Sandia National Laboratories

Multi-Scale Safety of Commercial Na-ion Cells - Layered Metal Oxide

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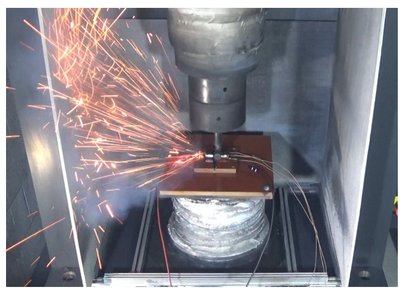
Motivation for Na-ion Safety Testing

Rechargeable, room temperature NIBs offer:

- Potential for reduced cost per unit of installed energy
- Compactable with existing LIB manufacturing
- Drop-in replacement for many LIB applications

Safety unknown!



Commercial Cell Destructive Testing

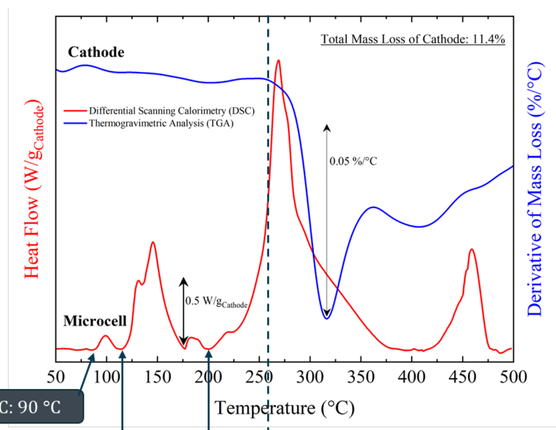
Destructive method	Cell Type	Max Temperature (°C)	Thermal Runaway Onset	Observable response
Nail Penetration	Na-ion	216.5	1.91 mm	**Vent, smoke, sparks, violent pressure release**
	Li-ion	98.1	1.88 mm	No observable effect
Crush	Na-ion	167.9	6.67 mm	Vent, smoke, sparks, lid pop
	Li-ion	296.3	9.71 mm	Vent, smoke, sparks, lid pop
External Short Circuit	Na-ion	132.8	N/A	**Vent, smoke, electrolyte leak,** swelling
	Li-ion	140.8	N/A	Swelling
Thermal Ramp	Na-ion	430.1	271.1 °C	Vent, LE leak
	Li-ion	398.1	269.1 °C	Vent, LE leak

Materials Scale Evaluation and Accelerated Rate Calorimetry (ARC)

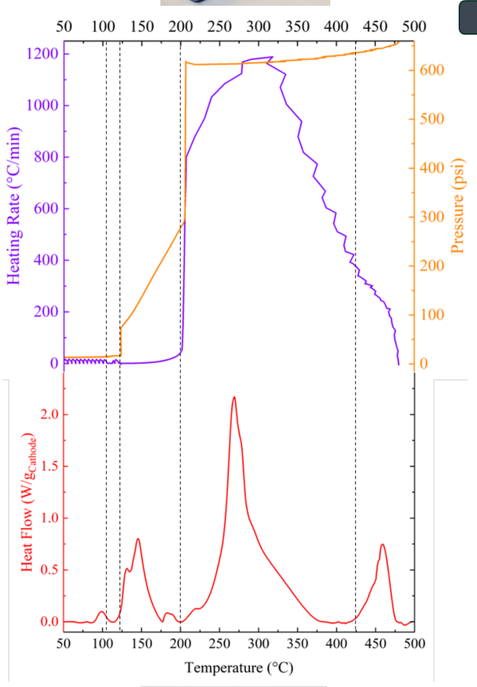
Na-ion Cell Specs

Specification	Value	Notes
Format	18650	Commercially purchased, branded Hakadi
Rated Capacity	1.5 Ah	123 Wh/kg (including case)
Experimental Capacity	1.43 Ah	1.5 to 4.1 V, C/5 rate, C/20 taper charge
Cathode	$Na_{2.5}Ni_1Mn_1Fe_1O_2$	ICP-MS
Anode	Hard Carbon	XRD
Electrolyte – Salt	$NaPF_6$	Assumed based on ICP-MS
Electrolyte – Solvent	46% PC, 21% EC, 14% EMC, 13% DMC	Area% from GCMS

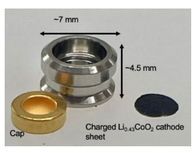
Differential Scanning Calorimetry (DSC) Thermogravimetric Analysis (TGA)



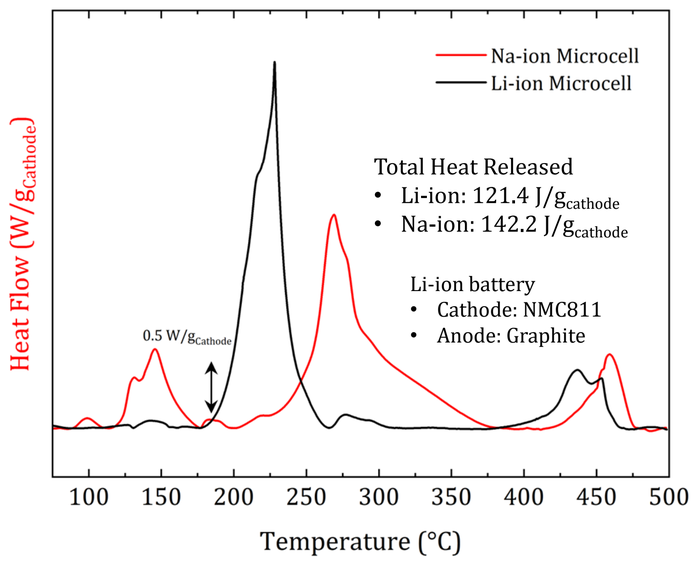
ARC



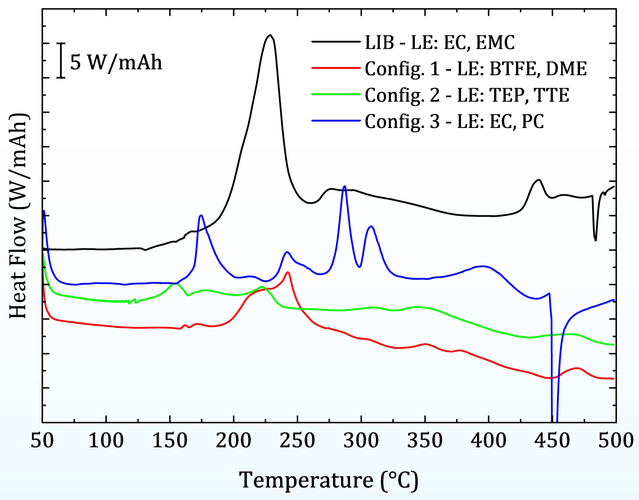
DSC



DSC: Na-ion vs. Li-ion

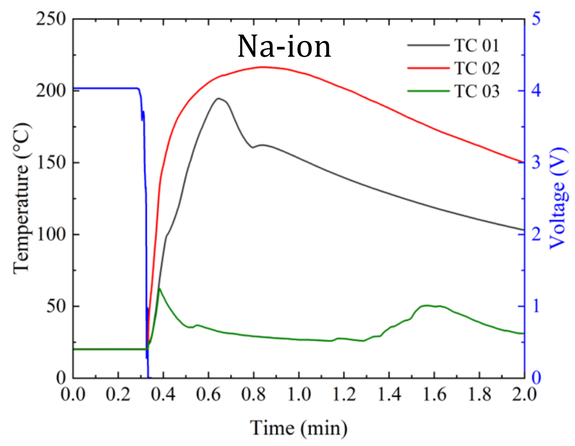


PNNL Collaboration

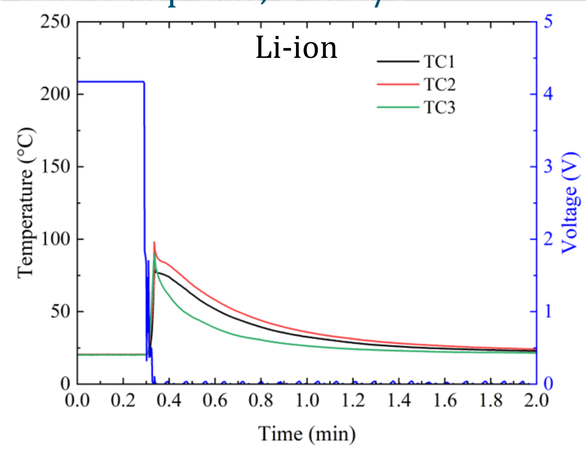


Innovations in electrolyte formulation may lead to safer cells at scale.

Nail Penetration –100% SOC, 3 mm sharp nail, 2 mm/s

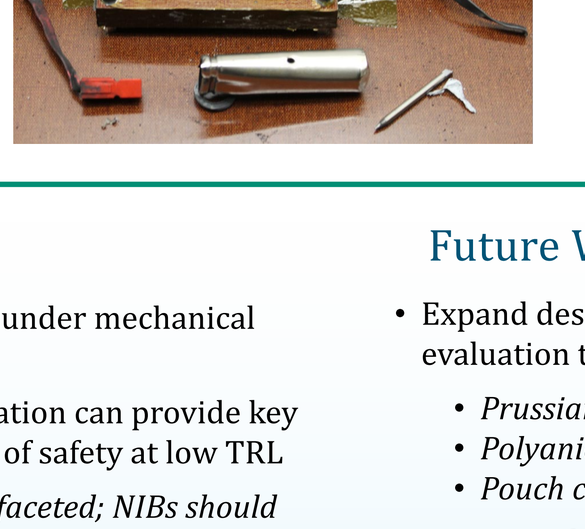


- Max temperature: 216.5 °C
- Nail penetration depth at voltage drop: 1.86 mm
- Venting, smoke, sparks, violent pressure release

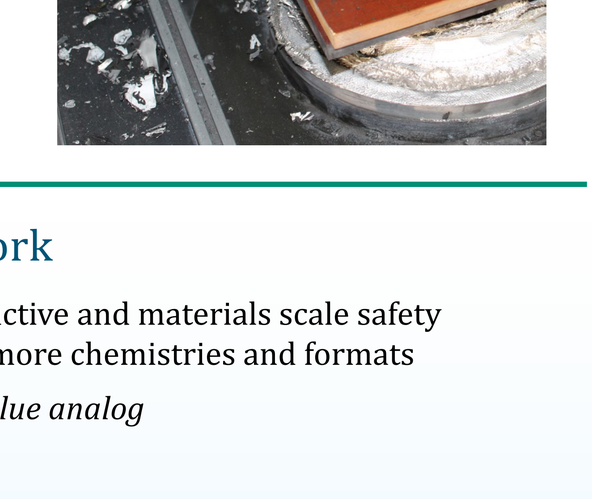


- Max temp: 98.1 °C
- Nail penetration depth at voltage drop: 1.84 mm
- No observable features

Mechanical Crush - 100% SOC, Hammer Implement, 0.1 mm/s

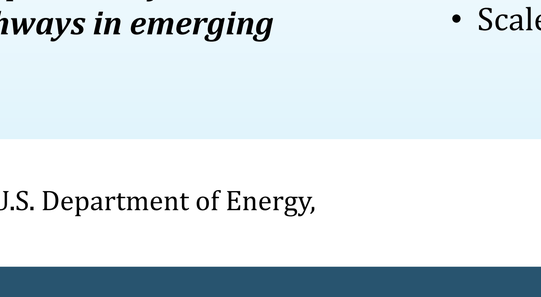


- Max temp: 296.3 °C
- Crush depth at voltage drop: 9.61 mm
- Vent, smoke, sparks, lid pop



- Max temp: 167.9 °C
- Crush depth at voltage drop: 6.46 mm
- Vent, smoke, sparks, lid pop, flame

Post-test Images



Post-test Images

Key Takeaways

- Na-ion cells are destructive under mechanical abuse conditions
- Materials scale safety evaluation can provide key insights and understanding of safety at low TRL
- *Safety is complex and multi-faceted; NIBs should not be assumed "safe"*
  - ***We must recognize the potential for non-standard reaction pathways in emerging technology***

Future Work

- Expand destructive and materials scale safety evaluation to more chemistries and formats
  - *Prussian blue analog*
  - *Polyanion*
  - *Pouch cell*
- Iterate with PNNL using materials scale safety evaluation to innovate electrolyte formulations
  - Scale to full cell validation

U.S. DEPARTMENT of ENERGY

NNSA National Nuclear Security Administration

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