Introduction

• Failures will happen, no matter what is claimed
• Appropriate Fire Protection and Life Safety Measures need to be implemented to make Risk Acceptable
• Early detection, rapid response
• STRATEGIC OPTIONS

Key Objectives
• Occupant safety
• Firefighter safety
• Structural protection
Configuration
Challenges

Battery Production
• Battery quality (six sigma quality line yields 99.9997% within spec → 3.4 batteries per million will have internal defects that aren’t caught)
• Battery production at 6 billion cells/yr and increasing → 18,000 defective cells/yr*

Module Configuration
• Cells in close proximity, failure in a single cell can rapidly lead to failure in others

Battery Chemistry
• Cells release significant energy during failure, H₂ and other flammables produced/released
• Combustion will occur even in O₂ limited environments (though spread is inhibited)
• Gasses/material will ignite upon ejection from cell

*based on actual production numbers and projected defects
Challenges

BMS
• Can shut off the battery to load or charge but will not stop thermal degradation/runaway process in a cell

Rack Configuration/Suppression Agent
• Effectiveness of agents not fully understood w/ regards to suppression or limitation of spread. Oxygen reduction vs. cooling, relative impacts
• Delivery of agent to target area challenged by rack configuration (physical barriers)

Venting, POC’s, and Potential Runoff
• CO, CO$_2$, H$_2$, O$_2$ (ignition, delayed ignition, no ignition)

Re-flash/Prolonged Events
• Battery events known to reignite hours/days after initial event
Additional Preliminary Questions

• How are BESS different from other hazards that may be encountered in a similar location, in particular by first responders?
• Increased risk from recycled/repurposed EV battery systems? Will failure rate/severity increase or decrease with age/use?
• Impact of rack required ventilation on detection (i.e. hot/cold aisles)
Battery Hazard

- Initial heating prior to thermal runaway should trigger safety vent, slow release of materials. Rate increases as thermal runaway nears.
- Testing has shown during battery failure that*:
  - Nominally 25% of energy is released into the body of the cell (~33 kJ)
  - Nominally 75% of energy is ejected from the cell (~113 kJ)
- On average, failure propagation speed was 7.5 times faster in air than in nitrogen.
- Propagation 8.5 times slower at 50% SOC than at 100% SOC.
- 3 times slower with a 5 mm gap between cells than without it.
- All tested cell arrays ejected minor mass yields of O\textsubscript{2} and H\textsubscript{2}, as well as comparatively large mass yields of total unburned hydrocarbons, CO and CO\textsubscript{2}.

*Specific battery chemistry and form
Safety Venting & Thermal Runaway vs. SOC

BESS Mitigation Methods

Variables affecting mitigation approach

• Technology Specific Location
• Spacing of racks
• Location of racks in structure
• Segregation/Compartmentalization
• MAQ in a volume
• Battery Management System
• Storage Monitoring System
Approach

Minimize probability of catastrophic event through BMS, early detection via system monitoring and initial response, reduce impact if failure occurs, manage outcome

- Prevention
- Monitoring
- Detection
- Activation
- Mitigation/Management
Approach: Prevention/Monitoring/Detection

- BMS to provide data on current, voltage, and Temp to ensure operations w/in spec
  - Isolate cell/module in the event of abnormal readings
- Module level gas sensors
  - Specialized sensors in each rack to provide early notification of cell off-gassing and venting of electrolyte
  - Isolate and shutdown battery/module
- Continuous monitoring of cell temperatures to determine if thermal runaway/propagation is occurring
Approach: Suppression & Activation

NFPA 770 Hybrid System and NFPA 13 Sprinkler System

• Hybrid is primary system with sprinklers as “failsafe”
  – Hybrid system integrates with gas sensing/BMS system
  – Activation of hybrid system based on gas/electrolyte sensor
  – Shut down of ventilation system to maintain room environment

• Wet Sprinkler system designed to 0.30 gpm/ft² density per FM and NFPA 855
  – Intended as backup system in case fire not suppressed by hybrid system
  – Intended to provide cooling to adjacent racks, contents, and prevent spread outside of room
Approach: System Activation

• NFPA 770 Hybrid system consisting of N\textsubscript{2} and water mist
  – N\textsubscript{2} provides a reduced O\textsubscript{2} environment which will reduce propagation rates as demonstrated by testing
  – N\textsubscript{2} will inhibit ignition and flame spread to other combustibles/cells
  – Target concentration of 14% O\textsubscript{2} in room after discharge
  – Water delivery of nominally 4 gpm for 5 minutes via 4 nozzles
  – Water droplets dv\textsubscript{50} of 10µm, suspended in air, penetration into cabinets possible
  – Hold conditions in room and continue monitoring of cells

Heat absorption capacity if 25% of water is converted to steam: 11.4 MJ, ample water available to absorb energy and cool
Monitoring & Suppression Conceptual Layout
# Hybrid System Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen Requirement $W_{N_2 \text{req}}$</td>
<td>2693.5 scf</td>
</tr>
<tr>
<td>Number of Cylinders $n_{\text{cylinder}}$</td>
<td>5 cylinders</td>
</tr>
<tr>
<td>Cylinder Size</td>
<td>80L</td>
</tr>
<tr>
<td>Required Nitrogen Flow $Q_{N_2 \text{min}}$</td>
<td>538.7 scfm</td>
</tr>
<tr>
<td>Number of Emitters $n_{\text{emitters}}$</td>
<td>4 emitters</td>
</tr>
<tr>
<td>Emitter Size</td>
<td>1/2&quot; Dome Foil</td>
</tr>
<tr>
<td>Water Flow cartridge</td>
<td>1.06 gpm</td>
</tr>
<tr>
<td>Estimated Actual Discharge Time $t_{\text{actual}}$</td>
<td>5.1 minutes</td>
</tr>
<tr>
<td>Estimated Final O2 level (nominal temperature) $O_2%_{\text{actual_nomT}}$</td>
<td>13.9 %</td>
</tr>
</tbody>
</table>
Venting, POC’s, & Runoff

- Venting of space will provide cooling for racks and maintain <LEL concentration.
- In the event of abnormal conditions the cell/module will be isolated.
- If conditions are exacerbated ventilation will cease upon activation of hybrid system:
  - Concentration will be well below LEL.
  - Hybrid system requires “hold” time to not flush out the gas/mist.
- If the event continues ceiling sprinkler system will activate and cool adjacent racks.
- Blast vent on wall sized per NFPA 68.
- Build concrete curbing sized to contain sprinkler water plus hose stream allowance, nominally 20” tall.
- Hybrid is clean/non-toxic so runoff solely electrolyte, POC’s, etc. disposal of contaminated water.
Manual Response

• The POC’s aren’t significantly more hazardous than other POC’s, however unburned gasses pose explosion hazard
• Fire department may need to provide manual suppression of individual module/rack and monitor room conditions for LEL
• Stranded energy/leakage still a concern even after isolation of the system, safe standoff distance and appropriate agents should be employed by fire fighters (i.e. training)
Conclusions

• Numerous challenges with BESS
  – High energy density (why they are popular)
  – Subject to thermal runaway and rapid spread
  – Production of $\text{H}_2$ and $\text{O}_2$ make suppression challenging

• Detection
  – High airflow environments can make “typical” detection a challenge
  – In-rack or hot-aisle sampling recommended for earliest detection

• Method of Suppression
  – Heat needs to be removed
  – Simply lowering oxygen concentration (i.e. inert or other gaseous agents) not sufficient to prevent spread, though will slow it
  – Water/cooling agent needs to be able to reach the hot surface, rack configuration is key as is method of delivery and agent characteristics
Questions?
Additional Information

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