Utility Scale Battery Energy Storage Safety: Trends and Standards

Clean Energy Associates

July 27, 2020

AGENDA

INTRODUCTION

PRESENTATION OVERVIEW

PRESENTERS

INTRODUCTION – PRESENTATION OVERVIEW

As the global stationary storage market continues to adopt lithium ion technology at an exponential rate, it’s important to every stakeholder to understand how safety is being considered in each level of the system.

Today we will provide some background on lithium ion battery technology, review some major trends in safety and discuss the major standards driving energy storage safety.

Clean Energy Associates is a global technical advisory company that provides comprehensive engineering solutions for the solar and energy storage industries.

INTRODUCTION - PRESENTERS

Chris Wright, Director, Energy Storage Services

- 12+ years of experience in renewable energy; including Project Development, Operations, Engineering, Procurement and Construction
- Performed technical due diligence on numerous emerging energy storage and battery technologies while at NextEra Energy
- Led various engineering, procurement and construction efforts for over 650MW's of solar, wind and energy storage projects in six countries
- Master's Degree in Engineering from the University of Toledo, B.S. from the University of West Florida

Aaroh Kharaya, Product Manger, Energy Storage Services

- 9+ years of experience in designing Electrical Power Systems with over 6 years in Renewable Energy
- Subject Matter Expert in Li-ion Energy Storage systems with >300MWh of Energy Storage projects.
- Experienced in AC coupled, DC coupled storage system, Microgrids and DER
- Proposed and developed Renewable Energy projects in NY, MA, CA, NC, MI, LATAM and India
- Master's Degree in Green Technologies from University of Southern California and B.S. in Energy Engineering from the Maulana Azad National Institute of Technology

SAFETY CONCERNS IN BESS

- NOTABLE EVENTS
  - SOUTH KOREA
  - USA
  - REST OF THE WORLD
- INHERENT RISKS
  - TECHNOLOGY OVERVIEW
  - ANATOMY OF LI-ION BESS FIRE

NOTABLE EVENTS – SOUTH KOREA

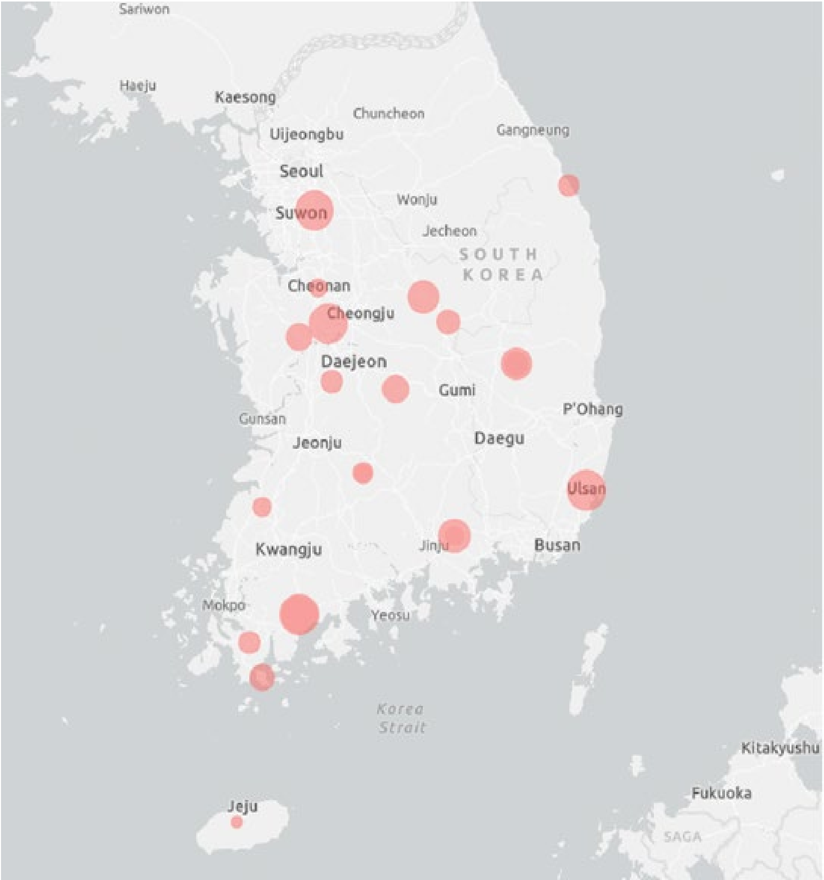
Beginning with a battery energy storage system fire at a wind farm in Gochan County, Jeollabuk-do in August 2017, there have been more than 25 Lithium Ion BESS project fires reported within South Korea.

On December 12, 2018, the South Korea Ministry of Technology, Industry and Energy (MOTIE) commissioned the "Joint ESS Fire Accident Investigation Committee" with the goal of objectively evaluating the causes of these fires and preventing future occurrences.

Initially, most of the installations which caught fire in South Korea were completely burnt and the investigation committee found it difficult to identify the root cause(s) of the fires.

As part of the ongoing investigation, the committee analyzed relevant information from available data, company interviews, field visits and in-depth discussions with experts. After the investigation was completed, the committee identified 4 probable root causes for the fires:

1. Lack of battery protection against electric shocks
2. Insufficient oversight in the battery's environment
3. Inattention to installation details
4. Missing BESS integration controls and protection systems



Project Locations of the First 23 Fires

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NOTABLE EVENTS - USA

McMicken Energy Storage Project

Background: Around 5 p.m. on April 19, 2019, there were reports of smoke from the building housing the energy storage system at APS's McMicken site in Surprise, Ariz. Hazardous Material units and first responders arrived on scene to secure the area. Approximately three hours after the reports of smoke and shortly after the door was opened, the site experienced a catastrophic failure. Injured first responders were transported to area hospitals. An investigation led by APS, with first responder representatives, the system integrator, manufacturers and third-party engineering and safety experts, is underway to determine the cause of the incident.

Investigation Update (April 27, 2020):
The battery modules believed to be where the event originated were thoroughly examined by a collaborative team of experts who have derived several key findings about the incident.
As a result of evidence-gathering and modeling efforts, the APS investigation team met and arrived at the following: A single rack of modules was compromised by the initiating thermal event; the fire did not spread to surrounding racks. After the initiating event, the fire suppression agent was discharged. The compromised modules emitted a mixture of explosive gases, which built up in the container. The battery modules did not themselves explode; the gas mixture reached certain concentrations, came in contact with an unidentified ignition source and subsequently exploded.

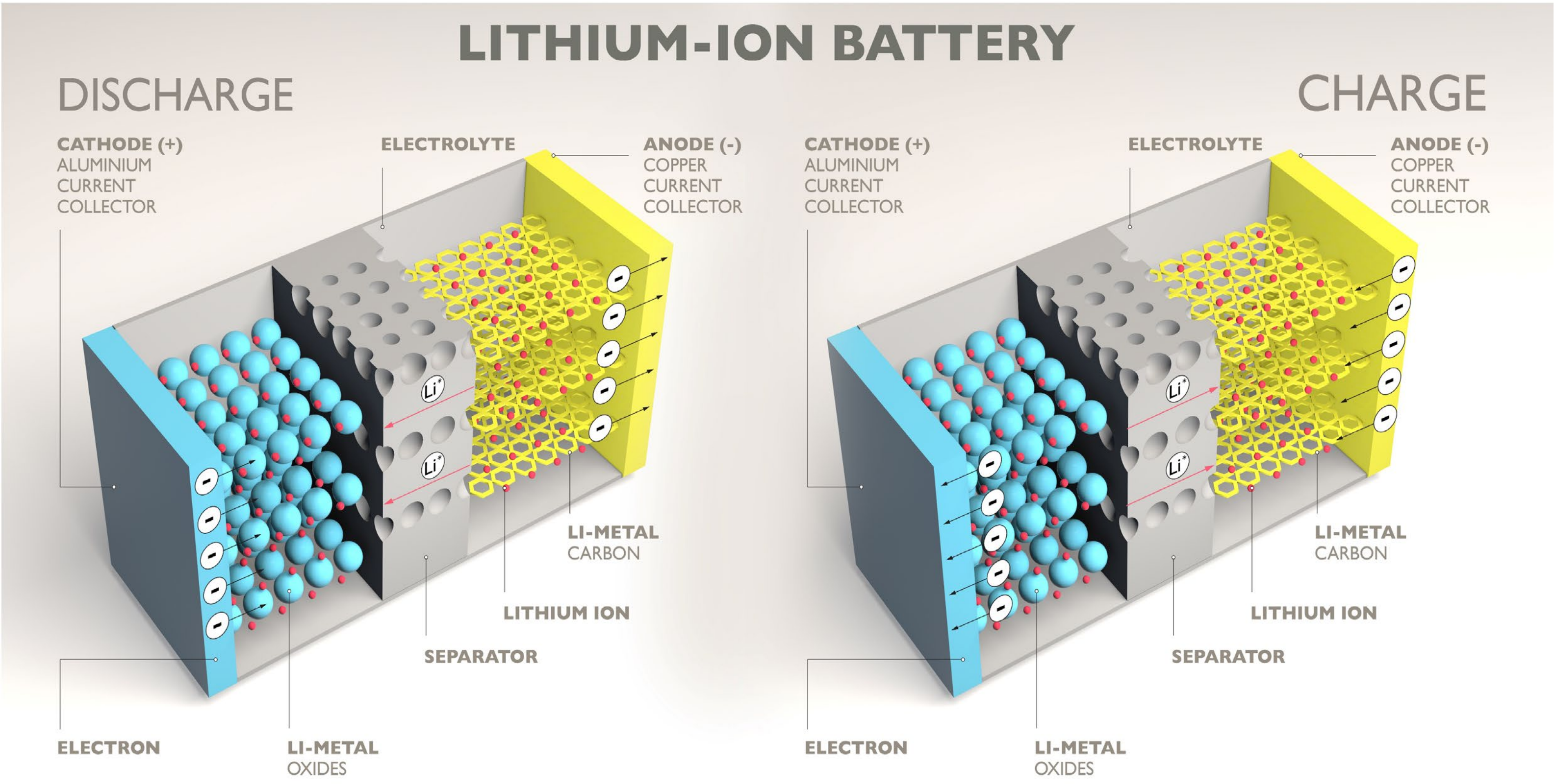
Ref: APS McMicken Battery Investigation website

NOTABLE EVENTS - REST OF THE WORLD

- In September 2011, a sodium sulfur (NaS) battery manufactured by NGK for the Tokyo Electric Power Company caught fire at Mitsubishi Materials' Tsukuba Plant. This battery technology was viewed as one of the most bankable energy storage solutions with installations at 174 locations in 6 countries. After the incident, NGK stopped production of the batteries and issued a notice to all customers to only use the batteries for limited applications. In August 2012 NGK published the results of their internal investigation which found short circuiting between battery cells due to the lack of overcurrent protection to be the underlying cause of the fires.
- In July 2013, a bank of batteries used for arbitrage at the Landing Mall in Port Angeles, Washington, caught fire due to an electrical fault. The fire reignited a few days later and was extinguished by local authorities.
- In November 2017, a fire started at Engie Electrabel's storage Park in Drogenbos, Belgium. The results of this investigation were not available as of this presentation.
- In December 2018, residential homes in Brisbane and in the Gold Coast of Australia experienced battery system fires which took significant efforts by local firefighting teams to extinguish. The results of this investigation continues to remain unclear.

TECHNOLOGY – LITHIUM ION BATTERY OVERVIEW

- Lithium Ion Batteries operate by transporting Li+ ions to the anode structure during charging and then by shuttling the same ions across a porous separator via the electrolyte to the cathode structure on discharge.
- The need to maintain charge balance at each electrode drives a current through an external circuit, performing work.
- As with many battery chemistries, Lithium-Ion requires electrically and ionically conductive anodes and cathodes, and electrically insulative but ionically conductive electrolytes and separators.
- There are three main lithium ion battery chemistries being used for grid storage; LFP, NMC and NCA.



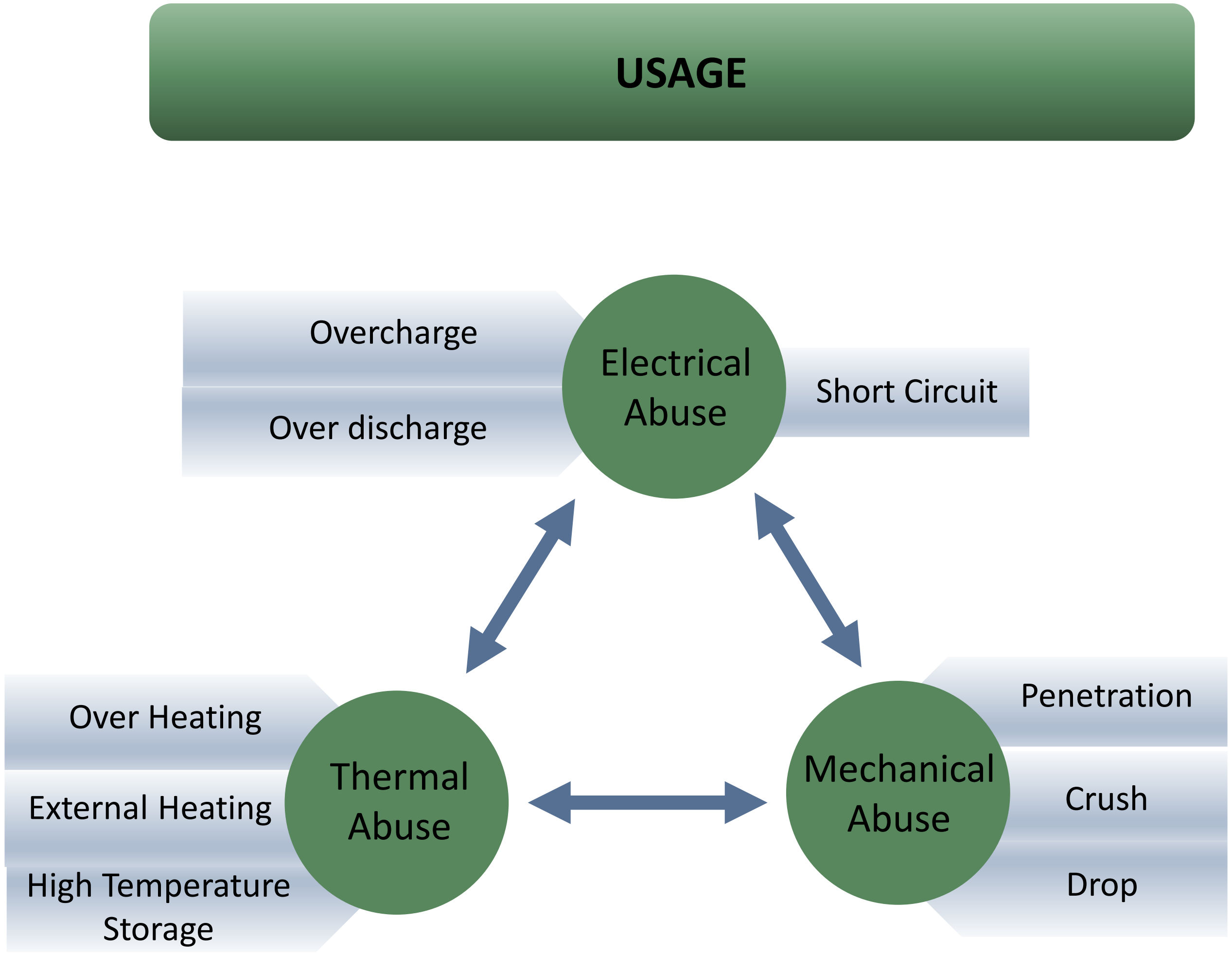
Lithium Ion Batteries are named for their active materials which are either written out or shortened by their chemical symbols. These series of letters and numbers are often abbreviated to make them easier to write and understand. As an example, Lithium Cobalt Oxide has the chemical symbols $LiCoO_2$ and the abbreviation LCO. When cobalt is the main active material, the term Lithium-Cobalt will often be used. Lithium-Ion battery cells typically consist of a graphite anode, metal-oxide cathode and a Lithium salt electrolyte gel.

INHERANT RISKS – TECHNOLOGY

Proper monitoring, testing and control can mitigate potential hazards; however lithium ion batteries can fail when exposes to “abuse factors”. The primary concern is an energetic failure, resulting in “thermal runaway” of the cell and subsequent system.

Thermal runaway is when an energetic failure causes an exothermic decomposition of the materials and creates more heat than the cell can dissipate

There are three types of abuse factors: **Electrical, Thermal and Mechanical**



Electrical Abuse Factors include:

- Short circuit
- Overcharge
- Over discharge

Thermal Abuse Factors include:

- Cell overheating from adjacent heat sources
- Inadequate cooling

Mechanical Abuse Factors include:

- Puncture of cell
- Compressive stresses
- Electrolyte expansion beyond mechanical strength of packaging

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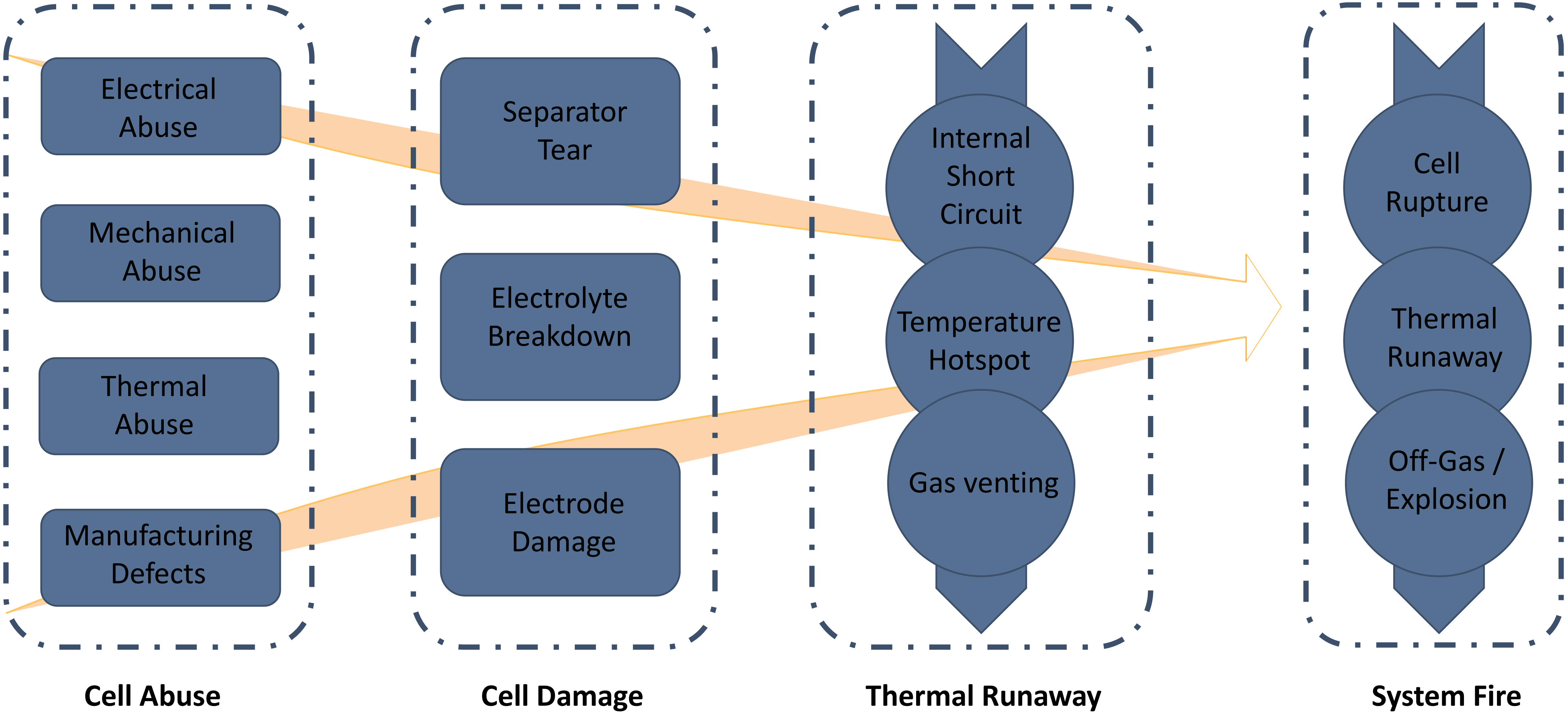
INHERANT RISKS – OVERVIEW OF SOME COMMON FAILURES

FAILURES	CAUSE	RISKS	PREVENTIVE MEASURES
Lithium Dendrite Growth	**Overcharging** The extra Li-ion transferred to the already saturated anode and deposited in form of lithium dendrite	Lithium dendrites consumes Li-ion and results in accelerated capacity degradation. Lithium dendrite penetrates the separator and can result in short circuit and thermal runaway events	Prevent overcharging event from BMS control logic
	Exposed Copper Creating local low potential attracting Li-ion to form dendrite		Improve coating strength and backing process
	High Charging Rate Accumulating Li-ion on the anode surface instead of saturating the inner anode, due to the current rush		Prevent abnormally high C-rate from BMS control logic
	Coating Density Anode is not well soaked with the electrolyte resulting from overly high coating density		Control anode coating density
	Uneven Coating Facilitating lithium dendrite formation		Control anode coating uniformity
Gas Generation	**Overcharging and Overheating** Leading to SEI and electrolyte decomposition, which releases gases, including oxygen	Battery fire/ explosion	Improve thermal and charging/discharging management Implement safety ventilation
Loss of Mechanical Integrity from the separator	**Overcharging and Overheating** Leading to SEI and electrolyte decomposition, which releases gases, including oxygen	Short circuit and thermal runaway events	Improve thermal and charging/discharging management

INHERANT RISKS – PATH FROM ABUSE TO THERMAL RUNAWAY



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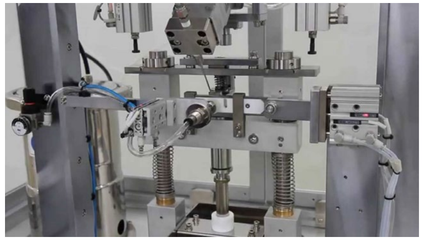
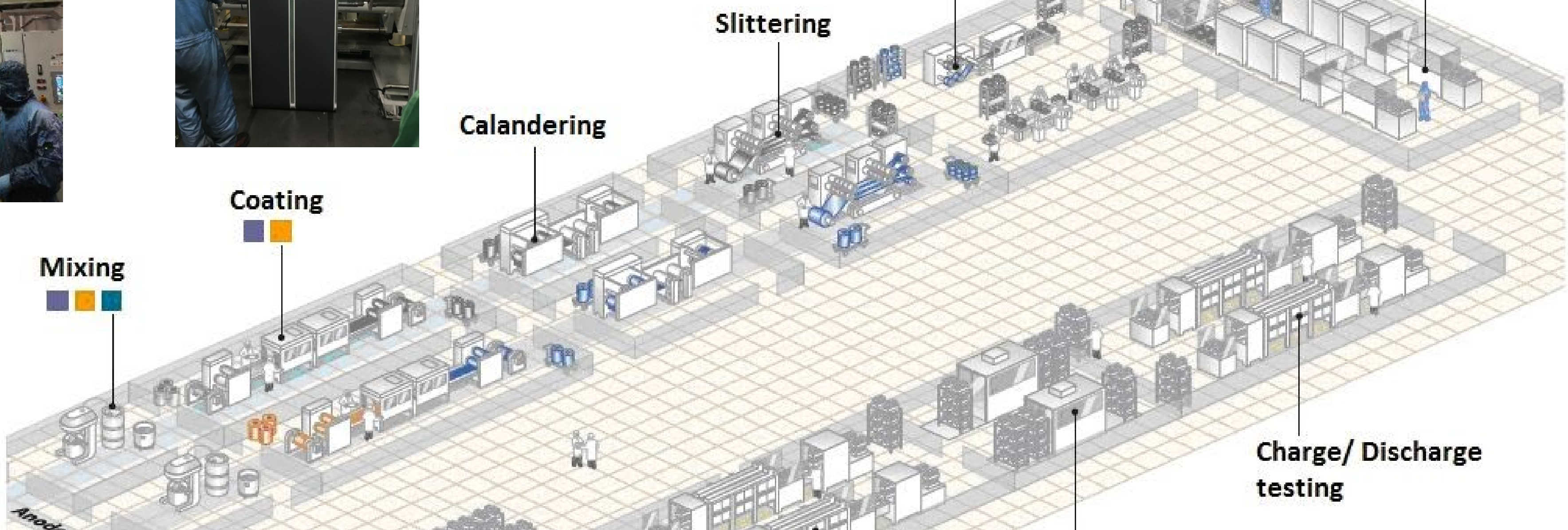
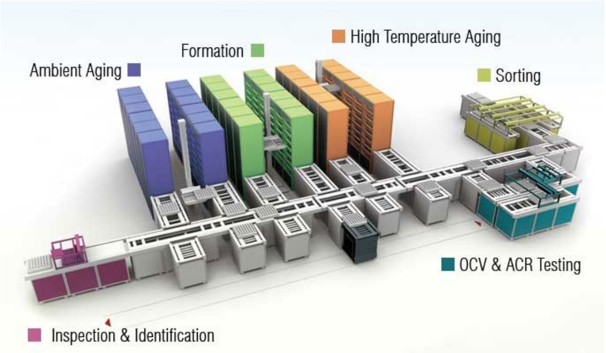
INHERANT RISKS – MANUFACTURING







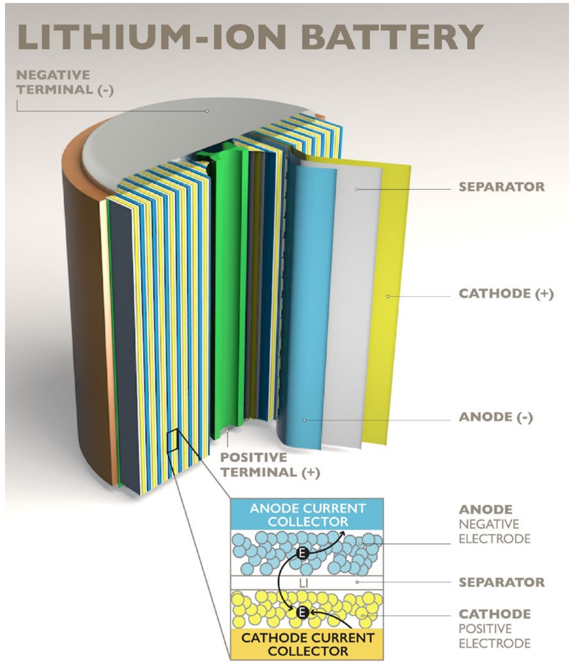
SAFETY TRENDS

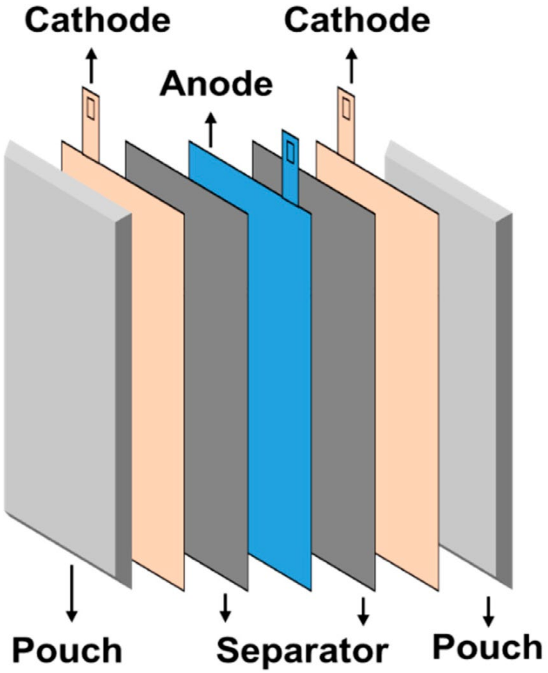
DESIGN

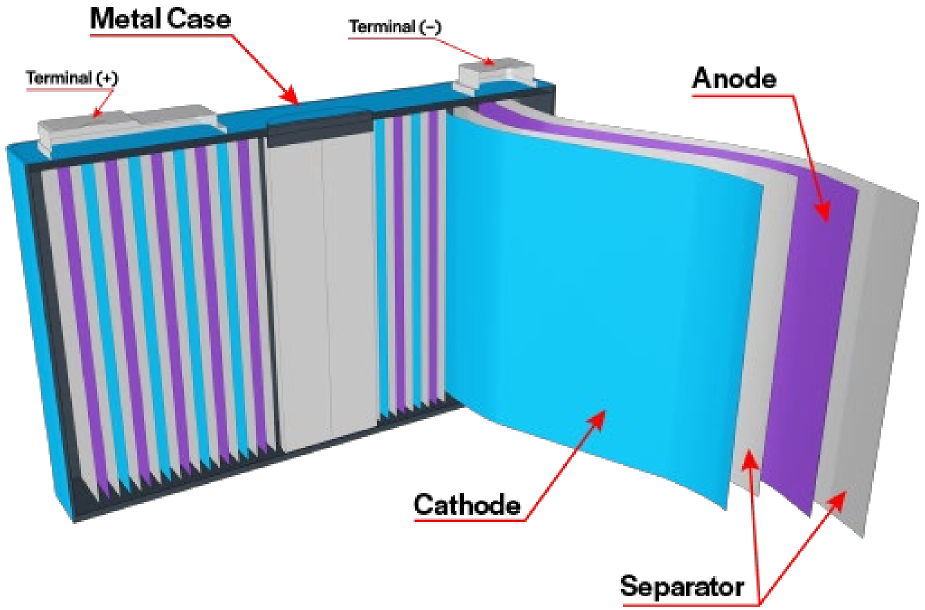
- BATTERY CELLS
- MODULES
- RACKS
- CONTAINERIZED SYSTEM

DESIGN – BATTERY CELLS

There are three main form factors of lithium ion battery cells; **cylindrical, pouch and prismatic**







A basic cell consists of two electrodes within an electrolyte. The electrodes are electrically separated from each other with the use of a separator. The entire assembly of the electrodes, separator and electrolyte – along with conductive current collectors – is confined within a container. The electrochemical reactions are set in motion when the terminals of the cell are connected to an external load. Aluminum (Al) and Copper (Cu) serve as the current collectors at the electrodes

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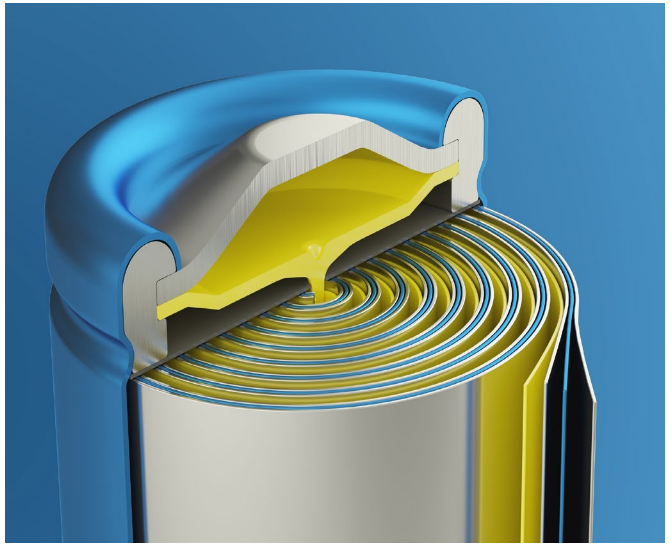
DESIGN – CELL SAFETY MECHANISMS

Burst Disk

Initiated by high inner pressure, will break open when internal pressure exceeds a threshold and releases gas.

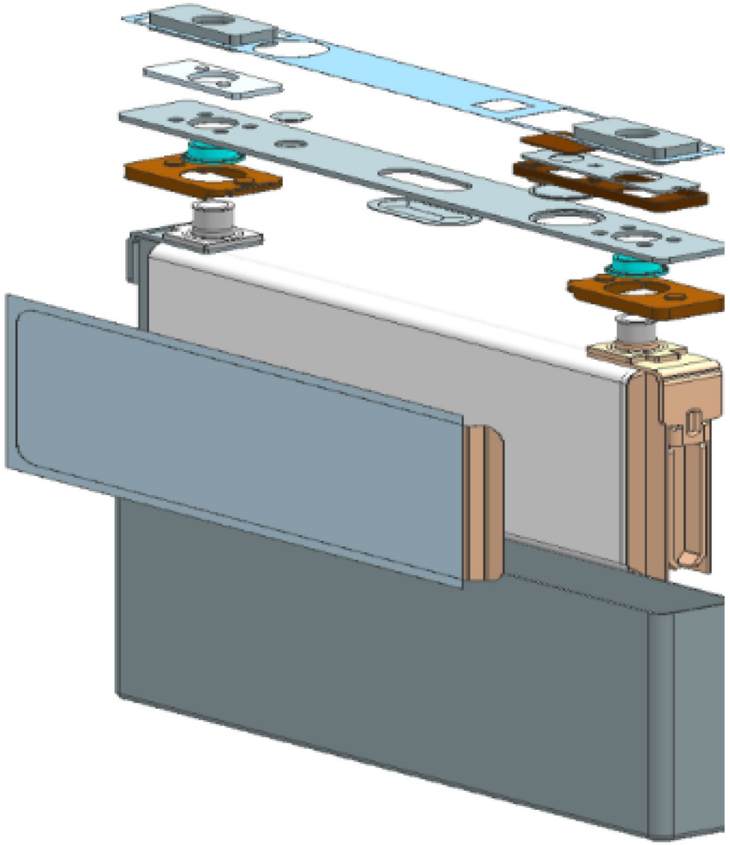


Nail Safety Device

Metal sheet is used as the nail safety device to protect inner cell components from nail penetration. During a short circuit event, NSD sheet can dilute the current flow to avoid overheating from the concentrated current flow.

Overcharge Safety Device

OSD membrane breaks the circuit open once the cell's inner pressure threshold is reached, by creating an external short circuit event to trigger the to stop battery cell from further charging/discharging operations.



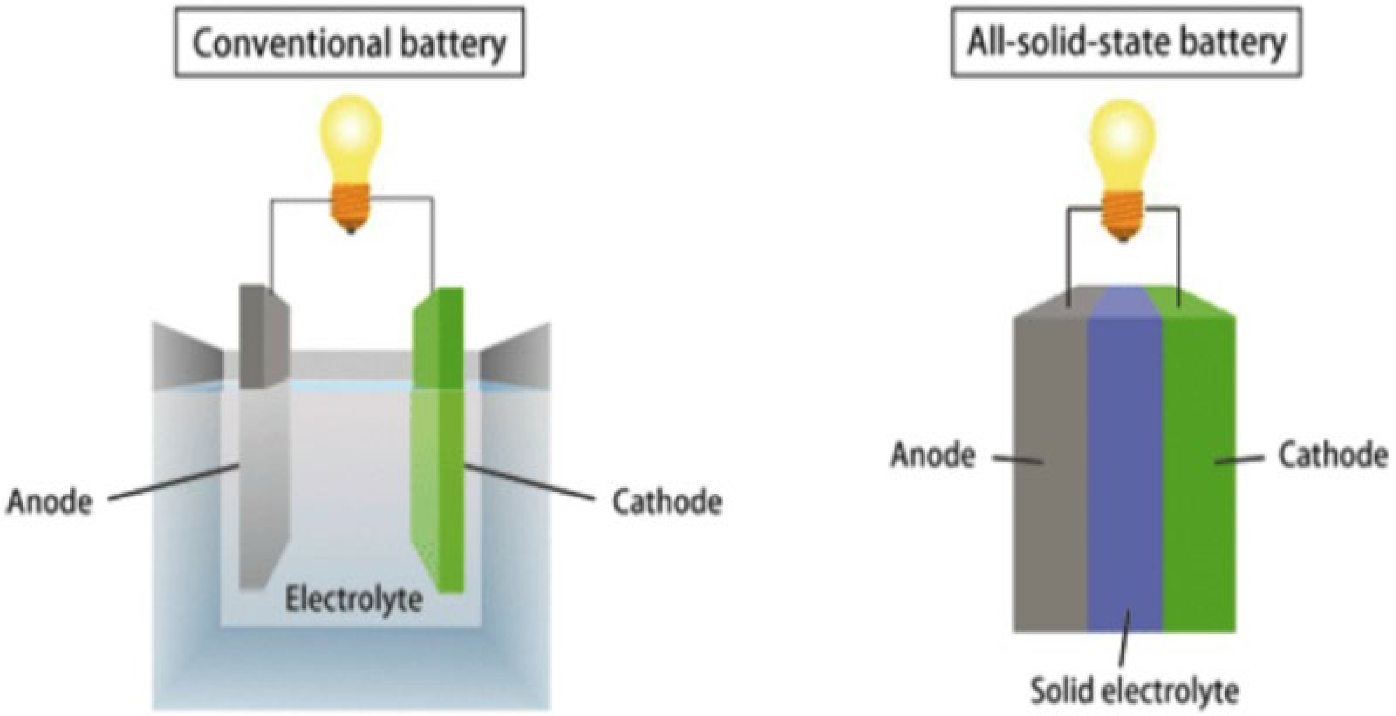
Thermal Fusing

Internal fuse opens when temperature or current exceeds threshold. Removes the cell from further charging/discharging operations.

DESIGN - ELECTROLYTES

Reducing the risk of flammable organic solvents from traditional electrolytes is key to increased safety. Many researchers believe that liquid electrolytes have inherent safety disadvantages that can not be sufficiently resolved. Additionally, lithium dendrites are still a possibility using liquid electrolyte. So future research has focused on solid-phase (i.e. 'solid state') electrolytes.

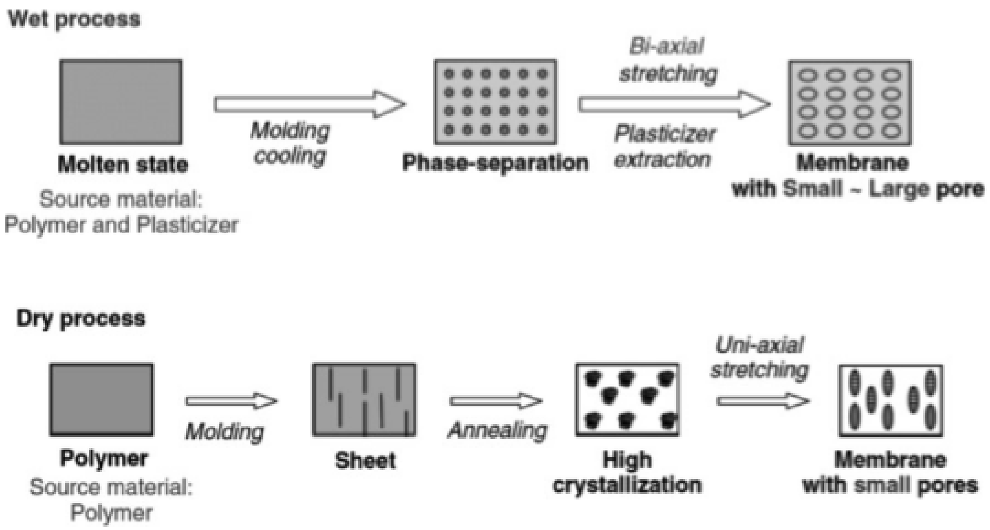
The solid-state and polymer electrolyte technologies represent the major advancement in next-generation lithium ion batteries. Batteries constructed using these electrolytes use either a gelled electrolyte or a solid polymer electrolyte. Organic solvents are eliminated or greatly reduced in polymer electrolytes, greatly reducing or eliminating this hazard and increasing the safety of the cell.
High cost and low ionic conductivity of polymer electrolytes remain substantial barriers to commercialization.
Semi-solid electrolytes are also in development, these may offer increased performance when compared to the solid-state version while also increasing safety



DESIGN - SEPARATORS

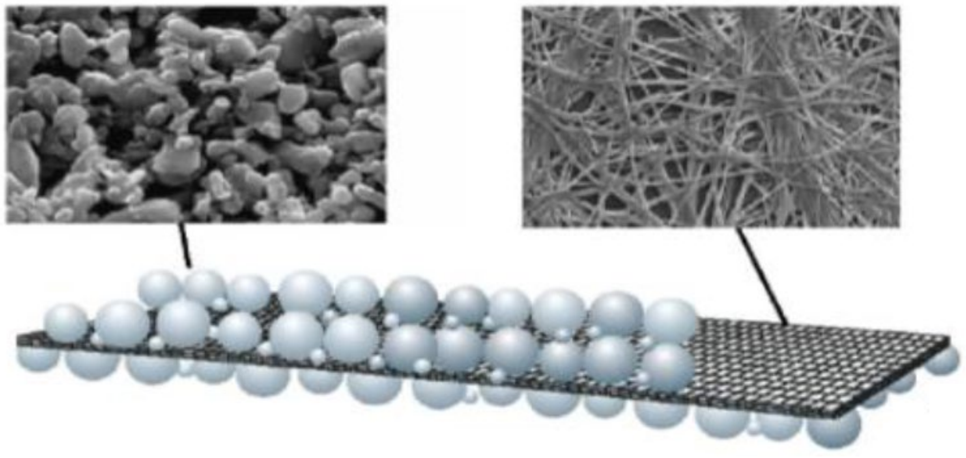
Wet-laid separator

Currently two main technology exists in separator production: dry-laid separator and wet-laid separator. The wet-laid PE (Polyethylene) separators are becoming mainstream separator technology due to its improved material uniformity, strength, and electrolyte permeability, which are important to enhance battery's cycle life and capacity.



Ceramic coating

On the surface of PP or PE separator, high heat resistance material such as Al2O3, SiO2, and Mg(OH)2 are applied to improve separator's heat resistance and mechanical strength. The ceramic coating also neutralizes a small portion of the HF (Hydrogen Fluoride) created through the battery cycling, avoiding inner pressure accumulation.



https://www.researchgate.net/publication/329457210_Separator_Membranes_for_High_Energy-Density_Batteries/figures?lo=1

DESIGN – BATTERY MODULE SAFETY

Thermal Safety
- Thermal fuse links
- Integrated thermocouples
- Cell spacing
- Flame retardant spacers

Thermal Safety

Electrical Safety

Battery Module Safety Goal

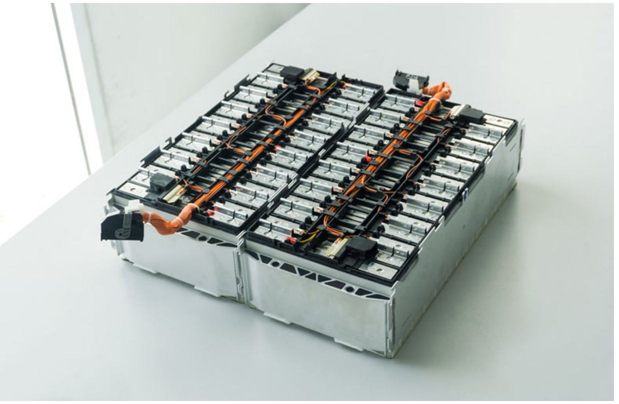
Mechanical Safety

Performance Safety

Electrical Safety
- High voltage resistance design
- Short circuiting protection
- Overcurrent fusing
- Grounding
- Touch-safe modules
- Coolant isolation from electrical system

Mechanical Safety
- Module structural strength
- Moisture and dust protection
- Seismic design
- Adhesive bonding of cells

Performance Safety
- Overcharge/overdischarge protection from BMS
- Cooling fans and heat sinks



DESIGN – BATTERY RACKS

High voltage safety	Thermal and fire safety	Mechanical and structural safety
• Insulation design • Over current/voltage protection device • Wiring safety • Proper grounding • Sealed liquid cooling system	• Temperature monitoring, management and control • Rack balancing • Voltage and power control • SOC, SOH control • Fire detection and suppression	• Fastener torqueing • Sheet metal strength • Anti-vibration and impact design

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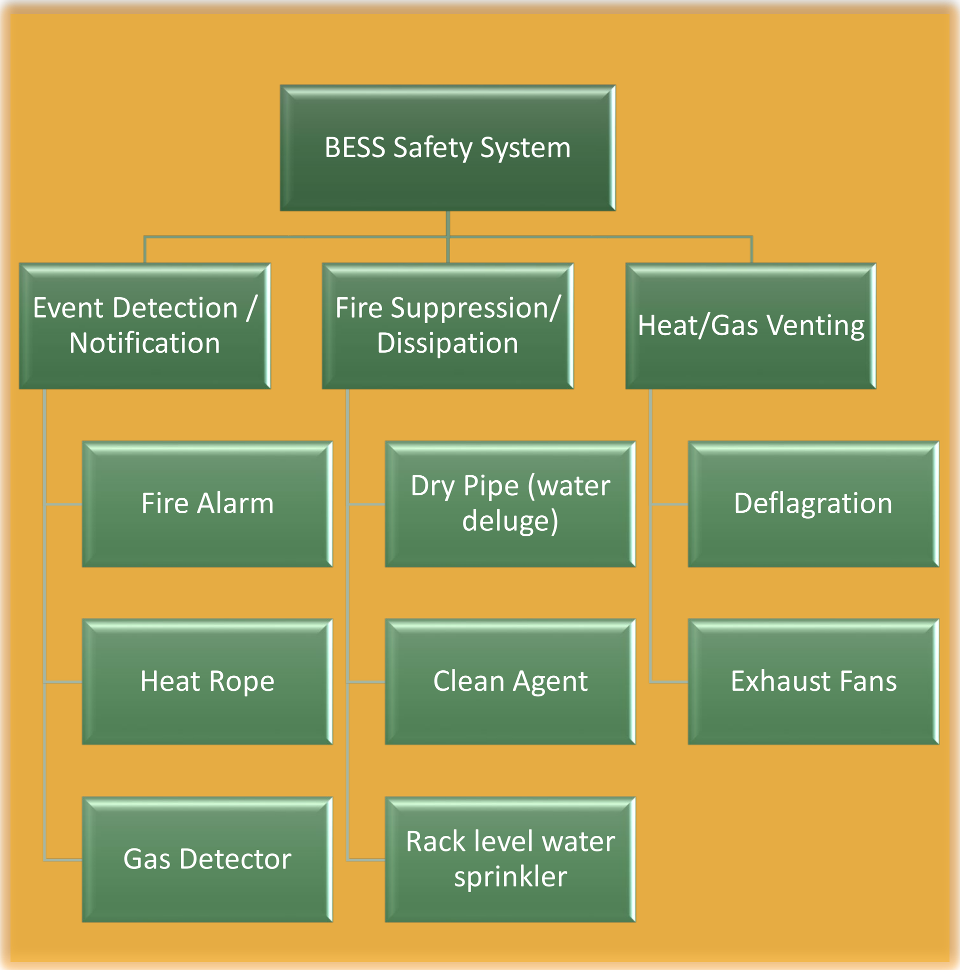
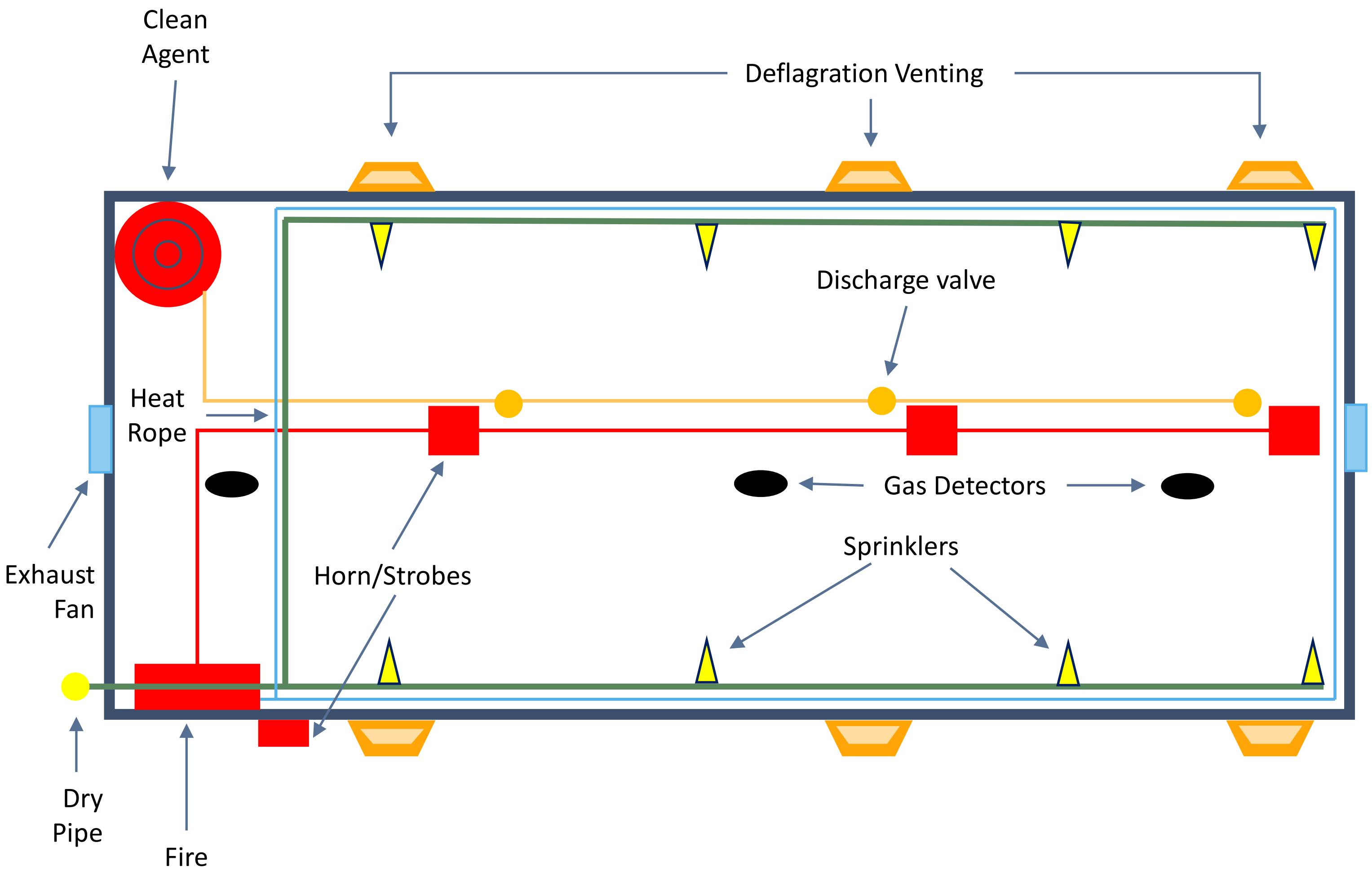
DESIGN – CONTAINERIZED SYSTEMS





Typical BESS Container

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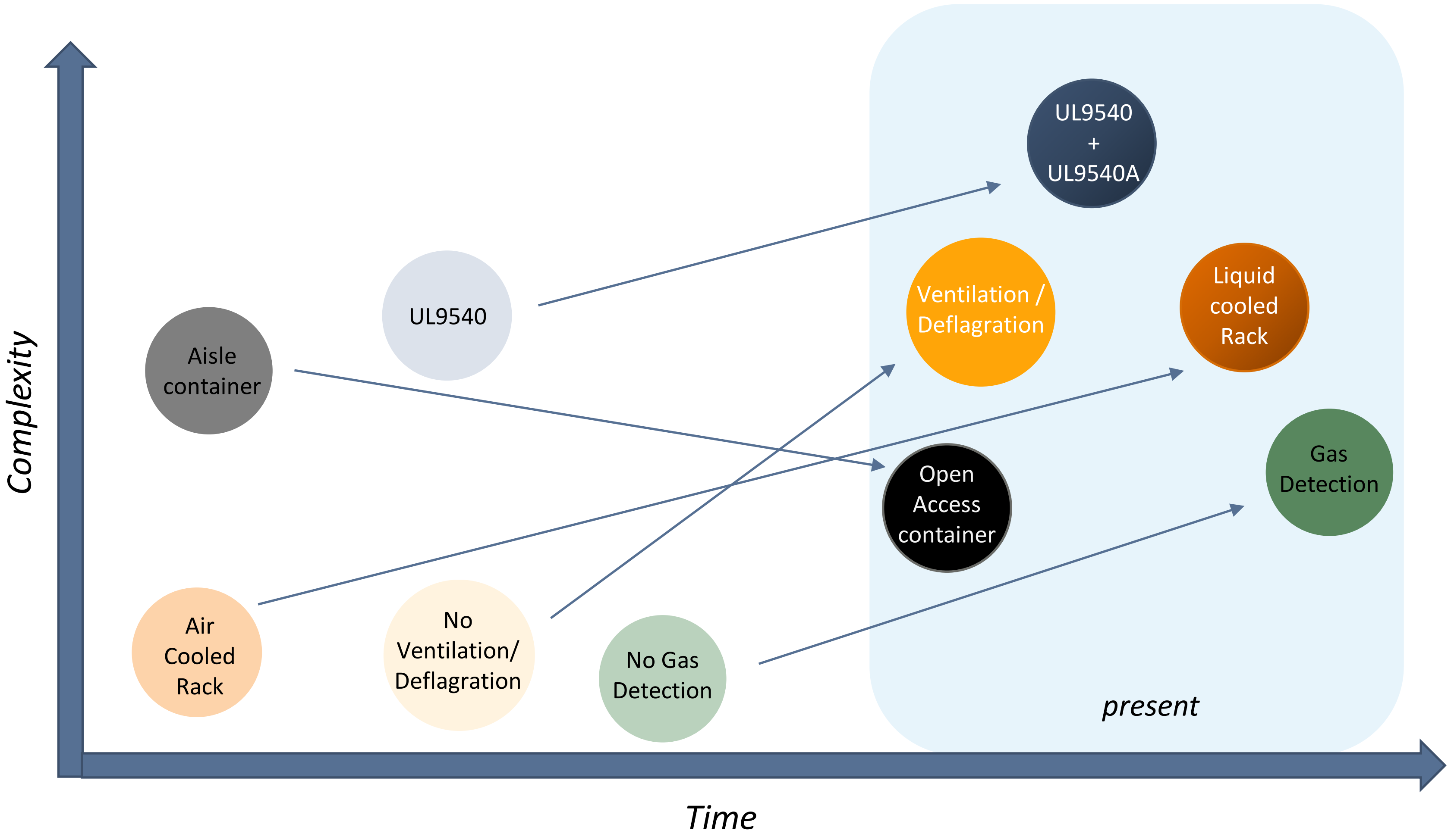
DESIGN – CONTAINERIZED SYSTEMS

- We have notice 5 major safety trends in BESS design
- Five major trends are
  - Open access containers
  - Gas detection
  - Liquid cooled racks
  - Ventilation/deflagration
  - UL9540A test requirement

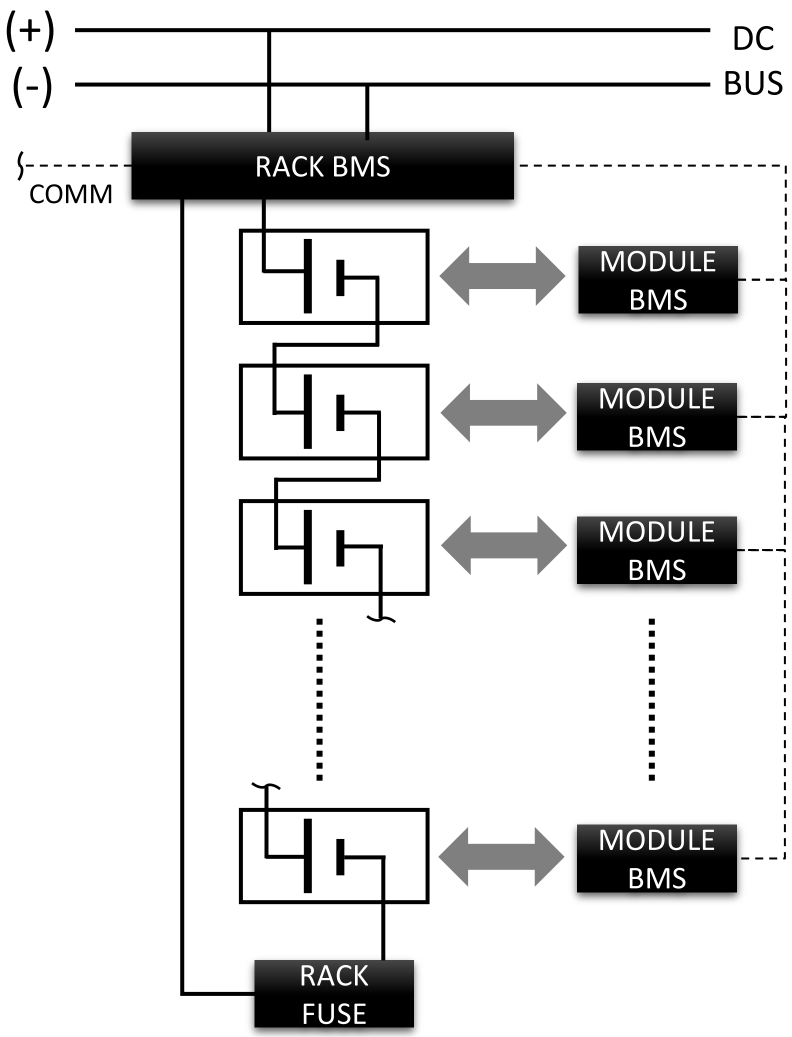


SAFETY TRENDS

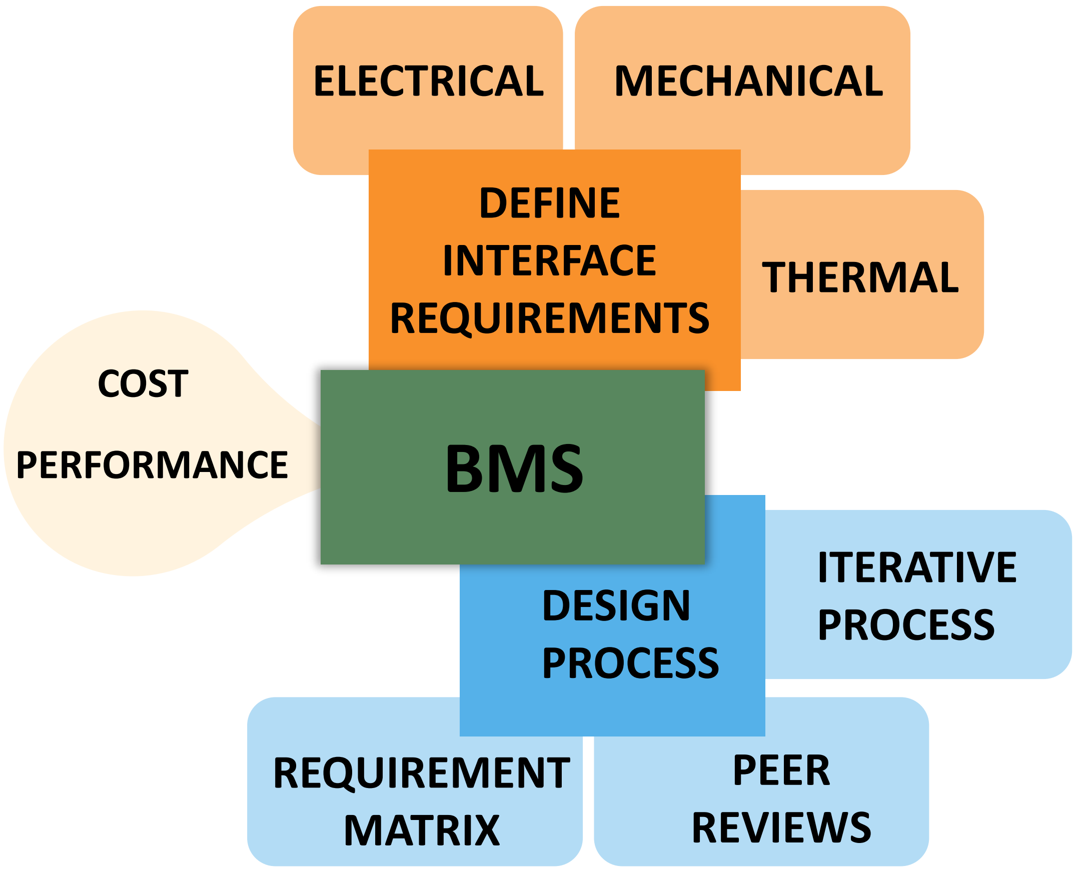
INTEGRATION

- BATTERY MANAGEMENT SYSTEM (BMS)
- ENERGY MANAGEMENT SYSTEMS (EMS)
- THERMAL MANAGEMENT SYSTEM (TMS)

INTEGRATION - BMS



TYPICAL RACK DESIGN



BMS SAFETY CONSIDERATION

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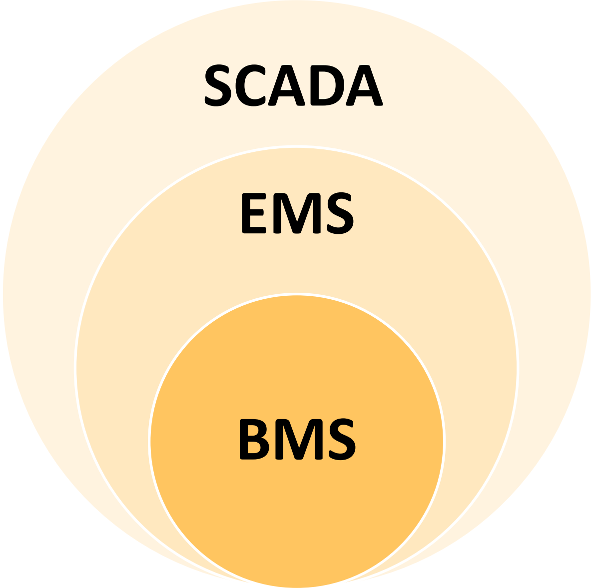
INTEGRATION – EMS



Energy Management System or EMS increasingly perform higher level safety task.

Main drivers of these are UL9540A, permitting requirement and BESS integrators moving up the value chain

We anticipate this trend to continue until codes and standards around BESS safety solidify across jurisdictions.

We see New York, Massachusetts and California to be much farther ahead in implementing newer standard compared to other part of USA and around the globe

- Safely and seamlessly controlling the entire BESS system.
- Shut down BESS during emergencies

- Notifying First Responders about BESS status
- Controlling increasingly complex Fire suppression and mitigation components within BESS

- Predicting and thus preventing BESS safety issues
- Detecting gas build up during thermal runaway event
- Automatic notification to First Responders, system operator about gases present in BESS container

Energy Management System

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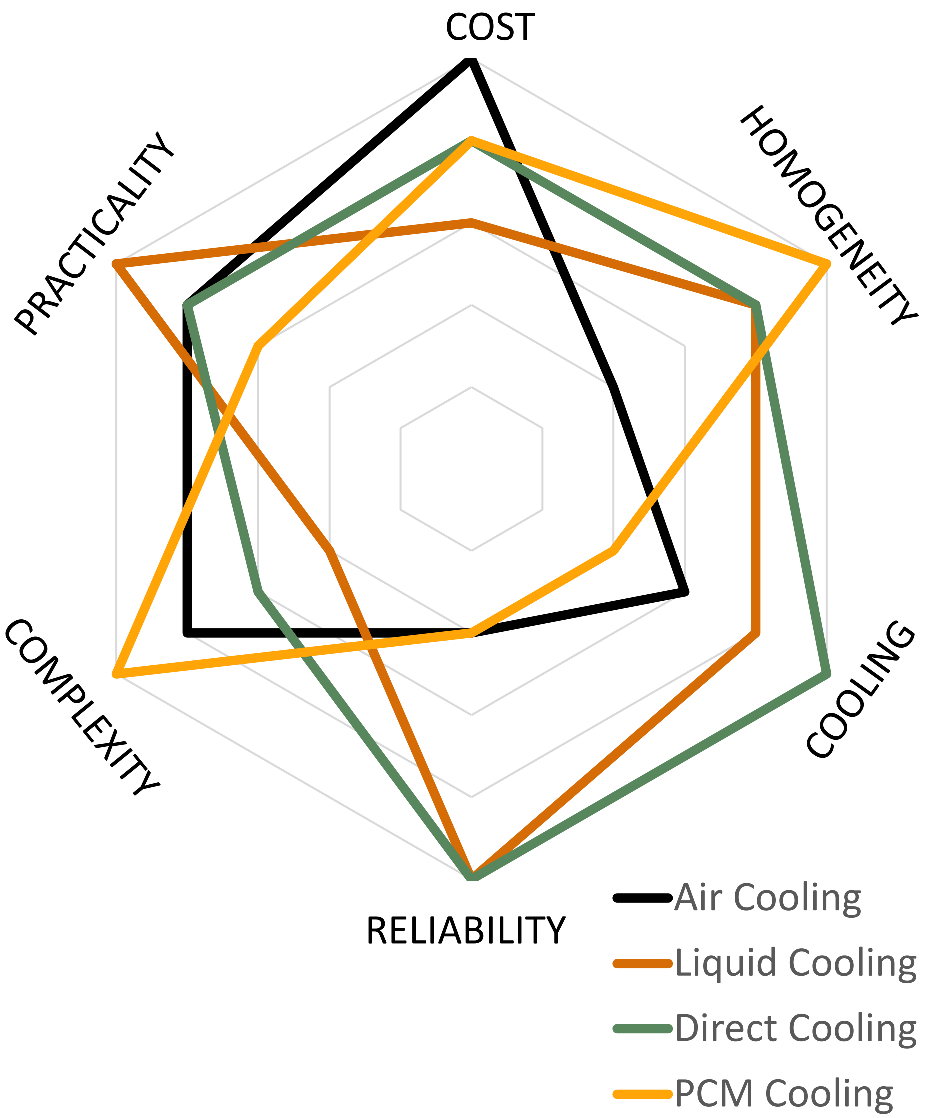
INTEGRATION – TMS

	AIR COOLING	LIQUID COOLING	DIRECT COOLING	PCM COOLING
ADVANTAGE	Simple structure, low cost, no leakage	Fast cooling speed, large specific volume, heat transfer coefficient	High cooling efficiency, compact structure, avoid liquid leakage risk of liquid cooling system	The volume change is small, the phase change latent heat is large, and the phase change temperature is constant
DIS ADVANTAGE	Low heat exchange efficiency and poor temperature uniformity	High complexity, high cost, risk of liquid leakage	Temperature, pressure and flow are not easy to control	Low thermal conductivity, slow heat dissipation



SAFETY TRENDS

INSTALLATION

SYSTEM AND SITE LAYOUT

INSTALLATION – SYSTEM AND SITE LAYOUT

BATTERY ENCLOSURE

- BESS system shall comply with UL9540A listing and NFPA 70
- Open Access containers are being introduced replacing older generation aisle containers to increase personnel safety, improve energy density per sq. ft.
- Door Mounted HVAC to enhance resilience and reliability

PCS

- We see PCS vendors move up in value chain and offer integrated PCS + Transformer skid option. Also, manufacturers are offering fully integrated DC converters, PCS and Transformer on skids. This will improve safety, reduce and increase installation speed.
- PCS vendors offering higher MW units to reduce cost, improve safety. With average size of BESS increasing, we see this as product rationalization w.r.t PCS offering

SITE

- System installation need to adhere to NFPA 855
- There are permitting challenges in constructing large buildings to house battery racks. Hence, containerized battery energy storage shall grab largest market share
- Install site are getting denser in energy content. Hence, careful equipment layout planning is required

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SAFETY STANDARDS

ENERGY STORAGE SAFETY STANDARDS

ENERGY STORAGE SAFETY STANDARDS

Cell
UL 1642
UN 38.3
IEC 62619

Module
UL 1973
UN 38.3
IEC 62619

Battery Rack / Bay
UL 1973, NFPA 70E
UN38.3
IEC 61508 (BMS), IEC 62040-1

FCC 47 CFR Part 15 Subpart B Class A
IEC 61000-6-2, 4, 5, and 7
EN 55011

CBC/IBC and IEEE 693

System
UL 9540 – UL9540A
NFPA 70 and 70E; NFPA 855
UN38.3
IEC 60529, IEC60950-1, IEC 62040-1
IEEE C-2 (National Electrical Safety Code)
CBC/IBC and IEEE 693

FCC 47 CFR Part 15 Subpart B Class A
IEC 61000-6-2, 4, and 5
EN 55011

IEEE 693
IEC 60529

UL 1741 SA
IEEE 519
IEEE 1547

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ENERGY STORAGE SAFETY STANDARDS

Safety

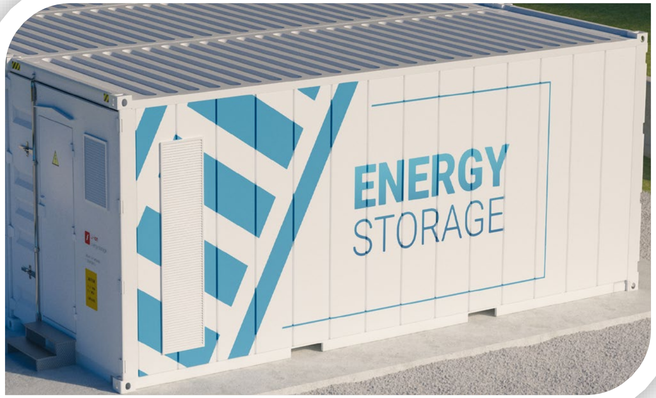
Cell	Module	Battery Rack / Bay
UL 1642	UL 1973	UL 1973, NFPA 70E
UN 38.3	UN 38.3	UN38.3
IEC 62619	IEC 62619	IEC 61508 (BMS), IEC 62040-1

Electromagnetic Compatibility

FCC 47 CFR Part 15 Subpart B Class A
IEC 61000-6-2, 4, 5, and 7
EN 55011

Seismic and Enclosure Integrity

CBC/IBC and IEEE 693



System

Safety

UL 9540 – UL9540A
NFPA 70 and 70E; NFPA 855
UN38.3
IEC 60529, IEC60950-1, IEC 62040-1
IEEE C-2 (National Electrical Safety Code)
CBC/IBC and IEEE 693

Electromagnetic Compatibility

FCC 47 CFR Part 15 Subpart B Class A
IEC 61000-6-2, 4, and 5
EN 55011

Seismic and Enclosure Integrity

IEEE 693
IEC 60529

Grid Interconnection

UL 1741 SA
IEEE 519
IEEE 1547

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SUMMARY

SUMMARY

Energy Storage market is moving toward a more complex and comprehensive fire safety requirement.

We expect IEEE and IEC standards to evolve and develop new standards as Energy Storage becomes mainstream.

Because of Thermal runaway risk and Energy Storage being deployed in populous areas, AHJs around USA are increasing requiring UL9540A test reports and expecting safer design. We see FDNY to be much farther along than other. We expect this trend to continue.

Large scale project development is undertaken by owner with limited integration capabilities, bypassing system integrators to reduce CAPEX and absorbing safety risks.

Revenue optimization controller providers are providing end-to-end comprehensive Energy Storage solution to increase value of their core offering to provide safer and seamless integration.

Rack level liquid cooling is increasing being accepted as a means of thermal management as opposed to direct/forced air cooling.

Cell manufacturers are moving up the value chain to provide rack or even container level integration along with necessary warranties, performance guarantees to enable safer system.

PCS vendors are moving up the value chain to provide integrated skid offering inclusive of PCS, transformer and other BOS components to improve safety and reduce cost

THANK YOU