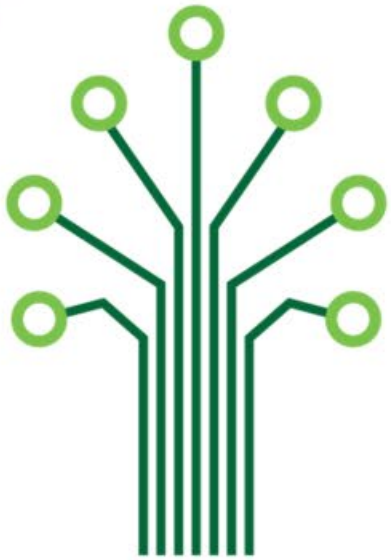


ENERGY STORAGE SYSTEMS

SAFETY & RELIABILITY FORUM

Taming the Beast: System designs to address cell-level safety concerns

Instructor: Jim McDowall

ENERGY STORAGE SYSTEMS
SAFETY & RELIABILITY FORUM

Learning objectives

- Understand the influence of safety incidents on the evolution of ESS system design and safety standards
- Learn how ESS vendors are approaching system safety and compliance with codes and standards

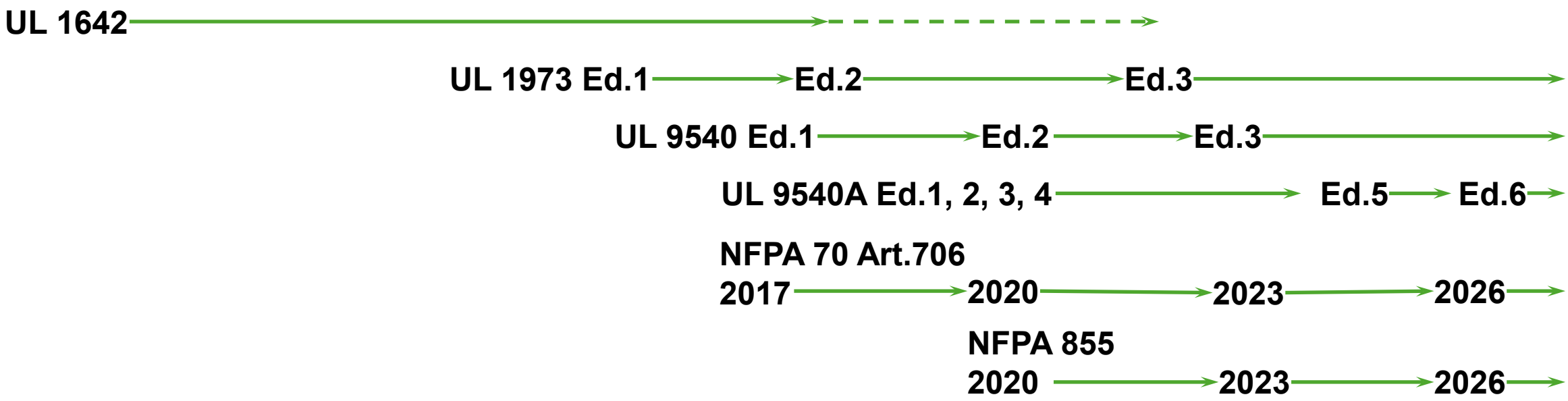
- Please ask questions as we go…

Trends in ESS design

- Mitigating cell-level safety issues – battery management systems
- Influence of codes and standards on ESS design
- System design
  - Early systems
  - Enclosure development
  - Thermal management
  - Safety systems
- Cell design
  - Chemistry
  - Format
  - Capacity

BMS functionality and limitations

- BMS functions
  - Verify battery operation within limits for voltage, current, and temperature
    - Open a current-rated switch if limits are exceeded
  - Report battery operating parameters to higher-level controllers
    - Direct measurements for V, I, and T
    - Calculated values for state of charge and state of health
  - Actively balance cell states of charge
  - Provide overcurrent protection
- BMS limitations
  - No active current control
  - Cannot prevent internal cell failures or external failures such as arcing ground faults



First Li-ion container system

Kahuku First major ESS fire (lead-acid)

S. Korean fires

McMicken

NY State fires

Moss Landing

Grandfathering or retroactivity?

- What happens with existing ESS as codes and standards are constantly changing?
- NFPA 855 does not apply to ESS that existed or were approved for construction or installation prior to the effective date of the standard

HOWEVER,

- The authority having jurisdiction (AHJ) can require a site-specific hazard mitigation analysis
- If the AHJ determines that an unacceptable degree of risk exists, they can apply any portion of the standard retroactively

Early systems

- Covering the period 2008 to around 2019
- Systems were mainly walk-in ISO containers (many 53-foot) and building-based
- A123 Systems had early success with LFP; others used NCA or NMC
- Fire suppression was standard
  - Sprinklers in buildings
  - Clean agents or aerosols in containers

BELCO, Bermuda and Moss Landing, CA

Evolutions

- Building-based systems no longer in fashion
  - Prominent fires at Gateway and Moss Landing
- Containers shifted to outside access (both sides)
  - Higher energy
  - Less stringent code requirements for non-walk-in units
- NMC chemistry yielded to LFP
  - Less expensive and improved safety
  - But not as easy to manage
- Cell formats changed from cylindrical and pouch to prismatic

Escondido, CA

Source: Marco Righi LinkedIn

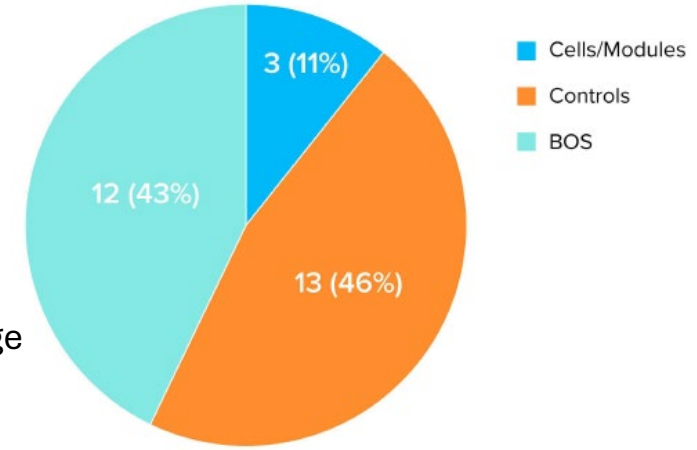
Evolutions (cont.)

- New thinking on fire suppression
  - Sprinklers can cause or worsen fires
  - Clean agents, if successful in suppressing fires, can create an explosion hazard
- Elimination of 40- and 53-foot containers
  - 20-foot containers or custom enclosures shipped fully assembled
  - Road transport weight limits
  - Now single-side access for higher site density
- Move from HVAC to liquid cooling
  - Cooling plate directly under cells
  - More effective cooling with lower aux power use
  - Better temperature uniformity within strings
  - May still have a small HVAC for humidity control

Surprise, AZ

Evolutions (cont.)

- Development of ‘big data’ approach with battery analytics
- Upload BMS data to cloud-based database for trending with AI
  - Provided that ESS vendor allows this
- Service offered by some ESS vendors and third parties
- Service providers claim to be able to spot impending cell failures for proactive response
  - But bear in mind that balance-of-plant failures are more common than cell/module failures



EPRI: Insights from EPRI’s Battery Energy Storage Systems (BESS) Failure Incident Database
Analysis of Failure Root Cause

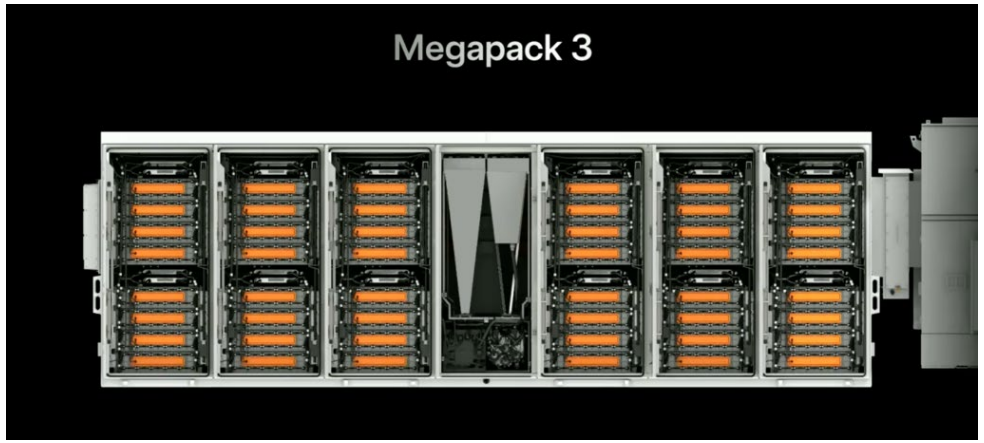
Today's systems – DC blocks

- DC system
  - Often based on 20 ft. ISO container footprint
  - Battery strings and associated BMS
  - May have string-level DC-DC converters
  - Managing multiple strings on a common DC bus can be challenging
- Separate DC-to-AC power conversion
  - May be matched with a medium-voltage power station (inverter, transformer, and switchgear)
- DC block can only be certified to UL 1973
  - Full system must be UL 9540 listed
  - May require field certification

Source: Fluence

Today’s systems – AC blocks

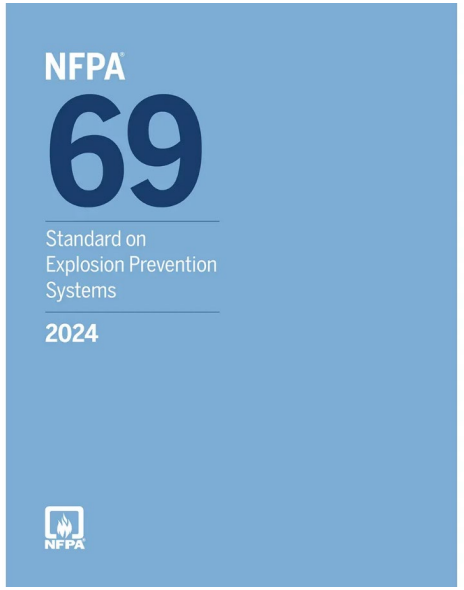
- AC blocks incorporate power conversion into the battery enclosure
  - May have string-level PCS and common AC bus or a separate PCS compartment
- UL 9540 system certification performed by the factory

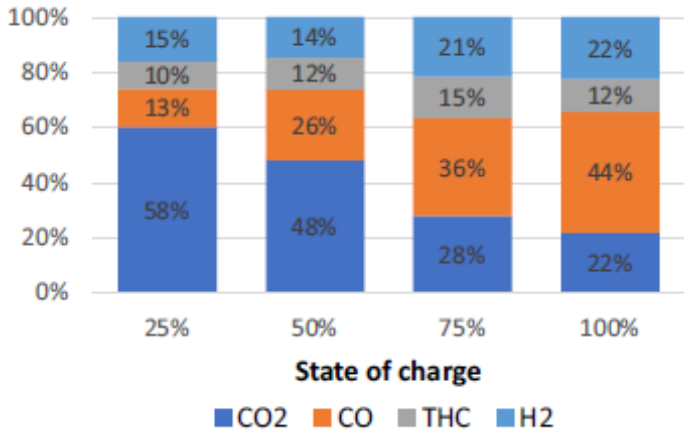


Source: Tesla

Critical safety systems

- Similar safety systems for AC and DC blocks
- NFPA 855 requirements for Li-ion outdoor facilities
  - Smoke and fire detection in accordance with NFPA 72
  - Explosion control and prevention
    - Securely powered combustible concentration reduction (CCR) system mandated in accordance with NFPA 69
    - Maintain average concentration of flammable gas below 25% of the lower flammable limit
    - CCR system required to function up to the point where fire occurs
    - Partial-volume deflagration analysis also required in accordance with NFPA 68
  - Engineered explosion control systems allowed as an alternative to NFPA 69
    - Controlled deflagration systems (sparkers), typically in combination with deflagration venting





Journal of Energy Storage 68 (2023) 107785
https://doi.org/10.1016/j.est.2023.107785

Maintenance considerations

- Critical safety systems are subject to mandatory inspection, testing, and recordkeeping requirements
  - NFPA 69: initially inspected and tested at 3-month intervals
  - Changes to schedule must be approved by the system designer and the AHJ
- NFPA 69 CCR systems require routine airflow measurements to verify design assumptions
- Secure powering systems (NFPA 110 or 111) have their own inspection and testing requirements

Large-scale fire testing

- Problem: systems passed UL 9540A propagation testing (up to 5th edition) with flying colors – and still suffered from fires
- Solution: require a full burn of an ESS enclosure and verify that propagation does not occur to adjacent enclosures at the spacing recommended by the manufacturer
- LSFT added in 2026 edition of NFPA 855
  - Included in CSA C800-25 and 6th edition of UL 9540A (March 2026)

Source: Hithium

Future evolutions

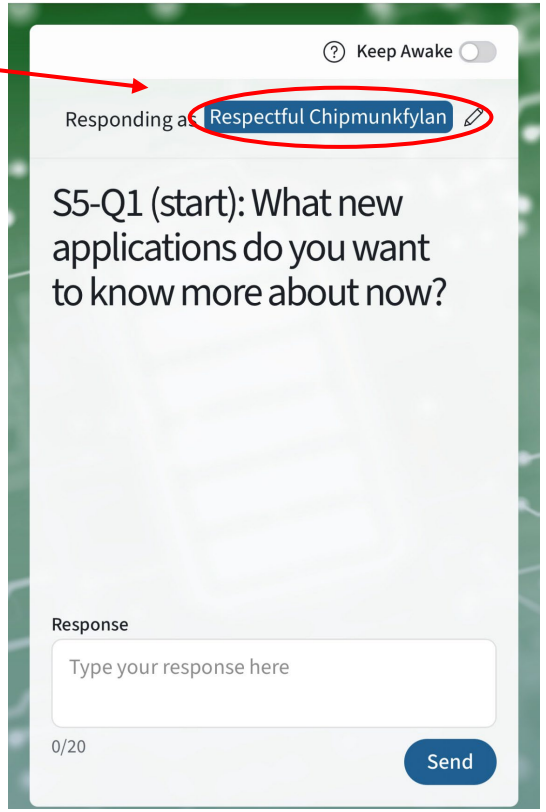
- LFP cell capacities have been increasing
  - Many systems today use 314 Ah cells
  - Some Chinese manufacturers have announced systems with cells of 565 Ah, 1,175 Ah, and even 2,710 Ah
  - Compliance with NFPA 69 is questionable for these systems
    - Thermal runaway vent gas volume scales with capacity
- Emergence of sodium-ion technology
  - Includes multiple chemistries, as with Li-ion
  - Beware of statements that these batteries are ‘safe’
  - Cells have similar electrolytes to Li-ion and hard carbon negatives that form a solid-electrolyte interphase, and will vent if abused
  - Advantage of Na-ion is that, unlike Li-ion, they can be transported and stored fully discharged

Poll Questions

Please visit Poll Everywhere via the **QR** code below (mobile) or at **pe.app/essrf** (laptop). If you would like to add your name, please update with the "pencil" icon. If not, feel free to remain anonymous

Respond at

pe.app/essrf



Poll:

A BMS can control current in a battery string

- True
- False

Poll:

ESS enclosures are equipped with fire suppression as standard

- True
- False

THANK YOU

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