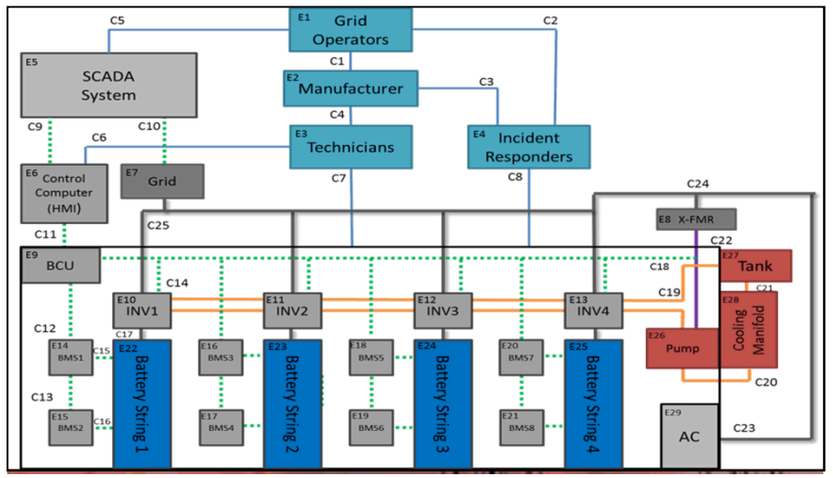
SAND2015-2072PE

Exceptional service in the national interest

Sandia National Laboratories

energy.sandia.gov



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

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Intro to Safety in the Electric Grid

Sandia National Laboratories

Codes, Standards, and Regulations (CSRs)

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

Source: www.nfpa.org/

When something isn't in the code

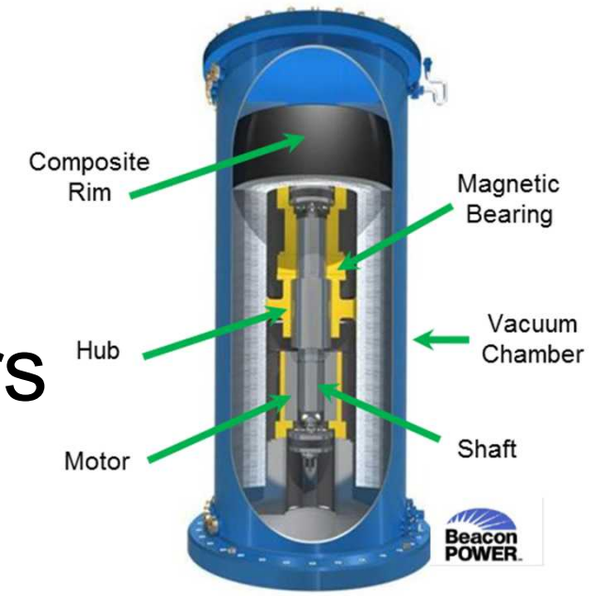
- Equivalence
  - No more hazardous nor less safe
- Independent Arbitration
  - Offload liability onto a third party who will verify that systems are compliant with all applicable standards.
- Insurance
  - Actuarial tables track failures and correlate them to payouts
  - Technical decisions are approved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

Grid Energy Storage

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

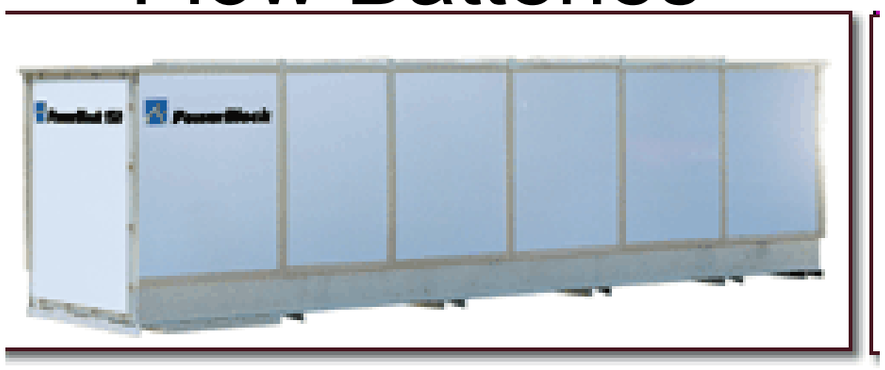
Batteries

Flywheels,



Ultra-capacitors

Flow Batteries



Picture Source: Energy Storage 101 Short Course Slides

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.

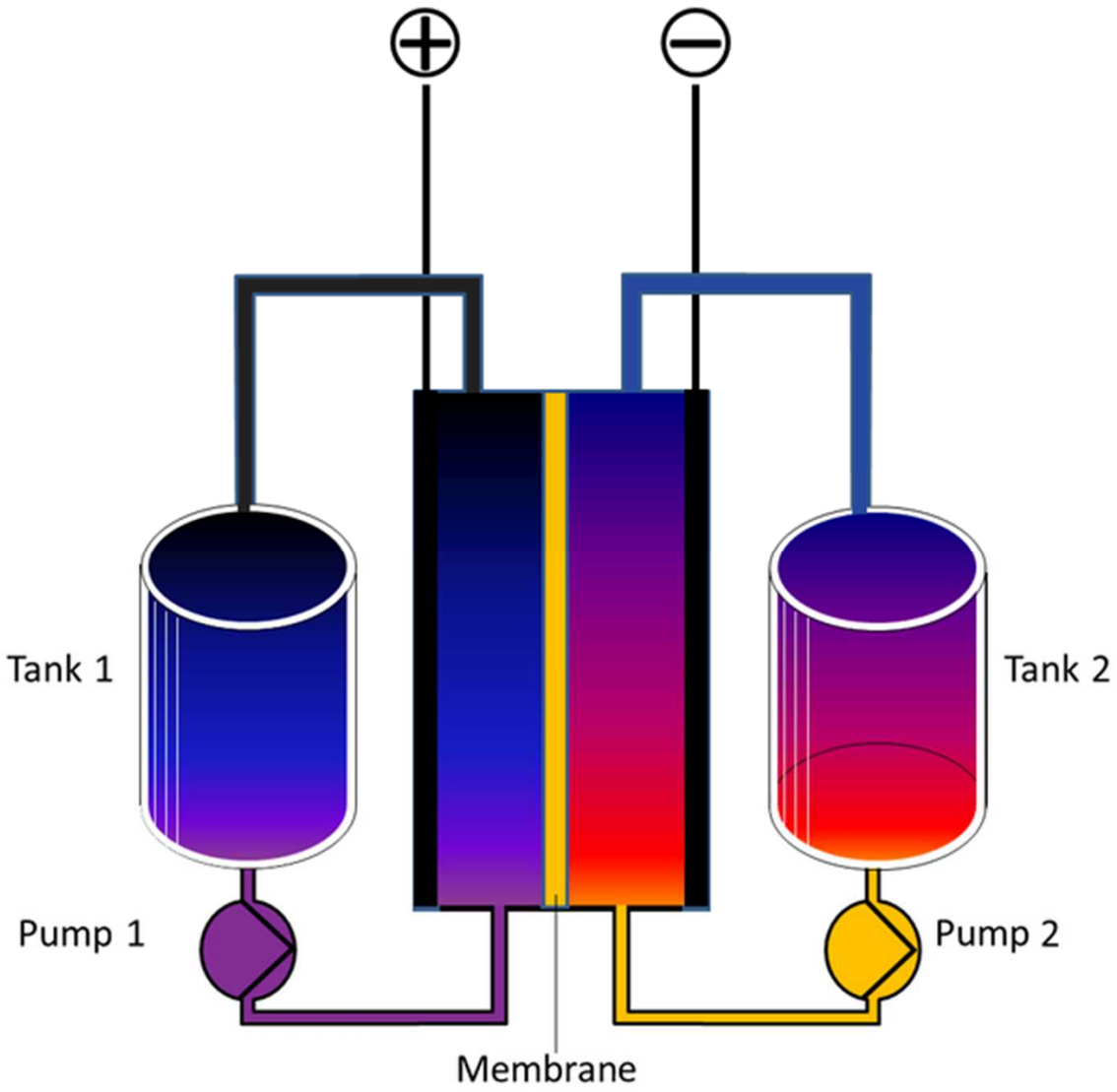
C. Decreasing Tolerance for Single Accidents

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.

Source: Engineering a Safer World: Chapter 1: Why we need something different?

Example of CAST

Generic Flow Battery

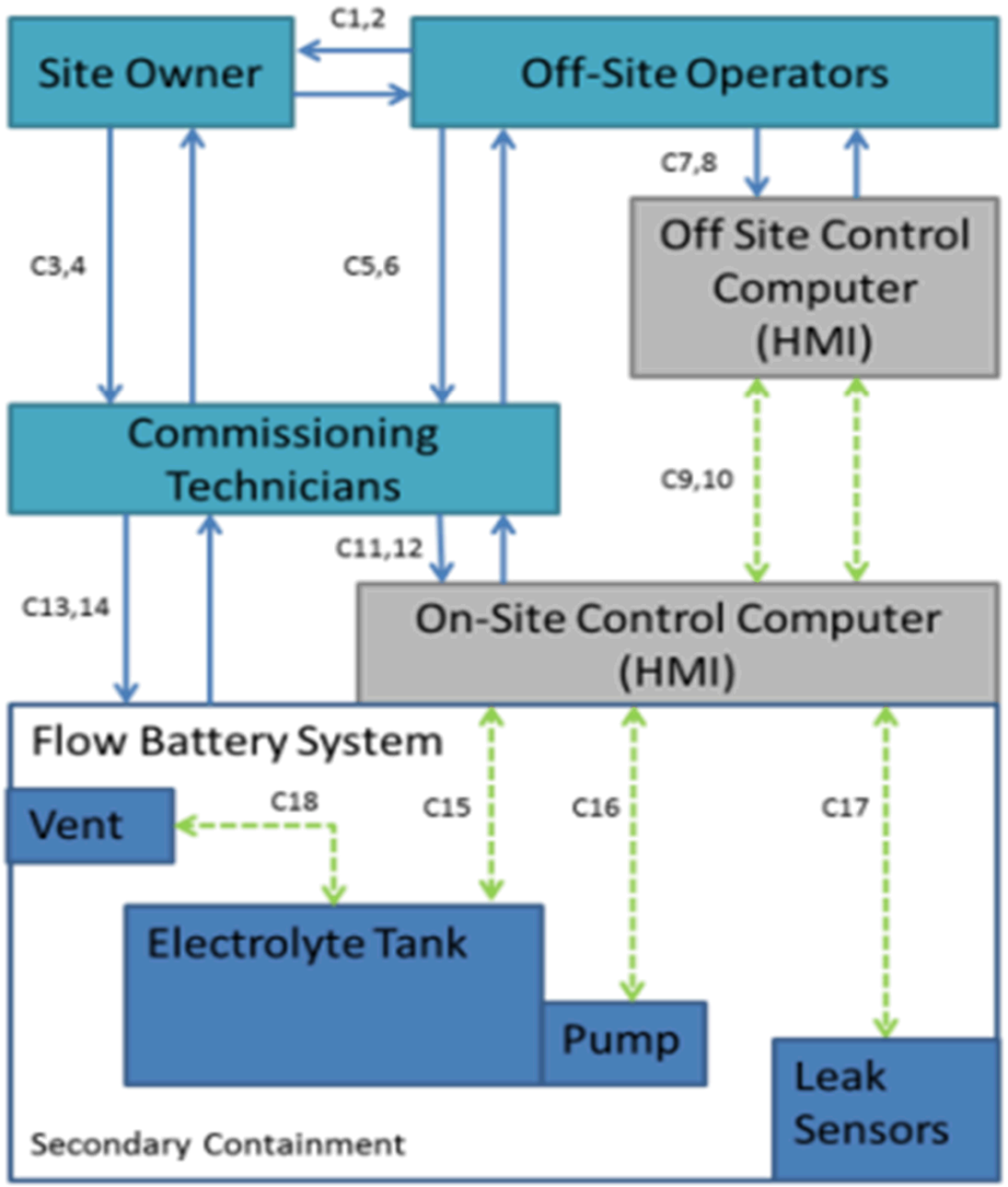


By Nick B, benboy00 [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

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.

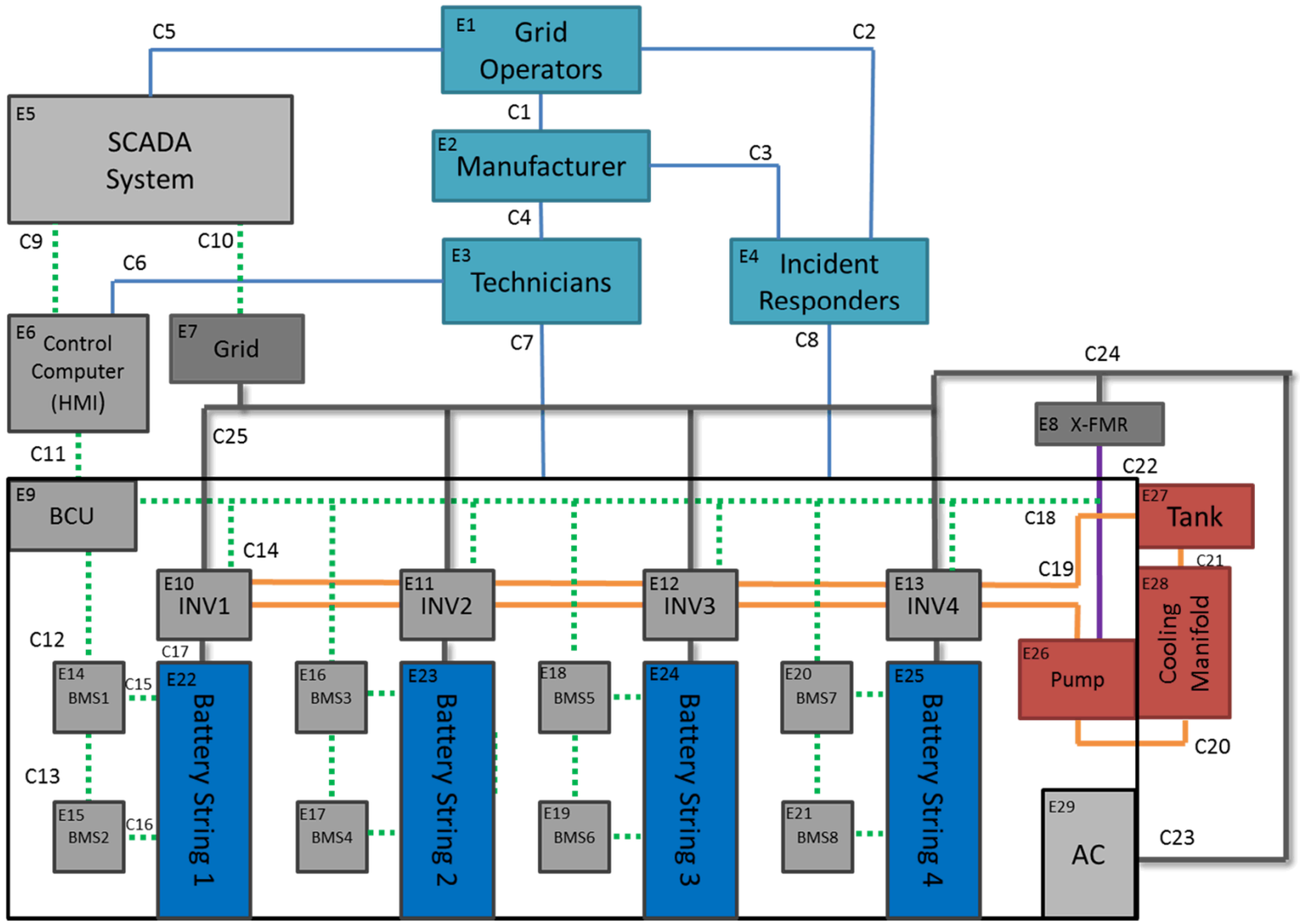
- Prototype 1 MW Lithium-Ion Battery
- Built into a 40” shipping container
- Four 900 volt strings,
- Over 1000 individual battery cells,
- Liquid cooling loop for its power inverters.

(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

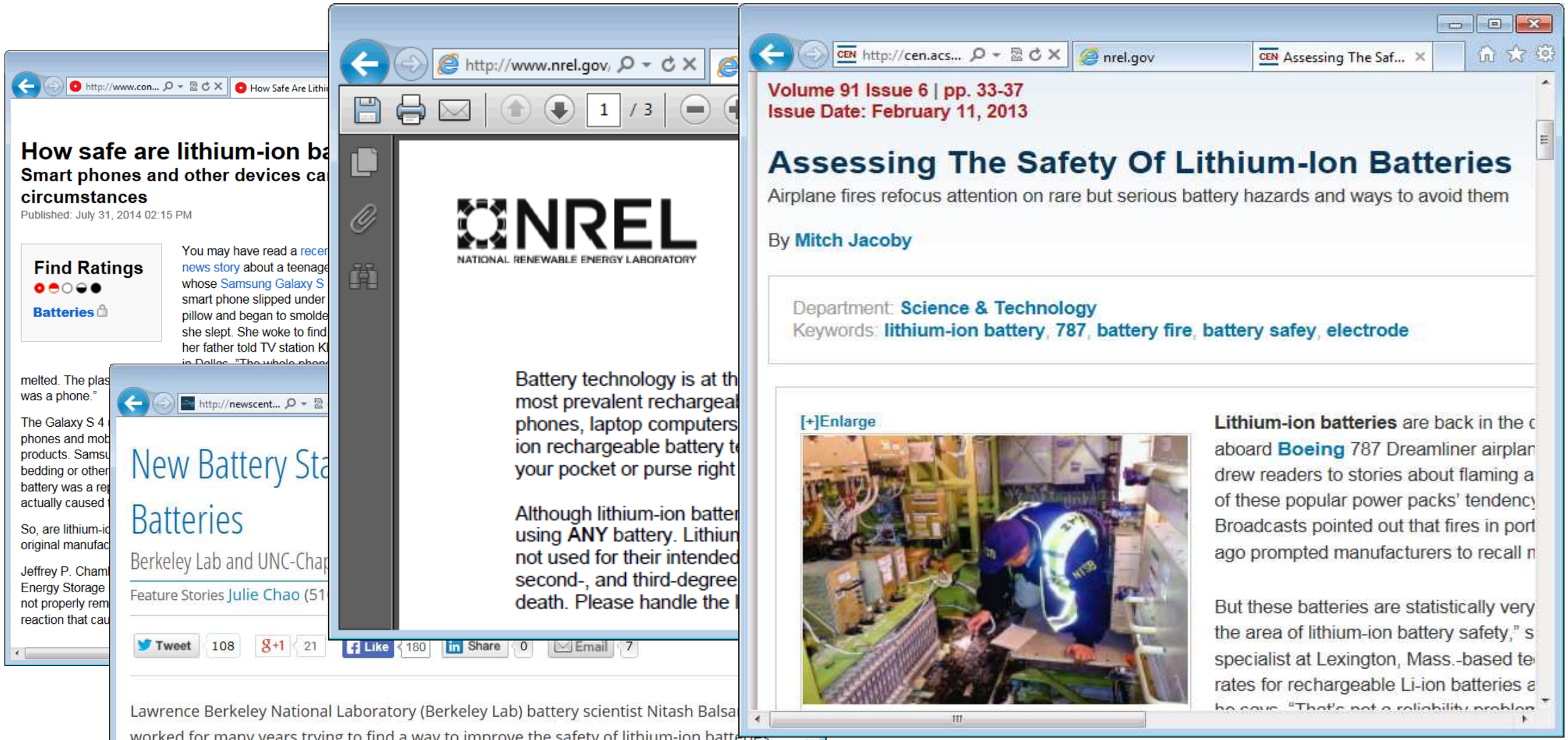
Selected Results to Date

- Unexpected causal factors
  - Not venting air form 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”



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

Kristoferb [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons

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

"Safety" is not a property of a component

Battery System Properties

By Jelson25 (Own work) [CC-BY-3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

- ✓ 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 then 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.

I also want to acknowledge professor Nancy Leveson and her team at MIT for the development of STAMP, STPA, and CAST. More information can be found at:

http://sunnyday.mit.edu/

Questions?

David Rosewater

dmrose@sandia.gov

505 844-3722