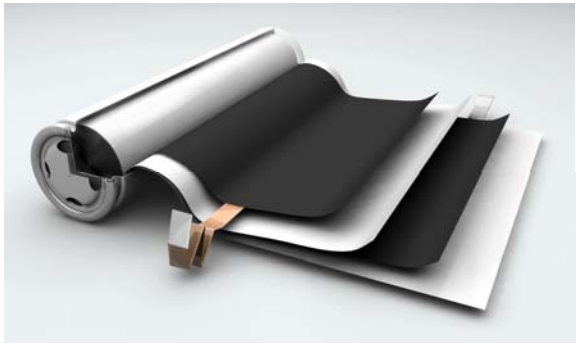
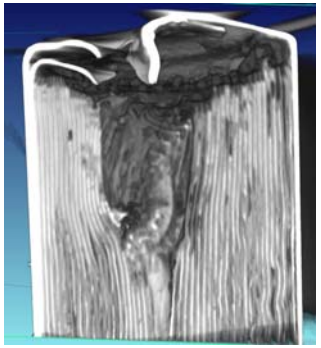
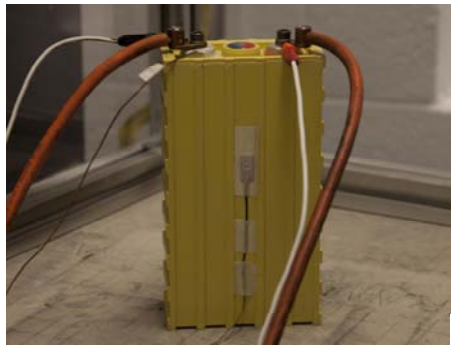
SAND2013-9227P

Exceptional service in the national interest

Sandia National Laboratories



Battery Safety R&D at Sandia National Laboratories

Christopher J. Orendorff

EESAT

October 22, 2013

San Diego, CA

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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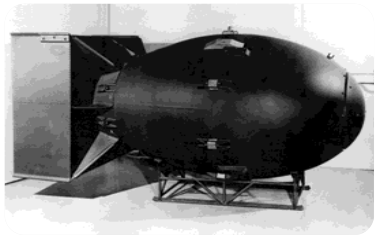
Energy Storage System Safety at SNL

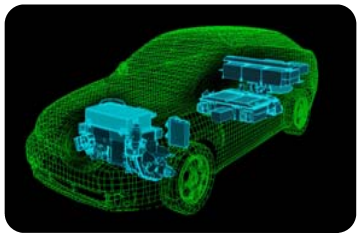
Sandia National Laboratories



Safety and Reliability of Energy Storage Systems for NW (NNSA)

- Cradle-to-grave responsibility for NW power sources including **safety and reliability**
- High value, **high consequence assets**
- Unique opportunities and **use conditions**

- Born out of capabilities developed in the NW program
- Program support by DOE EERE OVT
- **Cost and performance** are primary drivers in the automotive industry
- Unique opportunities and **use conditions**



Battery Safety R&D Program for Transportation



Safety and Reliability for Utility Energy Storage

- **Differentiated from transportation** safety by scale, technologies, and use conditions
- Currently **no government program** supporting energy storage **safety for the grid**
- Recent **utility safety incidents** have highlighted the **need for a focused effort** in this area

Differentiating the Grid Energy Storage Safety Challenge

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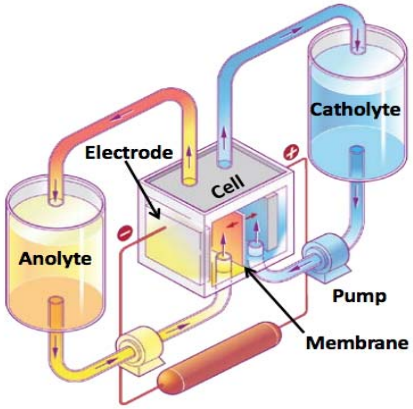
- ***Variety of technologies***
- ***Proximity to population***
- ***Use conditions***
- ***Design considerations***
- ***System complexity***
- ***Grid integration***
- ***Scale and size***


Subway regen system, SEPTA



Redox Flow Battery

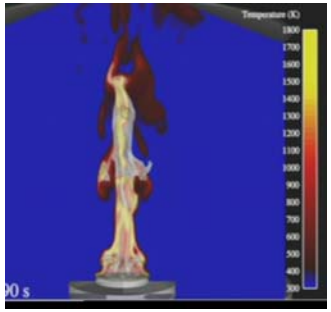
SAFT 10 MWh storage system

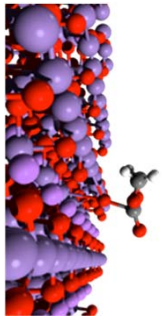

US Marine Corps FOB, Afghanistan

Infrastructure for Energy Storage Safety

Sandia National Laboratories

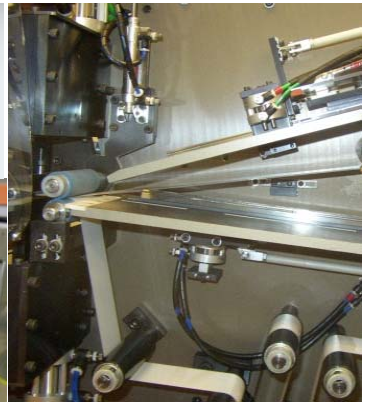
Simulation and Modeling



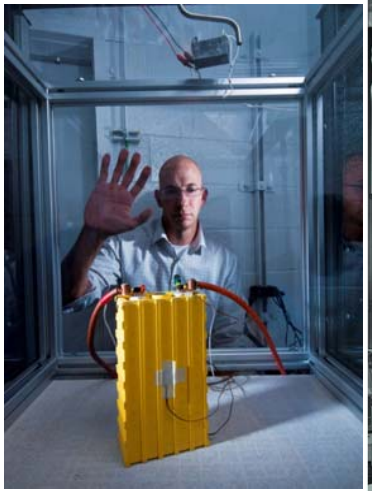


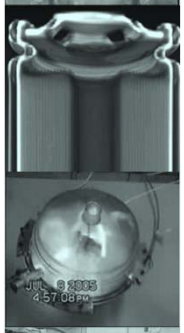
Thermal Test Complex

Cell Fabrication Facility



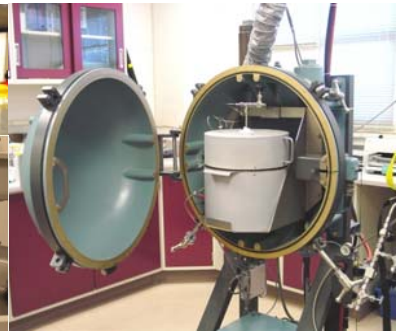
Battery Abuse Testing Laboratory





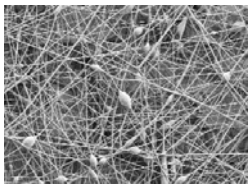
Energy Materials R&D

Battery Calorimetry



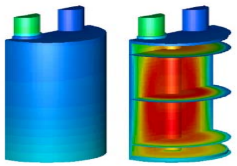
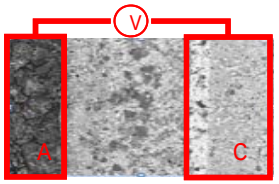
Understanding Battery Safety

Sandia National Laboratories




Materials R&D
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials


Testing
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Large scale thermal and fire testing (TTC)
- 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 Dynamic Simulations (FDS) to predict the size, scope, and consequences of battery fires

USABC
UNITED STATES ADVANCED BATTERY CONSORTIUM LLC
UL
SAE INTERNATIONAL
DEPARTMENT OF TRANSPORTATION
UNITED STATES OF AMERICA

Procedures, Policy, and Regulation
- USABC FreedomCAR Abuse Testing Manual
- SAE J2464, UL1642
- Testing programs with NHTSA/DOT to influence policies and requirements

Battery Safety R&D Program Support

Sandia National Laboratories

Examples from the Battery Safety R&D Program

Abuse Testing

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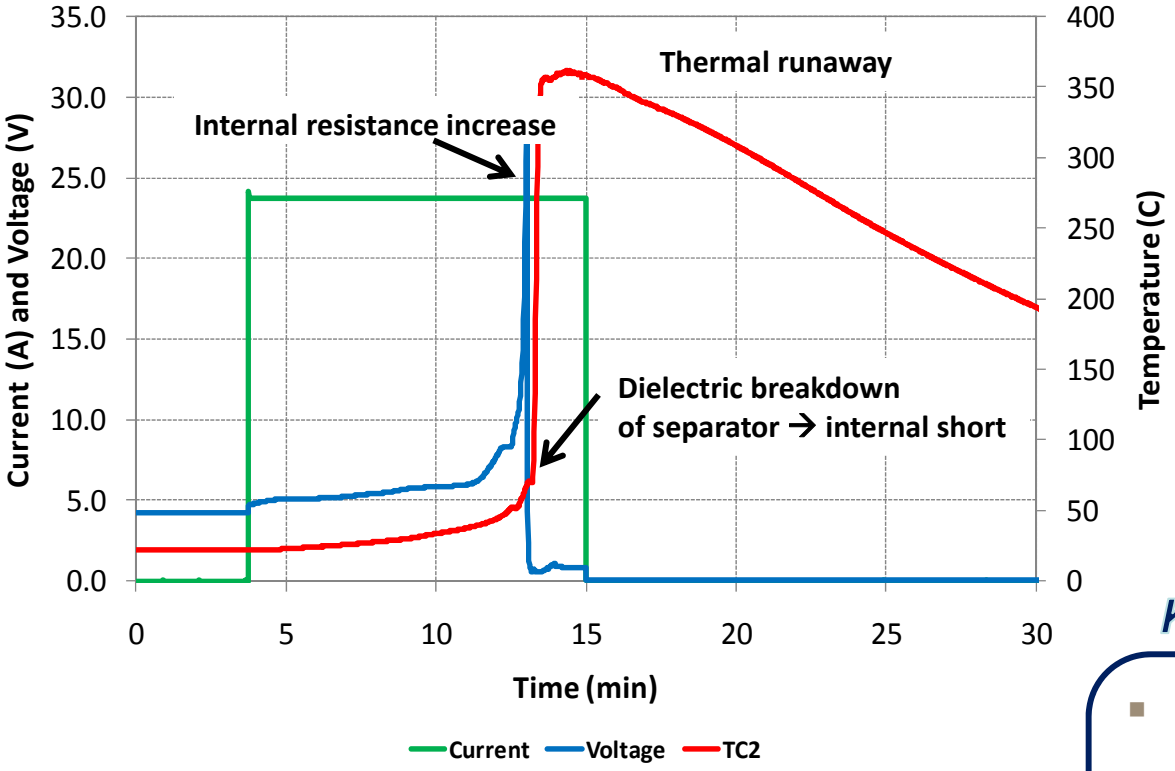
12 Ah (~50 Wh) Cell Overcharge Abuse



PL-8570170-2C_01 fire.mpg

(Internal temperature limited due to ejection of cell contents)

50 kWh battery failure? 50 Mh battery failure?

Key Questions:

- *Abuse tolerance?*
- *Heat generation?*
- *Flammability?*
- *What happens to neighboring cells in a battery?*

Battery Calorimetry

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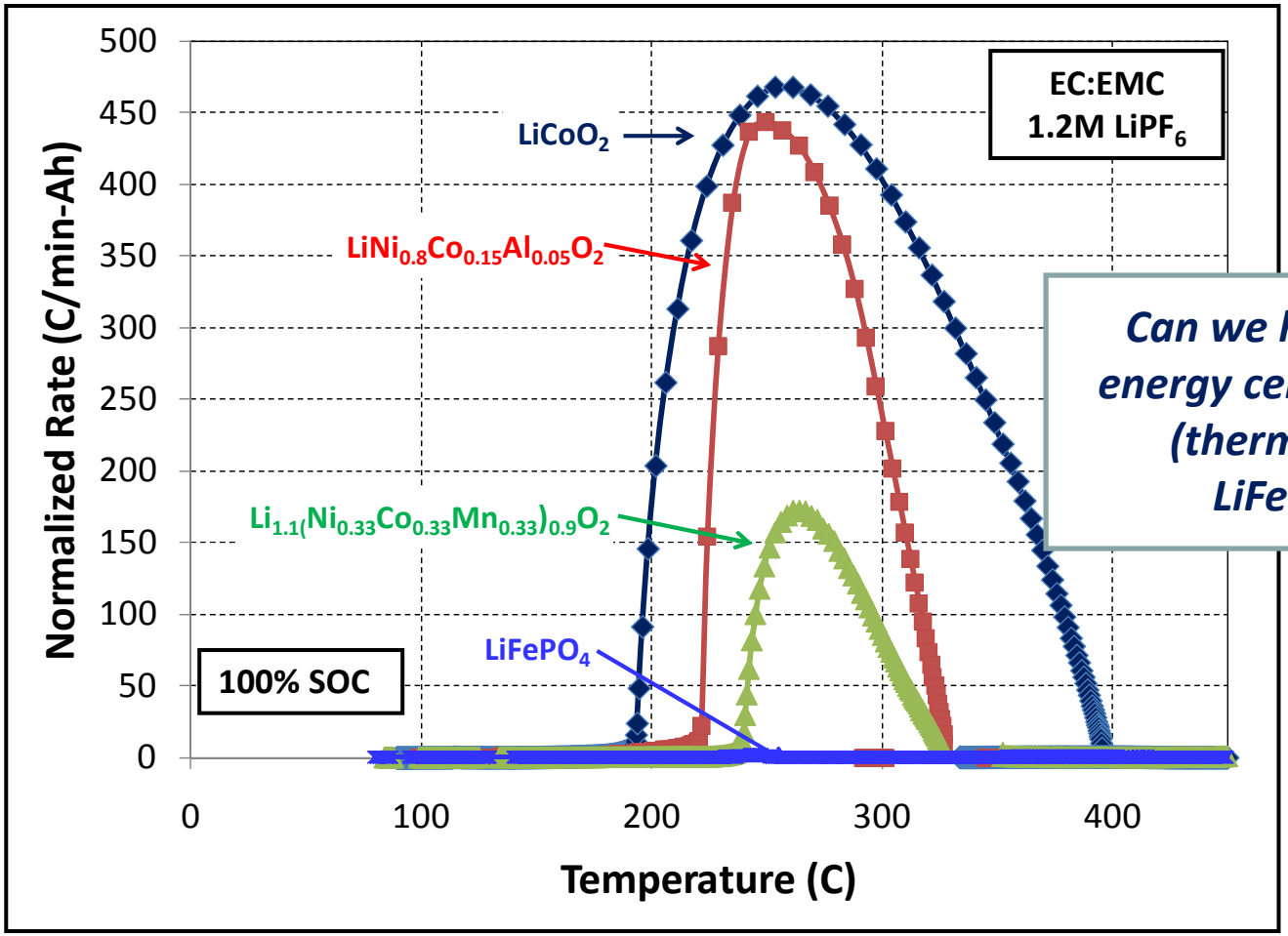
Calorimetry of lithium-ion cells with different cathode chemistries



Can we have a higher energy cell that behaves (thermally) like a $LiFePO_4$ cell?

Differences in runaway enthalpy and reaction kinetics are related to oxygen release from the cathode and the electrolyte combustion

Improving Runaway Response

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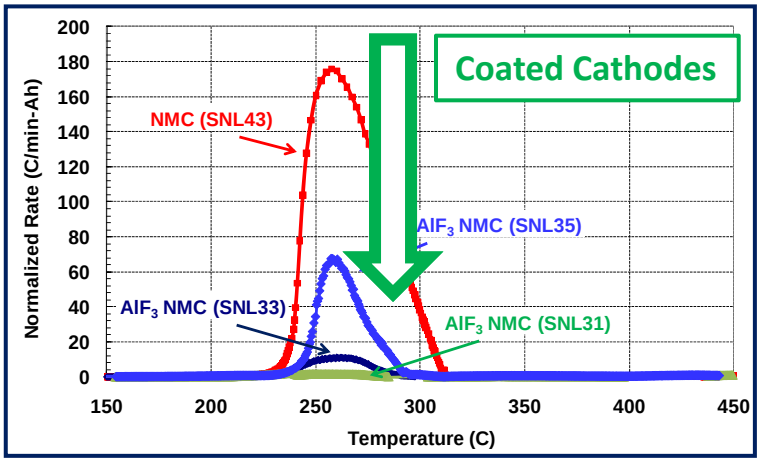
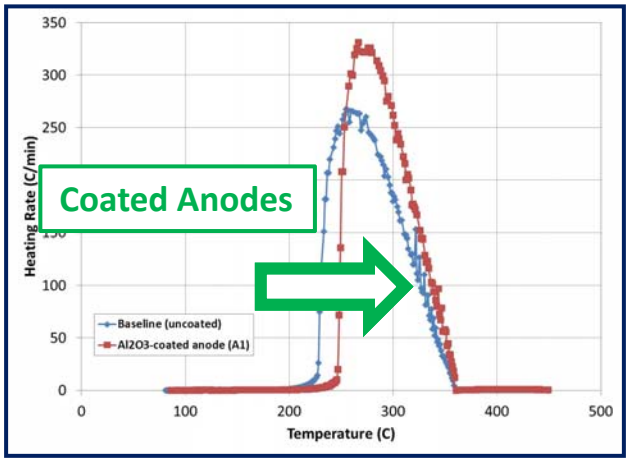
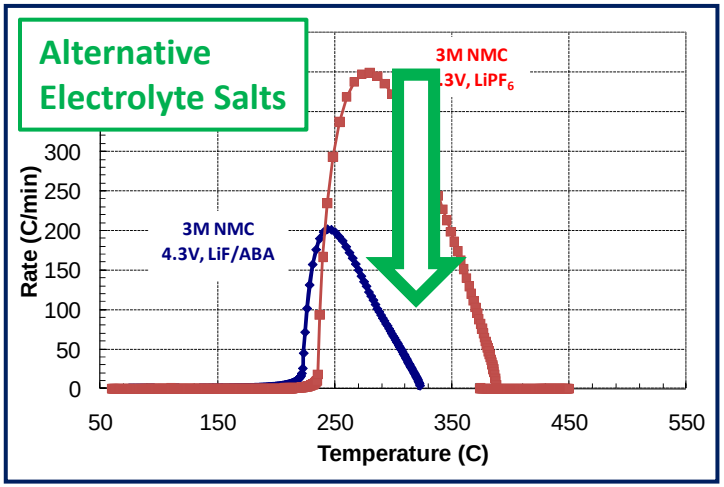
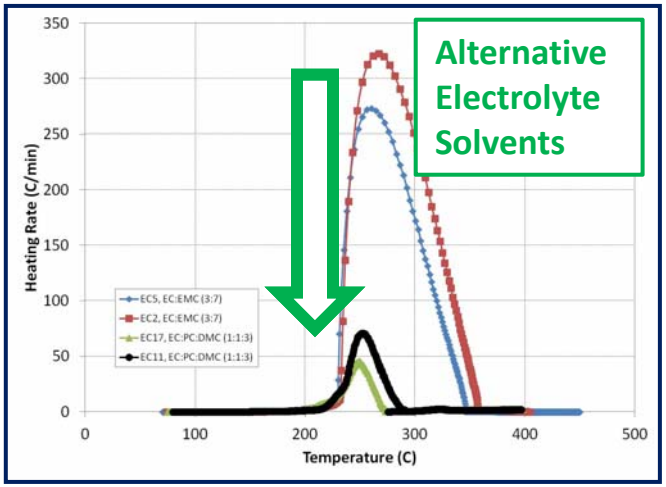
NMC/Graphite cells









Materials choices can be made to improve the runaway response in cells
Reducing runaway enthalpy and kinetics has direct implications in battery system safety

Electrolyte Flammability

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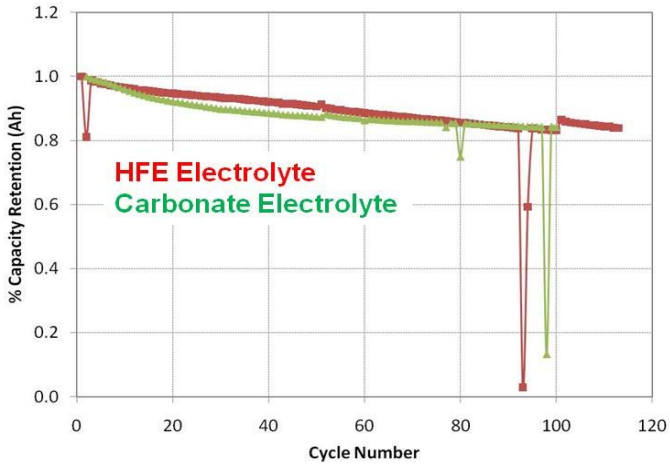
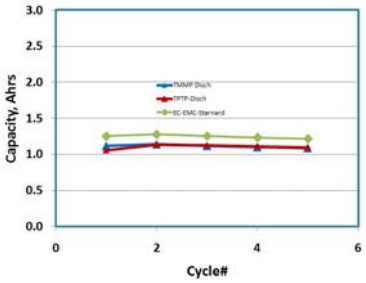
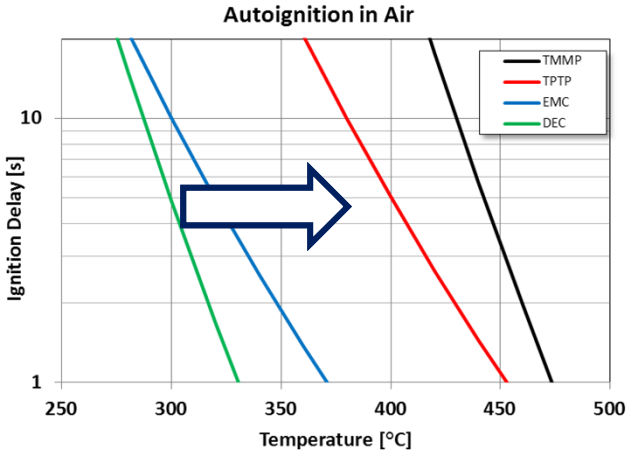
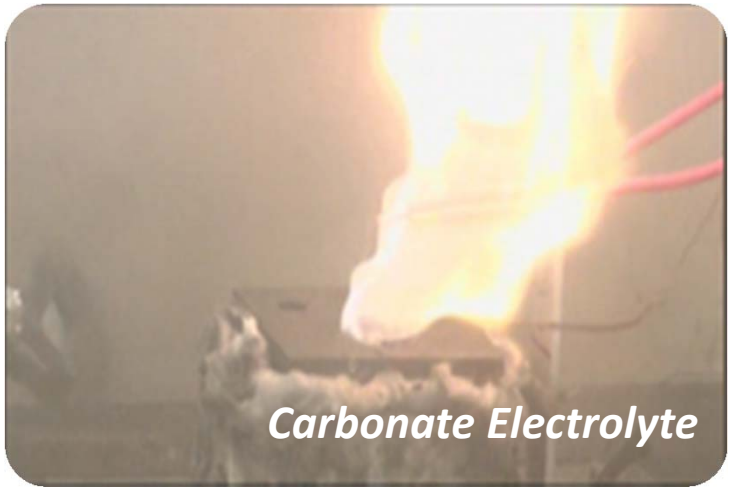
Hydrofluoro ether (HFE) Electrolytes









- ***HFEs show higher autoignition temps in air compared to carbonates***
- ***50% HFE electrolytes show no ignition or flammability***

G. Nagasubramanian et al. J. Power Sources 196 (2011) 8604-8609

Battery System Field Failures

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Field failures could include:

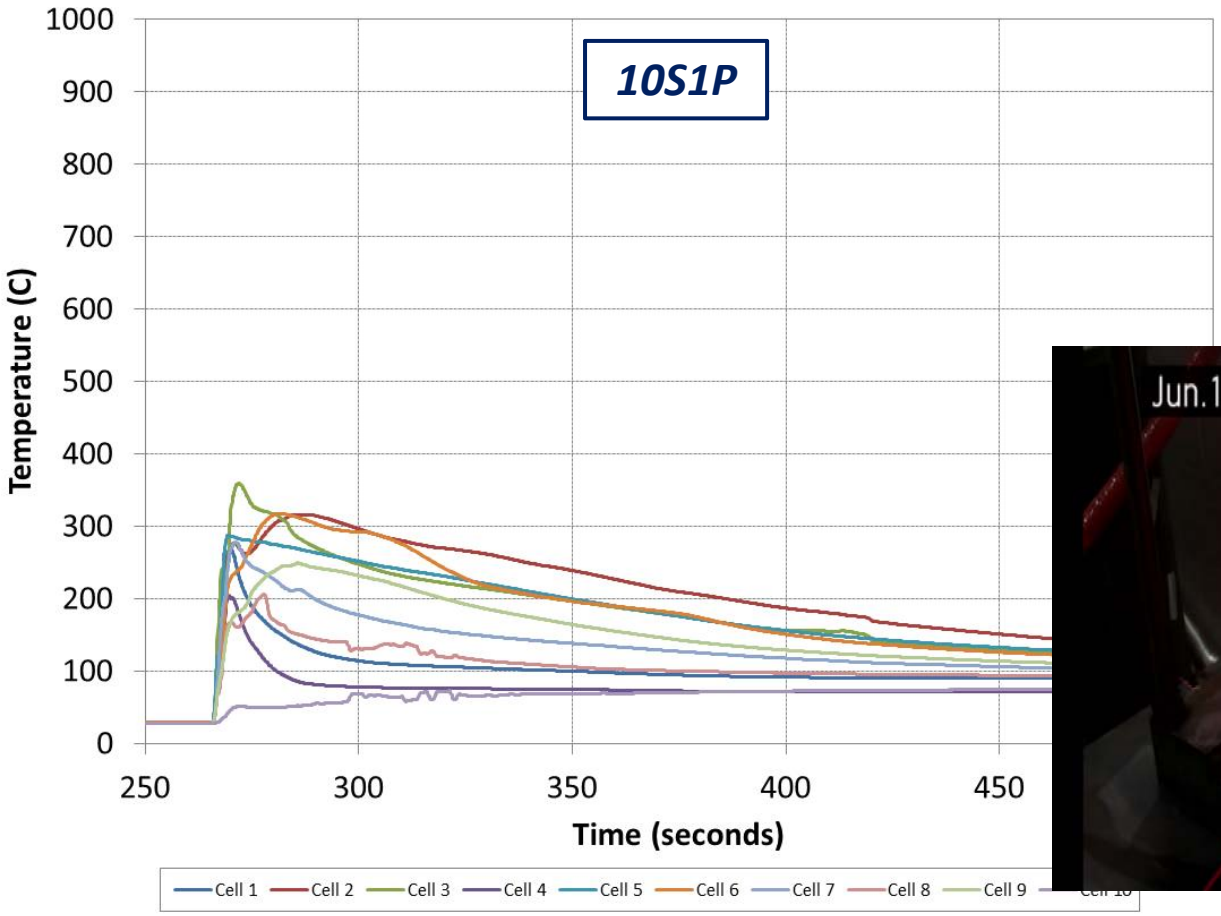
- Latent manufacturing defects
- Internal short circuits
- Unique use or **abuse conditions**
- Control failure (low voltage, control systems, connectors, boards, not battery initiated)

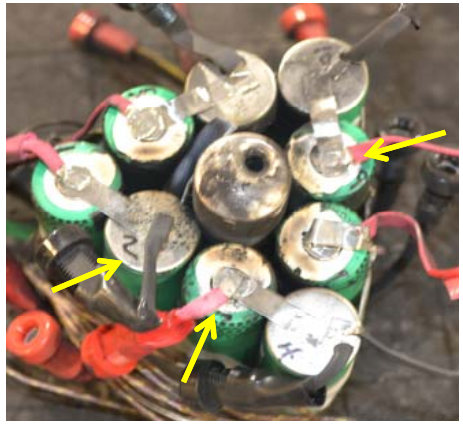
Any **single point failure** that **propagates** through a entire battery system is an **unacceptable** scenario to ensure battery safety

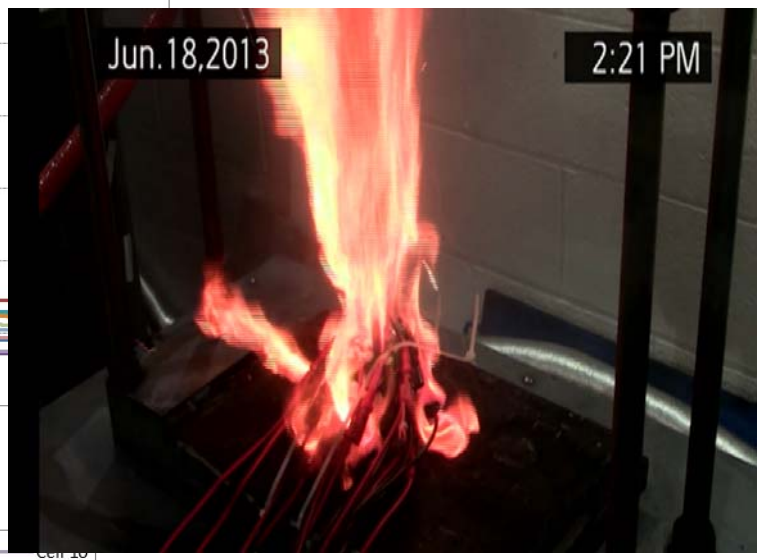
Tesla Model S fire in October 2013, Washington

Failure Propagation Testing

10S1P and 1S10P configurations
2.2 Ah 18650 cell packs (92 Wh at 100% SOC)
Failures initiated by mechanical insult to the center cell (#6)





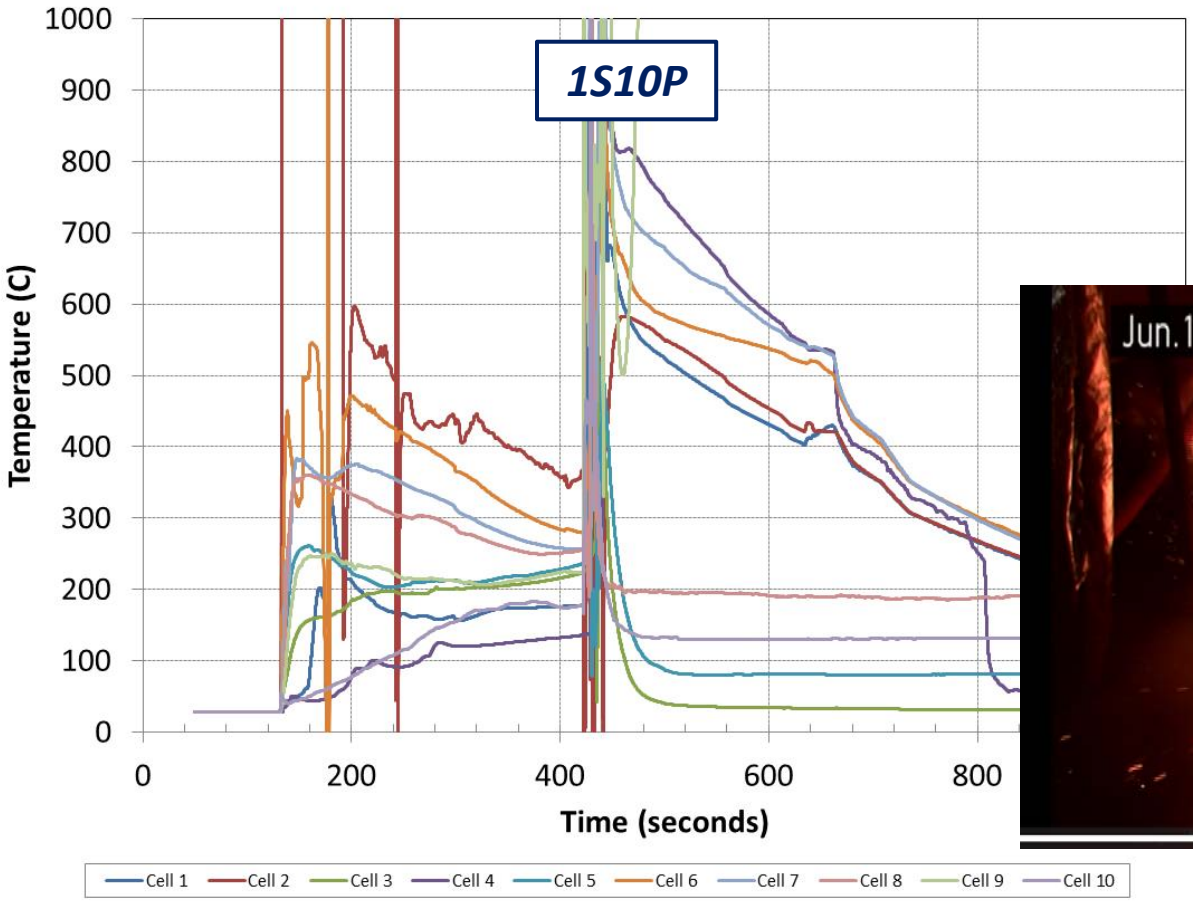


10S1P pack.mp4

Limited propagation of the single point failure in the 10S1P pack

Failure Propagation Testing

10S1P and 1S10P configurations
2.2 Ah 18650 cell packs (92 Wh at 100% SOC)
Failures initiated by mechanical insult to the center cell (#6)



Complete propagation of a single point failure in the 1S10P pack

1S10P_1.mp4
1S10P_final.mp4

Quantifying Battery Fires

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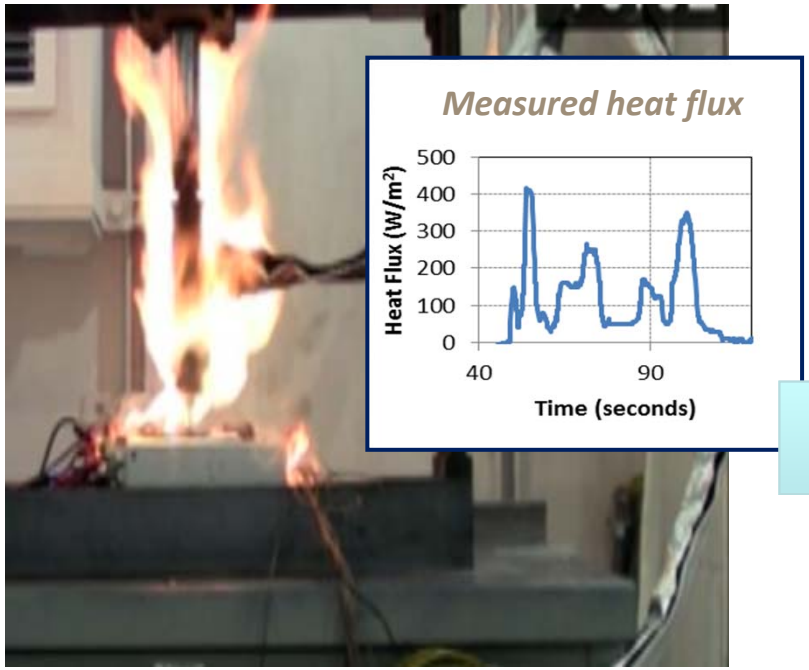
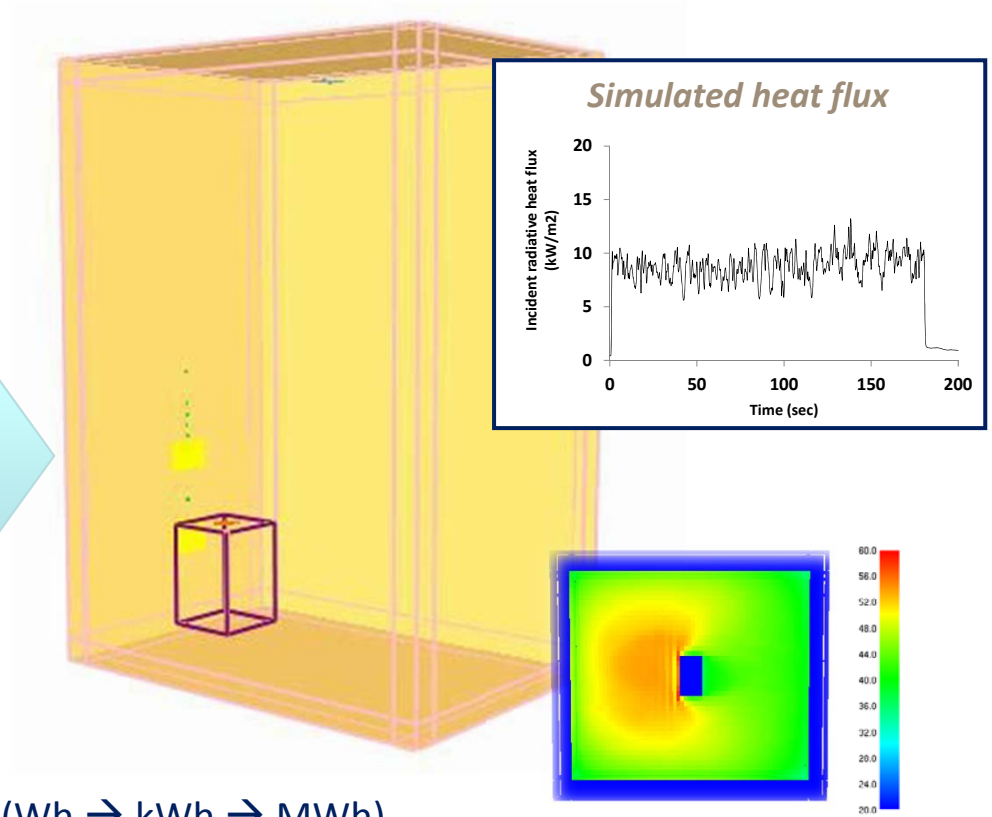
Experimental Data from Battery Fires



Fire Dynamic Simulations (FDS) of Battery Fires



Test bay ceiling temperature

- Scale up experiments to **validate FDS models** (Wh → kWh → MWh)
- Feedback to **design** storage systems
- Inform **fire suppression** system design
- Provide to regulatory agencies (NFPA, NHTSA), utility companies, etc.

Standards, Regulation, and Policy

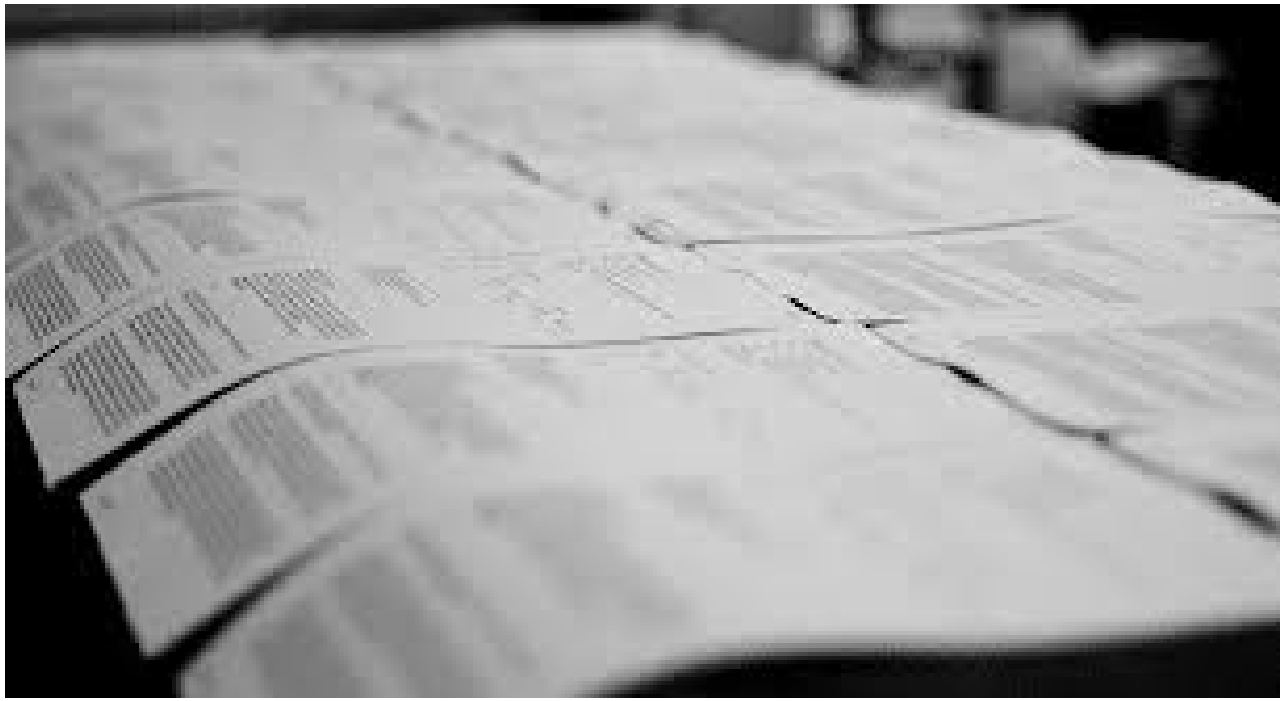
Sandia National Laboratories

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

Standards, Regulation, and Policy

Sandia National Laboratories

- **USABC** FreedomCAR Abuse Manual
- Testing development, evaluation, and validation
- Work on **SAE J2464, UL 1642**
- Testing support for **NHTSA** to influence **regulation and policy**



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Summary

Sandia National Laboratories

- Sandia has a long history of supporting battery safety and reliability for a variety of customers
- There is a gap in programs focused on grid storage safety and reliability
- Significant infrastructure and capabilities exists for performing this much needed work
- Examples from the lithium-ion/vehicle field highlight the progress that has been made, challenges with deploying new technologies/scaling technologies, and opportunities ahead
- Fielding the most inherently safe chemistries and designs can help address the challenges in system-level safety and reliability

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- Denise Bencoe
- Dave Johnson
- Scott Spangler
- June Stanley

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*