Battery Safety Concerns – *An overview of how Safety Codes should fit into economic reality*

Presented by:

Christopher G. (Chris) Searles

Consultant to Sandia National Laboratories

CGS and Associates

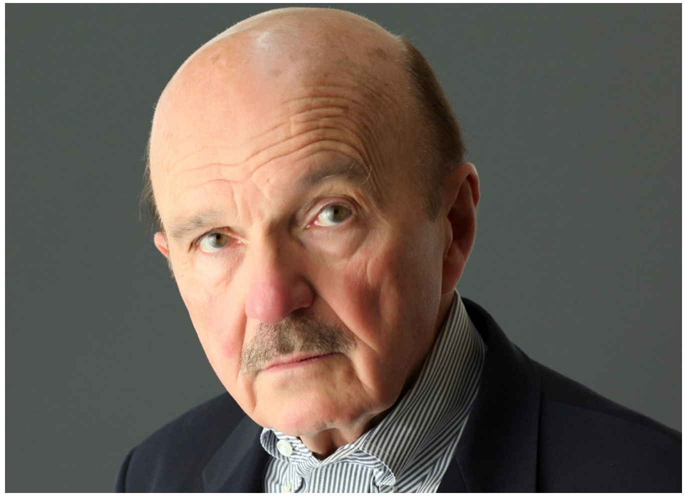
McKinney,TX

chris.searles@cgsandassociates.com

214.850.1183

Let Me Introduce Myself

- 40+ year Veteran in Vdc Power and Stationary Battery Industry.
- Chair Emeritus of IEEE PES Energy Storage and Stationary Battery (ESSB) Committee
- Recent Co-Chair of the IEEE ESSB Safety Codes and Standards Working Group and IEEE IAS/PES Joint Technical Codes Council (JTCC) Co-Chair.
- Inducted into the Battcon Hall of Fame in 2016
- Active member of NFPA 855 2026 Committee
- Active participant in the ICC BESS Ad Hoc Committee
- Advisory Consultant to Sandia National Laboratories



Christopher (Chris) Searles

All Energy Sources have Associated Risk

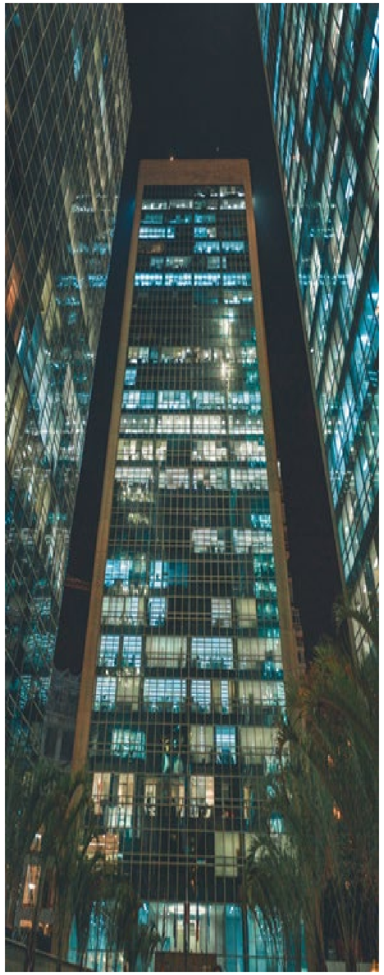
- *In 2024, there were ~ 211,500 highway vehicle fires reported in the United States which caused property damage worth of 1.9 billion U.S. dollars.* NFPA: A Fire Loss Report, 2025

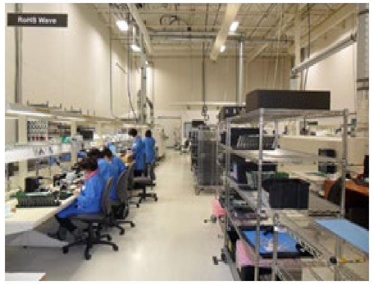
- *"Heating equipment is the number one cause of household fires in the US. It is estimated that 333,000 residential fires are caused by space heaters every year."*
  Housegrail, February 2024

  Note: Conforms closely to NFPA report on average number of house fires with corresponding deaths.

- *"Fire departments in New York City and San Francisco report handling more than 660 fires involving lithium-ion batteries since 2019. In New York City, these fires caused 12 deaths and more than 260 injuries from 2021 through early 2023.* The Conversation, September 2023

General Categories of Current Safety Codes and Standards



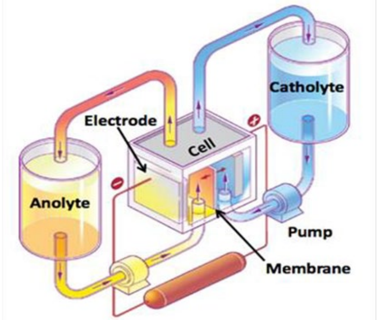



- **Fire Protection and Safety**
  - Includes fire suppression
  - Includes explosion control
- **Occupational risks and hazards**
  - Includes worker safety
  - Includes workplace safety
- **Design & Materials Safety**
  - Components are safe and products are reliable
  - Inspection, Testing & Maintenance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

Current & Future Focus for ESS Safety Codes R&D

- **Li-ion batteries have been the focus for most R&D efforts until recently.**
  - ✓ 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 now being addressed – including V2G and G2V.

- **Newer technologies introduced** (e.g., Flow batteries, Li-Metal, Sodium-ion, Zinc, Hydrogen Fuel Cells, etc.) pose different sets of concerns.



Redox Flow Battery

- Large long-duration storage systems (LDES) targeting non-traditional applications.
  - ✓ Required in high population dense areas – LDES systems are much more complex.
  - ✓ Includes large battery systems with sophisticated high-power electronics (IBR/DER).

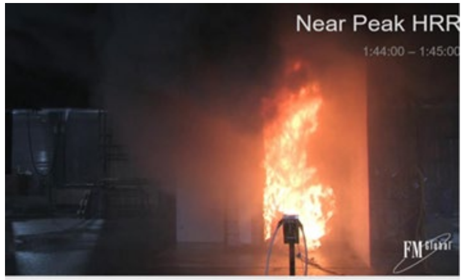
- Questions needing answers :
  - ✓ Can we identify safety issues ahead of the experience curve?
  - ✓ Is full-scale system-level testing necessary instead of just cell/unit level testing?
  - ✓ How do we get SDO's, Regulatory bodies and AHJ's to fast-track codes and standards to validate new technologies while ensuring their integrity?


SAFT 10 MWh storage system

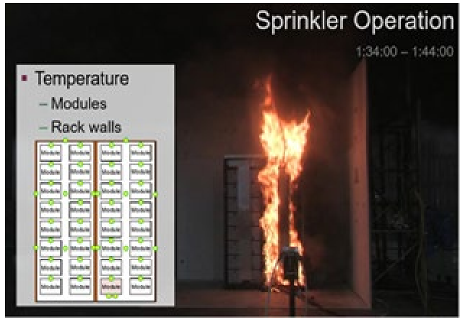
Unfortunately, we can't answer everything today, but let's transition to what safety codes can provide today!

Behind Recent Fire Interest in Battery Safety Codes/Standards

1. **Advancing safety measures against fire and explosions due to a rash of incidents in many parts of the world in the last several years (especially but not exclusively w/Lithium-ion).**



2. **New applications such as DER, micro-grids, V2G.**
   - ✓ Density of energy storage in residential homes, community commercial complexes, high-rise buildings as well as critical healthcare facilities.
   - ✓ Islanding (both standalone and grid-connected)
   - ✓ Utility interconnected (parallel ESS/Bulk Power systems serving common loads)



3. **First Responder Safety**

WHICH CODES/STANDARDS ROADS SHOULD I FOLLOW?

WHICH CODES/STANDARDS ROADS SHOULD I FOLLOW?

Oh, Did I Forget to Mention . . . .

OSHA

FERC

NERC

DOT

NHTSA

SAE

FM GLOBAL

OTHERS

ALL OF THE ABOVE – REALLY ??

Answer: They all are Important in Individual Contexts

ESS SAFETY CODES & STANDARDS

- **Let’s define the difference between a Safety Code and a Safety Standard.**
  - **“Code: 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’*]**
  - **“Standard: 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**

References a Standard
- **NFPA 855**

AHJ or Regulatory Agency Adopts

- **A Code (or standard) is only enforceable when adopted by the AHJ or Regulatory Agency!**
- **Standards become part of the Code when included as a Normative Reference (vs. an Informational Bibliographic Reference**

Map Showing Code Alliances

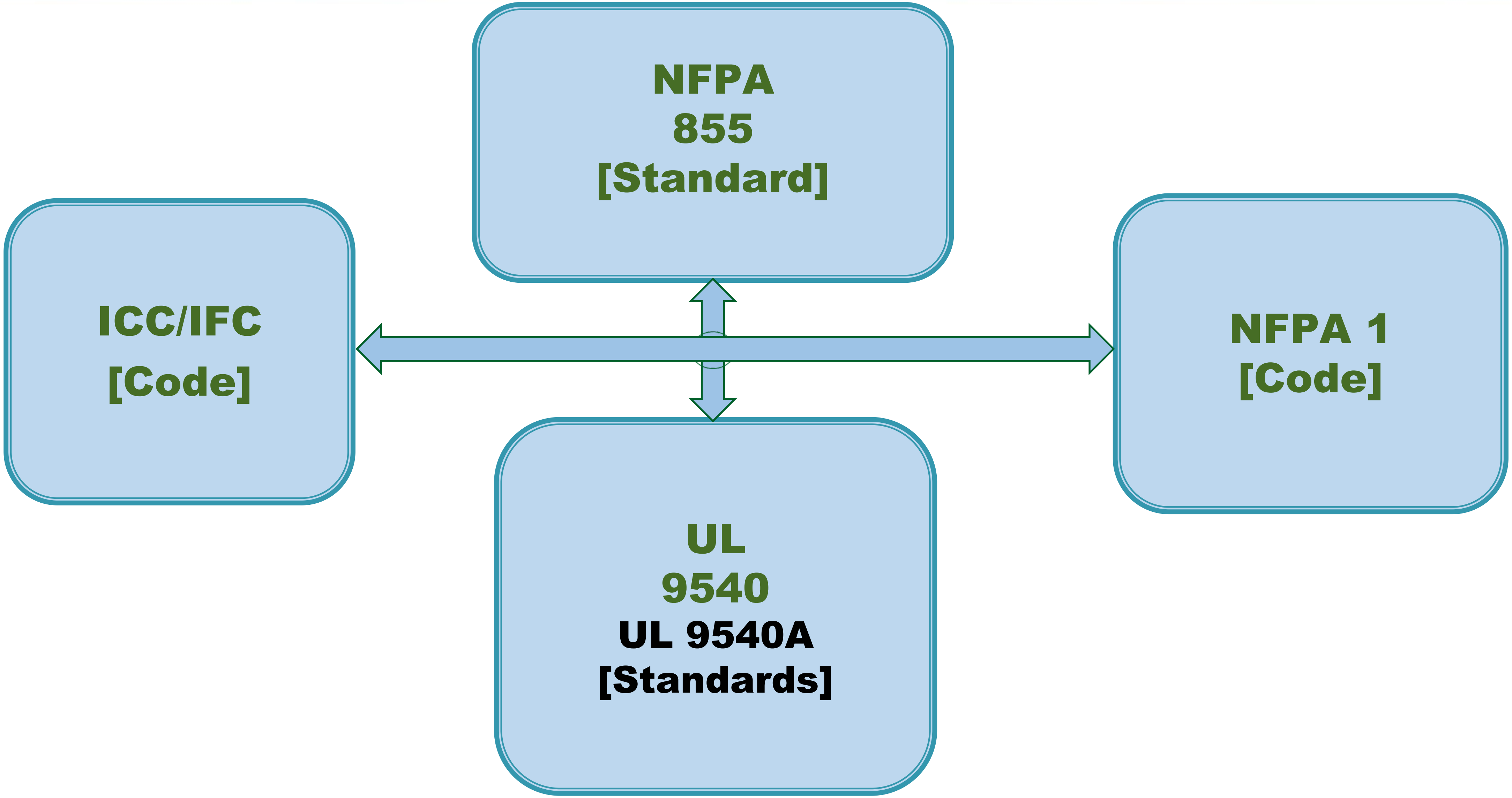
Adding Layers of Complexity

1. All states do not follow the same revision level.

2. Many cities have their own code.

3. Some adopt only a portion or limited sections of the IFC or NFPA codes

Energy Storage Safety Codes Matrix



Energy Storage Safety Codes Matrix – One Level Down

NFPA 855
NFPA 1
NFPA 70/70B/70E
NFPA 68/69
NFPA 110 & 111

ICC
IFC
IBC
IRC

IEEE
IEEE 1635
IEEE 1547
IEEE 1547.9

UL 9540
[UL 9540A]
UL 1973
UL 1989
UL 1778
UL 1741
UL 1012

IEC
IEC TC 120
UL 60079-0
UL 60086-4
UL 62133-2

Majority of Jurisdictions[1] Follow/Modify This Code

- **Ventilation for standby power applications**
- **Operational permits**
- **More construction documentation**
- **Decommissioning**
- **Aligns in large part with NFPA-855[2]**
- **Limits indoor array size to 50[3]/250[4] kWh**
- **Residential Battery Code (Tied closely w/ IBC)**
- **Full-scale fire testing (UL 9540A)**
- **Listing to UL9540 w/exemptions**
- **Larger outdoor separation distances**

[1] Includes District of Columbia, Puerto Rico & US Virgin Islands
[2] Not Completely; [3] IFC 2021/2024; [4] IFC 2018
Note: It is anticipated that IFC 2027 will incorporate all NFPA 855 references similar to NFPA 1 2024.

Available at [2024 International Fire Code (IFC) | ICC Digital Codes (iccsafe.org)]

A Few States, Counties, Municipalities Follow This Code

- **Chapter 52 – Energy Storage Systems**
  - **Completely Aligns with NFPA-855**
  - References are to 2023 Edition of NFPA 855
- Section 52.1.1 states *"Energy Storage Systems having an aggregate quantity exceeding the threshold quantities established in Table 1.3 of NFPA 855 shall comply with Chapter 52."*
  [Carryover from 2021 Edition]
  - **Chapter 52 is composed of 8 sections .**
  - **All 8 sections refer to Chapters within NFPA 855 and state they comply with NFPA 855 requirements. This is a big change from the 2021 Edition.**
- **There are a total of 75 Chapters and six (6) Annexes, parts of which are often referenced in the IFC.**

Note: See previous Copyright Note at beginning of presentation.

Code available at [Help Ensure Safety and Compliance. Order NFPA 1, Fire Code.]

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]	1 kWh (3.6 MJ)

See Threshold Levels defined in Table 1.3 of NFP 855, 2026 for other ESS Technologies including EDLC, Flywheels', Iron-air, Nickel-hydrogen, Sodium sulfur, several Zinc variants .

The actual Table 1.3 is protected by Copyright and can be viewed on line at NFPA.com/855.

[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

NFPA
855

Key Elements of NFPA 855 2026

- Thermal runaway testing to gather heat as well as combustible gas release quantities (UL 9540A) plus LSFT testing & UL 9540 listing.
- Explosion protection by explosion control/ prevention (NFPA 69) and deflagration venting (NFPA 68).
- Ventilation and Fire Protection devices play an important role in preventing and controlling gas **releases as well as fire**.
- Installation, commissioning, storage and decommissioning – all covered

NFPA 855 – The Bellwether ESS Standard

NFPA
855

- **Key Elements of NFPA 855-2026 (2)**
  - Covers most commercially available BESS technologies including Li, Pb-Acid, Ni-Cd, Na, Ni, Flow and Zn plus mechanical Flywheels and supercapacitors.
  - Addresses stationary storage applications including ESS with standby application exemptions for Pb-acid, Ni-Cd and most aqueous electrolyte BESS.
  - Requires UL listings for all devices used in ESS applications including BESS – inverters, UPS, related equipment (to UL 9540 as system).
  - Two sections deal with Emergency Power Supply Systems (EPSS) w/ tie-in to NFPA 110 and Stored Energy Emergency Power Supply Systems (SEPSS) w/ tie-in to NFPA 111.

NFPA 855 – The Bellwether ESS Standard

NFPA 855

More Key Elements of NFPA 855-2026 (3)

Hazard Mitigation Analysis is a feature of NFPA 855.

- Section 4.4.1 defines what is to be evaluated in HMA.
- Section 4.4.2 requires a single failure mode to consider on items in 4.4.1.
- Section 4.4.3 permits the AHJ to approve the HMA providing it demonstrates:
  - Fires will be contained within the unoccupied ESS rooms
  - All Occupants can be evacuated safely
  - Deflagration issues addressed via an explosion control and prevention system.

Note: There are 20 references to HMA in Chapters 1, 4, 8, 11, 13 as well as Annex A,B, G.

NFPA 855 – The Bellwether ESS Standard

NFPA 855

- **Logistical Elements of NFPA 855-2026 (4)**
  - Placed all electrochemical technology requirements (Chapter 9).
  - New Chapters for Flow Batteries (Chapter 16) and ESS on Barges and Vessels (Chapter 17).
  - Separate chapter addresses Lithium-Ion and Lithium Metal battery storage (Chapter 14).
  - Residential requirements for the most part are consolidated (Chapter 15). New Table15.5.2 offers Max kWh ratings for various ESS location placements. ***Note: Lead-acid and Ni-Cd batteries not limited to 20kWh maximums.***
  - Solid annex material in Annex B & Annex G (including LSFT).

NFPA 855 – A Few Key Takeaways

- **Work has already begun on the 2029 Edition**
  - Initial ~ 500 Public Inputs for 2029 edition closed in June.
  - First draft report is scheduled no later than 04/24/27. First Draft 855 Committee Meeting October 12-16 om Greenville SC.
  - Public Comment period will close 06/27/27.
    Note: comments can only address previous Public Input and Draft 1 comments.
  - Second Draft Report Posting Date scheduled for 03/21/2028.
  - NITMAM closing date is 03/29/2028.
  - Next release – late 4Q 2028.

Summary of Current 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.

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.

The biggest safety concern with Li-Ion (and NaS) is thermal runaway fire hazard as it may be to the uninitiated the least well understood and most difficult to control.

Fire / Explosion

- Aqueous batteries release small amounts of hydrogen gas which can combust if not ventilated properly.
- A battery spark can ignite nearby flammable materials.
- Some battery types go into thermal runaway, catching fire and/or generating combustible gas.

Chemical

- Battery electrolyte can be highly acidic or caustic or flammable.

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 – https://ul.org/research/electrochemical-safety/getting-started-electrochemical-safety/what-thermal-runaway.

Correlated with an 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 also thermal walkaway."*

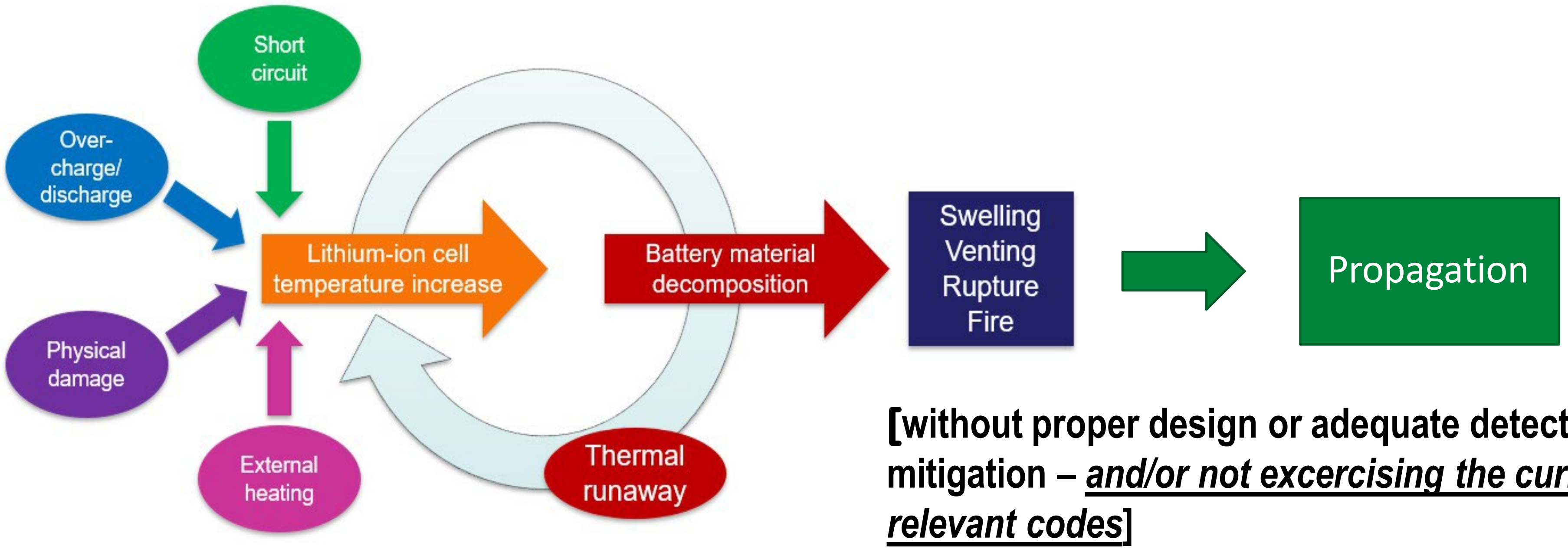
What are the Causes of Thermal Runaway?

Abuse Conditions

- Electrical abuse
- Mechanical abuse
- Thermal abuse

Latent Failures

- Contamination during manufacturing
- Material impurities
- Improper design
  Lack of Quality Control in production



[without proper design or adequate detection and mitigation – *__and/or not excercising the current relevant codes__*]

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

What is the Process of Thermal Runaway?

Another way to look at it – *thermal runaway in a Li-ion battery*:

(1) Heating starts (~>85˚F/~30˚C)

(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.***

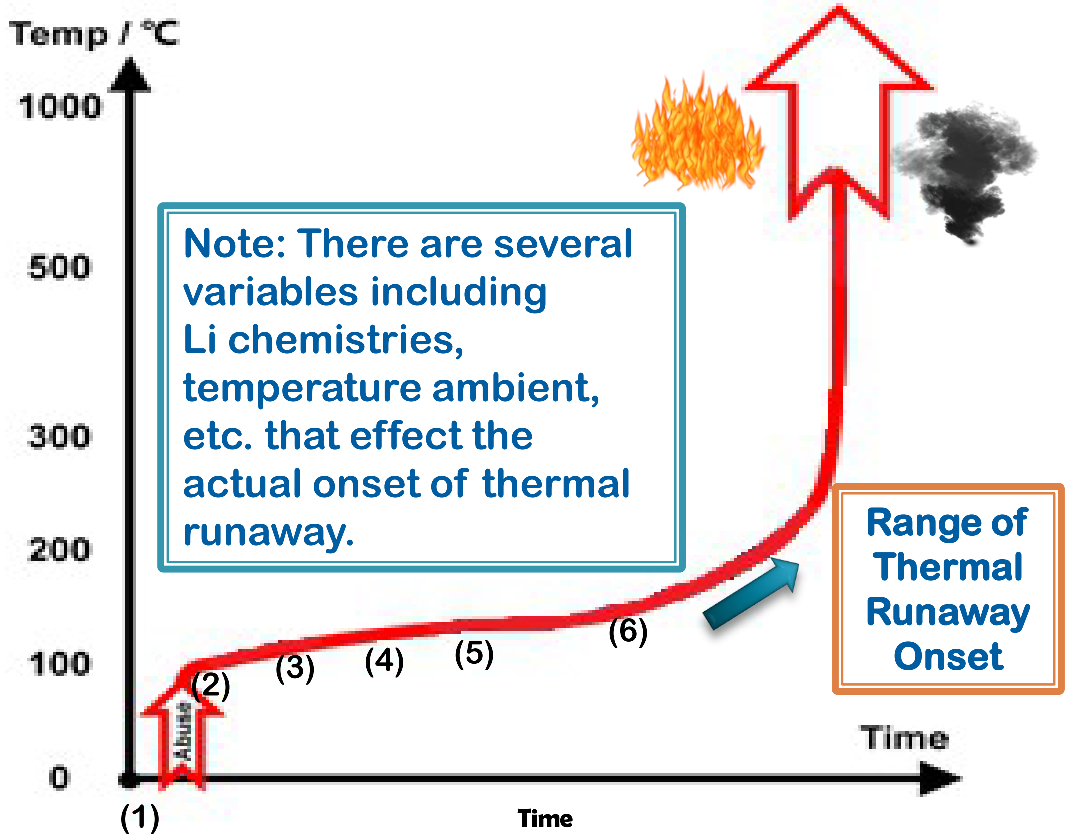
(4) Separator melts, possibly causing short circuit ($\geq 120^{\circ}C$)

(5) Positive electrode breaks down, generating oxygen (130-150℃) *Note: the LFP electrode breaks down ~275˚C.*

(6) Oxygen reacts with electrolyte (>150-180℃) producing thermal runaway

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.



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

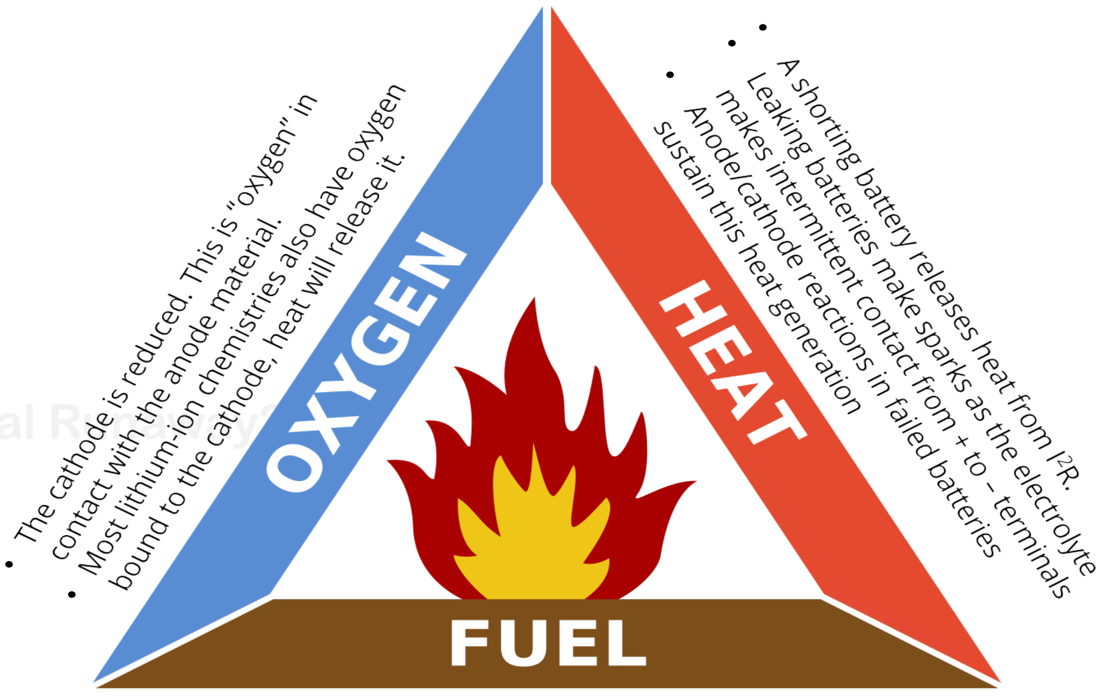
Li-ion batteries contain the complete elements of the fire triangle – therefore, the fire cannot self-extinguish.

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.



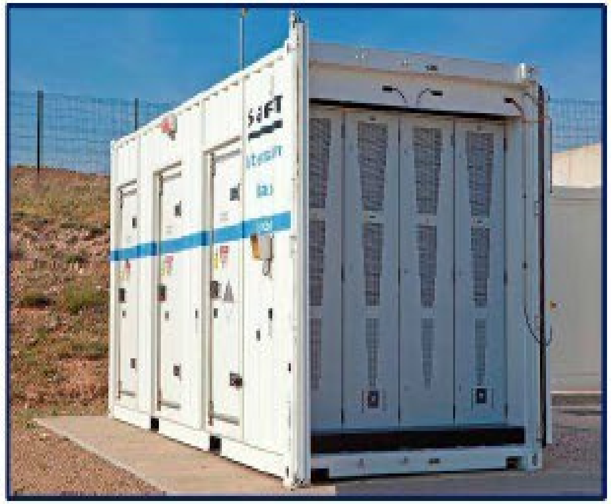
- The cathode provides internal oxygen when it breaks down during a battery heating event.
- The flammable solvents (fuel) will burn after the battery vents. This is MOST of the energy in a thermal runaway.

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. Be aware that reignition can be a remaining concern.

Impact of Scale on Safety

Safety issues and complexity increase with battery size



Consumer Cells (0.5-5 Ah)

Large Format Cells (10-400 Ah)

Transportation Batteries (1-50 kWh)

Utility Batteries (MWh)

SUMMARY and CONCLUSIONS to 20kWh maximums.

- The traditional technologies now face increased concerns with various stakeholders . . . . along with the newer emerging technologies and new application areas – Key areas of concern include:

- **Thermal Runaway vs. Thermal Walkaway**
- **Gas Detection & Ventilation**
- Various Minimum Threshold requirements
- Physical Separation Requirements
- Building/Container Restrictions (internal/external/setbacks)
- Energy Management System Criteria (Including BMS and ESMS requirements)
- **Operational Permitting**
- **Effective Hazard Mitigation Analysis**
- **Proper Equipment Listing/Certification**

Note: Includes 1 and 2 family dwellings.

SUMMARY and CONCLUSIONS

1. Education and training will be ongoing and important
   a. AHJ's,
   b. Local/Regional regulatory agencies
   c. Electric utilities and telecommunication groups
   d. Digital data center developers/implementers

2. Key stakeholders in the ESS space need to continue and share an involved role with the key SDO's.

3. A means to get all stakeholders using the current editions of ESS standards yet allowing local/regional differences if absolutely necessary.

Thank You!

Chris Searles,
Energy Storage and
Backup Power Systems
CGS and Associates
McKinney, TX
chris.searles@cgsandassociates.com
214.950.1183

Special and Grateful Acknowledgement

Curtis Ashton, currently Director of Training at American Power Systems, East Penn Manufacturing and William P. Cantor, Associate Professor, Penn State University – both senior members of IEEE Energy Storage and Stationary Battery Committee for their Peer Review and help in crafting parts of this presentation. Both are principal members of NFPA 855 Technical Committee. This material is not to be copied or presented by anyone without the advanced written permission of Chris Searles.