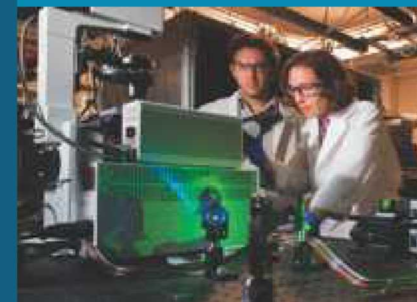
SAND2020-0956PE

Evaluating thermal runaway risks in high energy density cells



PRESENTED BY

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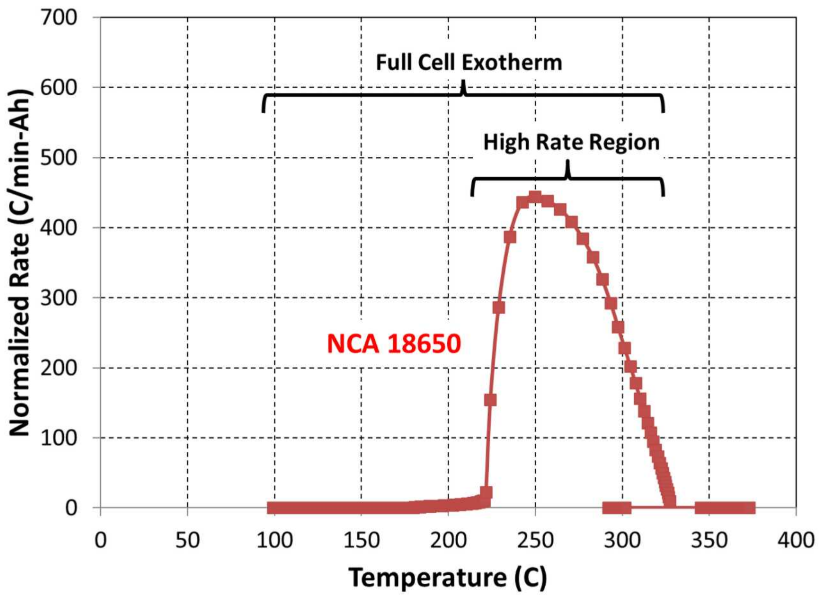
Approach and Capabilities

Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)

Battery Pack/System Testing
Thermal Test Complex (TTC) and Burnsite

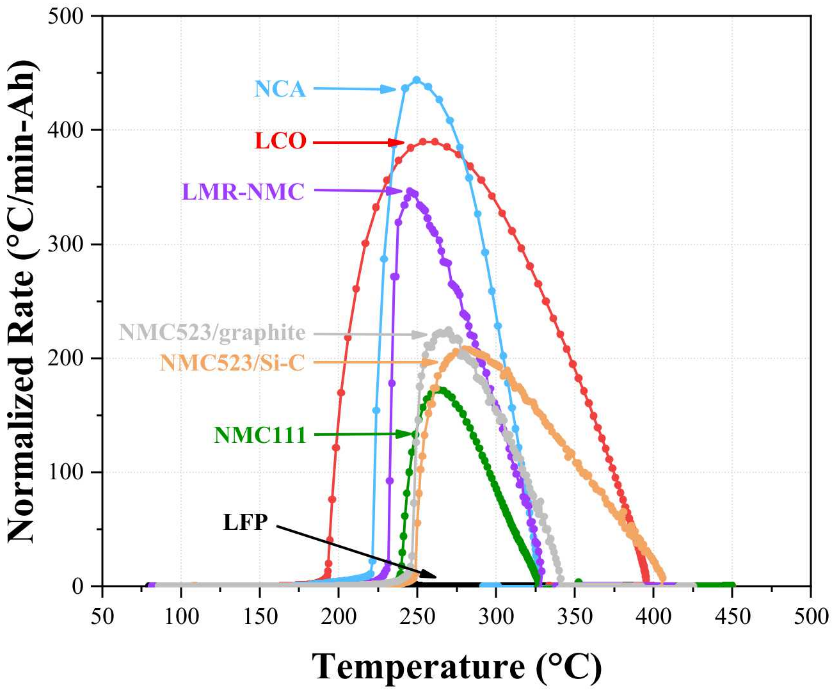
Battery Calorimetry

Characterizing Thermal Runaway



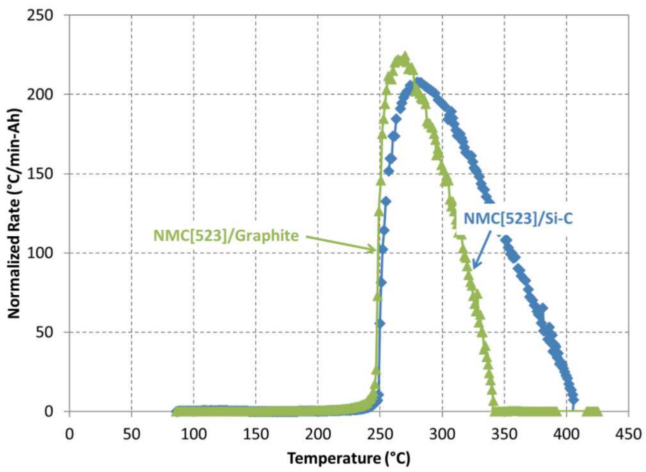
- In a practical scenario, thermal runaway begins when self heating reactions generated by a cell exceed natural losses to surroundings
  - Once a cell is able to self heat, it drives decomposition further decomposition leading to an accelerating rate effect
  - ARC testing essentially sets these natural losses to 0
- We evaluate two primary values, the peak heating rates and total enthalpy of the exothermic process
  - The enthalpy of the high rate region can also be determined
- High rate behavior has the best potential we have seen to date to evaluate the likelihood of a battery going into thermal runaway, essentially telling us the threshold for a cell going into thermal runaway in a practical scenario

Characterizing new materials



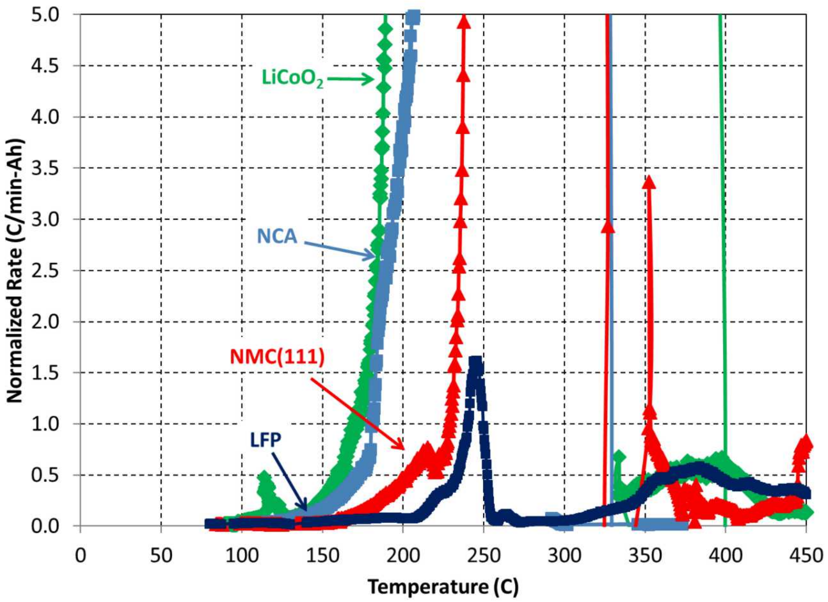
- Accelerating rate calorimetry shows the behavior of various chemistries.
- This gives information about peak heating rates and total energy of the thermal runaway.
- Newer materials such as LFP provide significantly reduced thermal runaway intensities, but have limited energy density.

- ARC has been a powerful tool in performing these evaluations of new materials
- However, all work is generally performed on 18650 cells, how results change as we scale cell size?

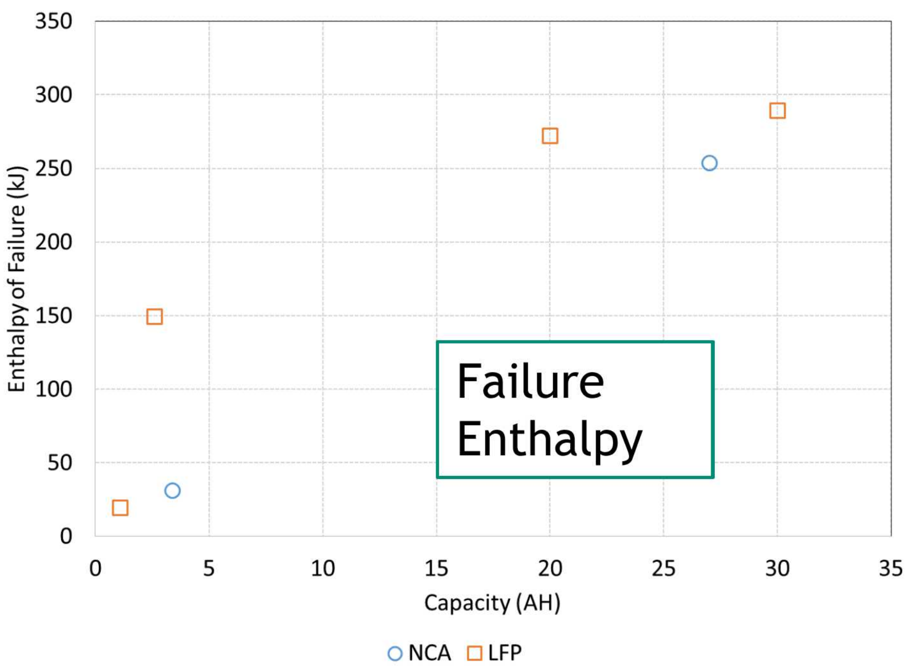


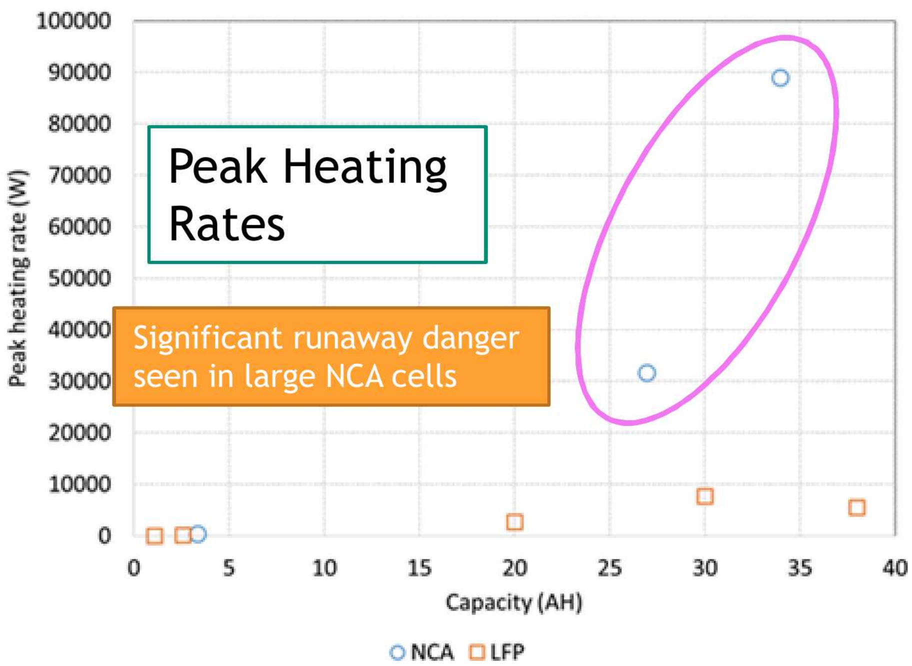
Chemistry vs. energy density – What has the greater impact on thermal runaway potential?

- Cell chemistries such as LTO and LFP have been held up as lower risk materials
- However energy density is also significantly lower
- When testing, we typically normalize to cell level capacity or energy density
- However, for low capacity cells the test apparatus makes up a larger portion of the total mass of the test setup
- Generally materials comparison has been done on 18650 cells of ~1-2 Ah and normalized to cell capacity



What about cell size and chemistry?

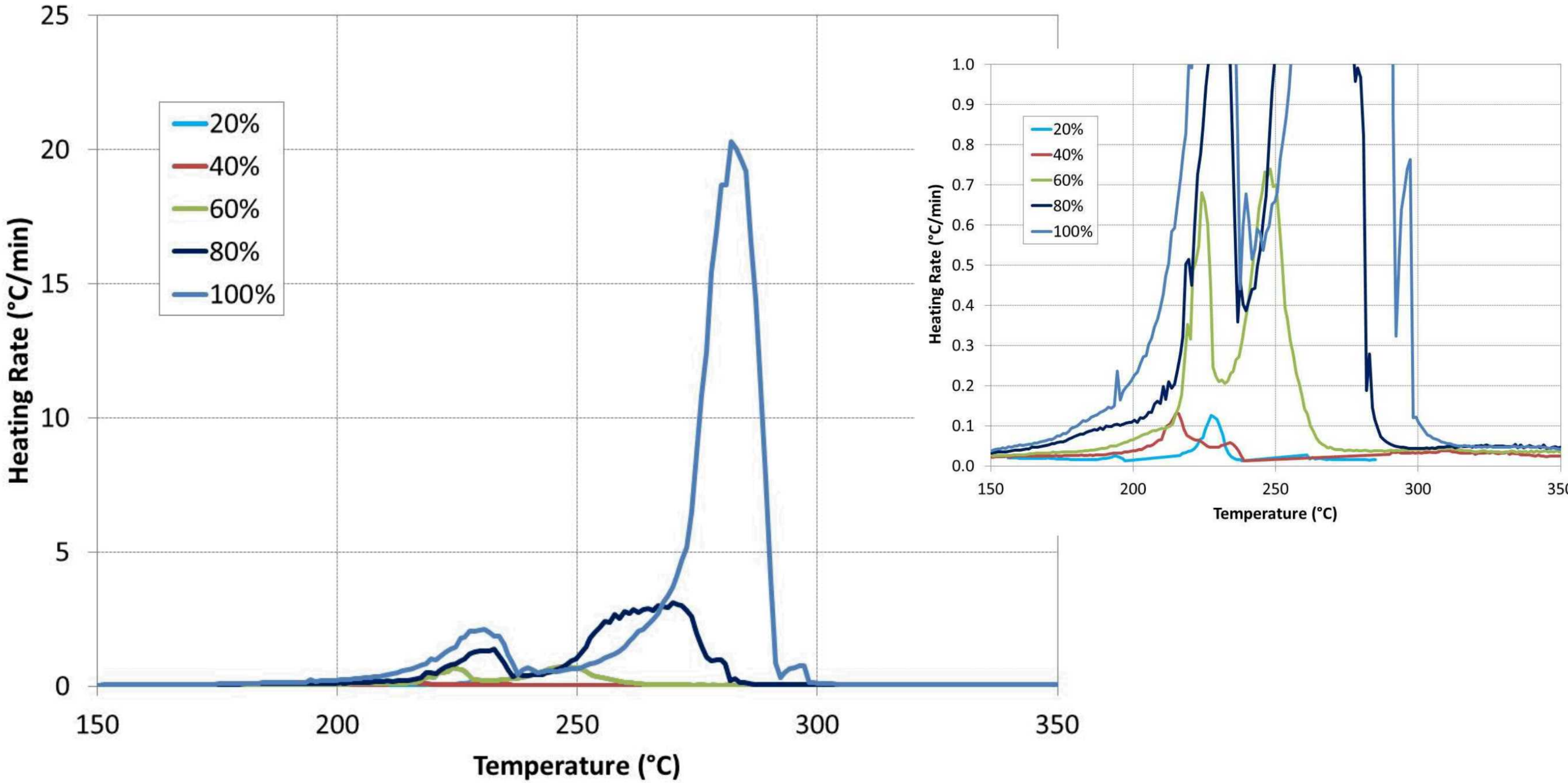




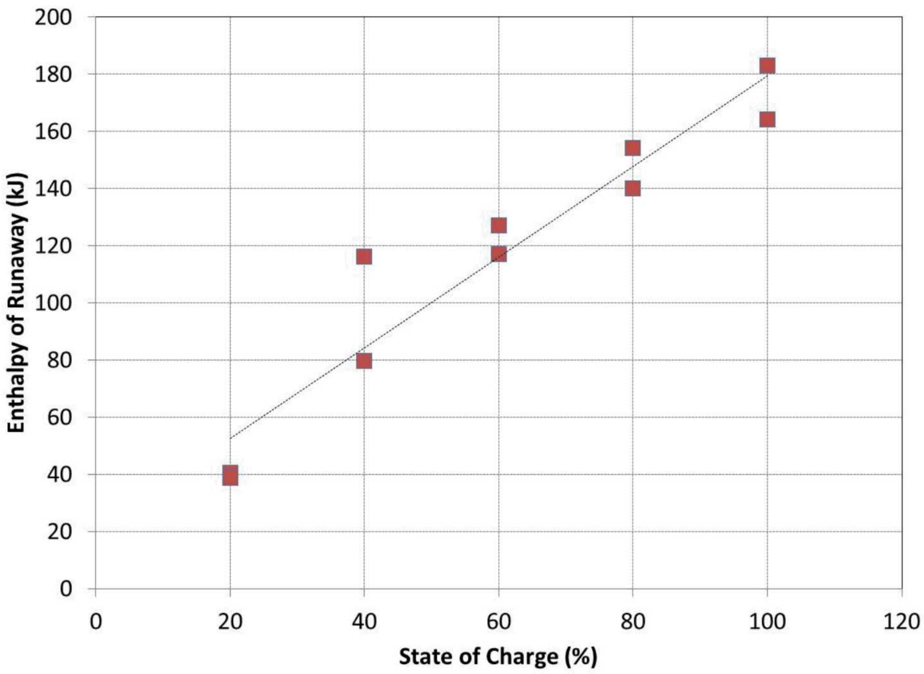
- Enthalpy scales generally linearly with size, and is similar for both chemistries – This early data suggests that failure enthalpy is largely tied to the available stored energy
- Peak heating rates significantly higher for large NCA cells
- High peak heating rates are generally thought to carry a higher thermal runaway risk, but what is the impact when significant energy is available in numerous smaller cells?

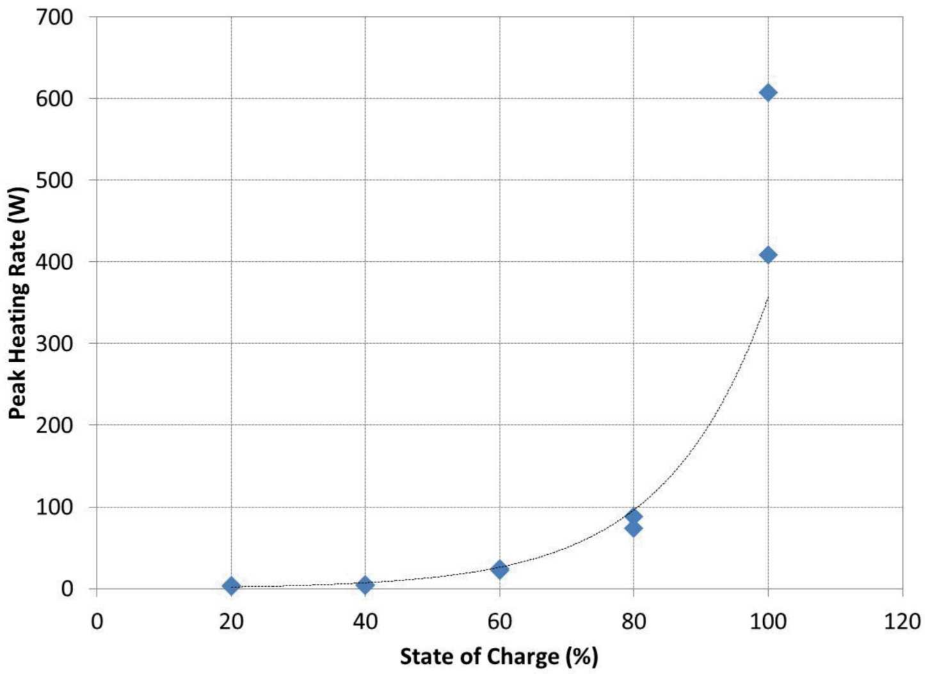
SOC and Thermal Runaway – A single cell case study

- 16 Ah automotive (PHEV) pouch cells (mixed $LiMn_2O_4$ spinel)
- Significant impact can be easily observed above 60% SOC, very low rate self heating below that



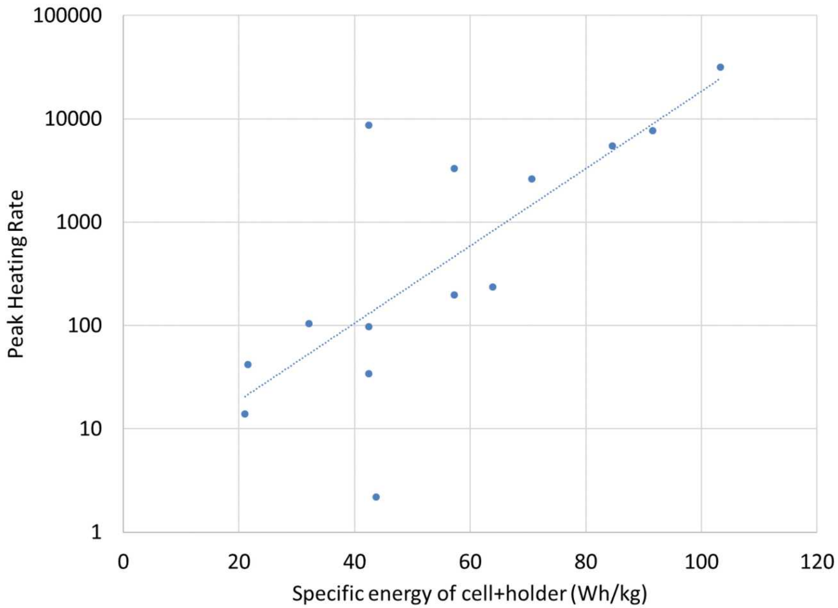
Impact of SOC on Runaway – A single cell case study

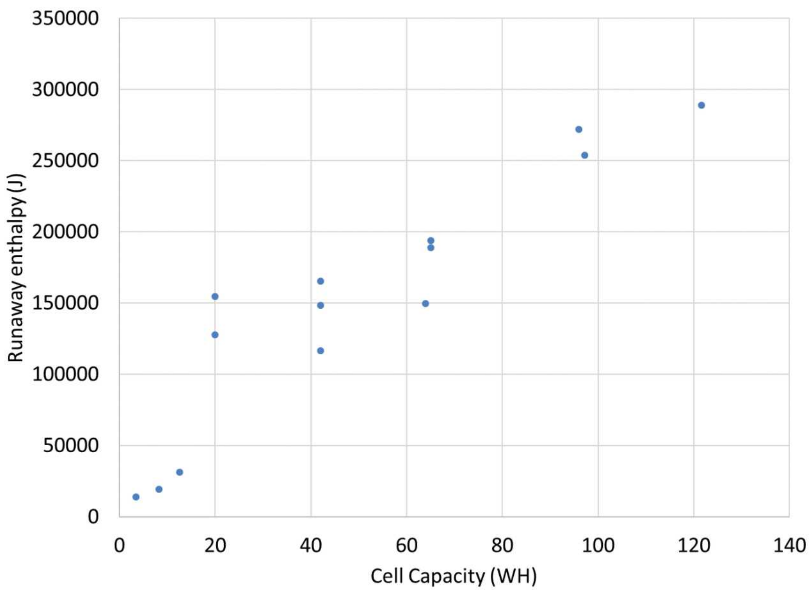




- Results show a nearly linear relationship between total heat release (kJ) and cell SOC – similar to data for cell size this suggests that failure enthalpy is based largely on the stored energy available
- Heat release rates (e.g. runaway reaction kinetics) follow an almost exponential relationship with cell SOC – again this is traditionally thought to cause a greater risk of thermal runaway
- Could a runaway still occur with large numbers of low SOC cells or cells in well insulated conditions?

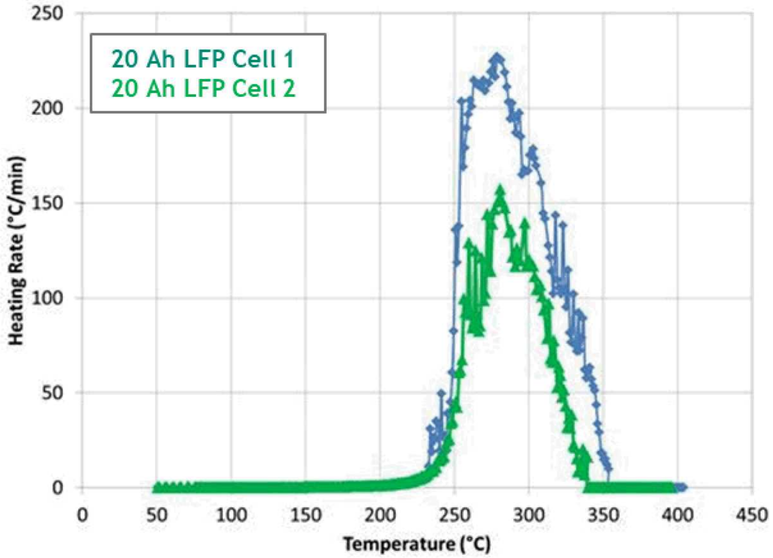
Evaluation of historic data

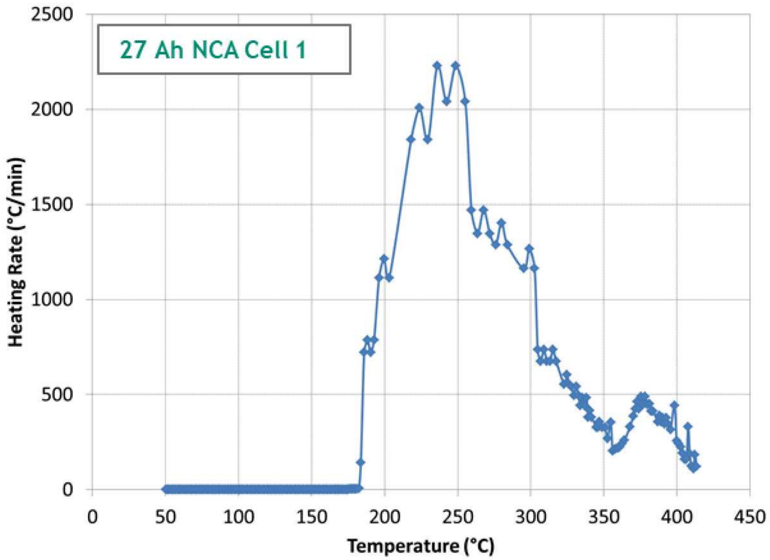




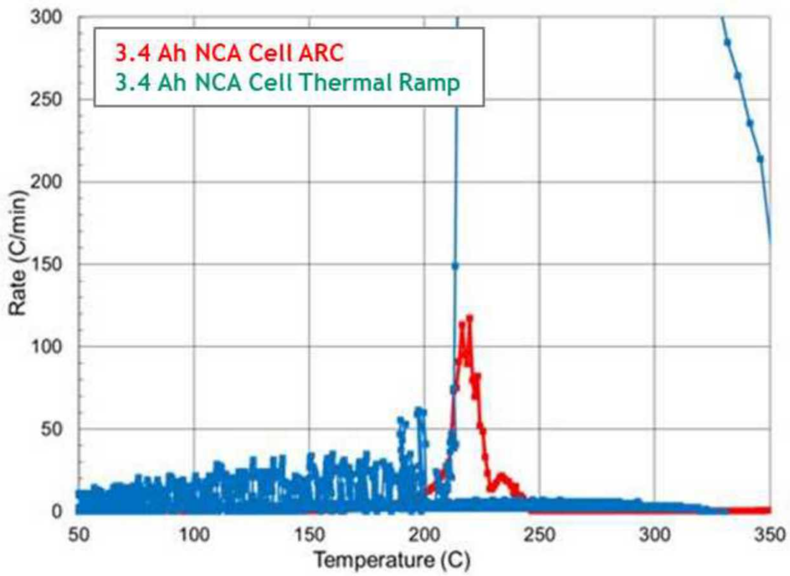
- Data includes cells from 1.08-38 AH (3.5-122 WH)
  - Chemistries include LFP, NMC and NCA
  - Formats include 18650, 26650, pouch cell, and large format cylindrical (steel cylindrical cells with machined stamped vents)
- Total energy of runaway maintains a linear relationship to cell capacity
- When we pair the peak heating rate with the specific energy of the tested system (the cell itself plus any material in intimate thermal contact with the cell) an exponential pattern emerges
- Peak heating rates do not give a complete story for runaway severity, as it excludes things like gas generation and peak temperatures
  - Peak heating rate may be the best metric we have for predicting likelihood of thermal runaway – if heating rates never exceed natural heat loss thermal runaway won’t normally occur

Selected NCA and LFP Results



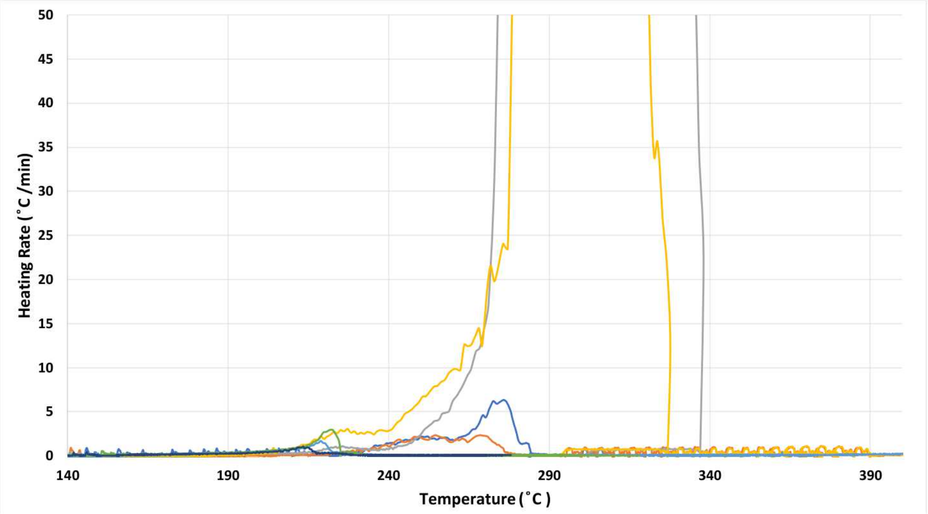


- High capacity LFP cells show thermal runaway rates not typically seen in smaller cells
- High capacity NCA cells push the limits of observable heating rates
- We see some variance in the behavior of NCA in ARC and traditional thermal ramp
    - A primary difference may be the combustion of the thermal ramp cell, this creates a source of energy not accounted for in the stored electrical energy



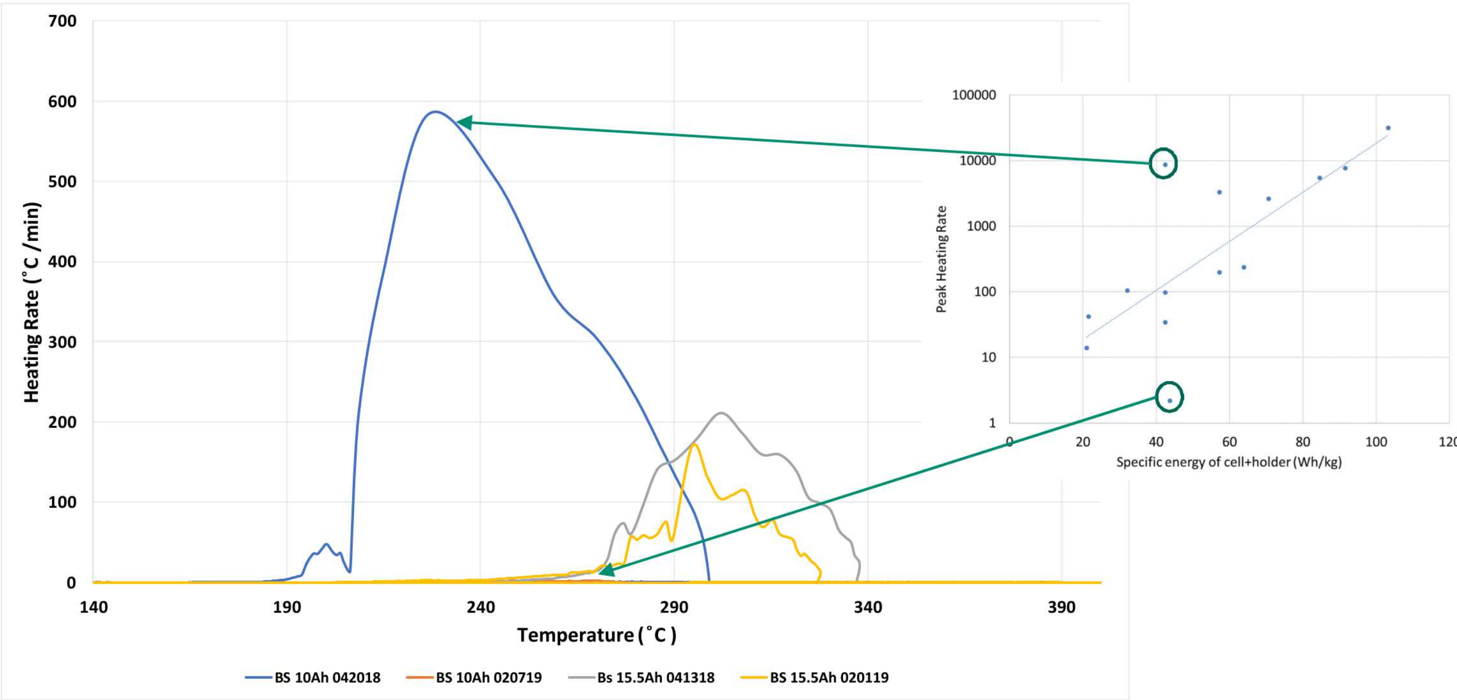
Scaling of NMC cells – Single chemistry case study

Battery	Onset Temp (C)	Max Heating Rate (kW)	Total Enthalpy (kJ)
NMC 5 AH	170	0.22	225
NMC 5 AH	150	0.42	155
NMC 5 AH	170	0.22	225
NMC 10Ah	208	9	148
NMC 10Ah	215	0.34	165
NMC 10Ah	225	10	117
NMC 15.5Ah	243	3	189
NMC 15.5Ah	242	3	193



- NMC cells tested from two different cell suppliers
- One particular cell in this set accounted for the primary outliers mentioned earlier, with both unexpectedly low and high rates in the same cell.

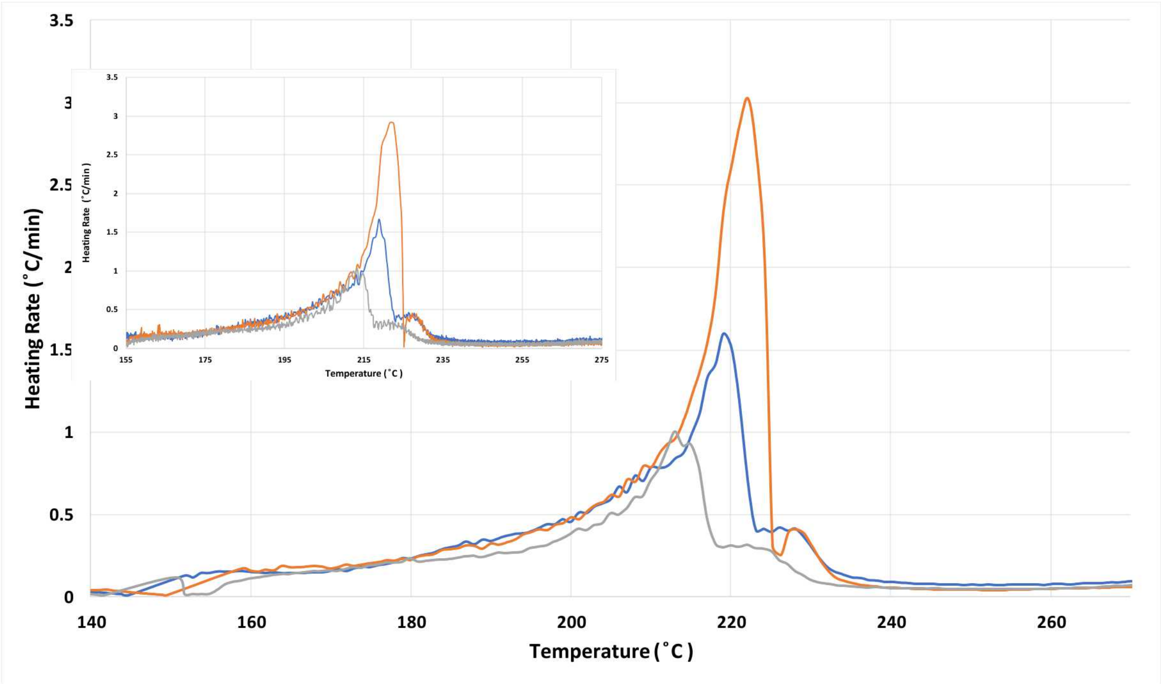
Revisiting the primary outlier



- One cell was responsible for the most abnormal runaway patterns
- Cell was a COTS pouch cell from a second tier supplier
- This suggests cell construction has an important role to play as well
- The large heating rates observed here may be indicative of an internal short circuit developing during failure; this would lead to significant heating due to the rapid self discharge

Exploring Variance in Larger Scale ARC Tests

Test No	Onset Temp (˚C)	Max Heating Rate (kW)	Total Enthalpy (kJ)
1	170	0.22	225
2	150	0.42	155
3	155	0.14	128



- Further exploration of the variance within one manufacturer
- Generally low heating rates observed, but some variance in peak heating rates in particular

Summary

- A first glance shows peak heating rates highly dependent on cell chemistry, state of charge, and cell format. However digging deeper we see that the primary driver may simply be the component level energy density.
  - In this case we define component level as the cell and inactive material in intimate contact with the cell
  - This may have implication for propagation mitigation strategies, potentially suggesting that the simplest way to mitigate failure risks is to reduce the system level energy density.
  - An open question is if it is possible to break this trend and achieve a low risk of thermal runaway along with significant energy density.
- Total enthalpy of runaway in contrast appears tied directly to total stored energy. This may have ramifications for large systems at low states of charge. A well insulated cell may be able to develop into a propagating failure situation as there is still significant energy available.
- Pouch cells have exhibited more signs of variance than have been previously seen with COTS 18650 cells, potentially complicating analysis.
- Production of pouch cells is highly non-standardized, leading to significant variance between manufacturers.
- A weakness of this analysis is that it does not take into account failures that have exothermic sources other than from decomposition of the active materials.
  - Internal short circuits potentially provide a high rate discharge of energy leading to heating rates beyond what would be expected for a particular cell otherwise, as the rapid discharge leads to significant resistive heating.
  - The combustion of inactive materials, particularly electrolyte presents a source of energy beyond the stored electrical energy.

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