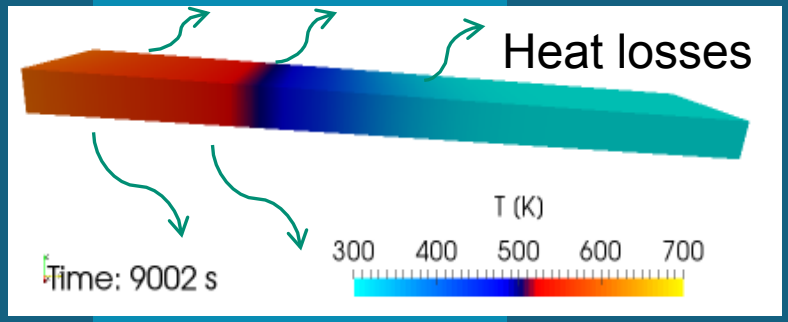
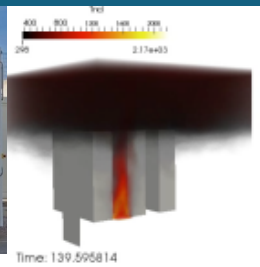
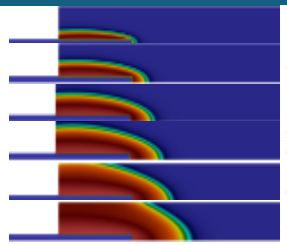
SAND2020-11060PE

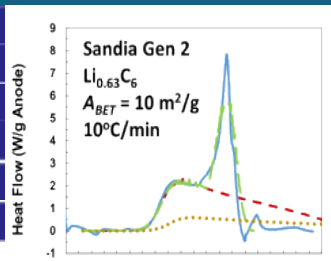
Sandia National Laboratories

Li-ion battery safety









Presented by

Andrew Kurzawski

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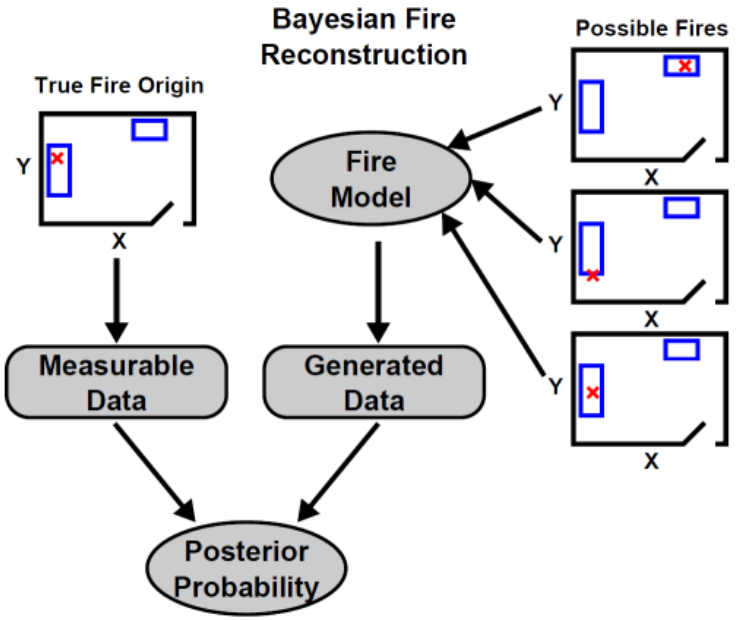
My research background

- Wildfires
- Compartment fires
- Fire forensics
- Machine learning

Source: https://www.nytimes.com/2020/05/14/opinion/wildfires-



Here's what can happen when Li-ion batteries fail

https://www.youtube.com/watch?v=uLzPSN8iasgk (FM Global LFP system)

Li-ion battery fire safety in the news

2006 Sony/Dell battery recall 4.1 million batteries

2008 Navy, $400M Advanced Seal Delivery Sub, Honolulu

2010 FedEx Cargo Plane Fire, Dubai

2011 NGK Na/S Battery Explosion, Japan (two weeks to extinguish blaze)

2011 Chevy Volt Latent Battery Fire at DOT/NHTSA Test Facility

2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm

2013 Storage Battery Fire, The Landing Mall, Port Angeles, (reignited one week after being “extinguished”)

2018-2019 A string of 21 energy storage system fires in South Korea leads to suspension of new projects

2013 Boeing Dreamliner Battery Fires, FAA Grounds Fleet

2018 Tesla Model S catches on fire during normal traffic/no accident

2019 A fire in an ESS in Surprise, AZ leads to an explosion injuring first responders

What is a Li-ion battery?

Operating principle

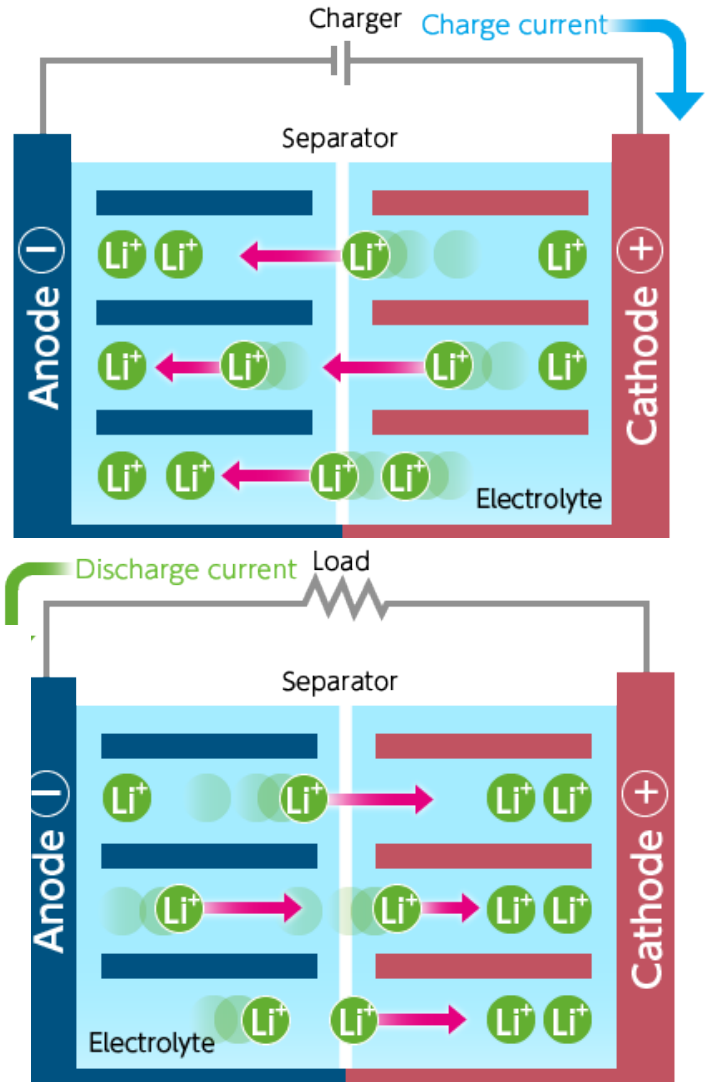
- Charge: lithium ions intercalated in anode
- Discharge: lithium migrates to cathode

Common chemistries (important for thermodynamic)

- Lithium cobalt oxide (LCO)
- Lithium nickel manganese cobalt oxide (NMC)
- Lithium nickel cobalt aluminum oxide (NCA)
- Lithium iron phosphate (LFP)

Form factors

- Cylindrical
- Pouch
- Prismatic



Source:
https://www.batteryspace.com/images/products/detail/2619.png

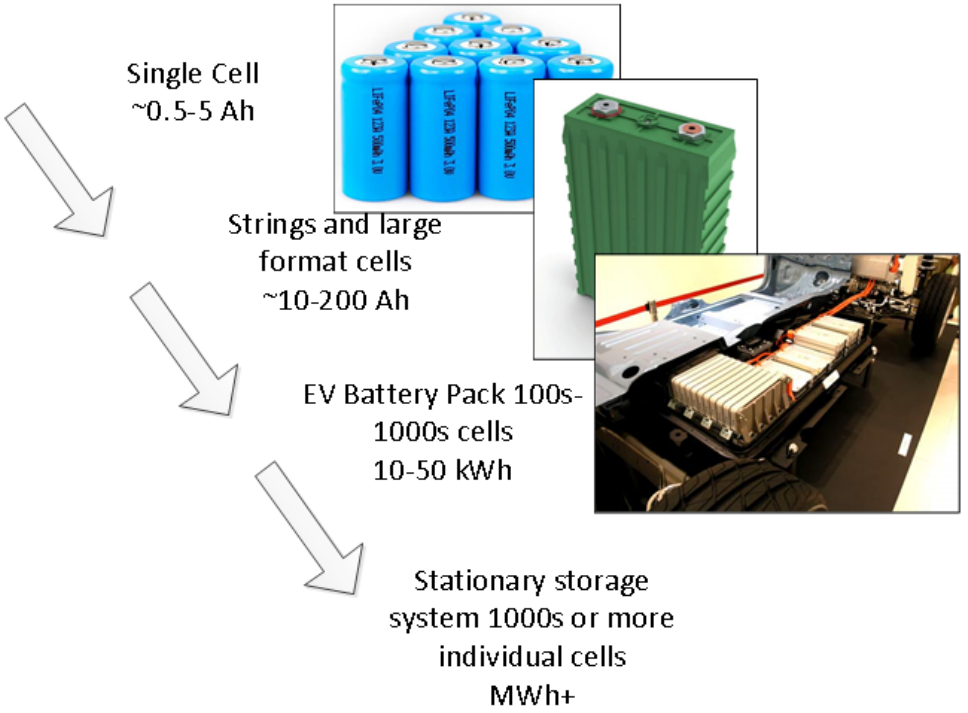
What happens when batteries fail?

How do cells fail? Manufacturing defects, improper cycling, accidents, end of life…

Most cells fail quietly

The failure probability is low (on the order of 1 in several million)

But for a large installation (~1000s of cells), this probability is not insignificant



How do we improve safety?

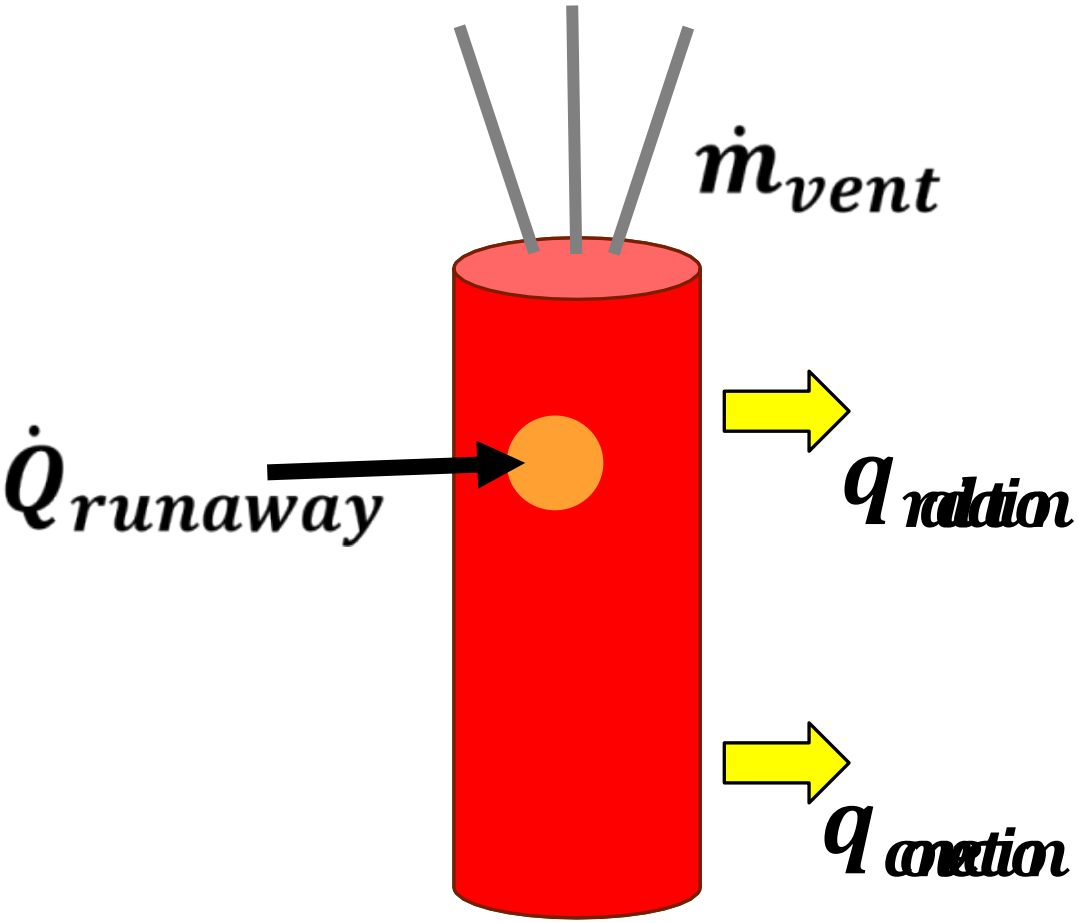
Experiments vs simulations

www.nissanusa.com
www.internationalbattery.com
www.samsung.com
www.saft.com

What happens when single cell fails?

https://www.youtube.com/watch?v=k0CL49cpkJ4 (UTFRG 94 Ah)

What happens when a single cell fails?



Chemical source terms for thermal runaway

Empirical chemical reactions:

- SEI decomposition (Richard 1999)

$$(CH_2OCO_2Li)_2 \rightarrow Li_2CO_3 + gas$$

- Anode-electrolyte (Shurtz 2018)

$$2C_6Li + C_3H_4O_3 \rightarrow 2C_6 + Li_2CO_3 + gas$$

- Cathode-electrolyte (Hatchard 2001)

$$CoO_2 + \frac{1}{5}C_3H_4O_3 \rightarrow CoO + gas$$

- Short-circuit

$$C_6Li + CoO_2 \rightarrow C_6 + LiCoO_2$$

- In reality these are messy reactions (electrolytes are proprietary mixtures, gases don't necessarily combust)

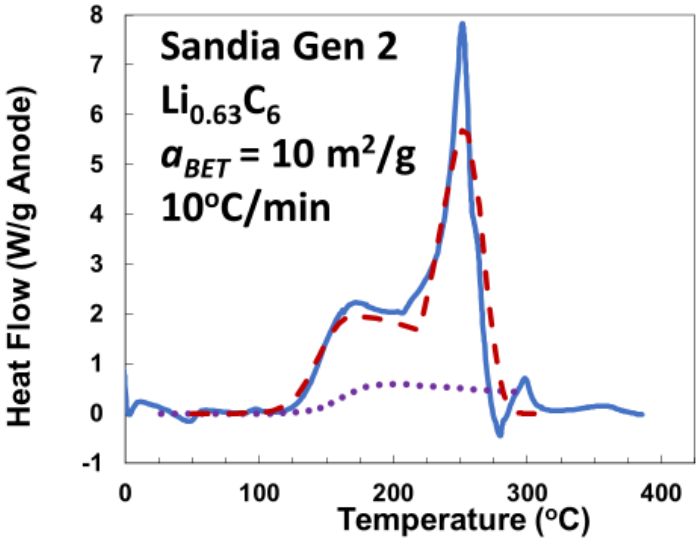
Chemical source terms

How do we figure out how much heat each reaction produces/consumes?

In class, you'll use heats of formation to derive the heat of the reaction.

For more complex systems of reactions, we use calorimetry

- Accelerating rate calorimetry (ARC)
- Differential scanning calorimetry (DSC)
- Single cell or smaller samples



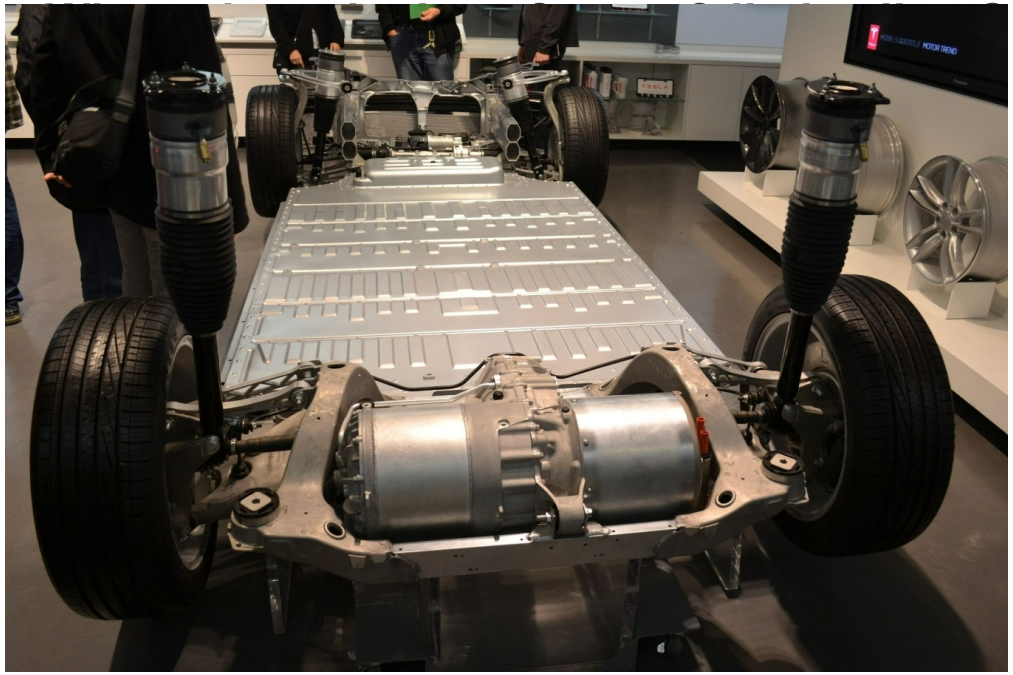
https://www.netzsch-thermal-analysis.com/us/produc
solutions/adiabatic-reaction-calorimetry/arc-244/

Safety of large scale systems

Cells are stacked together in a variety of configurations for energy storage systems (ESS), electric vehicles (EV), and personal electronics

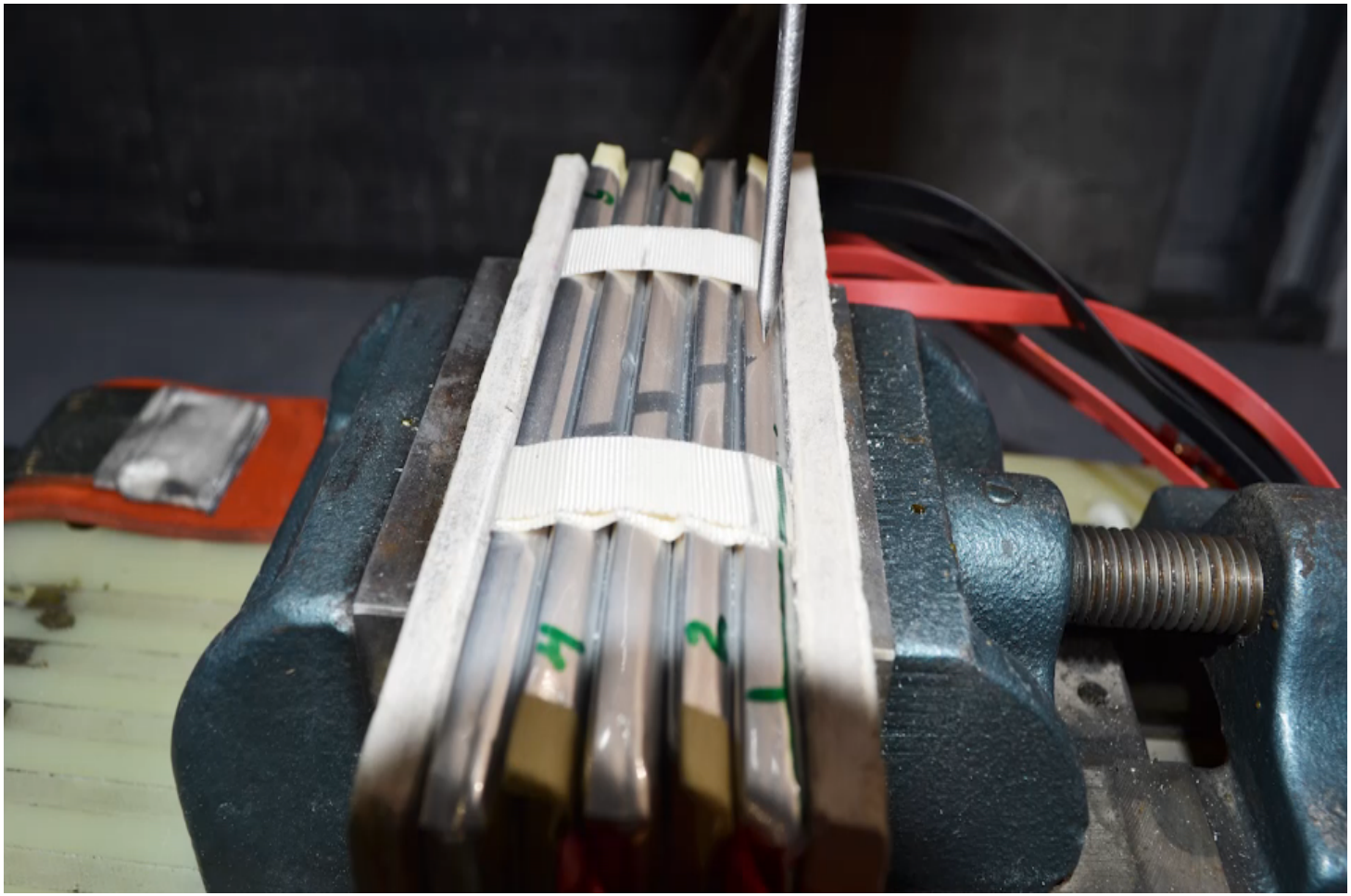
Energy density is a critical parameter

- Higher energy density (space efficiency)
- Lower energy density (safety)



https://www.lgessbattery.com/eu/grid/product-info.lg
https://en.wikipedia.org/wiki/Tesla_Model_S#/media/File:Tesla_Motors_Model_S_base.JPG

Cascading failure testing



Cascading failure testing with passive mitigation

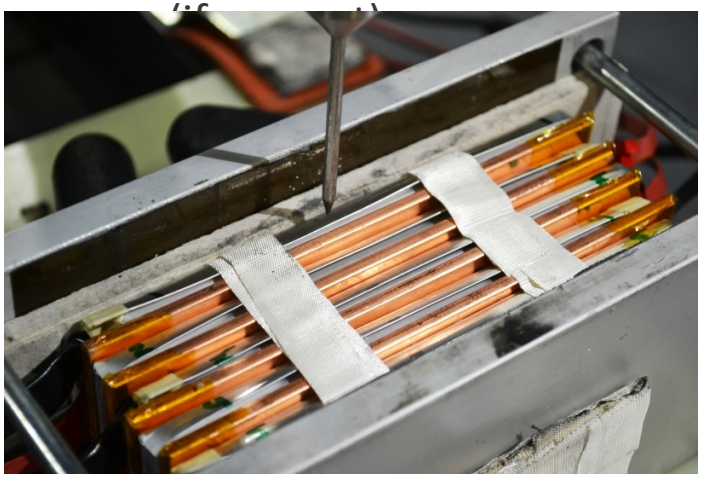
$LiCoO_2$ 3Ah pouch cells

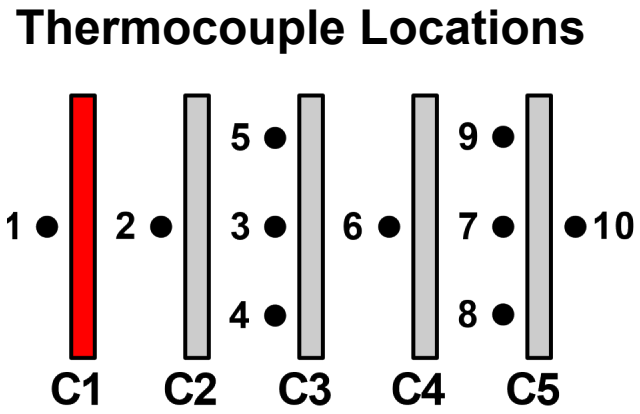
5 closely packed cells with/without aluminum or copper spacer plates

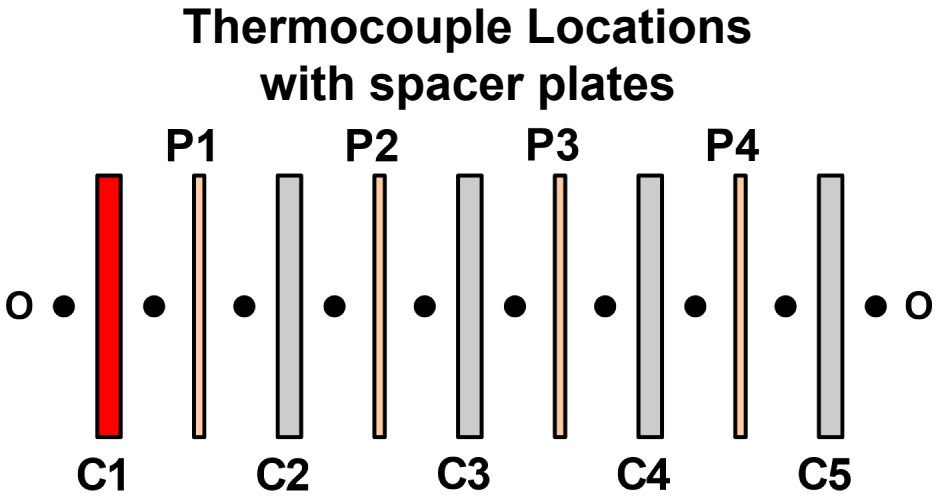
- Spacer thicknesses between 1/32” and 1/8”
- State of charge (SOC) between 50% and 100%

Failure initiated by a mechanical nail penetration in the outer cell (cell 1)

Thermocouples (TC) between cells and





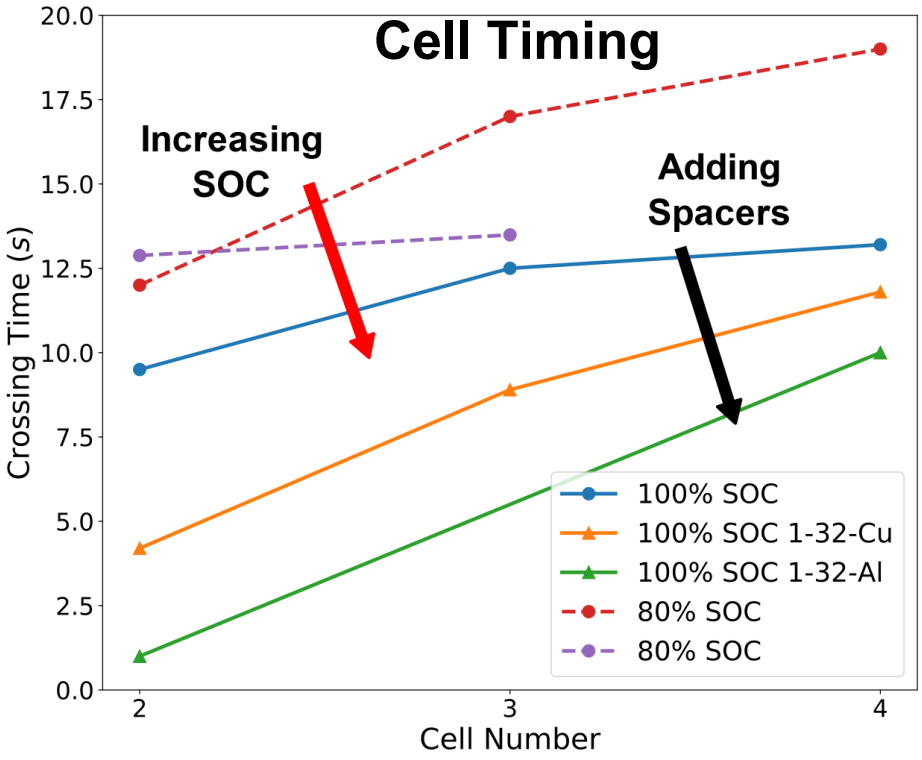


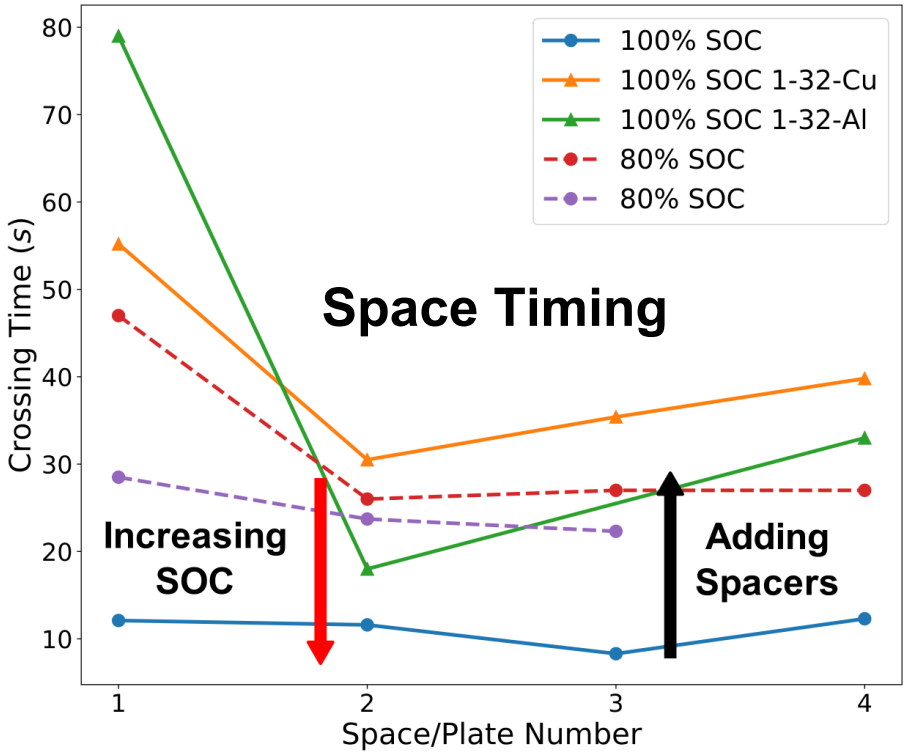
Cascading failure: propagation speeds

Adding spacers **increases** space crossing time, but **decreases** cell crossing time

Increasing state of charge (SOC) **decreases** both space and cell crossing time

Interplay between **heat capacity** of system and **energy release**





Finite element model for full cells in thermal runaway

Discretization in one direction (***x***)

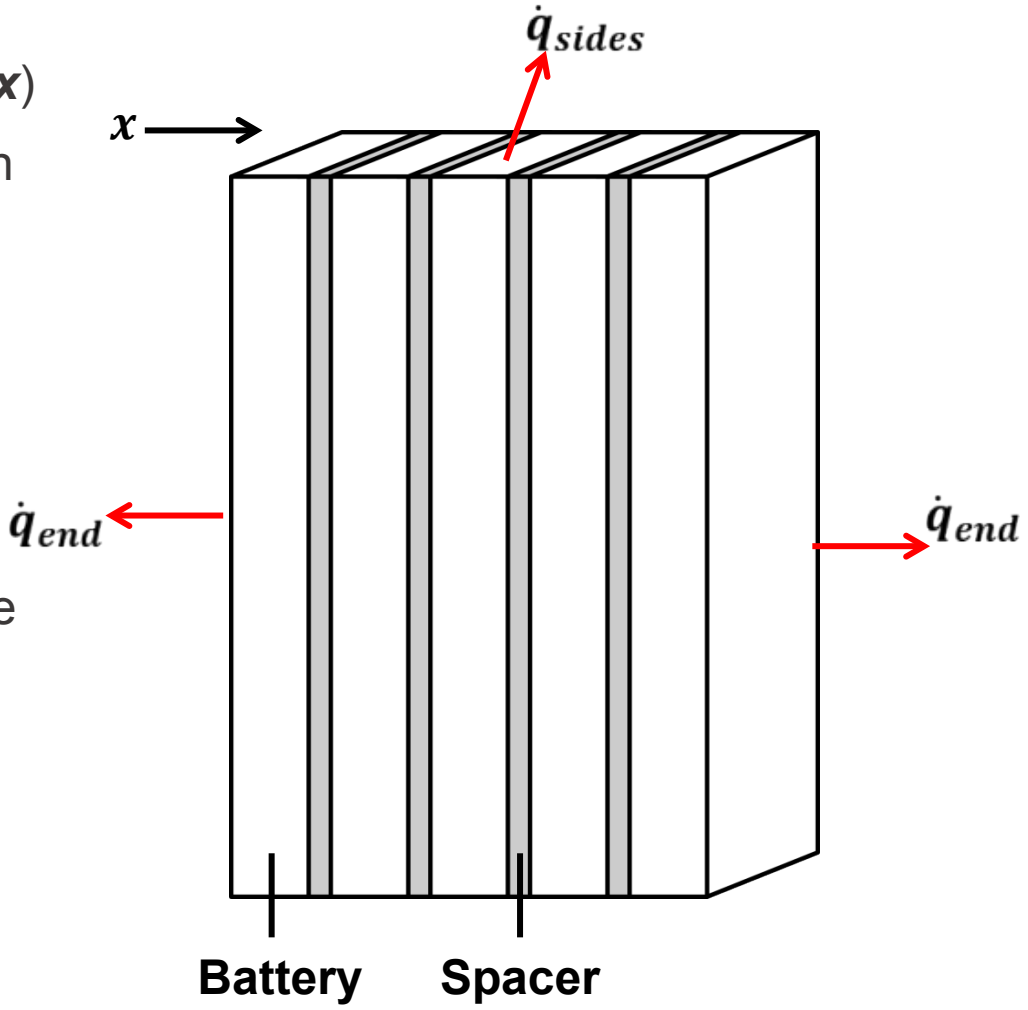
Modeled as a quasi 1-D domain of thin hexahedron elements

Multi-layered system
- Lumped battery material
- Spacers
- End block insulators

Convective heat transfer to surroundings (scaled by surface area to volume ratio for thin domain)

Heat conduction with chemical sources inside battery material

What inputs do you need to model this system?



Finite element model equations

Energy conservation:

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (K \nabla T) + \dot{q}'''$$

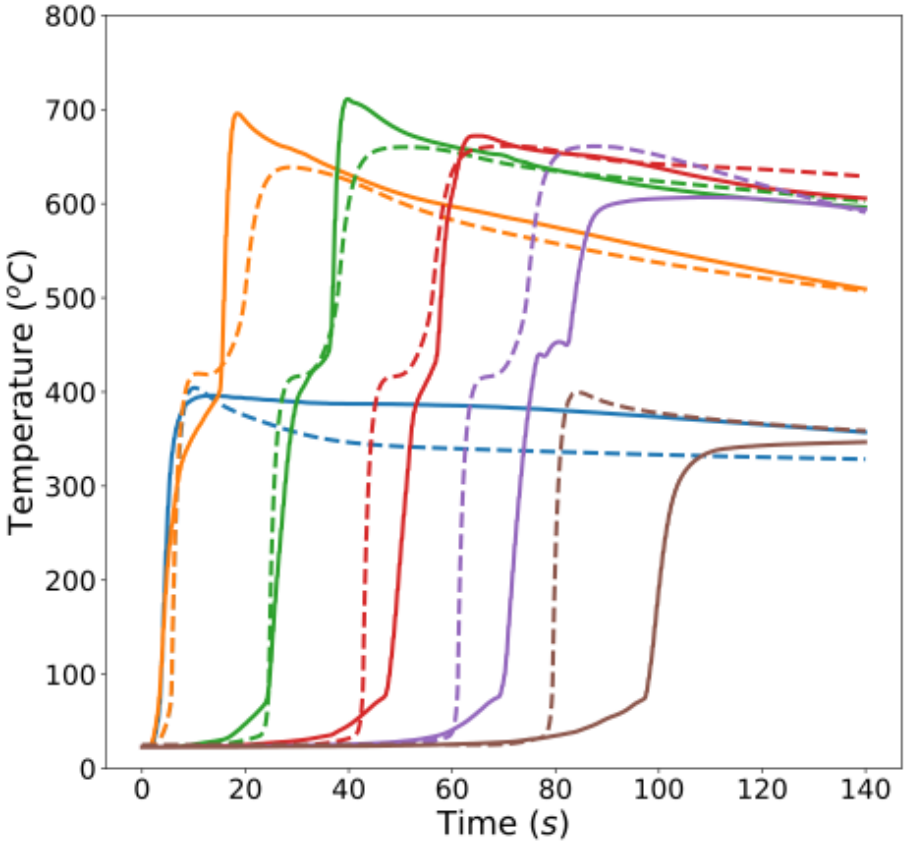
Mass conservation for species i with N_r reactions:

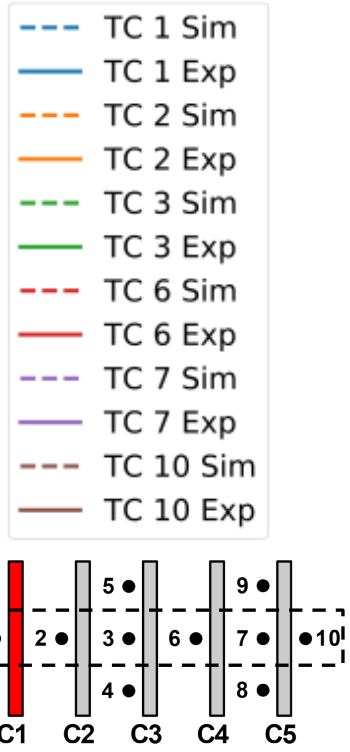
$$\frac{\partial \rho_i}{\partial t} = \sum_{j=1}^{N_r} \left(\nu''_{ij} - \nu'_{ij}\right) r_j$$

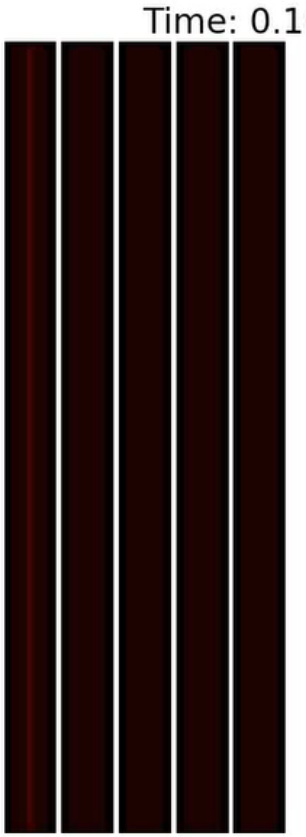
Energy source:

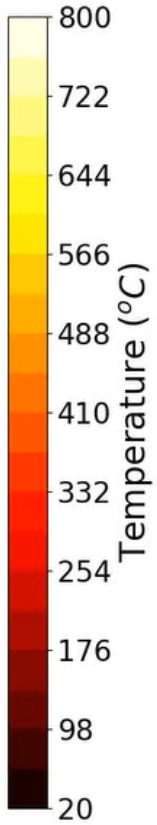
$$\dot{q}''' = -\sum_{j=1}^{N_r} \Delta H_j r_j$$

Simulation results: 100% SOC, no spacers





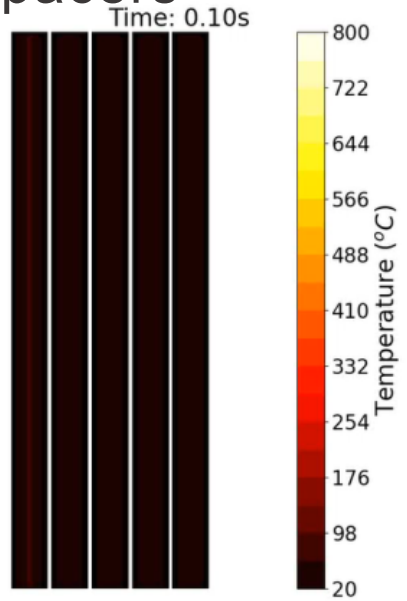


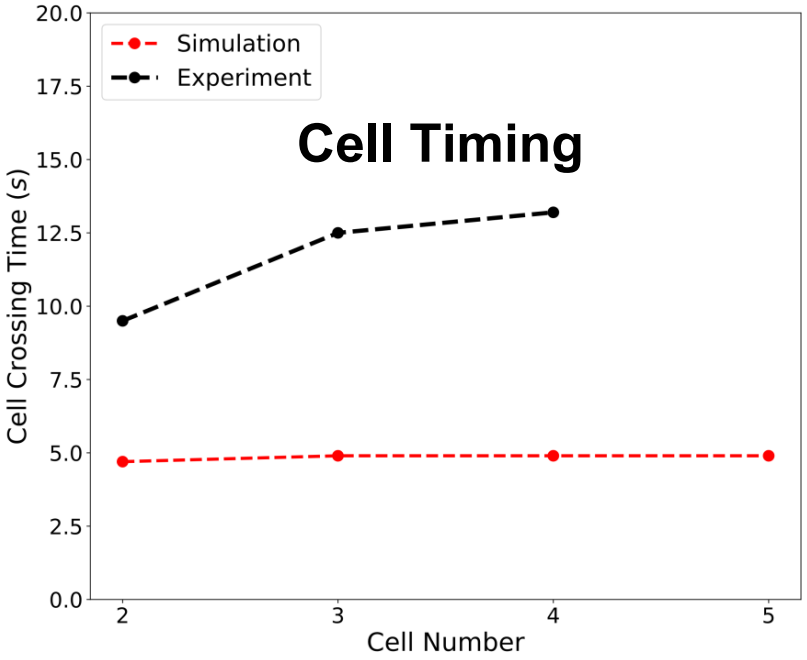


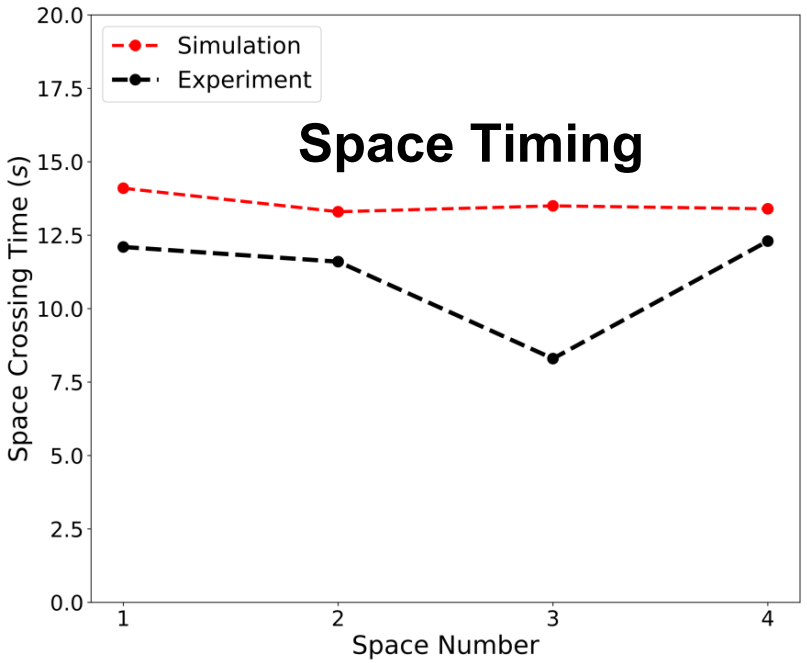
- Prediction of peak temperatures and cooling
- Cell crossing speed slightly over-predicted

Predicted crossing times: 100% SOC, no spacers

- Experimental cell and space crossing times are on the same order.
- Cell crossing times are under-predicted and space crossing times are over-predicted.







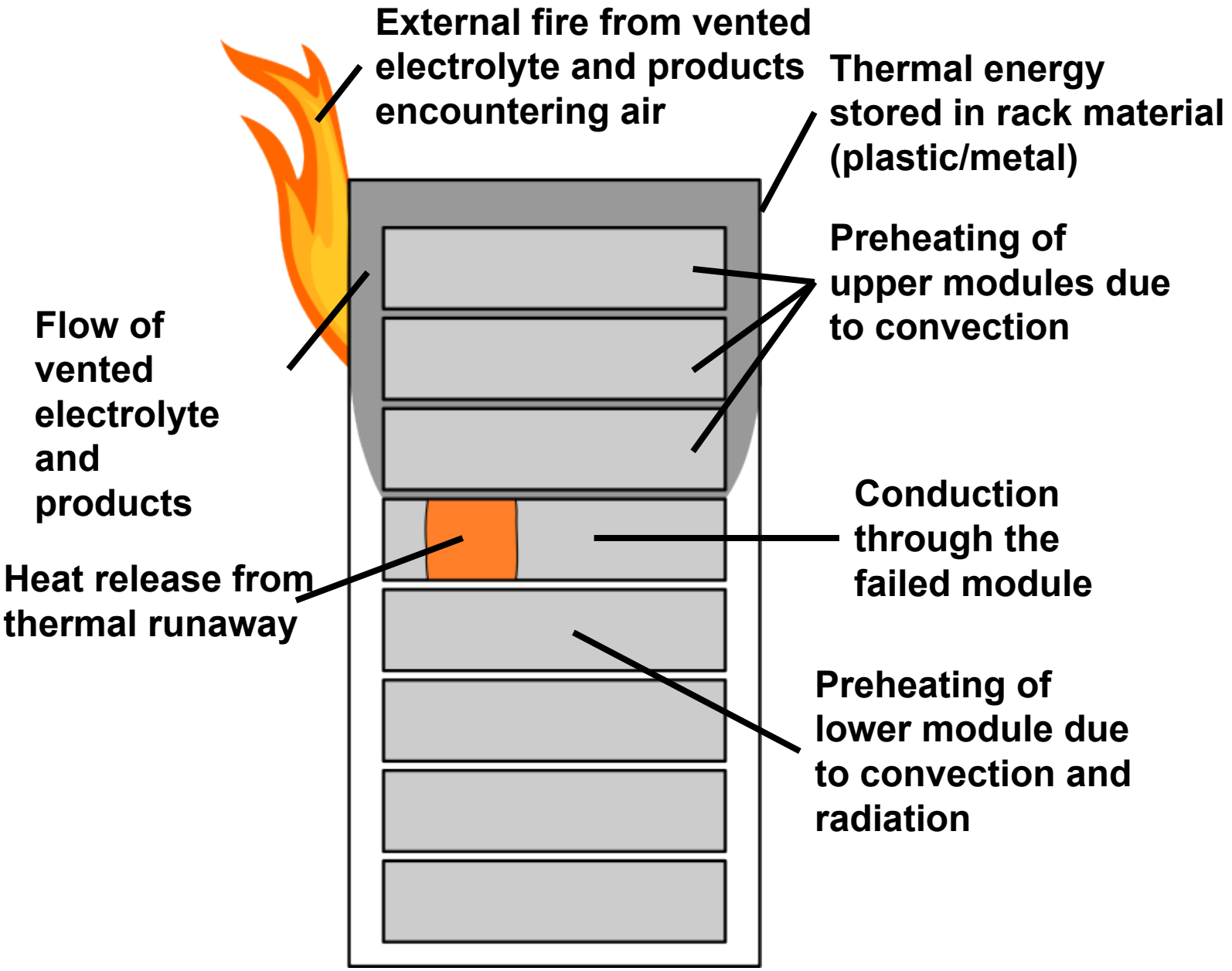
Large scale testing and simulation

Recall the energy storage rack from earlier…

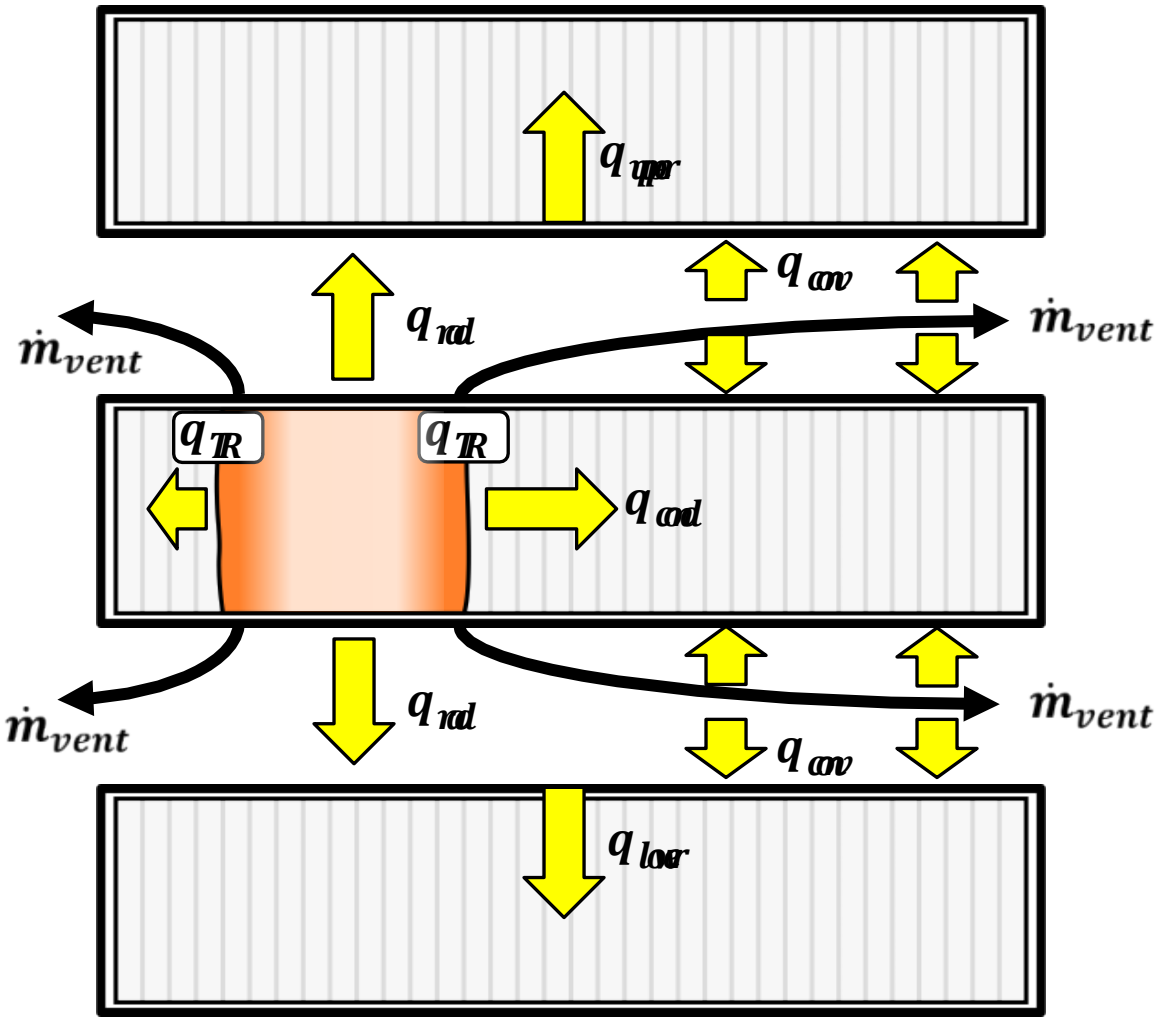
How would you model this system to predict failure?

https://www.youtube.com/watch?v=uLzPSN8iasgk (FM Global LFP system)

Large scale testing and simulation



Heat and mass transfer in an ESS



Thanks!
Questions?

More fire videos

https://www.youtube.com/watch?v=NoVUkUC_o7E (UTFRG – door)

https://www.youtube.com/watch?v=6IJkqvqJIKU (UTFRG single cell)

https://www.youtube.com/watch?v=Fc-eJFIT-bo (FM Global sprinkler)

Acknowledgements

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