Energy Storage Safety Codes& Standards

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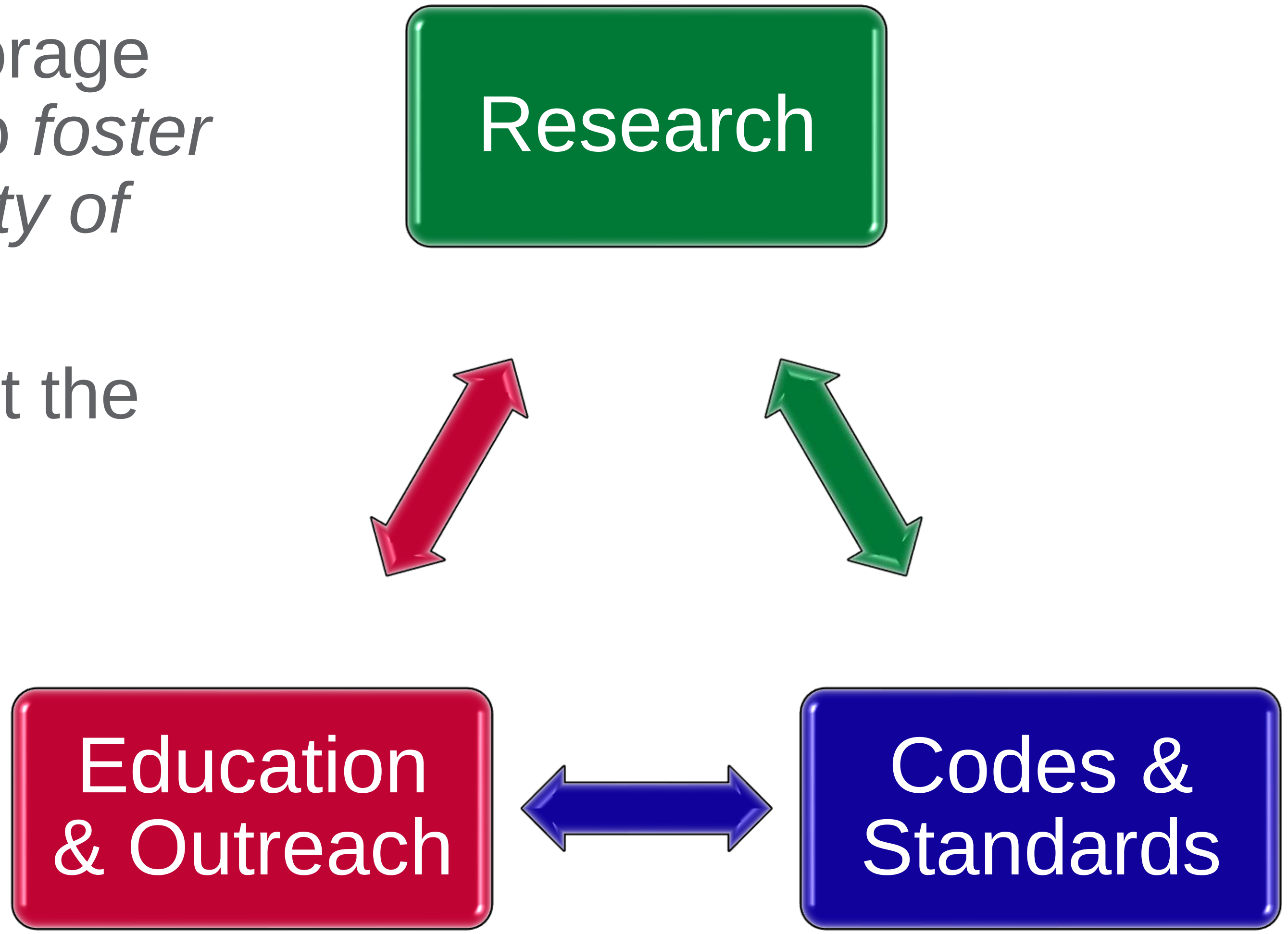
PNNL is operated by Battelle for the U.S. Department of Energy

Energy Storage Systems Safety Roadmap

- The goal of the DOE OE Energy Storage System (ESS) Safety Roadmap is to *foster confidence in the safety and reliability of ESS.*
- Three interrelated objectives support the realization of that goal.
  - Research
  - Codes & Standards Dev
  - Education & Outreach

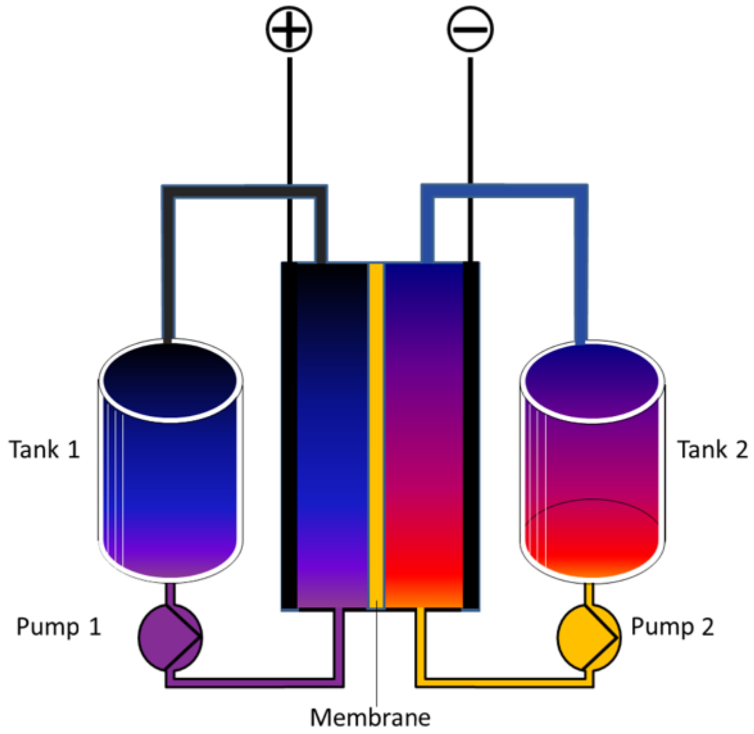


Objectives of Safety Codes & Standards

- Identifying key requirements to ensure safe operation of ESS.
- Create clear requirements for manufacturers of new products/technologies.
- Ensure ease of interpretation & enforcement for Authorties Having Jurisdiction (AHJ).
- Support demand for wide adoption of grid-connected ESS

Chemistries - Flow Batteries

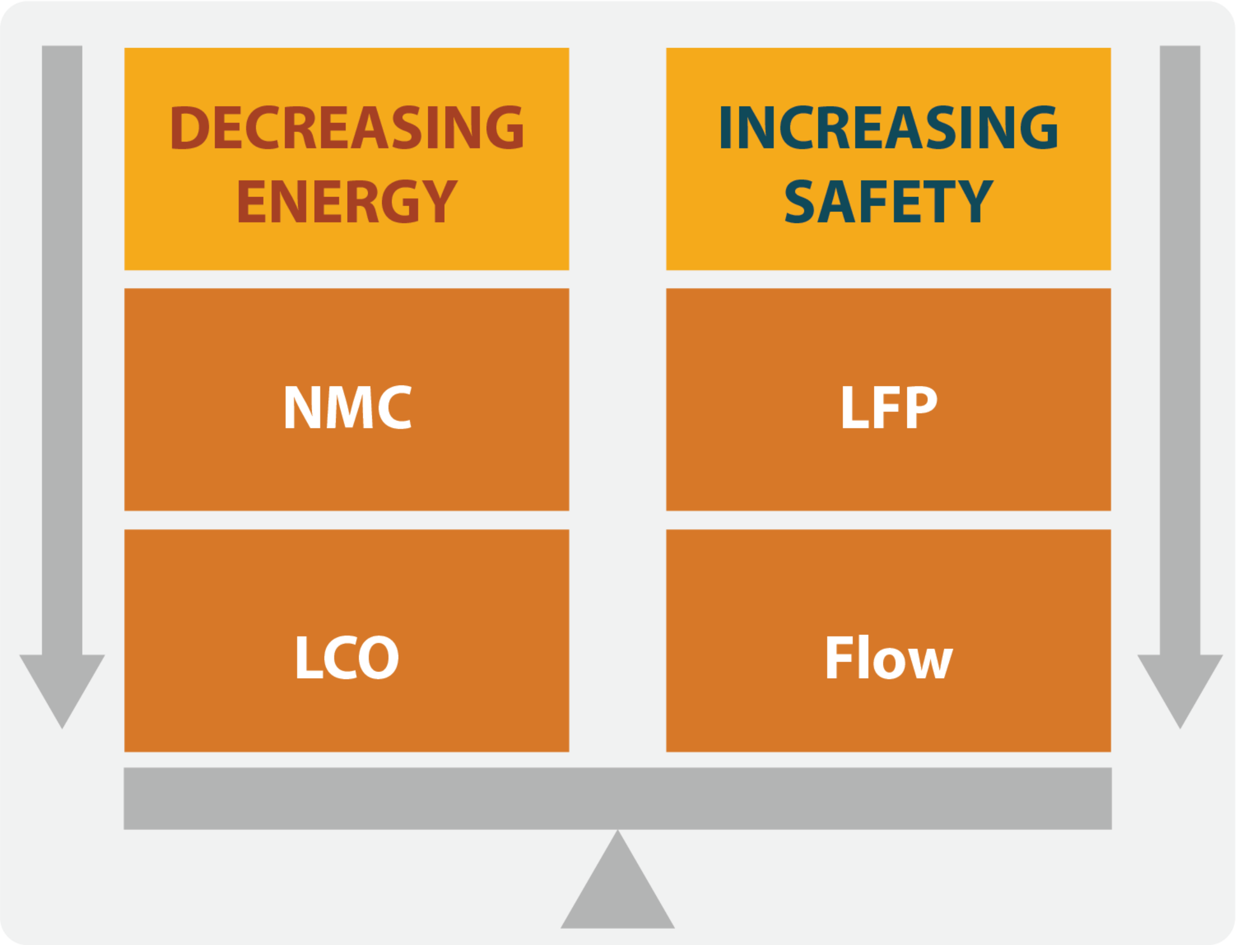
- Several different chemistries
  - Vanadium Redox, Bromine, Zinc
- Vanadium Redox – One or two tanks of liquids, pumped past a membrane between electrodes (fuel cell)
- Electric current only produced while both liquids circulate through cell stack
  - No stranded energy
- System includes pumps, sensors, control units, secondary containment.
- Extremely long cycle life, no degradation of electrolyte.
- Long durations 4-8 hrs avail today.



Chemistries - Lithium-Ion Family

Current Positive Electrodes

- **LiCoO2**
  Lithium Cobalt Oxide (LCO)
- **LiNiCoAlO2**
  Lithium Nickel Cobalt Aluminum (“NCA”)
- **LiNiMnCoO2**
  Lithium Nickel Manganese Cobalt ("NMC")
- **LiMn2O4**
  Lithium Manganese Oxide (LMO)
- **LiFePO4**
  Lithium Iron Phosphate ("LFP")



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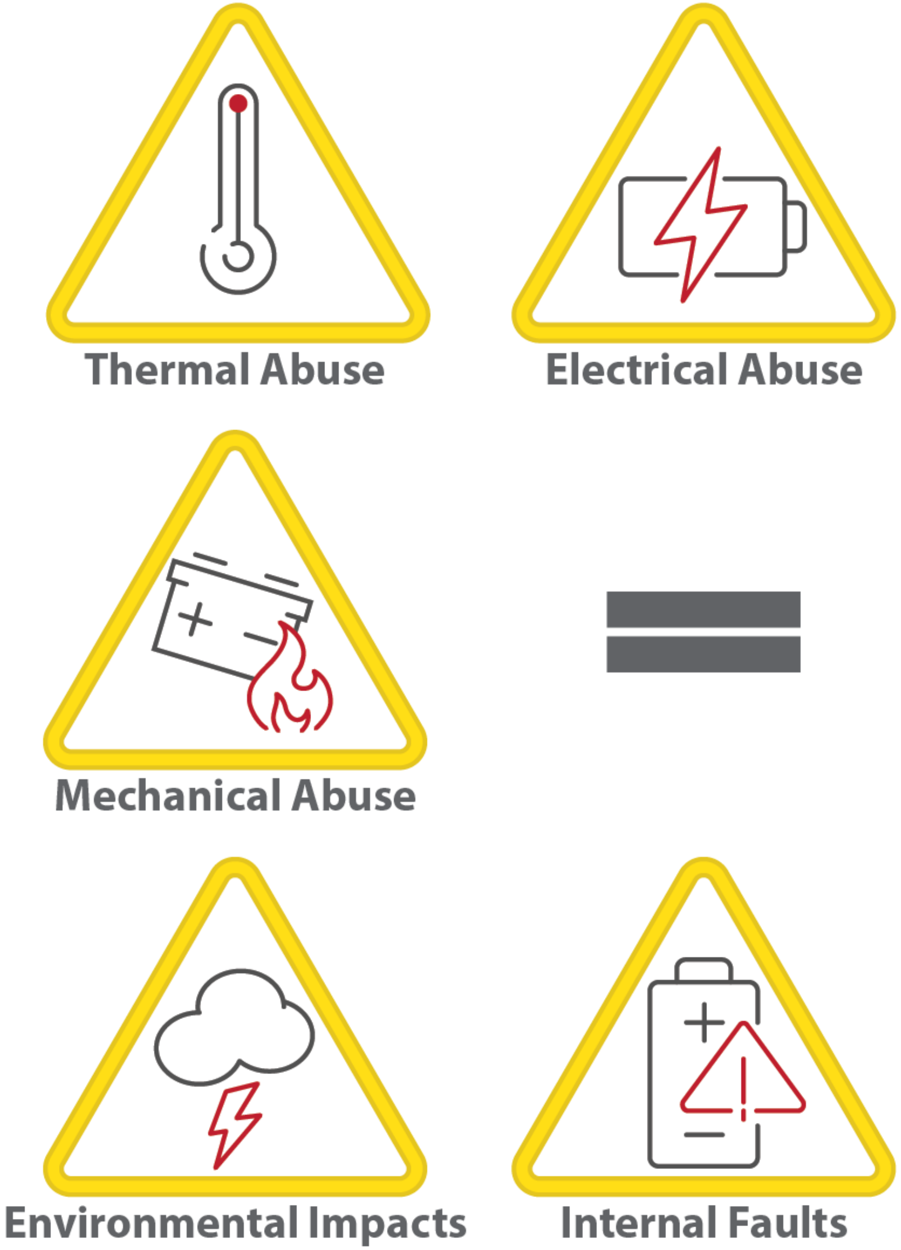
Safety: Li-ion Failure Modes/Hazards

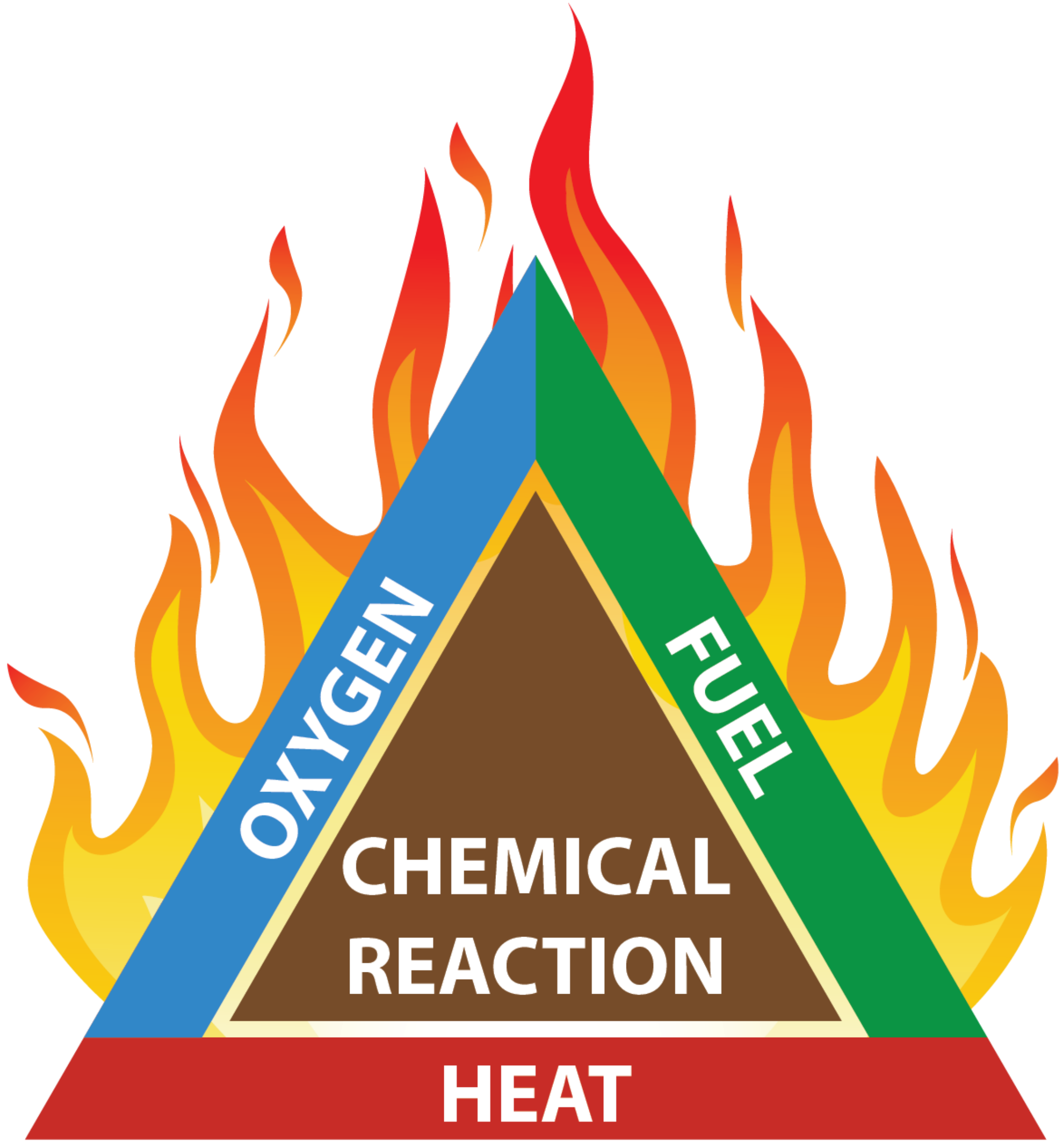


Safety: Li-ion Failure Modes/Hazards

- Thermal Abuse
  - Exposed to high heat from external source
- Electrical Abuse
  - Overcharging, rapid discharging, unbalancing
- Mechanical Abuse
  - Dropping, kicking, hitting
- Internal defects
  - Dendrites, separator QC, other contaminations
- Environmental Abuse
  - Seismic, flooding, absent or poorly designed HVAC

Fire Tetrahedron

- Typically all that is required for fires to occur is O_2, Fuel, and Heat.
- Some chemistries contain metal oxides that release O_2 rapidly under high heat conditions.
- Li-ion fires can occur in low O_2 atmospheres
- Flammable gasses will continue to be produced after clean agent systems discharge.

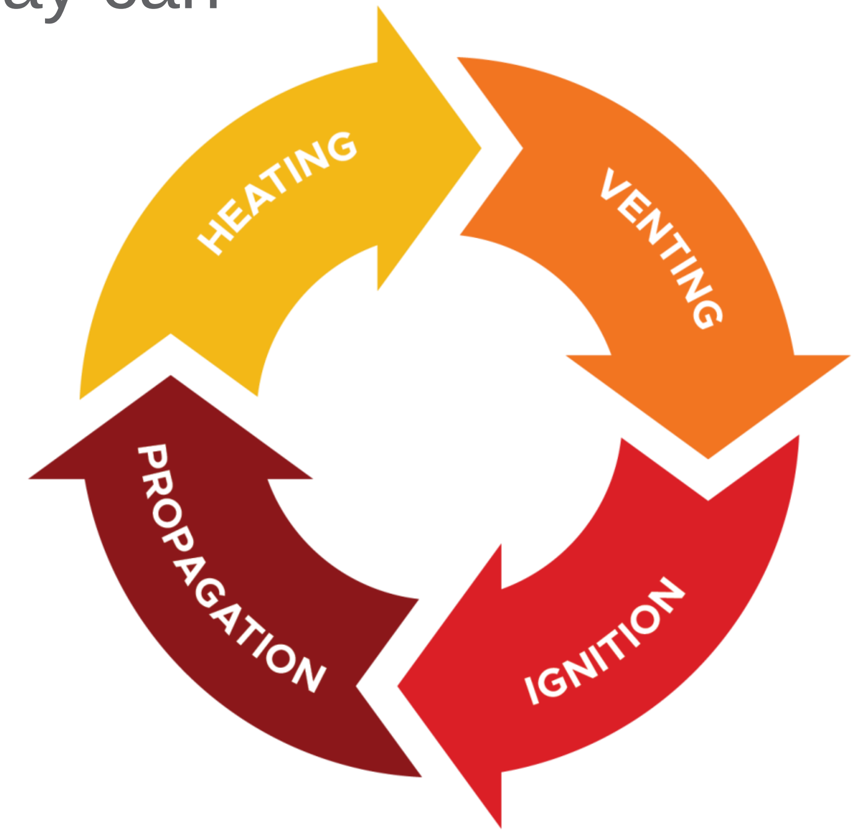


PREVENTING/REMOVING HEAT IS KEY

Hazards – Thermal Runaway

“The process where self heating occurs faster than can be dissipated resulting in vaporized electrolyte, fire, and or explosions”

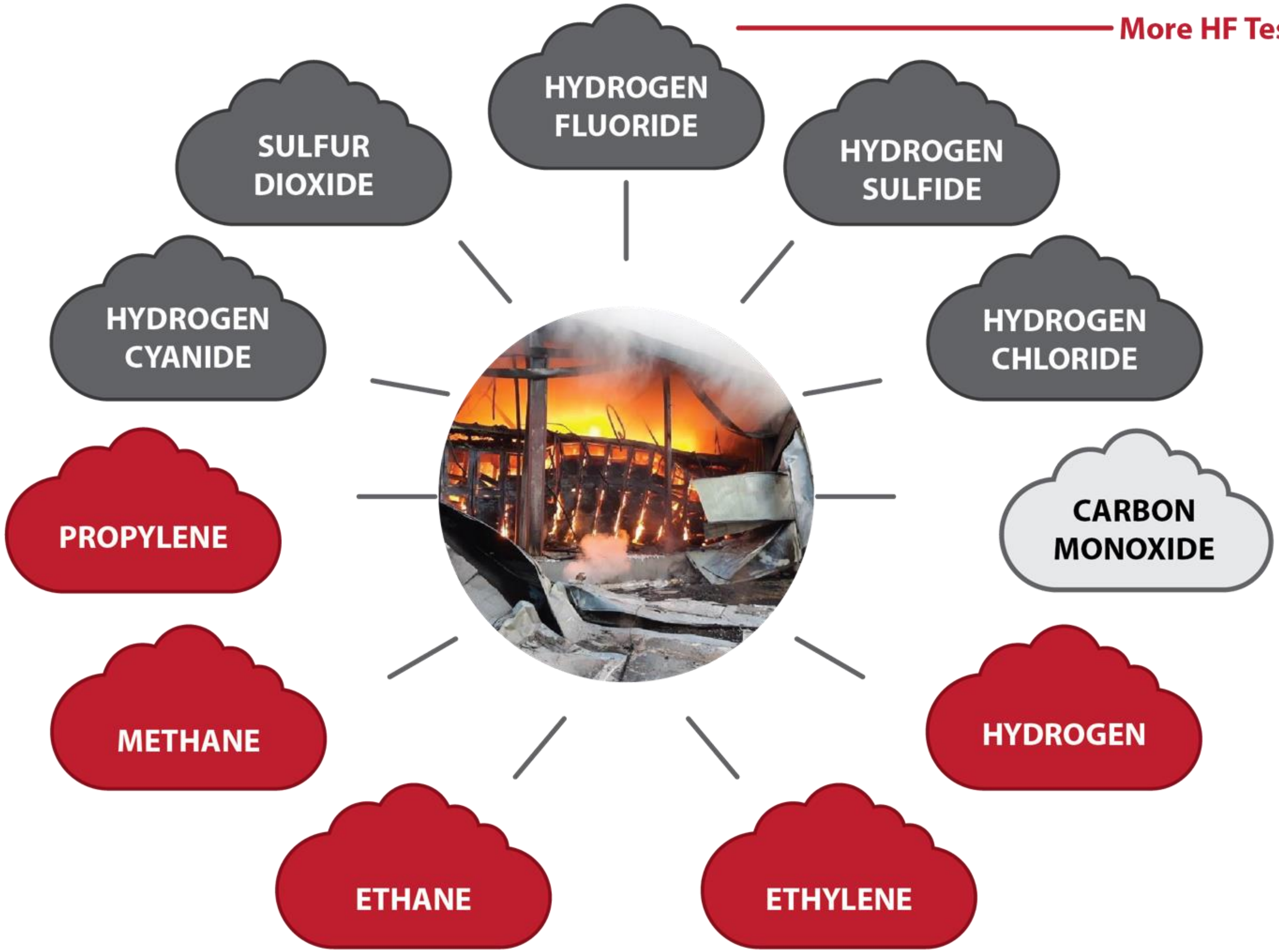
- Initial exothermic reactions leading to thermal runaway can begin at 80° - 120°C.
- Venting of electrolyte gasses
- Ignition of gasses (fire or explosive)
- Propagation within module
- External flame initiates preheating of additional cells/modules



Hazards – Thermal Runaway

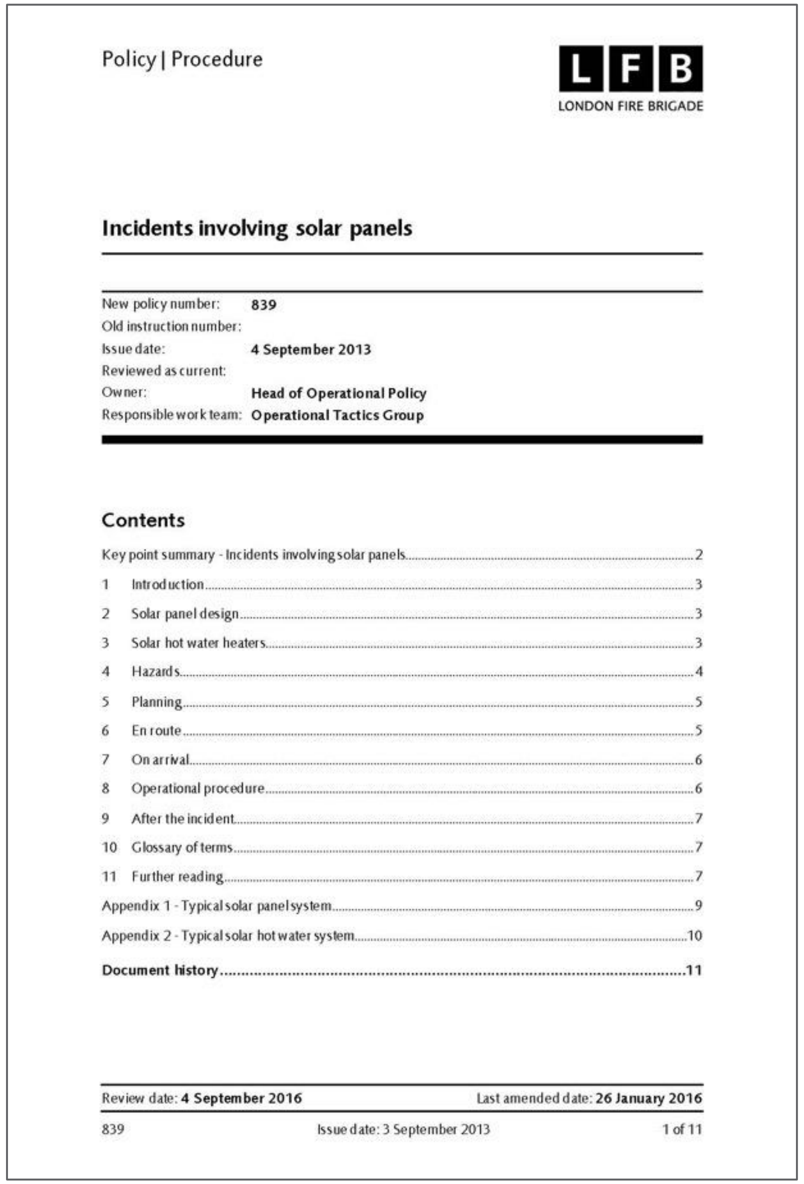
Hazards – Flammable/Toxic Gases

More HF Testing Needed



Pre-Incident Planning

- Begins with including local FD in permitting discussions
  - They are your partner in achieving acceptance
  - Education is a critical part of preparing a good pre-plan, and Standard Operating Procedure (SOP).
- Provide the following information:
  - General: Locations of all ESS installations
  - Site Specific
    - ✓ Battery chemistry
    - ✓ Hazards
    - ✓ Clear markings from fence (at least 20’)
    - ✓ External alarm annunciation
    - ✓ Contact information for qualified representative
    - ✓ Location of E-stops/Disconnects
    - ✓ Emergency Management Plan
    - ✓ Decommissioning Plan


Policy | Procedure

LFB
LONDON FIRE BRIGADE

Incidents involving solar panels

New policy number: 839
Old instruction number:
Issue date: 4 September 2013
Reviewed as current:
Owner: Head of Operational Policy
Responsible work team: Operational Tactics Group

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Review date: **4 September 2016** Last amended date: **26 January 2016**
839 Issue date: 3 September 2013 1 of 11

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Incident Management

- Initiate 911 at first notification of either BMS temp alarm, or alarm system signal.
- Dispatch qualified representative to liaison with FD Incident Commander
  - Will stay at command post and provide unified command
- Secure perimeter and initiate evacuations or shelter in place depending on occupancy/incident.
- Obtain data from SCADA/control center of BMS temp trending data, alarms, etc…
- Monitor/support suppression system (2-stage or clean agent only?).
- Activate exhaust if not already running.

Fire Service Risk Management Model

- Risk a life to save a life
- Risk very little to save savable property
- Risk nothing to save what is already lost

Incident Management - APS Explosion April 19, 2019

Key timeline events:

4:35 p.m.	Smoke detector triggers release of clean agent
5:41p.m.	911 called for possible grass fire near substation
5:48 p.m.	First FD Units on scene, updated event to a battery fire
6:28 p.m.	Hazmat Unit on scene, light white smoke low on ground outside, from HVAC units on side of building, and seeping from nearby switchgear.
6:51 p.m.	Hazmat getting readings of HCN outside building. No active smoke/fire present.
8:00 p.m.	Hazmat opens door to obtain temp & gas readings at threshold. Dense white smoke present 2’ up from floor. Temp 104F inside (exact spot not clear)
8:02:06 p.m.	Explosion occurs. 2 Firefighters seriously hurt. One lands 73’ away.

- *Still under investigation for root cause.*
- *Fire Department actions are public and just one side of the event.*

Incident Management - APS Explosion

Hose line and areas of smoke

Overview of container and fence

Detail of force damage to door

Fence section FF thrown under

Overview distance from contain

SCBA airline separated from pack

Photos credit: Surprise Fire Department

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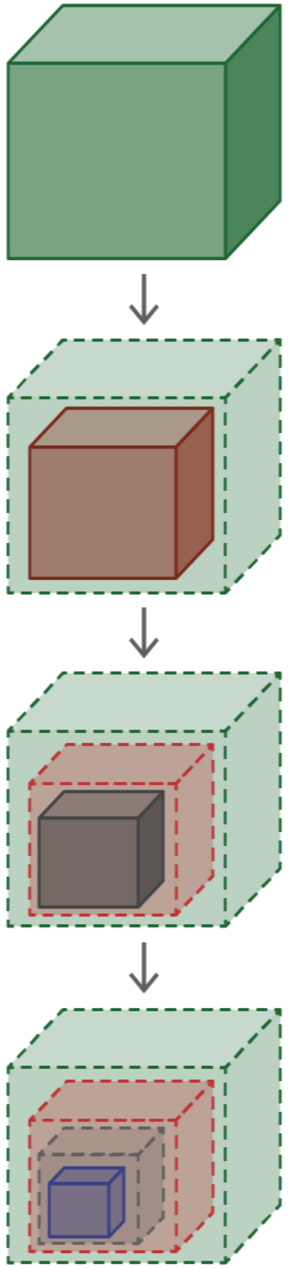
S. Korea ESS Fire Causes

1. Poor ground fault protection
2. Inadequate HVAC
3. BMS Failures
4. Systems control failures

None listed to UL 9540

Standards and Model Codes Hierarchy



BUILT ENVIRONMENT

- ICC IFC, ICC IRC, ICC IBC
- NFPA 5000
- NFPA 1

INSTALLATION / APPLICATION

- NFPA 855
- NFPA 70
- UL 9540 A
- IEEE C2
- IEEE 1635/ASHRAE 21
- IEEE P1578
- DNVGL GRIDSTOR
- FM GLOBAL 5-33
- NECA 416 & 416

ENERGY STORAGE SYSTEMS

- UL 9540
- ASME TES-1
- NFPA 791

SYSTEM COMPONENTS

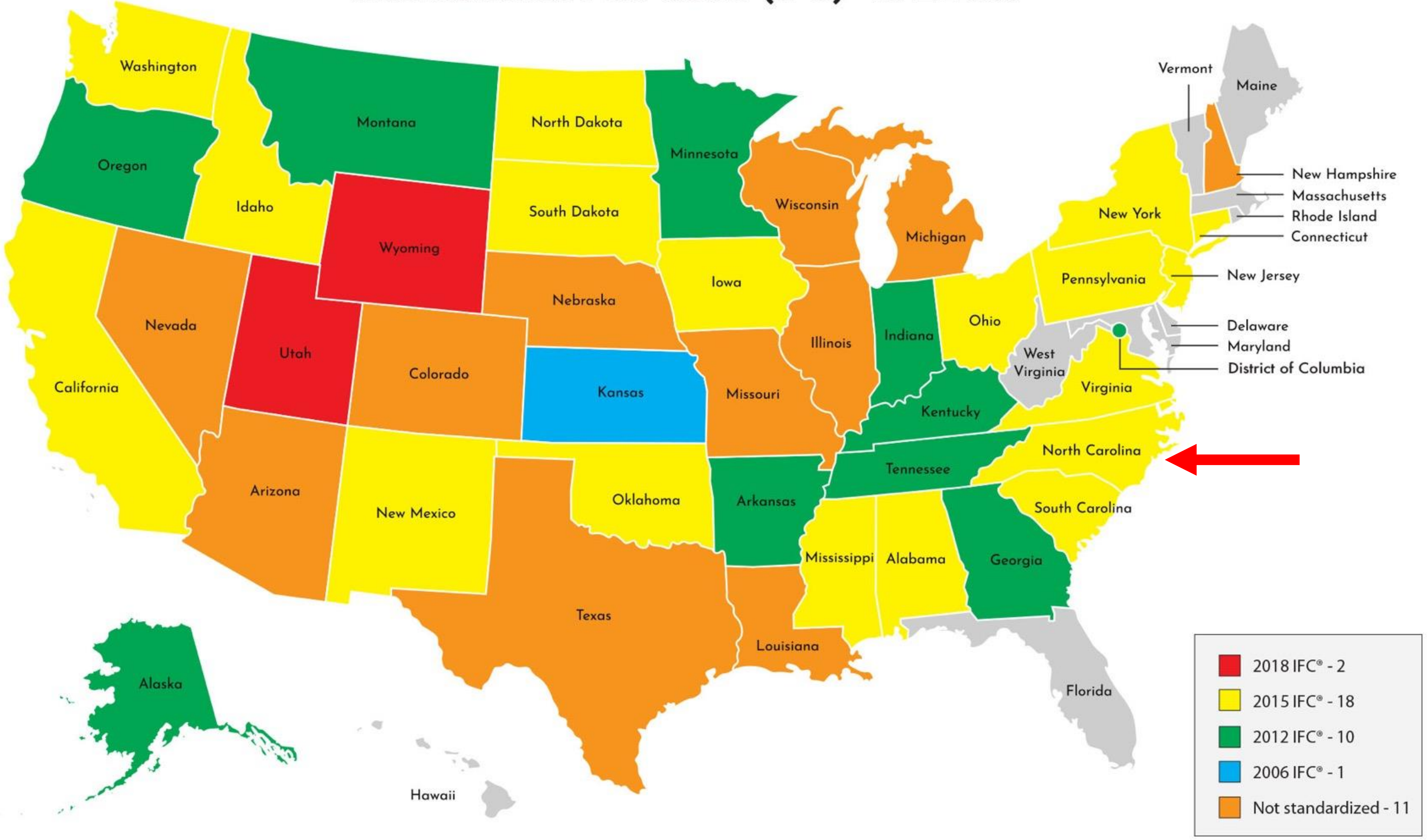
- UL 1973
- UL 1974
- UL 810A
- UL1741
- CSA 22.2 No. 340-201
- IEEE 1547
- IEEE 1679 Series

Codes & Standards – IFC 2015 (N. Carolina adopted)

- States still on 2015 IFC have minimal provisions protecting ESS
- Since 1997 (lead-acid) battery systems allowed in incidental use areas
- 1- or 2-hour fire-rated separations
- Hazmat requirements exempted
- Spill control, ventilation, smoke detection
- Battery quantities unlimited
- Location in building not regulated
- Primarily for Standby & emergency power, UPS use

IFC

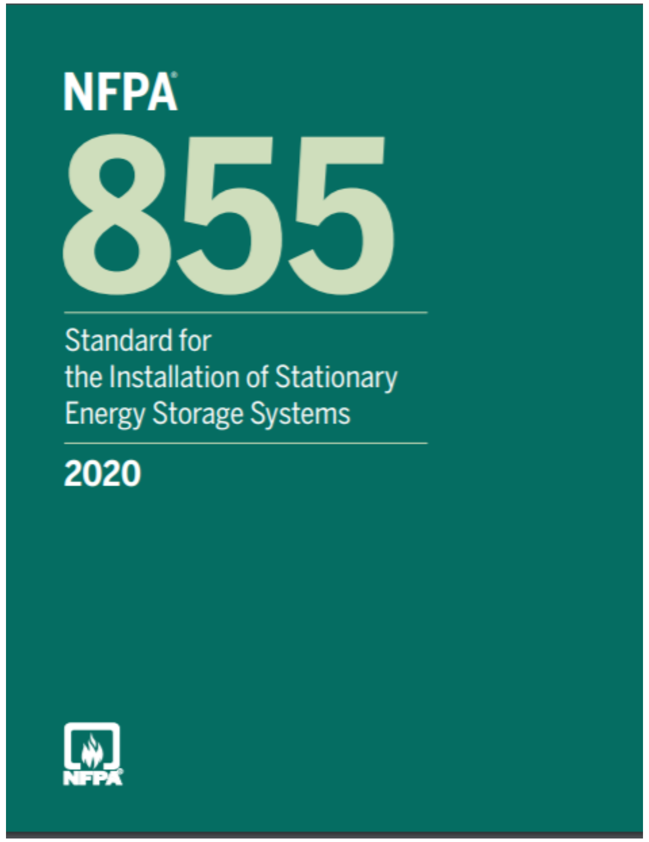
International Fire Code (IFC)® in Effect



https://www.iccsafe.org/wp-content/uploads/Master-I-Code-Adoption-Chart-OCT-2019.pdf

NFPA 855

- 2020 NFPA 855 Standard for the Installation of ESS
  - 1st Edition published
  - Scope reserved for next cycle based on appeal by utilities for exemptions.
  - Covers
    - ✓ Design
    - ✓ Commissioning
    - ✓ O & M
    - ✓ Deflagration Protection
    - ✓ Emergency Response
    - ✓ Decommissioning



Codes & Standards – IFC 2018

Example of some areas addressed:

- Hazard mitigation analysis
- Threshold & MAQ limits
- Size & Spacing requirements
- Explosion Protection
- Listed to UL 1973 or 9540
  - Modifications allowed based on large-scale fire testing (UL 9540a)

2018 IFC Threshold Limits

2015 threshold

50 gallons (190 l) electrolyte for lead-acid, Ni-Cad, VRLA
1,000 pounds (450 kg) for lithium-ion, lithium metal polymer
Other technologies not covered
Use - Standby and emergency power or UPS

2018 threshold

Lead acid, Ni-Cad - 70 KWh
Lithium, Sodium all types - 20 KWh
Flow batteries - 20 KWh
Other battery technologies 10 KWh
Use - No limitations

2018 IFC MAQ's

2015 MAQ's

No restrictions on the quantity of batteries in an incidental use area

2018 MAQ's

MAQ for an incidental use area within buildings is 600 KWh

- 200 KWh for technologies not covered by the code
- No limit for lead acid battery systems

Fire areas containing battery systems above the MAQ shall comply with Group H requirements

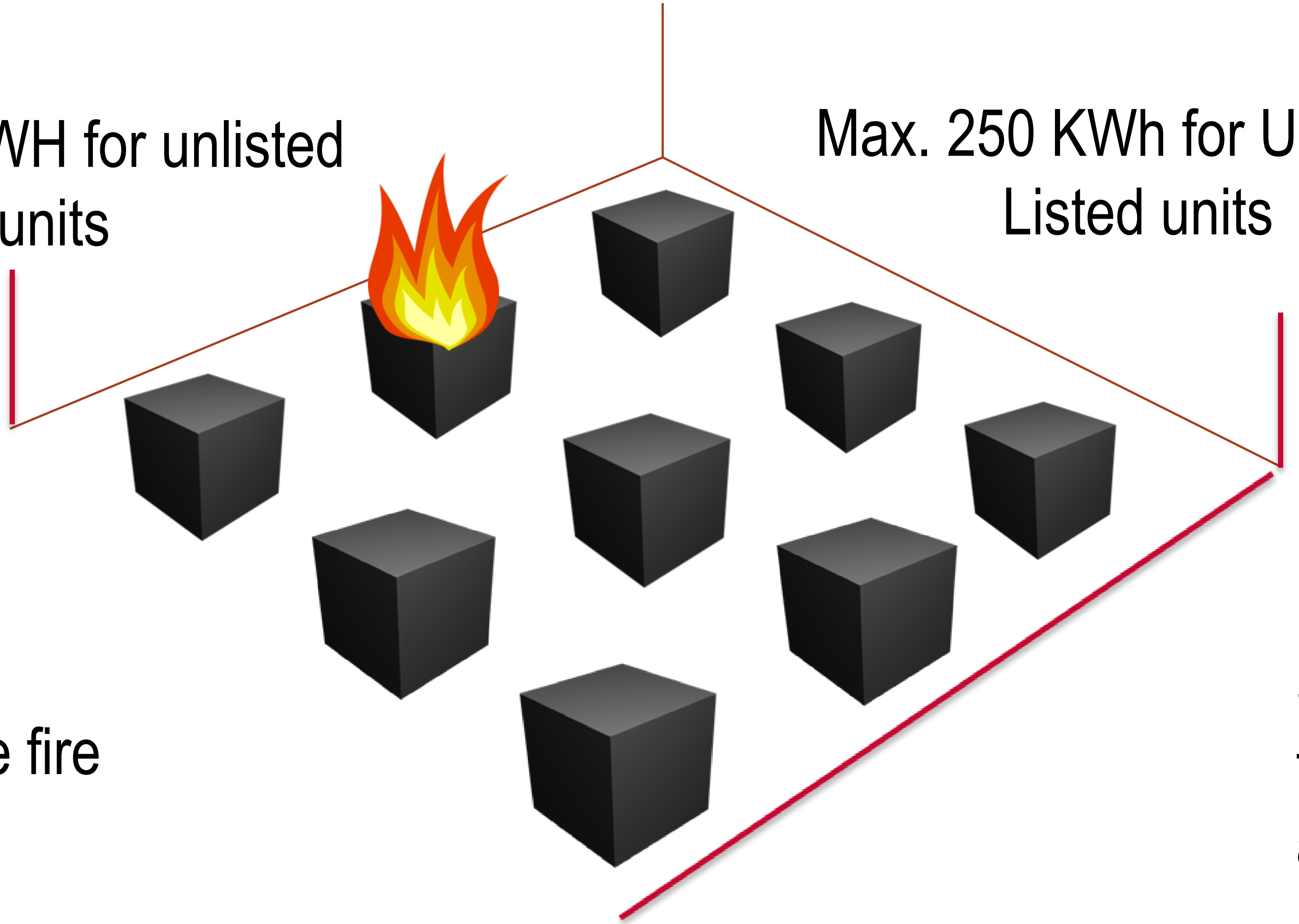
Exception

When approved, larger quantities allowed based on HMA and large scale fire testing by an approved test lab

2018 IFC Size, Separation & MAQ Limits

Max 50 kWH for unlisted units

Max. 250 KWh for UL 9540 Listed units



Other arrangements based on large scale fire testing

Spaced min. 3 ft. from other arrays and from walls

Max. 600 KWh aggregate/fire area (200 kWH other)

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2018 IFC Explosion Protection

Two options for meeting requirement:

1. NFPA 68 – Deflagration Venting.
   - Blow-out panels to protect structure from explosion based on max gas production in cell tests.

2. NFPA 69 – Deflagration Prevention.
   - Exhaust system designed to keep below 25% of LEL in area.

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2018 IFC - Large Scale Fire Testing

The fire code official can approve the following installations based on large-scale fire testing:

- Increased array (unit) size
- Reduced spacing to adjacent units and/or walls
- Increased MAQ in a fire area

Testing to be conducted by an approved test lab and show:

- A fire in one unit will not propagate to an adjacent unit
- A fire in one unit will be contained within the test room
- UL 9540A was developed to conduct these fire propagation tests

2021 IFC specifies UL 9540A for this testing

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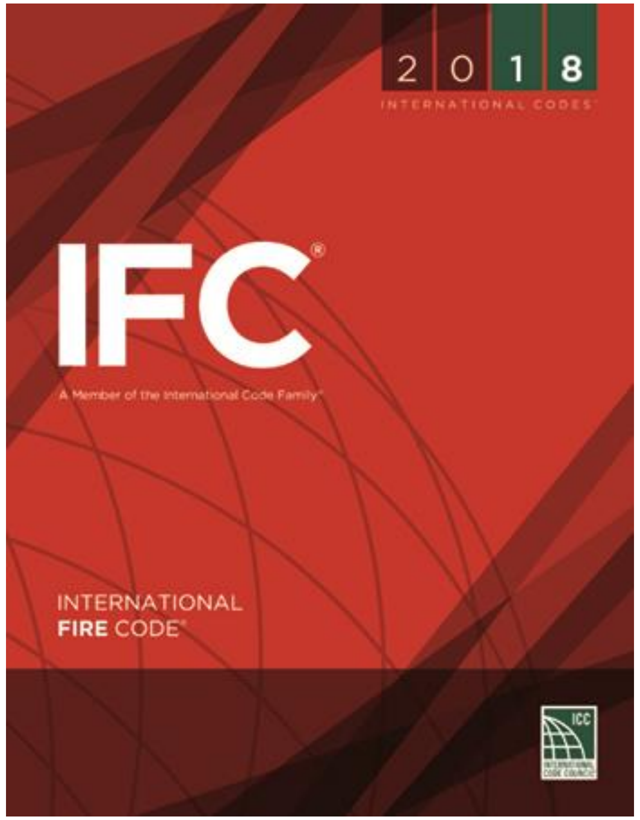
IFC

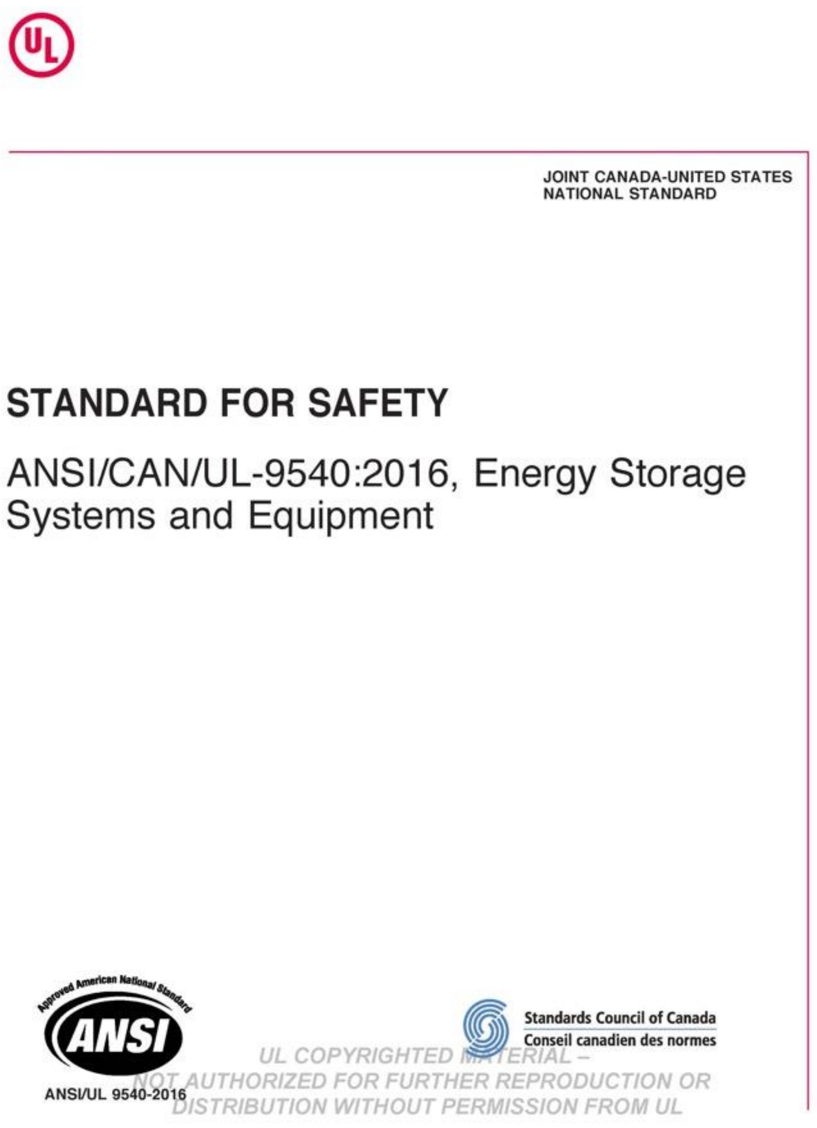
- 2021 International Fire Code
  - Section 1206
  - Changes from 2018
    - ✓ Scope ads O&M, retrofit, commissioning, decommissioning
    - ✓ Exemption for telecom using Pb & NiCd @ < 60VDC
    - ✓ Suppression system based on 9540a
    - ✓ Dedicated/Non-dedicated use buildings
    - ✓ Explosion control: NFPA 68 or 69
    - ✓ Almost identical to NFPA 855



UL 9540A Test Method

Scope

- Evaluate fire characteristics of a battery ESS that undergoes thermal runaway.
- Artificially forces cells into thermal runaway (if possible)
- Evaluates/documents the resulting fire/explosion characteristics
- Test results used to determine fire and explosion protection required for an installation
- Currently Not PASS/FAIL based



JOINT CANADA-UNITED STATES NATIONAL STANDARD

STANDARD FOR SAFETY

ANSI/CAN/UL-9540:2016, Energy Storage Systems and Equipment

ANSI/UL 9540-2016

Standards Council of Canada
Conseil canadien des normes

UL 9540A Test Methodology

- Evaluating/interpreting test results can be challenging

Credit: FM Global

Cell Level

↓

Module Level

↓

Unit Level

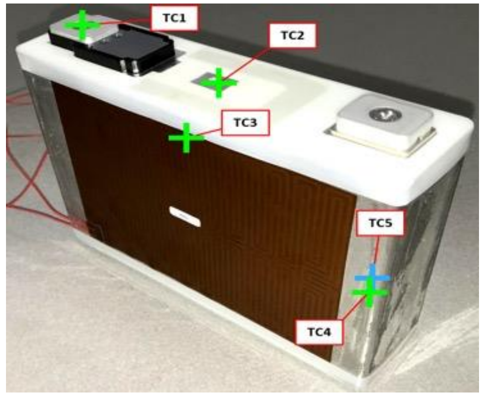
↓

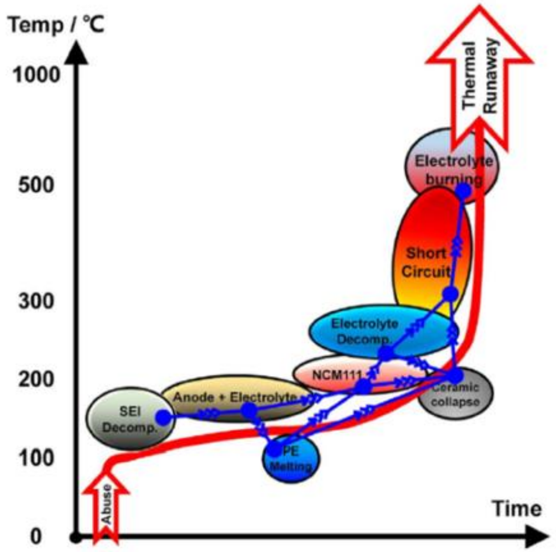
Installation Level

UL 9540A Cell Level Testing

Purpose:

- Determine if thermal runaway can be induced,
- If so, document thermal runaway methodology, instrumentation,
- Determine cell surface temp at venting and thermal runaway,
- Measure gas generation and composition.



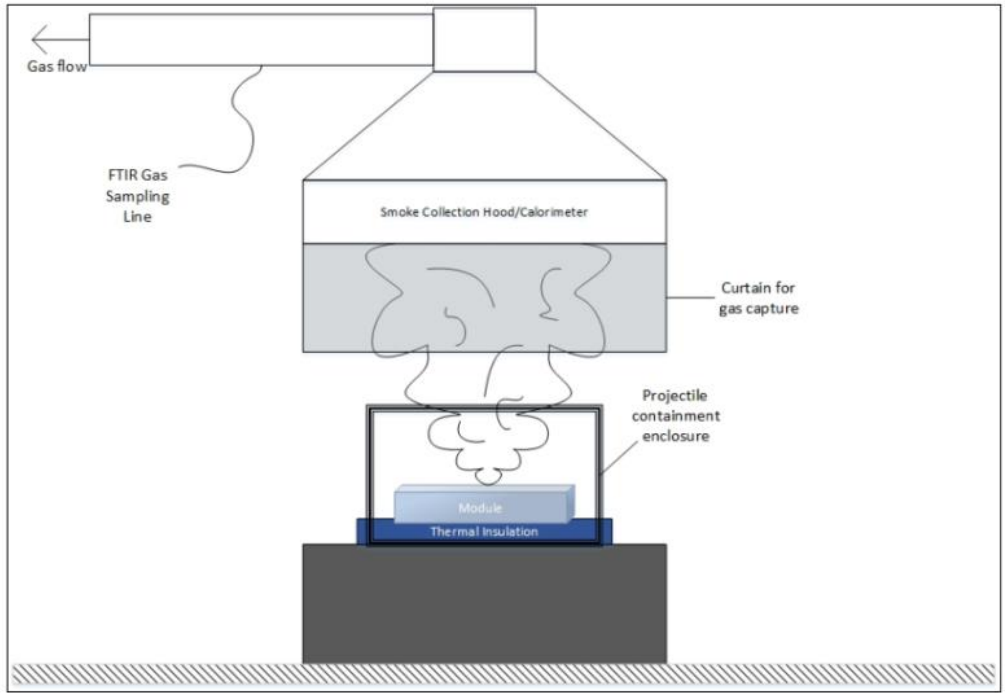


Credit: UL

UL 9540A Module Level Testing

Purpose:

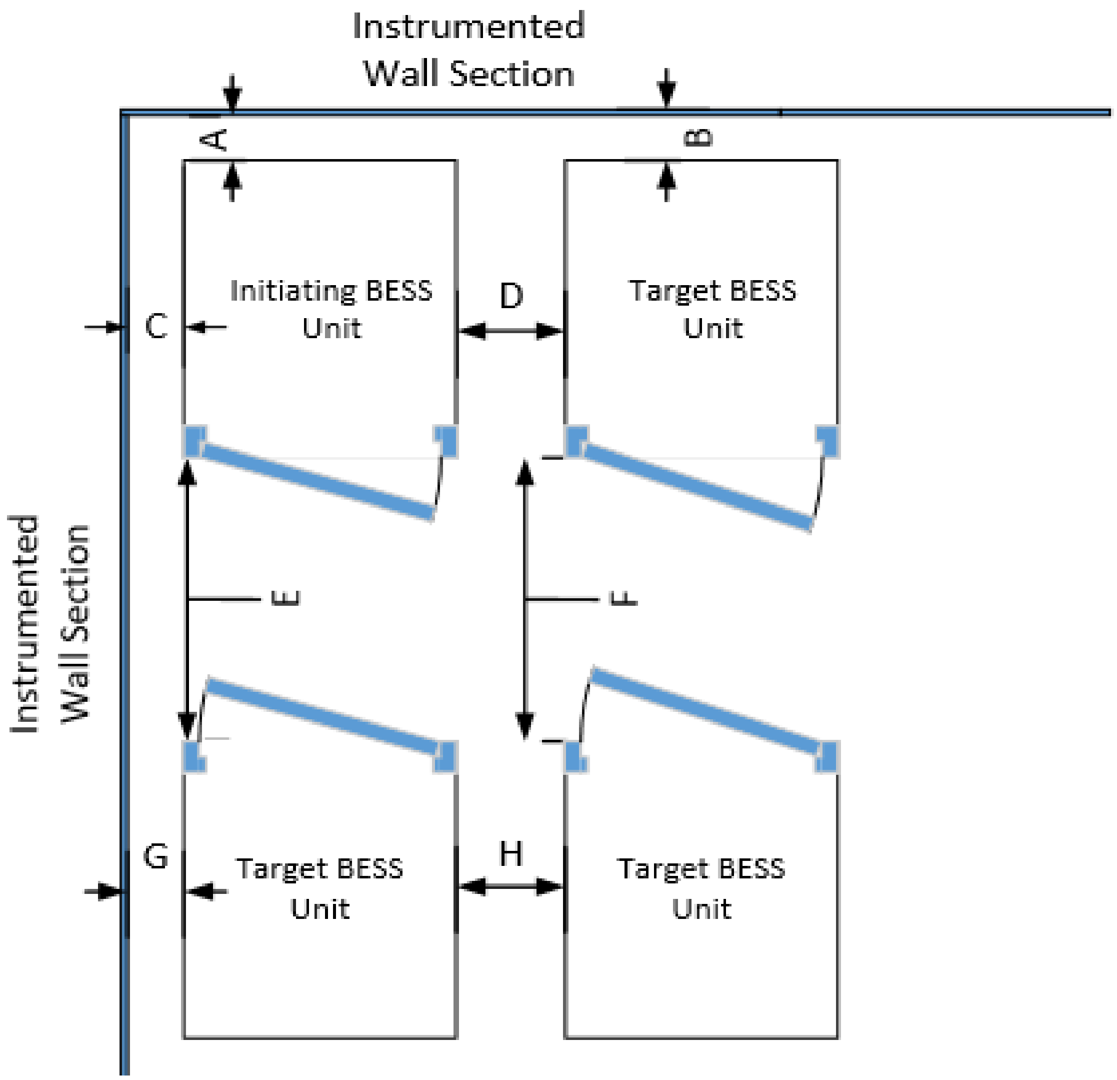
- Evaluate thermal runaway propagation within a module,
- Develop data on heat release rate and vent gas generation rate and composition,
- Document fire and deflagration hazards.



Credit: UL

UL 9540A Unit Level Testing

- Document thermal runaway progression within the unit,
- Document if flaming occurs outside the unit,
- Measure heat and gas generation rates,
- Measure surface temperatures and heat fluxes in target units,
- Measure surface temperatures and heat fluxes on walls.



Credit: UL

UL 9540A Unit Level Performance

Acceptable results:

- No flaming outside the unit under test *
- No explosion hazard observed
- Maximum temperatures on target units ≤ the vent temperature in the cell level test, and maximum surface wall temperature rise ≤ 97 °C (175 °F) above ambient.

* If flaming is observed, the test will be conducted with a manufacturer recommended automatic sprinkler system or other fire protection system present.

Credit: UL

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UL 9540 and UL 9540A Changes

- UL 9540A testing required for units > 50 KWh or with less than 3 ft separations
- New UL 9540A unit level tests for indoor and outdoor wall mounted ESS
- Acceptance criteria for the UL 9540A tests
- New requirements for ESS to be located inside habitable & living spaces in dwelling units

If adopted, the changes eliminate the need for AHJs to review a UL 9540A test report. Their approval will focus on the UL 9540 listing and manufacturer's installation instructions.

Credit: UL

Design Best Practices

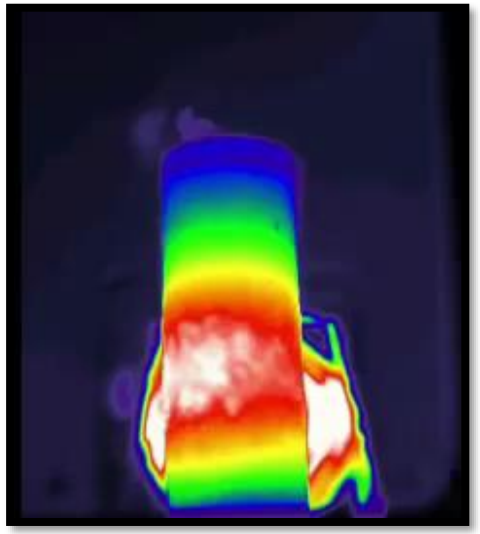
- Design Best Practices
- System Design
- Warning Systems
- Incident Pre-Planning
- Incident Management

System Design
(dedicated use buildings)

- Exterior marking & visible alarm annunciation
- Gas detection
- 2-stage suppression (clean agent + water)
- Smoke & heat sensors for delayed detection post agent discharge
- Auto exhaust w/ sprinkler activation (exterior manual option available)

Warning systems

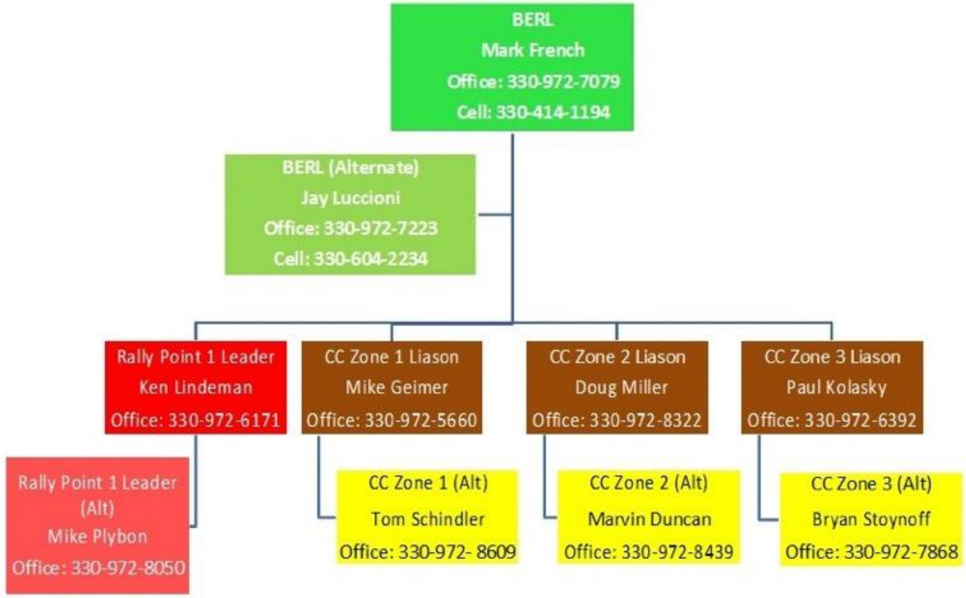
- BMS should remain powered and in communication with monitoring systems.
- Maintaining “eyes” on incident for long duration critical.
- Cell/module temperature & gas monitoring = key metrics



Incident Pre-Planning

- Provide local responders plans & locations of ESS.
- Plan for multiple scenario including decommissioning (detailed table-top exercises).
- Clear signage of hazards, disconnect locations, and contact info.

Emergency Contact List Phone Tree



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Incident Management

- Life, property, environment are priorities.
- Rapid notification of 911
- Evacuate/shelter in place notifications as appropriate
- Identification of site manager to liaison with responders
- Decom/EOL, Emergency energy discharge

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Acknowledgement

- Dr. Imre Gyuk, DOE – Office of Electricity

U.S. DEPARTMENT OF
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Thank you