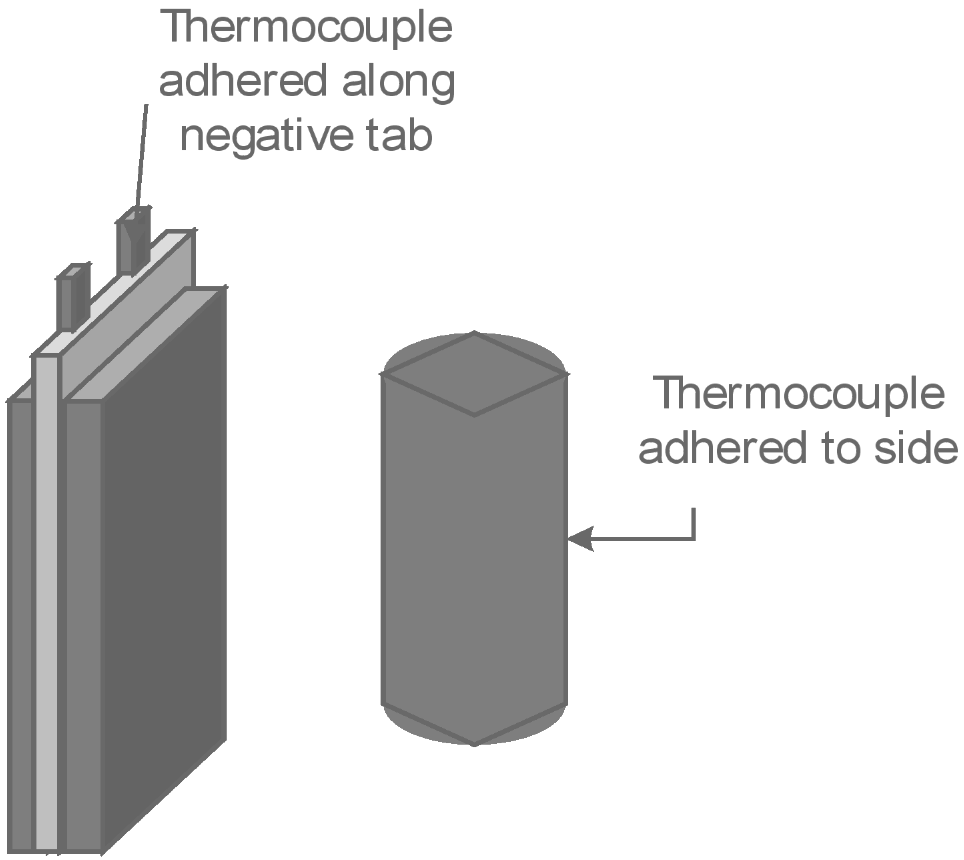
SAND2021-13023C

Accelerating Rate Calorimetry (ARC) testing of large format cells.



- Large format/high energy density ARC testing performed in Thermal Hazard Technologies EV ARC
- Large format cells tested in open air
- Cylindrical cells unconstrained
- Pouch cells constrained with ¼" aluminum plates
  - Heat capacity of constraint considered in total heat capacity of cells
- Thermocouples placed per diagram

- Overtemperature testing started at 50 °C
- Forced heating in 5 °C steps
- Self-heating threshold of 0.02 °C/minute
- Maximum forced heating temperature of 400 °C

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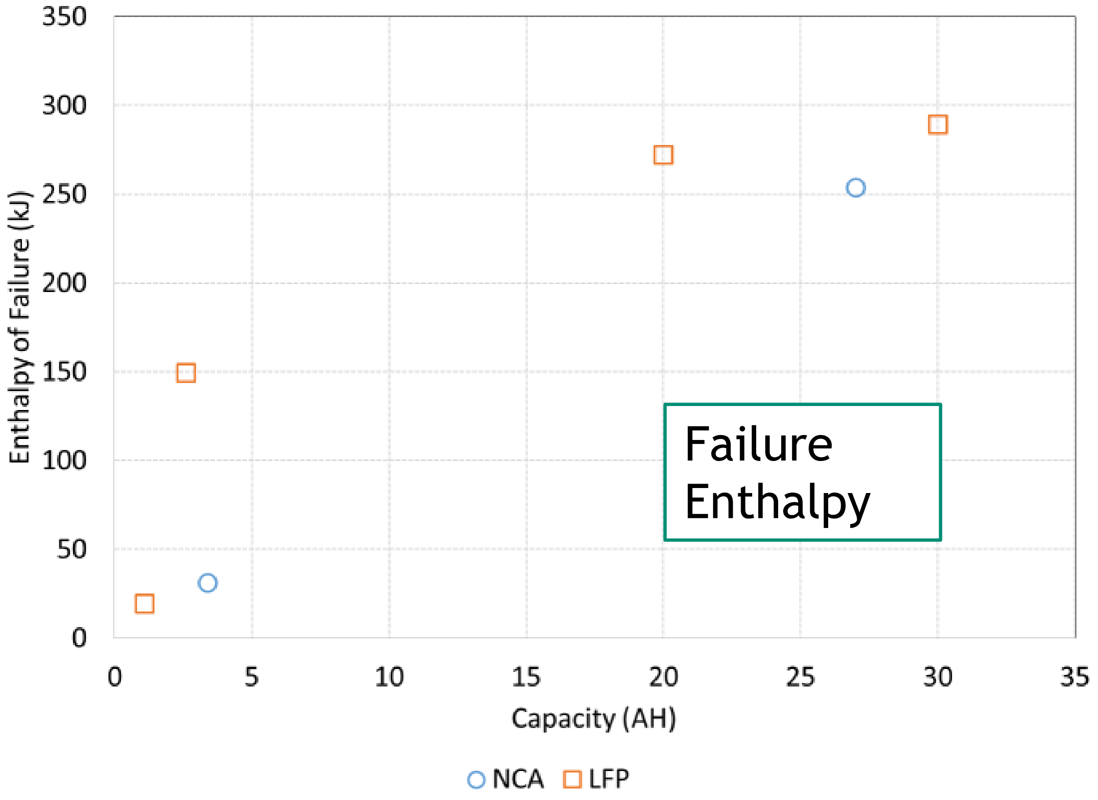
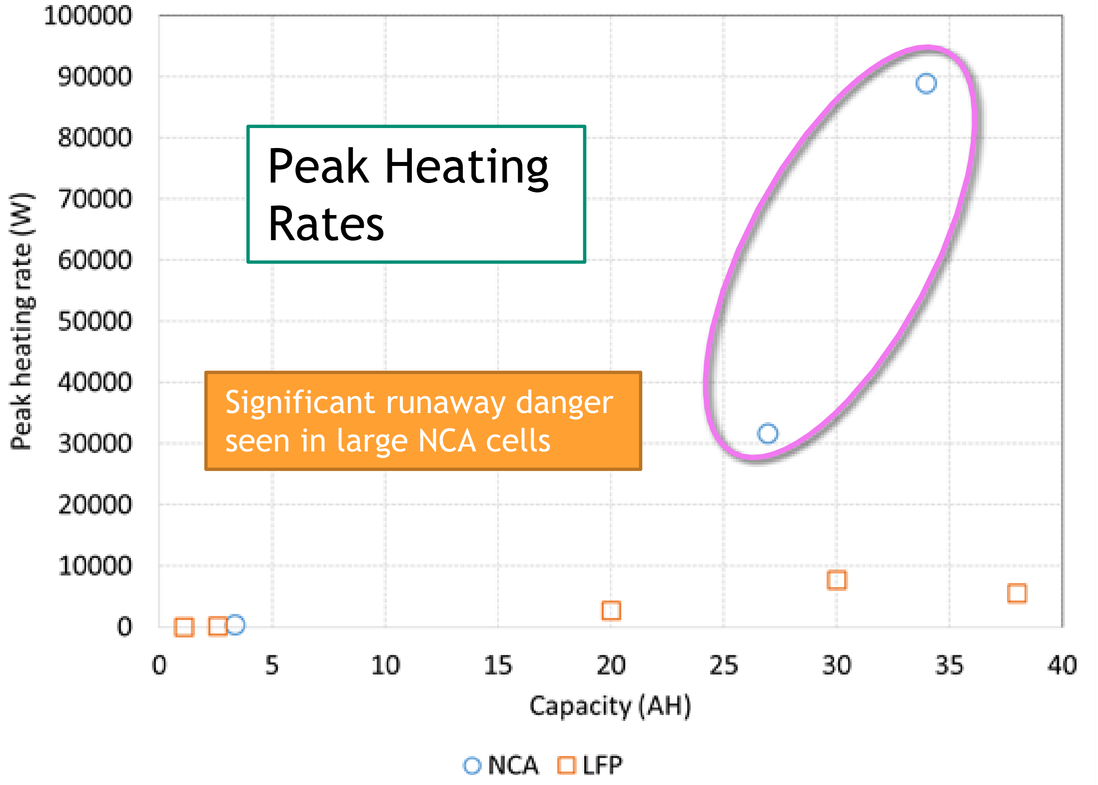
Cell Size and Thermal Runaway

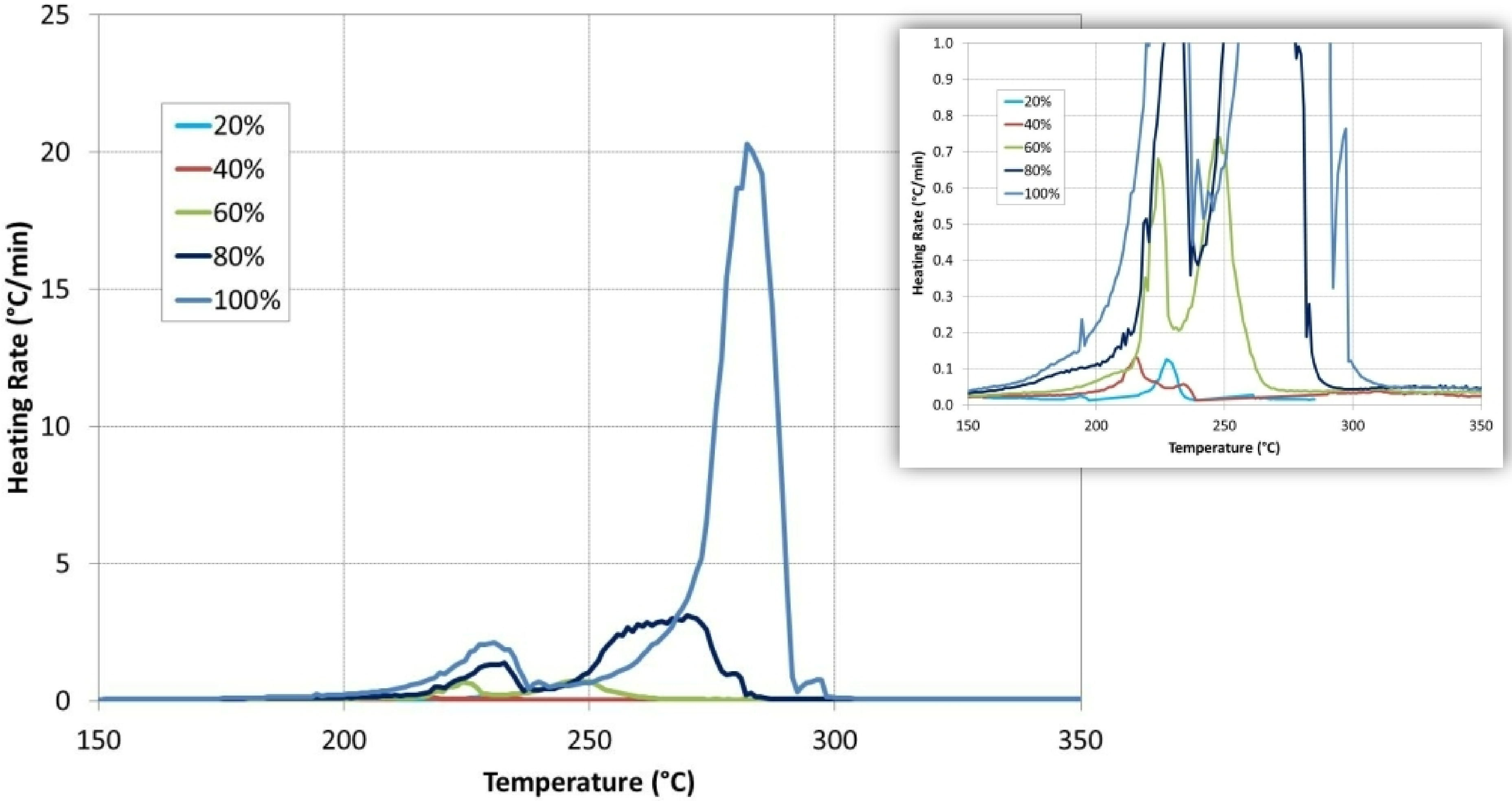




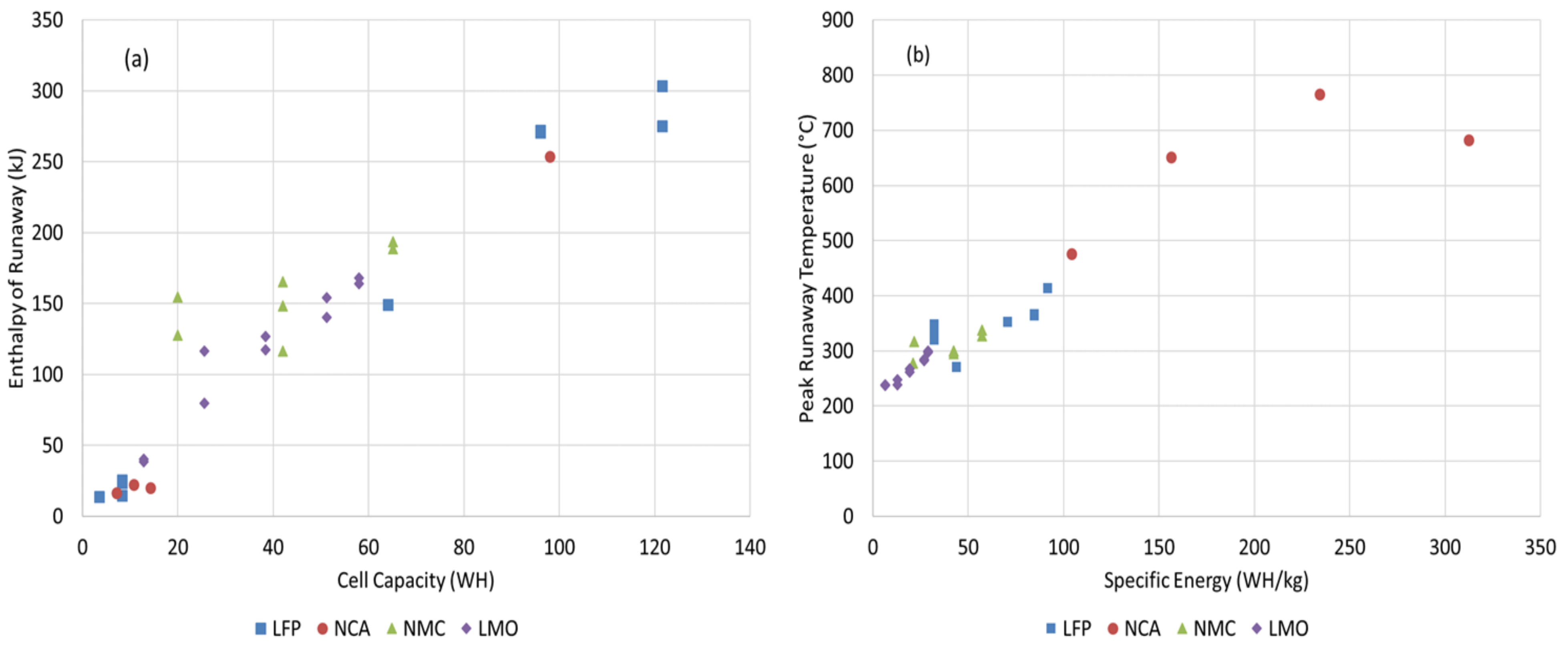
- Enthalpy scales generally linearly with size, and is similar for both chemistries – This early data suggests that failure enthalpy is largely tied to the available stored energy
- Peak heating rates significantly higher for large NCA cells
- High peak heating rates are generally thought to carry a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

SOC and Thermal Runaway

- 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

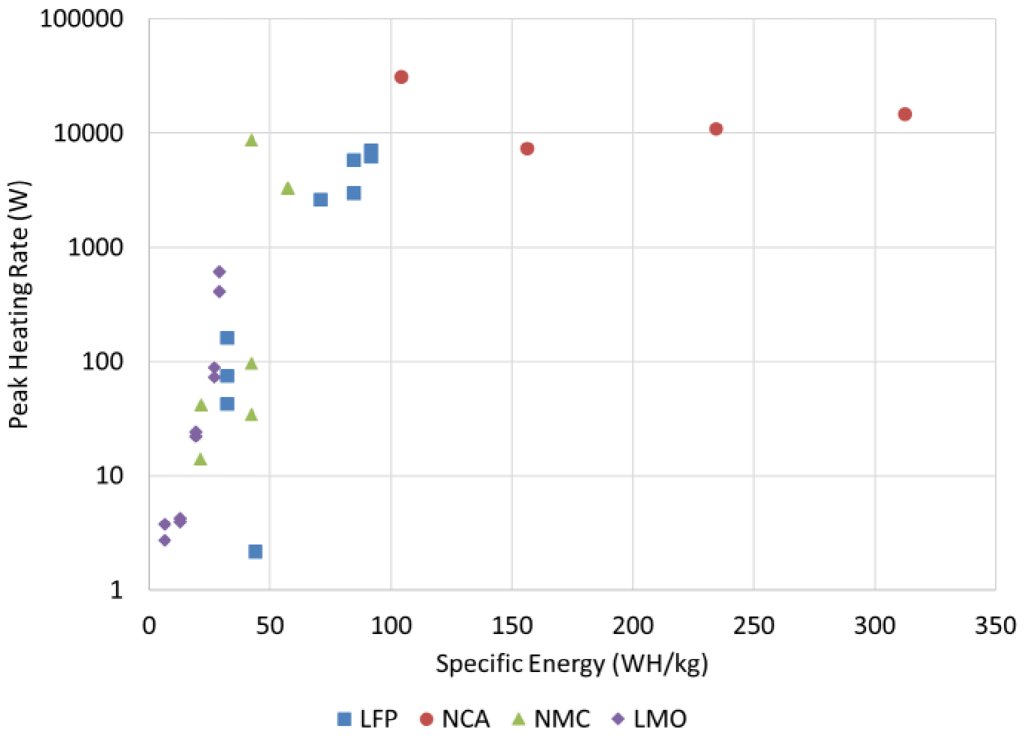


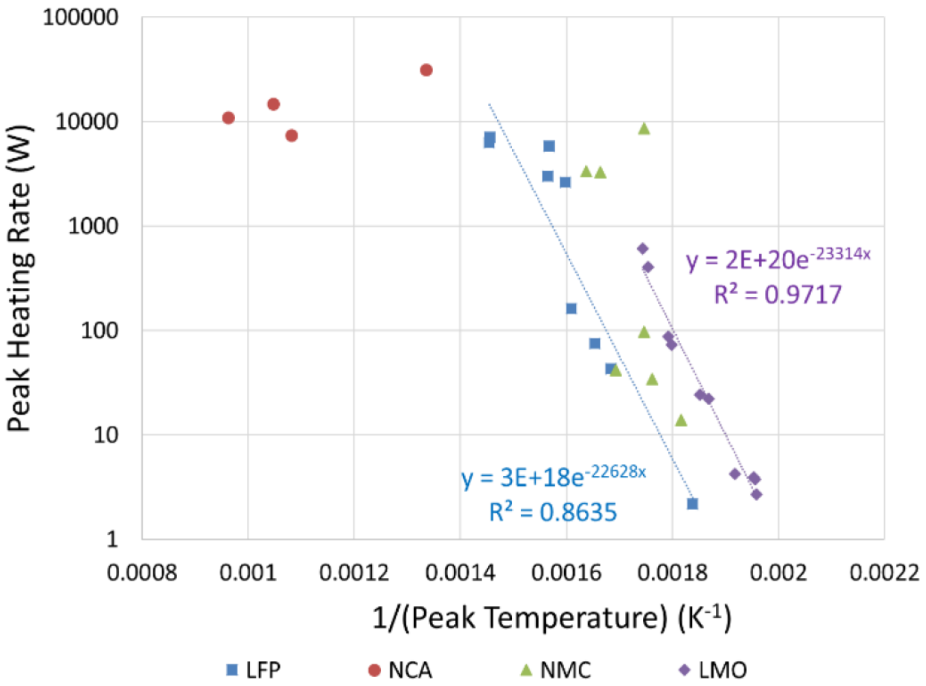
Evaluation of historic data



- 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
- Peak runaway temperatures also appear highly tied to specific energy

Peak heating rates





- Evaluation of peak heating rates shown as a function of specific energy and 1/Peak temperature
- Show a logarithmic behavior up to very high specific energies
  - Ability of equipment to evaluate very high peak heating rates is limited- the flat line behavior at this point may be because of this
- Evaluation vs 1/peak temperature shows activation energies of ~190 kJ/mole for LFP, LMO, and NMC, with the most variability in NMC
  - NCA precludes meaningful evaluation
  - Literature reports show a range of 108-682 kJ/mol with most values below 225 kJ/mol*

*C.-Y. Jhu, Y.-W. Wang, C.-M. Shu, J.-C. Chang, and H.-C. Wu, *Journal of Hazardous Materials*, **192** (1), 99-107 (2011).
*C.-Y. Jhu, Y.-W. Wang, C.-Y. Wen, and C.-M. Shu, *Appl. Energy*, **100** 127-131 (2012).
*W. C. Chen, Y. W. Wang, and C. M. Shu, *J. Power Sources*, **318** 200-209 (2016).

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