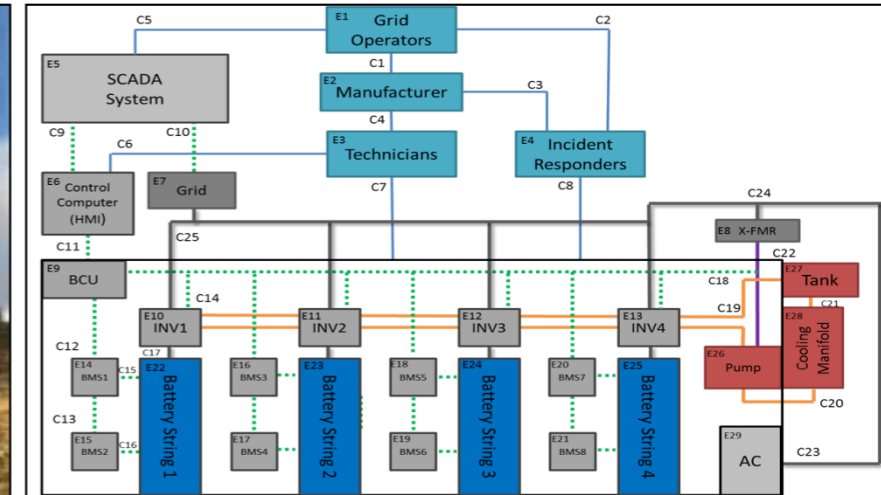


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System's Safety in Grid Energy Storage: Challenges and Solutions through the Application of STAMP

03/25/2015 David Rosewater PE
Energy Storage Test Engineer



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Codes, Standards, and Regulations (CSRs)

- National Electrical Code (NEC) was first published in the 1897



When something isn't in the code

- Equivalence
 - No more hazardous nor less safe
- Independent Arbitration
 - Offload liability onto a third party who will verify that systems are compliant with all applicable standards.
- Insurance
 - Actuarial tables track failures and correlate them to payouts
 - Technical decisions are approved by lawyers and economists

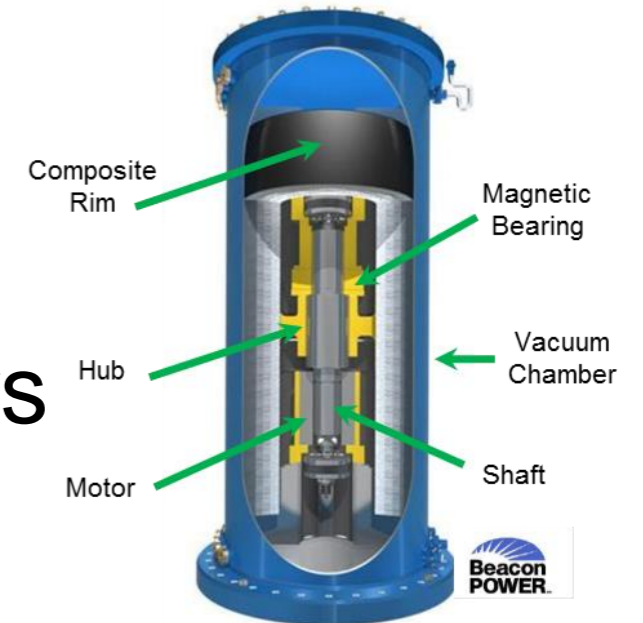
Grid Energy Storage

- Storage can provide significant value to the grid
- Example technologies:

Batteries



Flywheels,



Ultra-capacitors



Flow Batteries



Safety in Grid Energy Storage

A. Fast Pace of Technological Change

In many cases the technology is improving too quickly to properly adjust for the impact that changes have on safety. In the past decade the number of energy storage technologies has greatly expanded. These dynamics make safety difficult for standards bodies to properly control, as they are continuously acting on lagging information.

B. Increasing Complexity and Coupling

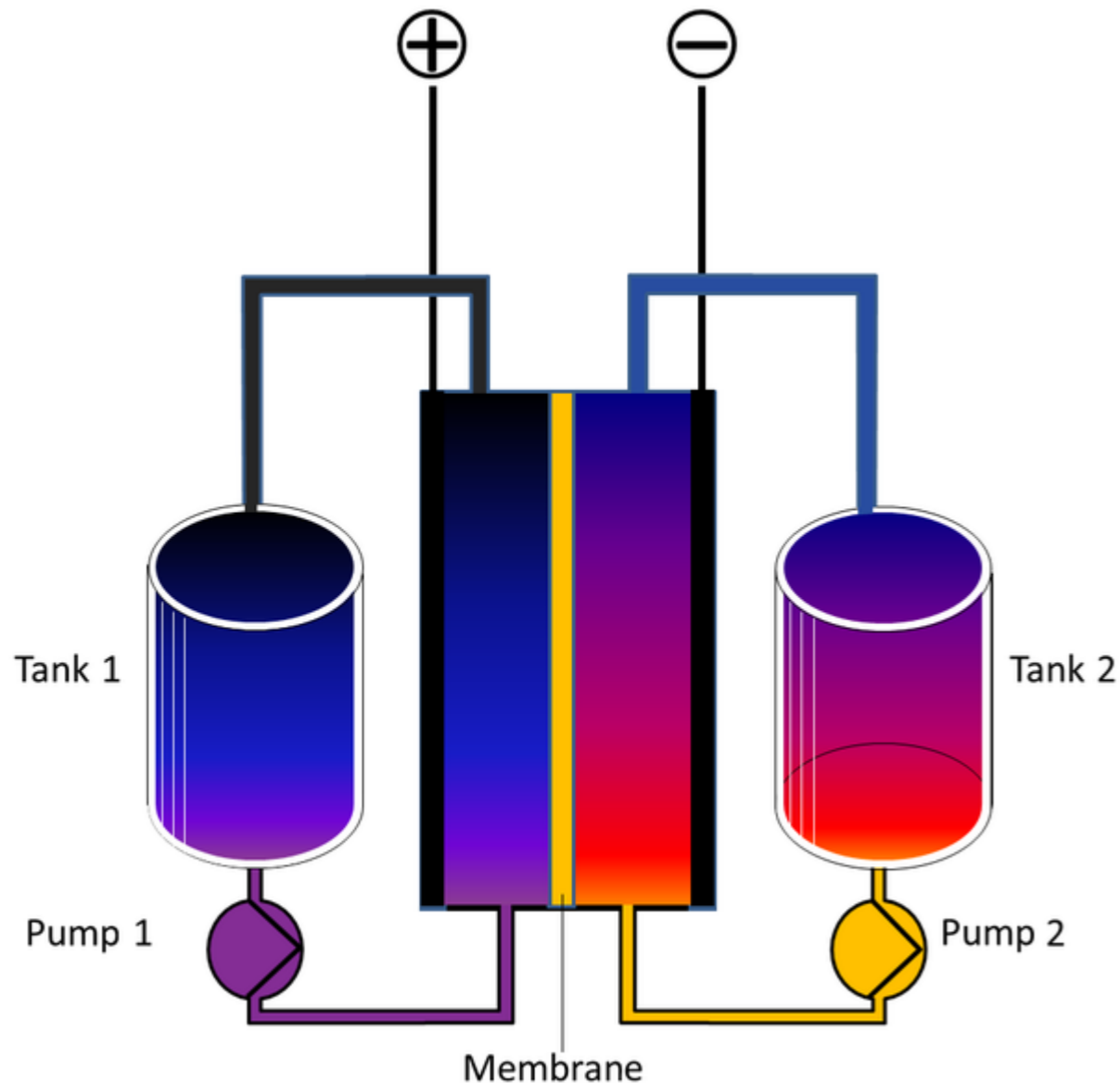
Even while the quantity of grid connected energy storage has been steadily increasing, its complexity has increased exponentially. This has made existing safety analyses tools much more difficult to apply and costs to companies to validate safety to increase.

C. Decreasing Tolerance for Single Accidents

Injuries generate lawsuits, fires raise insurance premiums, and reputation damage can result in significant lost business. The effects do not then stop with the company responsible. By association, the whole energy storage industry can be affected.

Example of CAST

Generic Flow Battery

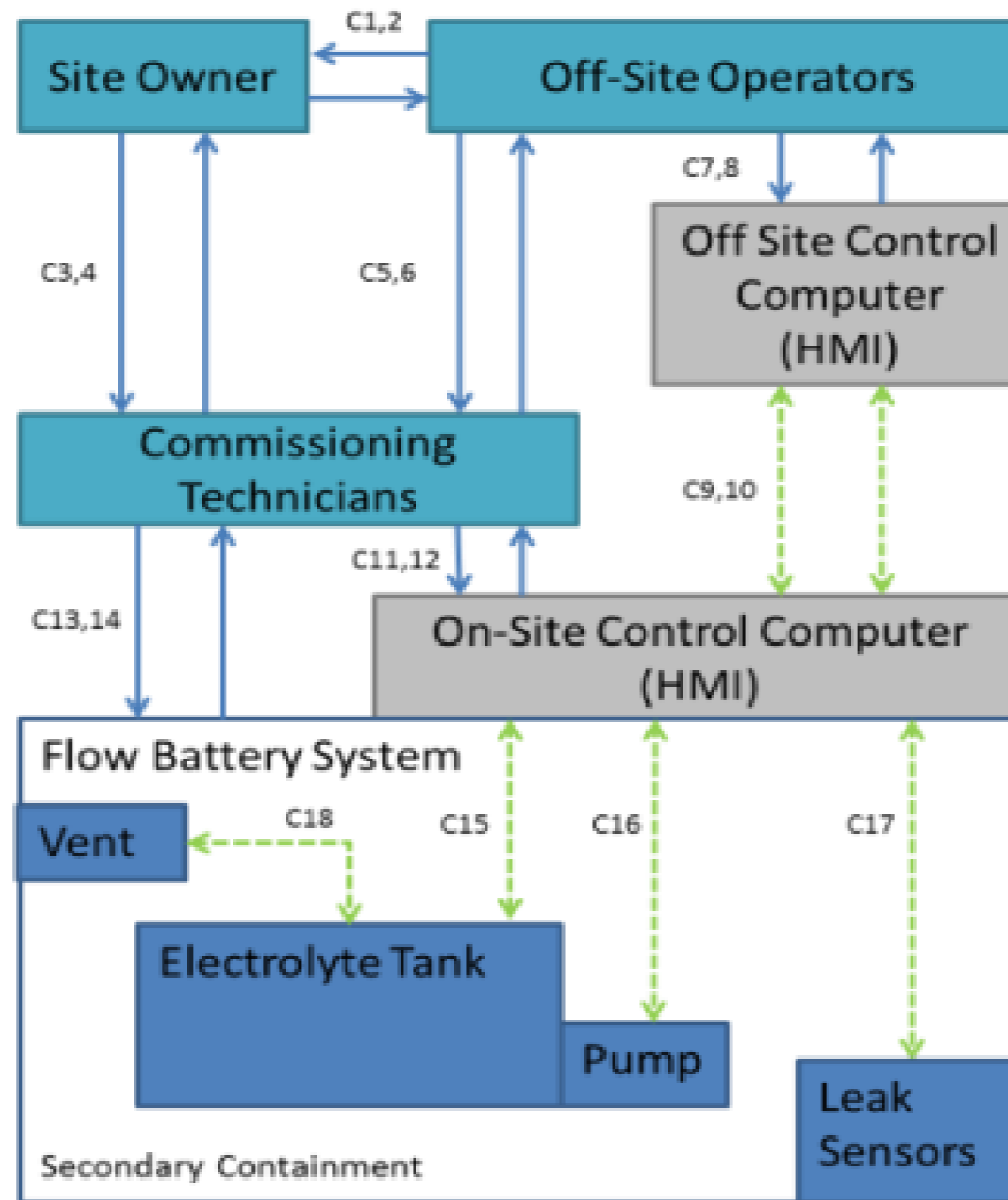


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Accident: Loss of effective electrolyte containment

- Several month delay for commissioning
- Leak sensors were removed to fill tank
- The vent had been blocked by nesting insects
- Electrolyte heated during use causing tank pressure to rise
- Tank was damaged by pressure rise and leaked
- Secondary containment filled and started to overflow

CAST of a Flow Battery Electrolyte Spill



Flow battery functional control diagram

CAST of a Flow Battery Electrolyte Spill

- 3 Proposed corrective actions from initial incident report
- 9 Additional recommendations from applying CAST

Outcome of Root Cause Analysis

Proposed Actions
Develop Emergency Call List
Protection circuit verification to be performed before operation
Install Vent Tube Screen

Actions for Sandia/DOE

1. Develop consistent and complete Codes Standards and Regulations (CSR) for ESS
2. Develop general commissioning Requirements for ESS
3. Develop energy storage System Safety Protocols for flow batteries

Site Owner

4. Develop clear site use requirements

Actions for Off-Site Operators

5. Ensure communication with on-site personnel is consistent throughout commissioning

Energy Storage Vender

6. Update commissioning plan to include inspection and testing of all critical elements before operation
7. Design a feedback mechanism to detect tank overpressure
8. Conduct practice commissioning sessions for technicians
9. Design more effective secondary containment

Application of STPA

- Transpower GridSaver

Quick Stats.

- Prototype 1 MW Lithium-Ion Battery
- Built into a 40" shipping container
- Four 900 volt strings,
- Over 1000 individual battery cells,
- Liquid cooling loop for its power inverters.



(a) External

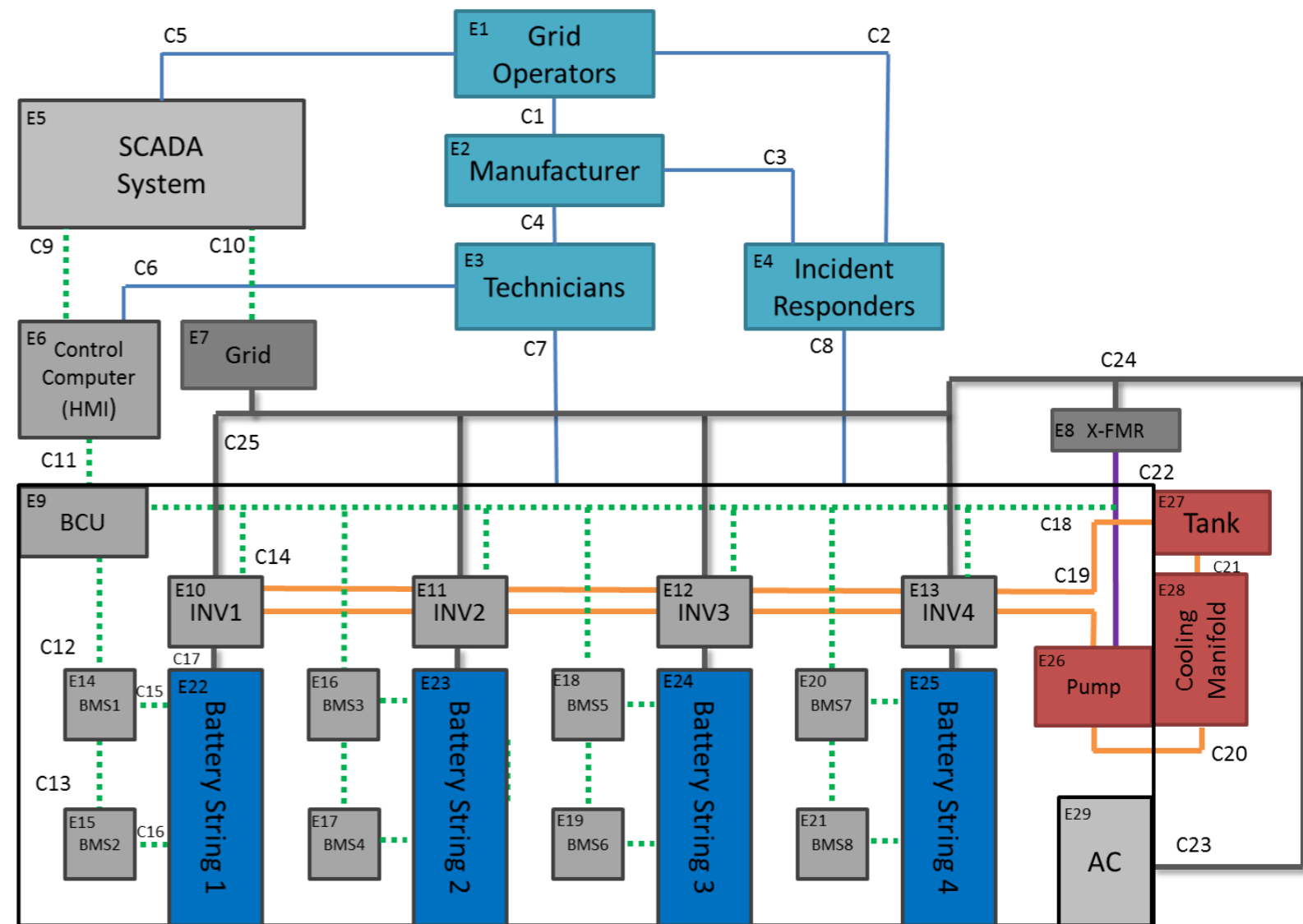


(b) Internal

Transpower GridSaver Battery Energy Storage System

The complexity of battery systems

- Control loops
 - Battery Parameters
 - Inverter
 - Air Conditioning
 - Inverter Parameters
 - Coolant
 - Grid Interaction
 - Maintenance
 - Incident Response
- 100's of safety control actions
- 1000's of causal factors



Safety Control Structure for the Transpower GridSaver

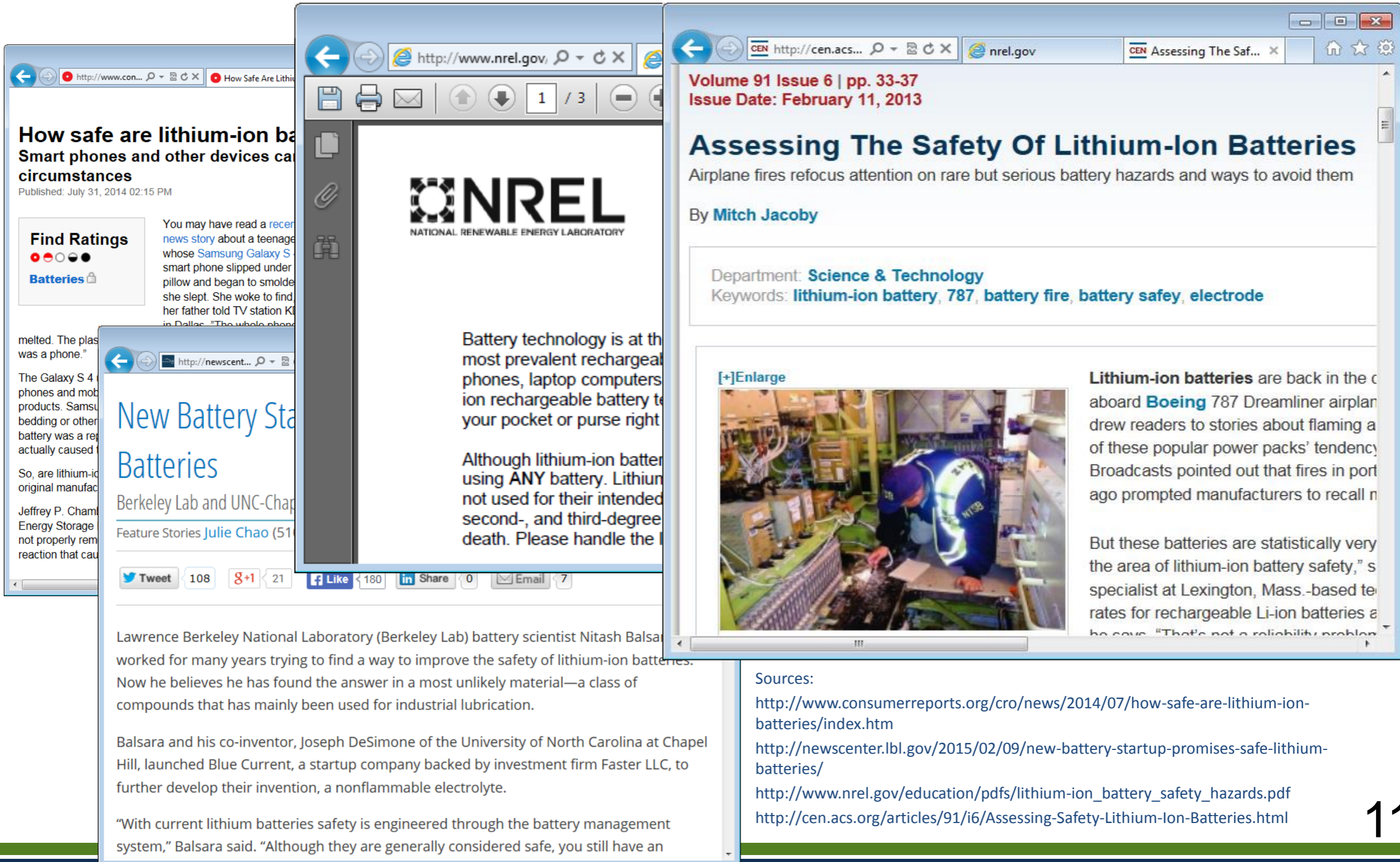
Selected Results to Date

- Unexpected causal factors
 - Not venting air from the enclosure
 - Profile used from a difference battery string
- Causal factors help develop tests for leading indicators

Test	Leading Indicator
Test for Measurement Accuracy	Measurement accuracy or delay is out of compliance
Operator Qualification Testing:	Operator does not meet the predefined minimum standard for qualification

Broader Impacts of STAMP

-Google Search for "Battery Safety"



The collage consists of four overlapping browser window screenshots:

- Top Left:** A search result for "How safe are lithium-ion batteries? Smart phones and other devices can catch fire under certain circumstances". It includes a "Find Ratings" widget and a snippet of text: "You may have read a recent news story about a teenage whose Samsung Galaxy S smart phone slipped under pillow and began to smolder while she slept. She woke up to find her father told TV station KDFW in Dallas, 'The whole phone melted. The plastic was a phone.'"
- Top Center:** A screenshot of the NREL (National Renewable Energy Laboratory) website. The main heading reads "Battery technology is at the most prevalent rechargeable phones, laptop computers, and even your pocket or purse right now." Below it, a sub-heading says "Although lithium-ion batteries are not used for their intended second-, and third-degree death. Please handle the..."
- Top Right:** A screenshot of a CEN (Chemical Engineering News) article titled "Assessing The Safety Of Lithium-Ion Batteries". The article is from Volume 91 Issue 6, pp. 33-37, dated February 11, 2013. The author is Mitch Jacoby. Keywords include "lithium-ion battery, 787, battery fire, battery safety, electrode".
- Bottom Left:** A screenshot of a news article titled "New Battery Startup Promises Safe Lithium-Ion Batteries". It mentions Berkeley Lab and UNC-Chapel Hill, and features stories by Julie Chao. It includes social media sharing buttons for Tweet (108), Google+, Like (180), Share (0), and Email (7).
- Bottom Right:** A screenshot of a text snippet: "Lithium-ion batteries are back in the cockpit aboard Boeing 787 Dreamliner airplanes. It drew readers to stories about flaming aircraft and the tendency of these popular power packs' tendency. Broadcasts pointed out that fires in port of California last year prompted manufacturers to recall..." Below this is a photo of a person in a blue protective suit working with equipment in a laboratory setting.

At the bottom of the collage, there is a list of sources:

Sources:

- <http://www.consumerreports.org/cro/news/2014/07/how-safe-are-lithium-ion-batteries/index.htm>
- <http://newscenter.lbl.gov/2015/02/09/new-battery-startup-promises-safe-lithium-batteries/>
- http://www.nrel.gov/education/pdfs/lithium-ion_battery_safety_hazards.pdf
- <http://cen.acs.org/articles/91/i6/Assessing-Safety-Lithium-Ion-Batteries.html>

Broader Impacts of STAMP

“Battery Safety” is a buzz word around which many conferences, research programs, and products are organized.

Battery Cell Properties



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- ✓ Capacity
- ✓ Volatility
- ✓ Temperature Range
- ✗ Safety

“Safety” is not a property of a component

Battery System Properties



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- ✓ Capacity
- ✓ Service Life
- ✓ Control Algorithm
- ✓ Safety

Safety is a system property

A systems perspective on safety offers better language to communicate how batteries can be kept safe and why they sometimes are not kept safe (rather than are or are not safe)

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

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<http://sunnyday.mit.edu/>

Questions?

David Rosewater

dmrose@sandia.gov

505 844-3722