

Battery Safety and Abusive Battery Testing Overview



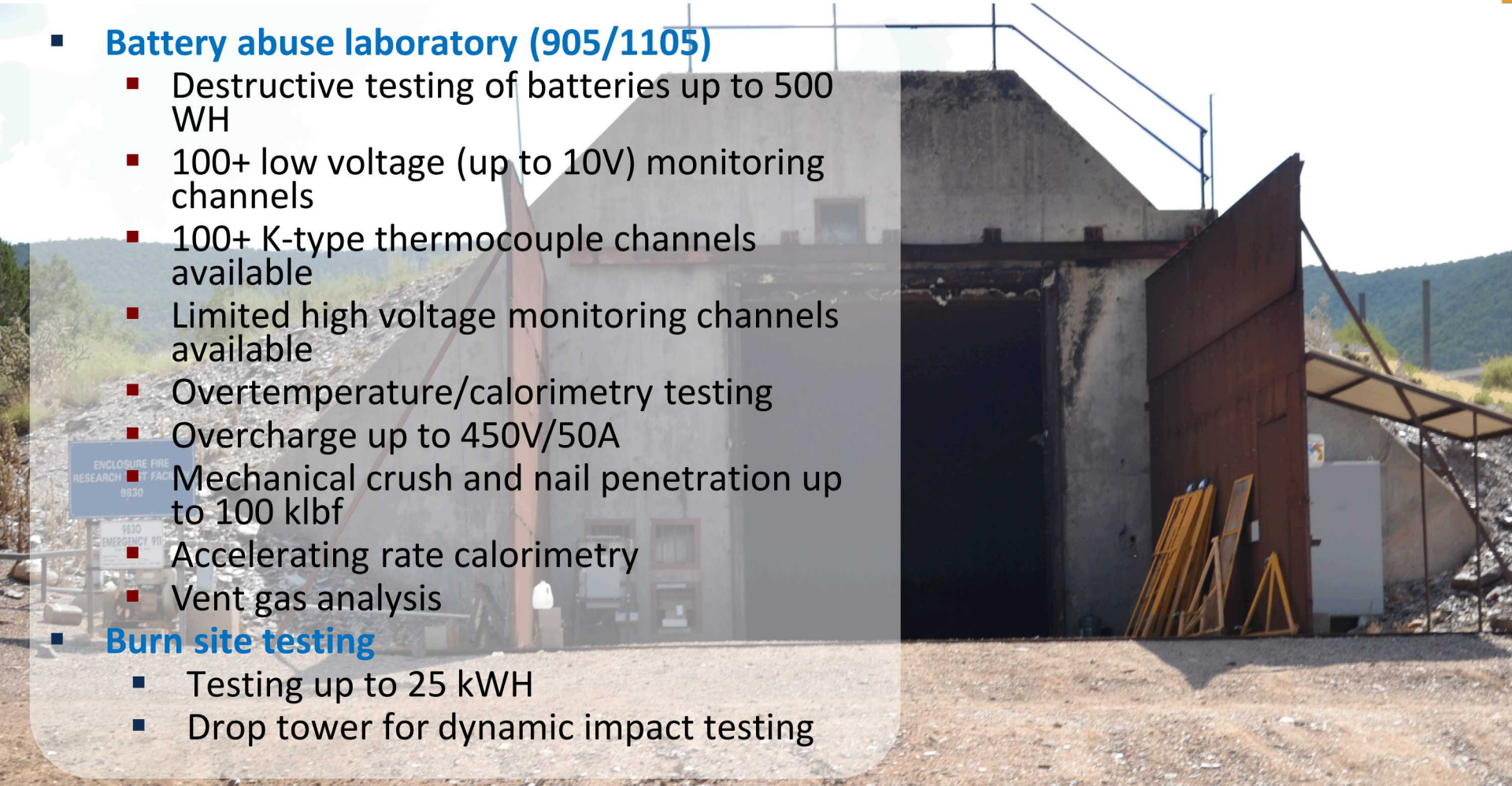
Joshua Lamb



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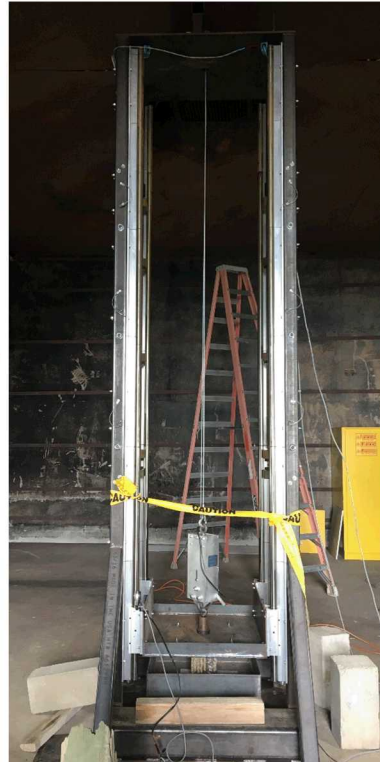
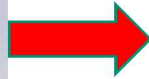
Abuse testing capabilities

- **Battery abuse laboratory (905/1105)**
 - Destructive testing of batteries up to 500 WH
 - 100+ low voltage (up to 10V) monitoring channels
 - 100+ K-type thermocouple channels available
 - Limited high voltage monitoring channels available
 - Overtemperature/calorimetry testing
 - Overcharge up to 450V/50A
 - Mechanical crush and nail penetration up to 100 klb
 - Accelerating rate calorimetry
 - Vent gas analysis
- **Burn site testing**
 - Testing up to 25 kWh
 - Drop tower for dynamic impact testing

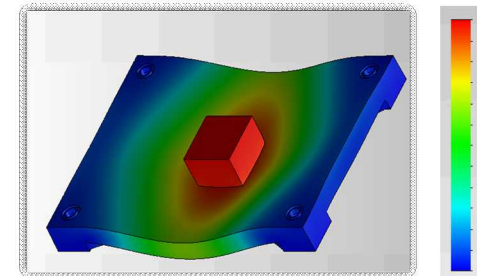
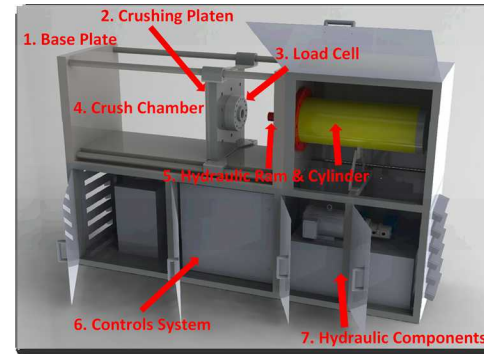


Large Scale Test Capabilities

Drop Tower



Large battery crusher



Understanding Battery Safety



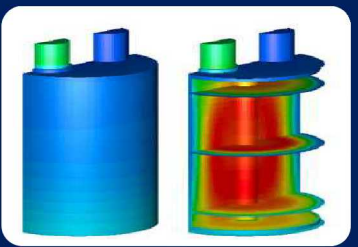
Materials R&D

- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials



Testing

- Electrical, thermal, mechanical abuse testing
- Large scale thermal and fire testing (TTC)
- Failure propagation testing on batteries/systems
- Diagnostic techniques for battery state of stability
- Development for DOE Vehicle Technologies and USABC



Simulations and Modeling

- Multi-scale models for understanding thermal runaway
- Validating vehicle crash and failure propagation models
- Fire Simulations to predict the size, scope, and consequences of battery fires



Stakeholder outreach and procedures

- USABC Abuse Testing Manual (SAND 2005-3123)
- SAE J2464/UL 1642 procedures and standards
- R&D programs with NHTSA/DOT to inform best practices, policies, and requirements

Lithium-Ion Battery Challenges

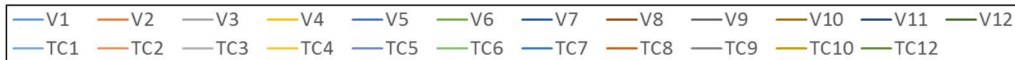
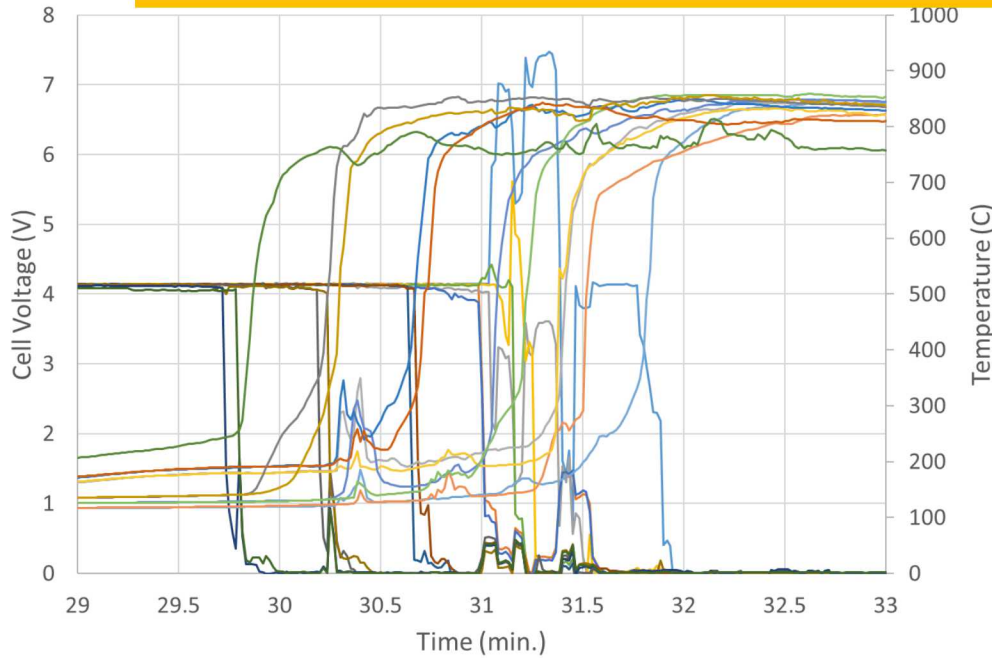
- **Energetic thermal runaway**
 - Anode and cathode decomposition reactions
- **Electrolyte flammability**
 - Low flashpoint electrolyte solvents
 - Vent gas management
 - Fuel-air deflagrations
 - Wide flammability range of decomposition products
- **Thermal stability of materials**
 - Separators, electrolyte salts, active materials
- **Failure propagation from cell-to-cell**
 - Single point failures that spread throughout an entire battery system
- **Managing residual stored energy**
- **Diagnostics/prognostics to understand stability in the field**

6 | Example of a thermal runaway

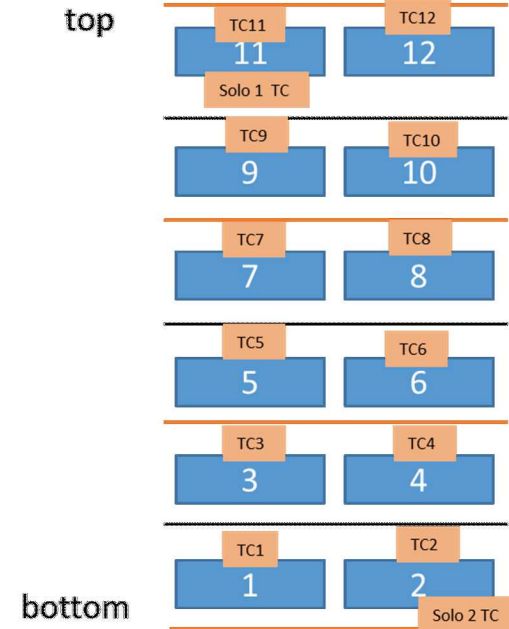


1 kWh propagating battery failure test

1 kWh battery pack: heaters between cells ramped a 5C/min until failure



Battery Schematic

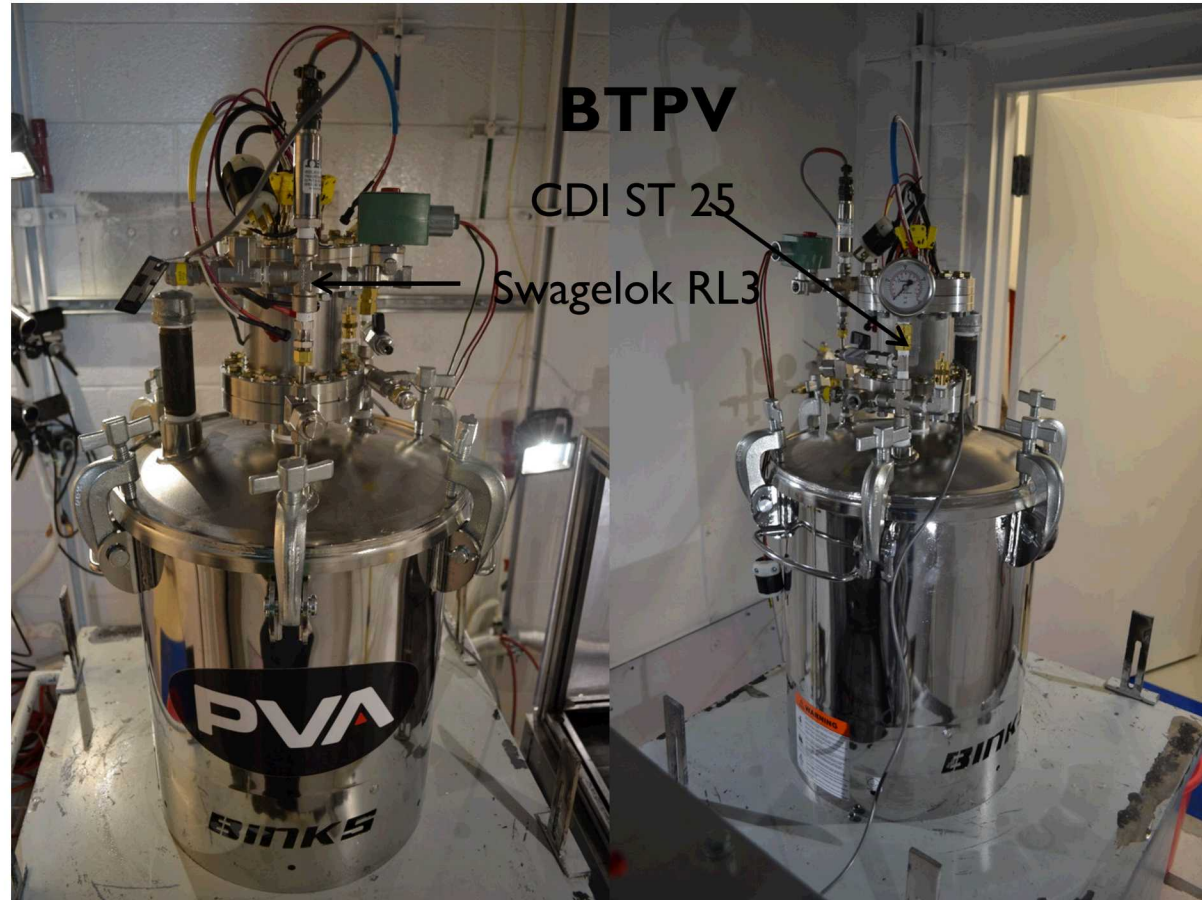


[1 kWh_no_chamber](#)

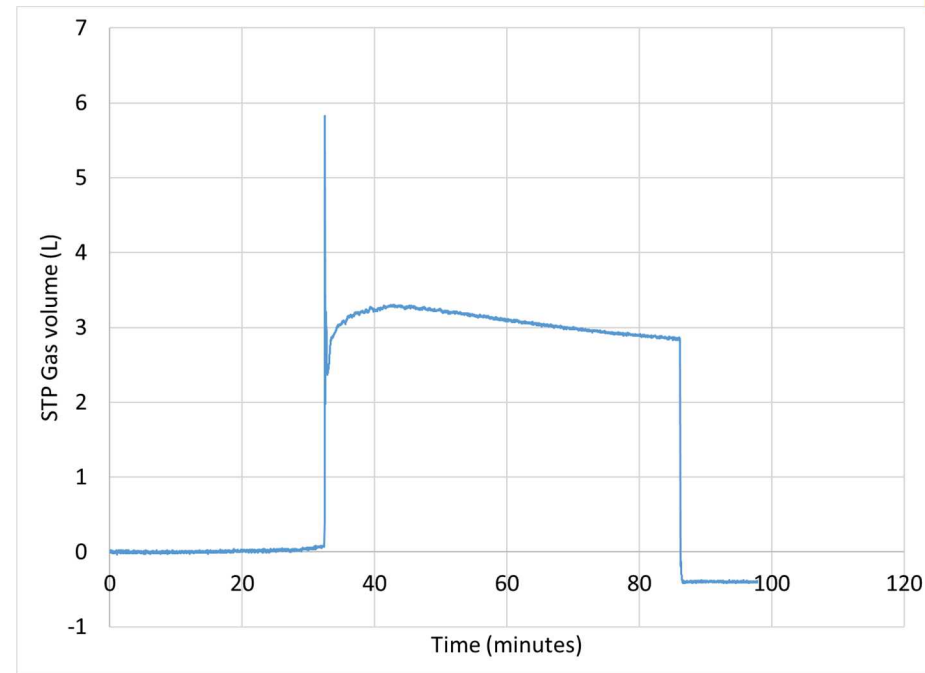
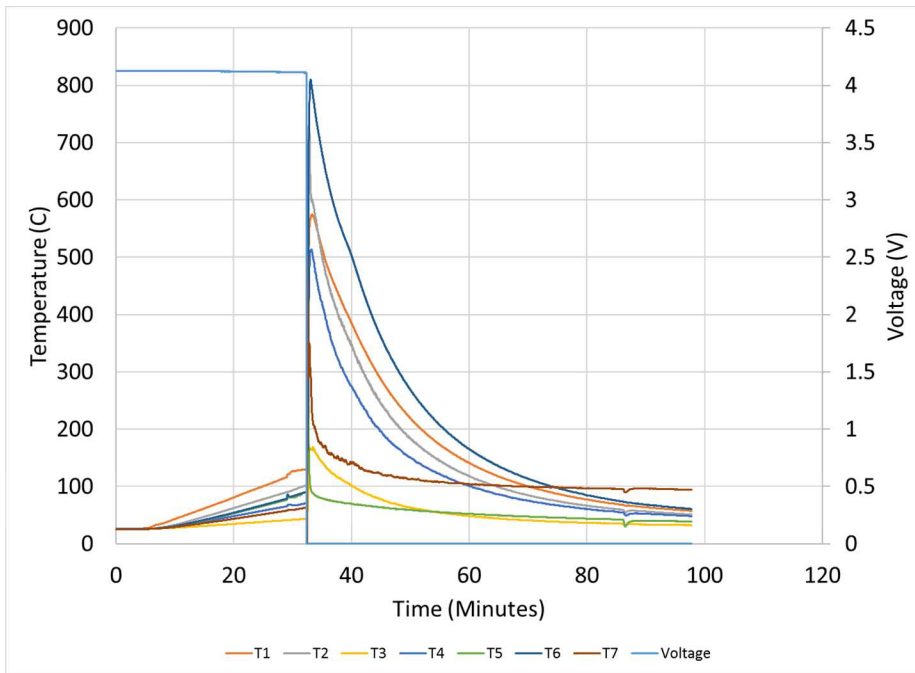
- Propagation through the pack achieved starting with failure of cell 11 and 12 cascading down to 1 and 2.
- The total burn time was ~ 4 min + 6 min smoldering of battery materials
- Peak temperatures were ~800°C on the battery during failure

Evaluation of Li-ion gas production

- Pressure tank and custom header used for testing
- Volume measured through nitrogen expansion into a separate known volume
 - Measured volume 40.82 L
- For FTIR sampling a draw line was attached for live sampling during the test
- For ex-situ sampling a 500 mL sample cylinder was attached



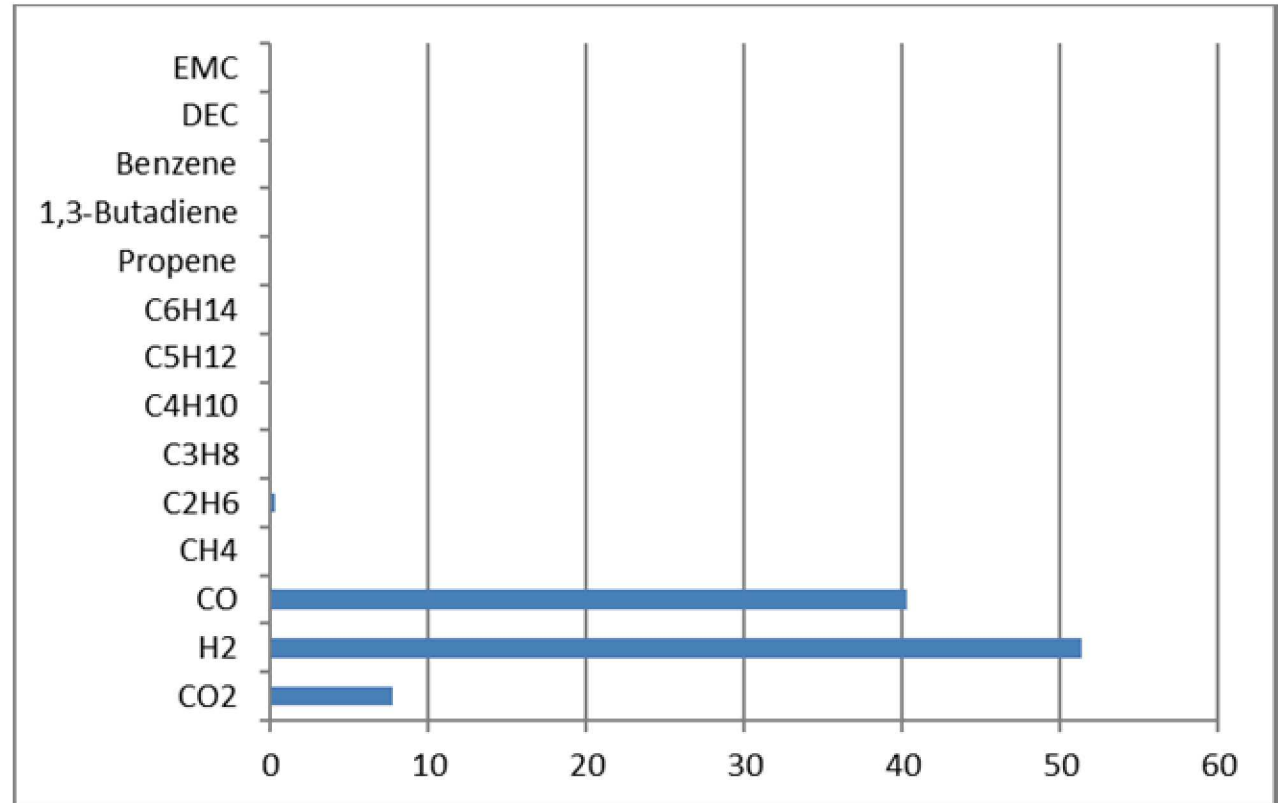
Gas Production from a Li-Ion battery pack



- One of the largest risks from large battery systems is a release of flammable gas into an enclosed space
- Sandia has capabilities for evaluating the total gas production and its constituents
- Thermal ramp of central cell resulted in rapid failure of the entire pack
- After an initial pressure wave a rough equilibrium equivalent to $\sim 3.3 L_{STP}$ was observed

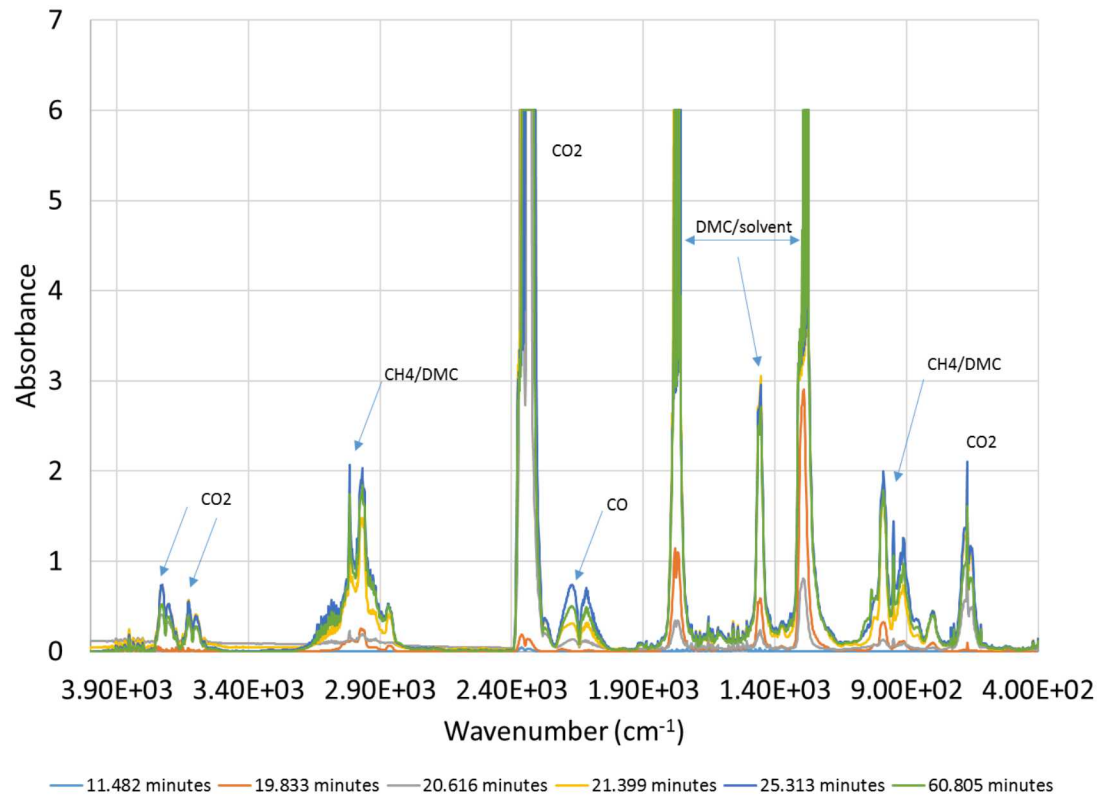
Gas Production in Li-Ion thermal runaway

- Most prominent constituents observed are CO, H₂ and CO₂
- N₂ and O₂ were subtracted out for this comparison
- N₂ and O₂ present were roughly equivalent to in-air proportions, suggesting little combustion occurred



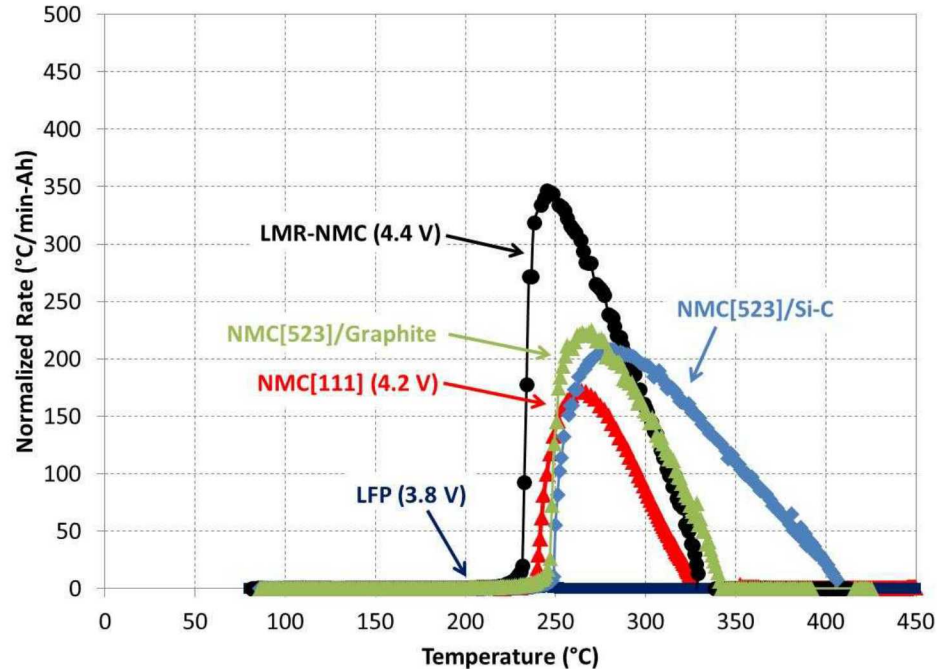
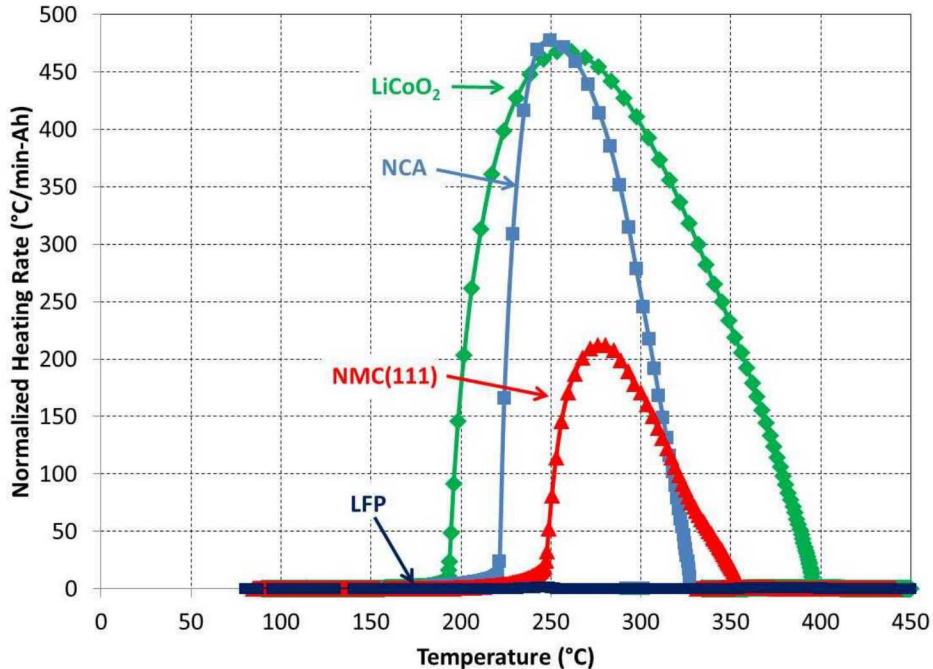
Gas Production in Li-Ion thermal runaway – FTIR live results

- FTIR peaks show an initial venting at ~19 minutes
- The initial gas observed shows DMC (dimethyl carbonate) gas most prominently
- CO_2 rapidly becomes apparent after this initial venting
- Some CO develops over time, peaking 6 minutes after the initial vent
- Some CH_4 peaks may be present (but overlap with DMC)



Cathode chemistry impact on safety

Accelerating rate calorimetry (ARC) of lithium-ion 18650 cells with different cathode materials



- *All measurements at 100% SOC and for cells with 1.2 M LiPF₆ in EC:EMC (3:7)*
- *Significant differences in thermal runaway response related to the amount of oxygen released from the cathode material*
- *5% silicon composite anode increases the runaway enthalpy by ~10% relative to a graphite cell with the same cathode*

Commercially available options for Powering 24h, 72h missions

	Rated power, Watts	24 h Specific energy, Wh/kg	72 h Specific energy, Wh/kg	Sources for comparison
Direct methanol fuel cell	110	110	900	SFC EFOY 2400
Li-ion battery	100-275	170	170	Brentronics BB2590

- Li-ion battery
 - Comparatively inexpensive
 - Power can be easily scaled by adding cells in series and parallel configurations
 - Large numbers of cycles possible
 - Recharging requires a primary electrical power source
 - No noise
- Methanol/propane fuel cells
 - Scale well with size as mission endurance is increased
 - Require propane (SOFC) or methanol (DMFC) fuels
 - Quiet compared to diesel generators