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Ensuring Safety of Energy Storage Systems

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Sandia National Laboratories

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Growth of the Energy Storage in the Grid

- Pace of deployments of energy storage picking up
  - Grid reliability, solar + storage, resiliency applications
- Large new manufacturing capacity for Li-ion batteries primarily for EVs coming up fast
  - 2 TWh of new manufacturing capacity projected for 2030
  - Spill over into grid energy storage applications
- Refurbishment of existing pumped hydro storage fleet to become more flexible
- Other technologies such as flow batteries, alkaline batteries continue to be interesting

Li-ion BESS Driving Large Commercial Deployments

Saft 6 MW / 4.2 MWh ESS
Kauai - Grid Stability

AES 30 MW / 120 MWh ESS, Escondido, CA
Peaker replacement

GWh size BESS Plants no longer at the conceptual stage

Tesla 100 MW / 129 MWh ESS
Australia - Grid stability

Vistra Energy, Moss Landing, Monterey, CA - 300 MW / 1200 MWh – Peaker Replacement, Grid Reliability

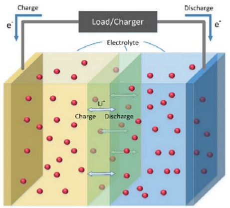
Images: Company websites and Wikipedia

Energy Storage is New to Grid Operators

Making Energy Storage Mainstream - Gaps

Technology

- Lower cost, longer duration energy storage is a major gap
- Technologies that can scale from microgrids to large transmission applications
- **Further improvements in safety and reliability**



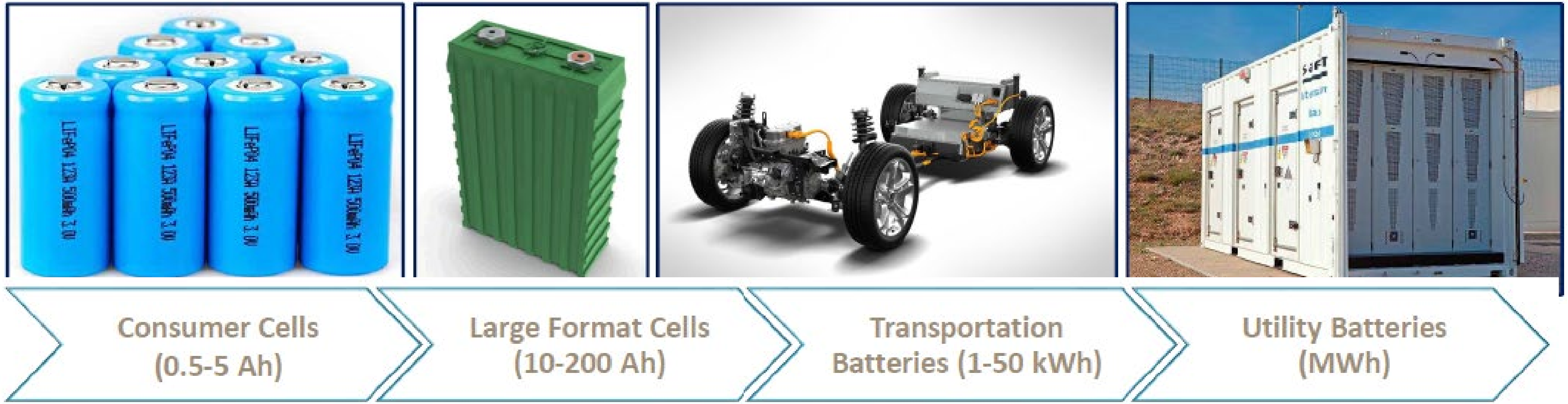
Manufacturing

- Industry needs cycles of learning – manufacturing scale through deployments
- Project finance – bankable, warrantees, performance guarantees, risk management
- **Standardization – equipment, permitting, construction processes**

Grid Operation

- Markets and Operations – business models and operational tools
- Analytics – economics and planning tools
- Appropriate Regulatory Policy – business models, asset classification

Impact and consequence of scale on safety

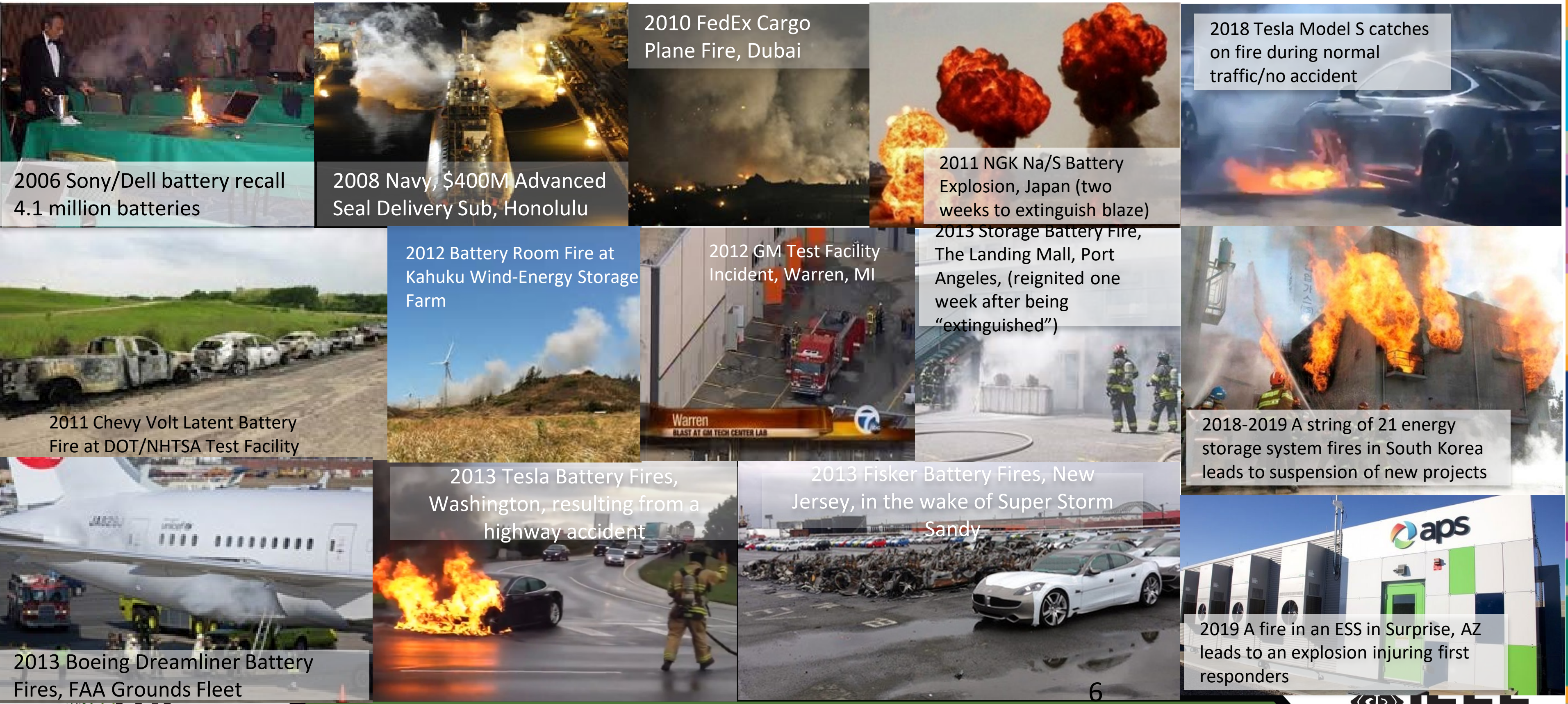


Safety issues and complexity increase with battery size

Safety research is heavily focused on lithium-ion as the primary application ready technology.

Many other emerging technologies are less well studied.

Battery Energy Storage Systems – Safety Concerns



2006 Sony/Dell battery recall 4.1 million batteries

2008 Navy, $400M Advanced Seal Delivery Sub, Honolulu

2010 FedEx Cargo Plane Fire, Dubai

2011 NGK Na/S Battery Explosion, Japan (two weeks to extinguish blaze)

2018 Tesla Model S catches on fire during normal traffic/no accident

2011 Chevy Volt Latent Battery Fire at DOT/NHTSA Test Facility

2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm

2012 GM Test Facility Incident, Warren, MI

2013 Storage Battery Fire, The Landing Mall, Port Angeles, (reignited one week after being "extinguished")

2018-2019 A string of 21 energy storage system fires in South Korea leads to suspension of new projects

2013 Boeing Dreamliner Battery Fires, FAA Grounds Fleet

2013 Tesla Battery Fires, Washington, resulting from a highway accident

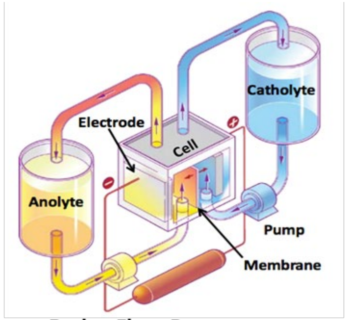
2013 Fisker Battery Fires, New Jersey, in the wake of Super Storm Sandy

2019 A fire in an ESS in Surprise, AZ leads to an explosion injuring first responders

Safety R&D is largely focused on Li-ion BESS

- Li-ion batteries: knowledge base mostly form consumer electronics, safety issued adequately addressed.
    - Safety issues for larger size (EV, grid) just beginning to be dealt with
- New technologies are being introduced
    - Is testing adequate to new technologies?
    - Li-ion – High energy anode materials
    - Li metal
    - Advanced aqueous batteries
    - Molten salt batteries
- Large storage systems targeting non-traditional locations, and areas near populations
- Grid-scale systems are complex, including not only a large battery but sophisticated power electronics
    - How do you qualify for safety? Is full-scale testing necessary?


Subway regen system, SEPTA



Redox Flow Battery


SAFT 10 MWh storage system


US Marine Corps FOB, Afghanistan

What is needed?

- How can we adequately prepare for new technologies to enable their rapid adoption?
- Are we adequately addressing current gaps in safety research?
- What gaps still hinder lithium-ion adoption? How best to ensure stakeholders are adequately informed of the risk they accept?
- Is full-scale testing necessary, and if so, is there lab capacity to adequately perform it.
- Do we have appropriate standards to ensure safety?
- Do first responders have adequate training/resources to handle incidents?

Ensuring Safety – Codes and Standards

Safety standards are developed through a consensus-based development process with diverse stakeholder participation.

Advantages:

- Broad agreement in the field
- Good at learning from past accidents

Disadvantages

- Slow to change (3-10 year revision schedules)
- Bad at preventing accidents before they happen

A few prominent examples are:

- IFC – defines what safety standards shall be used in regions that have adopted it
- UL 9540 – provides a hierarchy of safety standards for energy storage components, tests, and system integration
- NFPA 855 – covers: installation, commissioning, O & M, emergency response, and decommissioning

Energy Storage Safety Codes and Standards Update

Publication released quarterly

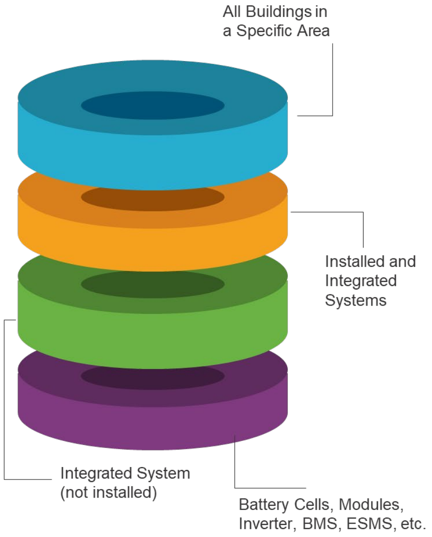
[Available: https://www.sandia.gov/energystoragesafety-ssl/](https://www.sandia.gov/energystoragesafety-ssl/)

4 **Built Environment**
International Codes – IFC, IRC, IBC
IEEE – C2, SCC 18, SCC 21
NFPA 5000, NFPA 1, ISA

3 **Installation / Application**
NFPA 855, NFPA 70, IEEE C2, IEEE 1635/ASHRAE 21, IEEE P1578, FM Global 5-33, UL 9540A, NECA 416

2 **Energy Storage Systems**
UL 9540, MESA
ASME TES-1, NECA
NFPA 791

1 **System Components**
UL 1973, UL 1974, UL 810A, UL 1741, CSA 22.2 No. 340-201, IEEE 1547, IEEE 1679



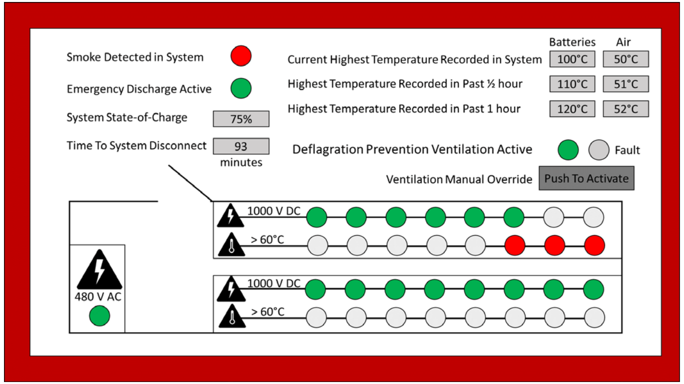
Responding to an Incident

Incident Response

- When firefighters arrive on the scene of a battery system fire, they initiate an ongoing hazard assessment with priorities being life, property, then environment.
- The system must be designed such that firefighters can understand the current state of the system without being exposed to a hazard.
- When firefighter action is required, such as in the case of an uncontrolled runaway reaction that may spread to nearby structures, options must be available for actions that do not expose personnel to the hazards inside.

Training Needs

- Should focus on hazard identification, determining safe entry, methods for limiting the spread of a battery fire, identifying when the best approach is to not put out the fire (letting hazardous stored energy be dissipated safely), and determining when it is safe to leave an incident site.



Example layout for an energy storage fire alarm control panel

The system should include a durable, external display, accessible from a safe location, for firefighters to access

From: https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf

ENERGY STORAGE R&D AT SANDIA

BATTERY MATERIALS

Large portfolio of R&D projects related to advanced materials, new battery chemistries, electrolyte materials, and membranes.

CELL & MODULE LEVEL SAFETY

Evaluate safety and performance of electrical energy storage systems down to the module and cell level.

POWER CONVERSION SYSTEMS

Research and development regarding reliability and performance of power electronics and power conversion systems.

SYSTEMS ANALYSIS

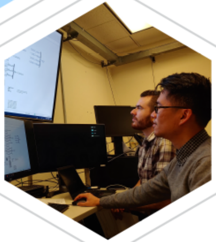
Test laboratories evaluate and optimize performance of megawatt-hour class energy storage systems in grid-tied applications.

DEMONSTRATION PROJECTS

Work with industry to develop, install, commission, and operate electrical energy storage systems.

STRATEGIC OUTREACH

Maintain the ESS website and DOE Global Energy Storage Database, organize the annual Peer Review meeting, and host webinars and conferences.

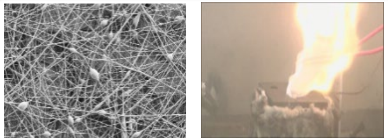


GRID ANALYTICS

Analytical tools model electric grids and microgrids, perform system optimization, plan efficient utilization and optimization of DER on the grid, and understand ROI of energy storage.

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

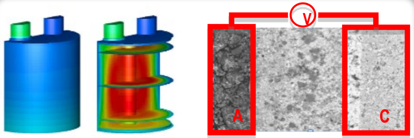
Battery Safety – Stationary Storage



Materials R&D to date:
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

Materials R&D needs:
- Viable flow batteries
- Aqueous electrolyte batteries
- High specific heat suppressants
- Vent gas composition

Testing
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Suppressants and delivery with systems and environments
- Large scale thermal and fire testing (TTC)



Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating failure propagation models
- Fire Dynamic Simulations (FDS) to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation
- UL 1973-13 Batteries for Use in Stationary Applications
- ANSI/UL 9540-P (ESS Safety)
- UL 1974 (Repurposing)
- IEEE 1635-12 (Ventilation and thermal management)

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Questions?

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Questions?

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Additional References

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- http://www.firefighternation.com/wp-content/uploads/sites/10/2020/07/document.pdf
- https://docket.images.azcc.gov/E000007939.pdf
- https://ulfirefightersafety.org/docs/Four_Firefighters_Injured_In_Lithium_Ion_Battery_ESS_Explosion_Arizona.pdf

Full Scale Fire Test Reports

- https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFFireHazardAssessmentLithiumIonBattery.ashx
- https://ulfirefightersafety.org/docs/UL9540AInstallationDemo_Report_Final_4-12-21.pdf
- https://www.nfpa.org/News-and-Research/Data-research-and-tools/Suppression/Sprinkler-Protection-Guidance-for-Lithium-Ion-Based-Energy-Storage-Systems

2021 Energy Storage Safety and Reliability Forum Presentation Archive

- https://www.sandia.gov/ess-ssl/2021-essrf/

Firefighter Training Video / Resources

- https://www.nfpa.org/News-and-Research/Resources/Emergency-Responders/High-risk-hazards/Energy-Storage-Systems

ES Codes and Standards Update

- https://energy.sandia.gov/wp-content/uploads/2021/02/SC-Report-by-SDO-WINTER-2021_Final.pdf

Hazard Analysis on Grid-scale Energy Storage

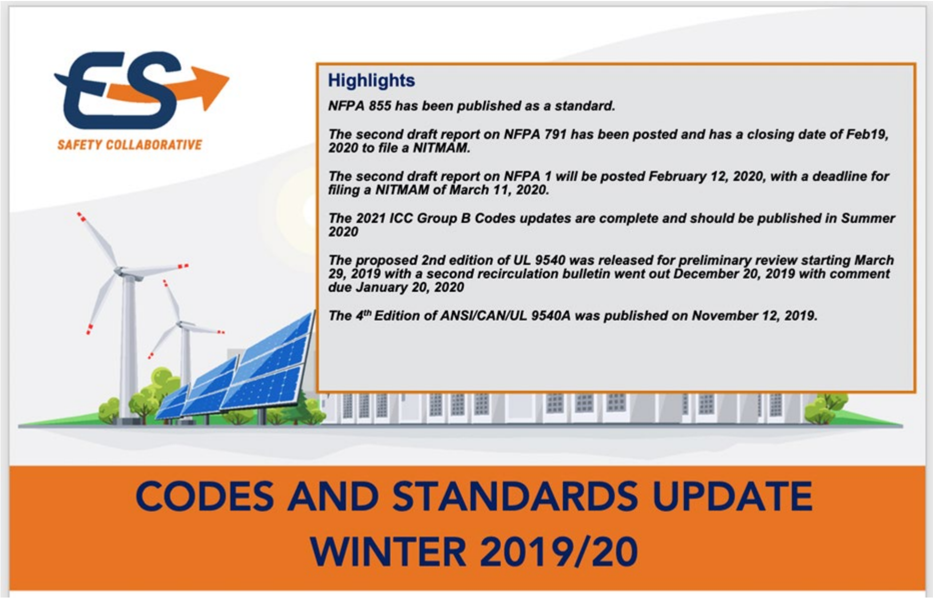
- https://www.sandia.gov/ess-ssl/wp-content/uploads/2020/09/Rosewater-APS.pdf
- https://www.epri.com/research/products/000000003002017136

Journal Articles

- https://www.osti.gov/pages/biblio/1257985
- https://iopscience.iop.org/article/10.1149/1945-7111/ab84fa

Energy Storage Safety Collaborative Reports

Get the free reports to remain alerted to key ESS Codes & Standards updates!



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