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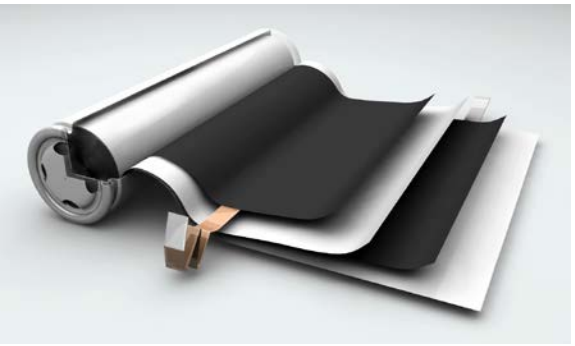
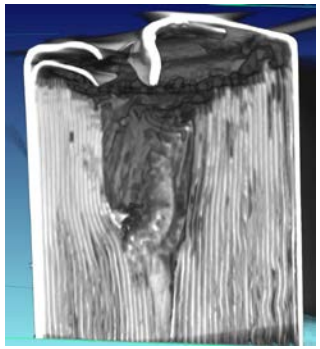

Battery Safety Testing

Christopher J. Orendorff, Leigh Anna M. Steele, Josh Lamb, and Scott Spangler

Sandia National Laboratories

ES203

2014 Energy Storage Annual Merit Review

Washington, D. C. 6/17/2014

This presentation does not contain any proprietary, confidential, or otherwise restricted information

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Overview

Sandia National Laboratories

Timeline

- Start Date: Oct. 2013
- End date: Oct. 2014
- Percent complete: >75%

Budget

- FY14 Funding: $1.4M
- FY13 Funding: $1.4M
- FY12 Funding: $1.2M

Barriers

- Barriers addressed
  - Safety continues to be a barrier to widespread adoption
  - Understanding abuse response for a variety of cell and battery chemistries and designs
  - Failure propagation in battery systems limits inherent safety
  - Issues related to cell safety are represent significant challenges to scaling up lithium-ion for transportation applications

Partners

- NREL, INL, ANL, ORNL,
- USABC Contractors, USCAR

Relevance and Objectives

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Abuse tolerance evaluation of cells, batteries, and systems

- **Provide independent abuse testing support for DOE and USABC**
- **Abuse testing of all deliverables in accordance with the USABC testing procedures**
- **Evaluate single point failure propagation in batteries**
- **Study the effects of cell age on abuse response**
- **Provide experimental support for mechanical modeling battery crash worthiness for USCAR**

Milestones

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Demonstrate improved abuse tolerant cells and report to DOE and the battery community

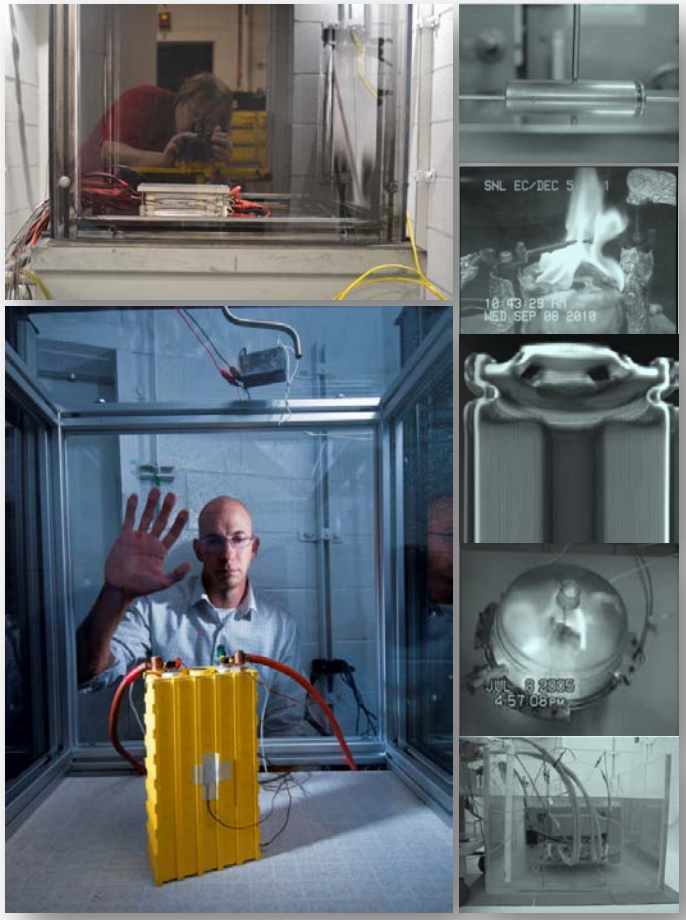
Milestone	Status
Complete Phase I USCAR side/end impact testing	
Complete Q1 USABC deliverables (SKI)	
Complete Q2 USABC deliverables (Cobasys, Farasis, Maxwell)	
Complete Phase I Propagation testing (10-cell cylindrical and 5-cell pouch)	
Complete Q3 USABC deliverables (Entek, LG, Maxwell modules)	Q3
Age Sanyo SA cells to 50% capacity fade	Q4
USCAR CSWG mechanically constrained battery testing	Q4
Thermal and failure analysis of batteries for propagation testing	Q4
Complete Q4 USABC deliverables (JCI, Leyden 12V, Saft 12V)	Q4

Milestone Complete

Approach and Capabilities

Sandia National Laboratories

Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)



Battery Pack/System Testing
Thermal Test Complex (TTC)

Battery Calorimetry

Technical Accomplishments/ Progress/Results

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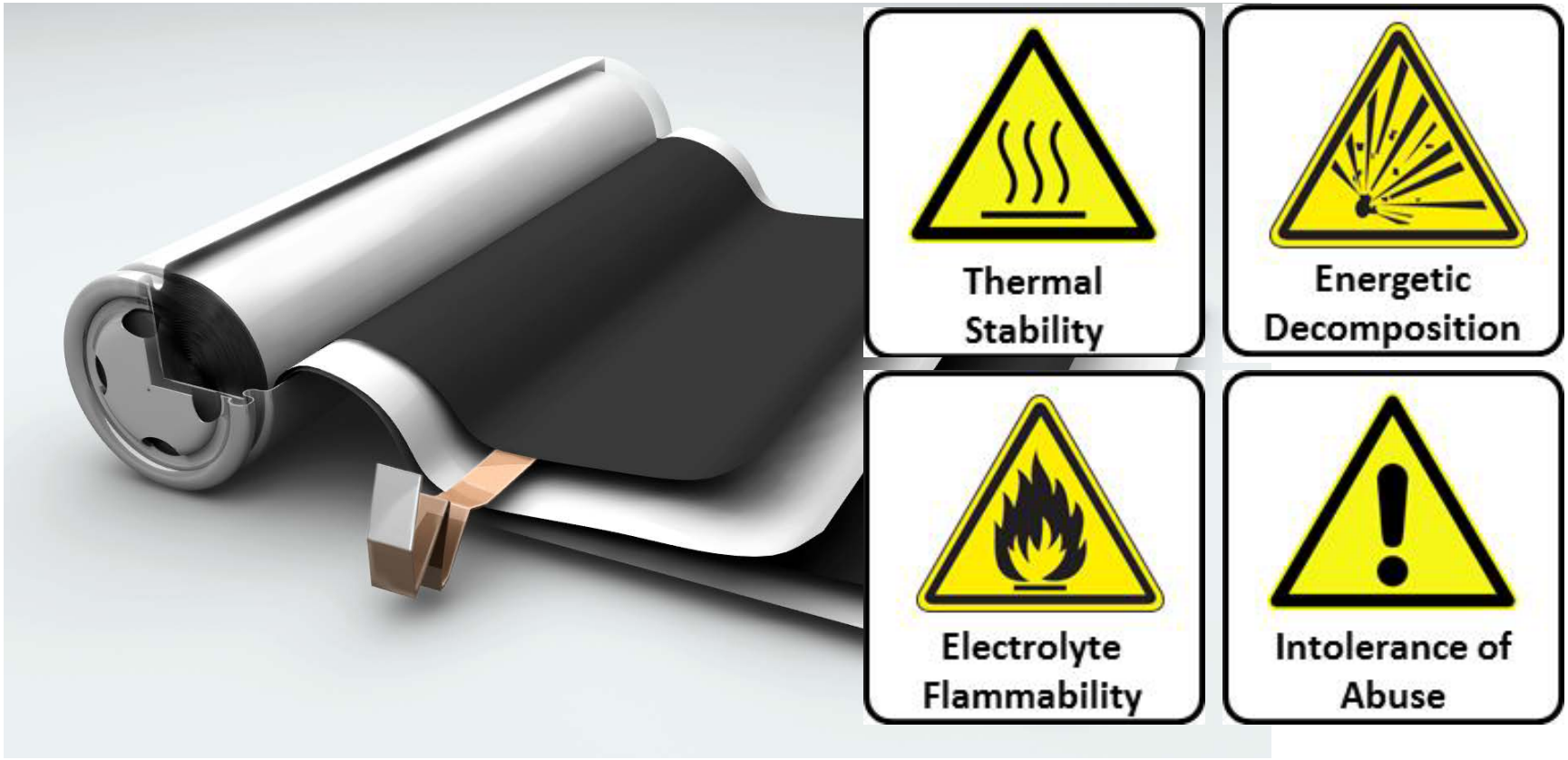
Abuse Tolerance Improvements:

- Completed testing of all USABC deliverables and reported results to the USABC TAC
- Evaluated the abuse and thermal runaway response of cells aged to 20% capacity fade and show no significant difference to fresh cells.
- Cycle aged cells to 50% capacity fade to evaluate abuse and thermal runaway response.
- Initial evaluation of single cell failure propagation show measureable differences in the cylindrical and pouch cell battery performance as well as in the electrical configuration of those cells (parallel/series connections)
- Initial mechanical testing of batteries provides the USCAR Crash Safety Working Group (CSWG) information to build and validate a battery crash worthiness model

Lithium-ion Safety Issues



Testing program aimed at understanding and improving abuse tolerance of energy storage systems

USABC Program Deliverables to SNL

Sandia National Laboratories

Program	Deliverable
SKI EV	NCM cells (14) Blended cathode cells (14)
Cobasys EV	Cells (25)
JCI PHEV	Cells (11)
Saft 12V	Cells (TBD)
LGChem PHEV	Cells (8) Modules (3)
Farasis TAP	Cells (16)
Maxwell TAP	Cells (8) Modules (4)
Leyden 12 V	Cells (TBD)
Entek	Cells (19)

Testing results are protected information

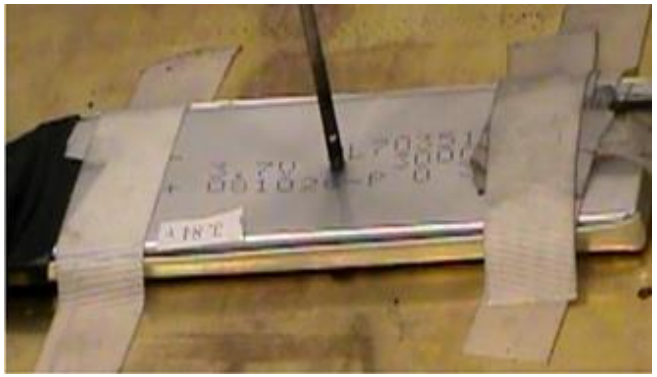
Abuse Testing

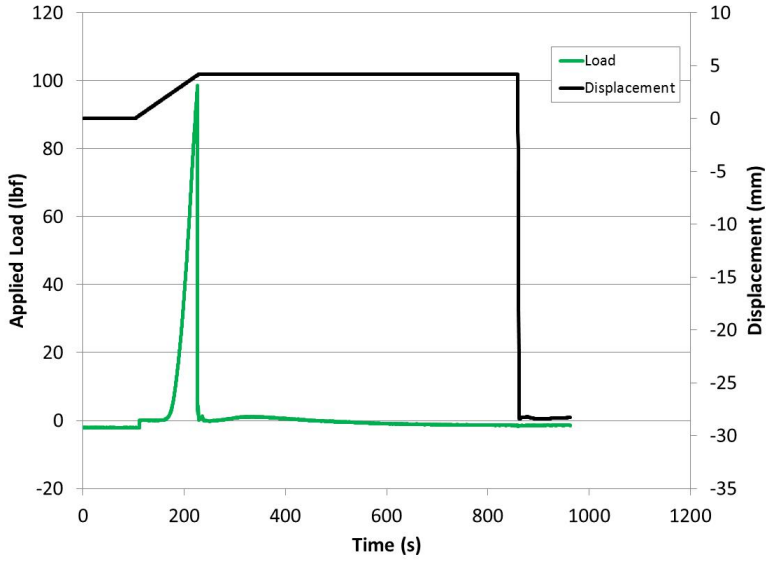
Sandia National Laboratories

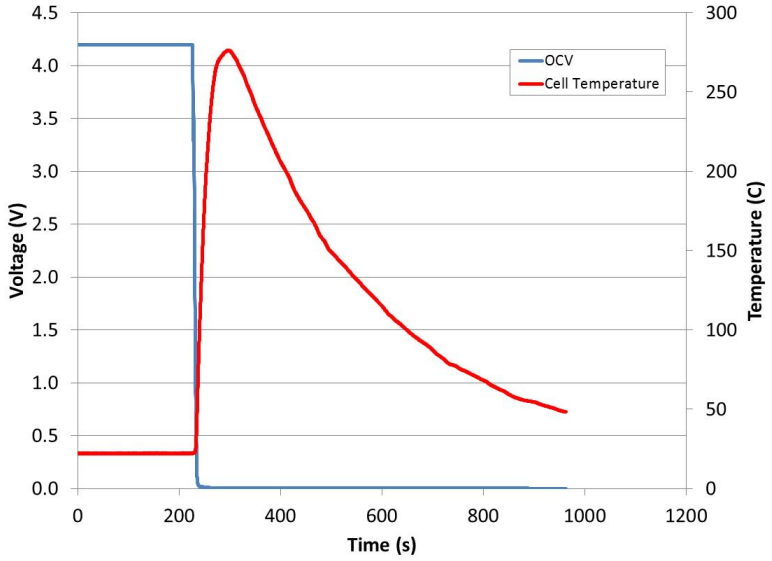
Representative mechanical abuse test of a COTS lithium-ion cell (non-USABC)

USABC-adopted blunt rod test:

- Blunt rod, 3 mm dia.
- 0.1 mm/s travel speed
- 25-55 C, 50-100% SOC







Representative mechanical abuse test of a COTS lithium-ion cell (non-USABC)

J. Power Sources 247 (2014), 189-196

Failure Propagation Testing

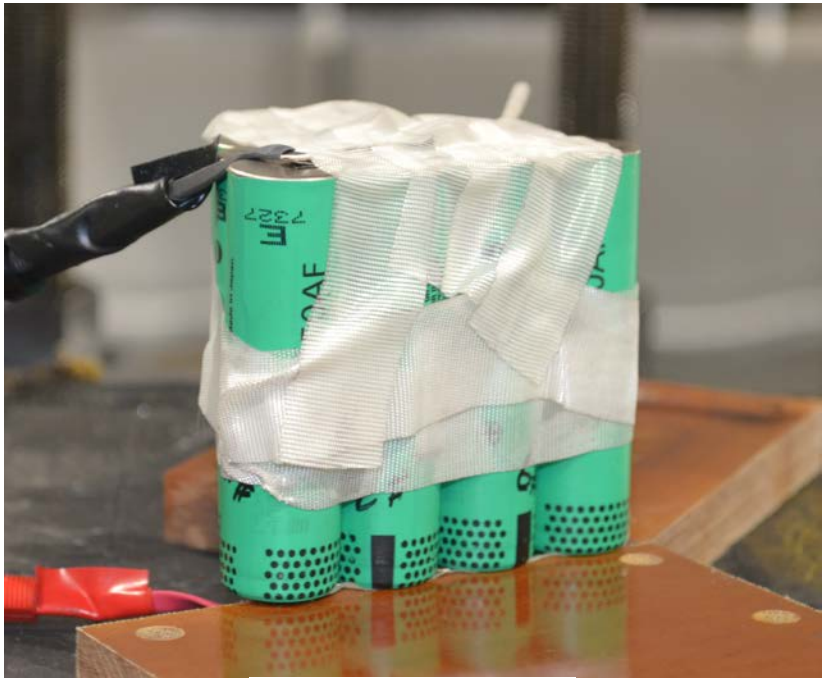
Sandia National Laboratories

Methodology:

- Experimentally determine a reproducible thermal runaway initiator for each cell type
- Use this initiator to trigger a single cell thermal runaway failure in a battery
- Evaluate the propagation of that failure event

Experiment

- COTS Panasonic 2.2 Ah 18650 cells
- 10S1P, 1S10P configurations (81 Wh)
- Failure initiated by a mechanical nail penetration along longitudinal axis



1S10P Battery

Failure Propagation Testing

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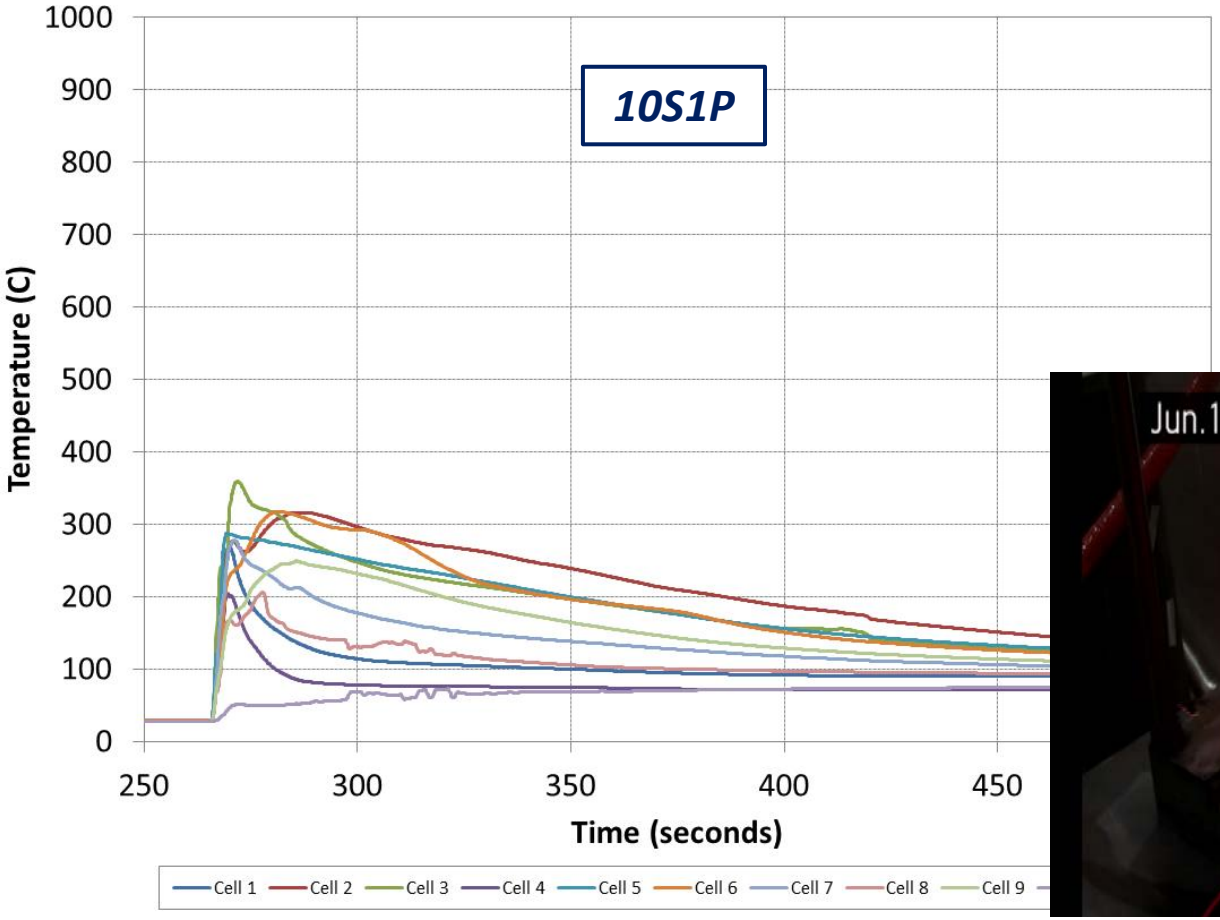
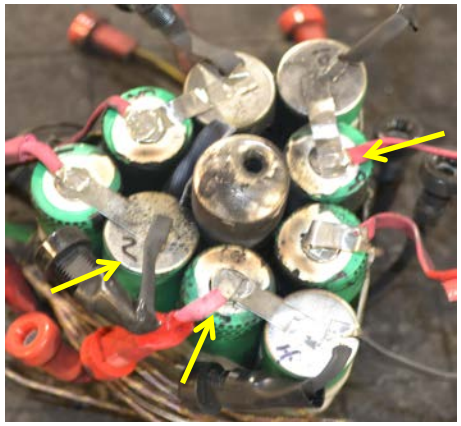
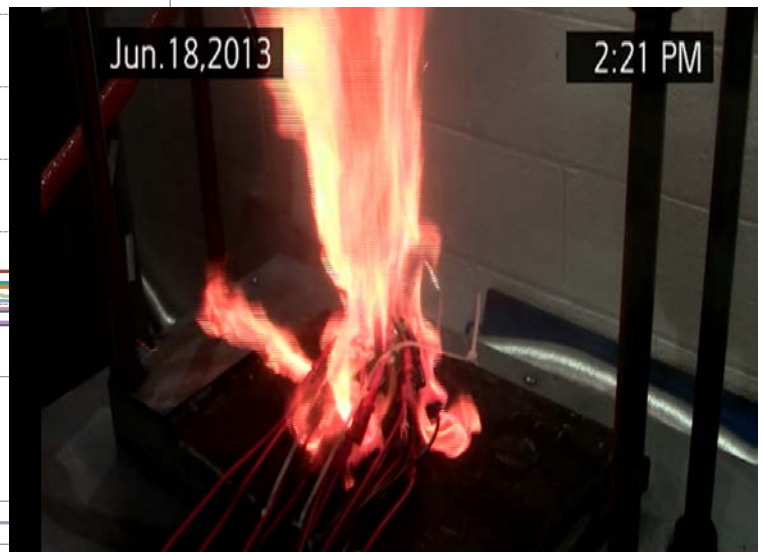
Failures initiated by mechanical insult to the center cell (#6)







Limited propagation of the single point failure in the 10S1P pack

Failure Propagation Testing

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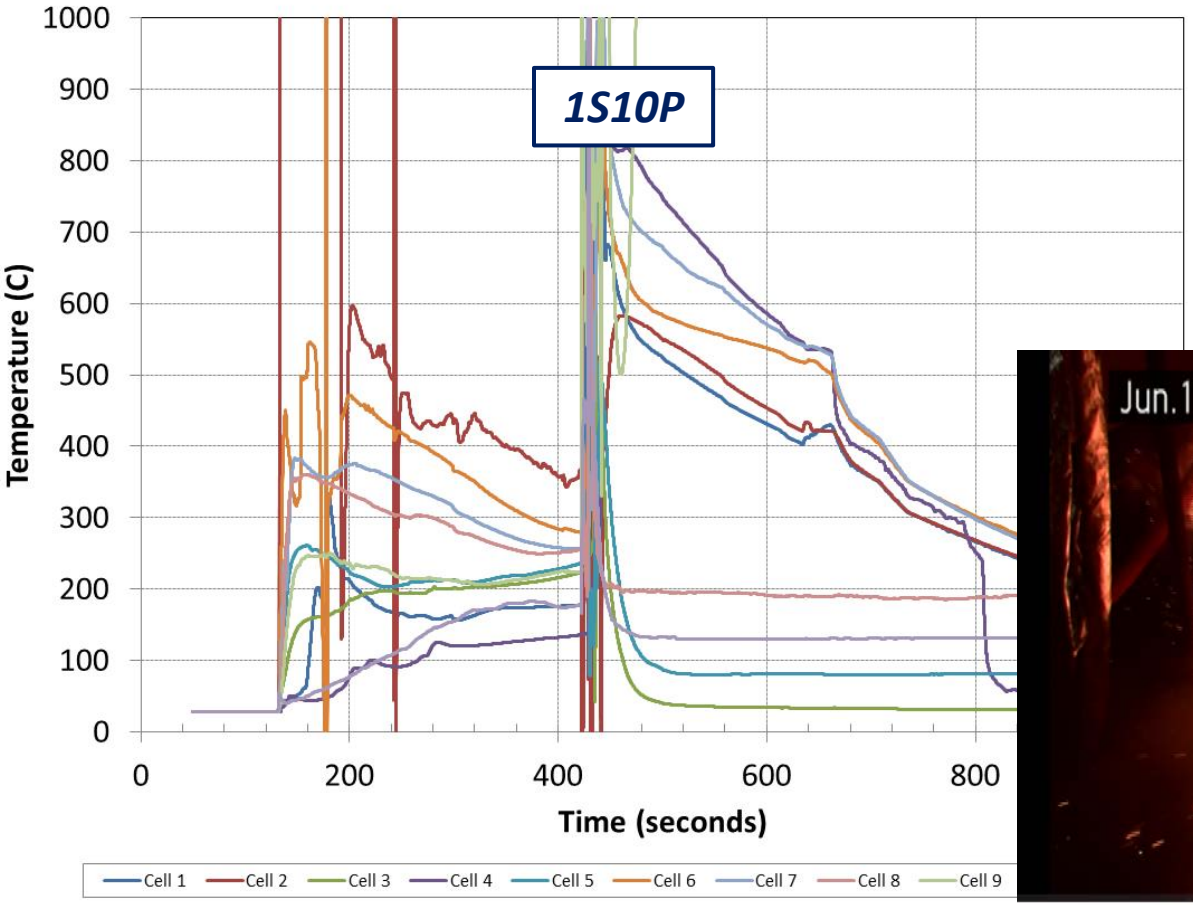
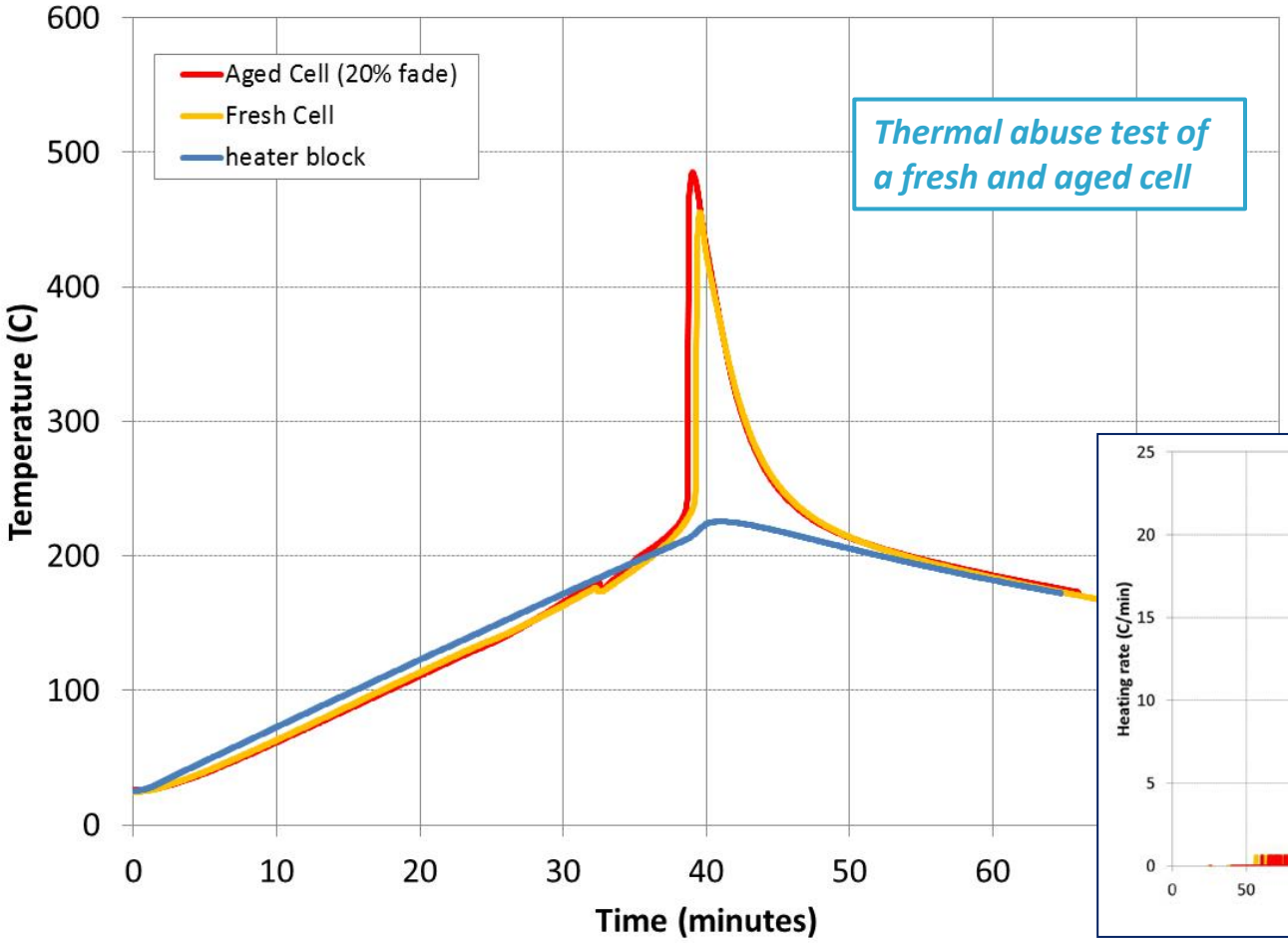
Failures initiated by mechanical insult to the center cell (#6)



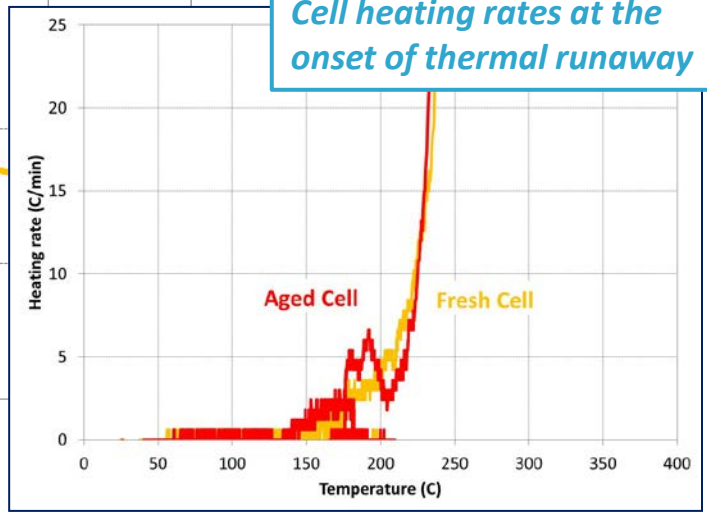
Complete propagation of a single point failure in the 1S10P pack

Abuse Response of Aged Cells



Thermal abuse test of a fresh and aged cell

Cell heating rates at the onset of thermal runaway



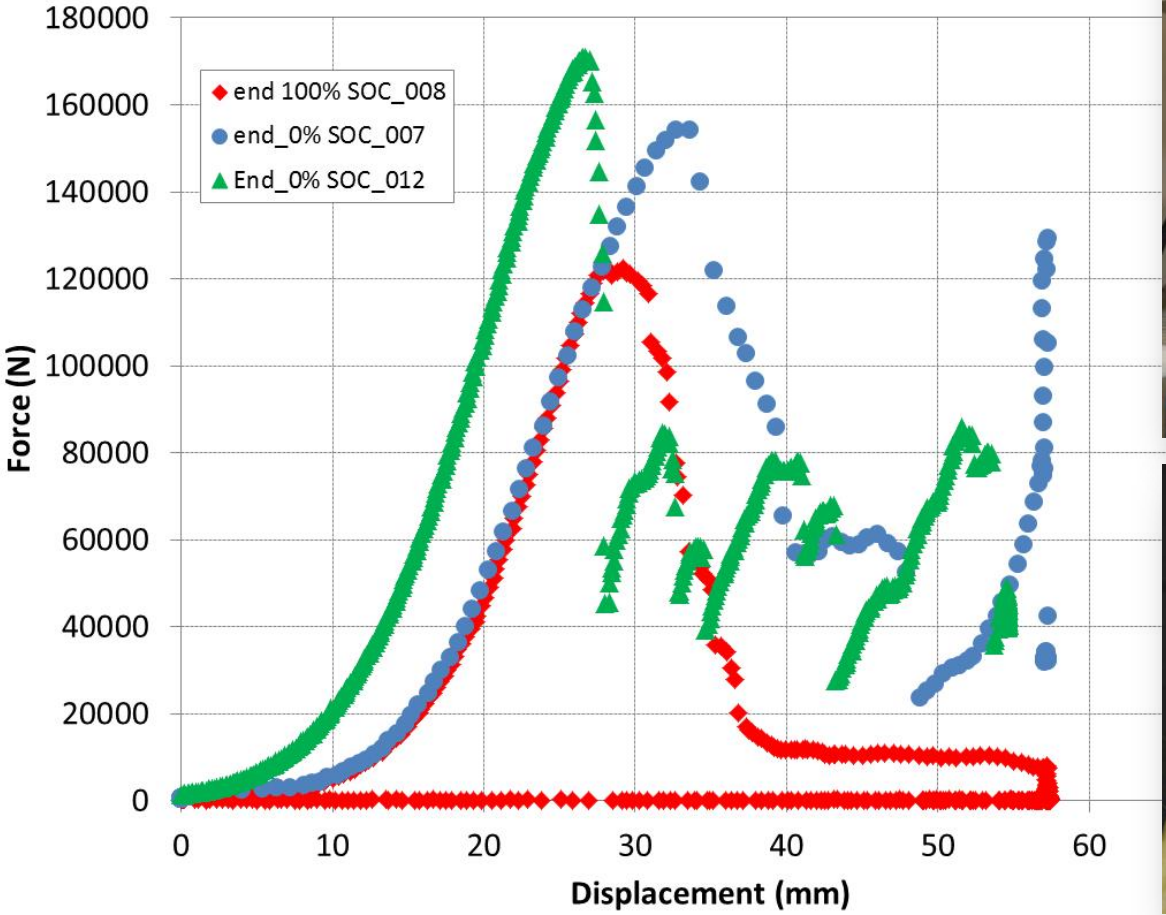
Aged cells to 20% capacity fade so not significant different in abuse or thermal runaway response compared to fresh cells

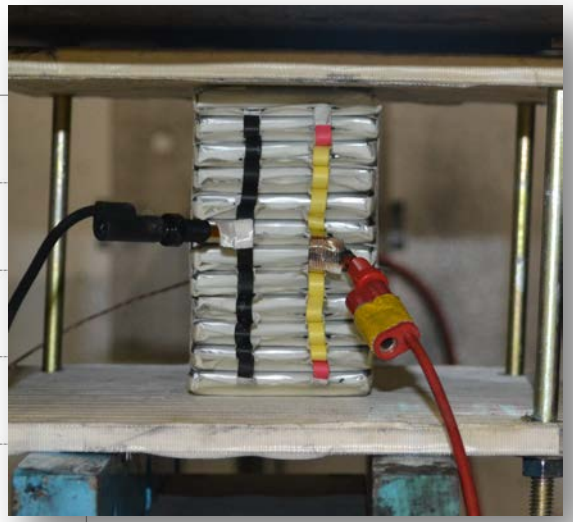
USCAR – Battery Crash Worthiness

Sandia National Laboratories

Mechanical testing support of battery mechanical model development

End crush orientation

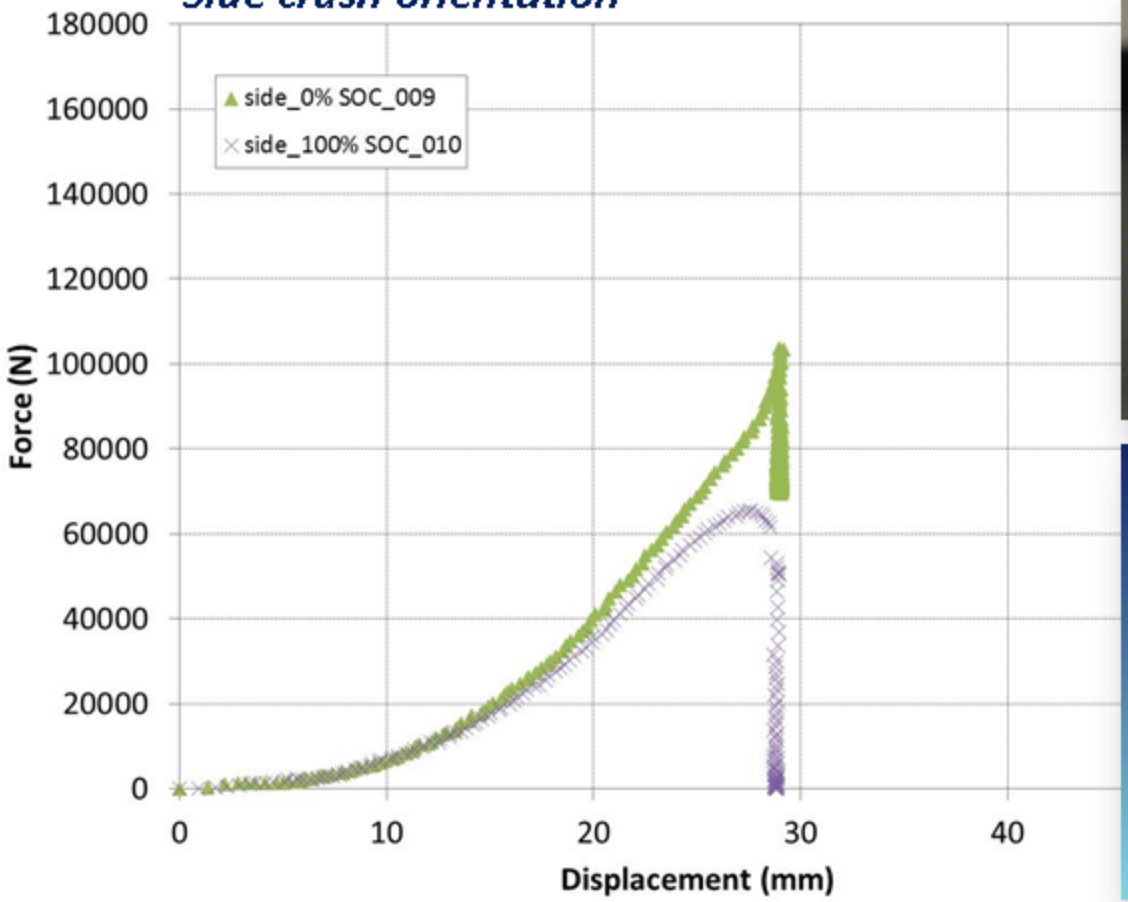


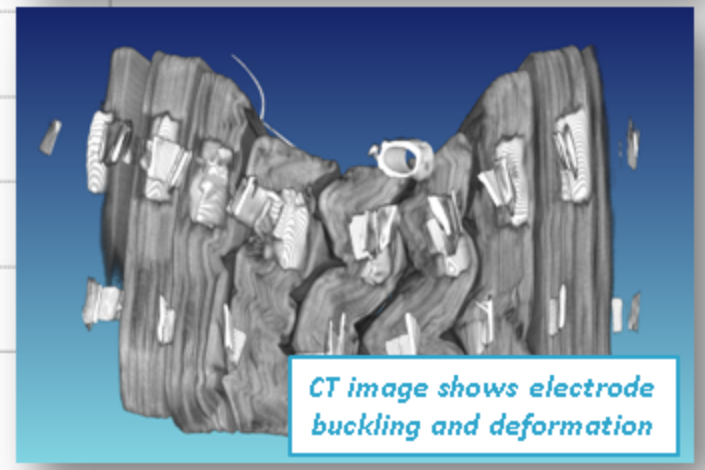


USCAR – Battery Crash Worthiness

Sandia National Laboratories

Side crush orientation





Analysis from the mechanical testing will be used to validate the mechanical models developed for EV batteries

Collaboration and Coordination with Other Institutions

Sandia National Laboratories

- NREL (Propagation testing)
- INL (Aged cell evaluation)
- INL, NREL, ANL, ORNL (USABC)
- USABC Technical Advisory Committee (TAC)
- USABC Contractors
- USCAR Crash Safety Working Group (CSWG)

Proposed Future Work

Sandia National Laboratories

- Abuse testing cells and batteries for upcoming USABC deliverables and new contracts
- Propagation testing of batteries with increasing levels of designed passive and active thermal management to demonstrate the effectiveness of engineering controls to mitigate propagation in batteries
- Propagation test of batteries of varying chemistries to determine the chemistry effect (thermal propagation)
- Evaluation of thermal runaway profiles for cells aged to 50% capacity fade
- Dynamic mechanical testing of batteries and model validation to demonstrate battery crashworthiness (USCAR)

Summary

- **Fielding the most inherently safe chemistries and designs can help address the challenges in scaling up lithium-ion**
- **Materials choices can be made to improve the inherent safety of lithium-ion cells**
- **Completed abuse testing support for all USABC deliverables to date and on track to complete all work by the end of FY14**
- **Initial evaluation of single point failure propagation shows differences in cell design and configuration**
- **Abuse and thermal runaway response of 20% capacity faded aged cells is not significantly different than fresh cells**
- **Analysis of mechanically crushed batteries will feed into the battery crash worthiness model**

Acknowledgements

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- Jill Langendorf
- Mani Nagasubramanian

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