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Sandia National Laboratories

POWER SOURCES TECHNOLOGY GROUP 7540

CENTER 7500 CSEP

COMPONENT SCIENCE, ENGINEERING, & PRODUCTION





Accelerating Rate Calorimetry Investigations of Thermal Runaway in Multiple Formats and Capacities

PRESENTED BY

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Symposium …

Society Meeting

U.S. DEPARTMENT OF ENERGY | NNSA

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Capabilities and Infrastructure

Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)

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

Battery Calorimetry

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Battery Calorimetry

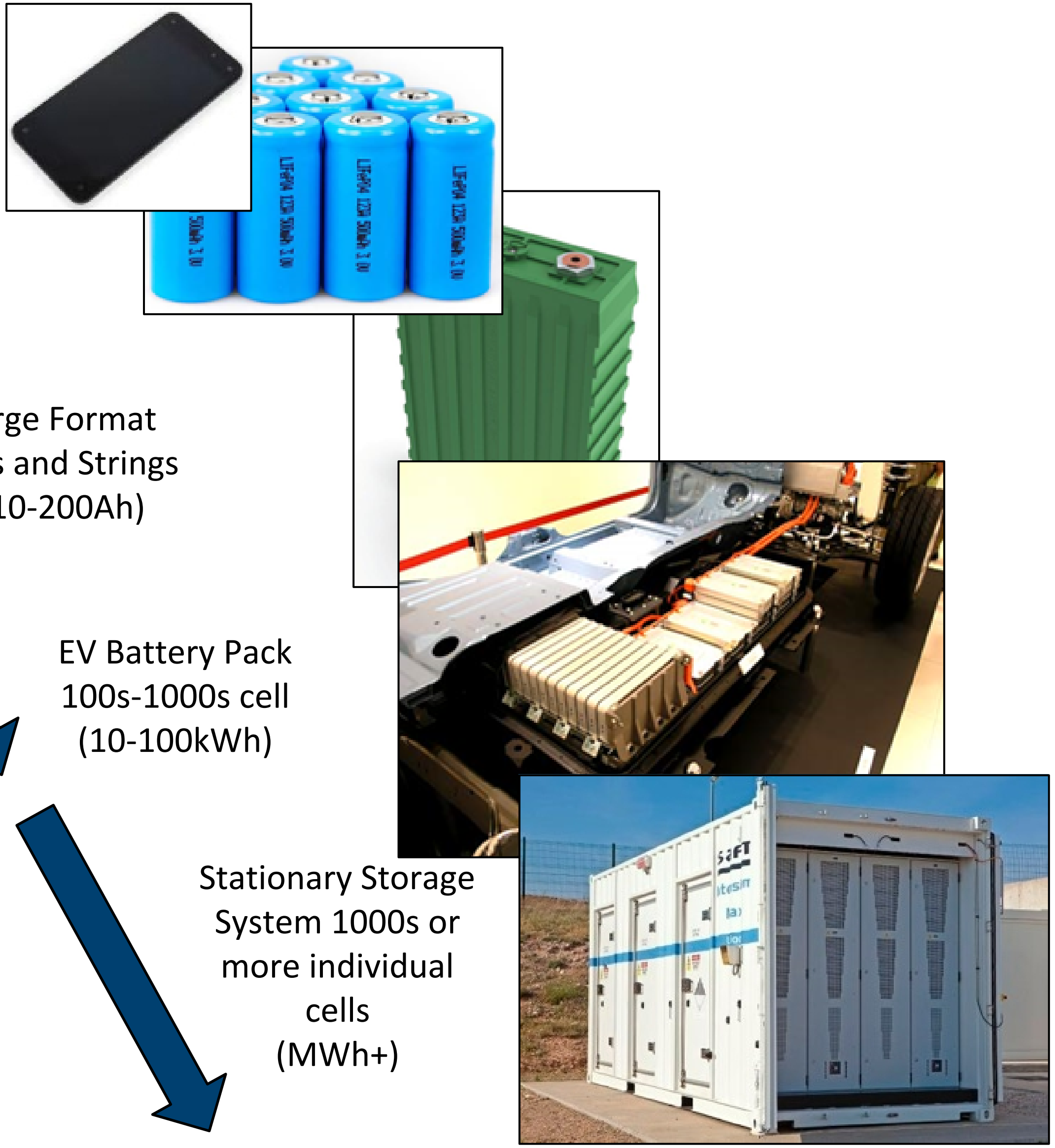
High Energy Batteries Enable Increased Electrification

Consumer cell
(0.5-5Ah)

Large Format
Cells and Strings
(10-200Ah)

EV Battery Pack
100s-1000s cell
(10-100kWh)

Stationary Storage
System 1000s or
more individual
cells
(MWh+)

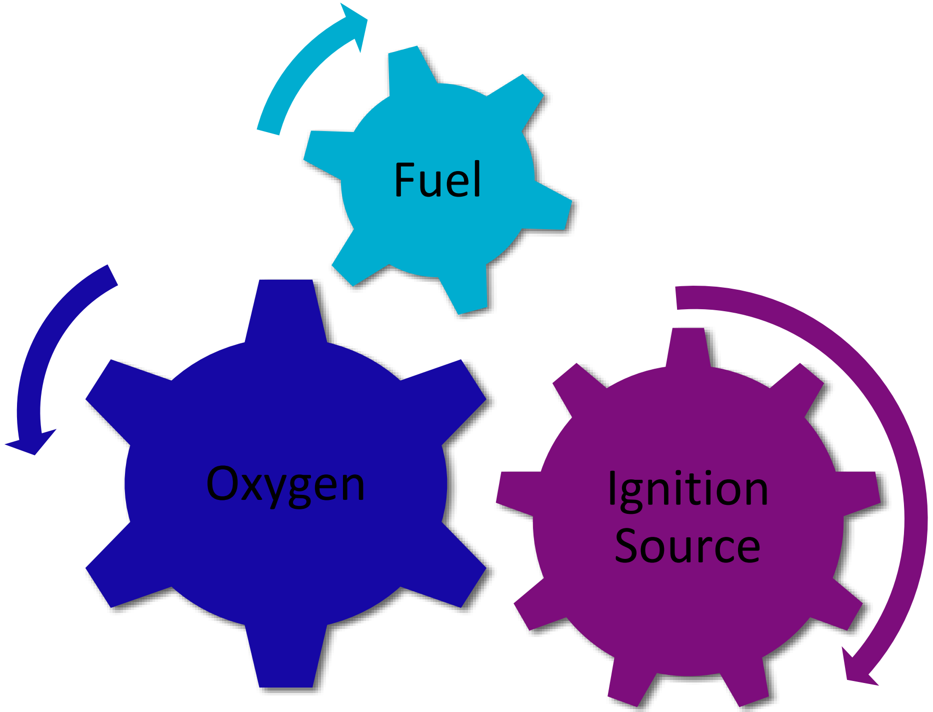


As these batteries are scaled up in size, the safety issues associated with these battery systems merit increasing concern.

www.nissan.com
www.internationalbattery.com
www.samsung.com
www.saft.com

What Are the Risks?

- **A fully charged battery holds fuel and oxidizer in intimate contact**
  - ✓ Electrolyte flammability
  - ✓ Thermal stability of materials



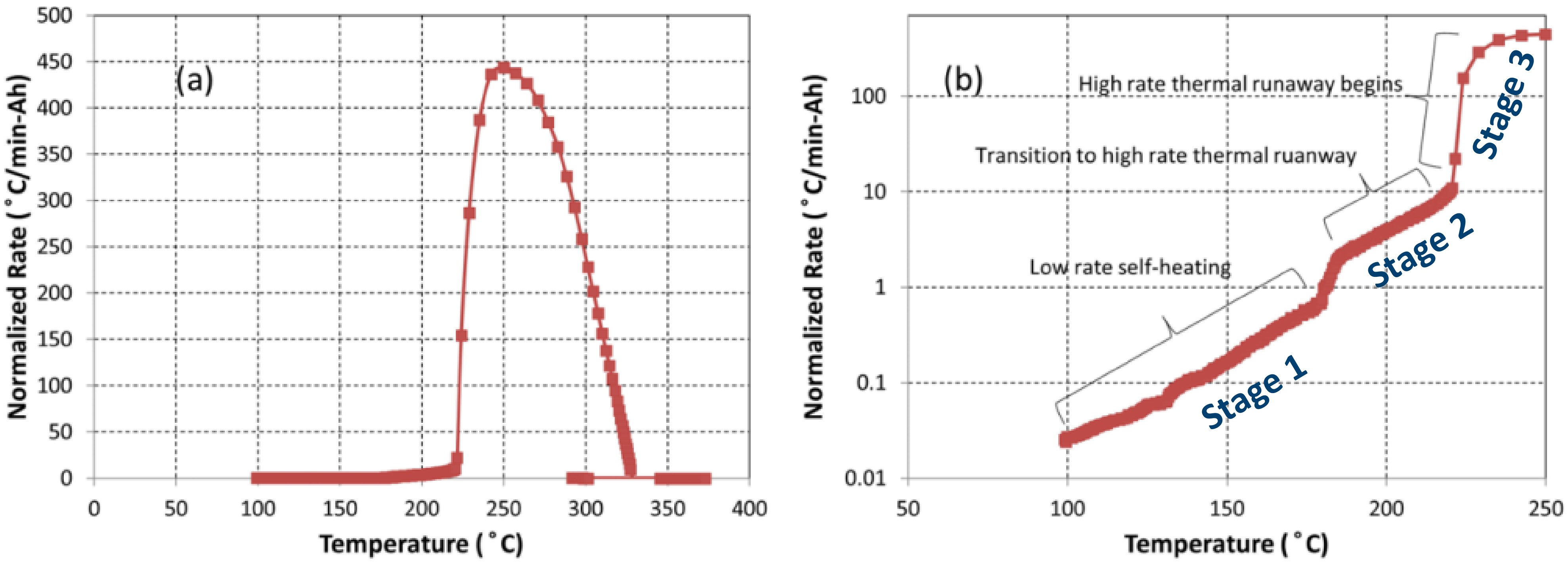
What Are the Risks?

- **A fully charged battery holds fuel and oxidizer in intimate contact**
  - ✓ Electrolyte flammability
  - ✓ Thermal stability of materials
- **Energetic thermal runaway**
  - ✓ Failure propagation from cell-to-cell/module-to-module

Thermal Runaway = **Cell Heat Generation > Cell Heat Dissipation**

Thermal Runaway Video

Characterizing Thermal Runaway

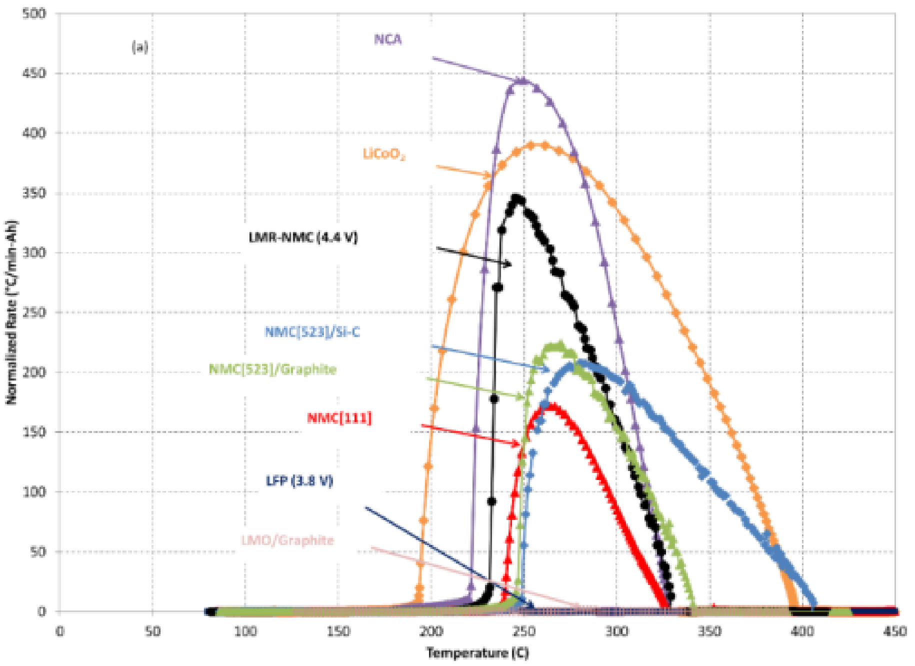


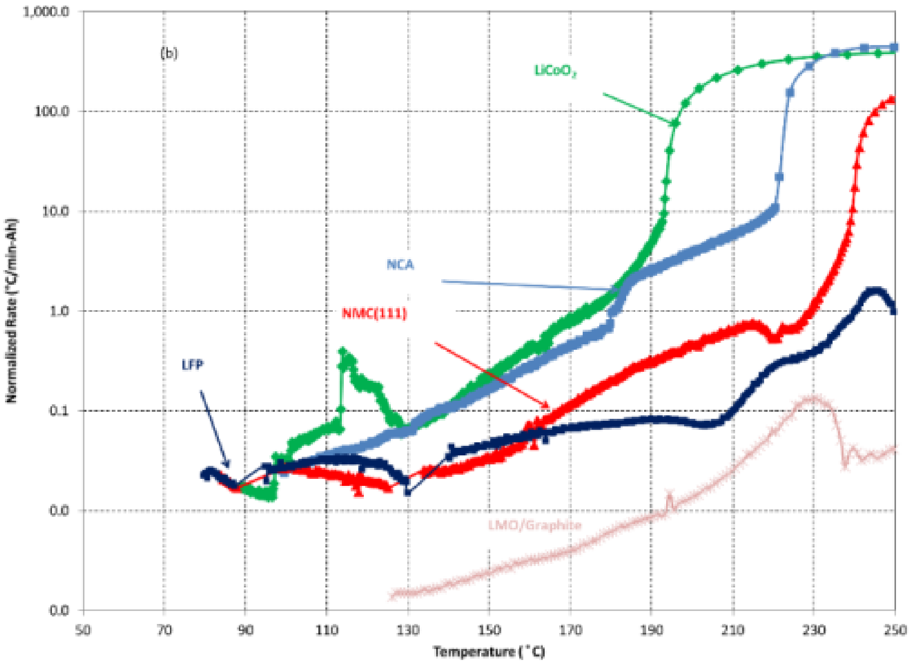
Initial low-rate self-heating as electrolyte breakdown, SEI dissolution begin	As SEI breaks down bulk reactions with the anode can occur	These reactions accelerate as temperature increases	At higher temperatures bulk decomposition of active materials leads to high-rate thermal runaway

Stage 1 **Stage 2** **Stage 3**

Characterizing New Materials

ARC has been a powerful tool in performing evaluations of new materials by providing information about peak heating rates and total energy of the thermal runaway



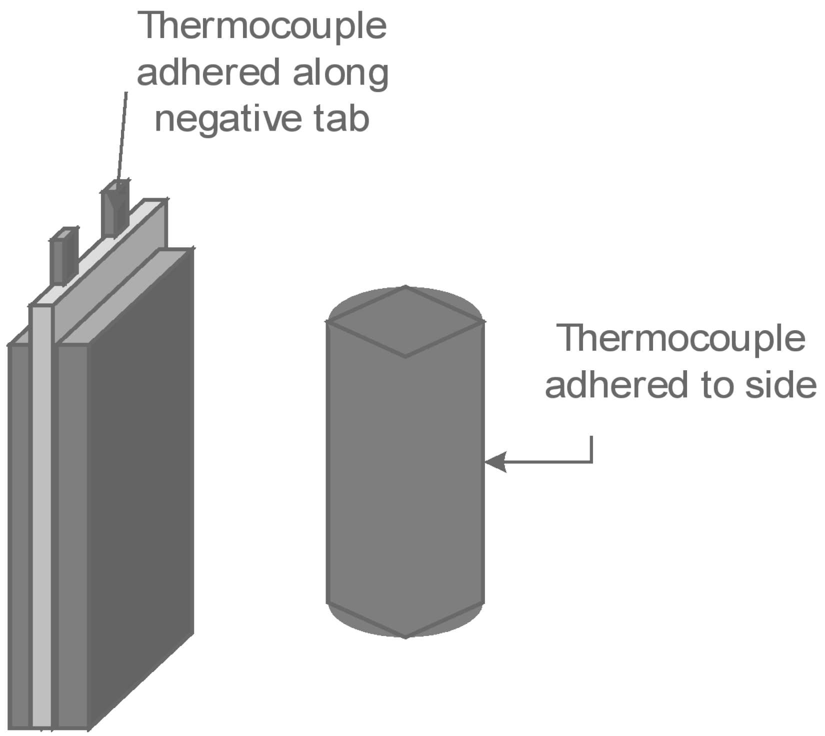


Most ARC investigations reported have considered relatively small cells (<3 Ah) and form factors

How results change as we scale cell size?

Experimental Details

ARC results from cells ranging from 1 Ah 18650 cells to large-format cylindrical and prismatic cells up to 38 Ah



<u>Large format/high energy density cells</u>

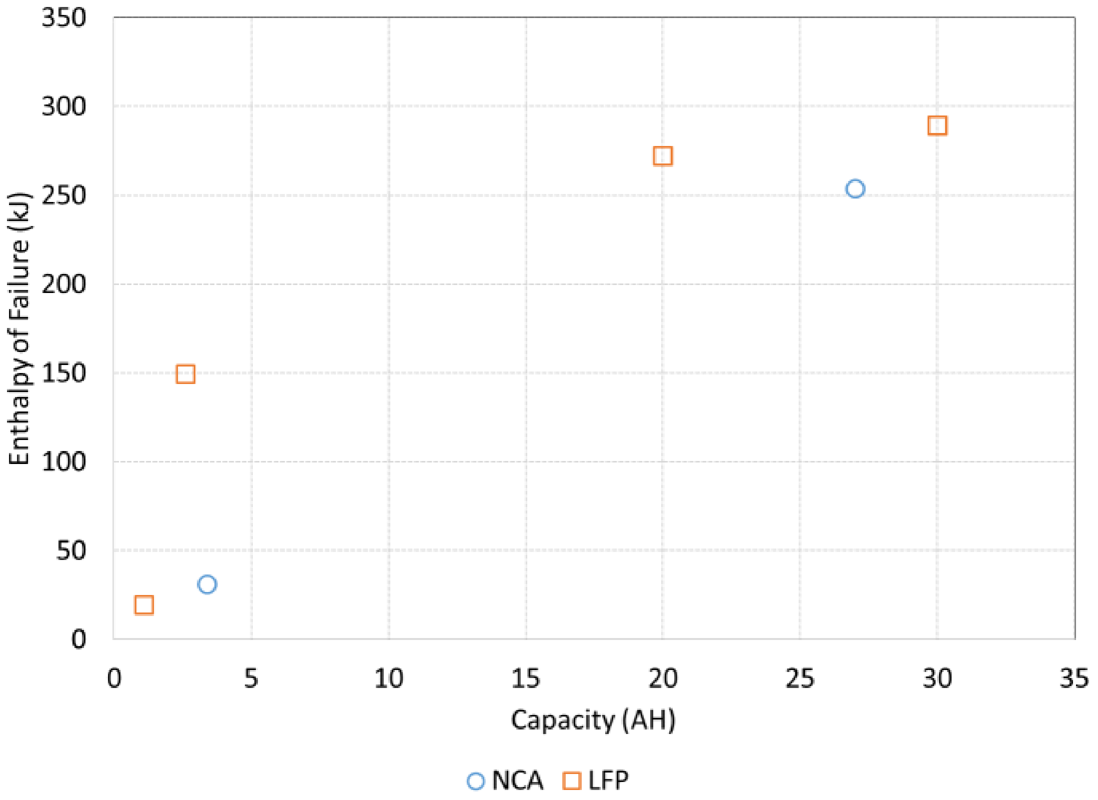
- Thermal Hazard Technologies **EV ARC**
- Pouch cells constrained with ¼" aluminum plates
  - ✓ Heat capacity of constraint considered in total heat capacity of cells

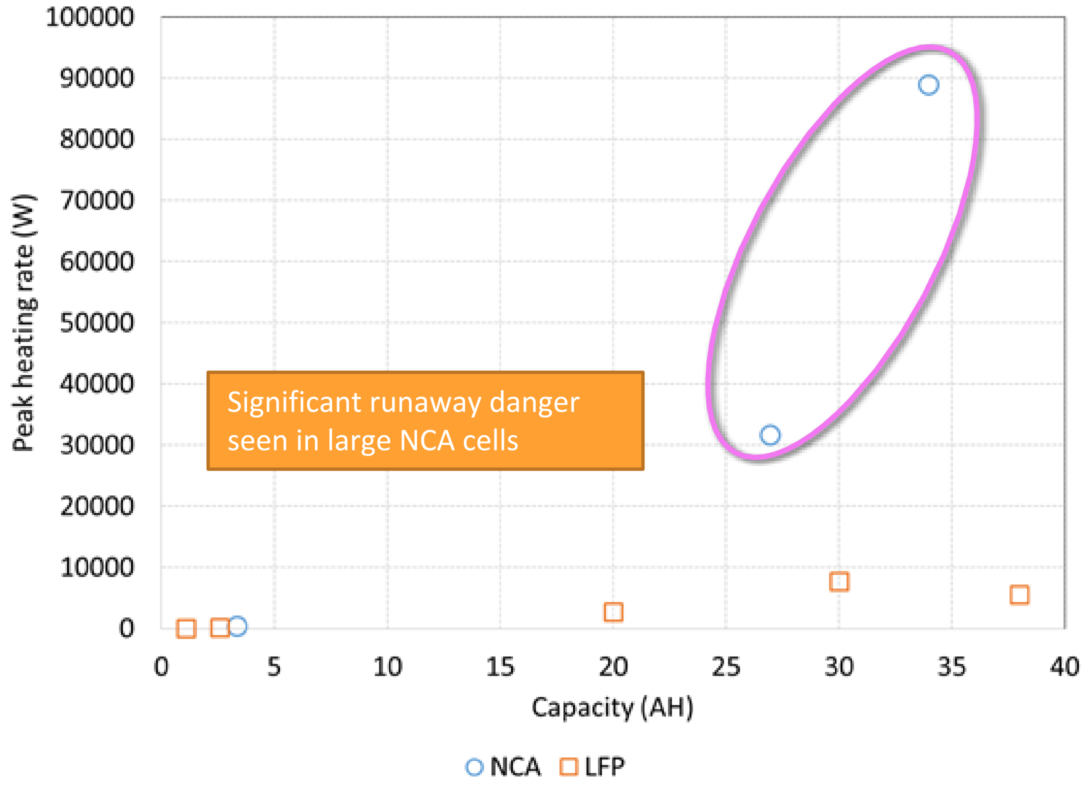
<u>18650 cells</u>

- Thermal Hazard Technologies **ES ARC**
- Tested unconstrained

•Test started at 50 °C	Forced heating: 5 °C steps	Self-heating threshold: 0.02 °C/minute	Maximum forced heating temperature: 400 °C

Enthalpy Generally Scales Linearly with Size

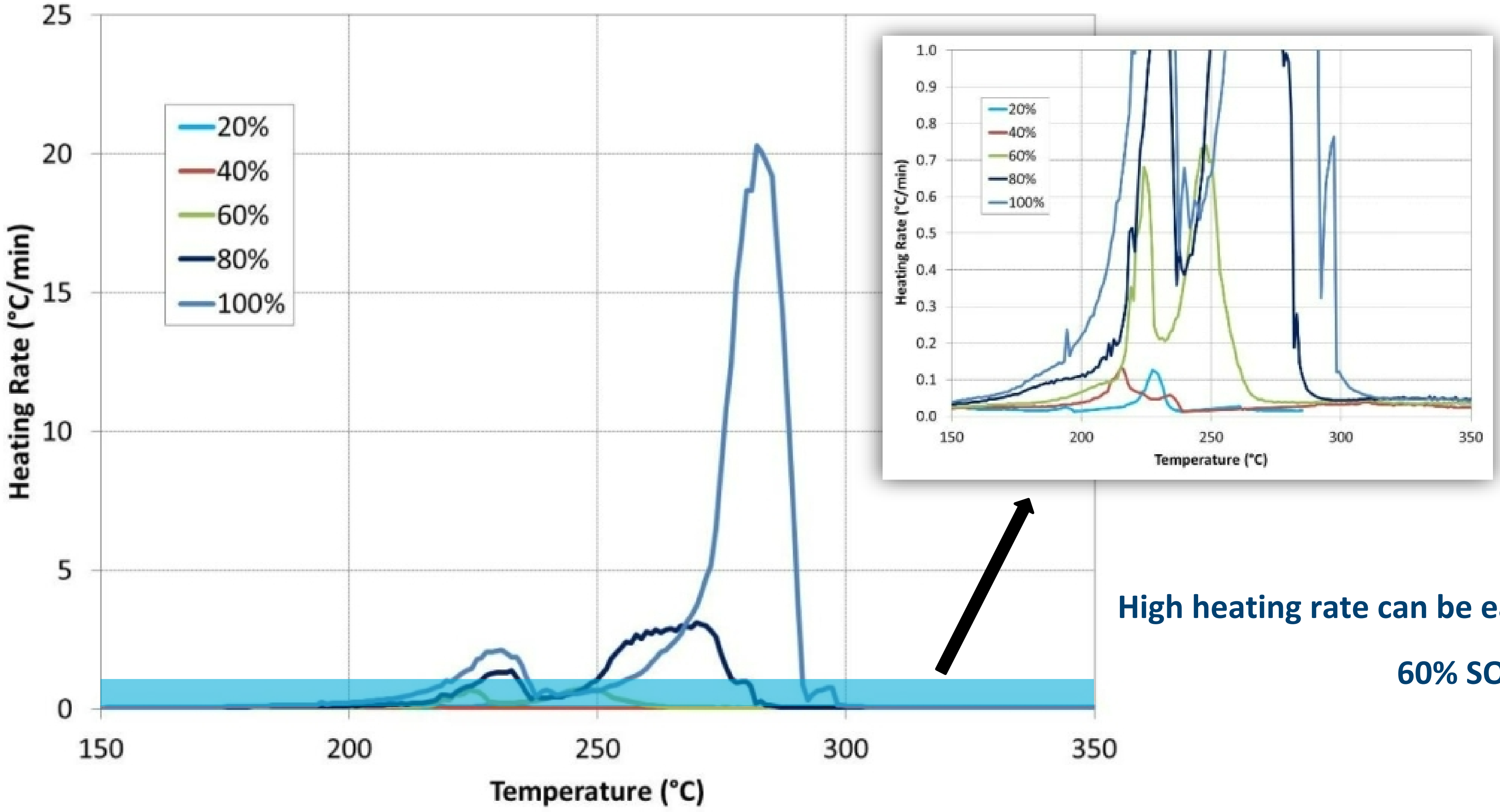




Early data suggests that failure enthalpy is tied to the available stored energy

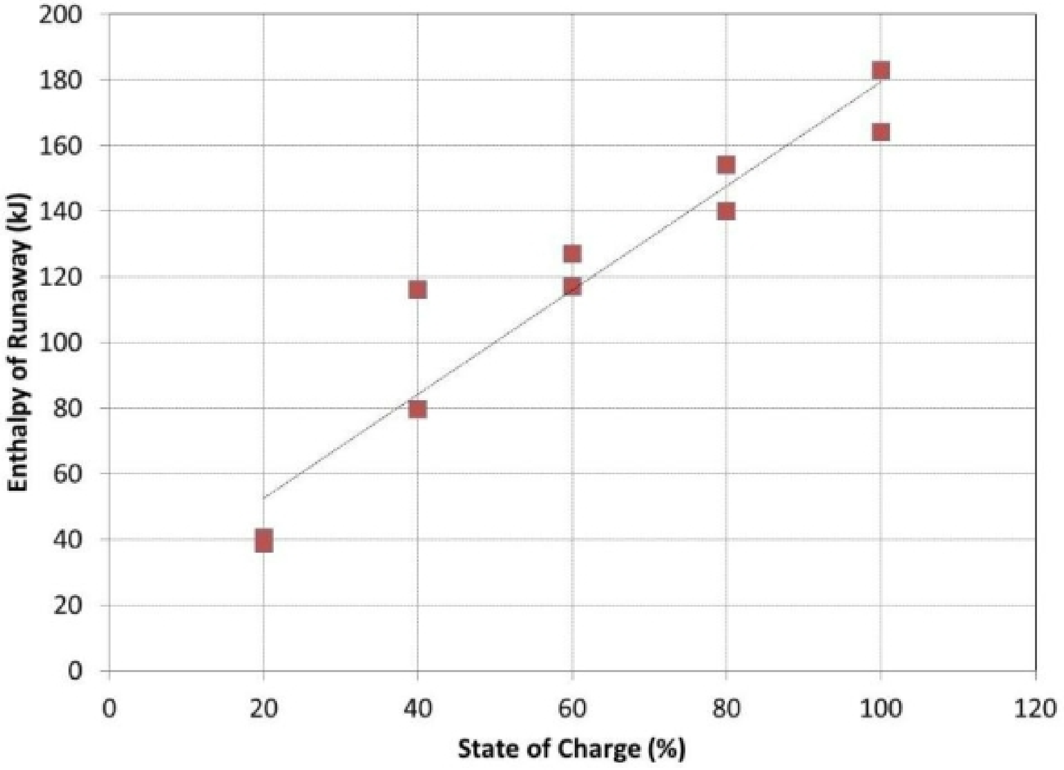
State of Charge >60% Results in Increased Heating Rates

16 Ah automotive (PHEV) pouch cells (mixed $LiMn_2O_4$ spinel)

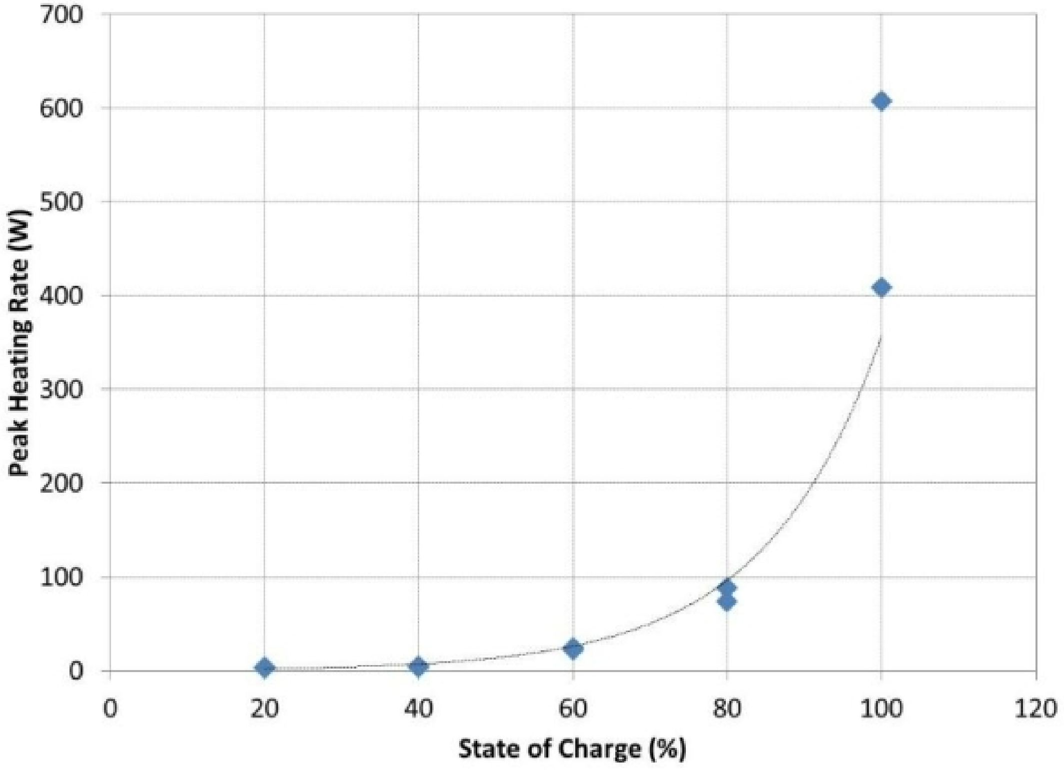


High heating rate can be easily observed above 60% SOC

Linear Relationship Between Total Heat Release and State of Charge



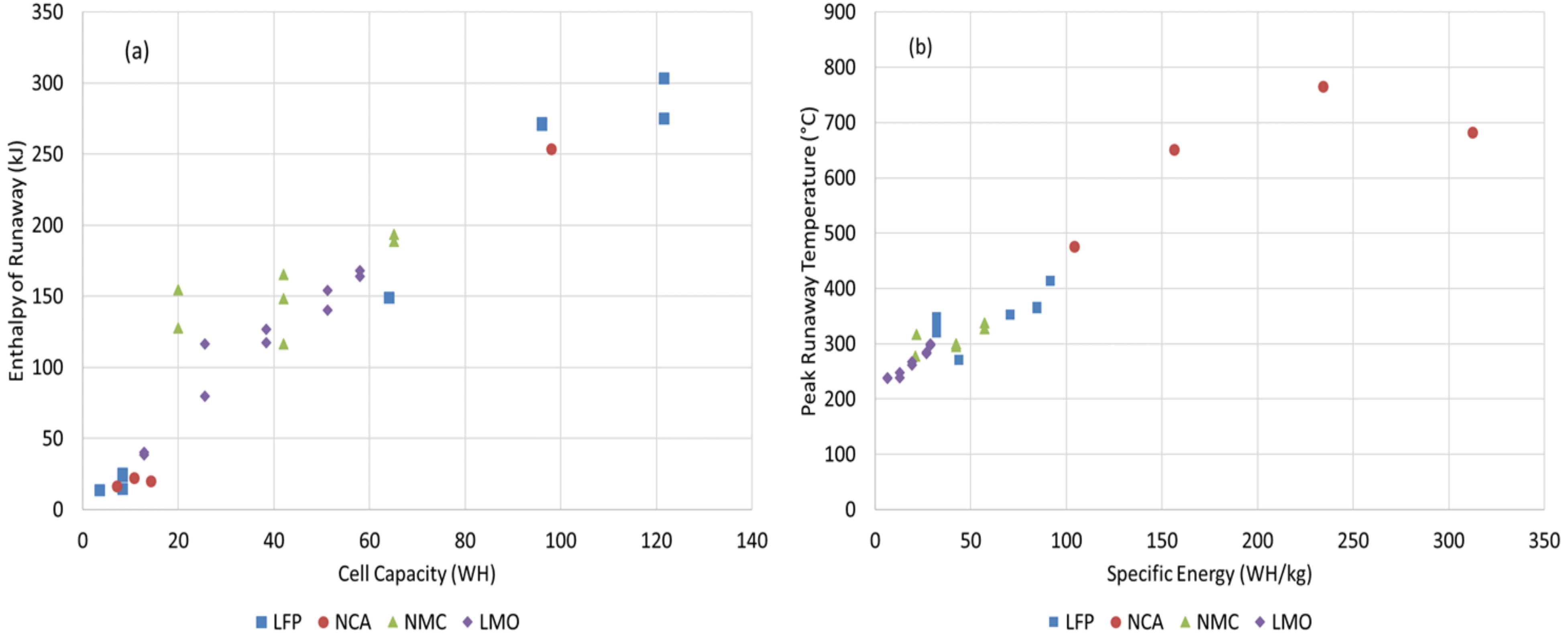
Nearly linear relationship between total heat release (kJ) and cell SOC – failure enthalpy is based largely on the stored energy available



Heat release rates (e.g. runaway reaction kinetics) follow an almost exponential relationship with cell SOC

Evaluation of Sandia's Historic Data

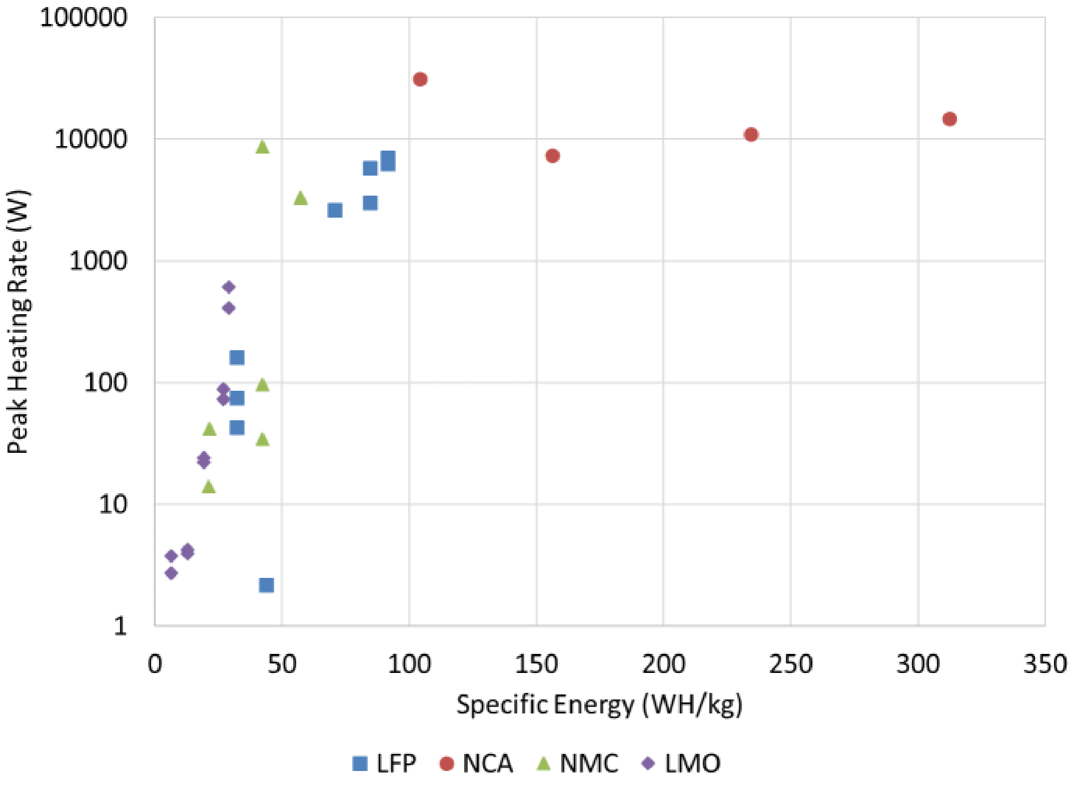
Data include cells from 1.08-38 Ah (3.5-122 Wh); LFP, NCA, NMC, and LMO; 18650, 26650, pouch, and large format cylindrical



Total energy of runaway maintains a linear relationship to cell capacity

Peak runaway temperatures also appear highly tied to specific energy

Peak Heating Rates



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

*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).

Summary

- Data collected suggests the total energy of a failure is largely only dependent on the stored energy
- A further refinement of the data, looking at the specific energy of the cell show that peak heating rates may be scaling well with specific energy
- Future questions include how large amounts of stored energy might impact a system even at low states of charge

How results change as we scale cell size?

Total energy of failure scales with cell size

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Thank you!

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