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# Safety and Reliability of Energy Storage Systems

Let's push the limits of technology while ensuring safety and reliability are always in the driver's seat!

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Battery Safety Lead, Sandia National Laboratories

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2025 OE Peer Review



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## Safety is our Vigilant Guardian

Prevent accidents by eliminating, reducing, or controlling hazards

**Hazard** – a system state or set of conditions that could lead to an accident



## Reliability is our Steadfast Partner

Prevent loss of service by eliminating,  
reducing, or controlling risk

**Risk** – a combination of the probability of  
a failure with its severity

## **Safety and Reliability are Interconnected**

Safe energy storage systems are more reliable

&

Reliable energy storage systems reduce the risk of failures



# Increased Media Attention on Energy Storage Systems Safety, But...



## **Bloomberg** NEWS

### **Blaze Triggers Alarm Over Rapid Growth of Big Batteries**

*A massive California battery fire has become a rallying cry for opponents of the technology*



<https://www.bloomberg.com/news/articles/2025-04-12/blaze-triggers-alarm-over-rapid-growth-of-big-batteries>

## *The San Diego* **Union-Tribune**



**Fire in Otay Mesa puts battery storage projects under scrutiny and neighborhoods on edge.**

<https://www.sandiegouniontribune.com/2024/06/20/fire-in-otay-mesa-puts-battery-storage-projects-under-scrutiny/>

## **THE KOREA TIMES**

**At least 22 dead in fire at lithium battery plant**



<https://www.koreatimes.co.kr/southkorea/society/20240624/at-least-22-dead-in-fire-at-lithium-battery-plant>

# ...Battery Fires Are Not New



2006

Sony/Dell Laptops



2010

UPS Cargo Plane



2011

DOT/NHTSA Facility



2013

Boeing Dreamliner



2019

ESS Arizona



2022

Electric Vehicle (Tesla)



2023

Battery Storage Facility



2024

Manufacturing Facility



Each incident has provided valuable lessons, leading to advancements in battery technology, improved safety standards, and better risk management practices.

# Stored Energy Carries Inherent Risk



Potential Energy



# Stored Energy Carries Inherent Risk



How to reduce the risk of energy storage systems?

Safe by Design

## Key Questions

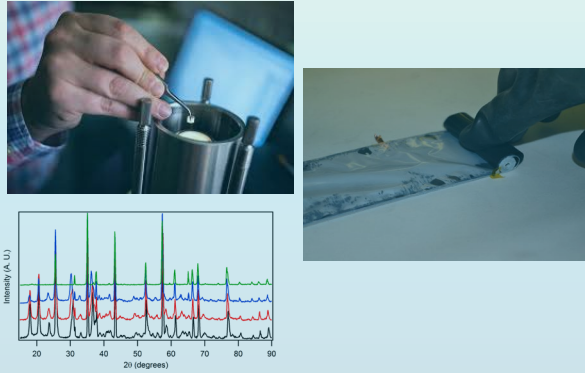
- What are the hazards?
- What are the risks?
- What is the level of acceptable risk?
- What are the mitigation strategies for those risks?

Safety must be addressed at the cell, battery and system level to ensure the safety and reliability of the energy storage system.

# Comprehensive Overview of ESS Safety and Reliability



## Materials R&D



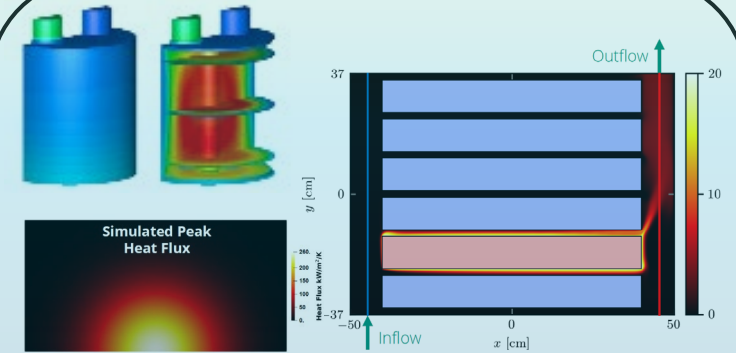
Thermal stability  
Gas evolution  
Degradation  
Mfg. Defect Evaluation

## Cell and Module Testing



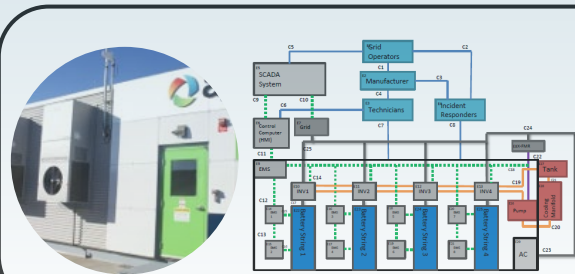
Aging  
Diagnostics  
Abuse testing  
Thermal propagation

## Simulations and Modeling



Multi-scale models  
Fire dynamic simulations  
Predictive simulations  
Machine Learning

## System Level Design and Analysis



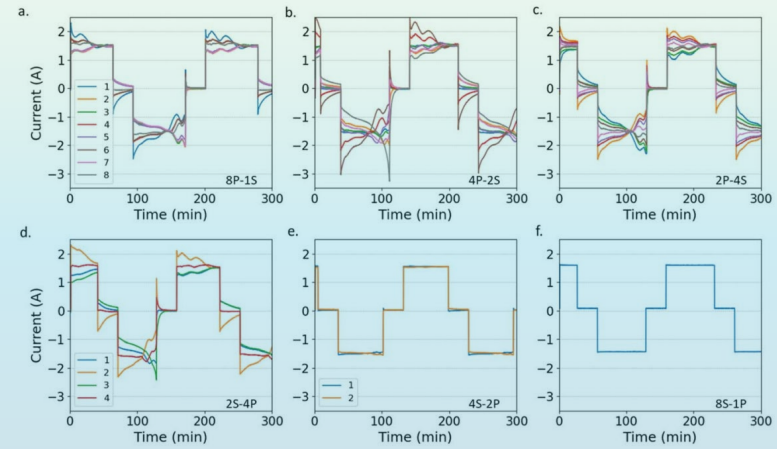
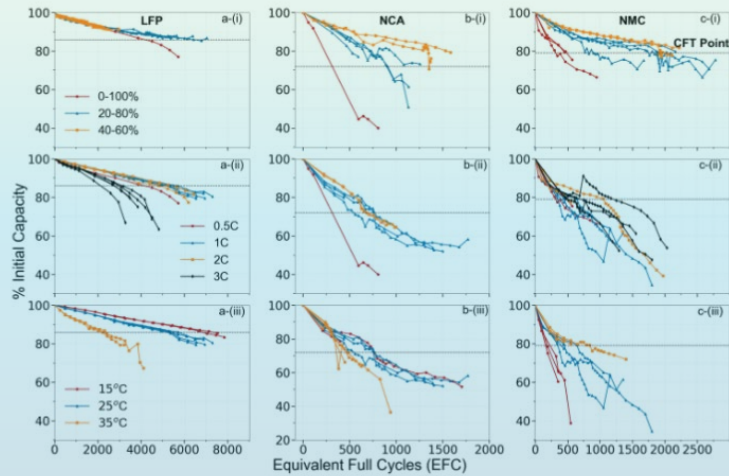
Hazard analysis methods  
Predictive maintenance  
Power electronics

## Outreach, Codes, and Standards

ES safety working group  
IEEE BMS standard  
EPRI ESS data guidelines

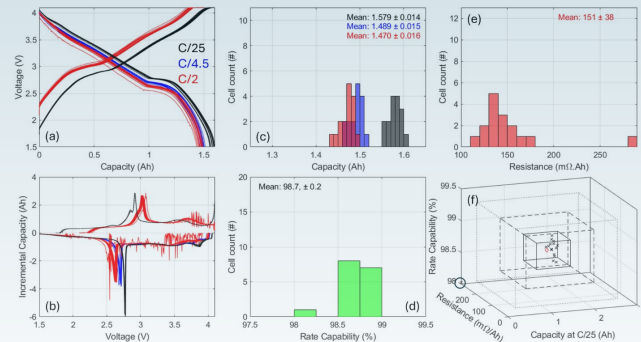


# Addressing Reliability Gaps Through R&D at National Labs



Li-ion impact of module configuration

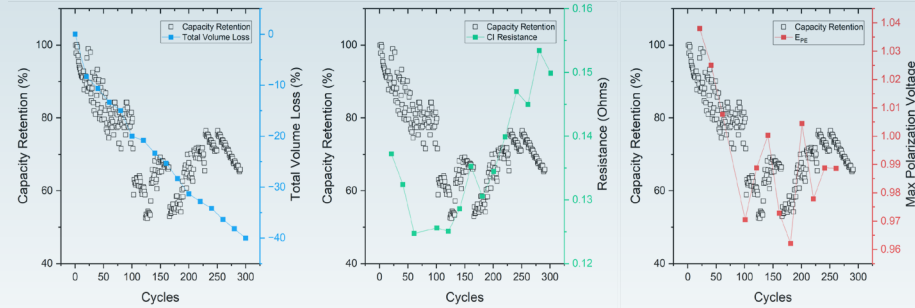
## Li-ion cell degradation beyond 80% capacity



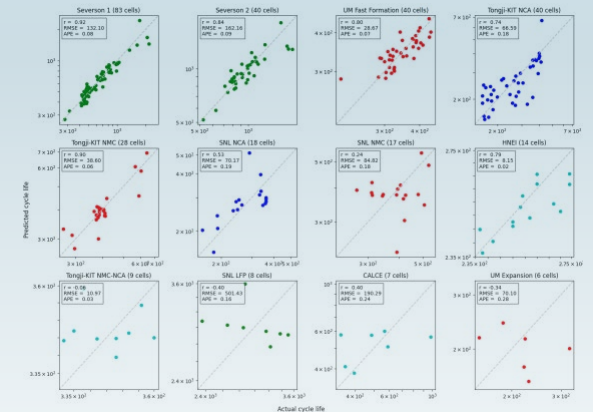
volume loss – side reactions leading to capacity fade

Ohmic cell resistance shows decrease (wetting/conditioning) then increase (membrane deg)

Polarization voltage trends well with capacity output response



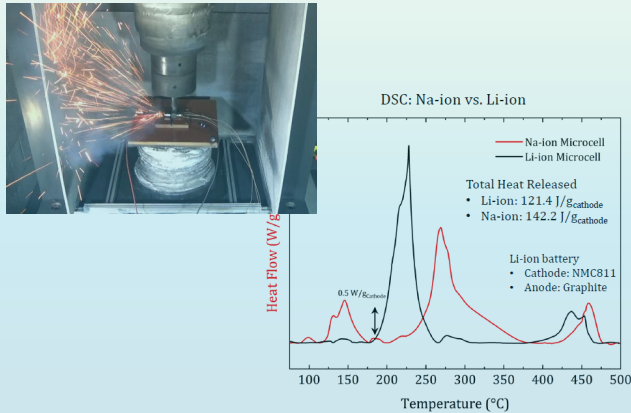
## Flow Battery Diagnostic Development



## Battery Archive and Life Prediction

## Na-ion cell degradation

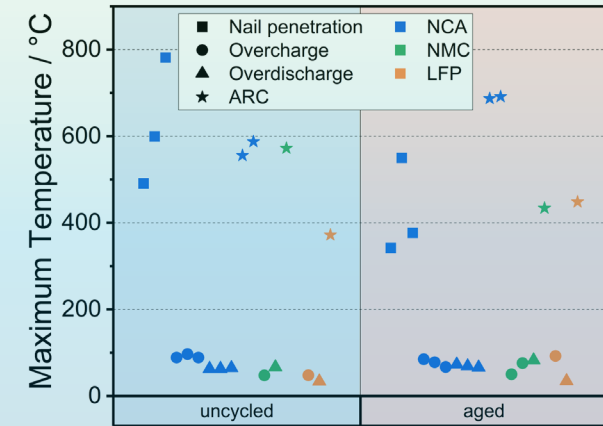
# Addressing Safety Gaps Through R&D at National Labs



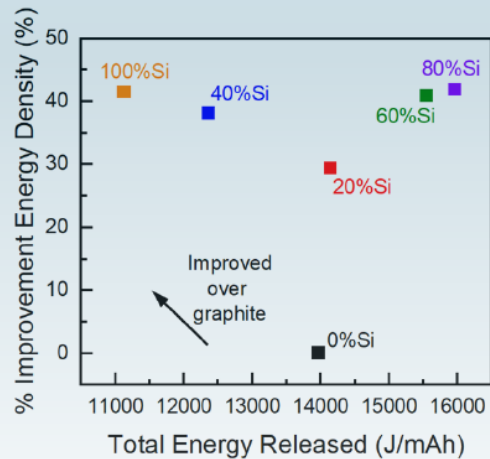
**Multi-scale approach to delineate the safety of sodium-ion batteries**



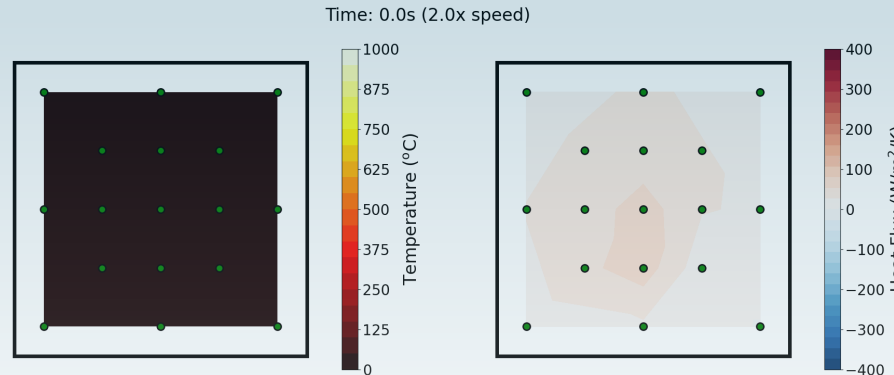
**Thermite Reactions**



**Safety of Aged Cells**



**Safety implications of Si content in Si/Graphite anodes**



**Venting Heat Flux with Inverse Simulations**



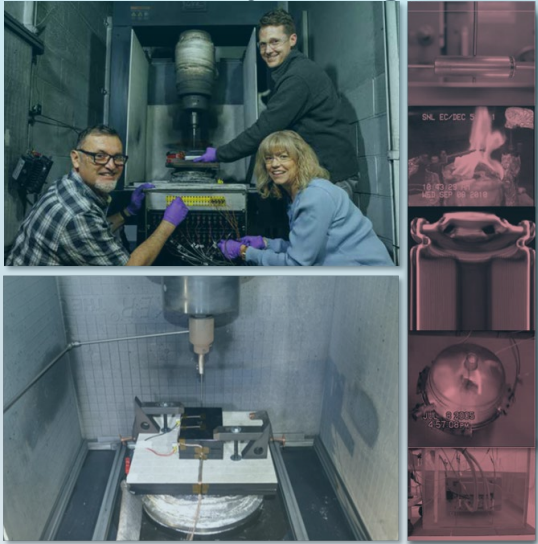
**Large-scale testing**

# Advancing Safe and Reliable ESS with SOA Facilities at National Labs



**Pacific Northwest**  
NATIONAL LABORATORY

## DOE Core Capability for Destructive Battery Testing



## 5,000 Sq Ft Facility for Analysis within Spec



## Grid Storage Launchpad



## Remote Site for Large-Scale Destructive Testing



# Don't Miss the Posters!



| <b>Presentation</b>   | <b>Presenter</b> | <b>Organization</b>          |
|---|------------------|------------------------------|
| <i>Hardware Validation of a Direct DC-AC Dual Active Bridge Converter for Single-Stage Energy Storage Interfacing</i>                     | Alvaro Cardoza   | Sandia National Laboratories |
| <i>Understanding the Thermal Behavior and Safety of Silicon-Graphite Anodes</i>   | Bryan Wygant     | Sandia National Laboratories |
| <i>Practical Battery Arc Flash Models</i>   | David Rosewater  | Sandia National Laboratories |
| <i>Pioneering the Largest Battery Abuse Test at SNL</i>   | Emily Kowalchuk  | Sandia National Laboratories |
| <i>First Responder Visibility During Battery Fires</i>  | Emily kowalchuk  | Sandia National Laboratories |
| <i>Toward predicting thermal runaway propagation and mitigation for safer energy storage systems</i>                                      | John Hewson      | Sandia National Laboratories |
| <i>Toward algebraic modeling of natural convection inside simplified energy storage systems</i>   | Michael Meehan   | Sandia National Laboratories |
| <i>Are Solid-state Batteries Non-Flammable? Identifying Lithium Thermite Reactions</i>  | Nathan Johnson   | Sandia National Laboratories |
| <i>Modeling Thermal Runaway Behavior of Silicon-Graphite Anodes and Microcells</i>  | Randy Shurtz     | Sandia National Laboratories |
| <i>Initial Reliability Evaluation of Emerging Sodium Batteries</i>  | Reed Wittman     | Sandia National Laboratories |
| <i>Analogous Boost Converter Switching Scheme for Single-Phase Direct Dual Active Bridge (DAB) Battery Charger with Optimal Setpoints</i> | Ronald Matthews  | Sandia National Laboratories |
| <i>Diagnostic Tools to Investigate Impact on Failure Modes and State-of-Health of Vanadium Redox Flow Batteries</i>                       | Sam Macchi       | Sandia National Laboratories |

# Don't Miss the Posters!



| <b>Presentation</b>  | <b>Presenter</b>           | <b>Organization</b>                   |
|--|----------------------------|---------------------------------------|
| <i>Battery Archive - A Standardized Data Repository to Accelerate Evaluation of Energy Storage Systems</i> | Yuliya Preger              | Sandia National Laboratories          |
| <i>Impact of Aging on the Safety of Lithium-ion Batteries</i>  | Yuliya Preger              | Sandia National Laboratories          |
| <i>Impact of Module Configuration on Lithium-ion Battery Performance and Degradation</i>                   | Yuliya Preger              | Sandia National Laboratories          |
| <i>Understanding Li-ion Battery Module Performance under Peak Shaving using Single Cell Data</i>           | Daiwon Choi                | Pacific Northwest National Laboratory |
| <i>Lead Acid Battery Performance Analysis for Grid Peak Shaving Application</i>                            | Nimat Shamim               | Pacific Northwest National Laboratory |
| <i>A Thermal Perspective on Battery Degradation Mechanisms</i>   | Qian Huang                 | Pacific Northwest National Laboratory |
| <i>Development of Temperature Sensitive Paint for Energy Storage System (ESS) Safety</i>                   | Chanaka Ihala Gamaralalage | Oak Ridge National Laboratory         |
| <i>Li-ion Pouch Cell Thermal Abuse Test and Cylindrical Cell Mechanical Abuse Test</i>                     | Lianshan Lin               | Oak Ridge National Laboratory         |
| <i>Integrated Inductively Coupled DC-DC Battery Interface</i>  | Marcio L Magri Kimpara     | Oak Ridge National Laboratory         |
| <i>Evaluating Safety of Battery Cells in Energy Storage Systems</i>  | Marm Dixit                 | Oak Ridge National Laboratory         |

# Center Stage: Presentations



| Time     | Presentation  | Presenter        | Organization                          |
|----------|---|------------------|---------------------------------------|
| 9:10 AM  | Understanding BESS Fire Hazards at the System Level with Experiments and Modeling             | Andrew Kurzawski | Sandia National Laboratories          |
| 9:25 AM  | Reducing Cost and Increasing Confidence Through Interoperability                              | Jaime Kolln      | Pacific Northwest National Laboratory |
| 9:40 AM  | Acoustic Emission During Thermal Runaway Induced by Mechanical Indentation and Thermal Abuse  | Hsin Wang        | Oak Ridge National Laboratory         |
| 9:55 AM  | Performance and Degradation of Li-ion Batteries from Cells to Systems                         | Yuliya Preger    | Sandia National Laboratories          |
| 10:10 AM | Microcell Safety Analysis of Silicon/Graphite Anodes Paired with High Energy Density Cathodes | Bryan Wygant     | Sandia National Laboratories          |



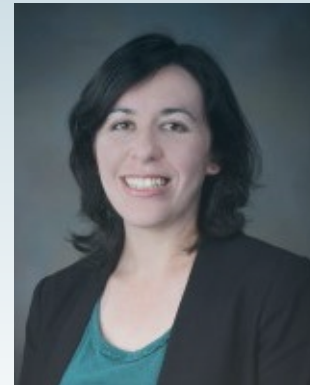
**Andrew Kurzawski**



**Jaime Kolln**



**Hsin Wang**



**Yuliya Preger**



**Bryan Wygant**