WHAT IS THE ROLE FOR SAFETY CODES and LDES ?

Presented by:
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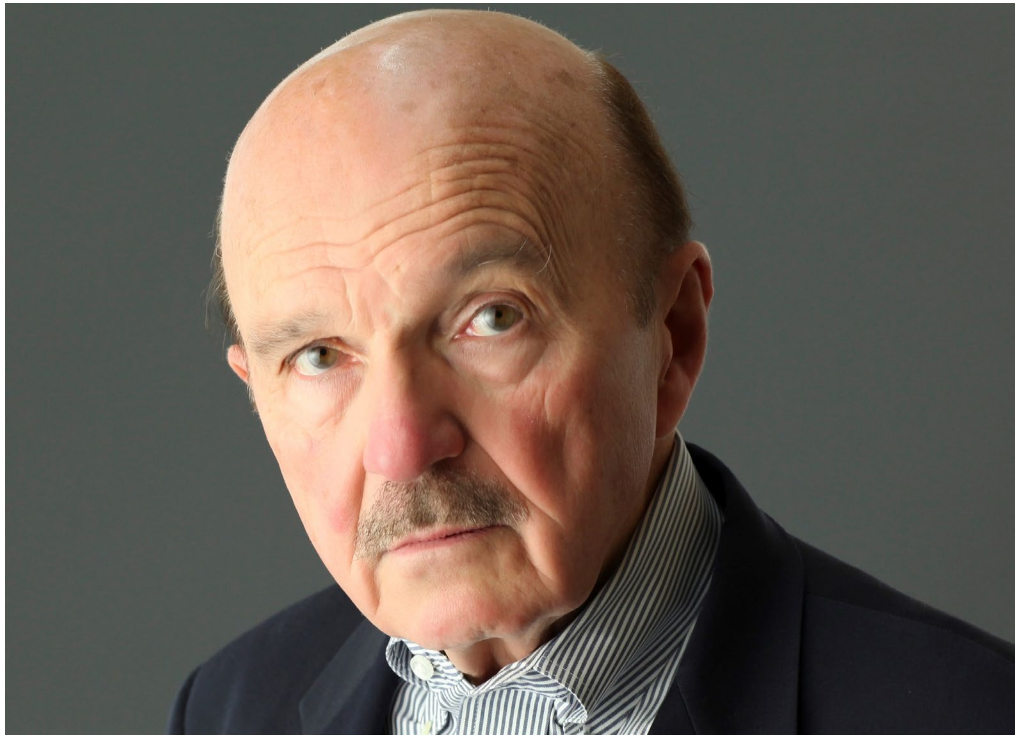
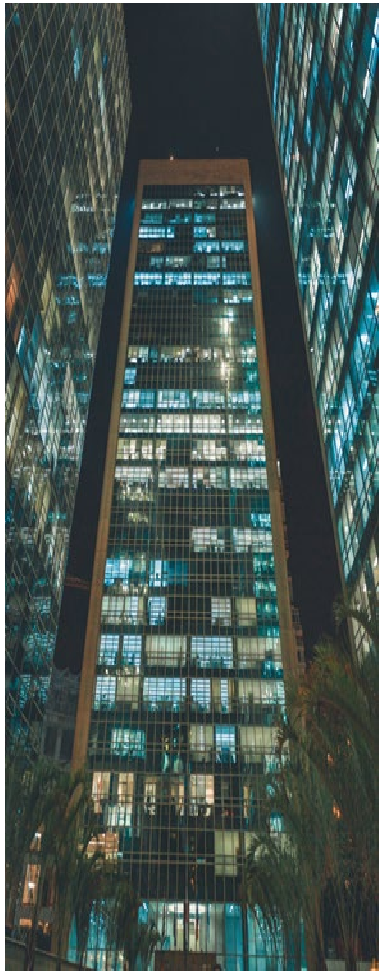
Let Me Introduce Myself

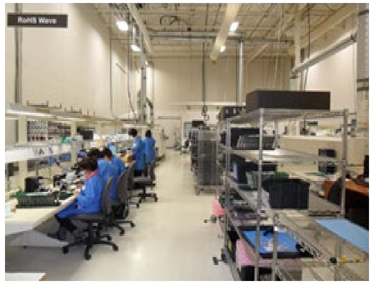
- 40+ year Veteran in Vdc Power and Stationary Battery Industry
- First Chair of IEEE PES Energy Storage and Stationary Battery (ESSB) Committee
- Current Co-Chair of the IEEE ESSB Safety Codes and Standards Working Group
- Active member of NFPA 855 Committee
- Active member of NFPA 70 CMP 13 Committee
- Active participant in the ICC BESS Ad Hoc Committee



Christopher (Chris) Searles

General Categories of Current Safety Codes and Standards





- **Fire Protection and Safety**
  - Includes fire suppression
  - Includes explosion control
- **Occupational risks and hazards**
  - Includes worker safety
  - Includes workplace safety
- **Design & Materials Safety**
  - Components are safe and products are reliable
  - Inspection, Testing & Maintenance (ITM) Requirements & Audits
- **Building & Environmental safety**
  - Infrastructure and Buildings
  - Transportation over highways and by air

For Battery Energy Storage Systems (BESS), a #1 Issue –

SAFETY

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

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

Tesla Battery Fires, Washington, resulting from a highway accident

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

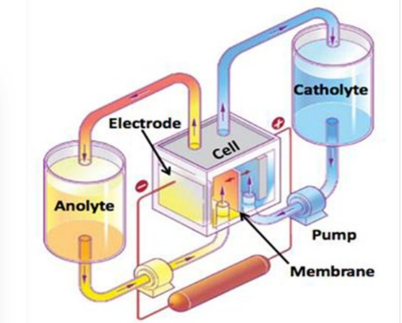
2018-2019 A string of 21 energy storage system fires in South Korea leads to suspension of new projects

Photos, Courtesy of Sandia National Laboratories

Current & Future Focus for ESS Safety Codes R&D

- **Li-ion batteries have been the primary focus for most R&D efforts to date.**
  - ✓ Lead-acid/Ni-cd safety issues largely addressed and proven basically safe.
  - ✓ Safer Li vis a vis materials and electrolyte improvements
  - ✓ Safety issues for EV and large utility-scale BESS just beginning to be addressed – including V2G and G2V.

- **New Technologies** (e.g., Flow batteries, Li-Metal, Sodium-ion, Zinc, Hydrogen Fuel Cells, etc.) will pose different set of concerns.



Redox Flow Battery

- **Long Duration Energy Storage,**
  - ✓ Required in high population dense areas – LDES systems are much more complex.
  - ✓ Includes large battery systems with sophisticated high-power electronics (IBR).
  - ✓ Series of DOE awards granted to create set of technology alternatives for LDES.
- **Questions needing answers :**
  1. **Can we identify safety issues ahead of the experience curve?**
  2. **Is full-scale system-level testing necessary instead of current cell/unit level testing?**
  3. **How do we get SDO's, Regulatory bodies and AHJ's to fast-track codes and standards that validate new technologies while ensuring their safety?**


SAFT 10 MWh storage system

Unfortunately, we can't truthfully answer all of these today, but let's briefly highlight what safety codes do provide today!

WHAT DO TODAY'S SAFETY CODES ROADWAYS LOOK LIKE?

WHICH CODES/STANDARDS ROADS SHOULD I FOLLOW?

OSHA

DOT

Oh, Did We Forget to Mention . . . .

FERC

NERC

FM GLOBAL

OTHER REGULATORY BODIES

ALL OF THE ABOVE – REALLY ?? ***Answer: They all are Important in Individual Contexts***

Current Key Battery Hazards . . . .

Electrical

- Shock – Current passing through the body.
- Arc Flash/Blast – Current passing through the air.
- Thermal Burn – Inadvertent skin contact with hot conductive metals including uninsulated tools.

Chemical

- Battery electrolyte can be highly acidic.

The biggest safety concern with Li-Ion, NaS (and a few other technologies) is thermal runaway as it can be uninitiated; not always results in a fire; xan lead to an explosion; is the least understood and most difficult to control.

Fire / Explosion

- ❑ Some battery types can go into thermal runaway, catching fire generating smoke, and/or combustible gas.
- ❑ Release of toxic gases can lead to significant explosions.

Mechanical

- Batteries can be very heavy.
- Lifting/hosting/moving batteries can create pinch/crush/cutting forces that can lead to an accident or defective malfunction.

What is Thermal Runaway ?

NFPA 855 defines Thermal Runaway as a *"Self-heating of an electrochemical system in an uncontrollable fashion [NFPA 855 2023 3.3.26*]"*. In Annex A it adds *"Thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate."*

Note: See previous Copyright Note at beginning of presentation.

UL Research explains it this way for Li-Ion cells:

> *"In ideal conditions, the heat is able to dissipate from the cell. However, in thermal runaway, the lithium-ion cell generates heat at a rate several times higher than the rate at which heat dissipates from the cell.*
>
> *"The cell reaches thermal runaway when its temperature rises uncontrollably at a rate greater than 20° centigrade per minute with maximum temperatures reaching greater than 300°C accompanied by gas and/or electrolyte venting, smoke or fire or a combination of all."*

What Is Thermal Runaway? | UL Research Institutes – correlated with https://ul.org/research/electrochemical-safety/getting-started-electrochemical-safety/what-thermal-runaway,

Article in the Journal of The Electrochemical Society on 3 different testing methods and conclusions:
Matthew Sharp *et al* 2022 Journal of Electrochemical. Society 169 020526

IEEE 1881 defines it as *"a rapid uncontrolled and uninterruptible rise in temperature resulting in a catastrophic failure of a cell, unit or battery." (See thermal walkaway)*

What are the Causes of Thermal Runaway?

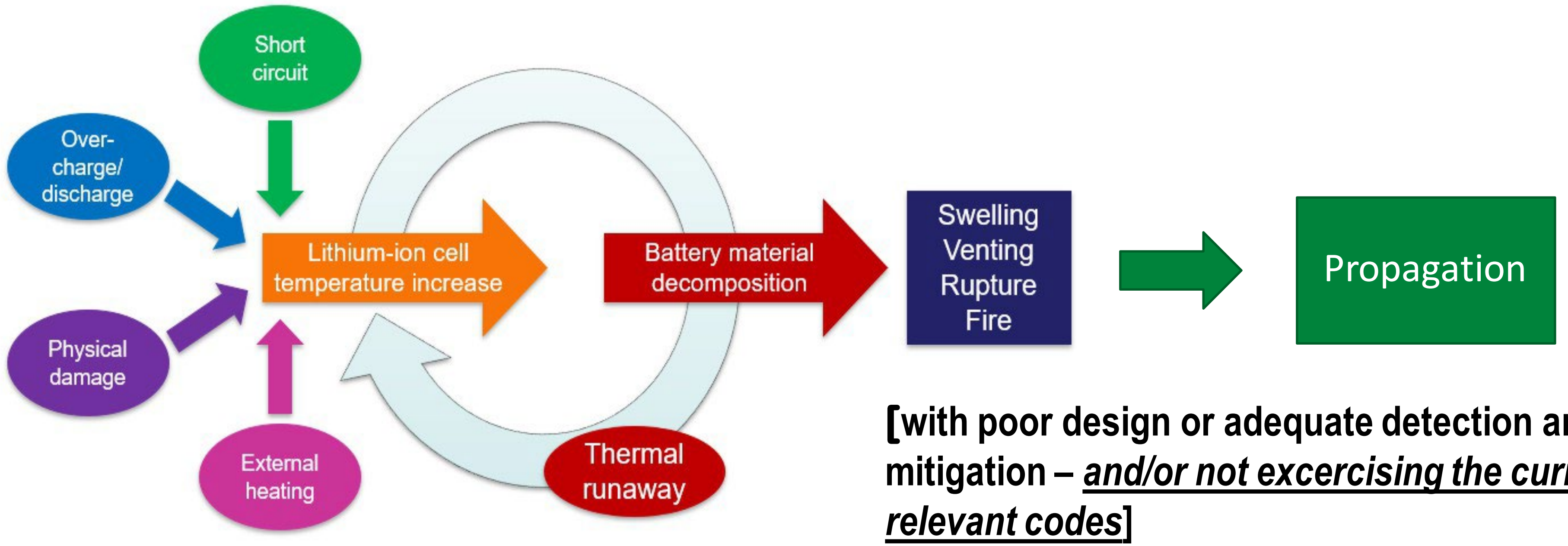
Abuse Conditions

- Electrical abuse
- Mechanical abuse
- Thermal abuse

Latent Failures

- Contamination during manufacturing
- Material impurities
- Improper design

  Lack of Quality Control in production



[with poor design or adequate detection and mitigation – *<u>and/or not excercising the current relevant codes</u>*]

Note: Used by permission from David Rosewater, PhD. Sandia National Laboratories

What is the Process of Thermal Runaway?

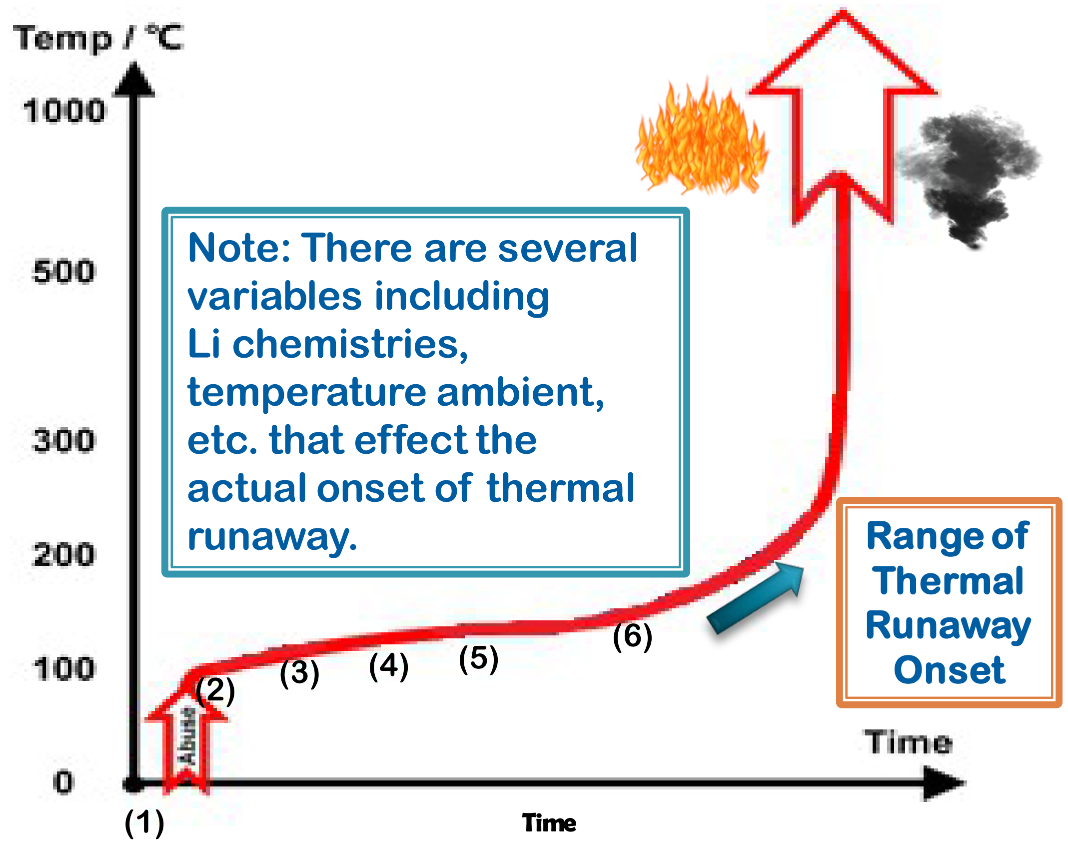
A Graphic Way to Look at it:

Thermal runaway in a Li-ion battery:

(1) Heating starts
(2) Negative electrode protective layer (SEI) breaks down (~80℃)
(3) Negative electrode breaks down with electrolyte ($\geq 100^{\circ}C$) *Note: LTO breaks down around 375°C.*
(4) **Separator melts, possibly causing short circuit ($\geq 120^{\circ}C$)**
(5) Positive electrode breaks down, generating oxygen (130-150℃) *Note: the LFP electrode breaks down ~275°C.*
(6) Oxygen reacts with electrolyte (>150-180℃)

Reference: John T Warner, Lithium Battery Chemistries 2009

During this process gasses (some toxic) are released, and fire can ignite inside the cell, but not in all cases.



Major BESS Technologies Overview (1)

	General Specifications[1]			Applications					Monitoring		
BESS TYPE	Wh/kg	Wh/L	Cycles to 80% DOD	Data Ctr UPS	Utility	Telco	PV Micro-grid	LDES	BMS	ESMS	Thermal Runaway
LFP	100	105	5,000	YES	YES[2]	YES[3]	YES[3]	YES	YES	YES	YES[5]
LMO	100	120	1,500	YES	YES[2]	YES[4]	NO	NO	YES	YES	YES
LNMC	135	120	2,000	YES	YES[2]	YES[4]	NO	NO	YES	YES	YES
LTO	80	80	15,000	YES	YES[2]	YES	YES	YES	YES	YES	YES[5]
NaNiCl	90	110	4,500	YES	YES[2]	YES	YES[3]	NO	YES	YES	NO
Na-Ion	90	100	2,000	YES	NO	NO	YES	NO	YES	YES	NO
NaS	200	350	4,500	NO	NO	YES	YES	YES	YES	YES	NO[7]
NiMH	50	35	3,000	YES	YES	YES	YES	YES	NO[10]	Option	NO[8]
NiZn	70	115	700	YES	YES	YES	NO	NO	NO[10]	Option	NO
Ni-Cd	55	80	1,500	YES	YES	YES	YES	YES	NO	Option	NO
VLA	25	50	3,000	YES	YES	YES	YES	YES[12]	NO	Option	NO[8]
VRLA (AGM)	40	90	2,500	YES	YES	YES	YES	YES	NO[11]	Option	NO[9]
VRLA (Gel)	40	90	3,500	YES	YES	YES	YES	YES[13]	NO	Option	NO[8]

NFPA 855 – The Bellwether ESS Standard

- Key Elements of NFPA 855-2023 affecting ESS Installations including LDES . . . .
  - Now covers most commercially available BESS technologies including Li, Pb-Acid, Ni-Cd, Na, Ni, Flow and Zn plus mechanical Flywheel.
  - Addresses all stationary energy storage applications including standby with application exceptions/ carveouts for Pb-acid, Ni-Cd.
  - Requires UL listings for all devices used in ESS applications including Li, Pb-acid, Ni-Cd (with carveouts), alternative BESS + inverters, UPS, related equipment (UL 9540).

NFPA 855 – The Bellwether ESS Standard

Maximum Allowable Quantities (MAQ)[1]

Table 9.4.1 defines *Allowable Maximum Stored Energy*

ESS Technology	kWh[a]
Lead-Acid, all types	Unlimited
Nickel Batteries[b]	Unlimited
Li-ion, all types	600
Sodium nickel chloride	600
Flow Batteries[c]	600
Other battery technologies	200
Batteries in 1 and 2 family dwellings*	80
Electrochemical double-layer capacitors	20
All other ESS	200

[a] For ratings in amp-hrs, kWh should equal maximum rated voltage multiplied by amp-hr rating divided by 1000

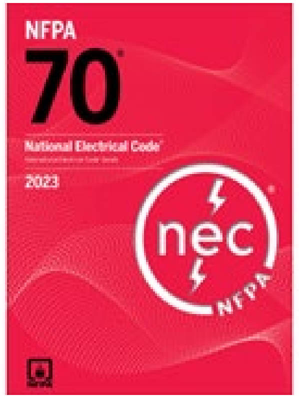
[b] Nickel battery technologies include nickel cadmium (Ni-Cd), nickel metal hydride (Ni-MH) and nickel zinc (Ni-Zn)

[c] Includes vanadium, zinc-bromine, polysulfide, and other flowing electrolyte-type technologies

** This requisite is taken from Chapter 15, Section 15.5.2.*

A Few Key Takeaways

- **Work has already begun on the folowoing:**
- **The 2026 Editions of NFPA 855 and the National Electrical Code**
- **The 2027 Editions of NFPA 1 and the International Fire Code**



Thank You!

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Curtis Ashton, Senior member of IEEE PES and NFPA 855 Committee Member; currently Director of Training at American Power Systems, East Penn Manufacturing for his Peer Review and excellent help in crafting the Technology Chart.

BACKUP SLIDES IF NEEDED!

Major BESS Technologies Overview (2)

Footnotes:

[1] Variables exist that can alter general results incl temperature, care & maintenance.

[2] High currents are limited by the BMS.

[3] Requires heater for colder climates.

[4] Indoor only due to temperature constraints.

[5] Thermal runaway is less likely with this particular Li technology.

[6] Battery will work in this application, but cost makes it impractical.

[7] Recent technology improvements are purported to have fixed fire issues. Time will tell.

[8] No internal cell generation of a fire possible; rare instances of thermal walkaway.

[9] Dryout/lack of maintenance can lead to thermal walkaway; no internal cell fire generated.

[10] Not technically needed for safety but can lengthen life and minimize thermal walkaway

[11] Not technically needed for safety but can lengthen cycle life.

ESS SAFETY CODES & STANDARDS

- **Safety Codes and Standards have become increasingly important to the BESS community.**
- **Let's define the difference between a Safety Code and a Standard.**
  - **"<u>Code</u>: A code is a model, a set of rules that knowledgeable people recommend for others to follow. It is not a law although "it can be adopted into law." [the *'what'*]**
  - **"<u>Standard:</u> A standard tends to be a more detailed elaboration, i.e. "the nuts and bolts of meeting a code." [the *'how'*]**

from NFPA - Reporter's Guide: About codes and standards

How Codes (and Standards) Get Administered

Safety (Model) Code
- **NFPA 1**
- **IFC**

A standard (or group of standards) become part of the code when referenced as such in the Code, e.g. *NFPA 1 2024, Chapter 2, Referenced Publications.*

Note[1]: These are different from References noted in the Bibliography [Annex F – Informational References]

Note[2]: There are 98 NFPA Standards referenced in 855:2.2 and 91 UL standards and 8 CAN/ULC standards in NFPA 1 2024. By contrast there are 21 other codes or standards and 11 UL standards or publications in Chapter 2 of 855 2023, including UL 9540 and 9540A.

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AHJ or Regulatory Agency Adopts

A Code (or standard) is only enforceable when adopted by the AHJ or Regulatory Agency

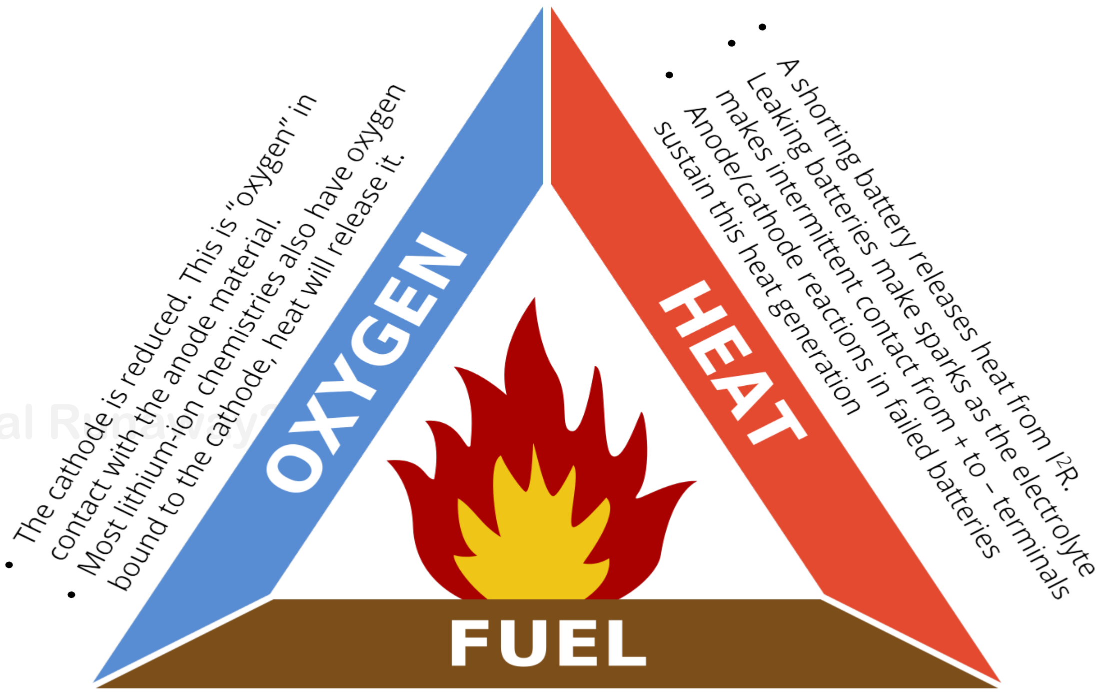
Why a Battery Fire can Occur in a Lithium-ion (or NaS) Battery

Li batteries contain the complete elements of the fire triangle; therefore, the fire cannot self-extinguish. Fire suppression involves cooling the battery to ensure the fire does not spread, internally within the battery or to adjacent cells outside the battery.

- **Water and CO_2 absorb a lot of heat, so even though they react with lithium, they are the preferred extinguishers for lithium battery fires.**

DO NOT !!

- **Attempt to use dry chemical extinguishers on the battery – they do not work.**
- **Use a Class D fire extinguisher – a lithium-ion battery is not burning metal, so a fire extinguisher will not fully extinguish a fire (and will create a huge mess).**
- **Breathe smoke. Batteries are burning plastic, and the smoke is very hazardous.**



- **The cathode provides internal oxygen when it breaks down during a battery heating event.**
- **The flammable solvents (fuel) will burn after the battery vents. This is MOST of the energy in a thermal runaway.**

The best approach is to leave the area; immediately implement the emergency action plan; call 911 or point of contact. First Responders – apply H_2O to outside of container; consider the "Let it burn" alternative where practical. Be aware of possible gas buildup.

Impact of Scale on Safety

Safety issues and complexity increase with battery size

Consumer Cells

Formatted Cells

Transportation Cells

Large Stationary & Grid Scale ESS

NFPA 855 – The Bellwether ESS Standard

Threshold Quantities[1]

Battery Capacity Threshold Covered by Codes	
Technology	Capacity Threshold (kilowatt hours)
Lead Acid (all types)	70 kWh (252 MJ)
Ni-Cd, Ni-MH, and Ni-Zn,	70 kWh (252 MJ)
Lithium-ion (all types)	20 kWh (72 MJ)
Sodium Nickel Chloride	20 (70) [2] kWh (70MJ) (252 MJ) [2]
Flow Batteries	20 kWh (72 MJ)
Other Battery Technologies (Emerging)	10 kWh (36 MJ)
Batteries in 1 and 2 family dwellings[3]	10 kWh (36 MJ)

Based on Threshold Quantities defined in Table 1.3 of NFP 855, *Standard for the Installation of Stationary Energy Storage Systems*, 2023.

[1] Certain threshold quantities applied in NFPA 1 2018 and IFC 2018 and 2021.
[2] Sodium Nickel Chloride when listed to UL 9540 .
[3] Includes townhouses.
Note: Quantities now specified for ESS flywheel (0.5 kWh) and electrochemical double layer capacitors (3 kWh).

NFPA 855 – The Bellwether ESS Standard

- **Key Elements of NFPA 855-2023**
  - Thermal runaway testing to gather heat as well as combustible gas release quantities
    9540A) plus UL 9540 listing.
  - Explosion protection by deflagration venting (NFPA 68) or explosion control/prevention (NFPA 69).

  - Interconnection and commissioning/ decommissioning

Pb/Ni-Cd Carveouts – NFPA 855 2023

What are the Carveouts for Lead-Acid (Pb) and Nickel Cadmium (Ni-Cd) Batteries?

For Telecommunications Facilities under the exclusive control of a telecommunications carrier.

For Substations and Power Generation Stations under the exclusive control of a registered electric utility.

For UPS installations registered to UL 1973/1778 and not occupying more than 10 % of the floor area.