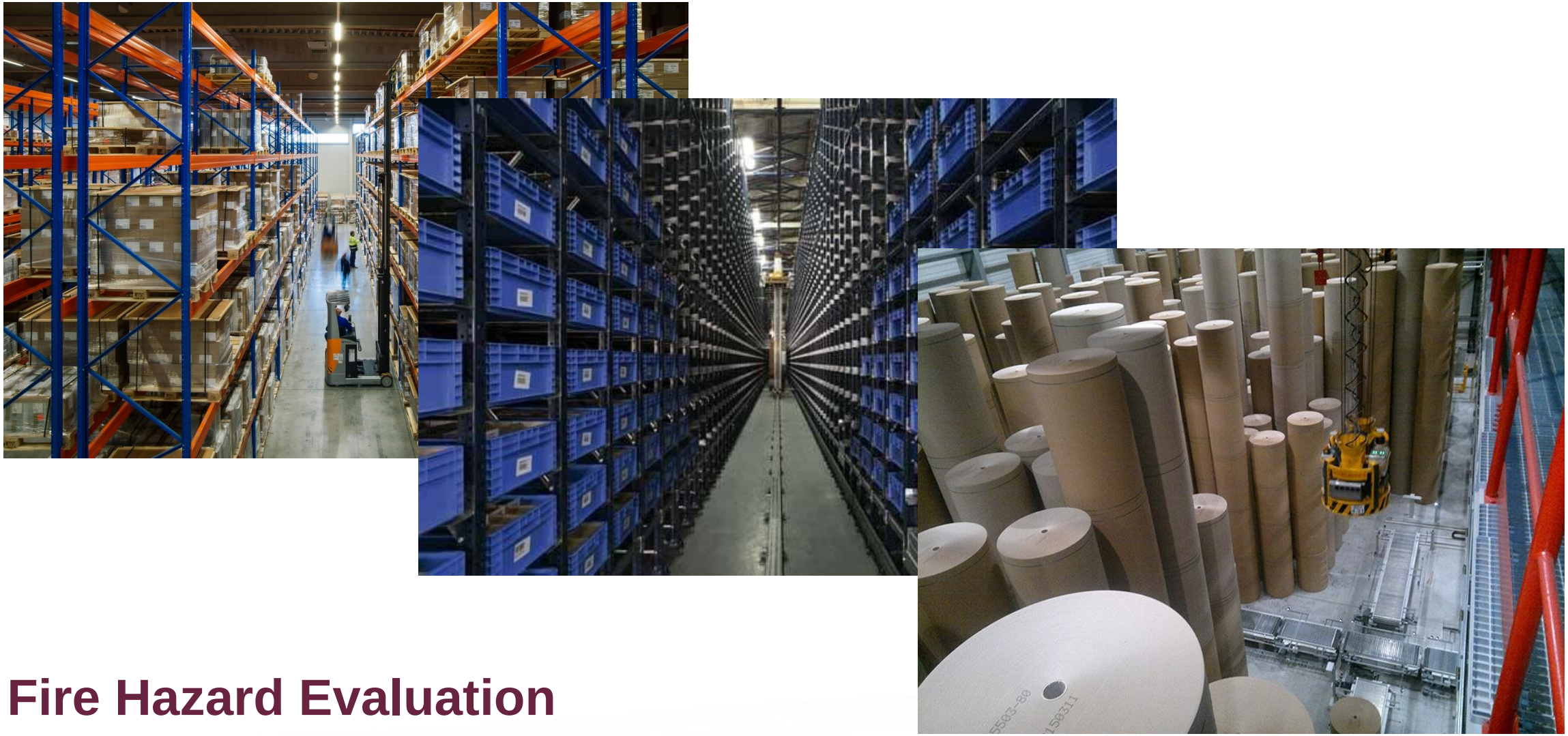
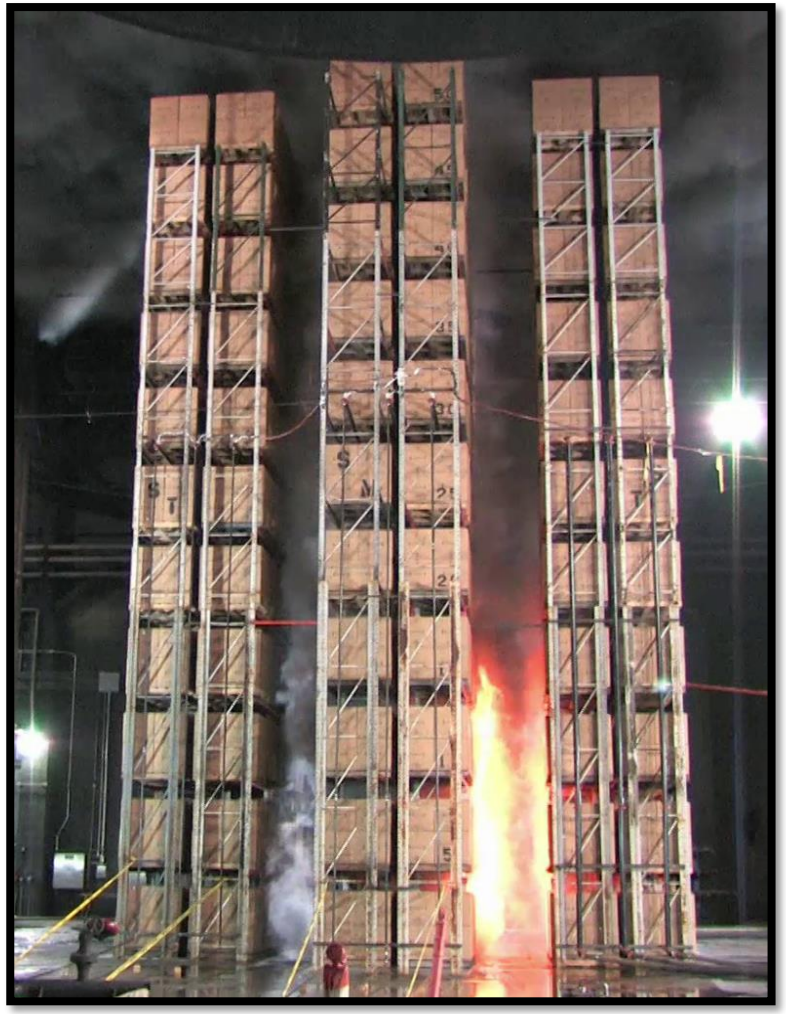
Research Division
FM Global

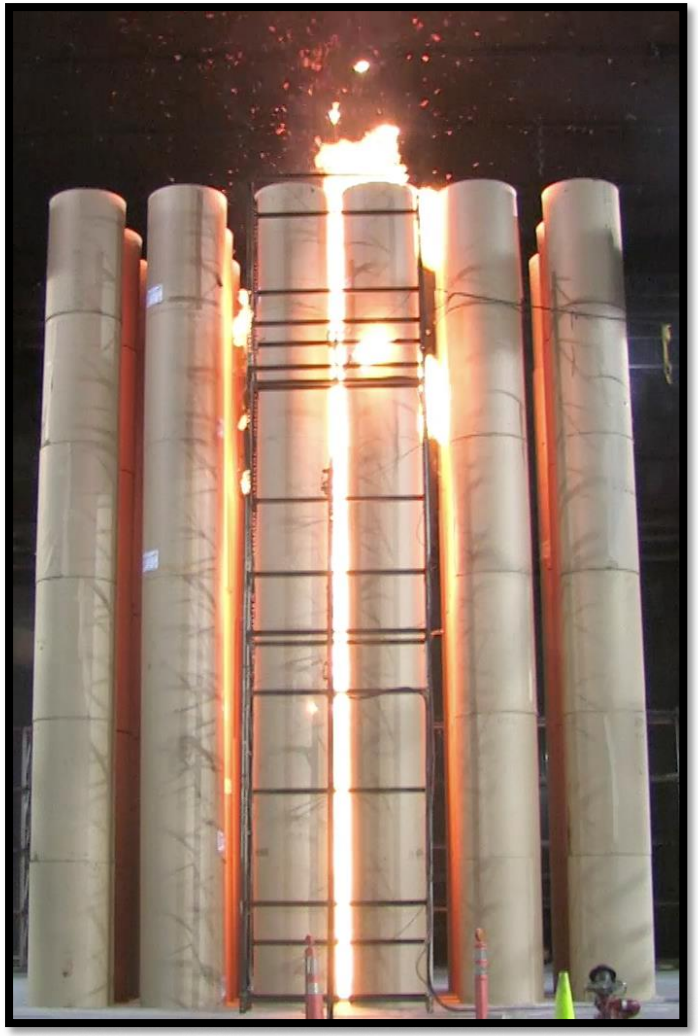
FM Global – A Specialty Insurance Company



Fire Hazard Evaluation

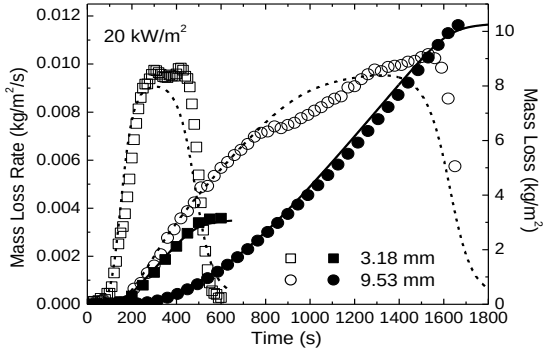
Large Scale Testing – An Expensive Tool!



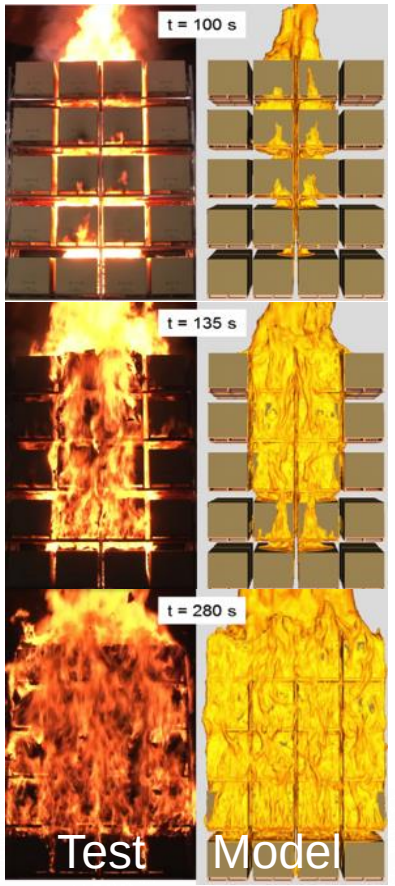


“Scale Up” Using CFD Modeling

- Flammability test provides parameters for pyrolysis model
- CFD deals with heat transfer, fluid mechanics, chemical reaction in gas phase



Model specific properties	
Conductivity	
Heat capacity	
Activation energy …….	



Li-ion Battery Related Risks

ESS

Battery Storage

Data Center

Battery ESS: Hazard Evaluation

Cell → Module → Pack → Installation

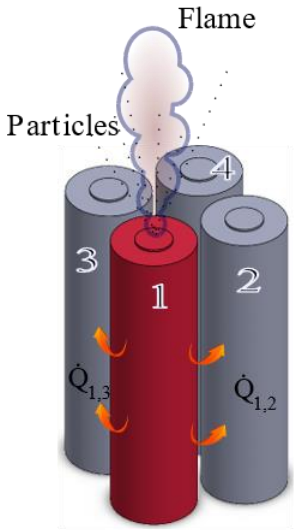
$10^{-3} – 10^{-1}$ (m)
~100 kJ

$10^{-1} – 10^{0}$ (m)
~ 10 MJ

$10^{0} – 10^{1}$ (m)
~10 GJ

$10^{0} – 10^{2}$ (m)

Thermal runaway

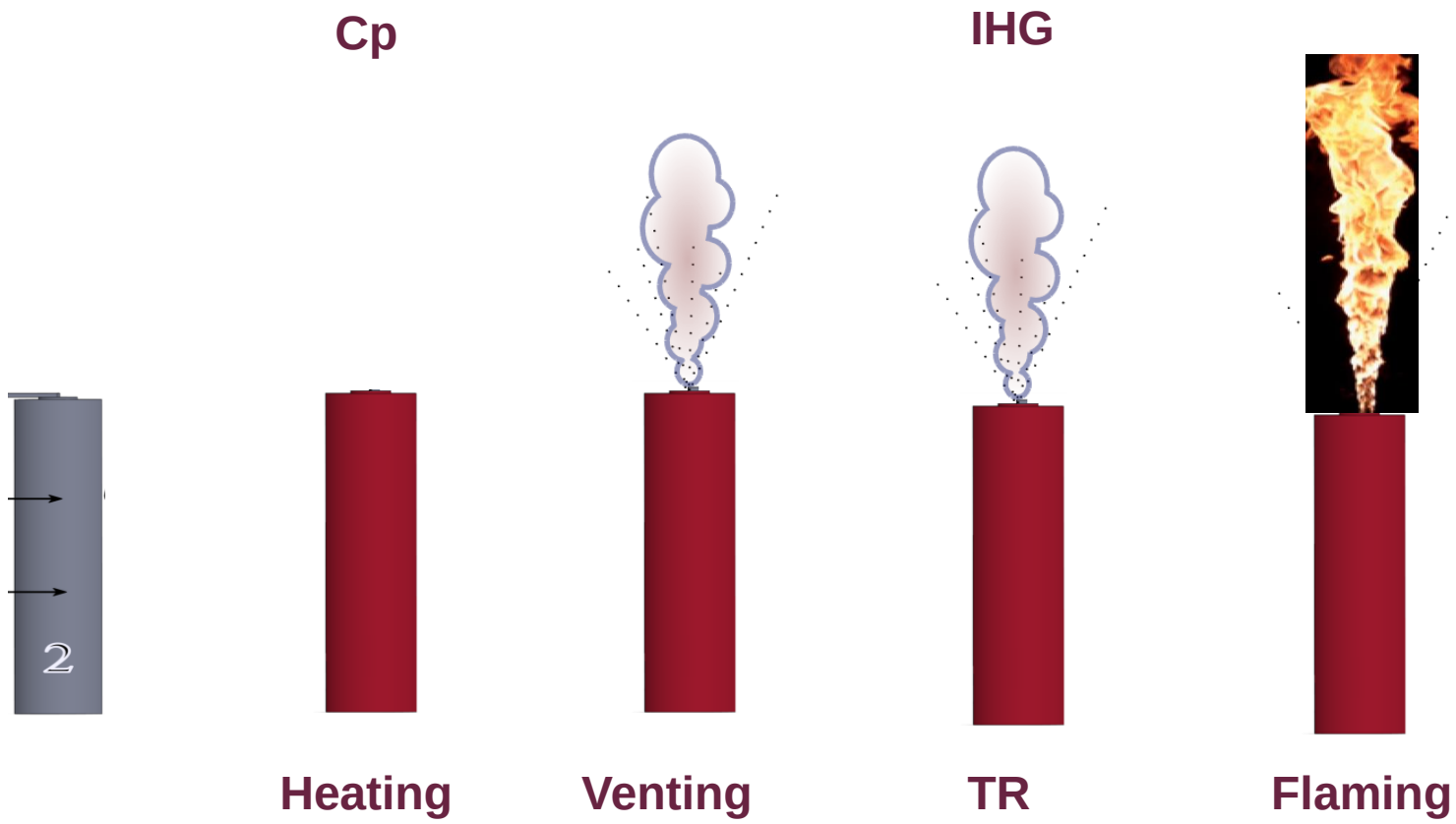


Thermal runaway propagation

Fire and explosion

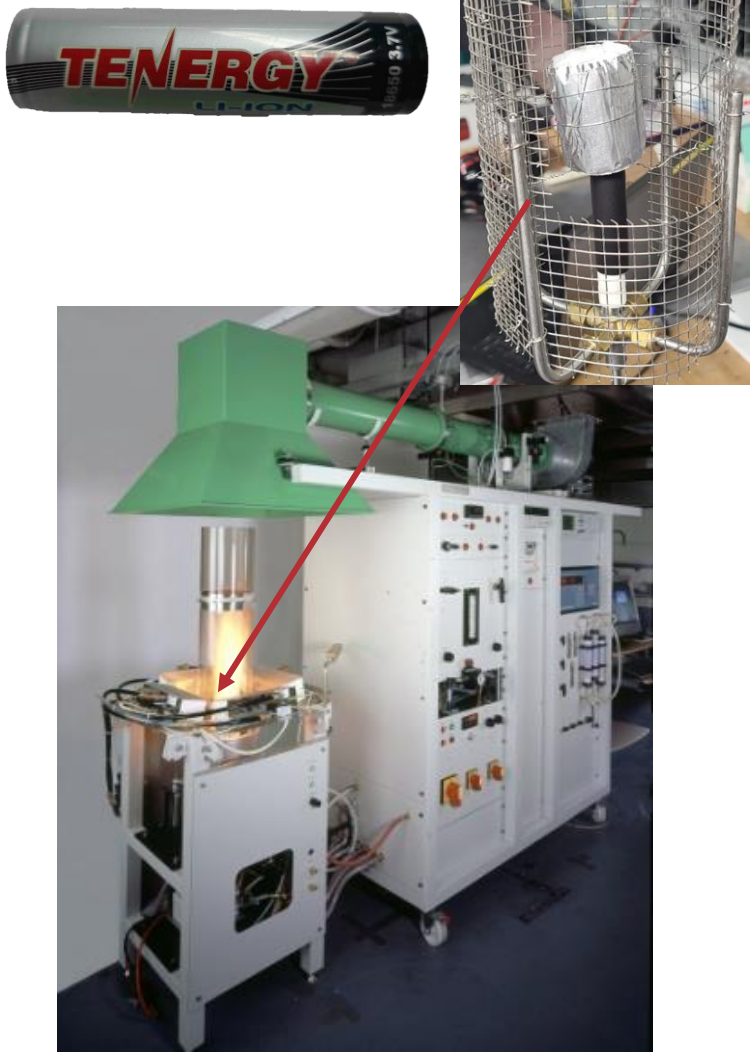
Passive & active protection

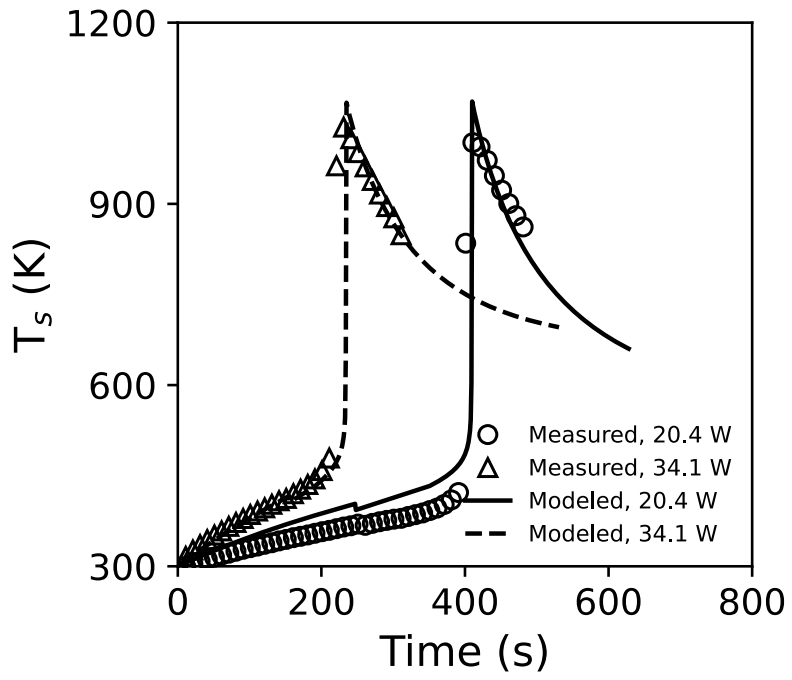
Cell Testing: Flammability Characteristics



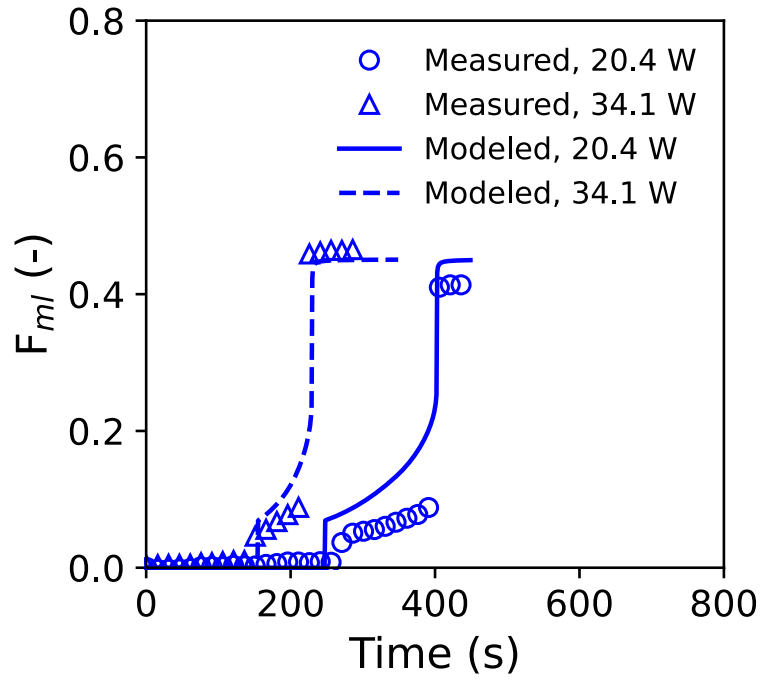
- Time and temperature of venting and TR
- Mass & sensible enthalpy distribution:
  - Retained in the cell
  - Vented
  - Ejected during TR
    - Gas
    - Solid particle
- Chemical enthalpy in vented gas

Cell Test: 1 – Fire Propagation Apparatus





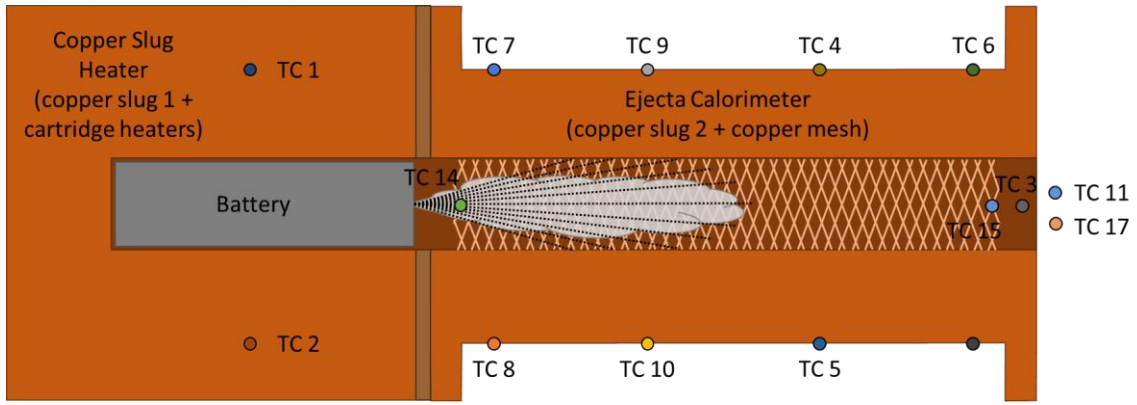
Surface temperature

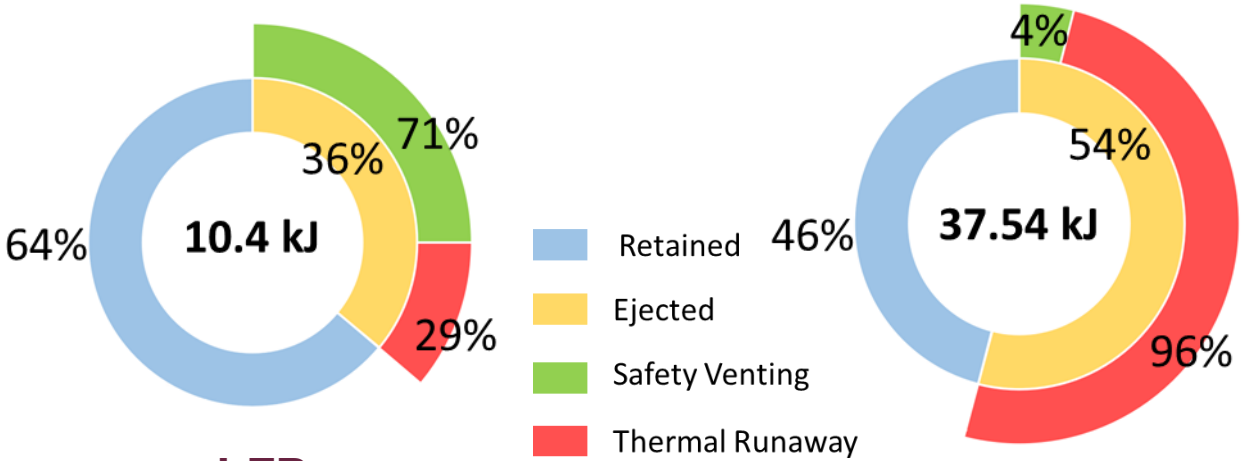


Mass loss fraction

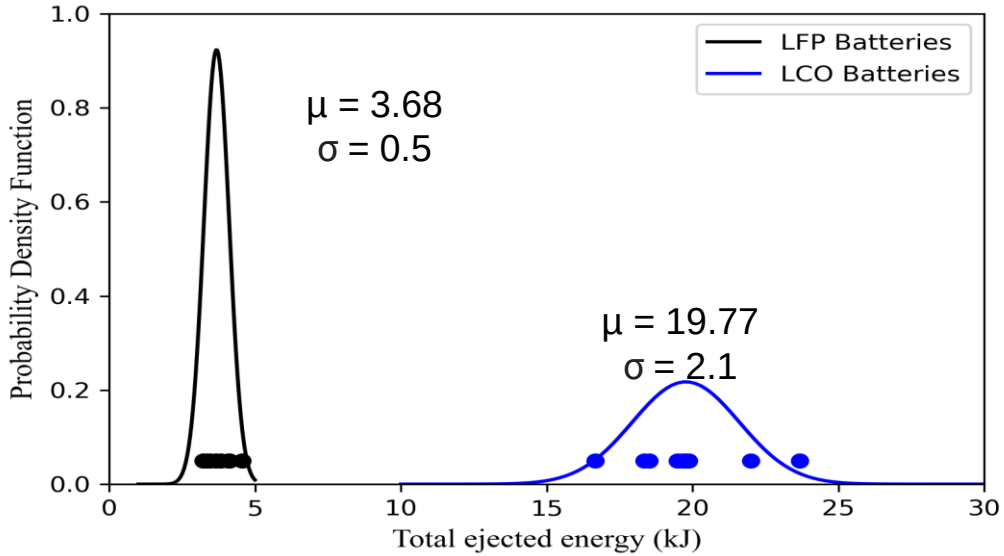
- D. Zeng, L. Gagnon, and Y. Wang, 2022, *Proc. Combust. Inst.*, **39**

Cell Test: 2 – Double Slug Battery Calorimeter





LFP **LCO**



PDF of Ejecta Energy

- P. Garg, D. Zeng, L. Gagnon, and Y. Wang, 2023, *13th U.S. National Combustion Meeting*

Lumped Model & Parameters Extraction

Chemical reactions and rates:

$$v_l \rightarrow g;\ \dot{\omega}_l = -(m_l/m_{l0})^{n_l} m_{l0} A_l e^{-E_l/(RT)}$$

$$v_h \rightarrow c + g;\ \dot{\omega}_h = -(m_h/m_{h0})^{n_h} m_{h0} A_h e^{-E_h/(RT)}$$

$$\dot{Q}_{ISC} = \eta ISC_{cond} H_{ISC} \cdot A_{ec} e^{-E_{ec}/k_b T}$$

Energy conservation:

$$\frac{dU_{cv}}{dt} = \dot{Q}_{ext} - \dot{Q}_l + \dot{Q}_{IHG} - \dot{m}_{vent} h_{vent}$$

$$\dot{Q}_{IHG} = \dot{\omega}_l \Delta U_l + \dot{\omega}_h \Delta U_h + \dot{Q}_{ISC}$$

Mass conservation:

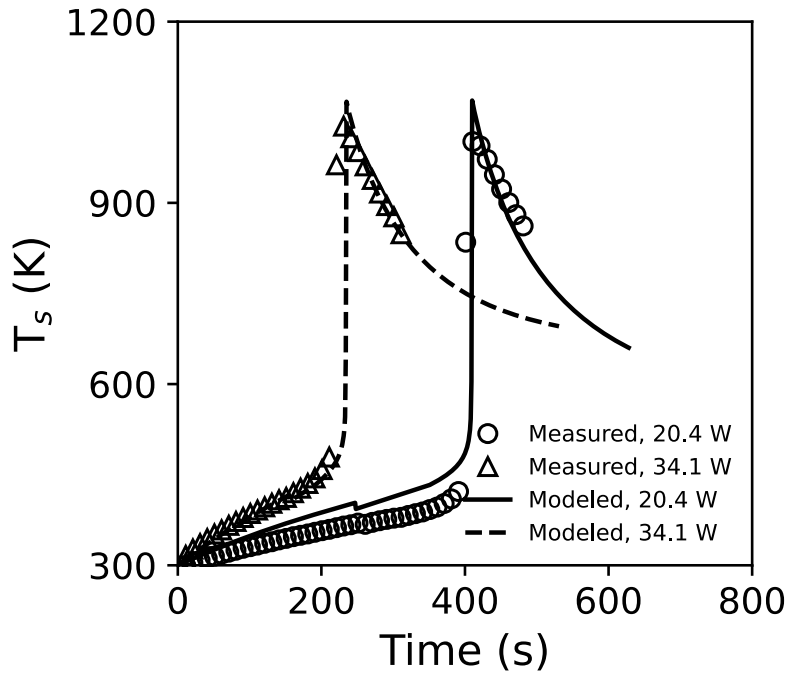
$$m_{cv} = m_s + m_g$$

$$\dot{m}_{cv} = \dot{m}_{vent}$$

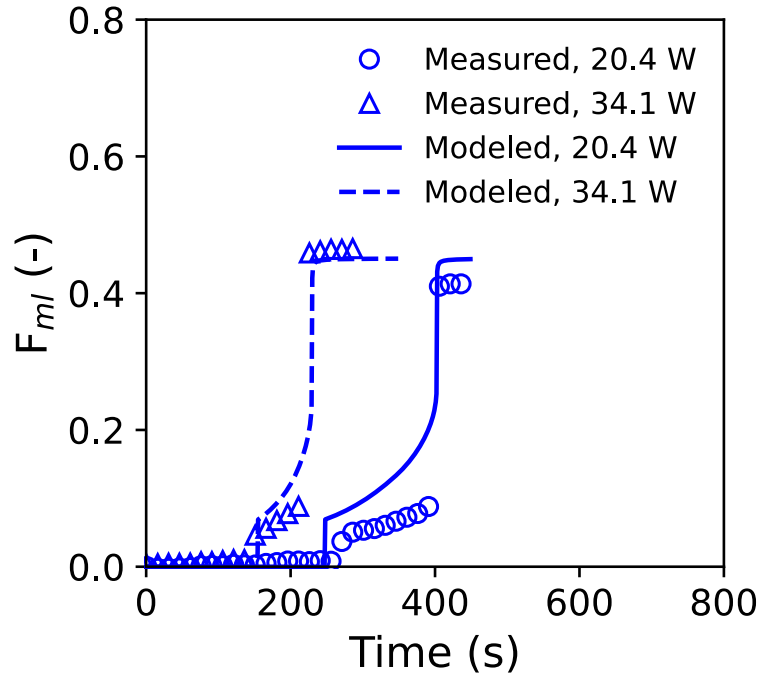
Species conservation:

$$\dot{m}_s = \dot{\omega}_s = \dot{\omega}_l + \dot{\omega}_h$$

$$\dot{m}_g = -\dot{\omega}_s - \dot{m}_{vent}$$



Surface temperature

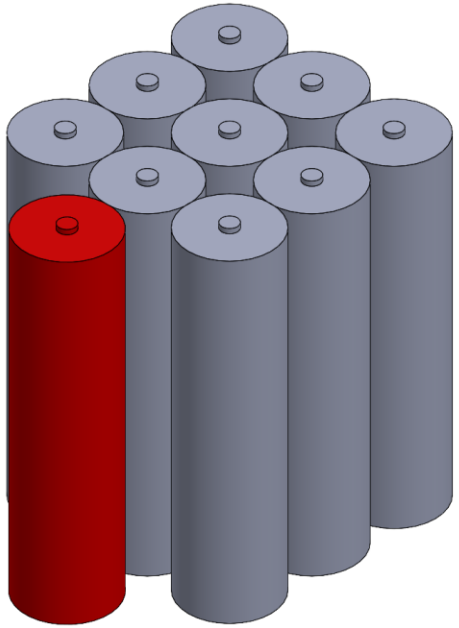


Mass loss fraction

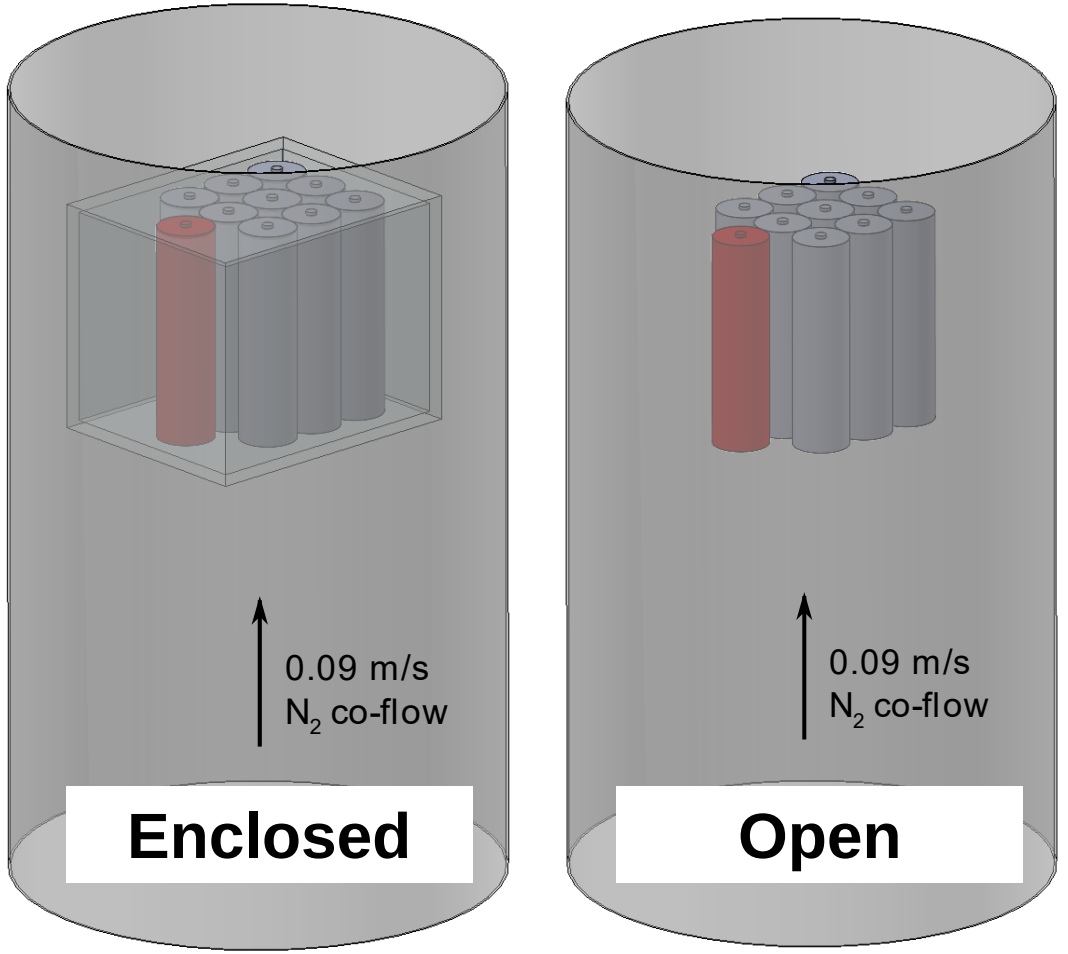
- D. Zeng, L. Gagnon, and Y. Wang, 2022, *Proc. Combust. Inst.*, **39**

TR Propagation Experiments

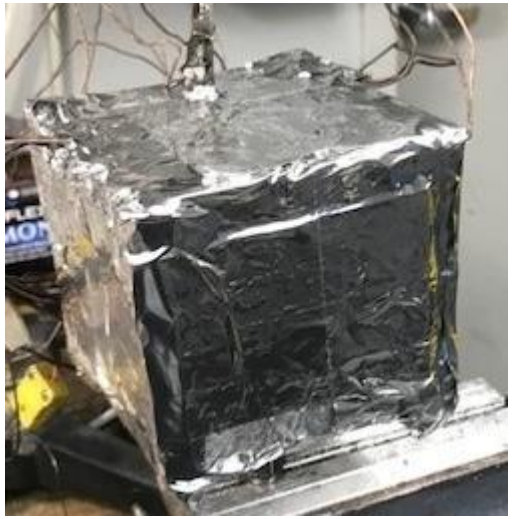
Heater



3×3 array

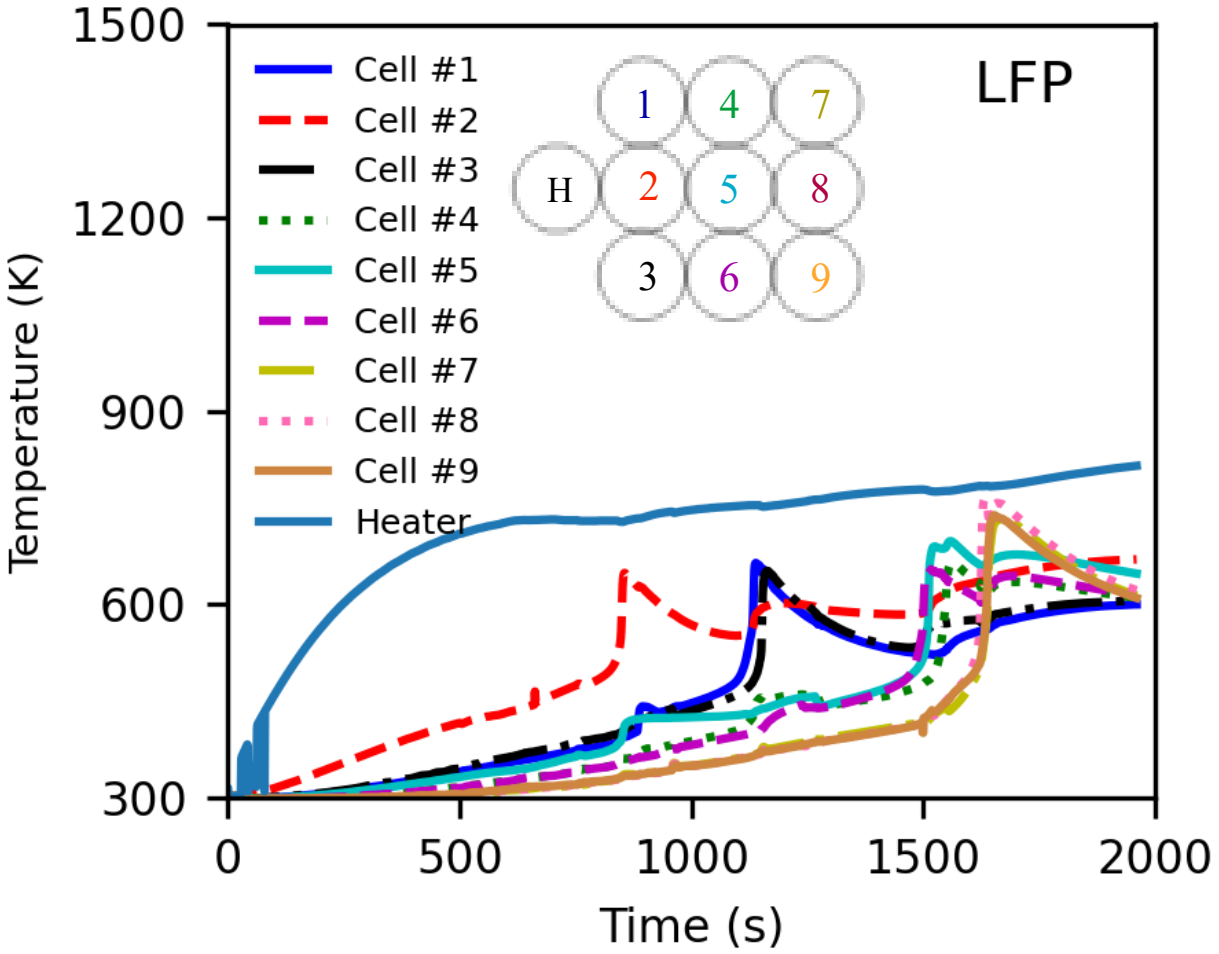


TR Propagation Test Result - LFP



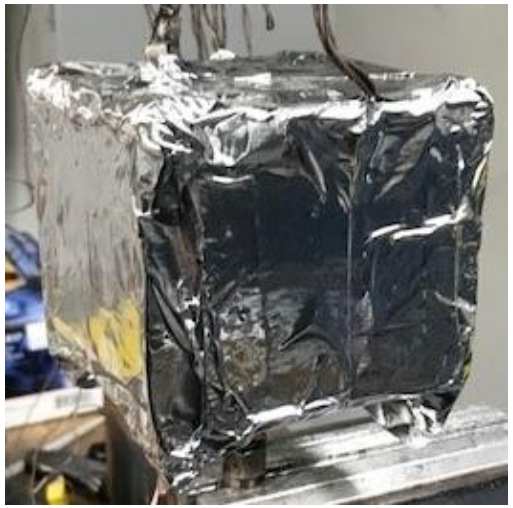
Before test

After test



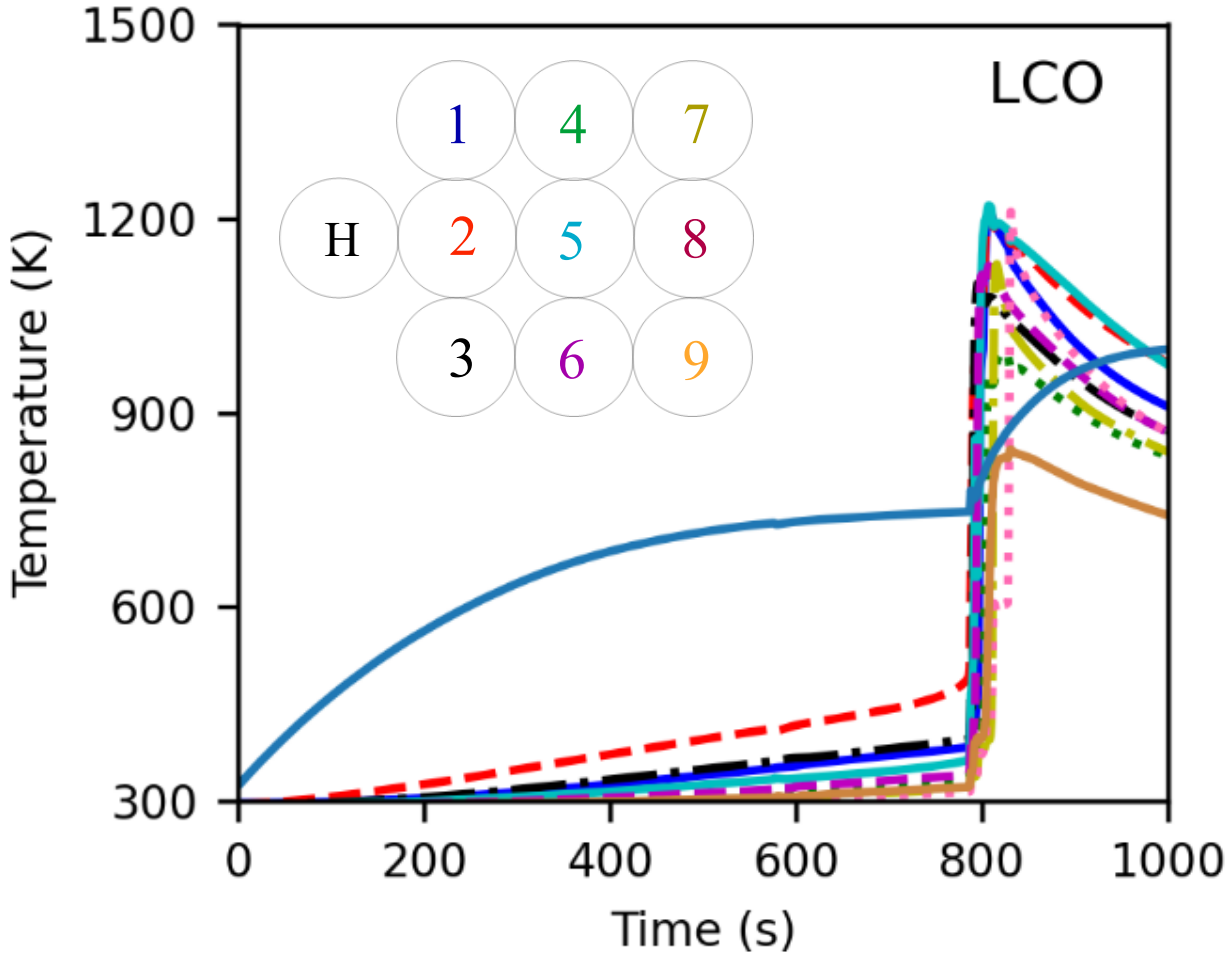
Couple cell TR response with heat transfer

TR Propagation Test Result - LCO



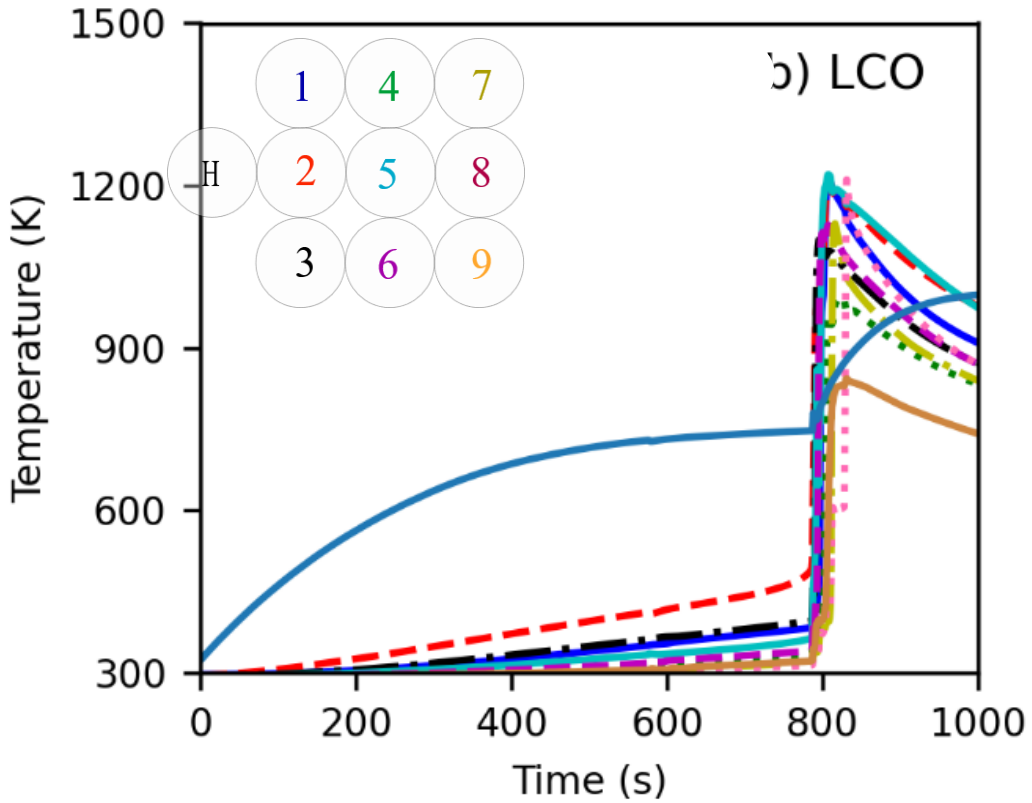
Before test

After test

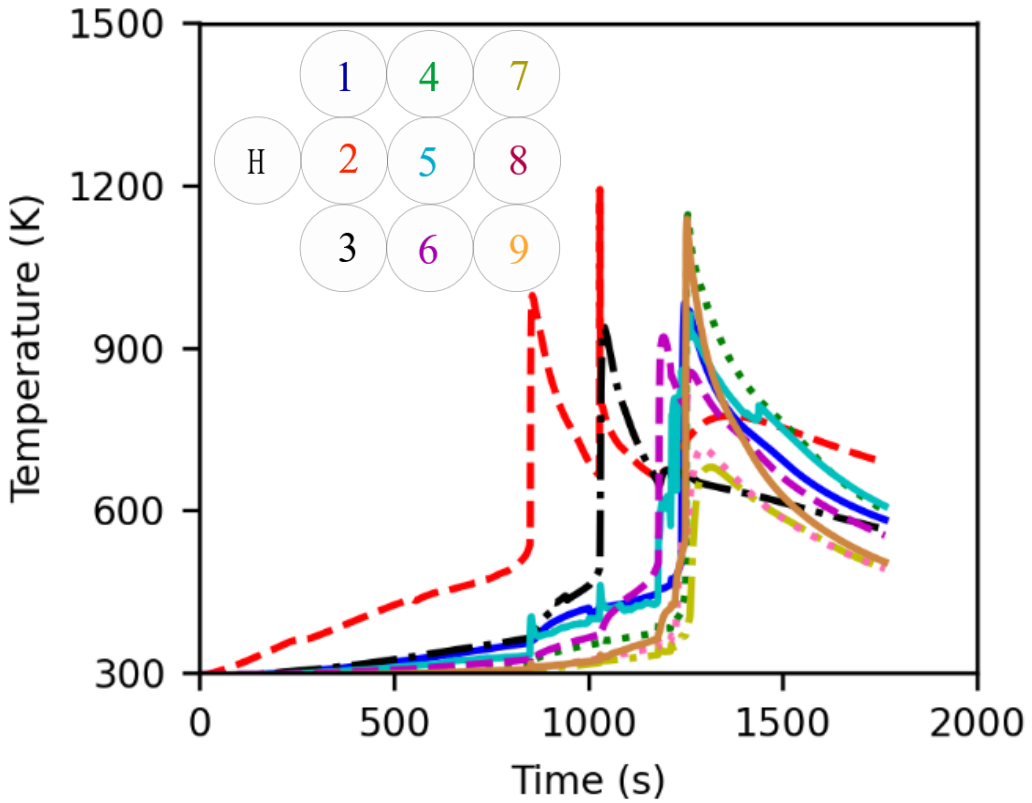


Couple cell TR response with heat transfer

Effect of Ejecta on TRP Rate - LCO



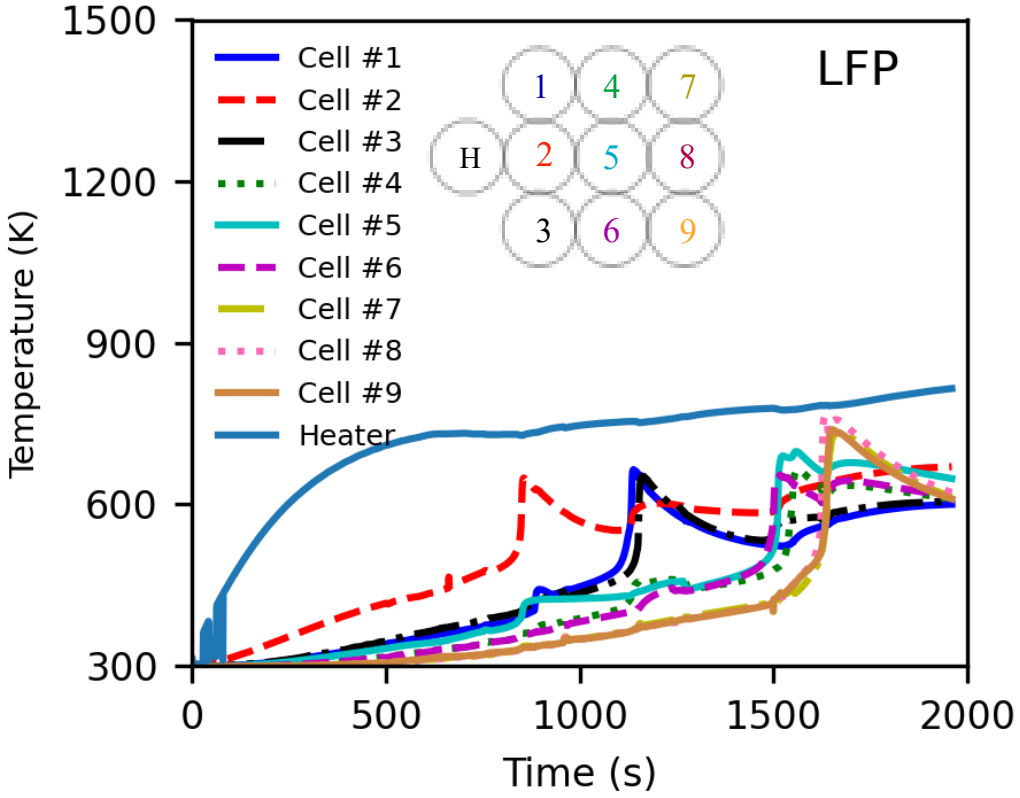
Enclosed environment



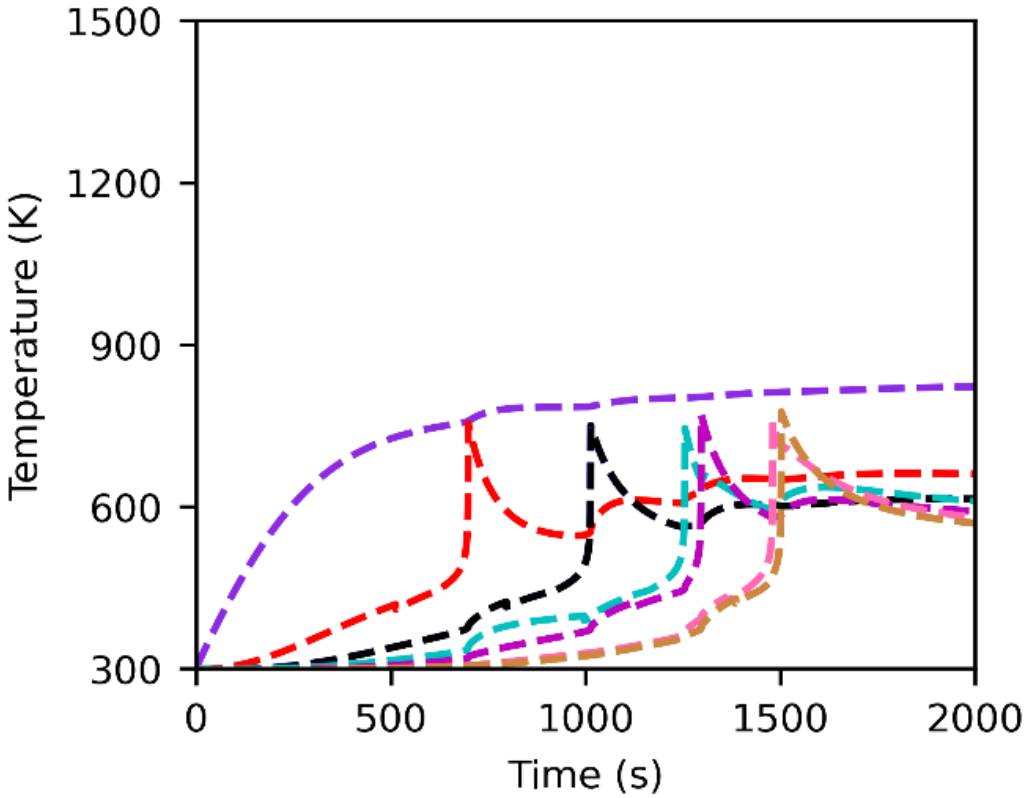
Open environment

Couple cell TR response with heat transfer

Network TRP Modeling – LFP



Experiment



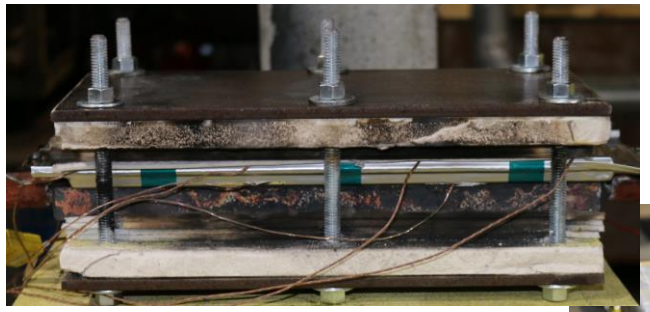
Model

Couple cell TR response with heat transfer

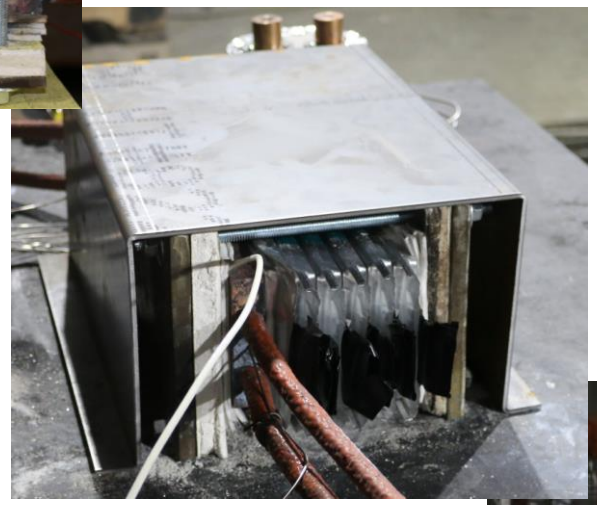
Large Format Battery Cells

63 Ah, 4.15V
(940kJ)

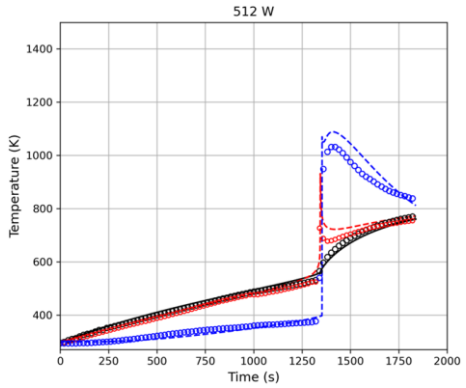
Battery Hazard Evaluation: Scale Up



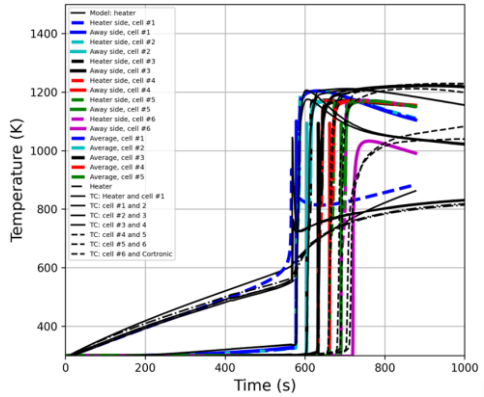
Single cell test



Cell array test

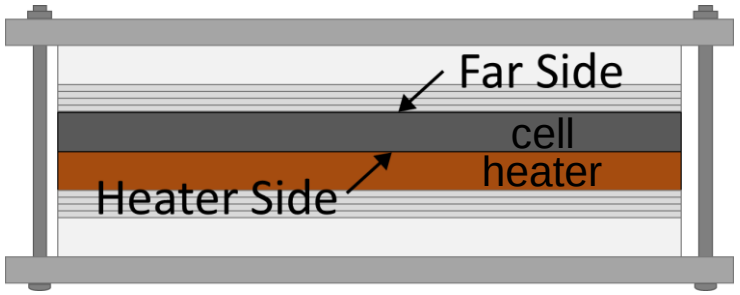


Modeling



Mutiple module test

Single Cell Test – 63 Ah Pouch Cell



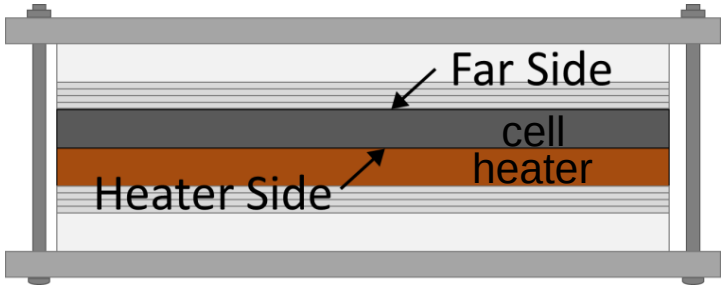
Temperatures for Different Heating Rates

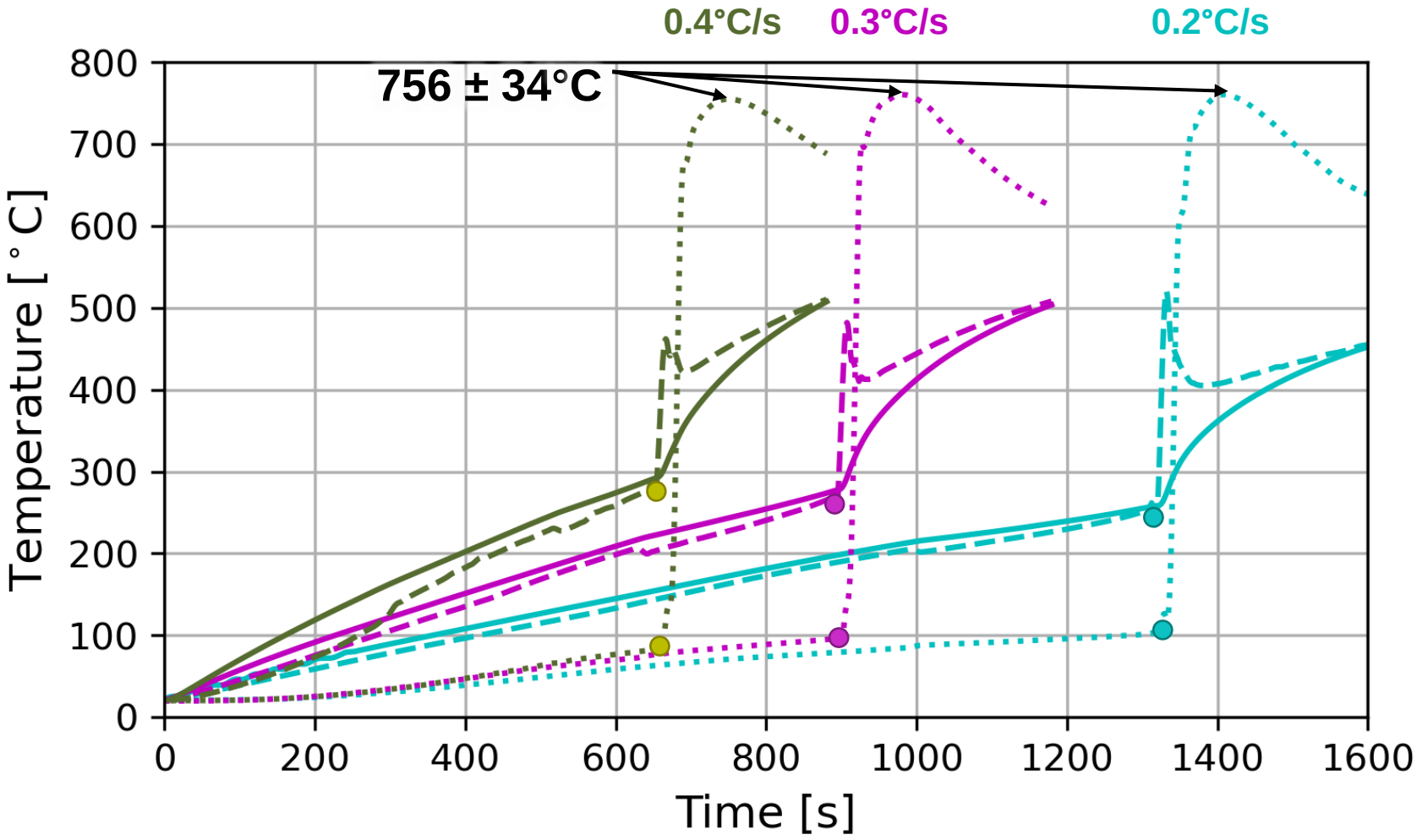
Heater Temperature

Battery Temperature

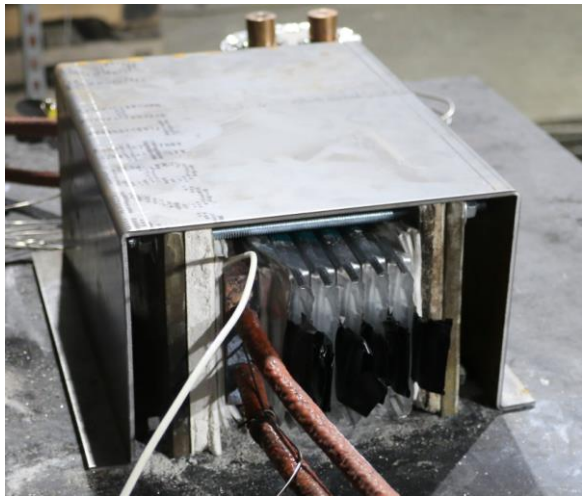
Heater Side

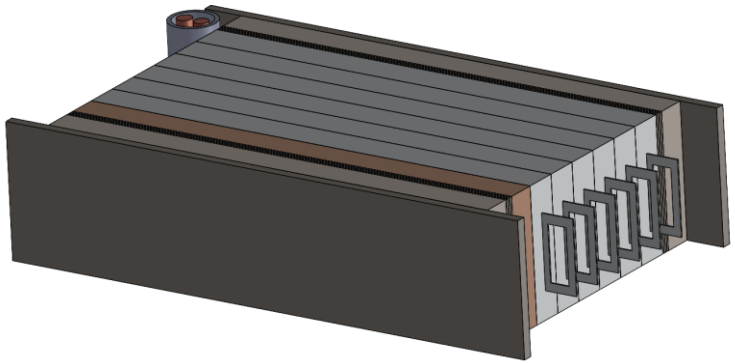
Far Side

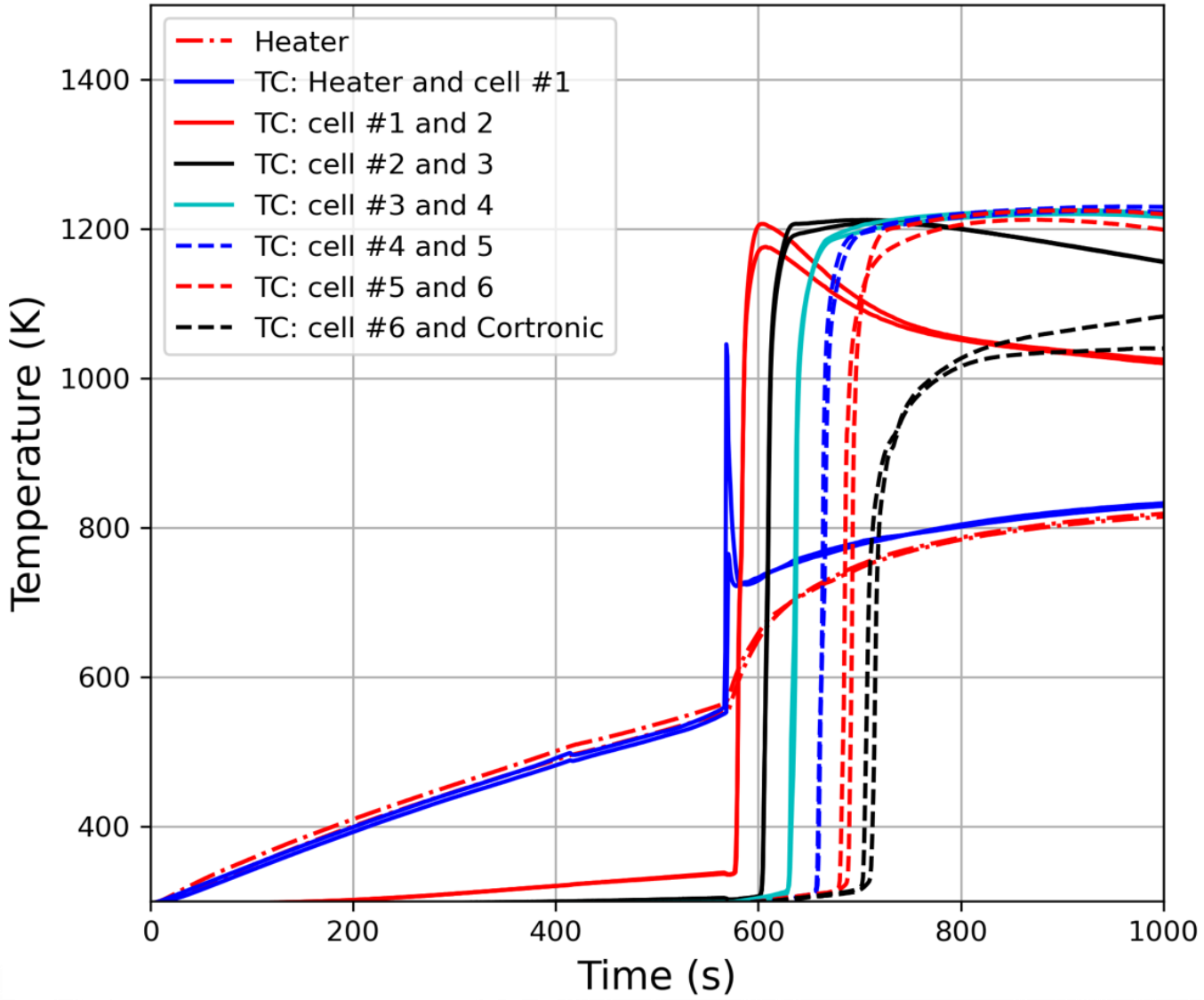




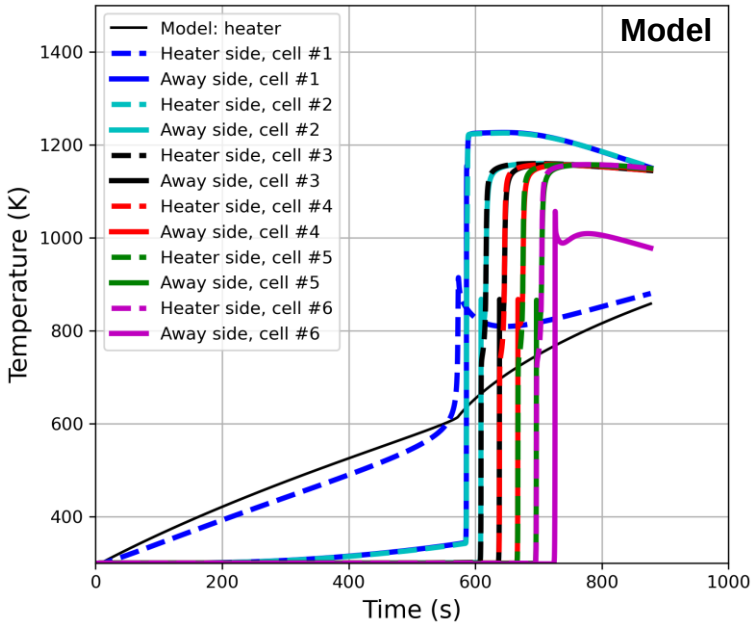
TR Propagation Test with 6 Pouch Cells

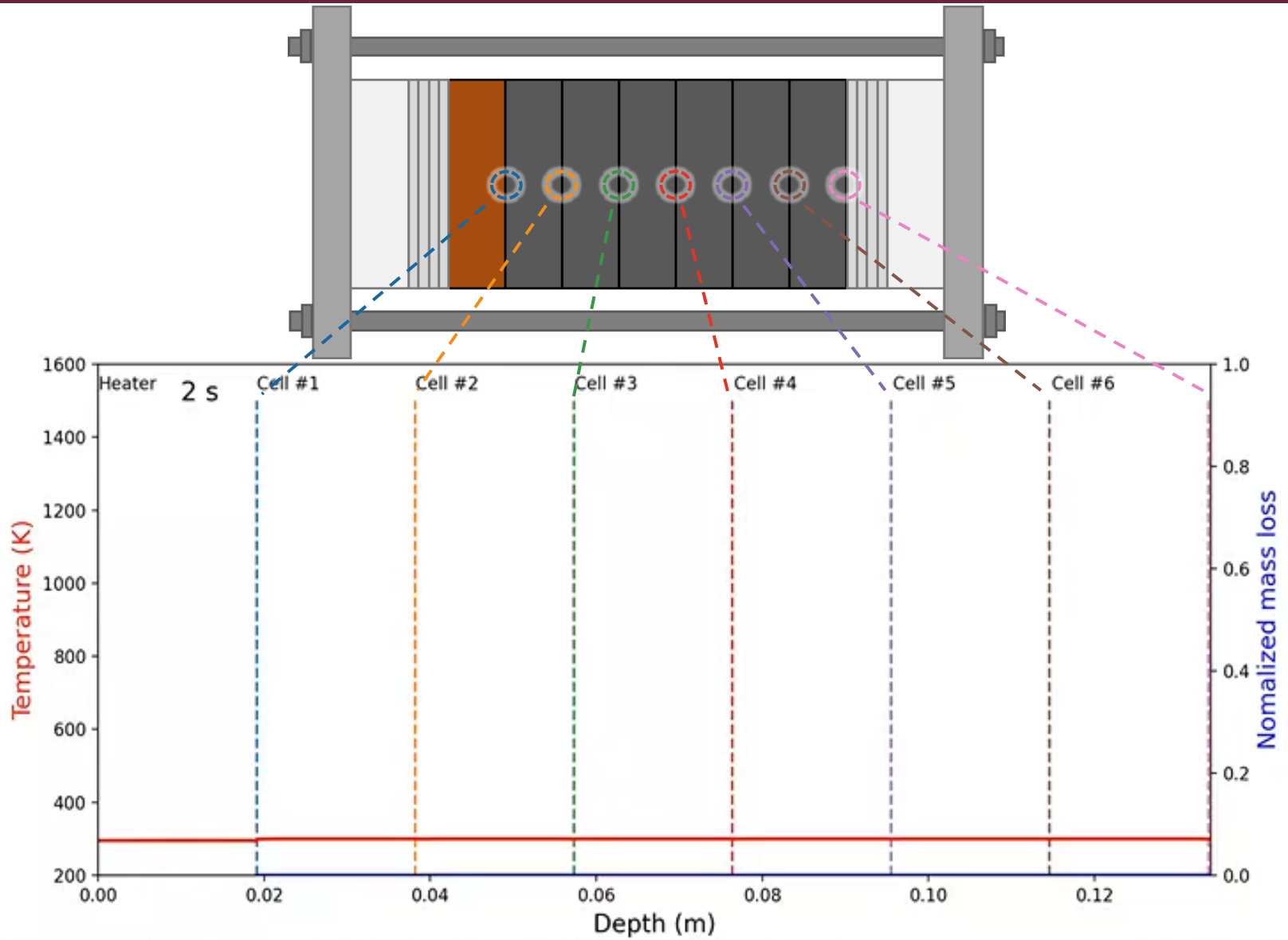




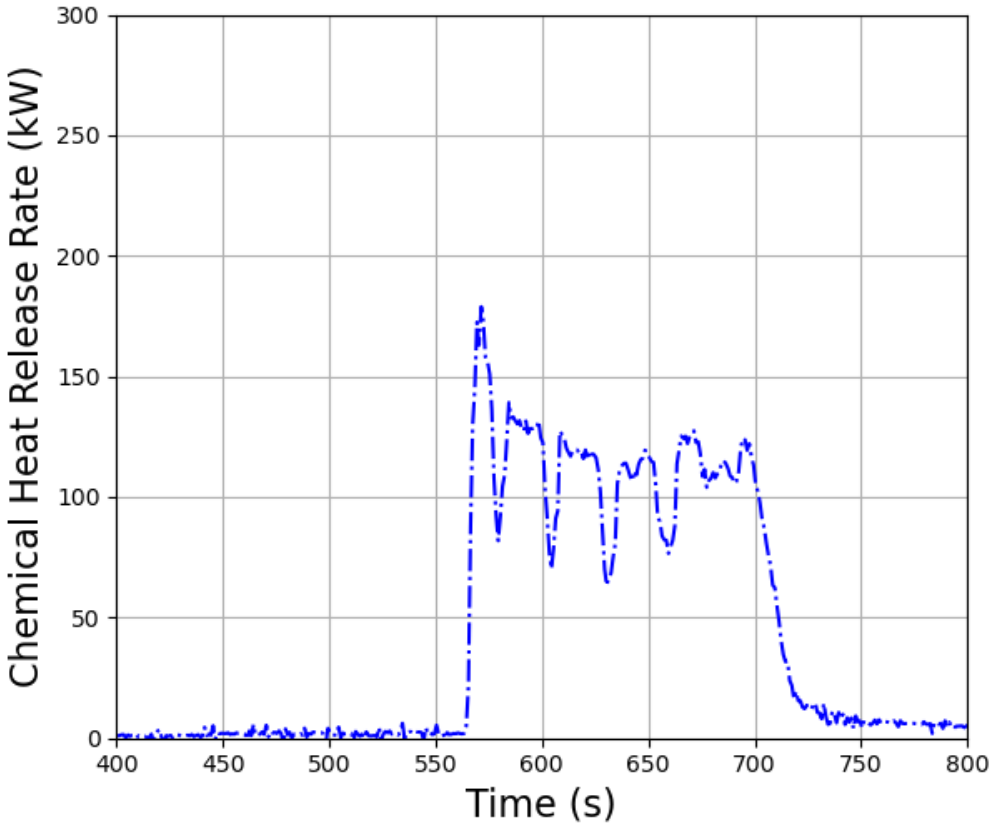


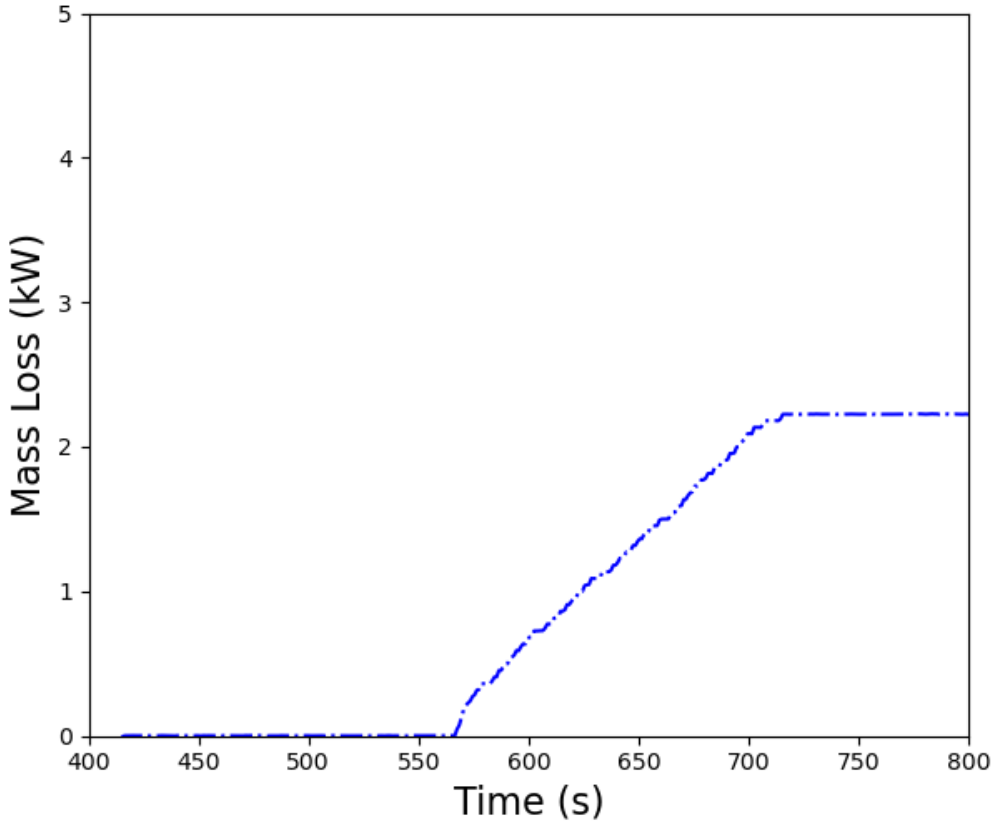
Thermal Runaway Propagation Modeling





Chemical Heat Release Rate and Mass Loss

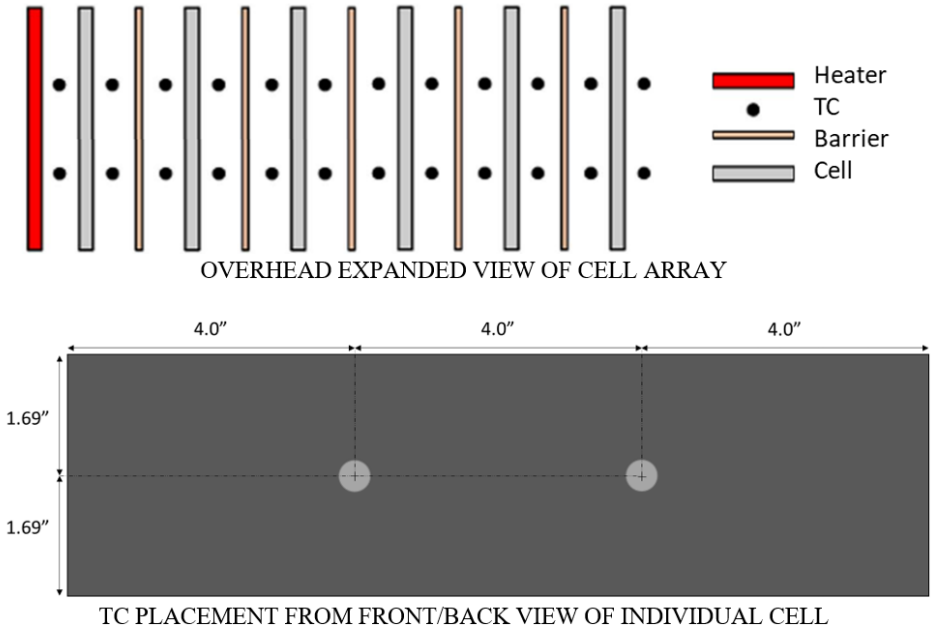


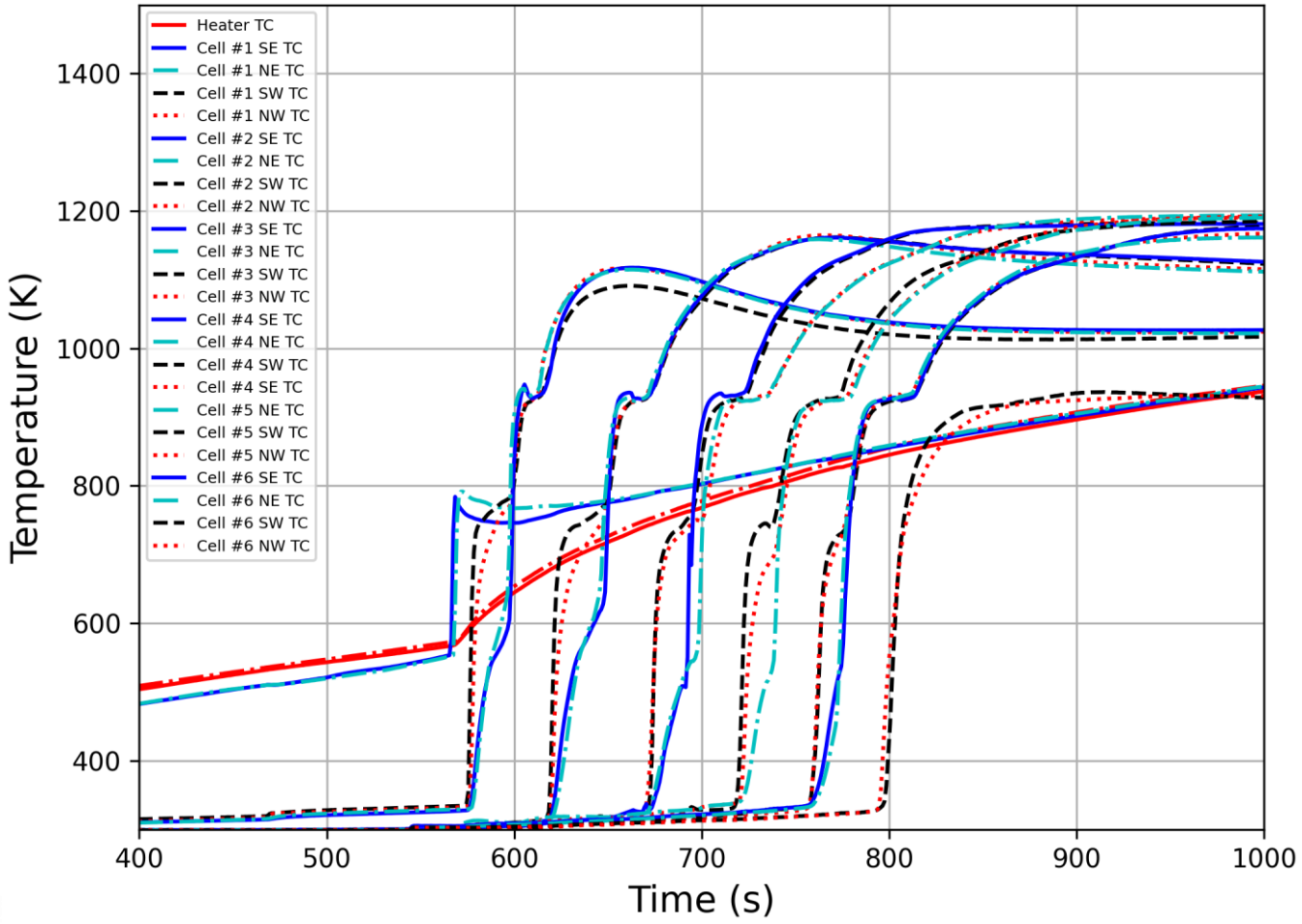


Mass loss per cell (g)	Chemical heat per cell (MJ)	Effective heat of combustion (kJ/g)
381±16	2.53±0.33	6.67±1.16

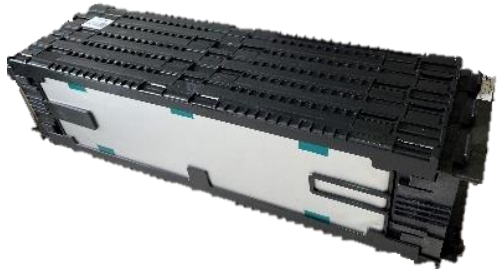
6 Cell Test With Aluminum Barrier

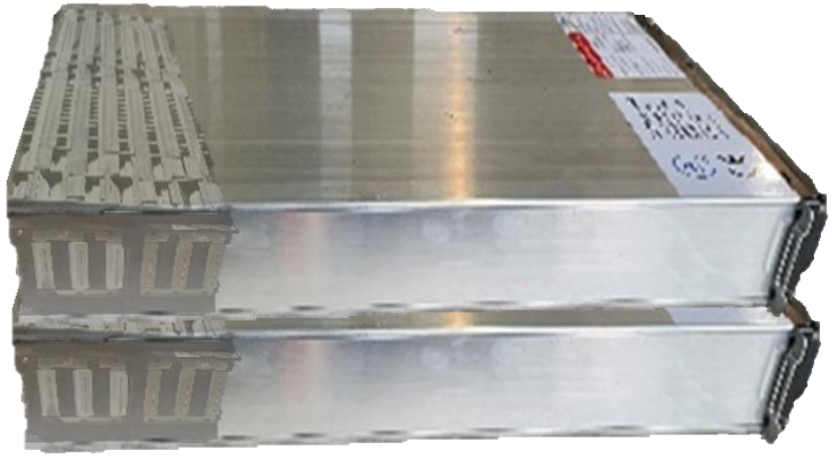
- 1mm Al plate between cells

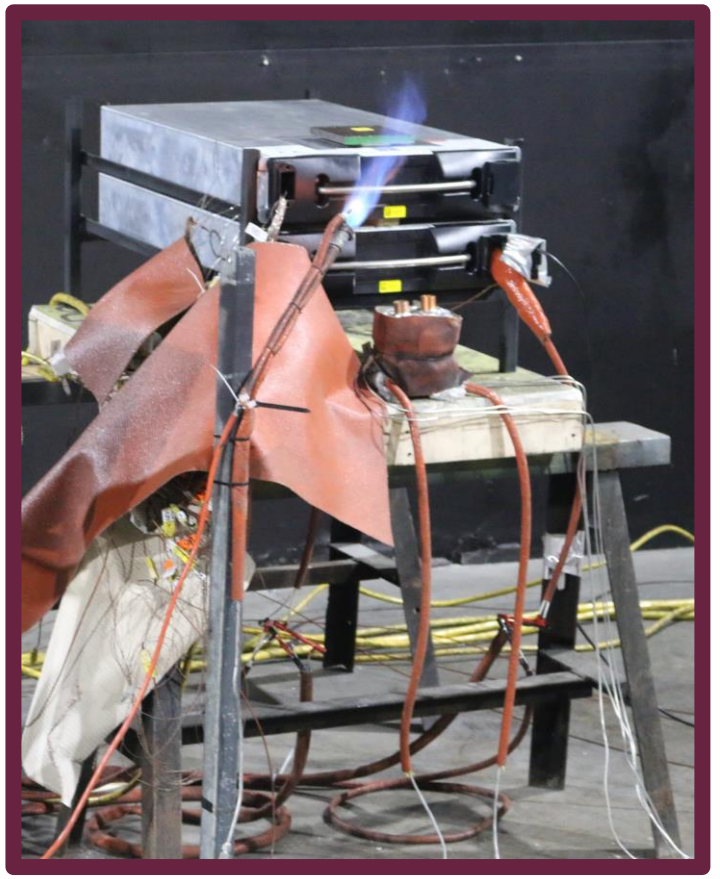




12-Cell Module to Module Propagation

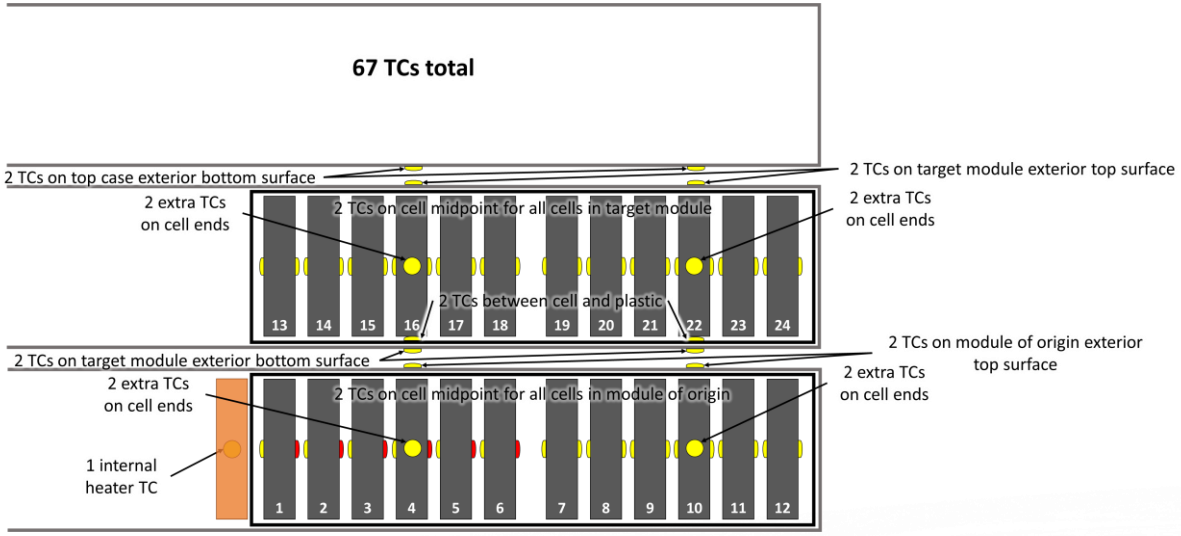


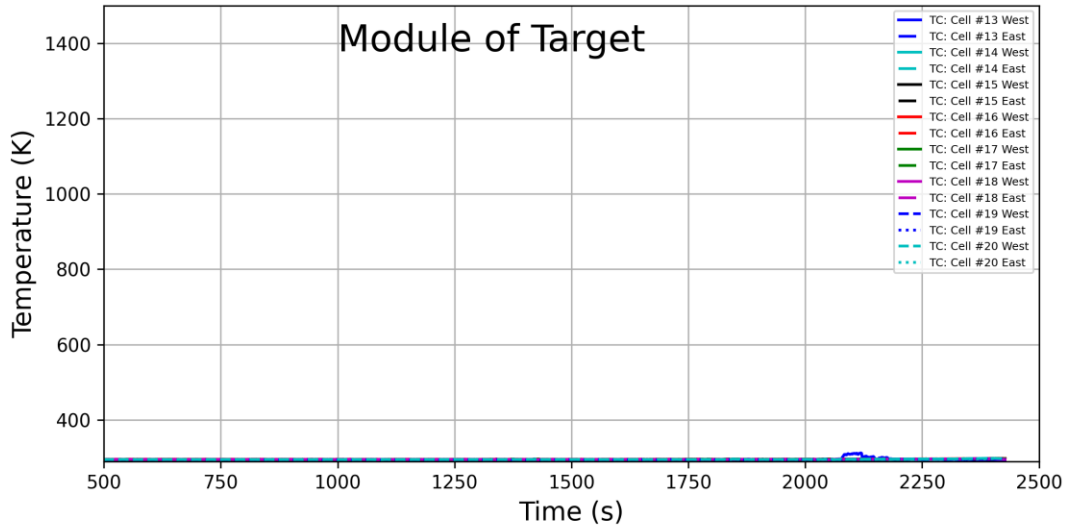


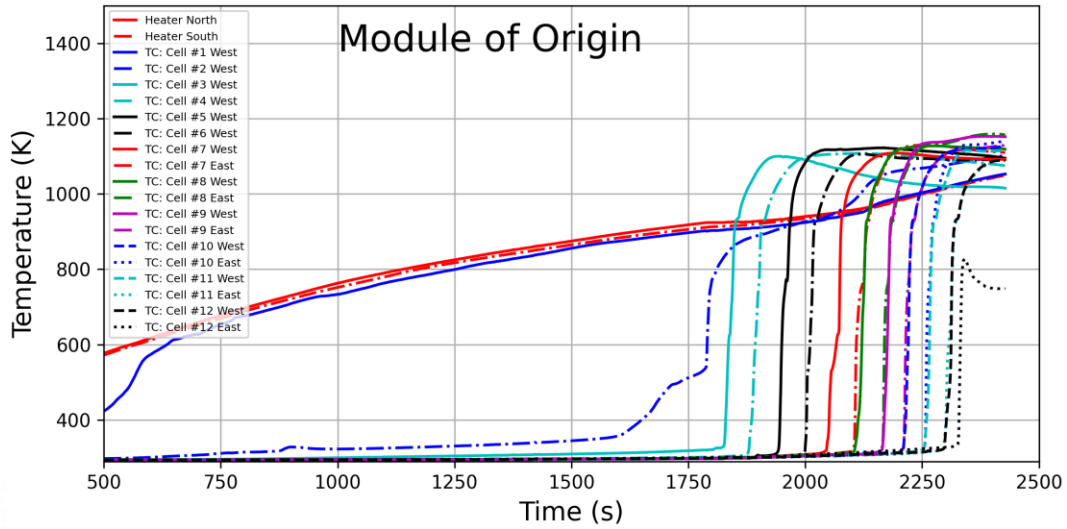


12-Cell Module to Module Propagation

- No external ignition source
- Quasi-steady state propagation
- Slower propagation compared to 6 cell case due to greater contact resistance

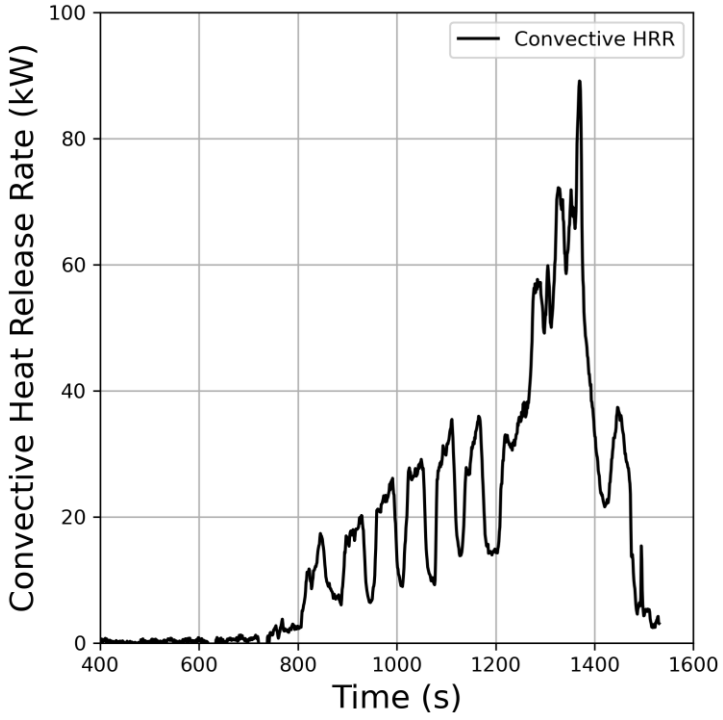






12-Cell Module to Module Propagation

- External ignition source
- Propagation to upper module through flame heating





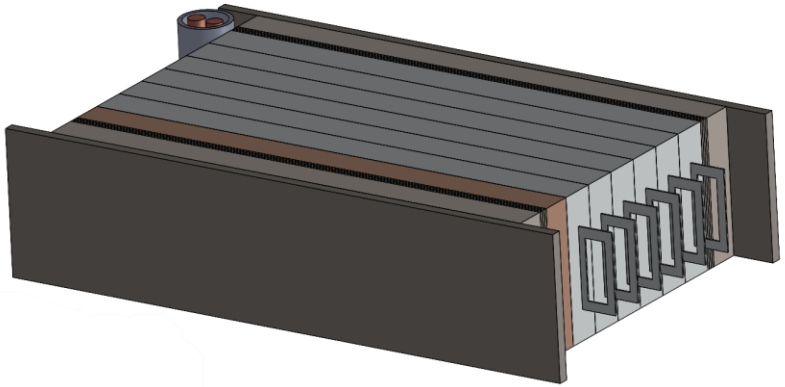



Summary – Scale Up

Single cell and array validation data

Thermal runaway propagation modeling

Model capture thermal runaway propagation



Future work

Real module test

Module to module fire spread

Coupling with CFD

Acknowledgements

Research team at FM Global

- Dong Zeng, Lauren Gagnon, Priya Garg, Ben Ditch



- The testing team at the FM Global Research Campus and Norwood office