SAND2018-11542PE

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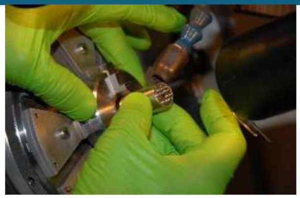
CSEP
COMPONENT SCIENCE, ENGINEERING, & PRODUCTION




Battery Safety Research and Development

10 October 2018

PRESENTED BY

June Stanley, Technical Staff for Power Sources R&D

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia's Histo...

Exceptional service in the national interest

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- November 1, 1...
  Sandia Labora...
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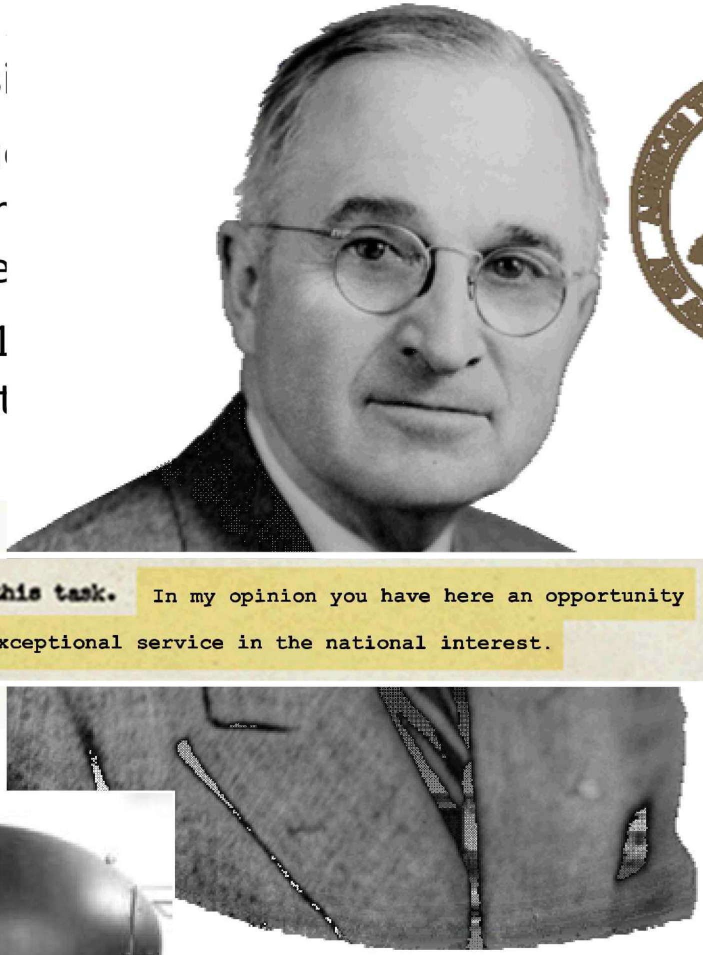
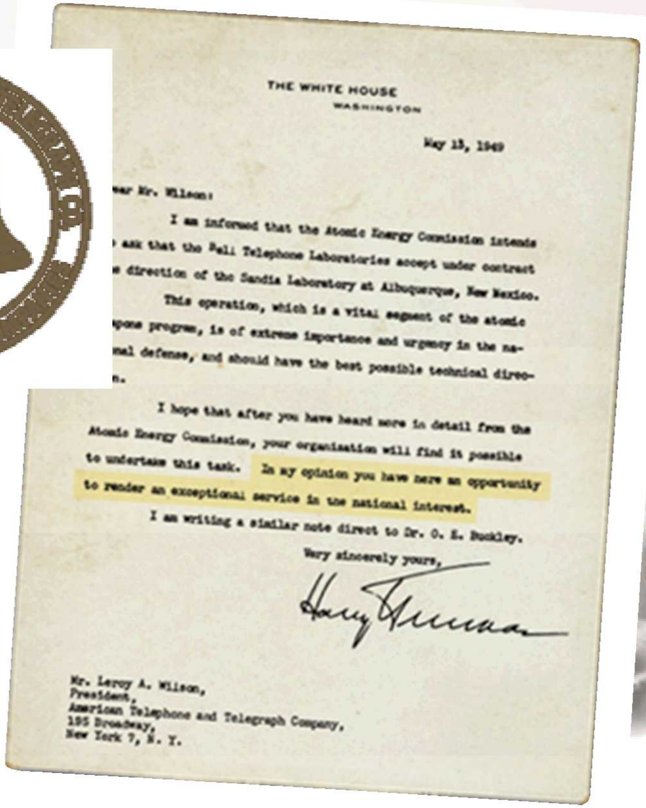


to undertake this task. In my opinion you have here an opportunity
to render an exceptional service in the national interest.


THE WHITE HOUSE
WASHINGTON

May 13, 1949

...ear Mr. Wilson:

I am informed that the Atomic Energy Commission intends
... ask that the Bell Telephone Laboratories accept under contract
...e direction of the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic
...pons program, is of extreme importance and urgency in the na-
...nal defense, and should have the best possible technical direc-
...n.

I hope that after you have heard more in detail from the
Atomic Energy Commission, your organization will find it possible
to undertake this task. In my opinion you have here an opportunity
to render an exceptional service in the national interest.

I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

Sandia Addresses National Security Challenges

1950s	1960s	1970s	1980s	1990s	2000s	2010s
Nuclear weapons	Development engineering	Multiprogram laboratory	Missile defense work	Post–Cold War transition	START Post 9/11	LEPs Cyber, biosecurity, proliferation
Production and manufacturing engineering	Vietnam conflict	Energy crisis	Cold War	Stockpile stewardship	National security	Evolving national security challenges

Governance of Sandia Laboratories

- AT&T/Bell: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–2017
- National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell Interactional Inc. 2017-present

Sandia Sites

Power Sources Technology Group

Power Sources Technology Group (PSTG)

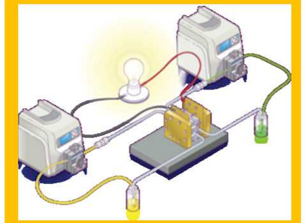

Enterprise Integration


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

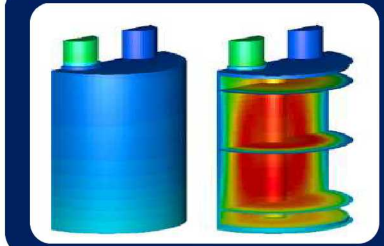
- *Field Failure*
  - Manufacturing defects
    - Separator damage, foreign debris
    - Can develop into an internal short circuit
- ***Abuse Failure***
  - **Mechanical**
  - **Electrical**
  - **Thermal**

Impact of Battery Safety/Reliability Issues

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

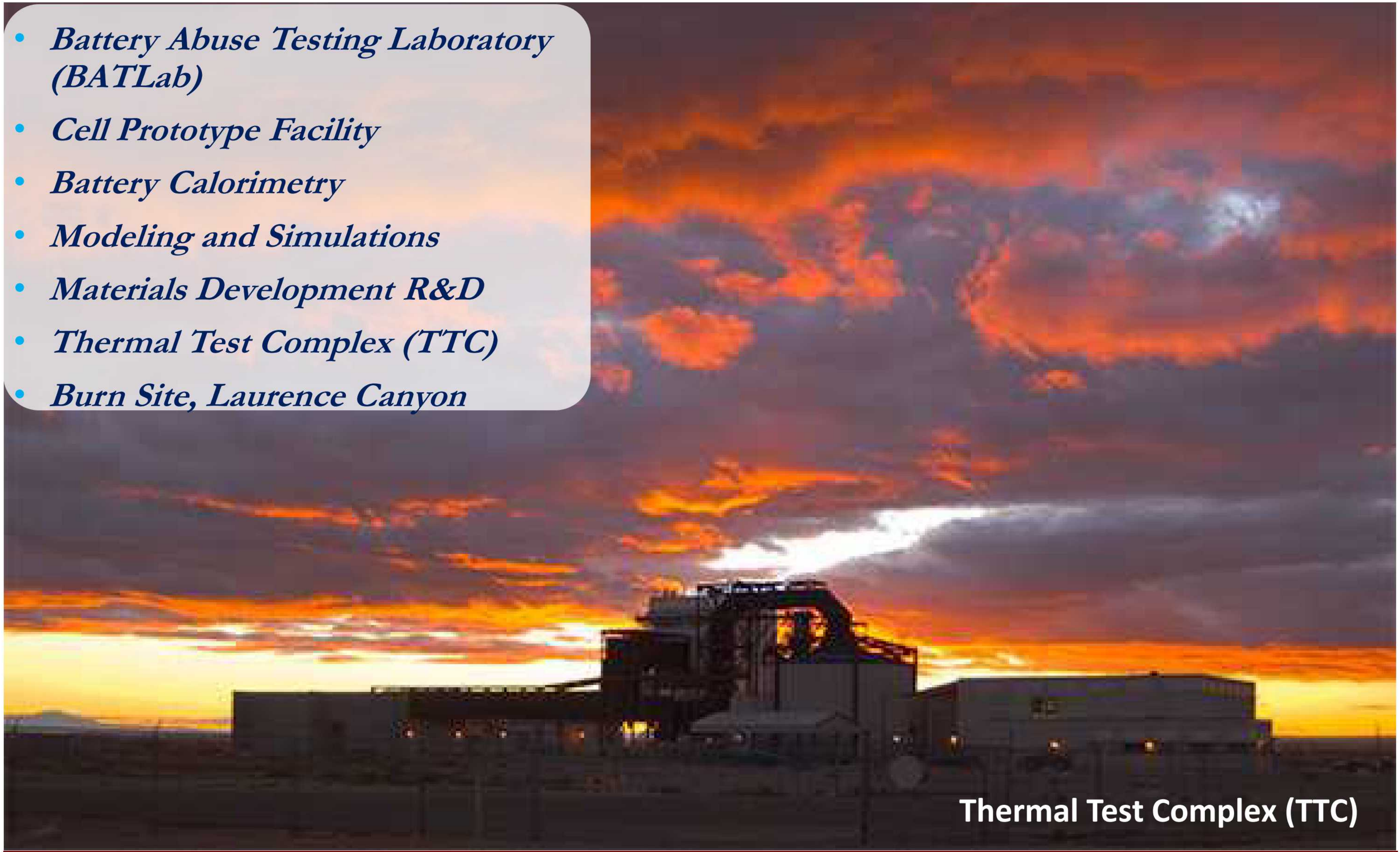


Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating vehicle crash and failure propagation models
- Fire Simulations to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation
- SAND2017-6925, Recommended Practices for Abuse Testing Rechargeable Energy Storage Systems (RESSs)
- SAE J2464/UL 1642 procedures and standards
- R&D programs with NHTSA/DOT to inform best practices, policies, and requirements

Capabilities and Infrastructure

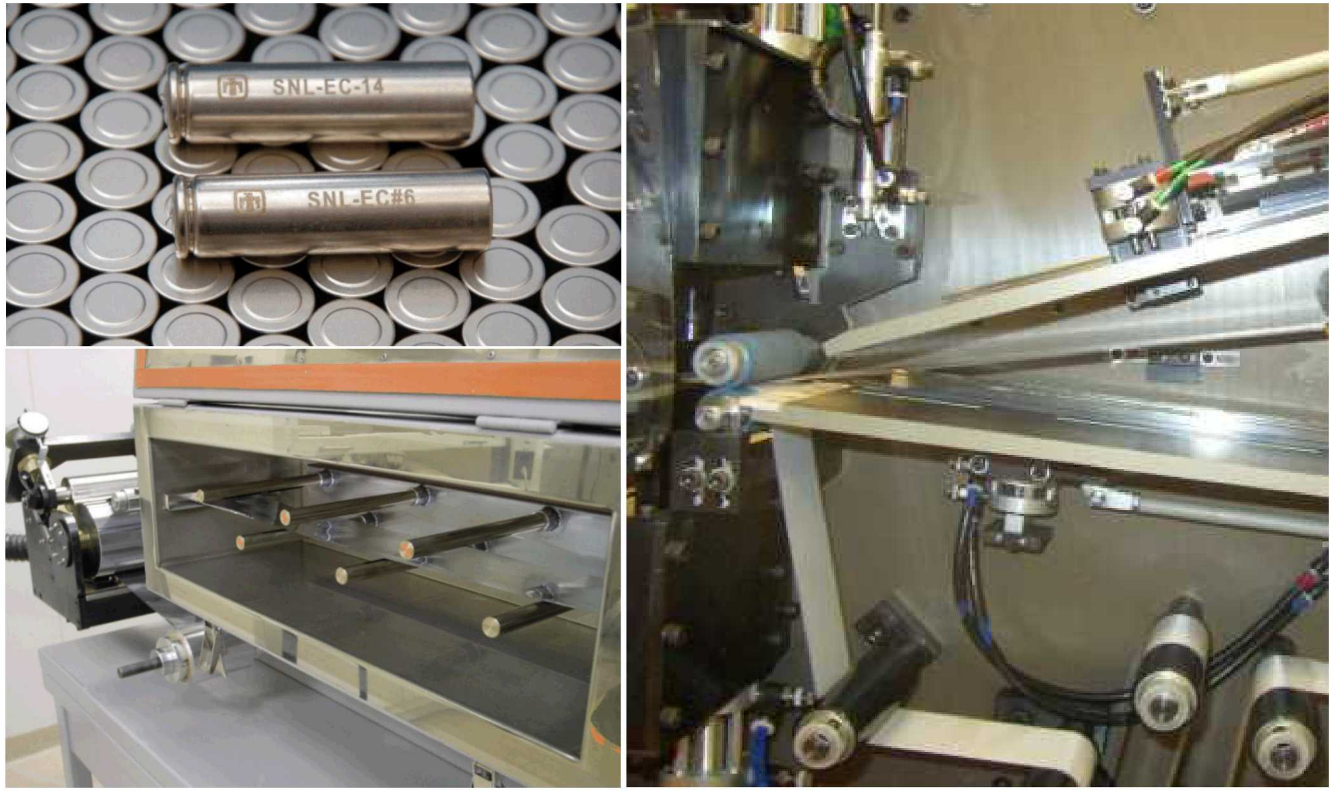
- *Battery Abuse Testing Laboratory (BATLab)*
- *Cell Prototype Facility*
- *Battery Calorimetry*
- *Modeling and Simulations*
- *Materials Development R&D*
- *Thermal Test Complex (TTC)*
- *Burn Site, Laurence Canyon*



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, $Li_4Ti_5O_{12}$, Li-S, $LiCoO_2$, NMC, LFP, and spinel cathodes ($LiMn_2O_4$ and $LiNi_{0.5}Mn_{1.5}O_4$)**

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

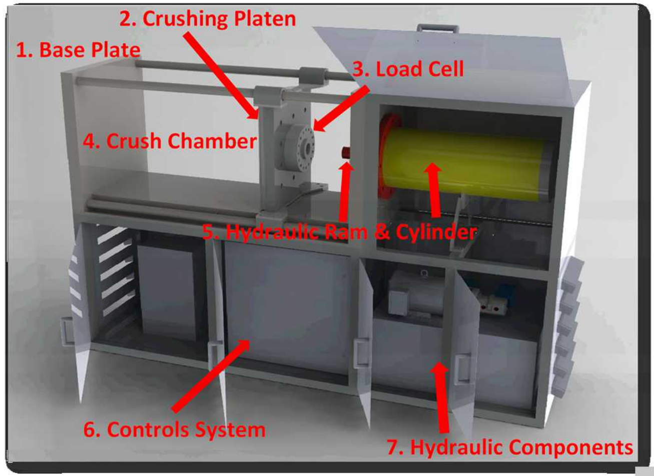
Burn Site: Remote/Large Scale Test Facility

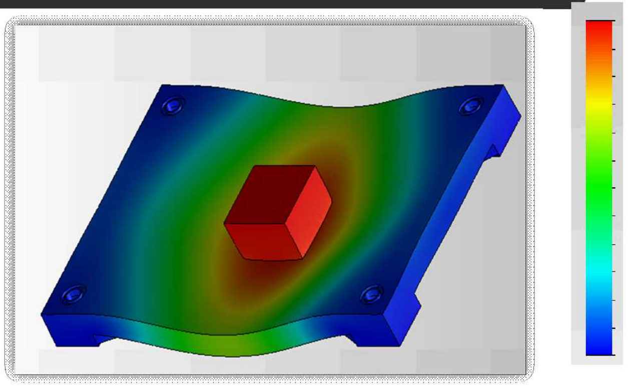
Full Scale Battery Testing Facilities

Large Scale Test Capabilities

Drop Tower

Large battery crusher





From Idea, to CAD Model, to Hardware!

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

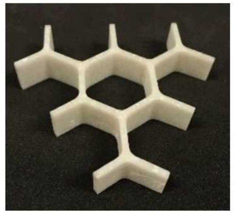
EUCAR Hazard Severity Level Ratings		
Hazard Severity Level	**Description**	**Classification Criteria for Severity Classification**
0	No effect	No effect. No loss of functionality.
1	Reversible Loss of Function	No defect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic 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 >= 50%	No fire or flame; no rupture; no explosion. Weight loss >=50% of electrolyte weight. Heavy smoke (electrolyte = solvent + salt)
5	Fire or Flame	No rupture; no explosion (*i.e.,* 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.e.,* disintegration of the RESS with externally damaging thermal & kinetic forces). Exposure to toxic substances in excess of OSHA limits

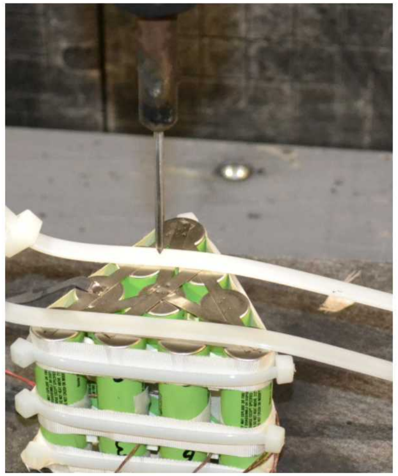
Transportation/Battery Safety

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.



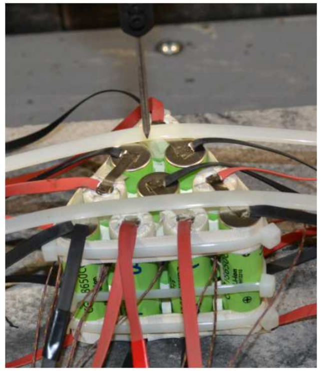


2 mm spacing; Full propagation through all 10 cells. Peak temperatures reach >800°C

Pretest

Posttest

4 mm spacing; no propagation. Only center cell went into runaway



Pretest

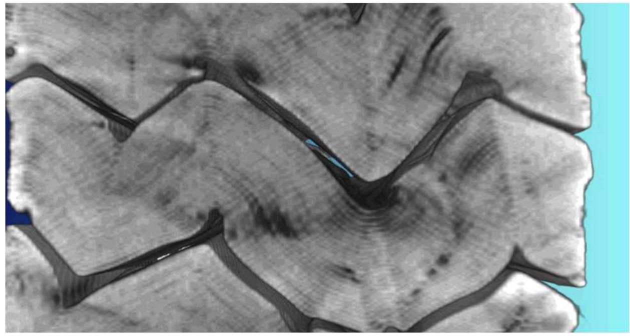
Posttest

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)

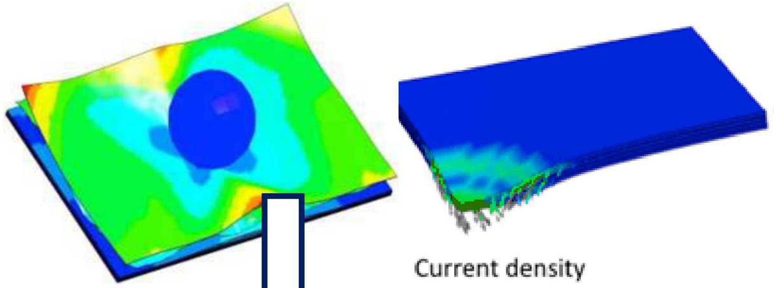
Crash Safety Modeling

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

Battery Crush Experiment (SNL, USCAR)

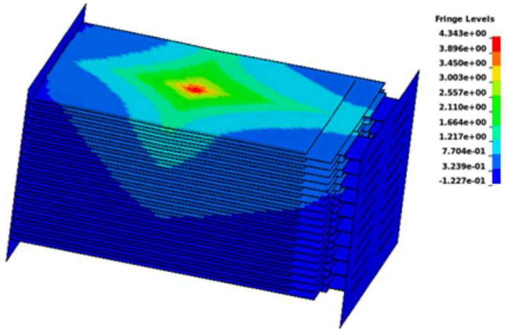


Cell-level Mechanical Model (MIT)

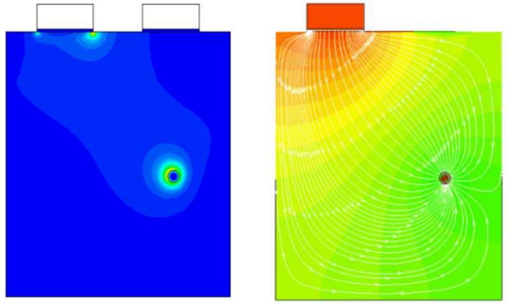


Integrated Thermoelectrochemical & Mechanical Model (NREL)

Thermal Cell-to-Cell Propagation Model



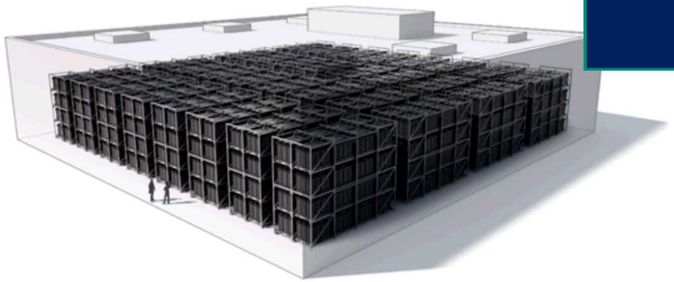
Thermoelectrochemical Model



Use battery crush data to validate the integrated model
Develop a predictive capability for battery thermal runaway response to mechanical insult

Advanced Battery Diagnostics

Transportation



Grid Storage

Advanced Battery Diagnostics

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

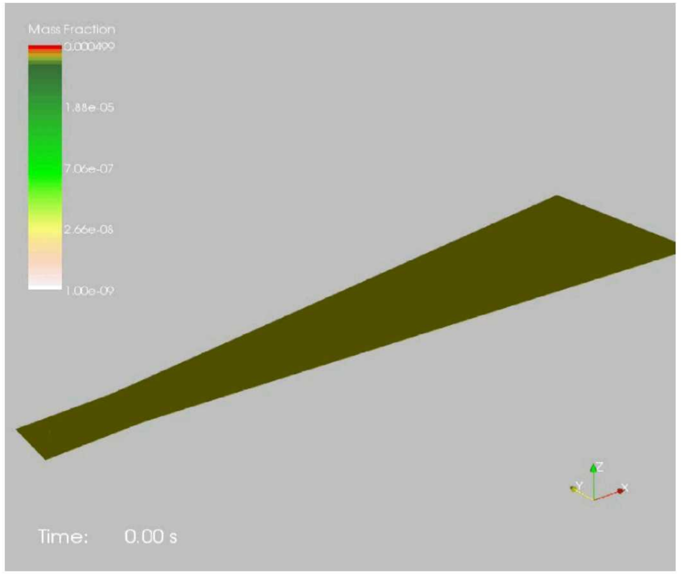
Predict *life, performance, and safety issues*

Inform *vehicle occupants, workers, and responders*

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



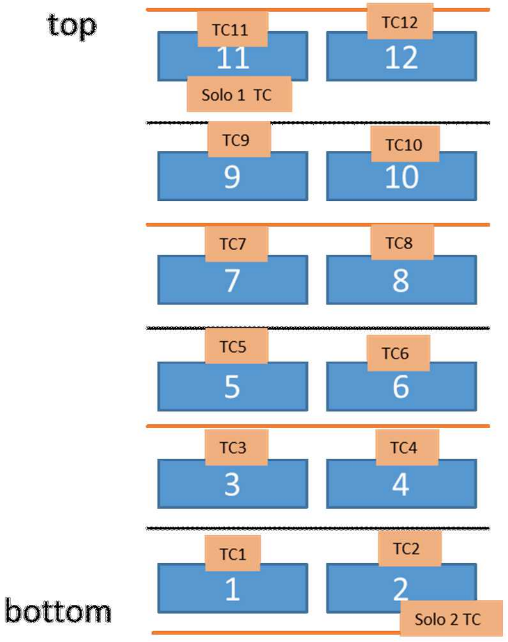
Predictive Simulation of Smoke Plume from Abnormal Event. The colors correspond to concentration of chemical species

Large Scale Propagation Through Heating

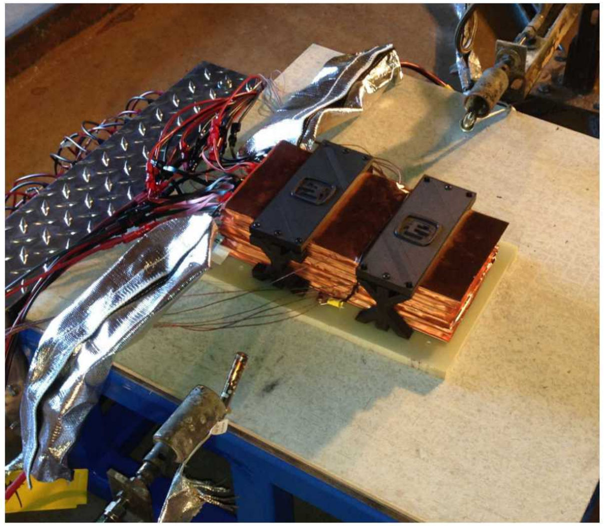
1kWh battery pack: heaters between cells ramped a 5°C/min until failure

Li-ion pouch cell

Battery Schematic



Assembled battery



1 kWh battery thermal ramp video

- 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
- Large amounts of gas generation observed

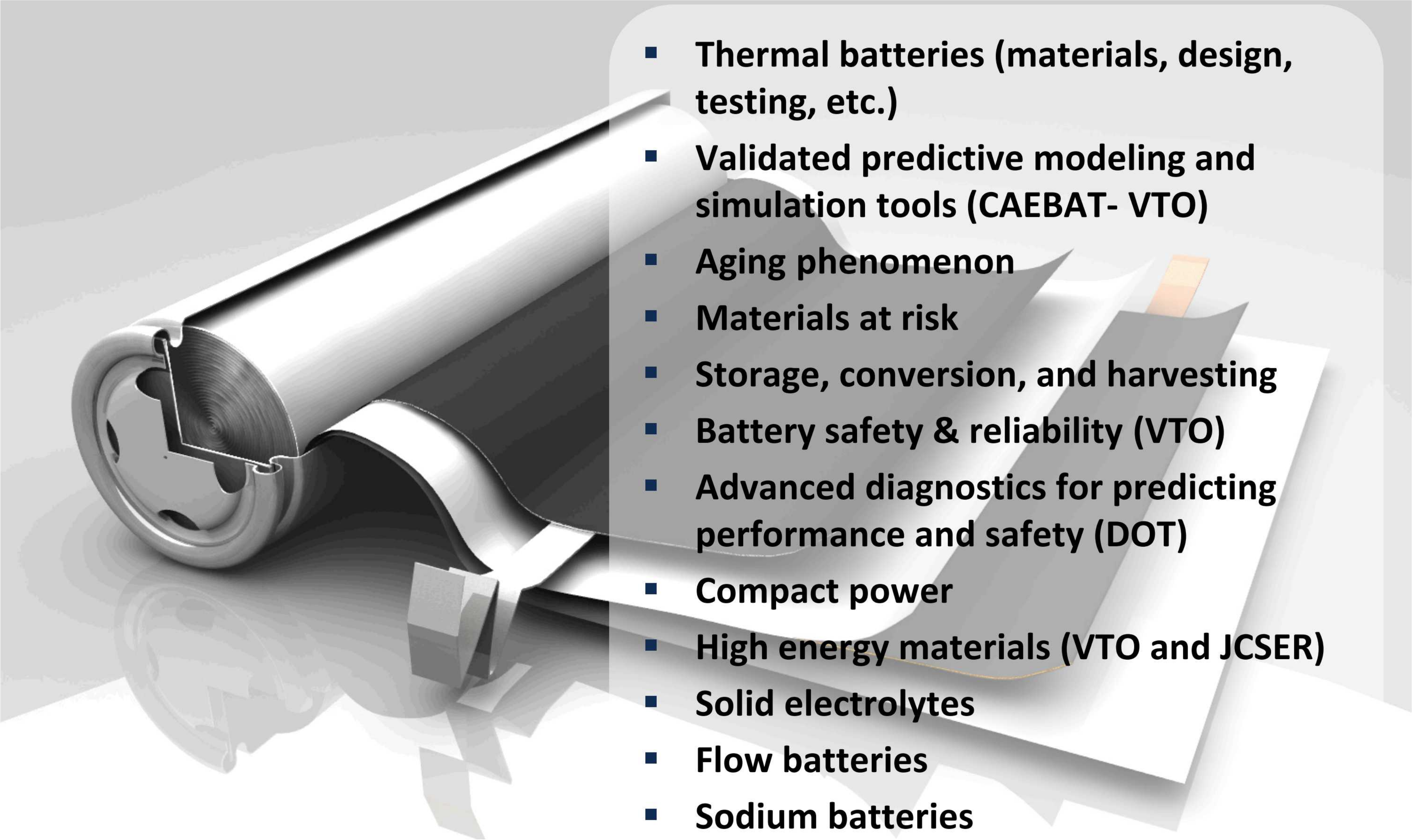
Acknowledgement

- David Howell (DOE)
- Brian Cunningham (DOE)
- Samm Gillard (DOE)
- Peter Faguy (DOE)
- Phil Gorney (NHTSA)
- Steve Summers (NHTSA)
- Scott Ashbaugh (SNL)
- Chris Orendorff (SNL)
- Babu Chalamala (sNL)

- Mani Nagasubramanian
- Joshua Lamb
- Kyle Fenton
- Chris Apblett
- Brian Perdue
- Jill Langendorf
- Chris Grosso
- Lucas Gray
- Loraine Torres-Castro
- Leigh Anna Steele
- John Hewson
- Anay Luketa

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*

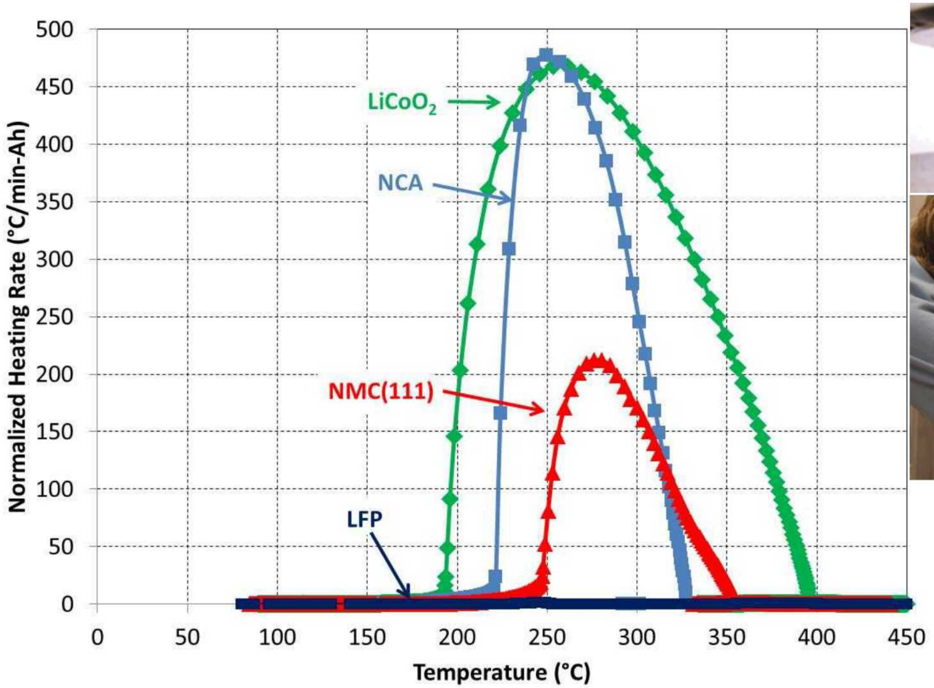
Research and Technology Interests



- 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 JCSER)
- Solid electrolytes
- Flow batteries
- Sodium batteries
- Impact Testing (CAEBAT)

Impact of Cell Chemistry on Runaway

- *One of the world's largest dedicated battery calorimetry facilities*
  - *Six accelerating rate calorimeters (ARCs)*
  - *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