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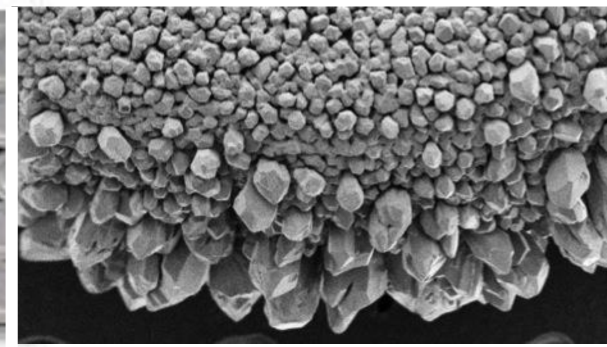

Safety Validation in Grid Energy Storage

Energy Storage Global Conference

Day 1, Session IV

November 19, 2014

David M. Rosewater PE

Energy Storage Technology & Systems

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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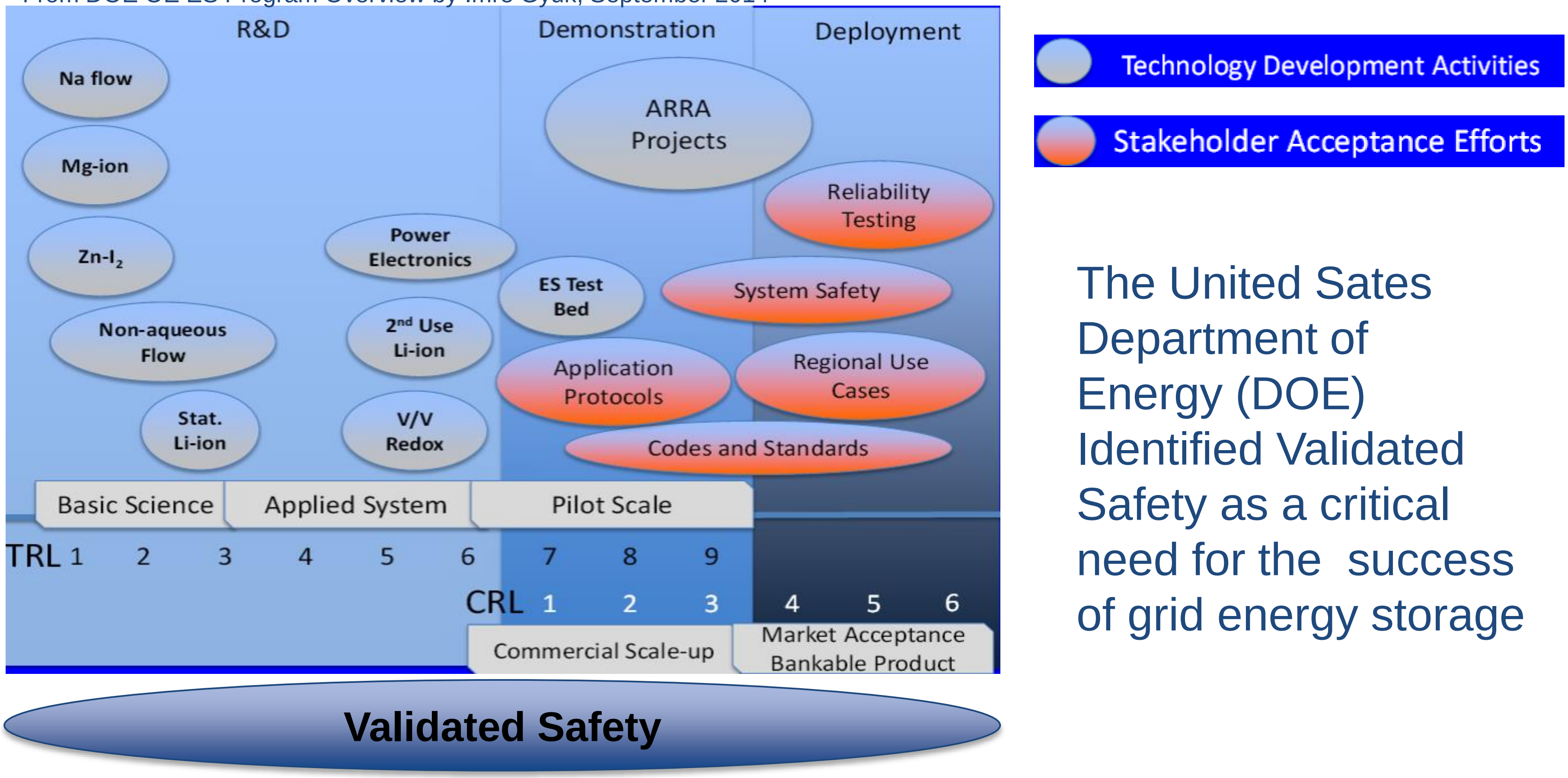
Outline

- Program overview and how we got here
- Sandia’s Approach to Grid Storage Safety
- My work in System Safety
- Parting Knowledge

DOE OE Energy Storage Program Overview

The Office Of Electricity (OE) Energy Storage Program aims at a wide Portfolio of Technologies and a broad Spectrum of Applications. Storage will contribute to a safer, greener, and more resilient Grid

From DOE OE ES Program Overview by Imre Gyuk, September 2014



The United Sates Department of Energy (DOE) Identified Validated Safety as a critical need for the success of grid energy storage

The Need for Energy Storage Safety Protocols

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As an increasing number of energy storage systems are deployed, the risk of safety incidents increases.

Damage to Facilities

2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm

- There were two fires in a year at the Kahuku Wind Farm
- There was significant damage to the facility
- Capacitors in the power electronics are reported to be associated with the failure.

Impact to First Responders

2013 Storage Battery Fire, The Landing Mall, Port Angeles WA

- First responders were not aware of the best way to extinguish the fire,
- It reignited a week after it was thought to be extinguished.

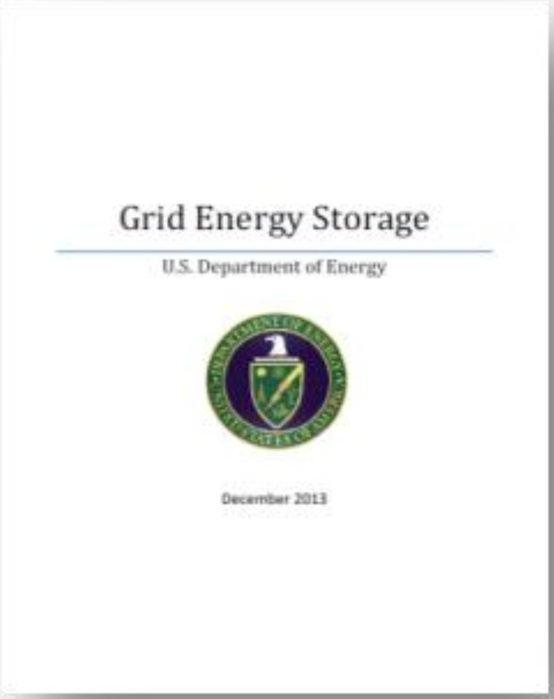
Challenges for Grid Energy Storage

During the commissioning hearings of Dr. Moniz to head US DOE, Senator Wyden requested a strategic plan for grid energy storage.

DOE Published the report in December 2013

<u>Four Critical Challenges were identified</u>

1. Cost Competitive Energy Storage Technologies
2. **Validated Reliability and Safety**
3. Equitable Regulatory Environment
4. Industry Acceptance



DOE OE Strategic Plan on Safety

Lack of standardized validation protocol

- Science based testing protocols are needed.
- Validation protocols must link the materials and cell level to full systems integration into the grid.
- Knowledge gained in testing and analysis must be fed back to develop new safer materials.

Insufficient Incident preparedness

- Fire control systems, e.g. fire suppression materials need to be identified for each storage technology
- First responders education
- Post-incident response

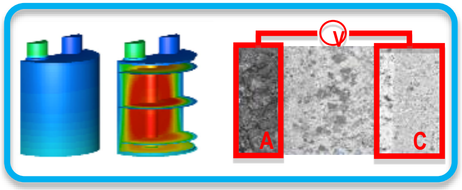
Incomplete and dispersed codes, standards and regulations (CSR)

- The CSR's for energy storage are dispersed throughout many sources (NEC, IEEE, UL, etc.). There is currently no centurial index of all the CSR's.
- The CSR's need continual updating due to rapid advances in storage technologies and new citing locations

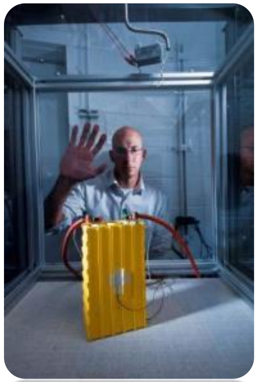
Sandia's Approach to Grid Storage Safety

Leverage existing leadership position in Safety Analysis of Vehicle Batteries

Simulations



Cell testing



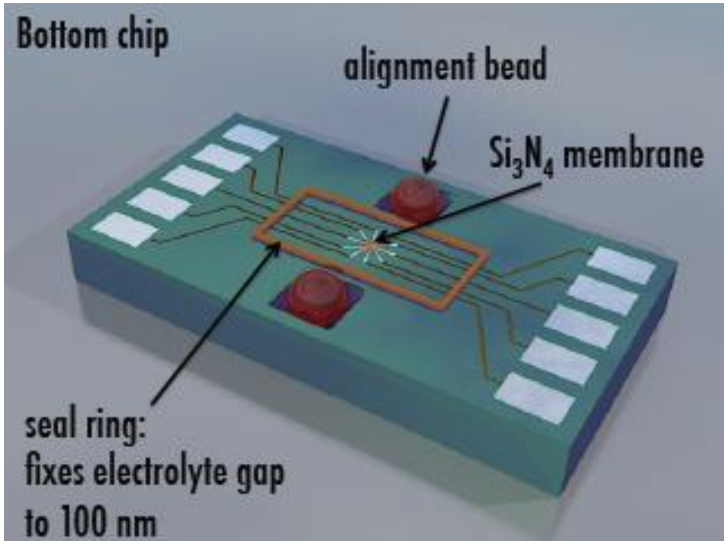
Informing policy

Large scale testing

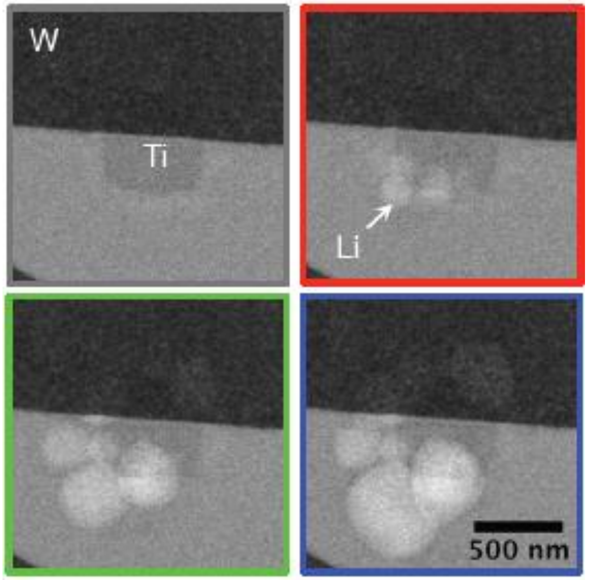
1. Develop a **science based** understanding of the processes that control and improve safety
2. Build **multi-scale models** for predicting incidences in storage systems to improved design
3. Analysis of cells through systems to **develop testing protocols**

Science Basis for Safety

Schematic of SNL fabricated TEM liquid cell



TEM images of Li growth during charging



Electrochemistry inside a TEM to observe dendrite growth in flow batteries

Travis Anderson: tmander@sandia.gov;

Modeling: Components through Systems

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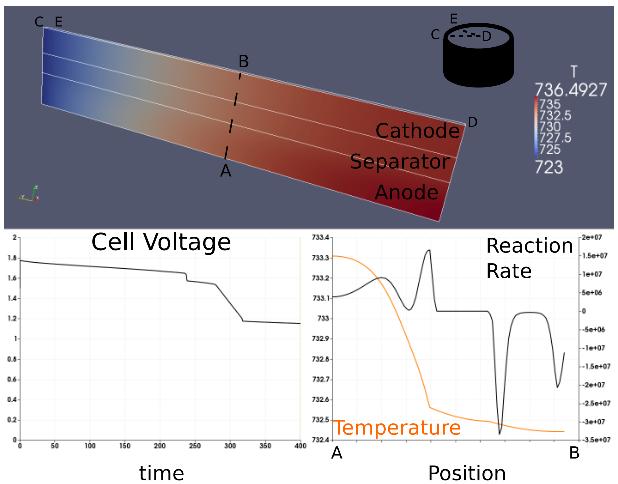
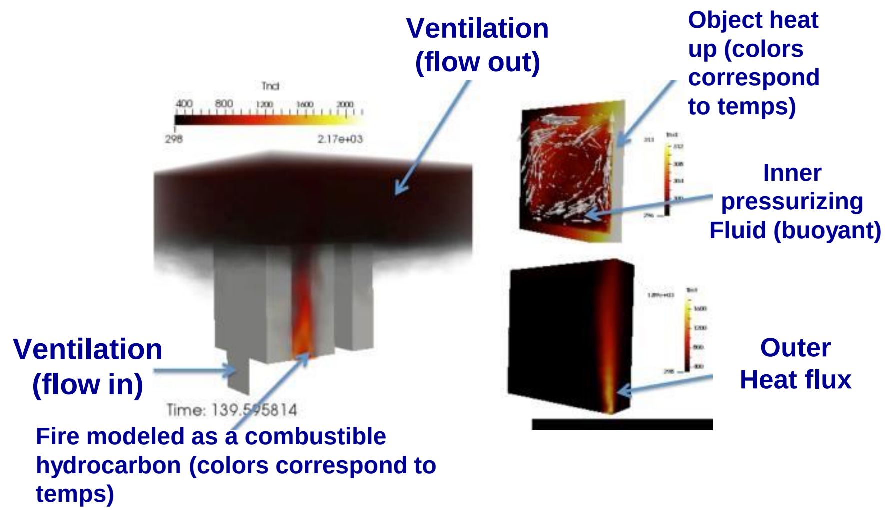
Modeling thermal events in cell

Model linking battery performance with thermal environment



Model of fire propagation between storage packs



- Sandia has been using its linked chemical / mechanical modeling capability to study failure in components through full systems.

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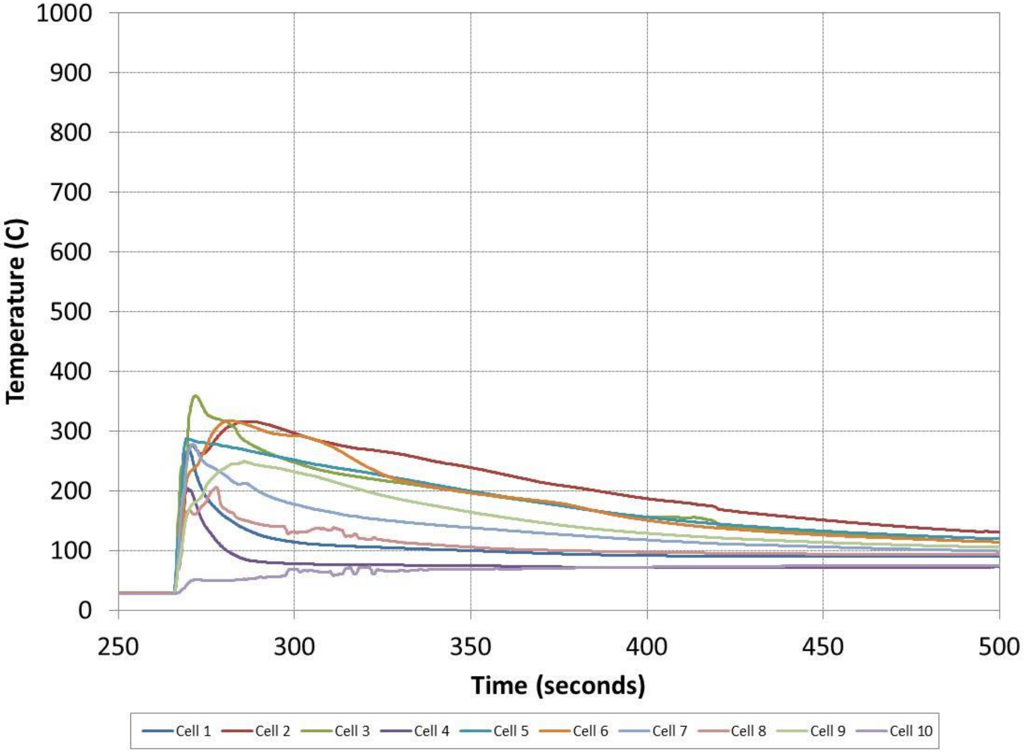
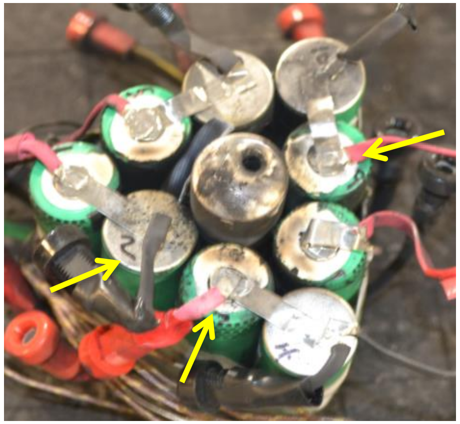
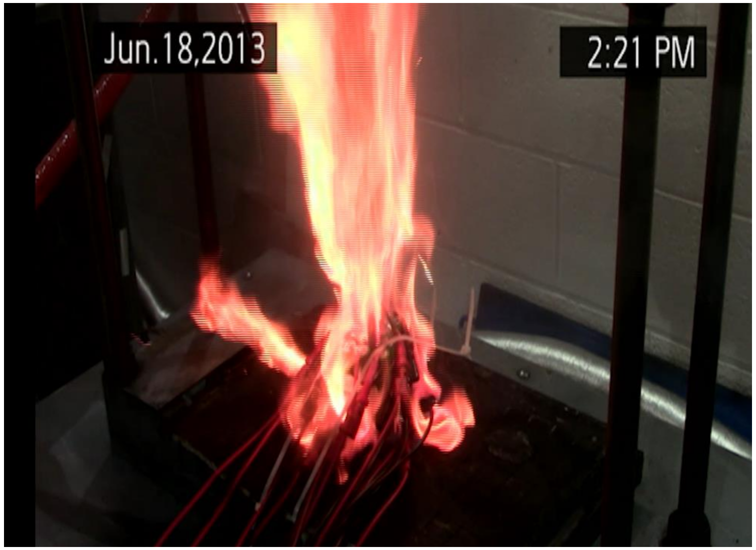
Failure Propagation Protocol Development

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)







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

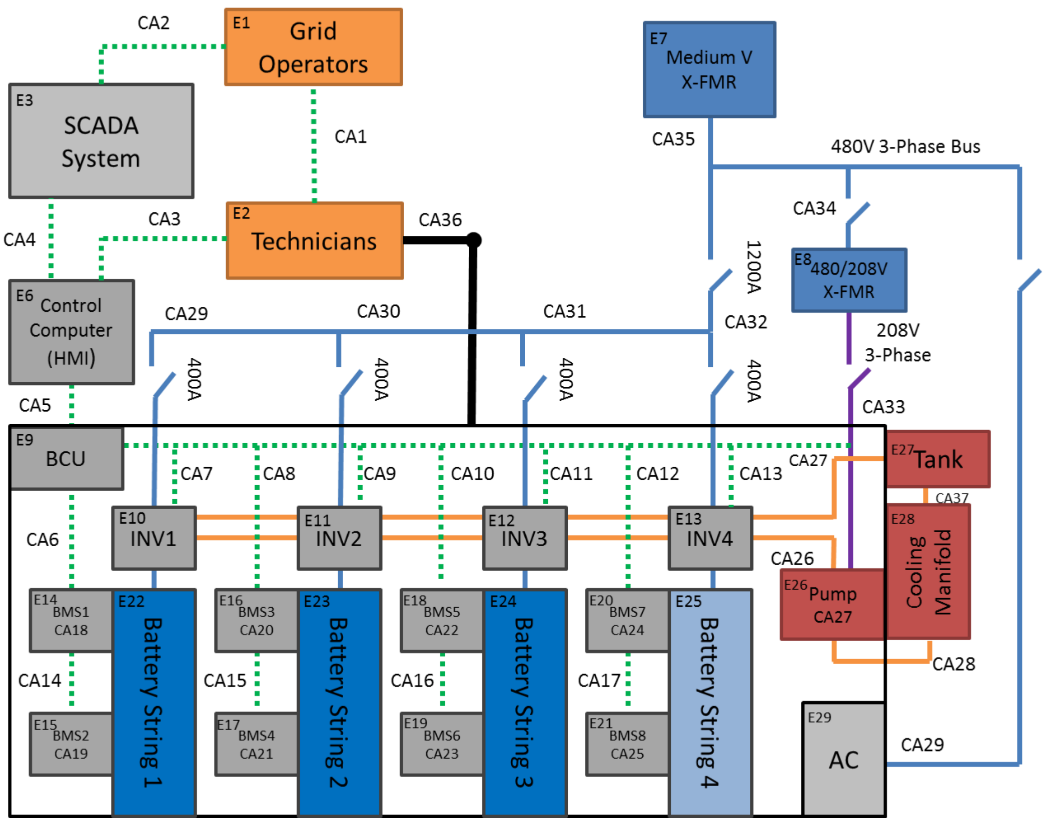
Safety Protocol Development

STAMP – a New Accident Model [Developed by Nancy Leveson of the Massachusetts Institute of Technology]

Accidents occur when interactions violate **safety constraints,**

The system enforces these constraints using control.

Systems-Theoretic Process Analysis (STPA)



Illustrative Example of a Safety Control Structure

STPA and CAST

Systems-Theoretic Process Analysis (STPA)

Goal: Identify how safety constraints can be violated in a design

Similar applications to: FMEA/Fault-Tree

Casual Analysis based on STAMP (CAST)

Goal: Identify what safety constraints were violated during an accident

Similar applications to: Root Cause Analysis

Both ask

How effectively does the system enforce its safety constraints?

How could it work better?

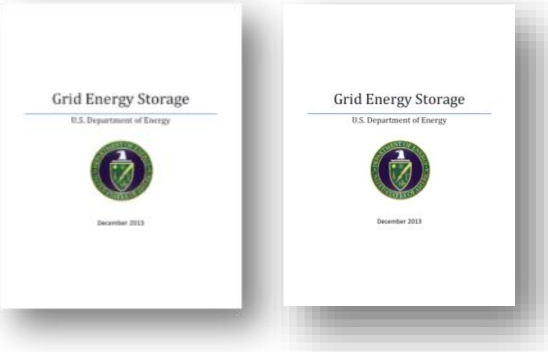
Energy Storage Systems Analysis Laboratory ESSAL
Proving ground for these and other safety protocols

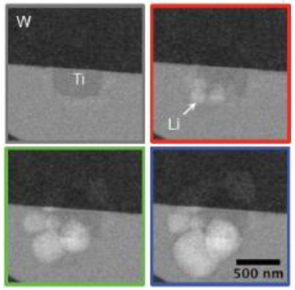
Summary

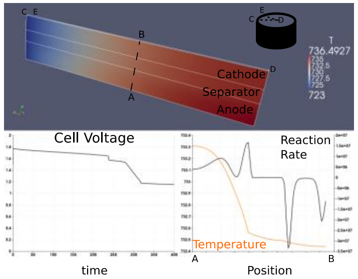
Gaps have been identified

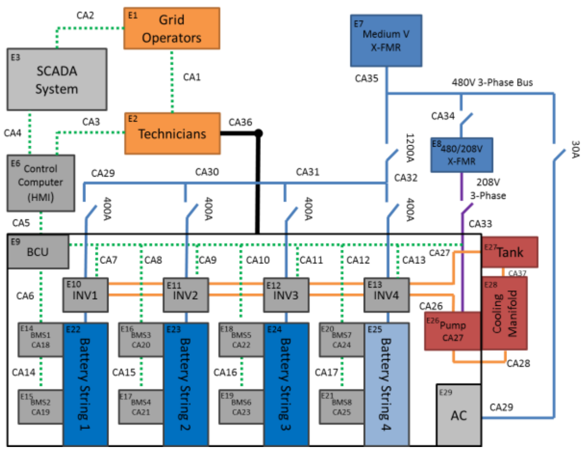
- Lack of standardized validation protocol
- Insufficient Incident preparedness
- Incomplete and dispersed codes, standards and regulations (CSR)

Sandia is leveraging its experience in vehicle battery and system safety to tackle the underlying mechanisms controlling safety to inform and develop validation protocols.









Thank You to the DOE OE and especially Dr. Gyuk for his dedication and support to the ES industry and Sandia's ES Program.

Questions?

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Backup Slides

Energy Storage System Requirement

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- **High Performance (High value)**
  - High *Energy* and *Power* density
  - Highly *efficient* device integration and operation (power electronics, control algorithms)
- **Low Cost**
  - Low unit production cost (materials, design, manufacturing)
  - Low Maintenance costs

Traditional focus

- **High Reliability / Low Degradation rate**
  - Long useful lifetime
  - Predictable degradation rate
  - Low frequency of stochastic failure (field failure)
- **Safe**
  - No unanticipated failure modes
  - No catastrophic failures
  - Minimize collateral damage

Economic and Human Impacts: Point to Need for ES Safety/Reliability Codes and Standards, Policies

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- **Fisker Karma/A123 Systems: Karma luxury PHEV**
  - **December 2011 – *recall of first 239 vehicles* after NHTSA described it as a fire hazard**
  - **May 2012 – Fisker Karma fire *damaged home* of a new owner**
  - **August 2012 – another Karma caught fire. Fisker and A123 *recalled over 600 Karmas***
- **December 2008, Navy Advanced Seal Delivery System**
  - ***Sub was not repaired* after explosion and battery fire**
- **August 2012, Kahuku Wind Energy Storage Farm fires**
  - **Damages caused by fire estimated to be *at least $8M***
- **September 2011, Tokyo Electric Power company, NGK NaS battery fire**
  - **NGK estimates losses associated with this incident to be *$9.8B in 2012***
- **June 2006 Dell laptop battery fires**
  - **Sony recall cost *exceeded $300M***
- **September 2010: Cargo fire on UPS Boeing airplane, large quantity of Li ion batteries**
  - **Both *crew members were killed* in crash**
- **May 2012: Shenzen, China EV taxi fire after high speed crash**
  - ***Three passengers were killed***