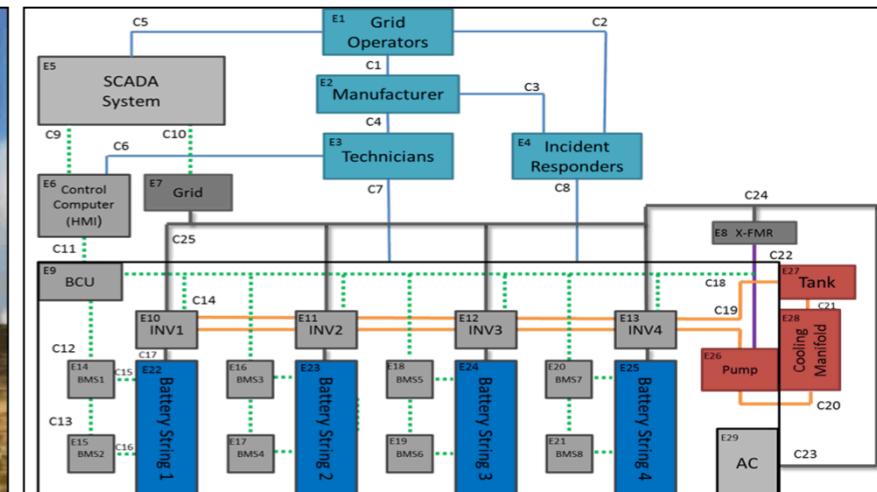


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System's Safety in Grid Energy Storage: Challenges and Solutions through the Application of STAMP

03/25/2015 David Rosewater PE

Energy Storage Test Engineer



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Intro to Safety in the Electric Grid

Codes, Standards, and Regulations (CSRs)

- National Electrical Code (NEC) was first 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:

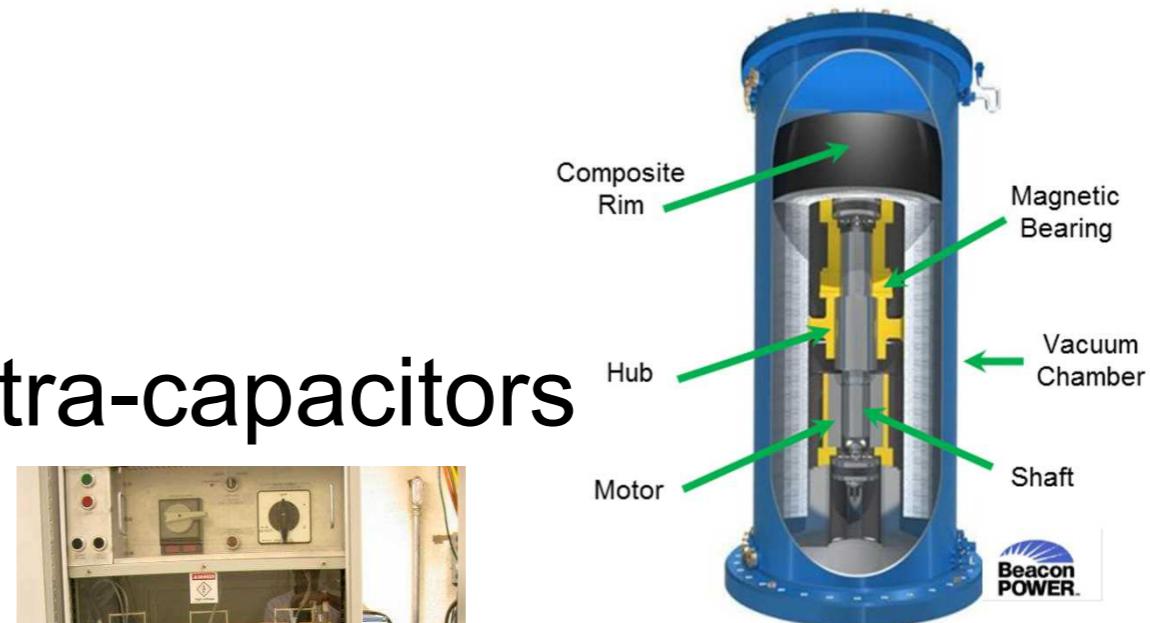
Batteries



Flow Batteries



Flywheels,



Ultra-capacitors



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

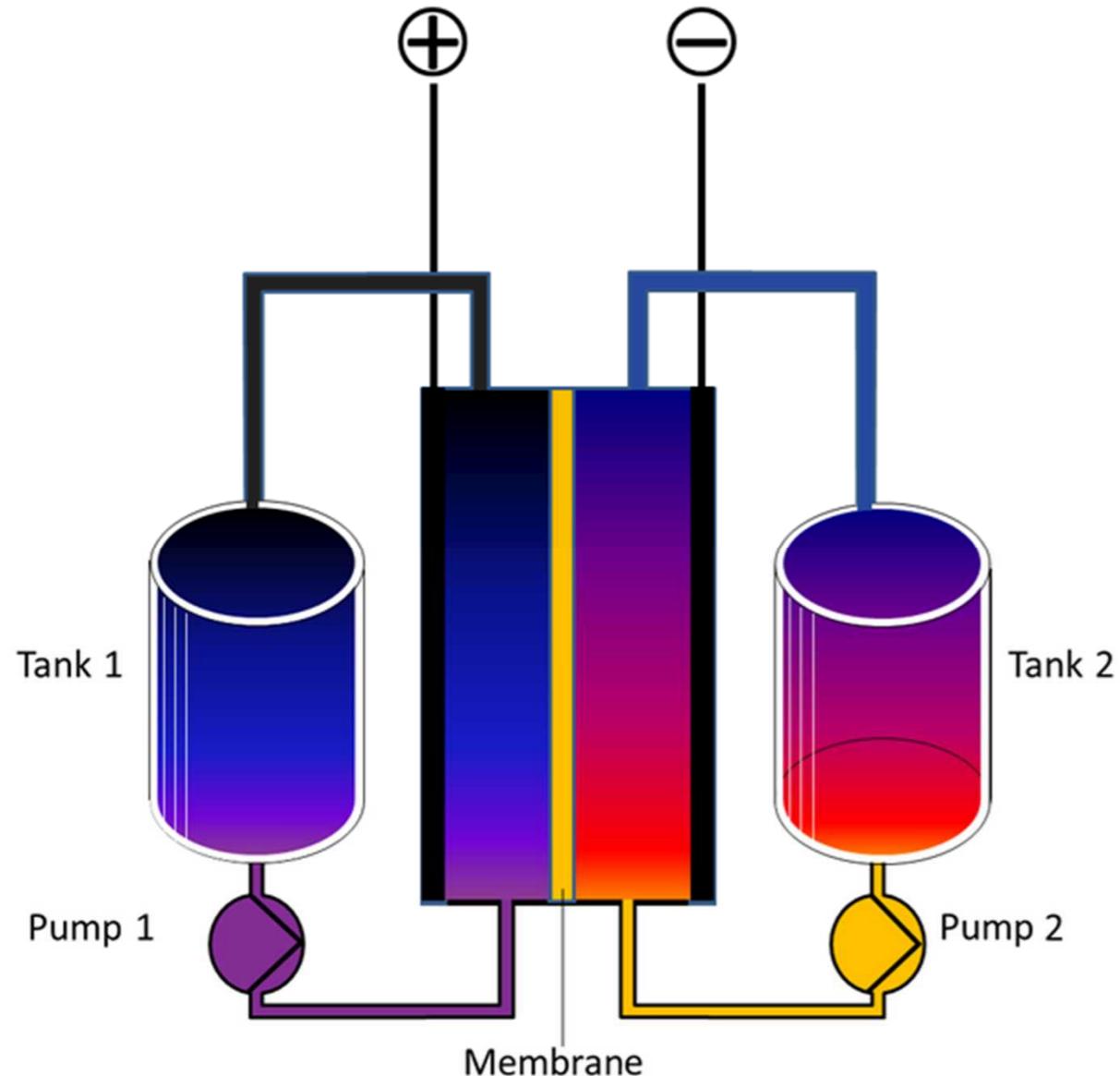
Even while the quantity of grid connected energy storage has been steadily increasing, its complexity has increased exponentially. This has made existing safety analyses tools much more difficult to apply and costs to companies to validate safety to increase.

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

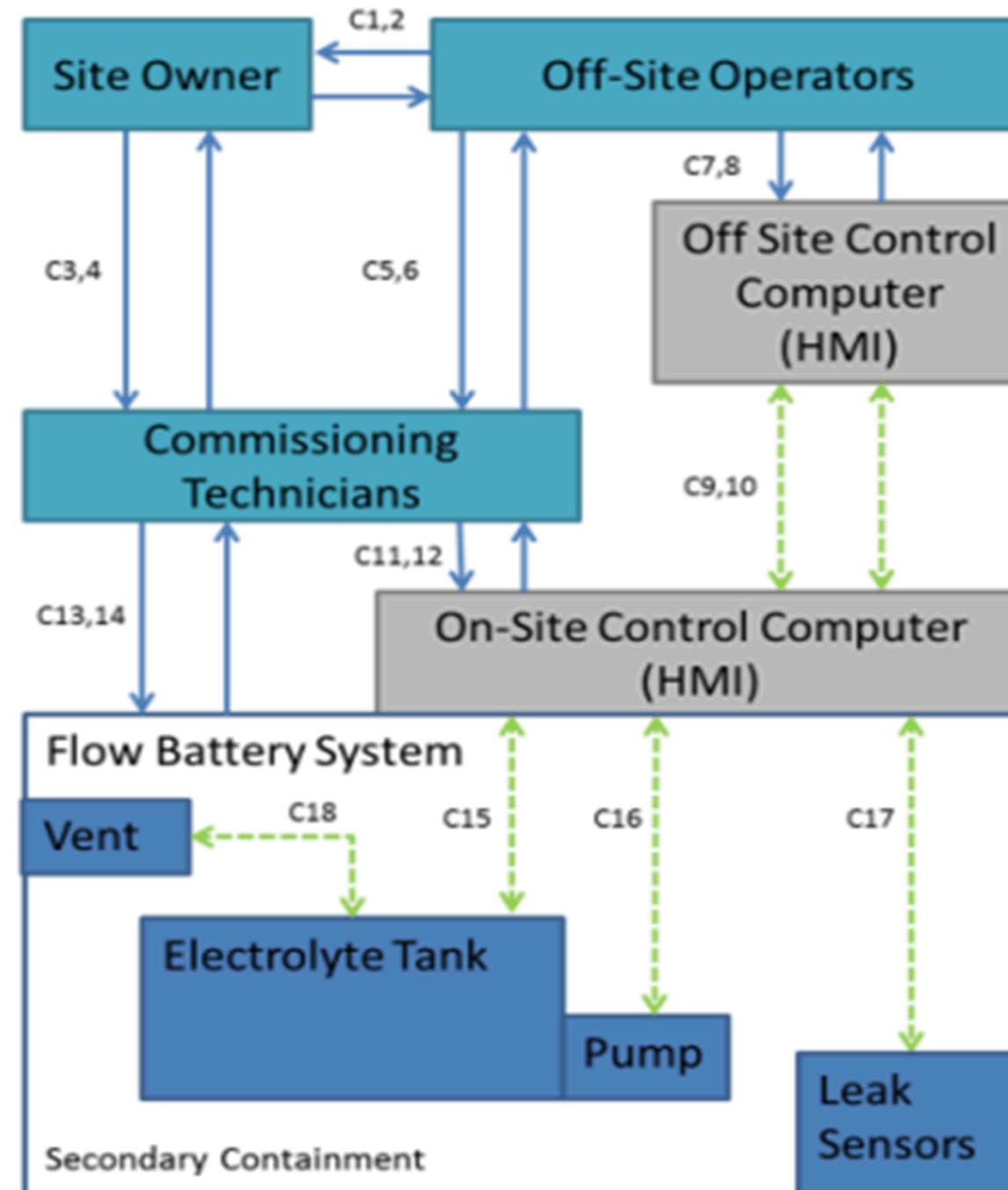


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Accident: Loss of effective electrolyte containment

- 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

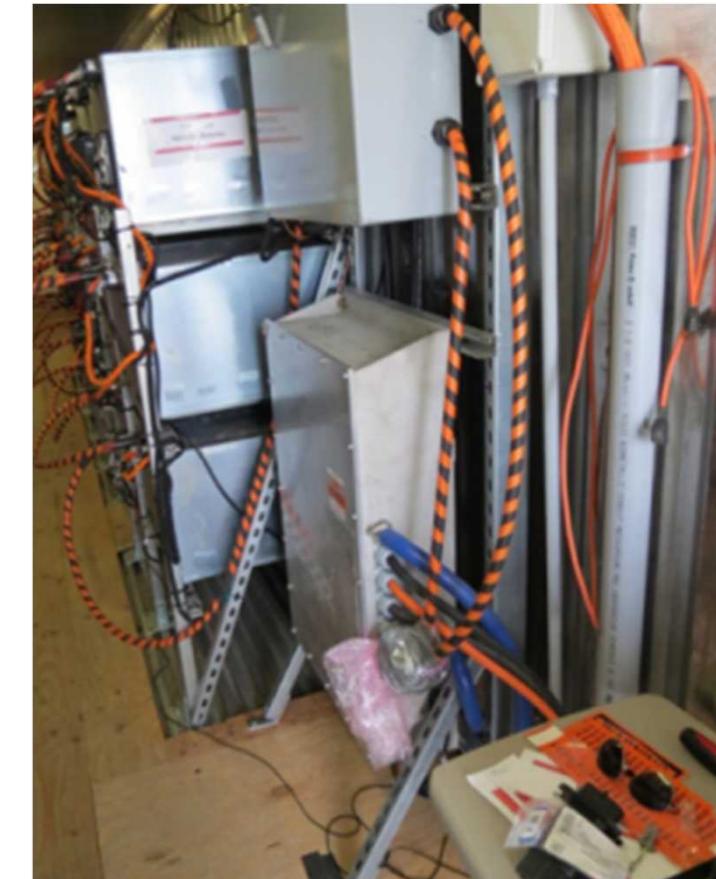
- Transpower GridSaver

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

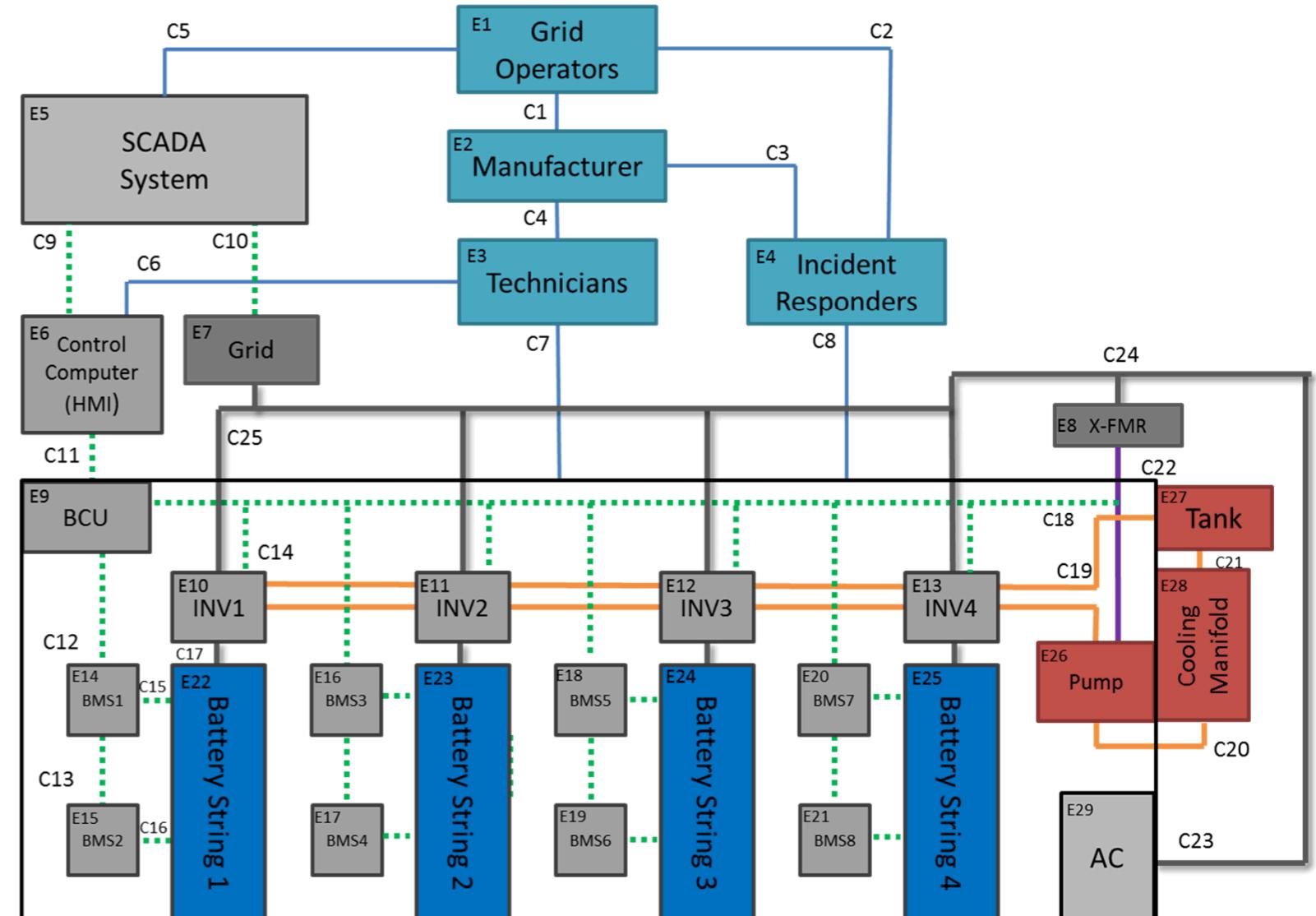


(b) Internal

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 different 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”

How safe are lithium-ion batteries?
Smart phones and other devices can catch fire in certain circumstances

Published: July 31, 2014 02:15 PM

Find Ratings
Batteries

You may have read a recent news story about a teenage girl whose Samsung Galaxy S smart phone slipped under her pillow and began to smolder while she slept. She woke to find her father told TV station KDFW in Dallas, "The whole phone melted. The plastic was a phone."

The Galaxy S 4 smartphone and mobile products. Samsung's bedding or other battery was a replacement. So, are lithium-ion batteries original manufacturers? Jeffrey P. Chamberlain, Energy Storage Systems, not properly removed, reaction that caused

New Battery Startup Batteries
Berkeley Lab and UNC-Chapel Hill

Feature Stories Julie Chao (51)

Tweet 108 **g+1** 21 **Like** 180 **Share** 0 **Email** 7

Lawrence Berkeley National Laboratory (Berkeley Lab) battery scientist Nitash Balsara has worked for many years trying to find a way to improve the safety of lithium-ion batteries. Now he believes he has found the answer in a most unlikely material—a class of compounds that has mainly been used for industrial lubrication.

Balsara and his co-inventor, Joseph DeSimone of the University of North Carolina at Chapel Hill, launched Blue Current, a startup company backed by investment firm Faster LLC, to further develop their invention, a nonflammable electrolyte.

"With current lithium batteries safety is engineered through the battery management system," Balsara said. "Although they are generally considered safe, you still have an

NREL
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Battery technology is at the most prevalent rechargeable phones, laptop computers, and ion rechargeable battery technology in your pocket or purse right now.

Although lithium-ion batteries are safe using ANY battery. Lithium batteries are not used for their intended purpose. Second-, and third-degree burns and death. Please handle the batteries with care.

[+Enlarge]



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Assessing The Safety Of Lithium-Ion Batteries

Airplane fires refocus attention on rare but serious battery hazards and ways to avoid them

By **Mitch Jacoby**

Department: **Science & Technology**
Keywords: **lithium-ion battery, 787, battery fire, battery safety, electrode**

Lithium-ion batteries are back in the headlines. A fire aboard **Boeing** 787 Dreamliner airplanes last year drew readers to stories about flaming batteries. Broadcasts pointed out that fires in portable electronic devices have also prompted manufacturers to recall products.

But these batteries are statistically very safe. "We're not talking about the area of lithium-ion battery safety," says Michael J. Ramsey, a specialist at Lexington, Mass.-based Teknion. "That's not a reliability problem."

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>

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Broader Impacts of STAMP

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

Battery Cell Properties



-  Capacity
-  Volatility
-  Temperature
-  Range
-  Safety

“Safety” is not a property of a component

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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 than are or are not safe)

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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?

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