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ESS Safety & Codes & Standards

December 7, 2021

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U.S. DEPARTMENT OF ENERGY BATTELLE

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PNNL-SA-152388

ESS Safety Topics

- Failure Modes
- Existing Codes & Standards
  - IFC
  - NFPA 855
  - UL9540/9540a
- Explosion Prevention

Failure Modes/Hazards


Thermal Abuse

- Thermal Abuse
  - Exposed to high heat from external source


Electrical Abuse

- Electrical Abuse
  - Overcharging, rapid discharging, unbalancing


Mechanical Abuse

- Mechanical Abuse
  - Dropping, hitting


Internal Faults

- Internal defects
  - Dendrites, separator QC, other contaminations


Environmental Impacts

- Environmental Abuse
  - Seismic, flooding, absent or poorly designed HVAC

Thermal Runaway

↓

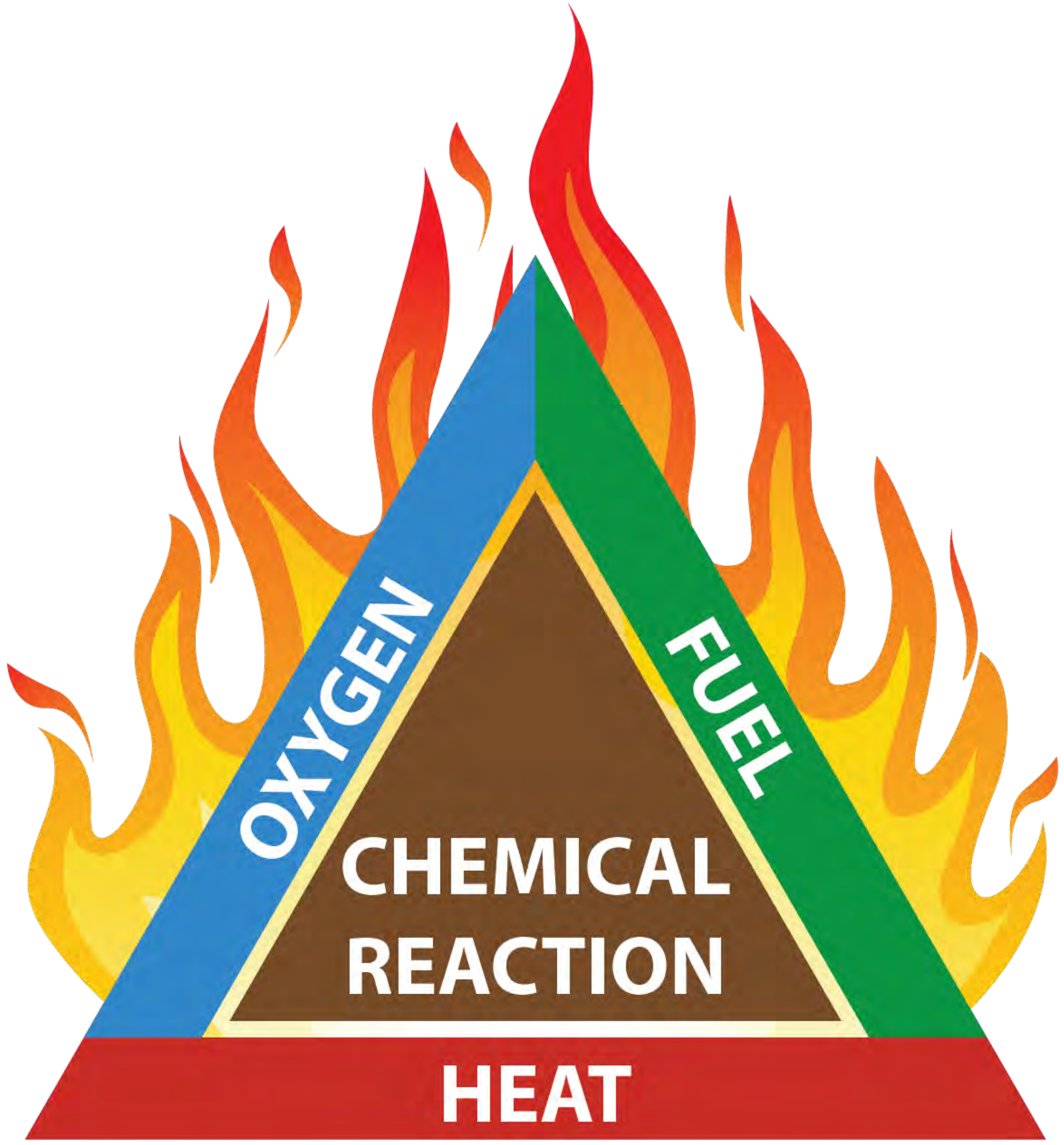
Flammable Gases

↓

Stranded Energy

Fire Tetrahedron

- Typically all that is required for fires to occur is O2, Fuel, and Heat.
- Some chemistries contain oxides that release rapidly under high heat conditions.
- Li-ion fires can occur in low O2 atmospheres
- Flammable gasses will continue to be produced.

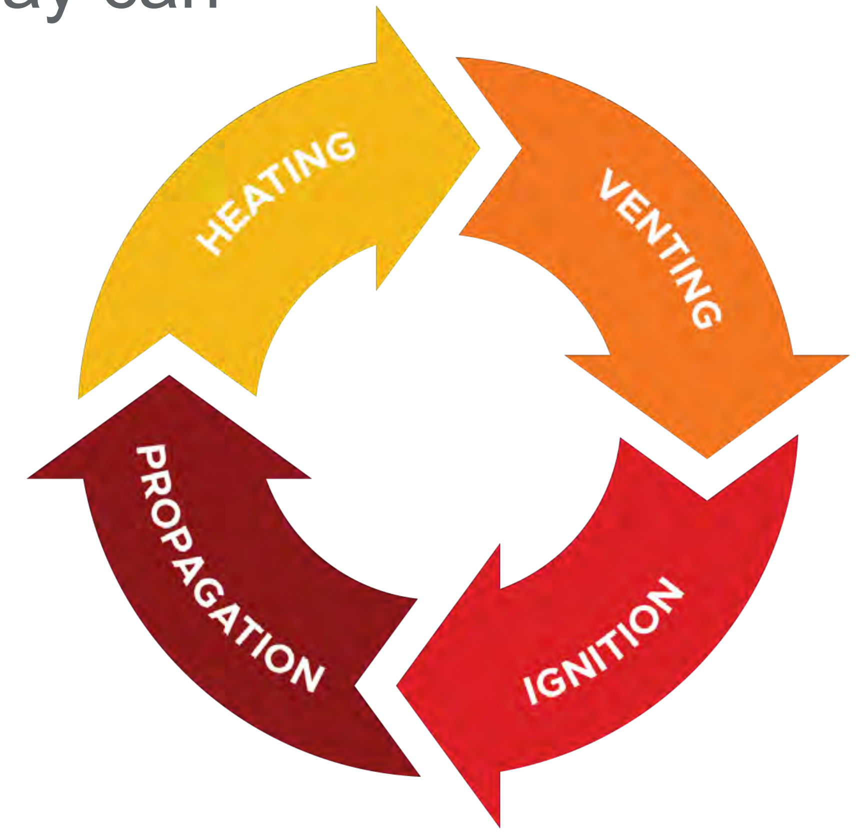


PREVENTING/REMOVING HEAT IS KEY

Hazards – Thermal Runaway

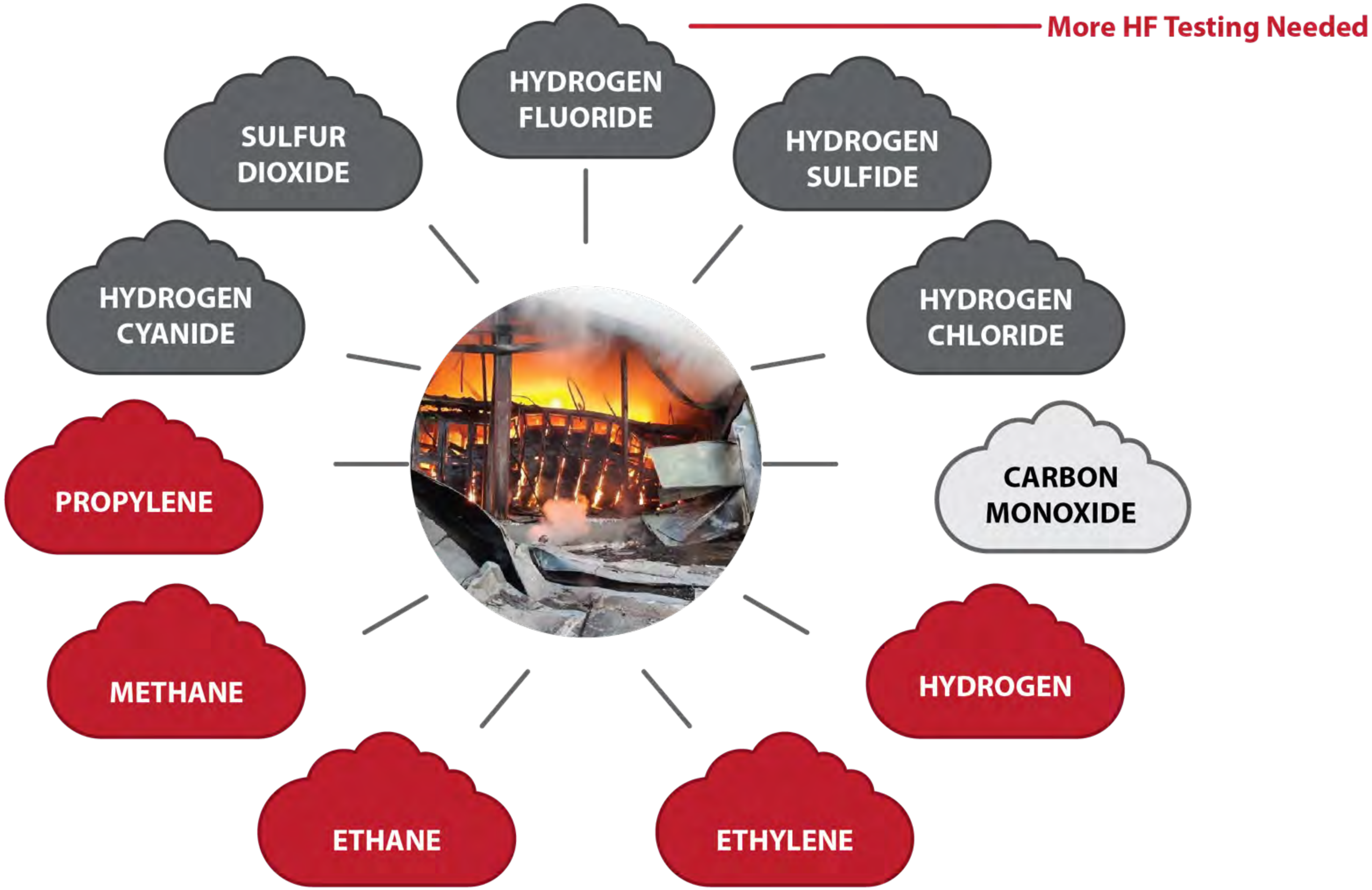
"The process where self heating occurs faster than can be dissipated resulting in vaporized electrolyte, fire, and or explosions"

- 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



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

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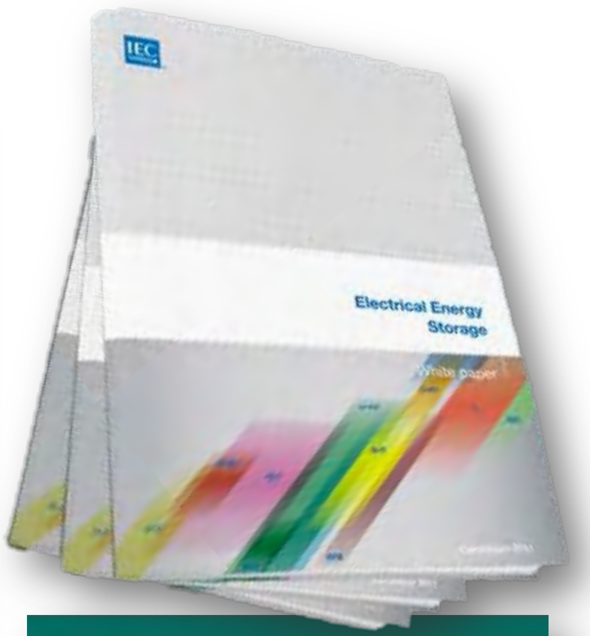
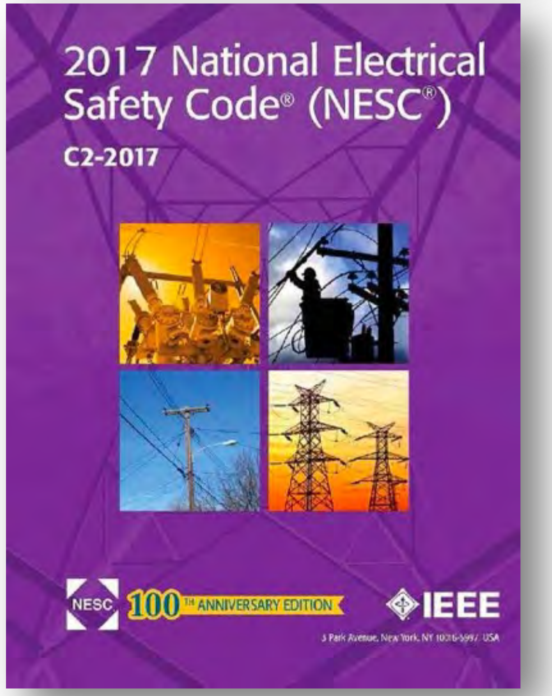
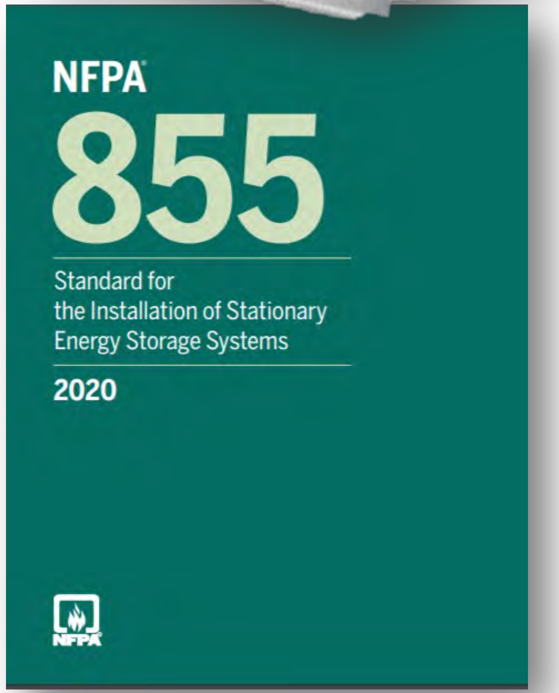
Codes & Standards



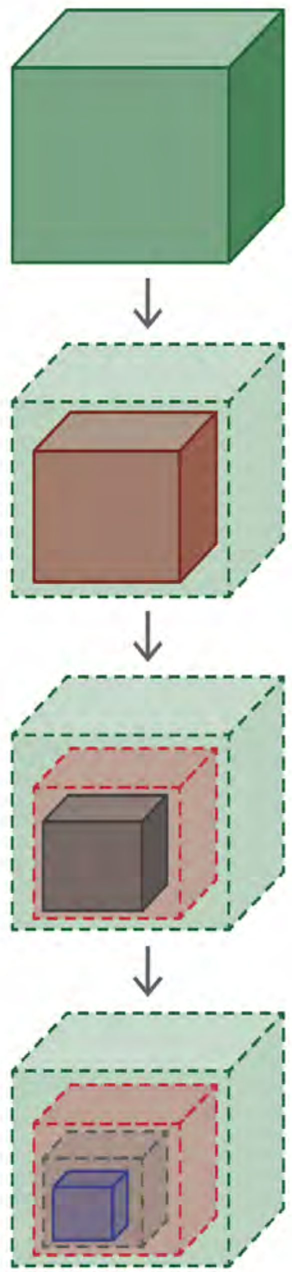




Codes & Standards Landscape

- Building & Fire Codes are adopted typically at a state level
- Product and installation Standards are referenced in the Codes.
- Codes & Standards have evolved, but much slower than deployments
  - Typically updated every 3 years.
- Listed ESS Cabinets more common
  - Cabinets added to NFPA 855
- Challenges with fire protection
- Product listing expensive and time consuming
- Inconsistent Code adoption state-state

Standards and Model Codes Hierarchy



BUILT ENVIRONMENT

- iCodes – IFC, IRC, IBC
- IEEE – C2, SCC 18, SCC21
- NFPA 5000, NFPA 1, ISA

ENERGY STORAGE SYSTEMS

- UL 9540, MESA
- ASME TES-1, NECA
- NFPA 791

INSTALLATION / APPLICATION

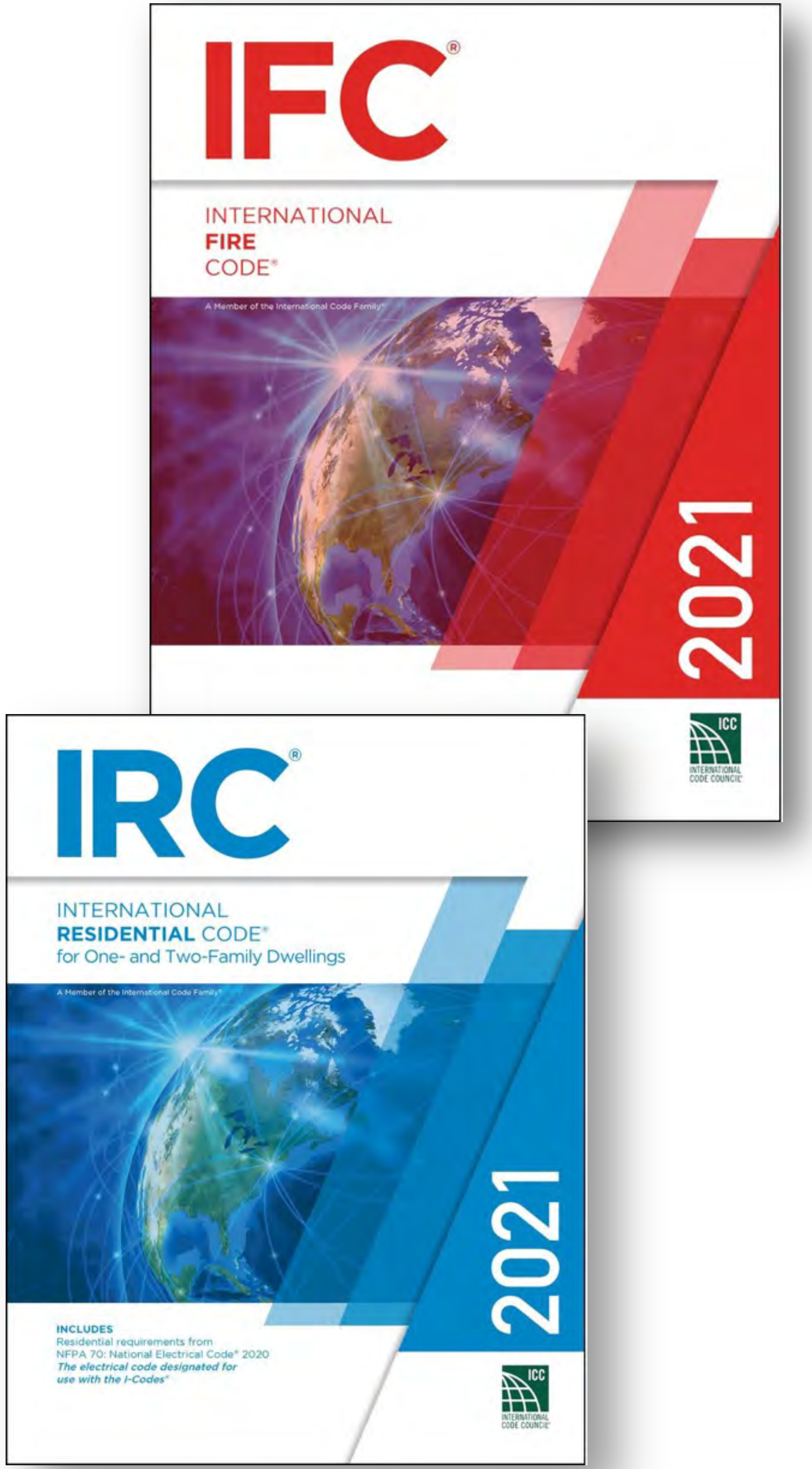
- NFPA 855
- NFPA 70
- UL 9540 A
- IEEE C2
- IEEE 1635/ASHRAE 21
- IEEE P1578
- DNVGL GRIDSTOR
- FM GLOBAL 5-33
- NECA 416 & 416

SYSTEM COMPONENTS

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

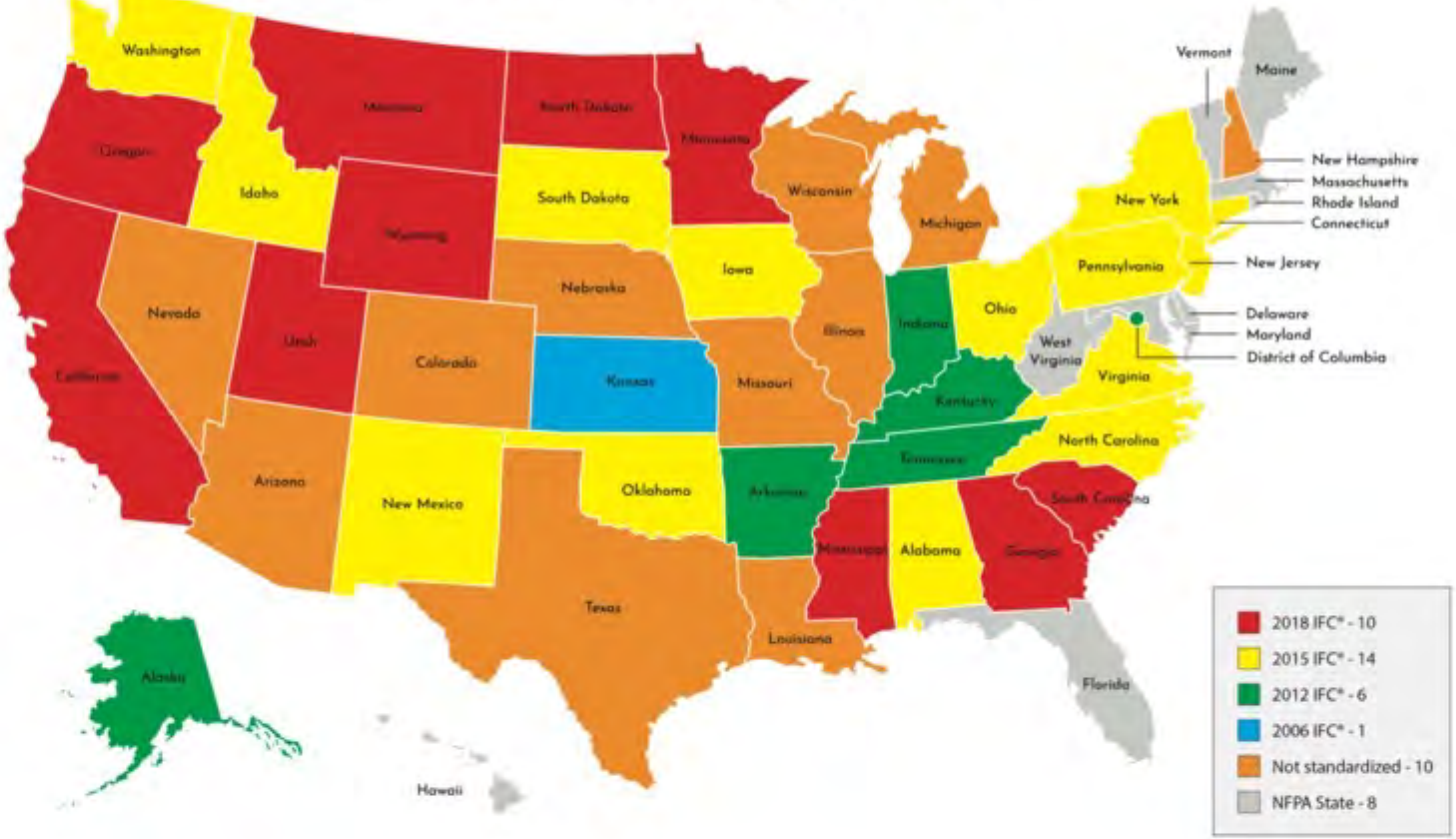
IFC

- 2021 International Fire / Residential Code
  - IFC Section 1207 – IRC Section 327
  - Changes from 2018
    - ✓ Harmonizes with NFPA 855
    - ✓ Requires listing to UL9540
    - ✓ Scope ads O&M, retrofit, commissioning, decommissioning
    - ✓ Exemption for telecom using Pb & NiCd @ < 60VDC
    - ✓ Suppression system based on 9540a
    - ✓ Explosion control: NFPA 68 or 69
    - ✓ Post-Fire Mitigation Personnel
    - ✓ Emergency Response Plan & Training



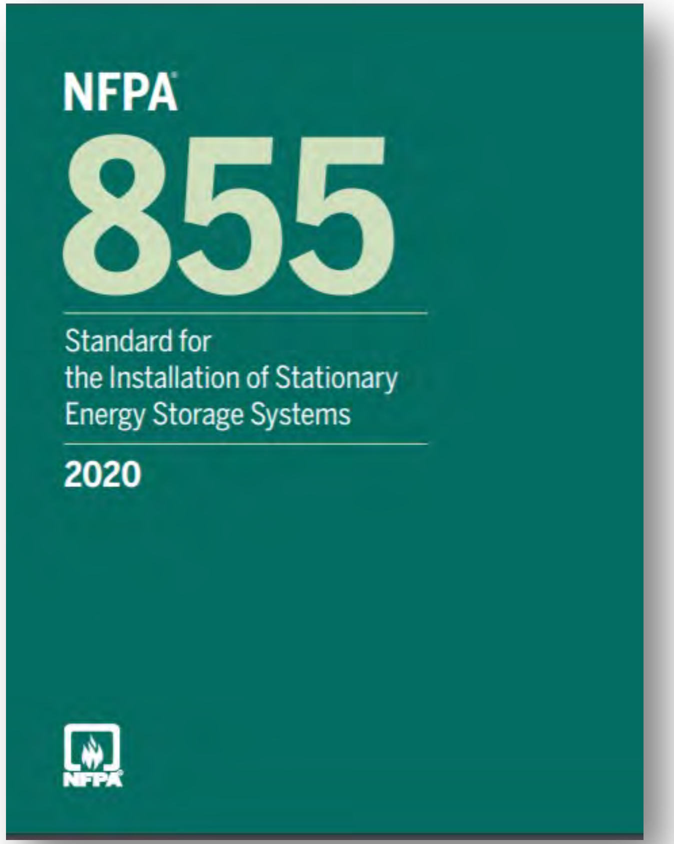
IFC Adoption Map

International Fire Code (IFC)® in Effect



NFPA 855

- 2020 NFPA 855 Standard for the Installation of ESS
  - 2nd edition in final stages of development
  - Covers
    - ✓ Installation
    - ✓ Commissioning
    - ✓ Explosion Control includes cabinets
    - ✓ Emergency Response
    - ✓ Decommissioning
  - Referenced directly in 2021 NFPA1 Fire Code and 2024 IFC

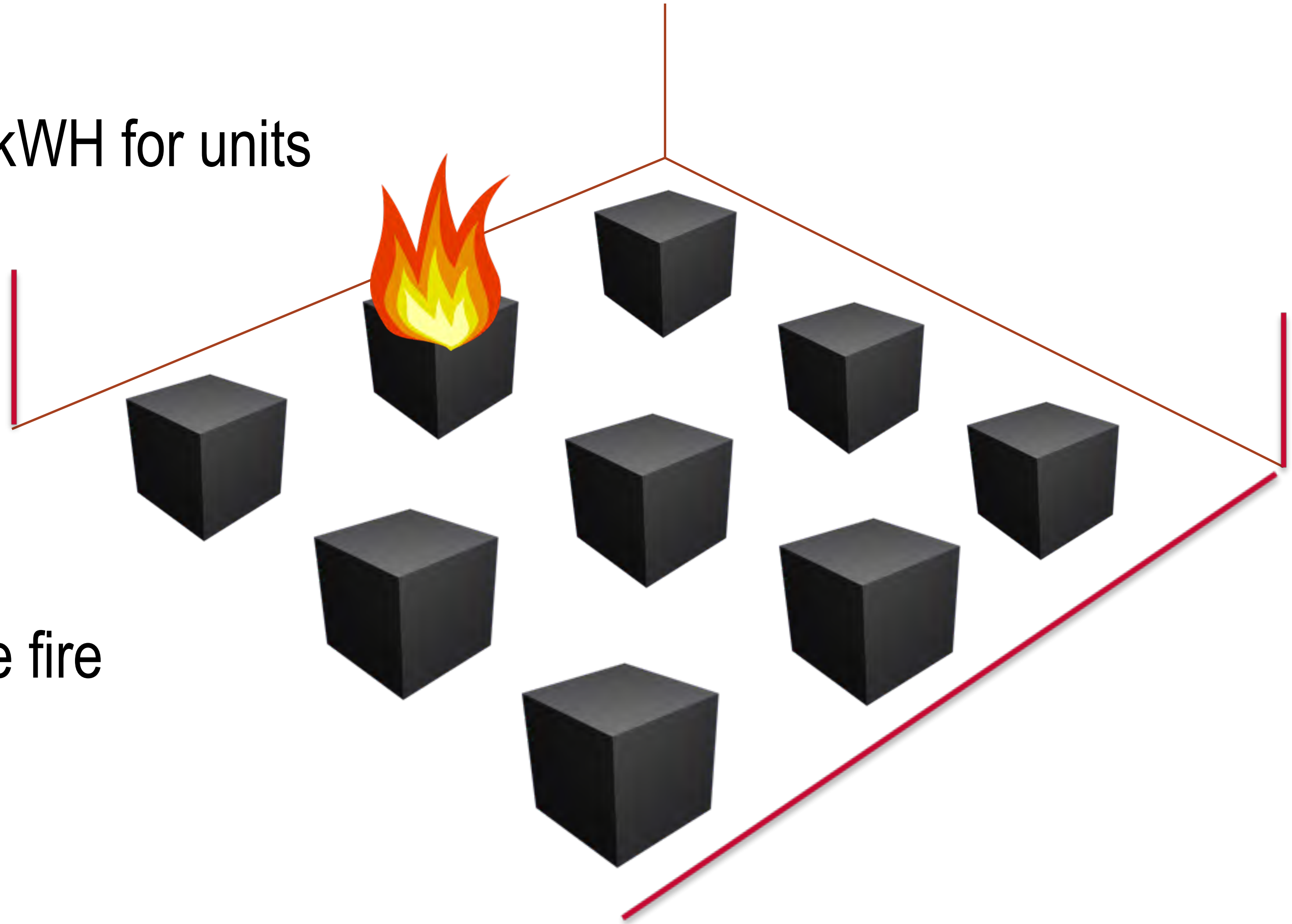


LIB Fire Suppression Challenges

- Clean agent suppression systems (FM200, Novec 1230, CO2, Stat-X) ineffective on deep seated Li-ion cell fires.
- Flammable gas generation not addressed.
- Water has cooling capability but can lead to additional arcing in undamaged modules.
- Quantity of water needed for extinguishment may dictate additional infrastructure or containment designs.
- Siting should consider exposure protection if enclosure allowed to burn.

Size, Separation & MAQ Limits

Max 50 kWH for 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)

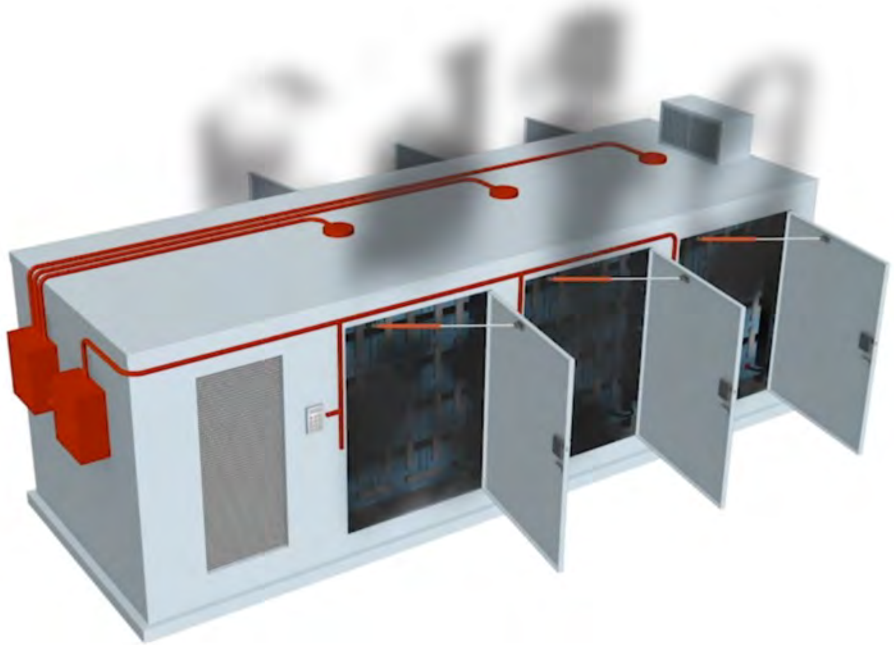
NFPA 855 Explosion Control

Three 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.

3. Engineered Cabinet – Based on Large Scale Fire Test has shown that no pressure waves will occur and no projectiles can be ejected.



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/NFPA1 specifies UL 9540A for this testing

UL 9540 Listing

- This is a SYSTEM listing, not for components.
- Includes a UL1973 listed battery & UL1741 listed inverter
- Construction & Performance
- Mechanical & Environmental Tests
- Communications Systems
- Functional Safety
- HVAC
- Includes requirements for UL9540a fire testing

JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL
9540:2020

STANDARD FOR SAFETY

Energy Storage Systems and
Equipment

Approved American National Standard
ANSI
ANSI/UL 9540-2020

Standards Council of Canada
Conseil canadien des normes

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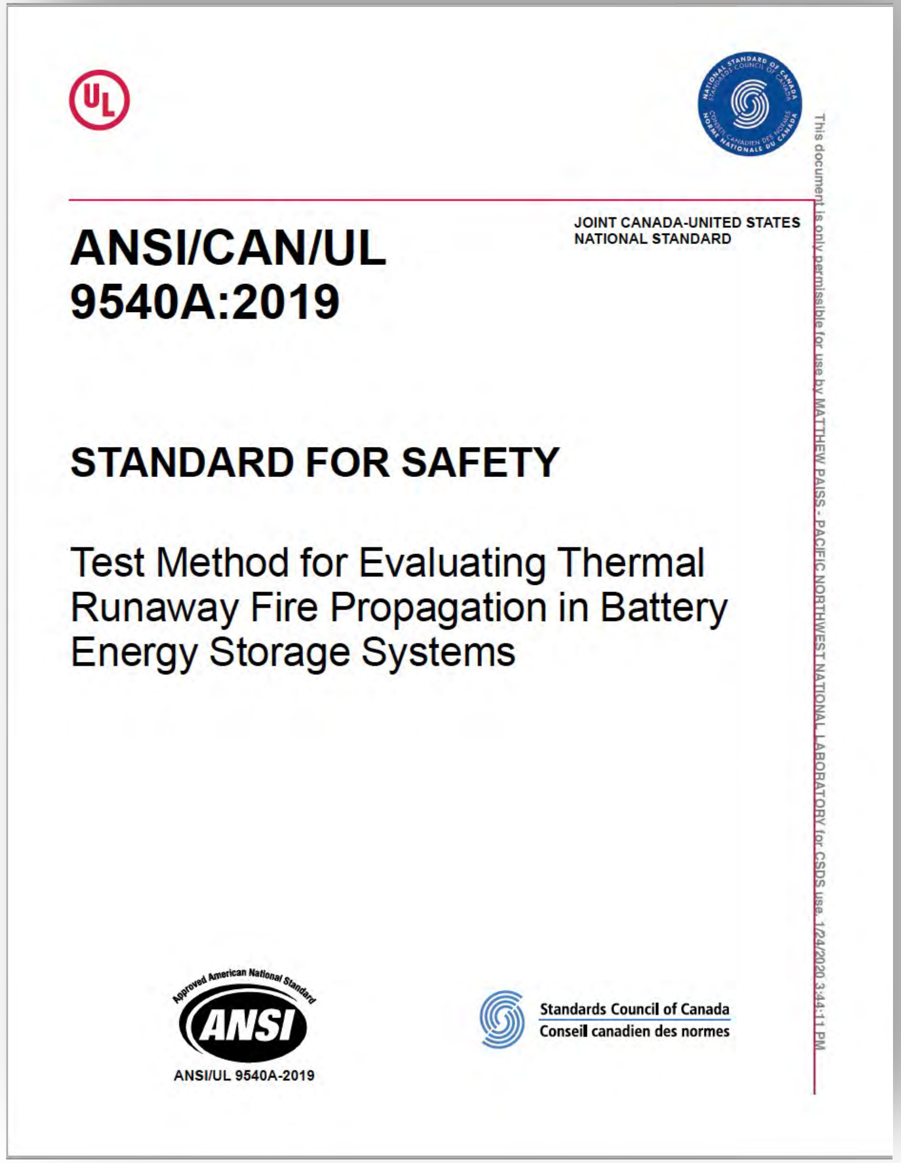
UL 9540a Test Method

- Test method, NOT a listing or certification
- 4th edition has clarifications on module test
- Used to characterize gas characterizations for chemistries that go into TR.
- Used to design fire protection and explosion studies.
- Required for any ESS unit >50kWh, where spaced <3’ apart, or residential wall mounted units.



UL

JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL 9540A:2019

STANDARD FOR SAFETY

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Approved American National Standard
ANSI
ANSI/UL 9540A-2019

Standards Council of Canada
Conseil canadien des normes

UL 9540A Test Methodology

- Evaluating/interpreting test results can be challenging

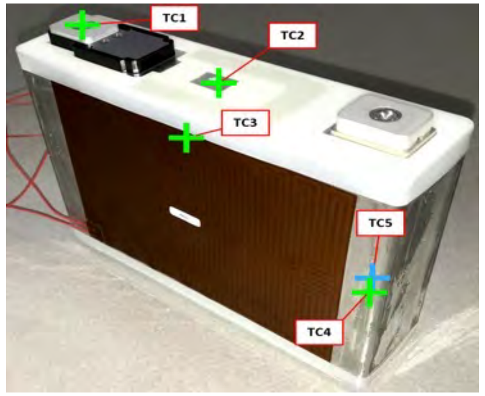
Credit: FM Global

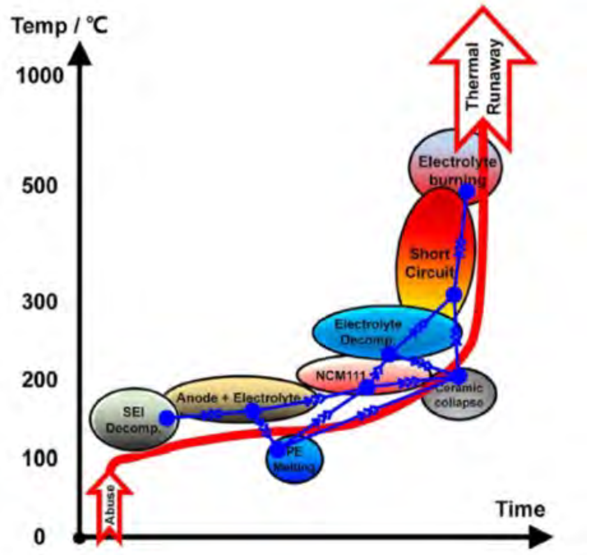
Cell Level
↓
Module Level
↓
Unit Level
↓
Installation Level

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.



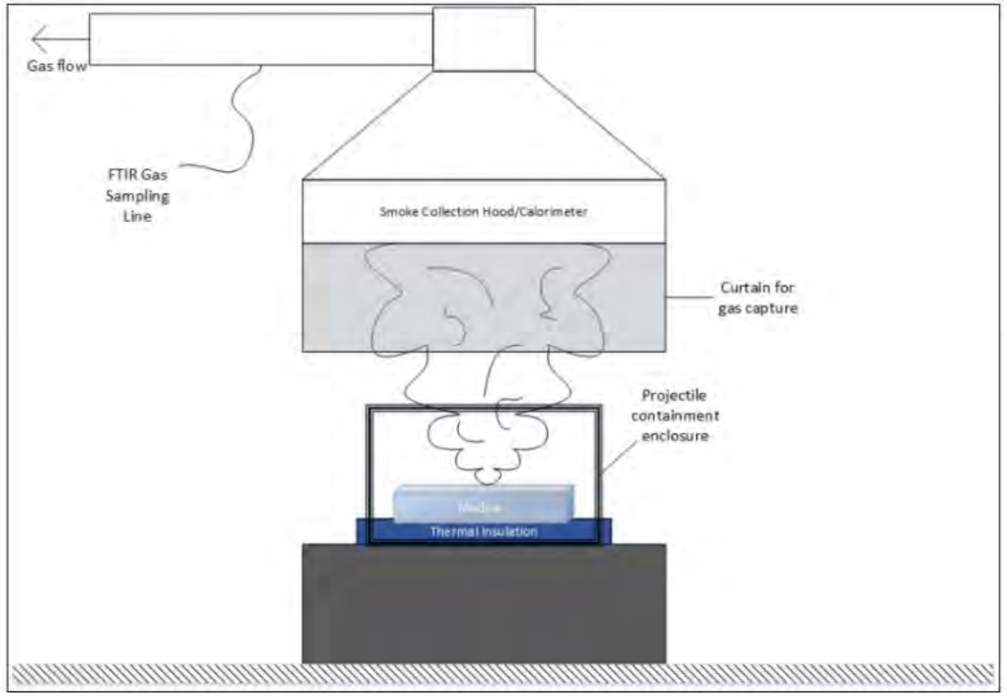


Credit: UL

UL 9540A Module Level Testing

Purpose:

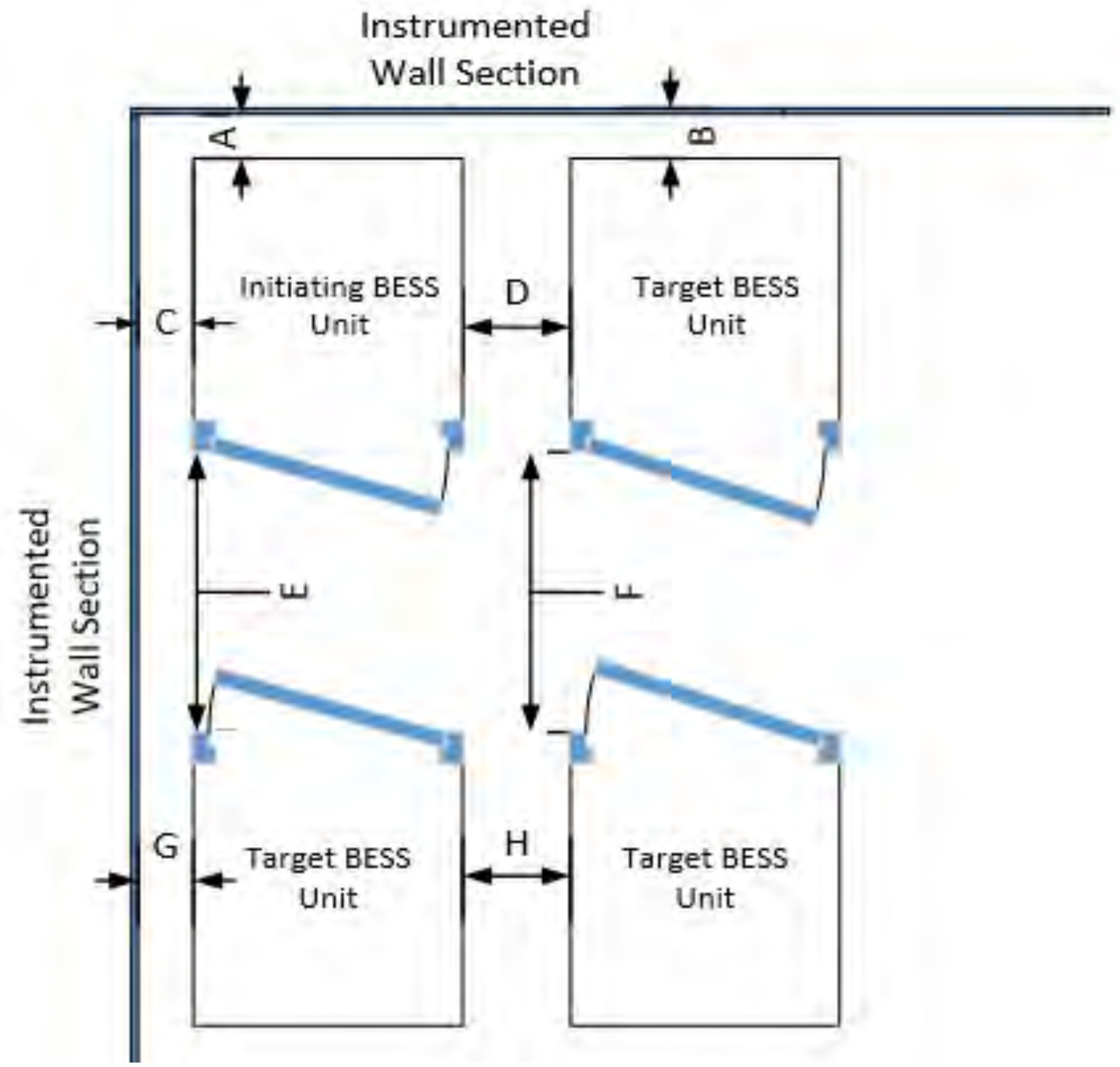
- Evaluate thermal runaway propagation within a module,
- Develop data on heat release rate and vent gas generation rate and composition,
- Document fire and deflagration hazards.



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

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Preventing ESS Explosions

Effect of fuel concentration, inert gas dilutions, inert gas–water mist twin fluid medium dilutions, and end boundary condition on overpressure transients of premixed fuel vapor explosion
Fuel, Volume 309, 2022

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Background

- Lack of exhaust ventilation was identified as leading gap in APS incident. Other explosions will occur in similarly designed systems.
- Deflagration prevention lacking in most systems.
- Listing to 9540 costly for large systems due to 9540a fire testing.

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Explosion Control

- Providing deflagration venting is a late-stage measure. Does not eliminate flammable gases prior to explosion
- Deflagration prevention is the key!
- But…smaller volume cabinets make exhaust ventilation even more challenging
- Exhausting must occur rapidly

Deflagration Challenges

- System with clean agent suppression system.
- TR continued after deployment
- Deflagration occurred @ 44min
- Event required direct water application.

Demonstration 2 – Timeline of Major Events

Smoke accumulation at second smoke detector activation [TR + 00:00:55]

Novec 1230 discharge [TR + 00:00:58]

Smoke stratification before ignition [TR + 00:26:51]

Ignition [TR + 00:28:32]

Partial volume deflagration [TR + 00:44:39]

Continued thermal runaway propagation [TR + 00:46:26]

Smoke plume from open door [TR + 02:09:27]

Flashover and flaming from open door [TR + 02:09:48]

https://ulfirefightersafety.org/docs/UL9540AInstallationDemo_Report_Final_4-12-21.pdf

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Deflagration Challenges

- System with 0.5 gpm sprinkler system.
- Deflagration 30 min post water application.
- UL demonstration of deflagration risks highlights that no matter what the suppression system – **deflagration still occurs**.

Demonstration 3 – Timeline of Major Events


Smoke accumulation and first response of LEL at the ceiling [TR + 00:00:29]


Ignition leading to sustained flaming [TR + 00:08:49]

Water flow initiated at 0.5 gpm/ft^2 [TR + 00:10:13]


Smoke and gas release from TR propagation [TR + 00:30:49]


Deflagration vent operation [TR + 00:42:02]


Water flow discontinued [TR + 01:05:55]


Thermal runaway propagation after end of water flow [TR + 01:13:05]


TR propagation continues after water flow restarted [TR + 01:49:54]

https://ulfirefightersafety.org/docs/UL9540AInstallationDemo_Report_Final_4-12-21.pdf

UL Demonstration Summary

Performance – Deflagration Protection

- The deflagration venting successfully vented overpressure, potentially preventing dangerous loss of integrity/rupture of the ISO container.
- Flames emitted from the deflagration vents indicate the need to site and orient the ISO container to mitigate secondary ignition/life safety hazards.
- Compartment filled to approximately 40-60% battery gas
- Flammable gas mixtures at elevated temperatures in all demonstrations
- Gas accumulation not prevented by clean agent or water suppression

https://ulfirefightersafety.org/docs/UL9540AInstallationDemo_Report_Final_4-12-21.pdf

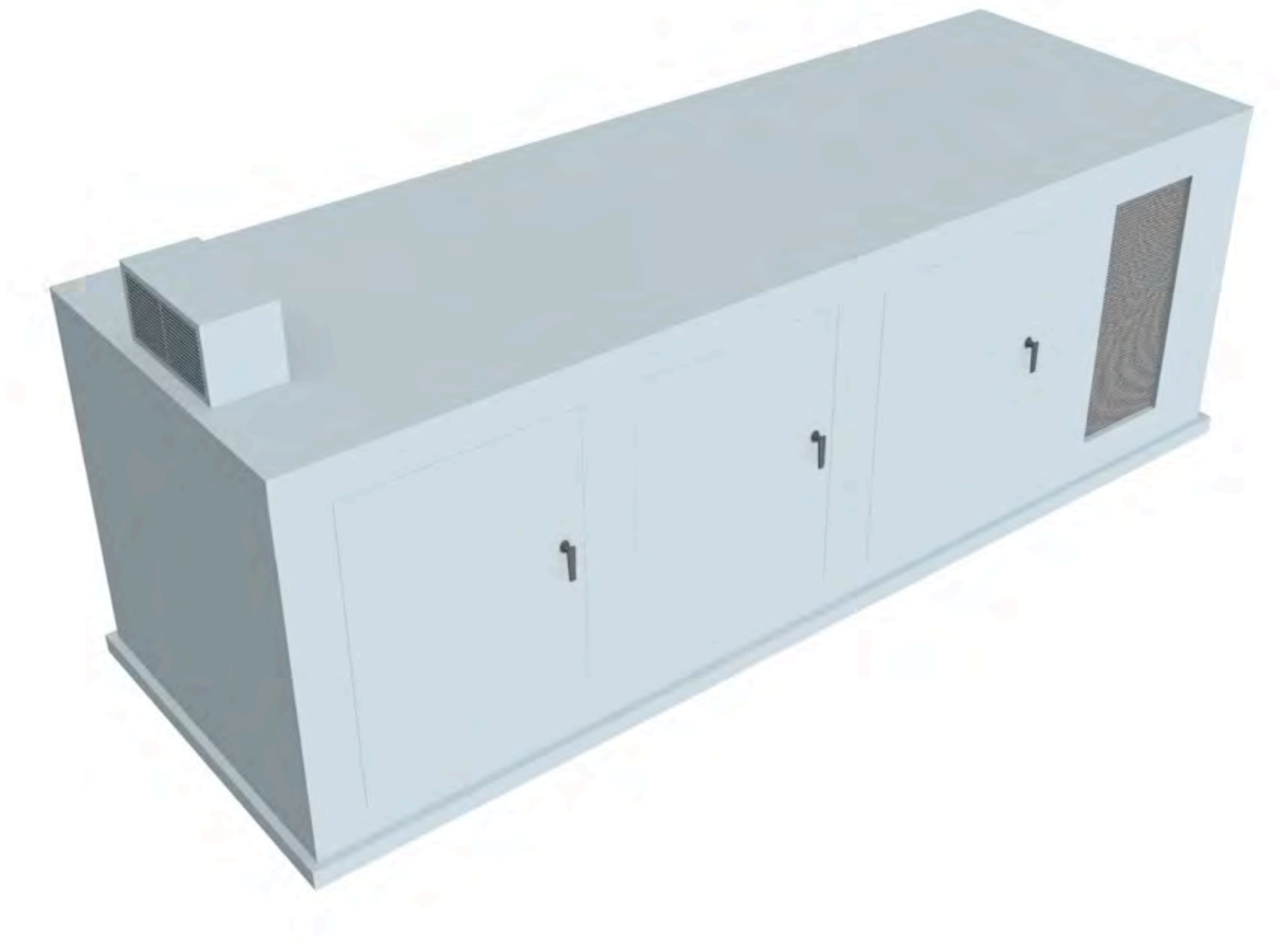
ESS Cabinet Pros & Cons

Pros:

- Trending due to modular design flexibility for smaller projects
- Simpler installation
- Easier to get UL9540 listed

Cons:

- Difficult to provide deflagration prevention due to small air volume
- Lower energy density for larger projects



PNNL available technology

INTELLIVENT

PNNL-SA-152388

December 7, 2021

Design Considerations

- Applicable to wide variety of enclosure designs
- Recommended smoke detector as activation sensor
- UPS battery backup for power failure
- Door access controls can be keypad, prox key, or key switch
- Door position sensor able to detect unintentional opening or sensor failure
- Automated system that will open all doors simultaneously
- Manual option for responder safety & suppression access
- Flexible design and signal inputs (smoke, heat, gas alarm, clean agent delay, etc)
- Minimal space requirements, retrofittable, low cost, & listed components

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Thank you

Dr. Imre Gyuk, DOE – OE

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