National Highway Traffic Safety Administration

Lithium-ion based Rechargeable Energy Storage System Real-World Incident Review GTR Status Update

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Medium/Heavy Duty Incident

- BAE systems equipped New Flyer and Orion transit bus
  - 47 buses recalled for potential electrical short in RESS
  - Air cooled batteries may accumulate moisture/debris
  - Loss of electrical isolation and conductive path (short)
  - Unintentional discharge produced smoke, melting, and fire
  - Fire damage did not pose a risk to passenger compartment
Chevrolet Volt Incidents

- Two vehicles involved in fires while parked

- Safety related concerns
  - First responders actions
  - Stranded Energy
  - Rekindle events
  - External fire exposure protection
Fisker Karma Incident

- Vehicle fire due to non-high voltage vehicle component

- Safety related concerns
  - Stranded Energy
  - First Responder Actions
  - External Fire Exposure
Tesla Model S Incidents

- Two vehicles strike objects on roadway
  - Objects penetrate HV battery enclosure
  - Mechanical abuse triggers thermal activity
Physical Battery Layout

Currently on Tesla Site

2011 Autoblog Article

2010 Cnet Article
Tesla Model S Incidents

- Safety related concerns
  - Multi-cell Abuse/ Crush
  - Thermal Propagation
  - Containment
  - Operator Messaging
  - Monitoring/Fault Detection
  - Discharge
  - Passenger compartment isolation
Real World Incidents Analysis and Conclusions

- Proper battery enclosure considerations
- HV fire containment and vent management
- HV vehicle identification
- First responder education and training
- Post incident handling
- Stranded energy management
- Rekindling of stored energy
Hurricane Sandy
Fisker Karma Inspections
338 Fisker Karmas were flooded in Newark, NJ
Fisker Battery
• Check for Thermal Activity
• Cut 12V power
• Remove MSD
• Check HV Battery Isolation and Voltages
HV Battery Removal
Inspection
Research Relevant Safety Observations

- Isolation (Many Batteries exhibited loss of isolation internal to the battery pack and to the vehicle chassis)
- Immersion in conductive liquids
- Battery health assessment (Not possible for damaged batteries)
- External Short Circuits (Internal to Battery Enclosure)
- Thermal Events (331 of 339 batteries had evidence of thermal activity)
- Mitigation (No thermal propagation or runaway)
- Containment (None of the battery thermal events breached the battery housing)
- Stranded Energy
Chevrolet Volt
Post –Crash Test Incident
Volt Incident Recap

- NCAP Side Impact 20 mph Pole Test with 5th female driver dummy
- Tested 5/12/2011 including a post-test vehicle 360 degree roll
- Vehicle placed in storage area with battery at SOC used for test (approx. 58% SOC)
- Fire occurred 6/5/2011
- 4 vehicles consumed in fire
Fire Scene at MGA
Volt Battery Pack
Cross-member Intrusion Into Battery Compartment
NCAP Pole Test Volt Crash Damage

Intrusion and Breach in Tunnel
NCAP Pole Test Volt Crash Damage
Volt Incident Analysis and Conclusions

• The battery and cooling system were damaged during the crash test
• Conductive liquid coolant leaked inside the battery compartment
• The monitoring electronics for the battery were exposed to the conductive coolant (rollover test)
• Fire initiated in the Volt 23 days after testing as a result of the damage and exposure.
• The fire was initiated and sustained by the stored energy in the battery.
Research Relevant Safety Observations

- Mechanical crush/structural integrity of the battery pack (multiple cells crushed)
- Isolation (isolation internal to pack unknown)
- Immersion in conductive liquids
- Battery health assessment (not available at time of test)
- External Short Circuits (Internal to Battery Enclosure with slow development)
- Containment
- Toxic Gas Vented
Boeing 787 Dreamliner
Li-Ion Battery Incident
Incident Overview

- APU battery pack suffered a thermal event with release of smoke and gasses on a JAL 787 while on the ground at Logan Airport in Boston, MA
Incident Overview

- Failure deemed the result of a single cell failure

“After an exhaustive examination of the JAL lithium-ion battery, which was comprised of eight individual cells, investigators determined that the majority of evidence from the flight data recorder and both thermal and mechanical damage pointed to an initiating event in a single cell. That cell showed multiple signs of short circuiting, leading to a thermal runaway condition, which then cascaded to other cells. Charred battery components indicated that the temperature inside the battery case exceeded 500 degrees Fahrenheit.”

NTSB press release dated 2/7/2013
Changes to Battery System Design

• Improved thermal materials and better isolation of individual battery cells

• Improved battery container to contain thermal events

• Improved vents to pass cell venting product to the outside
Research Relevant Safety Observations

- Propagation (single cell event that spread to all cells)
- Containment
- Exposure to toxic gases
NHTSA EV Crash Test Programs
# NHTSA’s Testing Protocol for EV/HEVs

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Enforcement</th>
<th>NCAP</th>
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<tbody>
<tr>
<td>Frontal Impact</td>
<td>FMVSS No. 208 (35 mph crash test into a flat barrier)</td>
<td>35 mph crash test into a flat barrier</td>
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<tr>
<td>Side Barrier Impact (MDB)</td>
<td>FMVSS No. 214 (MDB) (33.5 mph crash test with a MDB)</td>
<td>38.5 crash test mph with a MDB</td>
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<tr>
<td>Side Pole Impact</td>
<td>FMVSS No. 214 (Pole) (20 mph crash test into a pole)</td>
<td>20 mph crash test into a pole</td>
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<tr>
<td>Post Test Fuel, electrolyte observation, and isolation tests</td>
<td>FMVSS Nos. 301 &amp; 305</td>
<td>Same procedure</td>
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<tr>
<td>Post Test Inspection</td>
<td>Battery pack evaluation</td>
<td>Same procedure</td>
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<tr>
<td>MY</td>
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<td>Models</td>
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<tr>
<td>2011 Buick</td>
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<td>Sonata Hybrid</td>
<td>2013 Honda</td>
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<td>2011 <strong>Chevrolet</strong> Volt</td>
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<td>C-MAX Energi</td>
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<td>2013 Ford</td>
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<td>Civic IMA (Hybrid)</td>
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<td>Optima Hybrid (TF HEV)</td>
<td>2013 Lincoln</td>
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<td>2013 <strong>Nissan</strong> Leaf</td>
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<td>2012 Scion</td>
<td>iQ EV</td>
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<td>2013 <strong>Ford</strong> Focus BEV</td>
<td>2013 Honda</td>
<td>Civic 4DR Hybrid FWD</td>
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<td>Smart Coupe</td>
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<td>PRIUS Plug-In</td>
<td>2014 Chevrolet</td>
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<td>2013 Acura</td>
<td>ILX Hybrid</td>
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<td>2013 <strong>Tesla</strong> Model S</td>
<td>2014 Toyota</td>
<td>Highlander Hybrid AWD</td>
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<td>2013 Toyota</td>
<td>RAV4</td>
<td>2014 Toyota</td>
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Vehicles highlighted with bold and italicized are battery electric vehicle.
NHTSA’s Battery Evaluation Test Protocol

- **Pre-Crash Procedures**
  - Obtain battery cell MSDS from the manufacturer.
  - Install high speed video camera(s) and lighting.
  - Using the manufacturer’s supplied test hardware, read and record battery cell voltages and temperatures. (Additional data may be recorded if it is available)
  - Perform FMVSS No. 305 measurements for electrical isolation.

- **Post-Crash Procedures**
  - Perform FMVSS No. 305 measurements for isolation.
  - Inspect visually for damage to the battery. For liquid cooled batteries also inspect for battery coolant leakage.
  - Using the manufacturer’s supplied test hardware, read and record battery cell voltages and temperatures. (Additional data may be recorded if it is available)
  - Using an infrared thermometer or imager, inspect the battery for signs of thermal activity.
  - Perform FMVSS Nos. 301 and/or 305 rollover tests. Cell voltage and temperature data may also be collected if possible.

- **Post-Test Procedures**
  - If post-crash inspection indicates damage to the battery, have x rays taken of the damaged area.
  - Following the manufacturer’s instructions, remove the battery from the vehicle.
  - Open the battery pack and inspect for any movement or separation of components or wiring.
  - Inspect the battery for leakage on liquid cooled batteries.
  - Reinstall the battery pack into the vehicle.
  - Place the vehicle in an outdoor monitoring location for a minimum of 3 weeks.
20 MPH Side Impact Pole Test
Example of Static Rollover
Example of a Post Test Crashworthiness Inspection
Example of a Post-Crash Battery Pack Inspection

Impact Point
Summary of Safety Related Observations

• Mechanical crush/structural integrity of the battery pack
  - No battery cell damage was observed
• Electrical Isolation
  - Isolation was maintained
• Battery monitoring
  - Utilizes manufacturer support to monitor battery
  - No standard measurement solution available currently
• Battery health assessment
  - Based on physical (visual) inspection and prolonged post-test observation
  - Research would identify performance metrics that could be measured using better tools to evaluate the battery post-crash