BESS Part 6:
Overview of Li-ion BESS Failures and Risk Management Considerations

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This is the final article in a six-part series on Battery Energy Storage Systems (BESS), available for download here, which have examined:

1. Battery Failure Analysis and Characterization of Failure Types
2. BESS Frequency of Failure Research
3. Review of Fire Mitigation Methods for Li-ion BESS
4. Consequences of BESS Catastrophic Failure
5. Evaluation and Design of Structures to Contain Lithium-ion Battery Hazards

These articles explain the background of Lithium-ion battery systems, key issues concerning the types of failure, and some guidance on how to identify the cause(s) of the failures. Failure can occur for a number of external reasons including physical damage and exposure to external heat, which can lead to thermal runaway. Thermal runaway can also be triggered by numerous functional causes including overcharging, overloading, ageing, or design issues including internal component failures or short circuits.

We have also learned that the cause, likelihood and consequences of failure are dependent upon the many different designs and configurations of Lithium-ion batteries and associated systems. Forensic examination of a failed battery can determine cause and origin, although this can be difficult when there has been damage due to a major fire or explosion. However, other evidence, such as electronic data and video footage, can help piece together likely cause(s).

Lithium-ion battery technology is moving fast. At present, there is little data available on the reliability of BESS and as designs evolve to achieve higher charging rates, higher energy density, longer life, lower cost and improved reliability, any current data is likely to quickly become out of date. Nevertheless, data is being collected by various organizations and BakerRisk is working on developing statistical models to help our understanding of the likelihood of BESS failures.

Mitigation of fires involving Lithium-ion BESS was discussed in our third paper, which explained how the thermal runaway leads to the release of hot, flammable/toxic components. The high energy density of a typical BESS and the potential propagation/escalation of a runaway reaction incident presents a significant challenge in terms of specifying a suitable fire protection system. A water-based sprinkler system may not be effective in many situations and could make matters worse by causing electrical short-circuits. Water mist systems can be used, some of which use additives such as surfactants or gelling agents, but have limitations that need to be considered. While gaseous clean-agent systems can help extinguish or reduce the extent of the fire, they do not have sufficient cooling properties to prevent the escalation of a thermal runaway from a single cell or module/ rack, plus have the potential disadvantage of adding more toxic materials to the fire. The best strategy is to consider a layered approach that combines design features, early detection, and suppression methods.

The consequences of a thermal runaway can range from minor, localized damage or may escalate to a major event where an entire rack of batteries, or a whole BESS unit, go into thermal runaway with associated release of toxic and flammable/explosive vapors. If ignited, the released vapors can exhibit jet fire characteristics and in some cases, inner materials are ejected forcefully and ignite when they leave the batteries. Where there is a delayed ignition of flammable vapors, there could be a flash fire in an open area or possibly a vapor cloud explosion in an area of congestion similar to the incident where two firefighters were killed following an explosion while fighting a BESS fire in Beijing in April 2021.[1]

Thermal and blast loads that cause injuries and building damage can be evaluated on the basis of the rate and constituents of the gases released. The effect on the surrounding structures can be evaluated using a range of tools and techniques. Mitigation measures against the effect of blast loads include the provision of explosion relief panels.

Large Lithium-ion based BESS should have multiple layers of protection to minimize the likelihood of a thermal runaway occurring and cascading from a single cell or module as well as mitigating the resulting consequences associated with the potential fire, toxic release, or explosion. Mitigation measures start with the design and there is currently a lot of ongoing work to improve the reliability of the individual components. A well-designed Battery Management System (BMS) should monitor down to the module level and ideally isolate individual cells or modules that are displaying unusual behaviour well in advance of the onset of a thermal runaway.

Lithium-ion cells start to release gases in the early stages of a potential runaway event and gas detection can also be used as a signal to the BMS. There are several actions that can be taken to minimize the potential for runaway and escalation including:

- Electrically isolate adjoining modules, the rack, or an entire BESS unit.
- Activate fixed firefighting systems within the module or rack
- Pressure relief panels, either in buildings or the walls/roof of containerized BESS units can prevent damage to structures in the event of an explosion.
- Emergency Response Plans (ERPs) and procedures should ensure that any responding agencies are aware of the unusual properties of a Lithium-ion fire and do not allow air to mix with gaseous emissions (by not opening the doors of a containerized BESS unit[2]).

A simplified Bow-Tie diagram for Lithium-ion battery thermal runaway with various protection layer (barrier) concepts is shown in Figure 1. Many additional barriers could be added to both sides of the diagram.

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1 Two firefighters killed after Beijing battery blaze – pv magazine International (pv-magazine.com)

2 New reports look at 2019 Arizona battery explosion – pv magazine International (pv-magazine.com)

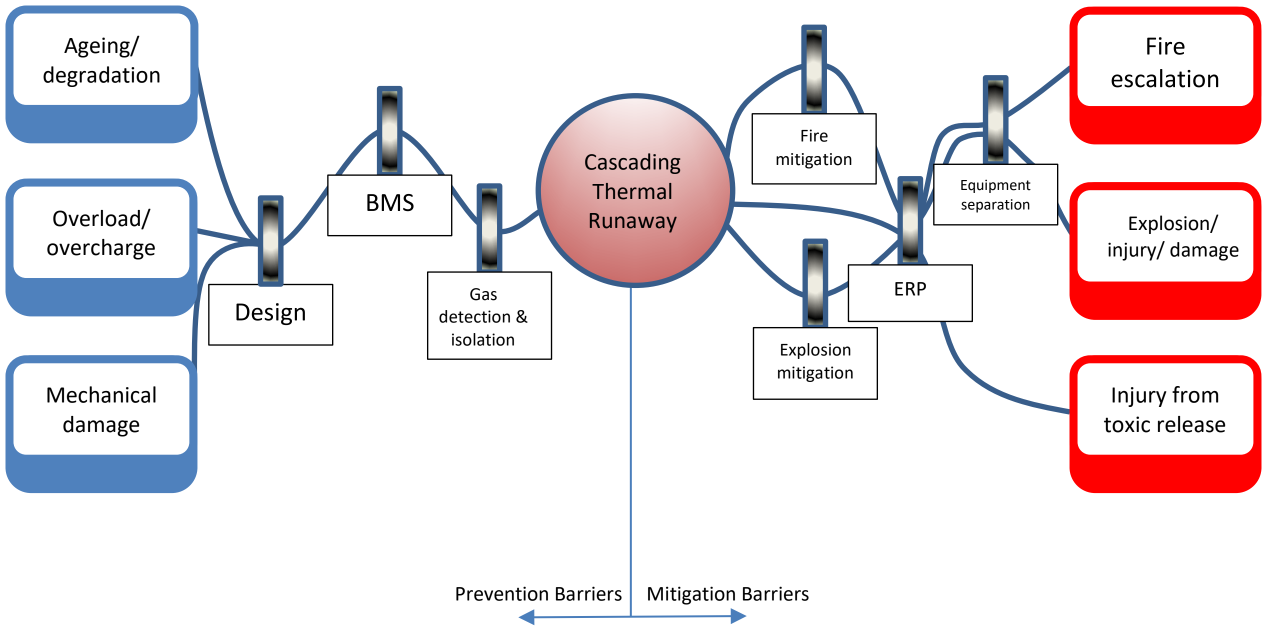

Figure 1: Simplified Bow Tie diagram for Thermal Runaway of Lithium-Ion Batteries

It has been demonstrated through multiple incidents that these protection layers (barriers) do fail occasionally as discussed earlier in this series. Incidents have resulted in injuries from explosions in containerised BESS that have undergone runaway and subsequently been exposed to air when the container doors were opened. Currently it appears that the best course of action is to design the BESS container system for the worst-case basis that a runaway will occur and assume that all of the cells/ modules/racks within the container will be involved.

The objective should be to prevent injury to personnel, escalation of the event to adjacent containers, and to provide suitable means for emergency response teams (ERT)/ fire brigade personnel to provide cooling for adjacent containers and other equipment.

BESS containers should be designed with explosion relief panels in the walls/roof that are sized to release at pressures well below those that might cause any structural damage to the container.

To prevent escalation, consider proper spacing, and, when space is constrained, consider using thermally resistive barriers to allow time for the ERT/fire brigade to set up cooling. The recommended container separation distances are likely to be reviewed/reconsidered as there is continued learning from BESS incidents; some incidents were able to contain damage to one container, but others have not. The layout of the BESS containers should provide ease of access for ERTs /fire brigades between containers and there should be an adequate supply of water available. ERTs also need to be aware of the hazard of ventilating a BESS container that is undergoing thermal runaway.

From the insurance and risk tolerance viewpoint, the total loss of an entire BESS container and its contents should be assumed to be a credible event provided that sufficient separation distance exists between BESS containers. Even if fire suppression/firefighting has prevented 100% involvement of the equipment within a container, it is unlikely that there would be any value in the salvage. If separation distances are inadequate, there is the potential for further damage and the involvement of any adjacent BESS units.

Environmental damage and clean-up costs could be significant where firewater and lithium-ion cell electrolytes contaminate the ground/water courses and secondary containment should be considered.

Throughout this series, it has been our intention to educate and inform the reader about the hazards and risks of Lithium-ion battery energy storage schemes based on current knowledge. Other battery types are also being developed, such as Lithium-air and flow batteries, and, as experience with BESS increases, it is important to keep up to date with this rapidly evolving technology. BakerRisk continues to monitor developments and will provide further updates as more information and knowledge becomes available.