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# Lithium-Ion Energy Storage Systems

# Deflagration and Venting Evaluations for Enclosures

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**Energy Storage Systems Safety and Reliability Forum**

SAFETY COLLABORATIVE

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

*4/21/2021*

# Unintended Consequences

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*Suppressing the fire can make the explosion hazard worse.*

*Addressing the explosion hazard can make the fire hazard worse.*

# Agenda

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- Arizona – Reports
- Gas Production
- Upcoming Code recommendation
- Evaluation NFPA 68/69
- Key Takeaways – How to move forward.

# Risk Based Assessment

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- A ~~fire~~ explosion system design is based on reasonably anticipated events to control the ~~fire~~ explosion until an informed party can determine the next course of action.

Doesn’t really apply.

# McMicken DNVGL Conclusions

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- Production of a large quantity of flammable gases
- Contributing Factor #4: Flammable off-gases concentrated without a means to ventilate
- Standards today fall short in addressing the issue and risks associated with off-gassing.
- The BESS door was opened allowing the gases to make contact with a heat source or spark.

# McMicken UL Fire Fighters Safety Research Report

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- Design did not include adequate protection based on NFPA 69/68 – Not required at the time
- Key Recommendations
  - Evaluate fire and explosion strategies

# Where do we go from here?

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- Arizona Explosion Relative impact
  - The free vent space was effectively the door area or about 24 sq feet and it was not adequate to release the pressure.
  - With out evaluation criteria, only designing for single cell failure still provides a significate risk.
  - A single cell failure in Arizona design would have determined the door size was probably adequate. Even if it was placed on the roof the doors still would have blown based on the actual failure.

# Gas Prodution

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# Gas Detection Events – Failure

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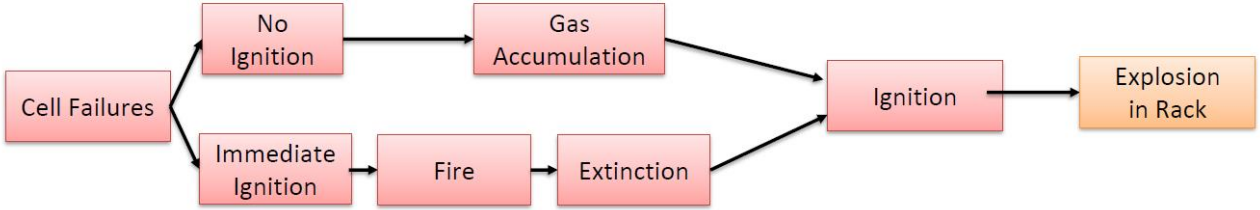
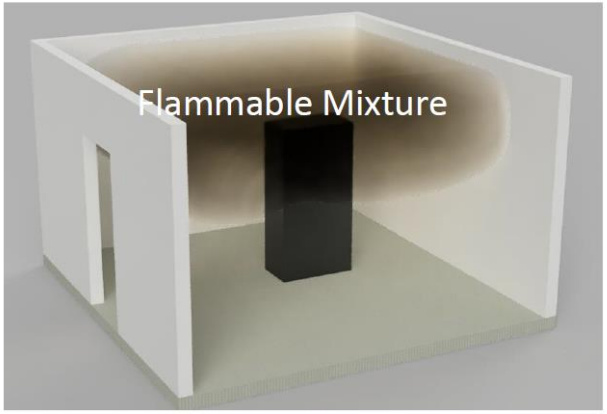
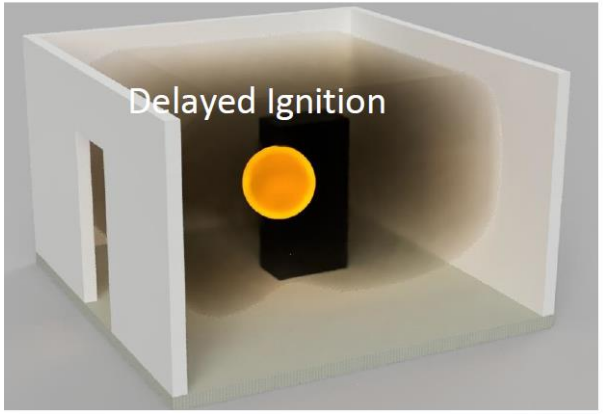
Mechanical Engineering
Cockrell School of Engineering

## Understanding the Hazard



# Gas Detection Events – Failure

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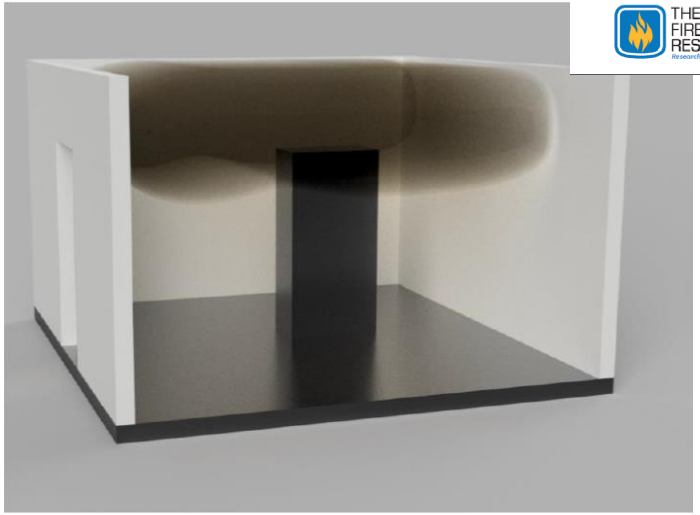
THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

ESSPI
"Fire and Safety Protection for the Energy Storage and Battery Industries"

## Characterizing the Vent Gas Production

- Gas production volume
- Gas composition
- Gas production rate
- Venting speed
  (failure propagation speed)
- Deflagration risk



# Gas Detection Events – Failure

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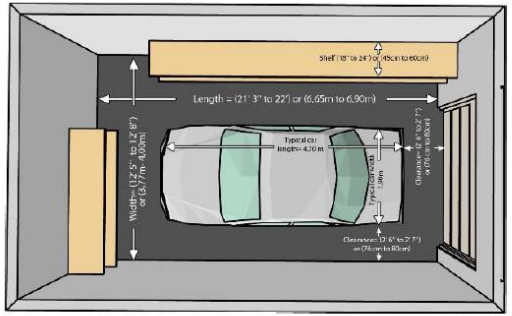
## Energy Density and Volume Analysis





**2 x Powerwalls in Garage**

Storage Density: 1.2 $\frac{kWh}{m^2}$

Gas Generation: 0.46 $\frac{m^3}{m^2}$

Volume of Gas: 10%

**Surprise Arizona Explosion**

Storage Density: 28 $\frac{kWh}{m^2}$

Gas Generation: 8 $\frac{m^3}{m^2}$

Volume of Gas: 412%

**20' or 40' Container**

Storage Density: 170 $\frac{kWh}{m^2}$

Gas Generation: 55 $\frac{m^3}{m^2}$

Volume of Gas: 2500%

# Gas Detection Events – Failure

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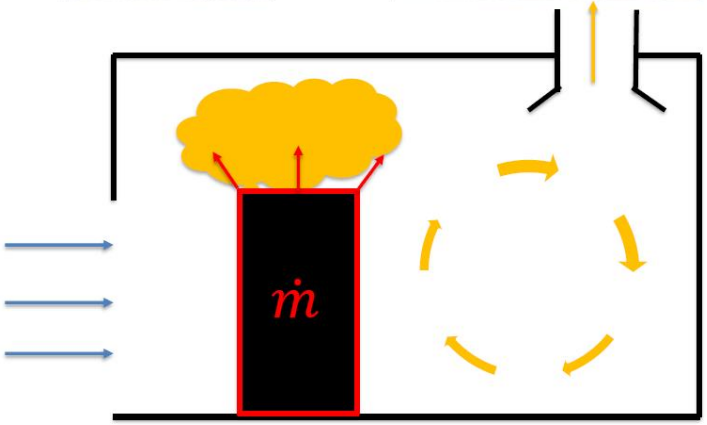
## Rack Vent Gas Production

- LFL
  - Maintain <25%
- Similar to gas leak
  - No shutoff valve
  - Can propagate/vent without fire/flaming combustion
- Ventilation system design
  - Rate of release
  - Gas composition



# Using NFPA 68/69



- 855 Chapter 4.12 has very limited information. Intent is to address ESS that off gases in Abnormal conditions. Such as Lithium Ion.
- Chapter 4.9 is meant to cover off gassing during normal conditions such as Lead Acid.
- Currently no set evaluation critical for performing NFPA 68 or 69 in these code nor in NFPA 855.

# Chapter 4.12 – Current

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4.12* Explosion Control. Where required elsewhere in this standard, explosion prevention or deflagration venting shall be provided in accordance with this section.

4.12.1 * ESS installed within a room, building, or walk-in unit shall be provided with one of the following:
(1) Explosion prevention systems designed, installed, operated, maintained, and tested in accordance with NFPA 69
(2) Deflagration venting installed and maintained in accordance with NFPA 68

4.12.2 Explosion prevention and deflagration venting shall not be required where approved by the AHJ based on largescale fire testing in accordance with 4.1.5 that demonstrates that flammable gas concentrations in the room, building, or walk-in unit cannot exceed 25 percent of the LFL in locations where the gas is likely to accumulate.

# Containers?

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- Provide clarification of Containers and walk in units – TIA submitted – September???
- The approach in the industry is to not meet 855 because the smaller units are not walk in and there for exempt.
- New definition and code requirements to close this loop.

- 3.3.9.2 Energy Storage System Cabinet.
  - An enclosure containing components of the energy storage system that is included in the UL 9540 listing for the system where personnel cannot enter the enclosure other than reaching in to access components for maintenance purposes.

# Chapter 4.12 – Proposed TIA

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4.12.1 * ESS installed within a room, building, ESS cabinet or ESS walk-in unit shall be provided with one of the following:

(1) Explosion prevention systems designed, installed, operated, maintained, and tested in accordance with NFPA 69.

(2) Deflagration venting installed and maintained in accordance with NFPA 68.

Add additional information to cover Cabinets and all enclosures

# Chapter 4.12 – Proposed TIA

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**4.12.1.2** Where approved, ESS cabinets that have been designed to ensure no hazardous pressure waves, debris, shrapnel, or enclosure pieces are ejected, as validated by installation level large scale testing and engineering evaluation complying with 4.1.5 that includes the cabinet, shall be permitted in lieu of providing explosion control complying with NFPA 68 or NFPA 69.

Add information to require Deflagrations studies, there is also information that would tie back to requirements in the HMA chapter

# Chapter 4.12 – Proposed

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A.4.12.1

The requirement recognizes that with some cabinet designs that have low internal volume, the application of NFPA 68 or NFPA 69 may not be practical. It is possible that a quantitative explosion analysis is necessary to show there is no threat to life and safety. As an example, the cabinet design may be installed such that any overpressure due to ignition of gases and vapors released from cells in thermal runaway within the enclosure are released to the exterior of the enclosure. There should be no uncontrolled release of overpressure of the enclosure. All debris, shrapnel, or pieces of the enclosure ejected from the system should be controlled. The UL 9540A unit level and installation level test identified in Section 4.1.5 will provide the test data referenced in this section which is necessary for verification of the adequacy of the engineered deflagration safety of the cabinet.

Due to possible accumulation of flammable gasses during abnormal conditions for Lithium Ion batteries, exhaust ventilation can be a viable mitigation strategy. Gas detection and appropriate interlocks can be used based on appropriate evaluation under a NFPA 69 deflagration hazard study. NFPA 69 allows concentration to exceed 25% LFL but not more than 60% with appropriate gas detection and exhaust interlocks.

# Chapter 4.12 – Proposed

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**4.12.3** ESS enclosures shall be designed so explosive discharge of gases or projectile are not ejected during large scale fire testing complying with Section 4.1.5.

**4.12.4** Where ESS batteries or cabinets are installed in a container outdoors, other than a walk-in unit, the installation shall comply with one of the following:
The container shall be provided with explosion control complying with 4.12.1
Combination of the container and cabinets shall be tested together to show compliance with 4.12.2

# Chapter 4.12 – Proposed

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- A new section addressing Gas Detection requirements for ESS that off gases on abnormal conditions.
- Review and comment during the PC cycle - Please!

# Chapter 4.12 – Proposed Gas Detection

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4.12.4 Where gas detection is used to activate combustible gas concentration reduction system per this section and based on appropriate NFPA 69 deflagration study, enclosures containing ESS shall be protected by an approved continuous gas detection system that complies with the following:
(1) The gas detection system shall be designed to activate the combustible gas concentration reduction system on detection of flammable gases at no more than 10 percent to keep the level of flammable gas in the enclosure below 25 percent of the LFL.
(2) The combustible gas concentration reduction system shall remain on to ensure the flammable gas does not exceed 25 percent of the LFL.
(3) The gas detection system shall be provided with a minimum of 2 hours of standby power.
(4) The gas detection system for Lithium-Ion Batteries shall be provided with a minimum of 24 hours of standby (secondary?) power and 2 hours in alarm or as required by the HMA per chapter 4.1.4
(5) The gas detection system shall annunciate the following at an approved central station, proprietary, or remote station in accordance with NFPA 72, a first responder's station, or at an approved constantly attended location.
a) A trouble signal upon failure of the gas detection system.
b) A low gas alarm signal if flammable gas concentration exceeds10 percent of the LEL
c) A high gas alarm signal if flammable gas concentration exceeds 25 percent of the LEL.
(6) The gas detection system shall initiate a visual high gas signal at each enclosure.

4.12.5 Explosion prevention and deflagration venting shall not be required for lead-acid and nickel-cadmium batteries installed with exhaust ventilation complying with Section 4.9.

# Chapter 4.12 – Proposed

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- The annex has been supplemented to address recommendation for Lithium Ion and the use of NFPA 68/69.
- It also address the problems with trying to evaluate small containers.
- Debris and shrapnel issues are added.

# Deflagration - Recommendations

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**Evaluation options -** More than one scenario should be evaluated during the Deflagration Hazard Study. It should include the 9540A cell and module test as a realistic option for failure. However this only provides one data point and this does not provide any margin of safety for potential other failure modes such an arc flash on a module.

Recommended evaluation modes

1. Best Case Scenario – one cell failure ( may be the same as UL 9540A if the cells do not show propagation)
2. UL9540A failure level, one or more cells, Module, or unit based on the test results.
3. Limited propagation Failure. This adds a safety margin to the UL9540A. Example if one cell failed with no propagation, then evaluate a 3 cell failure, one on either side. If a module failed but did not propagate, then evaluate 3 module failure the one above and below
4. 25% LFL failure - Determine how may cells does it take to reach 25% LFL in the enclosure.
5. Partial Deflagration - how many cells can fail with a resulting partial deflagration that does not produce a pressure value that will cause the enclosure to fail.
6. Worst Total Failure – Assumes all cell in the ESS fail. No evaluation required

Based on these levels of evaluation it can then be incorporated in the HMA with a determination of acceptable Risk.

# Deflagration - Recommendations

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**Alternate Evaluation options -** Recommended evaluation modes

1. 1 Cell
2. ½ Module
3. 1 Module
4. ½ Rack
5. 1 Rack
6. Installation Failure
7. Partial Volume Deflagration
8. Full volume  Deflagration

Based on these levels of evaluation it can then be incorporated in the HMA with a determination of acceptable Risk.

# Summary – Unintended Consequences

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- Events are rare but can be significate.
- Fire or Explosion?
- There are process to help define pathways!
- But requires assumptions on assumptions on assumption.
- Make sure you are covered.
- Any one technology is probably not going to be adequate, but each layer helps mitigate the failure pathways.
- We are still learning!

# Failure to Plan

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# Questions & Discussion

Thanks For Taking The Time To See This!!

We Hope This Will Help.

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