

Battery Safety Research and Development

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Power Sources Technology Group



Power Sources Technology Group (PSTG)



Enterprise
Integration



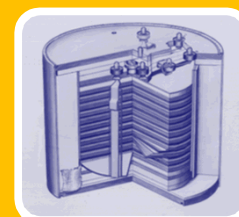
SNL External
Production



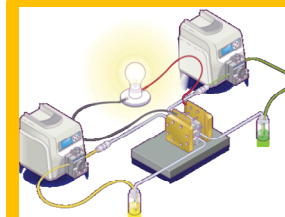
PS
Production



PS Design &
Development



PS Component
Development



PS Research &
Development

NW

Grid Storage

Transportation

Fundamental Science

- Thermal batteries
- Reserve batteries
- Lithium primary batteries

- Thermoelectrics
- Radioisotope power sources
- Lithium-ion batteries

- Sodium batteries
- Flow batteries
- Battery safety and reliability

- Electrolyte development
- Solid-state electrolytes
- Beyond lithium chemistries

- DOE National Nuclear Security Administration
- Other Government Agencies
- Department of Defense
- Strategic Partnership Programs

- DOE Office of Electricity
- DOE Vehicle Technologies Office
- DOE Basic Energy Sciences
- Department of Transportation

Lithium-Ion Battery Challenges

- **Energetic thermal runaway**
 - Anode and cathode decomposition reactions
- **Electrolyte flammability**
 - Low flashpoint electrolyte solvents
 - Vent gas management
 - Fuel-air deflagrations
- **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**

Increased Use of Lithium-ion Technology

Larger batteries in larger quantities:

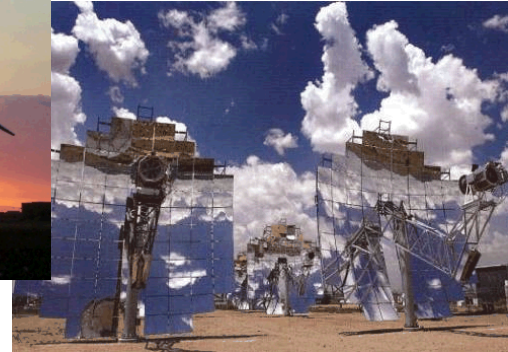
- EV and PHEV battery packs are much higher energy (15-50 kWh)
- Increasing consideration for lithium-ion cells for utility storage (MWh systems)



6 cells, 50 Wh battery



7000 cells, 50 kWh battery



??? cells, MWh battery

Increased # of cells and higher energy batteries leads to greater impact during failure

- **Field Failure**

- **Manufacturing defects**

- Separator damage, foreign debris
- Can develop into an internal short circuit

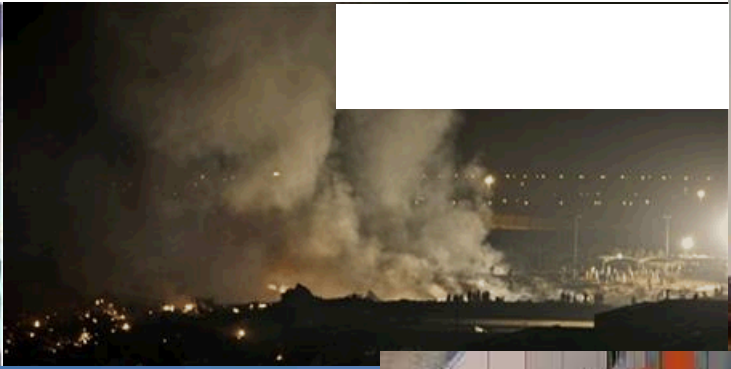
- **Abuse Failure**

- **Mechanical**
- **Electrical**
- **Thermal**

Impact of Battery Safety/Reliability Issues



2006 Sony/Dell battery recall
4.1 million batteries



2011 NGK Na/S Battery Explosion, Japan (two weeks to extinguish blaze)



2013 Storage Battery Fire, The Landing Mall, Port Angeles, (reignited one week after being "extinguished")



2011 Chevy Volt Latent Battery Fire at DOT/NHTSA Test Facility



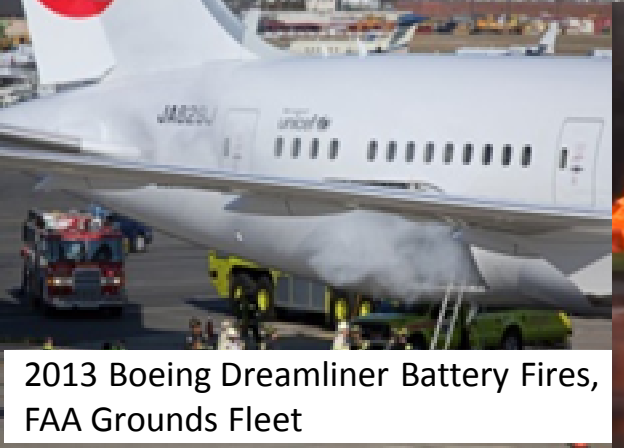
2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm



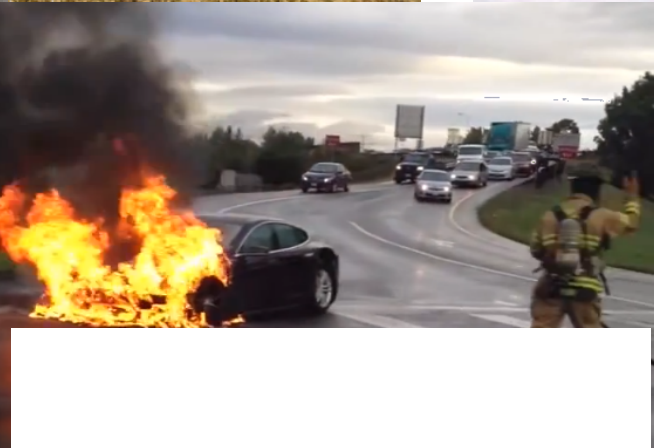
2012 GM Test Facility Incident, Warren, MI



2013 Fisker Battery Fires, New Jersey, in the wake of Super Storm Sandy



2013 Boeing Dreamliner Battery Fires, FAA Grounds Fleet

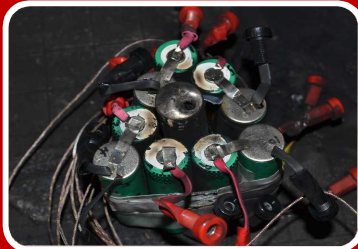


Understanding Battery Safety



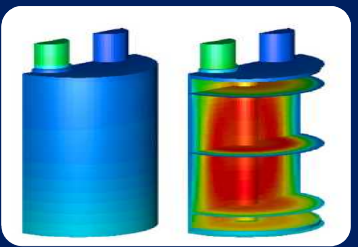
Materials R&D

- 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



Procedures, Policy, and Regulation

- 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

Capabilities and Infrastructure

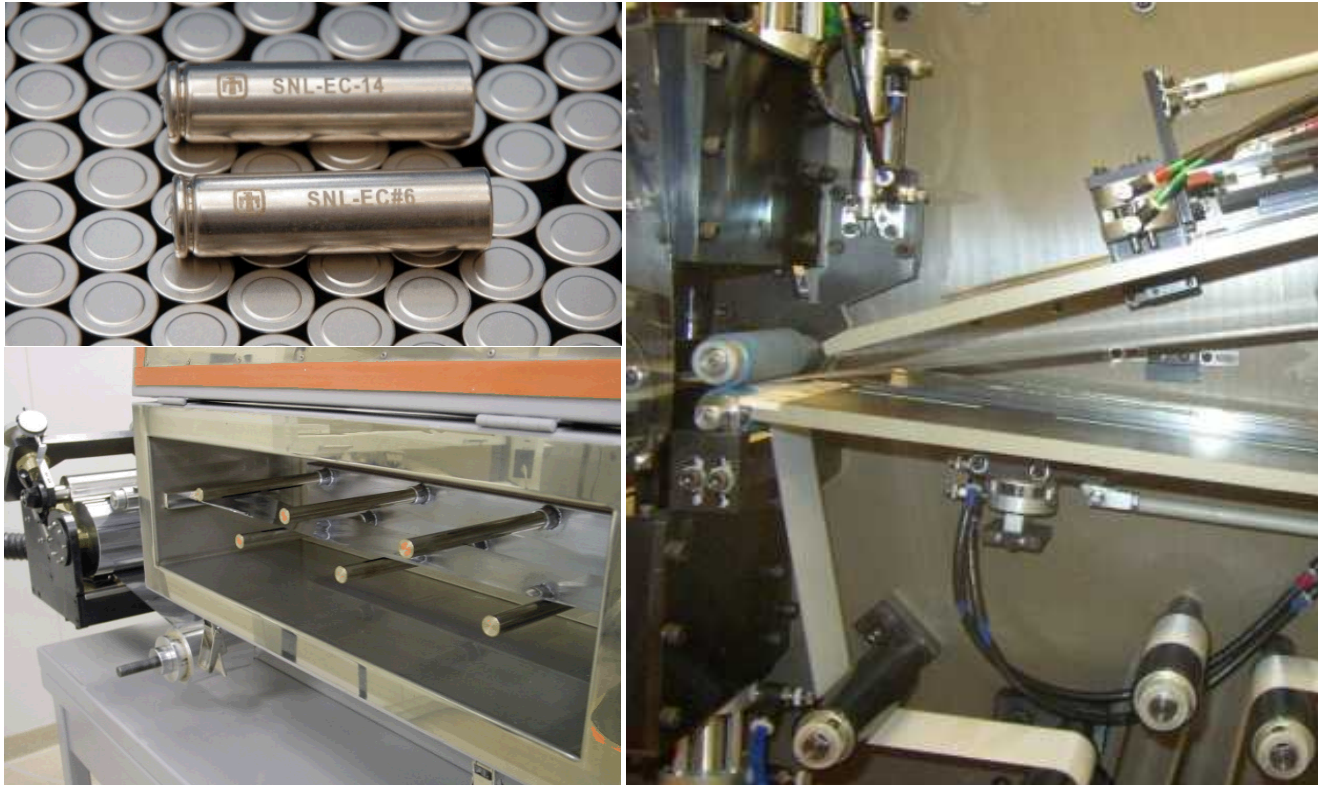
- *Battery Abuse Testing Laboratory (BATLab)*
- *Cell Prototype Facility*
- *Battery Calorimetry*
- *Modeling and Simulations*
- *Materials Development R&D*
- *Thermal Test Complex (TTC)*
- *Burn Site, Laurence Canyon*



Thermal Test Complex (TTC)

Cell Prototyping Facility

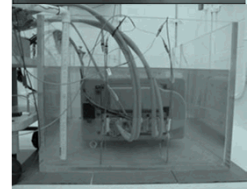
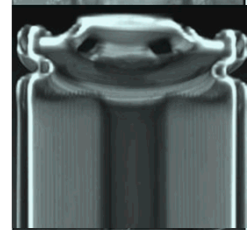
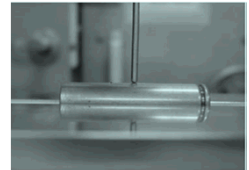
- The SNL cell prototyping facility largest DOE dedicated R&D facility equipped to manufacture small lots of lithium-ion cells of various sizes including 2032 coin cells, 18650s, D-cells, and prismatic cells



- Experience with numerous lithium-ion chemistries including natural and synthetic graphite anodes, $\text{Li}_4\text{Ti}_5\text{O}_{12}$, LiCoO_2 , NMC, LFP, and spinel cathodes (LiMn_2O_4 and $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$)

Battery Abuse Testing Laboratory (BATLab)

- Comprehensive abuse testing platforms for safety and reliability of cells, batteries and systems from mWh to kWh
- Cell, module, and battery system hardware deliverables for testing
- Mechanical abuse
 - Penetration
 - Crush
 - Impact
 - Immersion
- Thermal abuse
 - Over temperature
 - Flammability measurements
 - Thermal propagation
 - Calorimetry
- Electrical abuse
 - Overvoltage/overcharge
 - Short circuit
 - Overdischarge/voltage reversal



Burn Site Test Site

Full Scale Battery Testing Facilities

- *Owned by SNL Fire Sciences Dept.*
- *Design for large scale fire testing and high explosives (up to 100 kg)*
- *Construction/design suitable for large scale battery abuse testing (10s of kWh Li-ion)*
- *Fully instrumented data acquisition capabilities*



Information Gained by Abuse Testing

Using a well developed scientific foundation to understand:

- Battery failure mechanisms
- Fundamentals causes of failure
- Impact of failure:
 - Heat release
 - Gas emission
 - Pressure generation
 - Burn time
 - Waste generation
- Direct comparisons with like battery chemistries/sizes
- EUCAR rating for severity of outcome
- Provide information to manufactures to help aid in safer batteries:
 - Materials choice
 - Design
 - Engineering controls

EUCAR Hazard Severity Level Ratings		
Hazard Severity Level	Description	Classification Criteria for Severity Classification
0	No effect	No effect. No loss of functionality.
1	Reversible Loss of Function	No defect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Temporary loss of battery functionality. Resetting of protective device needed.
2	Irreversible Defect/Damage	No leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. RESS irreversibly damaged. Repair needed.
3	Leakage Δ mass < 50%	No venting, fire, or flame; no rupture; no explosion. Weight loss <50% of electrolyte weight. Light smoke (electrolyte = solvent + salt).
4	Venting Δ mass \geq 50%	No fire or flame; no rupture; no explosion. Weight loss \geq 50% of electrolyte weight. Heavy smoke (electrolyte = solvent + salt)
5	Fire or Flame	No rupture; no explosion (<i>i.e.</i> , no flying parts).
6	Rupture	No explosion. RESS could disintegrate but slowly without flying parts of high thermal or kinetic energy
7	Explosion	Explosion (<i>i.e.</i> , disintegration of the RESS with externally damaging thermal & kinetic forces). Exposure to toxic substances in excess of OSHA limits

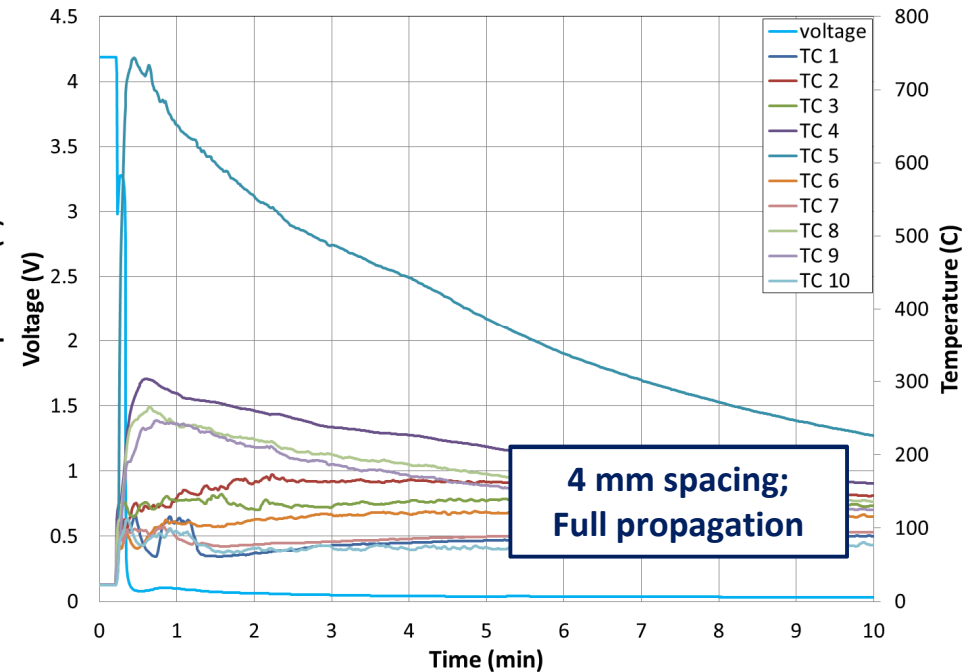
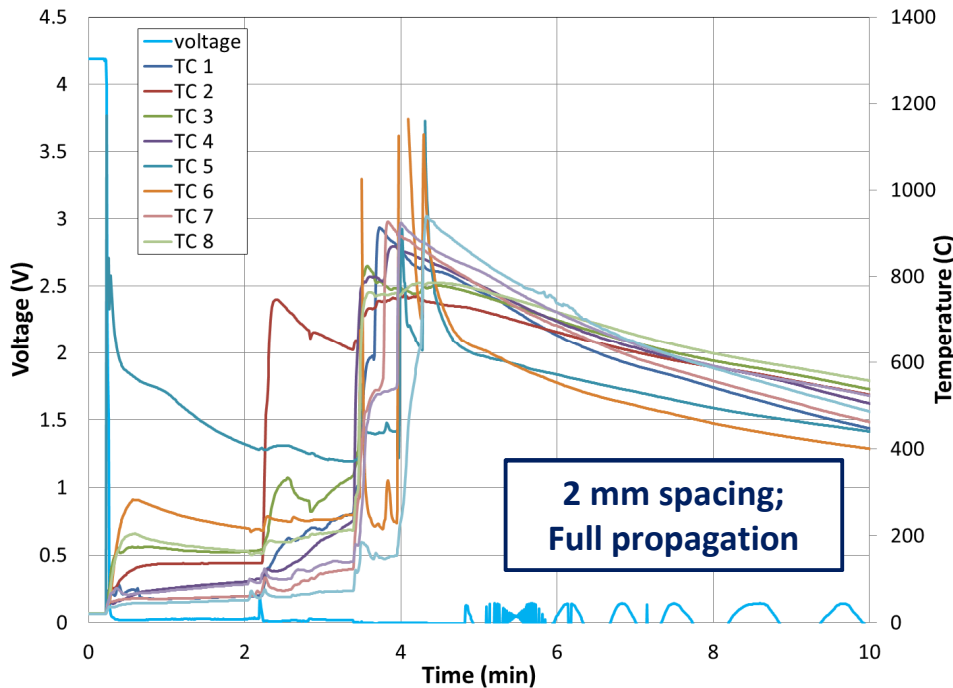
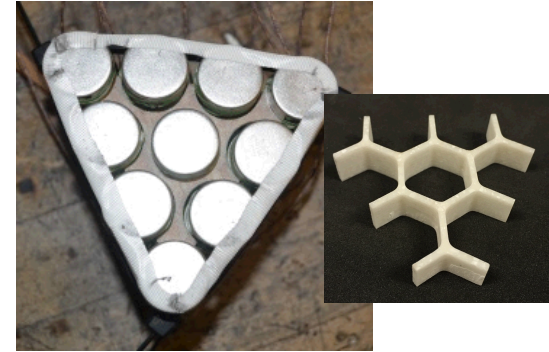
Transportation/Battery Safety



Fisker incident in the wake of Super Storm Sandy , New Jersey (2012)

Failure Propagation Research Scale

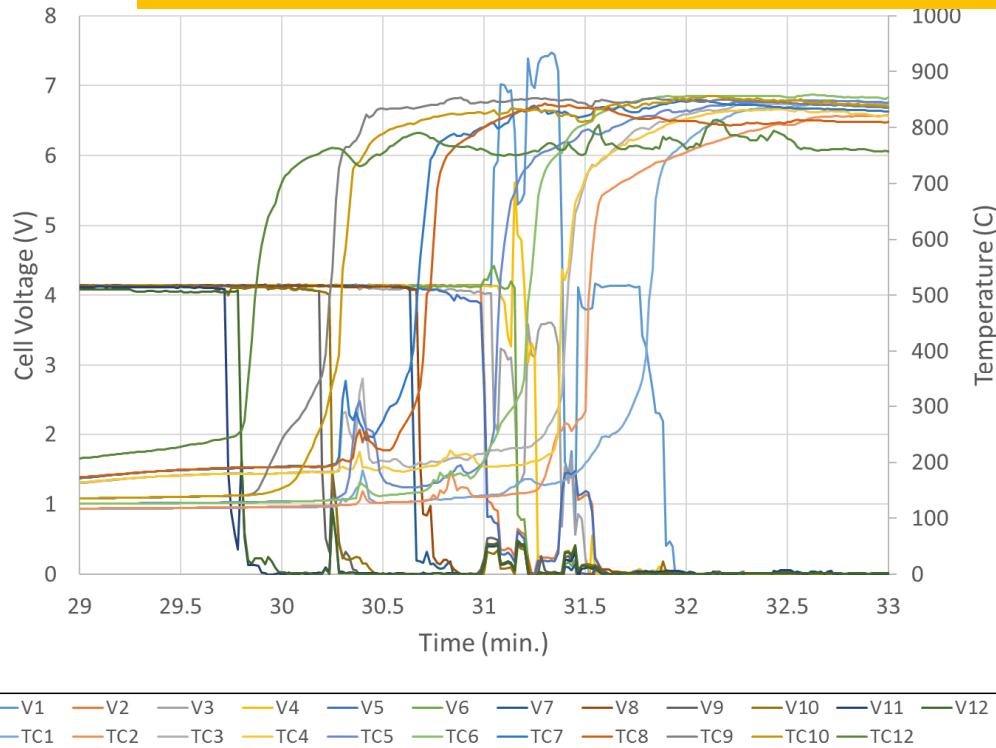
*Develop an understanding of how single point failures propagate cell-to-cell through battery systems. Variables include chemistry, **spacing**, configuration, format, passive and active controls.*



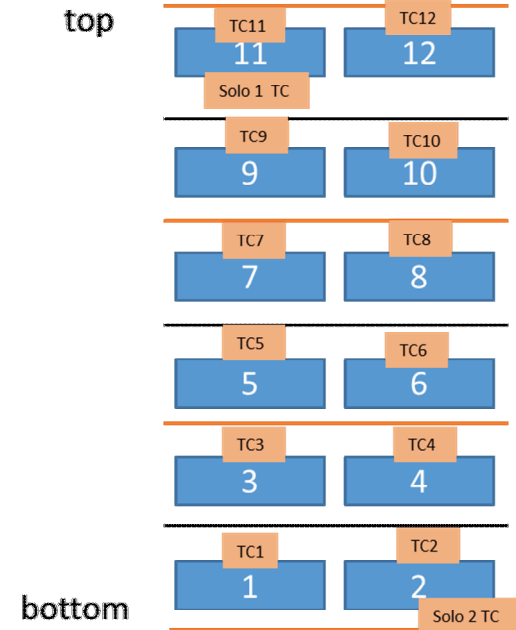
Complete propagation through pack with 2 mm spacing and no propagation when gap is increased to 4 mm (although skin temp. of cells increase, no cell besides failure point exhibit thermal runaway)

Large Scale Propagation Through Heating Sandia National Laboratories

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



Battery Schematic



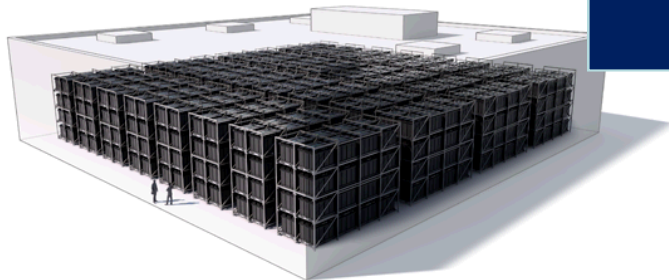
1 kWh no chamber

- 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

Advanced Battery Diagnostics



Transportation



Grid Storage

Advanced Battery
Diagnostics



*Development of advanced diagnostics for **battery health and stability***

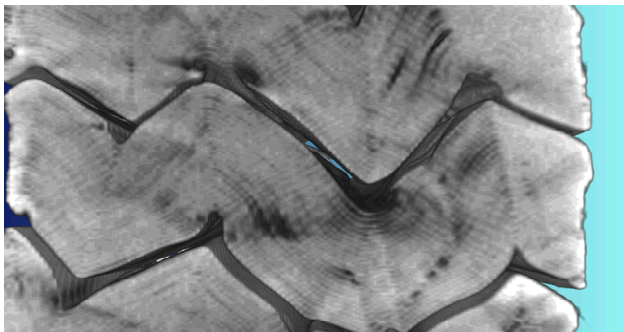
***Predict** life, performance, and safety issues*

***Inform** vehicle occupants, workers, and responders*

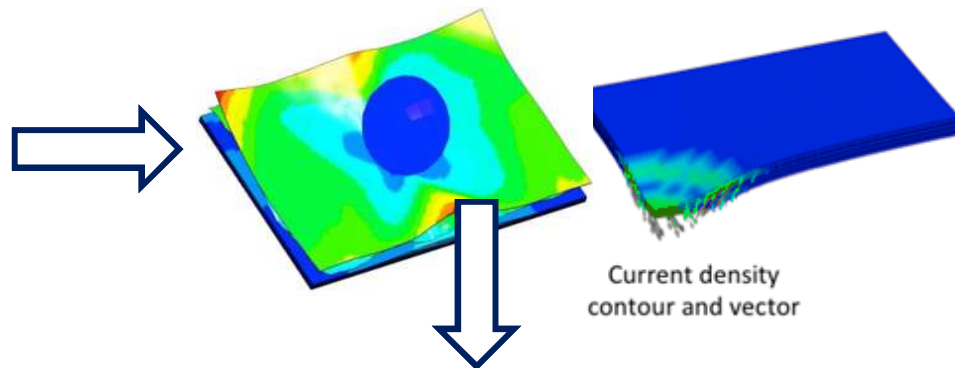
Crash Safety Modeling

Computer Aided Engineering for Batteries (CAEBAT) DOE VTO and NREL

Battery Crush Experiment (SNL, USCAR)

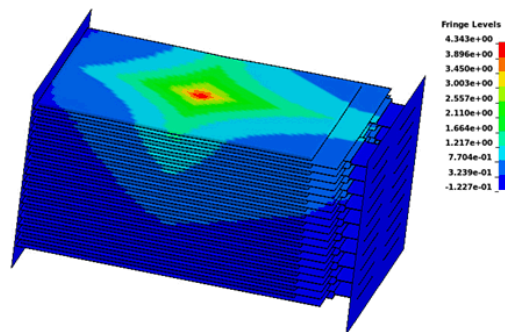


Cell-level Mechanical Model (MIT)

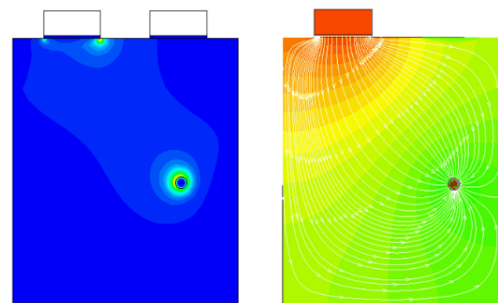


Integrated Thermochemical & Mechanical Model (NREL)

Thermal Cell-to-Cell Propagation Model



Thermochemical Model



Use battery crush data to validate the integrated model

Develop a predictive capability for battery thermal runaway response to mechanical insult

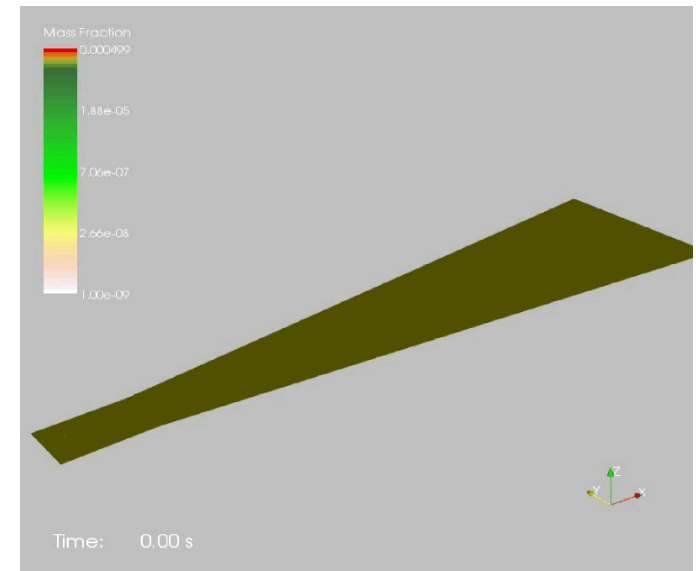
Predictive Modeling of Energy Storage Systems

- Materials chemistry for engineered safety of batteries – New electrolyte materials
- Modeling & simulation tools that predict thermal environments and the response of an object to that environment. (Advanced Scientific Computing (ASC) Program)
 - We can predict: Turbulent fluid mechanics (buoyant plumes); Participating Media Radiation (PMR); Reacting flow (hydrocarbon, particles, solids); Conjugate Heat Transfer (CHT)
- Adaption of ASC modeling framework to battery system to establish its' safety basis
 - We have demonstrated proof of concept



Image Source: WindPower Monthly

<http://www.windpowermonthly.com/article/1284038/analysis-first-wind-project-avoids-storage-30m-fire>



Predictive Simulation of Smoke Plume from Abnormal Event. The colors correspond to concentration of chemical species


Acknowledgement

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Battery Safety R&D Program at Sandia: http://energy.sandia.gov/?page_id=634

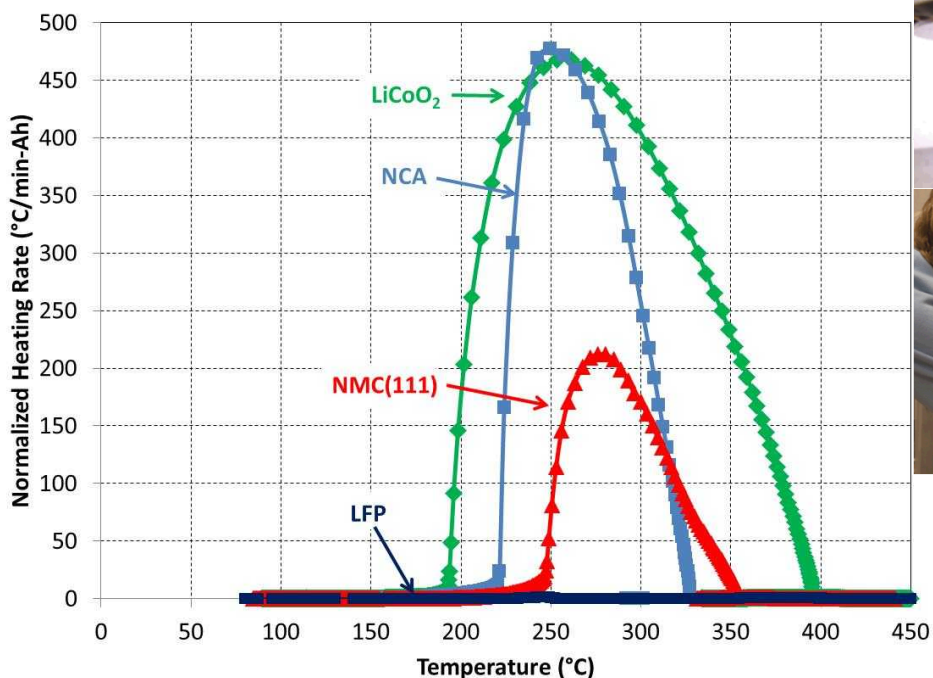
ECS Interface Issue on Battery Safety: http://www.electrochem.org/dl/interface/sum/sum12/if_sum12.htm

Research and Technology Interests

- 
- Thermal batteries (materials, design, testing, etc.)
 - Validated predictive modeling and simulation tools (CAEBAT- VTO)
 - Aging phenomenon
 - Materials at risk
 - Storage, conversion, and harvesting
 - Battery safety & reliability (VTO)
 - Advanced diagnostics for predicting performance and safety (DOT)
 - Compact power
 - High energy materials (VTO and JC SER)
 - Solid electrolytes
 - Flow batteries
 - Sodium batteries

Impact of Cell Chemistry on Runaway

- **One of the world's largest dedicated battery calorimetry facilities**
Six accelerating rate calorimeters (ARCs) for materials and cell-level measurements
- **Gas volume measurements for decomposition gas products**
- **Quantitative gas analysis capabilities from ARC samples**
Measurements on 1 to 150 Ah cells



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