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Evaluating thermal runaway risks in high energy density cells

PRESENTED BY

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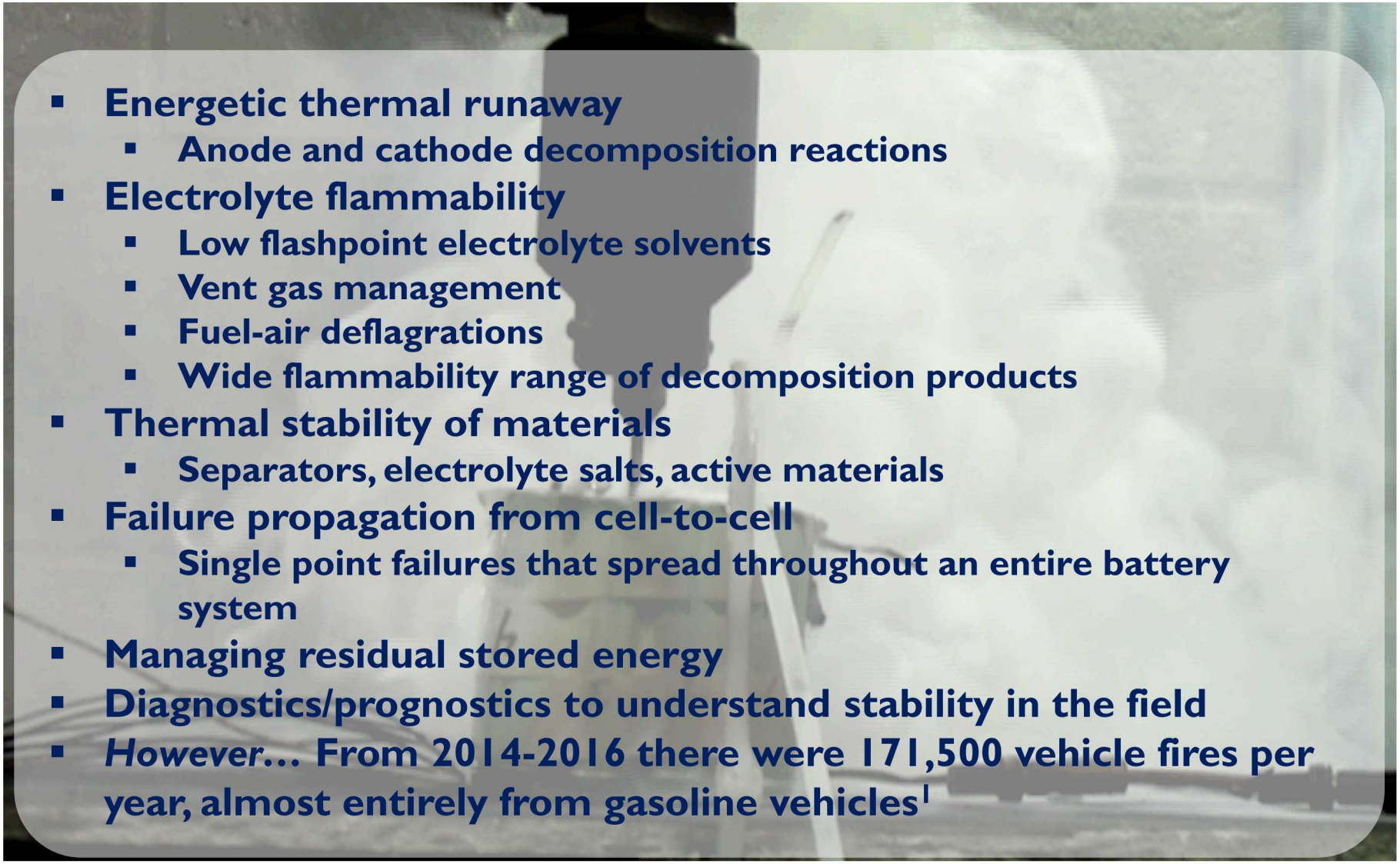
Lithium-Ion Battery Challenges



- Energetic thermal runaway
  - Anode and cathode decomposition reactions
- Electrolyte flammability
  - Low flashpoint electrolyte solvents
  - Vent gas management
  - Fuel-air deflagrations
  - Wide flammability range of decomposition products
- Thermal stability of materials
  - Separators, electrolyte salts, active materials
- Failure propagation from cell-to-cell
  - Single point failures that spread throughout an entire battery system
- Managing residual stored energy
- Diagnostics/prognostics to understand stability in the field
- *However…* From 2014-2016 there were 171,500 vehicle fires per year, almost entirely from gasoline vehicles[1]

[1] www.fema.gov

Capabilities of Power Source R&D Group

- 10,000 sq. ft. dry room space
- Synthesis of battery materials
- Prototyping for thermal batteries, Li primary, and Li-ion cells and batteries
- Battery design & development
- Performance and abuse testing
- Battery calorimetry facilities
- Forensics and analysis
- Fundamental electrochemistry
- Modeling and simulation*
- Environmental testing*
- High hazard test facilities (Burn Site)*

*Facilities leveraged from our Partners in SNL Experimental Sciences Center

Battery Abuse Testing Laboratory (BATLab)

Comprehensive abuse testing platforms for safety and reliability of cells, batteries and systems from mWh to kWh

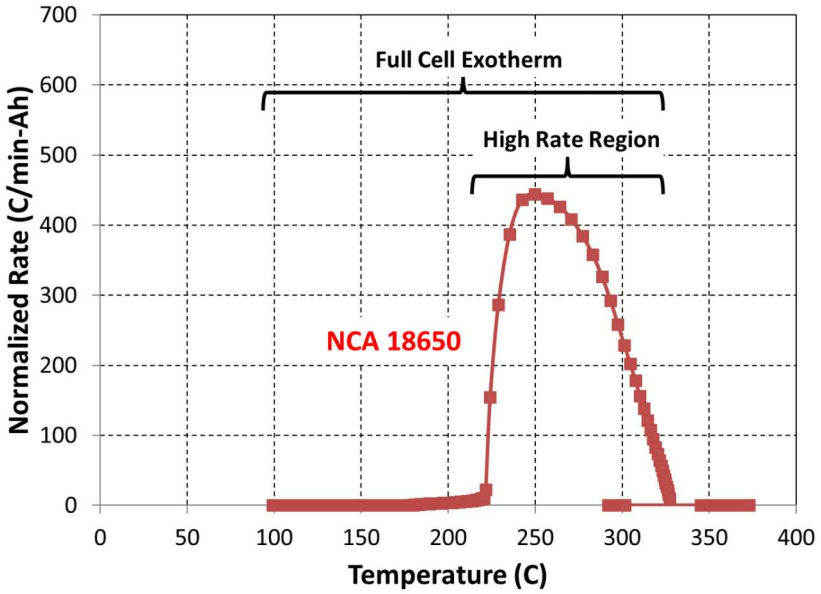
Cell, module, and battery system hardware deliverables for testing

Mechanical abuse
- Penetration
- Crush
- Impact
- Immersion

Thermal abuse
- Over temperature
- Flammability measurements
- Thermal propagation
- Calorimetry

Electrical abuse
- Overvoltage/overcharge
- Short circuit
- Overdischarge/voltage reversal

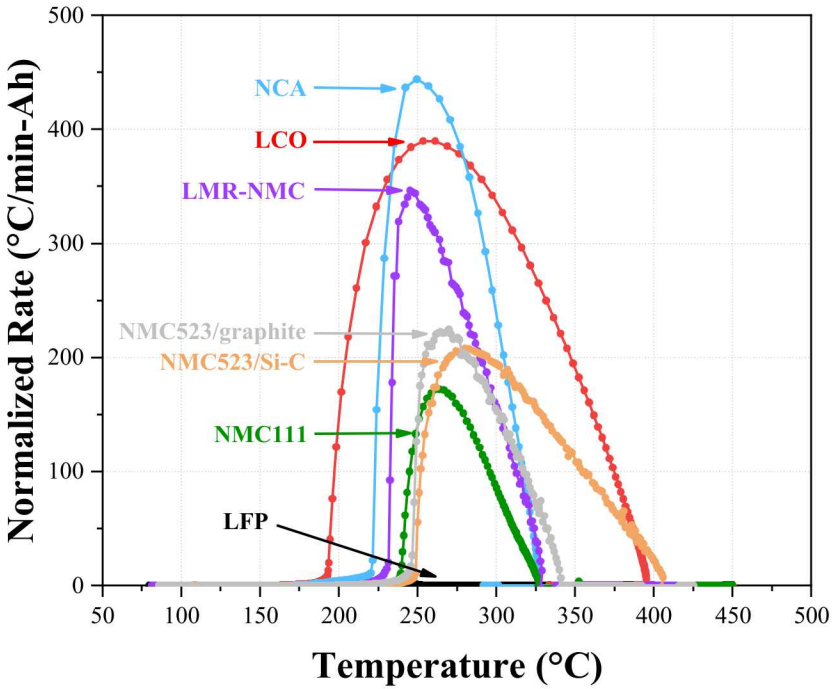
Characterizing Thermal Runaway



- Begins when self heating reactions exceed natural losses to surroundings
  - Upon self heating, a cell experiences further decomposition leading to an accelerated heating rate effect
  - ARC testing – sets natural losses to 0
- We evaluate two primary values:
  - Peak heating rates
  - Total enthalpy of the exothermic process

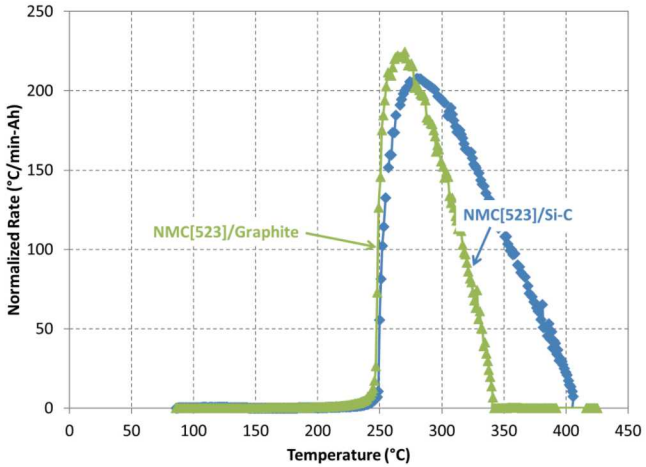
  (The enthalpy of the high rate region can also be determined)
- High rate behavior:
  - Best potential for evaluating the likelihood of thermal runaway
  - Identifies the threshold for thermal runaway

Characterizing New Materials

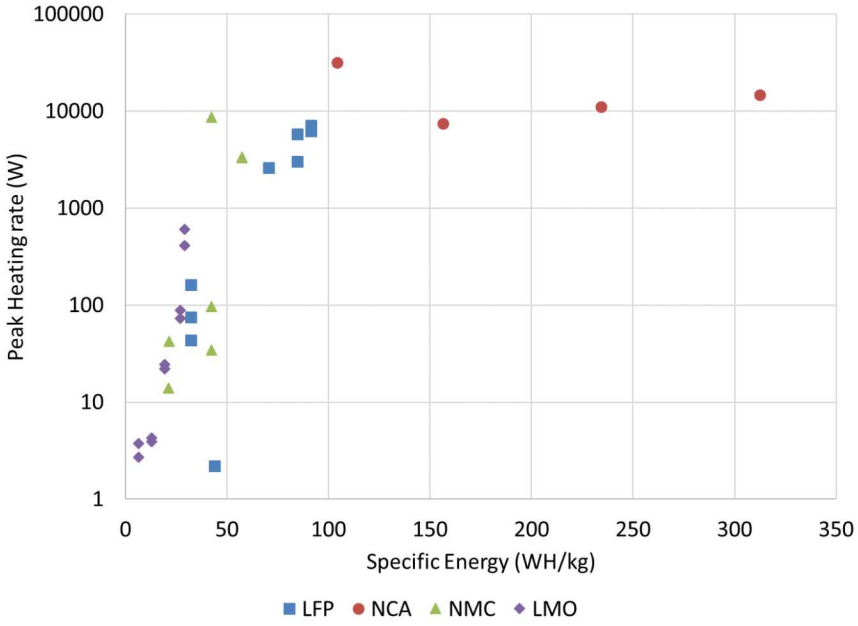


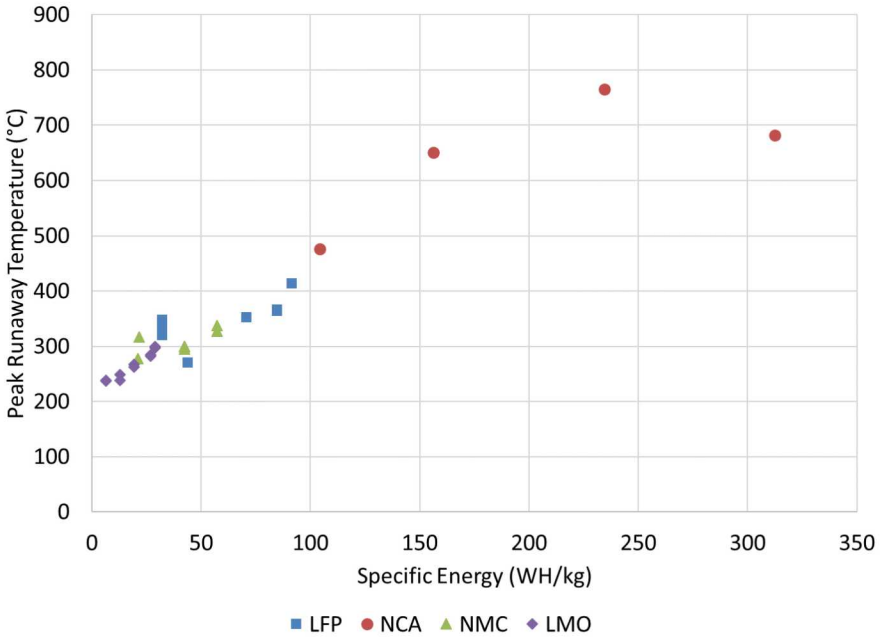
- ARC has been a powerful tool in performing these evaluations of new materials
- Work is generally performed on 18650 cells

- ARC data depicts behavior of various chemistries
- Peak heating rates and total energy of thermal runaway
- Newer materials (LFP):
  - Significantly reduced thermal runaway intensities
  - Limited energy density



Impact of specific energy

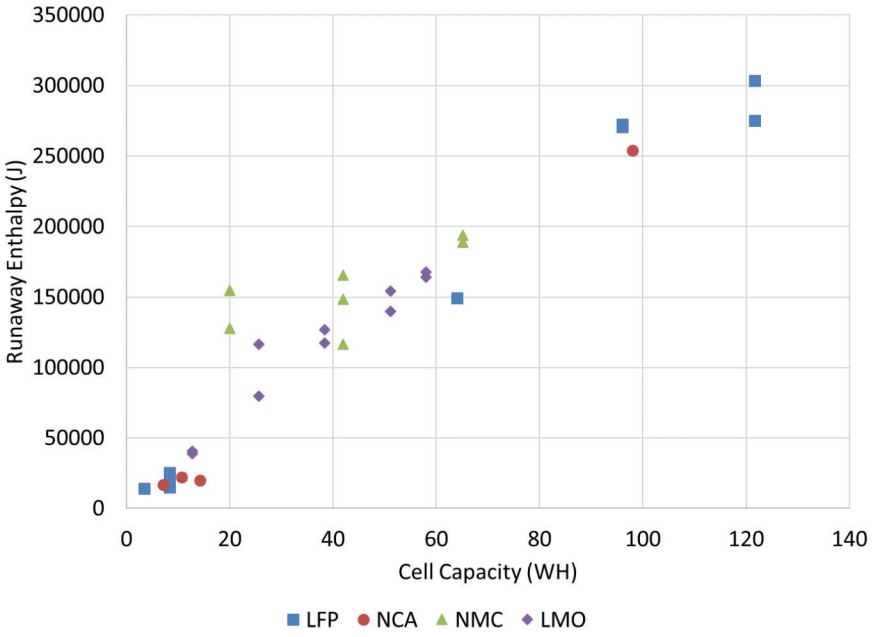




- Test data from the following:
  - Cell capacity = 1.08 to 38 AH (3.5-122 WH)
  - Chemistries = LFP, NMC and NCA
  - Formats = 18650, 26650, pouch cell, and large cylindrical*
- Pairing peak heating rate with specific energy of the tested system results in an exponential pattern, becoming more linear at highest specific energies
- Peak runaway temperatures scaling fairly linearly with specific energy – these are the temperatures reached during the high heating rate portion
- Peak heating rates do not give a complete story for runaway severity
  - Excludes gas generation and peak temperatures
  - May be the best metric we have for predicting likelihood of thermal runaway
  - When heating rates do not exceed natural heat loss - thermal runaway will not normally occur

*steel cylindrical cells with machined stamped vents

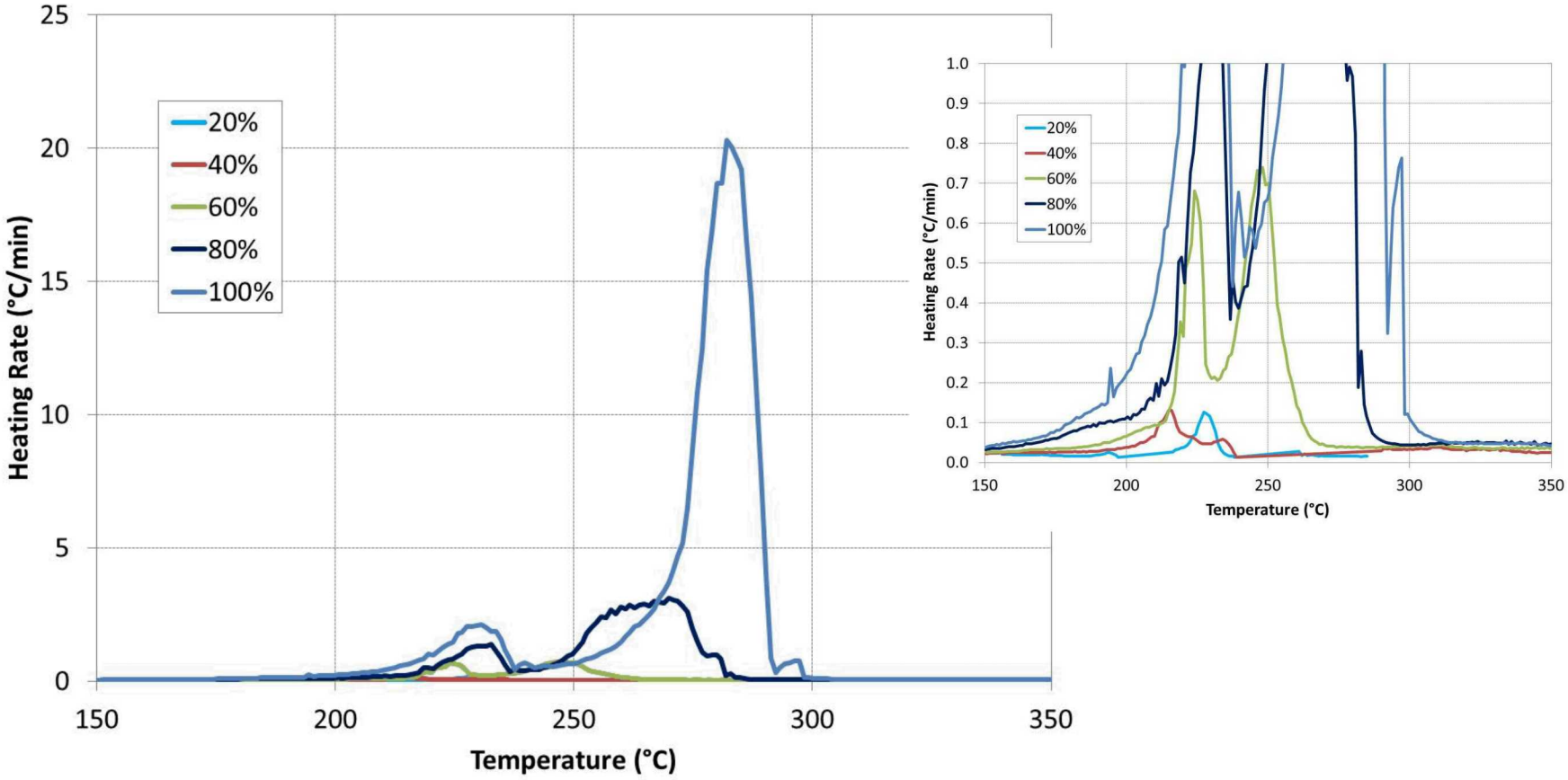
Total energy release



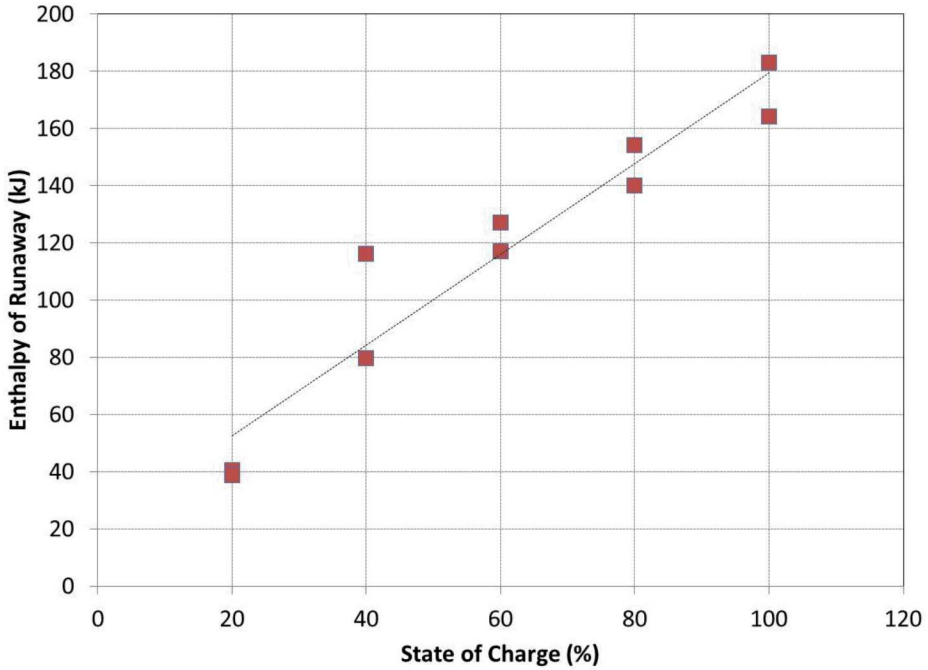
- Total energy released, measured from the overall exothermic temperature change
- Scales fairly linearly with total energy stored
- Note that the high capacity LFP cells studied were able to release a significant amount of energy. This has potential implications for well insulated systems

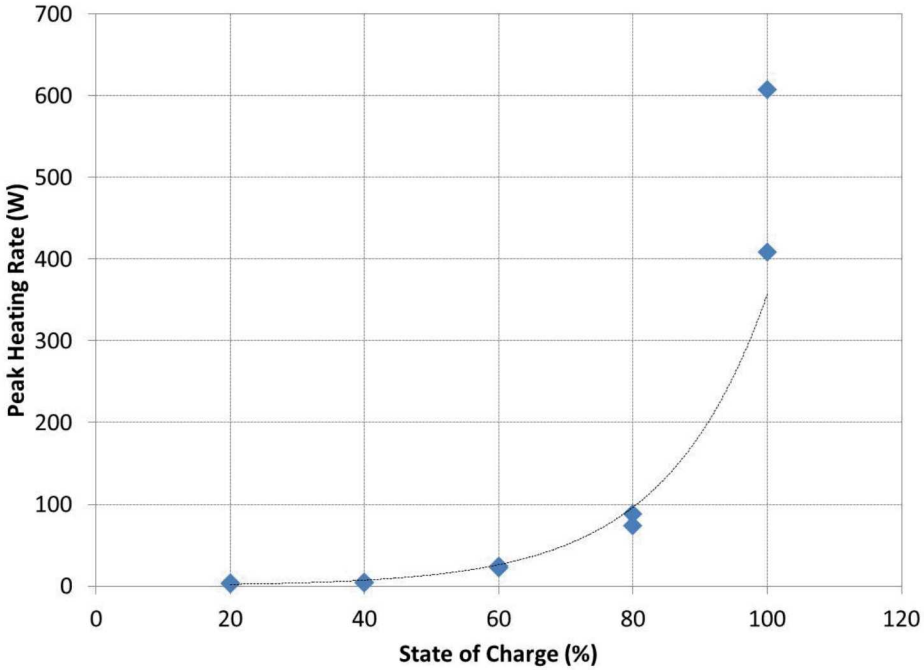
SOC and Thermal Runaway – A single cell case study

- 16 Ah Automotive (PHEV) pouch cells (mixed $LiMn_2O_4$ spinel)
- Significant impact observed above 60% SOC
  - Very low self heating rate at 40% and 20%



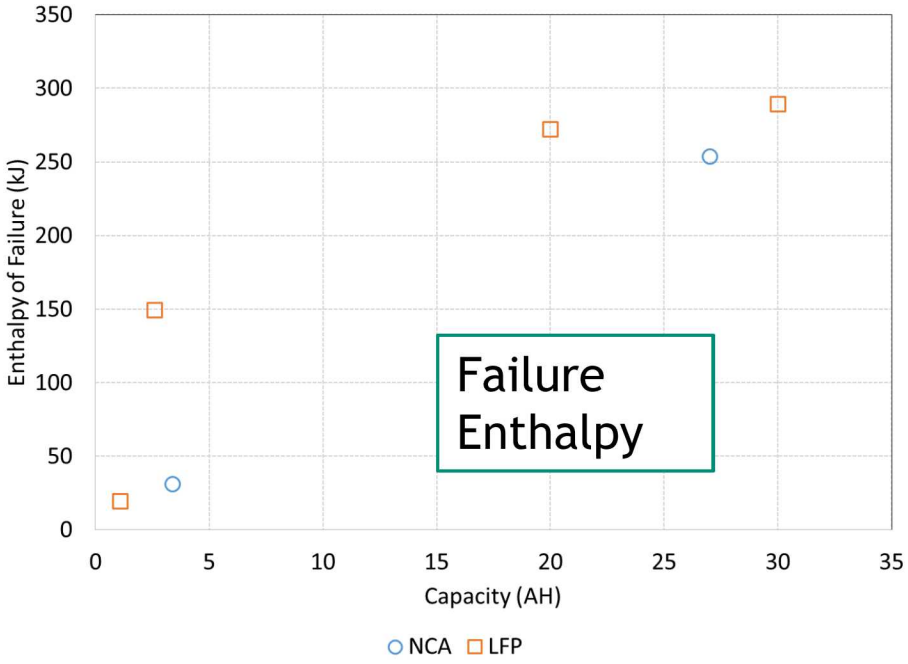
Impact of SOC on Runaway – A single cell case study

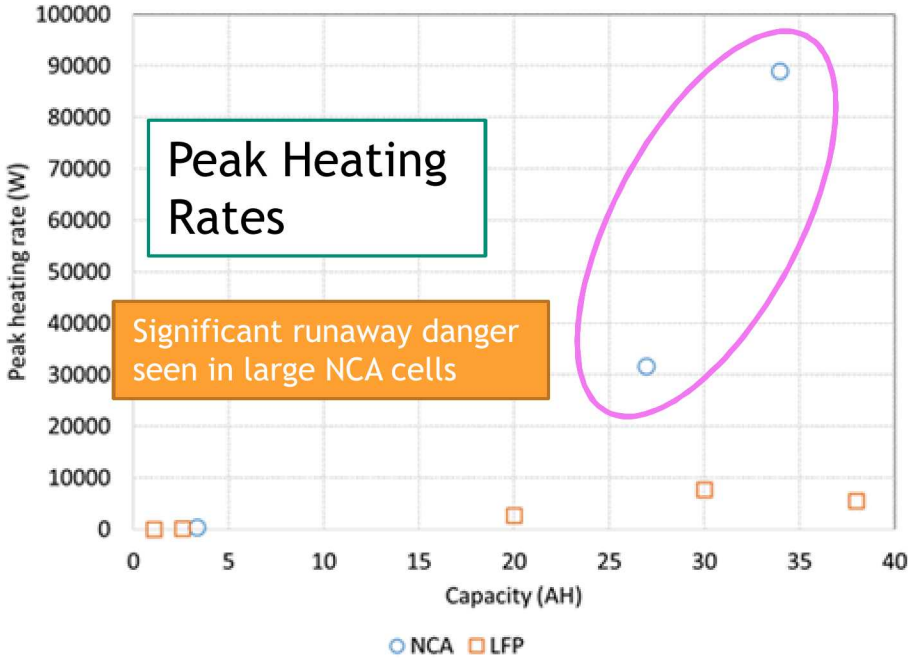




- Nearly linear relationship between total heat release (kJ) and cell SOC
  - Similar to data for cell size
  - Suggests failure enthalpy is based largely on the stored energy available
- Heat release rates (e.g. runaway reaction kinetics) follow an almost exponential relationship with cell SOC
  - Traditionally thought to cause a greater risk of thermal runaway

Cell Size vs. Chemistry





- Enthalpy – proportional to capacity
  - Similar for both chemistries
  - Early data suggests that failure enthalpy is largely tied to the available stored energy
- Peak heating rates significantly higher for large NCA cells
- High peak heating rates are generally thought to carry a higher thermal runaway risk

Summary

First Glance:

- Peak heating rates are highly dependent on:
  - Cell chemistry
  - State of Charge
  - Cell format
- Digging deeper reveals primary driver may simply be the component level energy density
- Component level = cell + inactive material in intimate contact with cell
- May have implications on propagation mitigation strategies
  - Mitigate failure by simply reducing system level energy density
- Open question: Is it possible to break this trend and achieve a low risk of thermal runaway, with a significantly high energy density?

Total Enthalpy – tied directly to total stored energy

Pouch cells – higher variance observed

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