Battery Safety Testing

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Sandia National Laboratories

2014 Energy Storage Annual Merit Review


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Overview

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 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

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**

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

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

Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)

Battery Pack/System Testing
Thermal Test Complex (TTC)

Battery Calorimetry
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

<table>
<thead>
<tr>
<th>Program</th>
<th>Deliverable</th>
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<tbody>
<tr>
<td>SKI EV</td>
<td>NCM cells (14)</td>
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<td>Blended cathode cells (14)</td>
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<tr>
<td>Cobasys EV</td>
<td>Cells (25)</td>
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<td>JCI PHEV</td>
<td>Cells (11)</td>
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<tr>
<td>Saft 12V</td>
<td>Cells (TBD)</td>
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<tr>
<td>LGChem PHEV</td>
<td>Cells (8)</td>
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<td>Modules (3)</td>
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<tr>
<td>Farasis TAP</td>
<td>Cells (16)</td>
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<tr>
<td>Maxwell TAP</td>
<td>Cells (8)</td>
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<tr>
<td></td>
<td>Modules (4)</td>
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<tr>
<td>Leyden 12 V</td>
<td>Cells (TBD)</td>
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<tr>
<td>Entek</td>
<td>Cells (19)</td>
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*Testing results are protected information*
Abuse Testing

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)
Failure Propagation Testing

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
Failure Propagation Testing

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

Limited propagation of the single point failure in the 10S1P pack
Failure Propagation Testing

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

Aged cells to 20% capacity fade so not significant different in abuse or thermal runaway response compared to fresh cells
USCAR – Battery Crash Worthiness

Mechanical testing support of battery mechanical model development

End crush orientation

![Graph showing force vs. displacement](image1)

![Battery module image](image2)
USCAR – Battery Crash Worthiness

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

- 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

- 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
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