BESS Technologies and UL Standards

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Laurie Florence
Principal Engineer for Stationary & Motive Batteries and ESS

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Battery technologies and associated hazards

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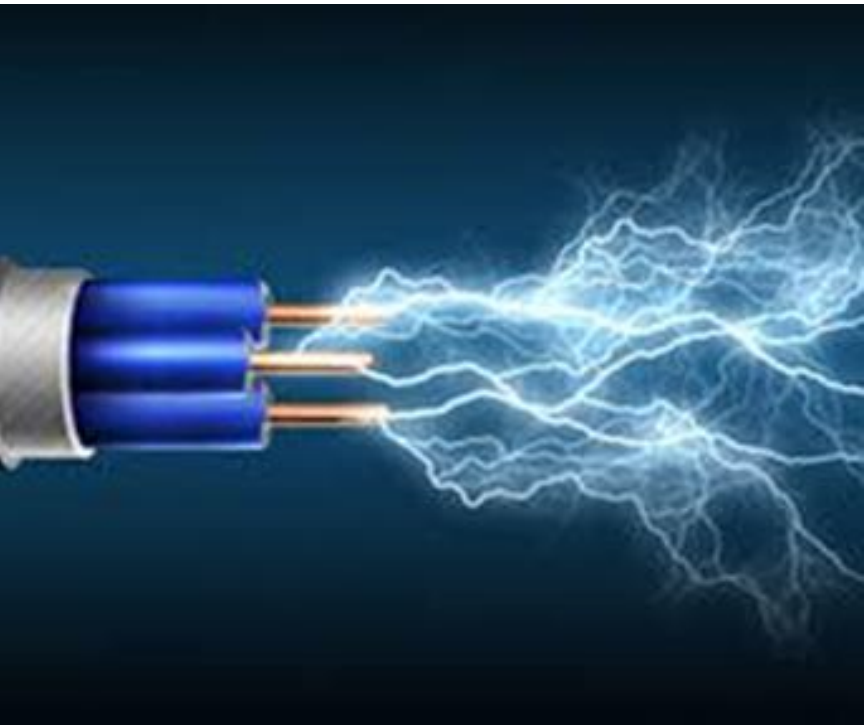
Electrical Hazards



Depending upon the design and size, all batteries have the potential to present an electrical safety hazard:

- Electric Shock
- Short Circuits that can result in very high current levels and potential fires

There is also the concern with stranded or stored energy

- Hazardous energy levels may remain within batteries that are:
  - Damaged
  - Thought to be depleted (but not)

Lead Acid Battery Hazards

Vented lead acid

- Off-gassing of H_2 as vents are open to atmosphere
- Free liquid sulfuric acid electrolyte
- High short circuit current

Valve regulated lead acid

- Gel or AGM constructions
- Off-gassing of H_2 when valve operates under pressure
- Sulfuric acid electrolyte
- High short circuit current
- Thermal runaway possible

Nickel Battery Hazards

Vented Ni-Cad, Ni-Zn

- Off-gassing of H_2 as vents are open to atmosphere
- Free liquid KOH electrolyte (caustic)
- High short circuit current
- Leakage current due to conductive KOH paths
- Thermal runaway possible

Valve regulated Ni-Cad, Ni-Zn, Ni-mH

- Off-gassing of H_2 when valve operates under pressure
- KOH (caustic) electrolyte
- High short circuit current
- Leakage current due to conductive KOH paths
- Thermal runaway possible

Lithium ion Battery Hazards

Lithium ion

- Two categories: metal oxide (e.g. LCO, NMC, NCA) or metal phosphate (e.g. LFP)
- Requires more complex controls
- Flammable off-gassing upon venting
- Thermal runaway possible
  - From external abuse
  - Internal defects/internal short circuit
- Stranded energy potential

High Temperature Sodium Battery Hazards

Sodium Sulfur

- High temperatures (operated at @310-370°C)
- Contains water reactive & toxic materials
- Thermal runaway possible

Sodium Nickel Chloride

- High temperatures (operated at @
- 270-350°C)
- Contains water reactive materials
- Thermal runaway possible

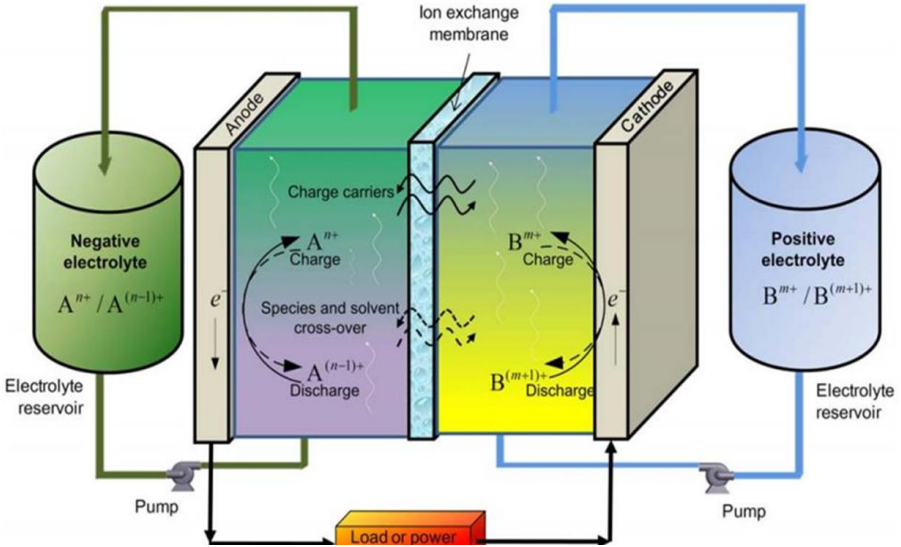
Flow Battery Hazards

Vanadium Redox

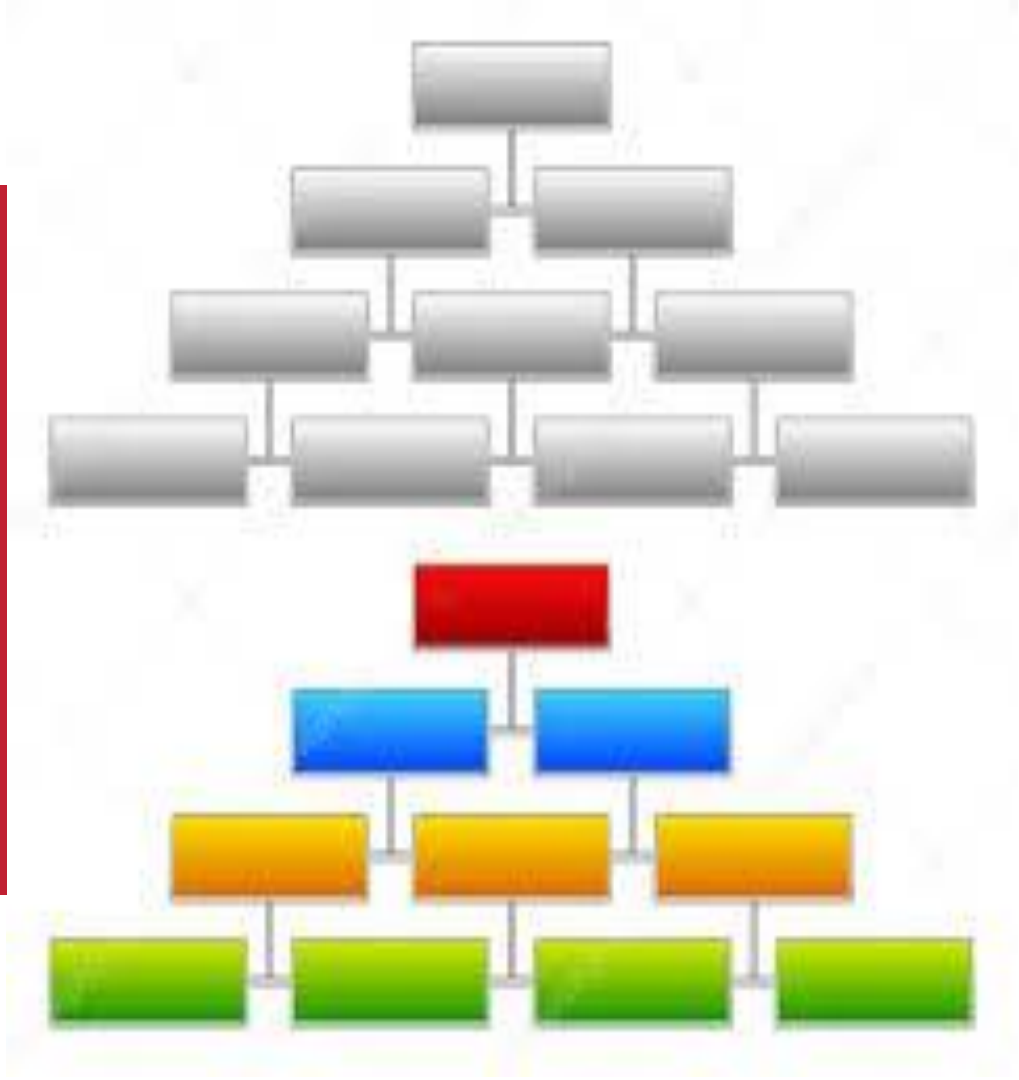
- H_2 off gassing potential
- Leakage of corrosive and toxic electrolytes (large quantities)
- Failure of pumps or other components

Zinc Bromine

- H_2 off gassing potential
- Leakage of very toxic electrolyte (large quantities)
- Failure of pumps or other components



Battery & ESS standards hierarchy

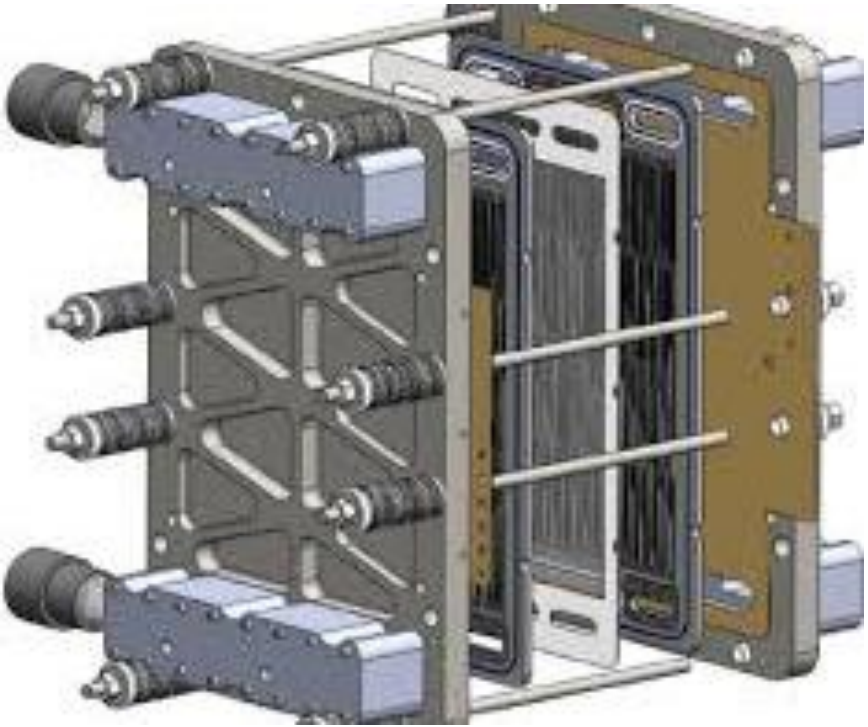


Battery & ESS standards hierarchy

There are safety requirements for each part of an energy storage system with sealed batteries:

- **Cell** – basic building electrochemical unit of a battery
- **Battery module** – component battery pack of a battery system
- **Battery system** – battery modules, BMS and battery system balance of plant (BOP)
- **Energy storage system** – battery system, power conditioning system (PCS) and BOP

Battery & ESS standards hierarchy



There are safety requirements for each part of an energy storage system with flow batteries

- **Stack** – Assembly of electrochemical cells that are the building block of a flow battery
- **Battery system** – battery stacks, electrolyte tanks, pumps, and flow battery system BOP
- **Energy storage system** – battery system, PCS and BOP

Battery & ESS standards hierarchy

Evaluation Approach:

Sealed Cells:

- Evaluated by test
  - Short circuit
  - Overcharging
  - Overdischarge/Forced discharge
  - Heating (thermal ramp)
  - Temperature cycling
  - Bar Impact
  - Crush
  - Projectile
  - Shock
  - Vibration

Battery & ESS standards hierarchy

Evaluation Approach:

Monobloc batteries (LA, Ni):

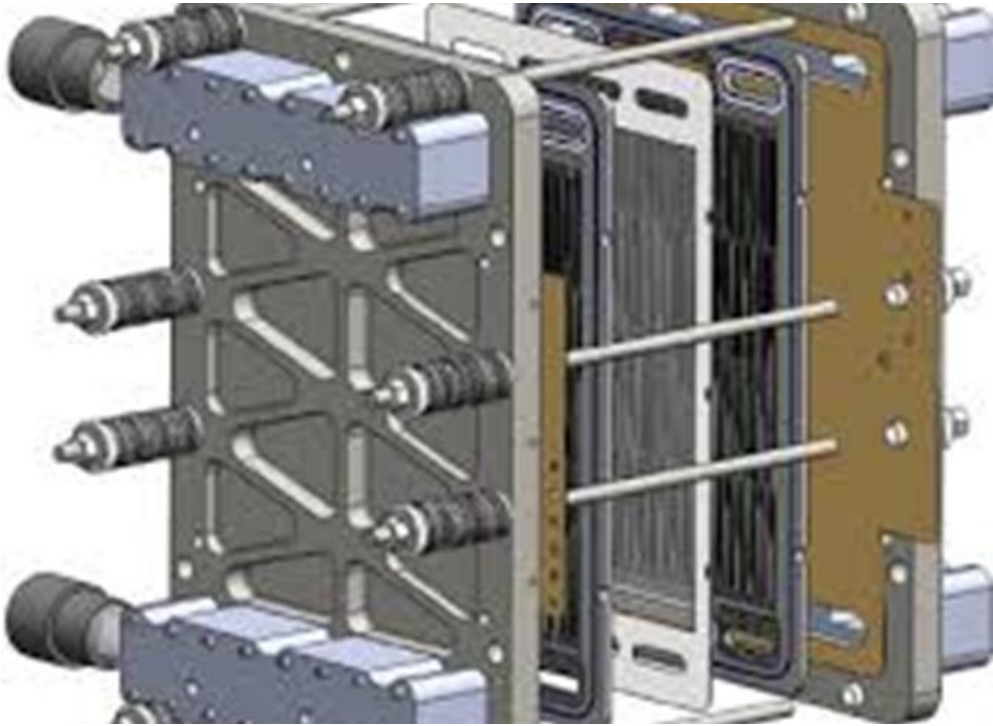
- Evaluation of protection mechanisms
  - Vented types
    - Flame Arrestor Tests:
      - Back Pressure
      - Sustained Burning
      - Flame Propagation
  - Valve regulated
    - Pressure Release

Battery & ESS standards hierarchy

Evaluation Approach:

Flow Battery Stacks:

- Evaluated by test
  - Short circuit
  - High temperature
  - Shock/Drop
  - Vibration



Battery & ESS standards hierarchy

Evaluation Approach:

Battery Module

- Construction
  - Cells
  - Materials
  - Enclosures
  - Electrical Spacings and Connections
  - FMEA
  - Controls/ Functional Safety
- Tests
  - Electrical Tests
  - Mechanical Tests
  - Environmental Tests
  - Single Cell Failure Design Tolerance

Battery & ESS standards hierarchy

Evaluation Approach:

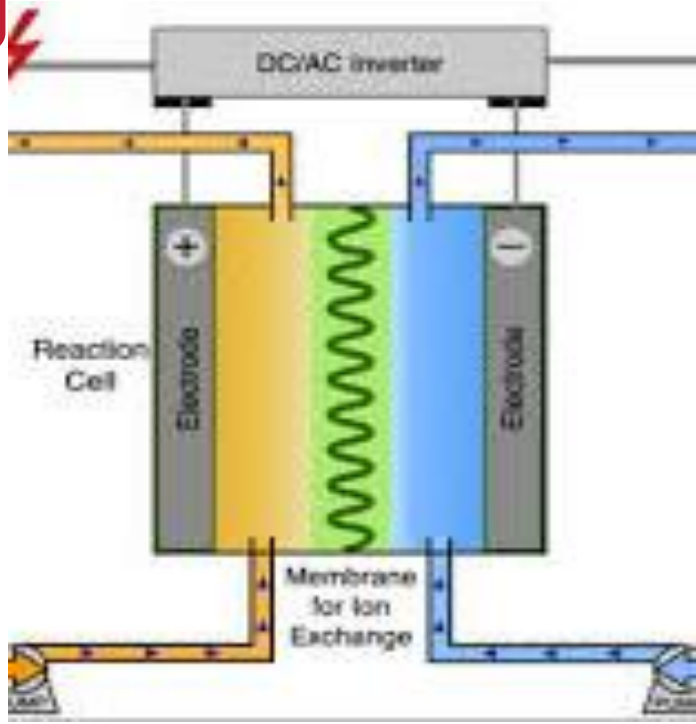
Battery System

- Construction
  - Cells
  - Materials
  - Enclosures
  - Electrical Spacings and Connections
  - FMEA
  - Controls/ Functional Safety
- Tests
  - Electrical Tests
    - Short circuit, Overcharge, Overdischarge, Imbalanced Charging, Temperature, Failure of Cooling/Thermal Stability, Dielectric Voltage Withstand, Continuity
  - Mechanical Tests
    - Ball Impact, Mold Stress, Drop Impact, Static Force
  - Environmental Tests
    - External Fire Exposure, Salt Fog
  - Single Cell Failure Design Tolerance

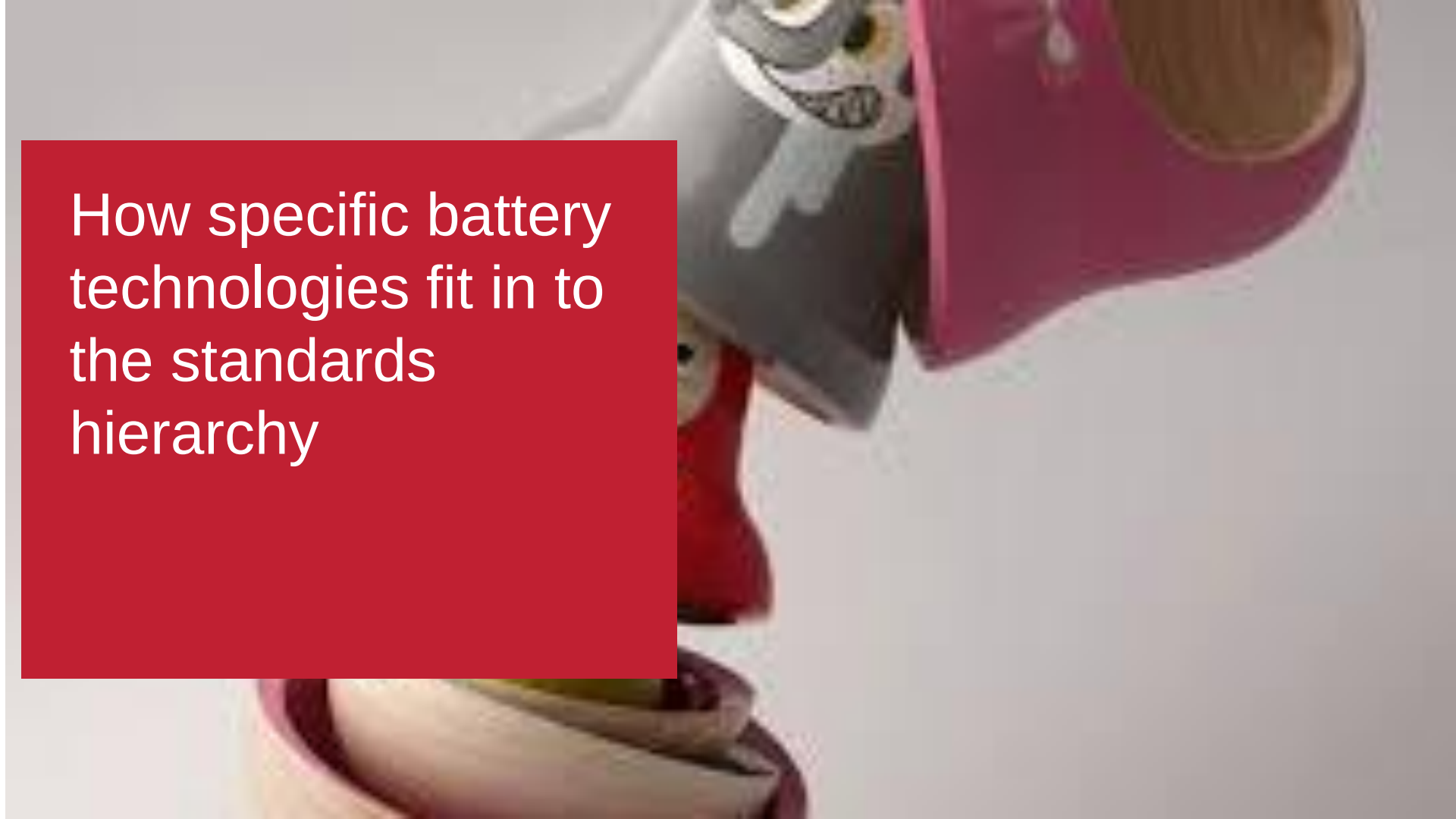
Battery & ESS standards hierarchy

Evaluation Approach: Flow Battery System

- **Construction:** Cells, Materials, Enclosures, Electrical Spacings and, Connections, FMEA, Controls/ Functional Safety, Spill Containment
- **Tests:**
  - Material Containing Electrolyte Tests
    - Resistance to Deterioration from Fluids, Temperature Exposure
  - Electrical Tests
    - Short circuit, Overcharge, Temperature, Failure of Cooling/Thermal Stability, Dielectric Voltage Withstand, Continuity
  - Mechanical Tests
    - Ball Impact, Mold Stress, Static Force, Hydraulic Pressure, Leakage, Electrolyte Blockage Tests
  - Environmental Tests
    - External Fire Exposure, Salt Fog



How specific battery technologies fit in to the standards hierarchy



Battery Standards Hierarchy

Chemistry	Device	Standard Applied	Comments
Lithium ion	Cell	UL 1973	UL 1642 (with modifications) or IEC test program
	Module	UL 1973	Battery and some controls
	System	UL 1973	Includes battery and BMS
	BESS	UL 9540	UL 1973 is a component standard
Sealed Nickel	Cell	UL 1973	UL 2054 (with modifications)
	Module	UL 1973	Battery and some controls
	System	UL 1973	Includes battery and BMS
	BESS	UL 9540	UL 1973 is component standard

Battery Standards Hierarchy

Chemistry	Device	Standard Applied	Comments
Sodium Beta	Cell	UL 1973	Appendix B
	Module	UL 1973	Battery and some controls
	System	UL 1973	Includes battery and BMS
	BESS	UL 9540	UL 1973 is component standard
LA, Ni-Cad, Ni-mH	Monobloc Battery	UL 1989	Flame arrestor & pressure release test
	System	UL 1973	Includes battery and protection
	BESS	UL 9540	UL 1973 is component standard

Battery Standards Hierarchy

Chemistry	Device	Standard Applied	Comments
Electrochemical Capacitor	Capacitor	UL 810A	
	Module	UL 810A	
	System	UL 1973	Includes Modules and controls
	BESS	UL 9540	UL 1973 is component standard
Flow Battery	Stack	UL 1973	Appendix C
	System	UL 1973	UL 1973 and Appendix C
	BESS	UL 9540	UL 1973 is component standard

Battery Standards Hierarchy

UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage System

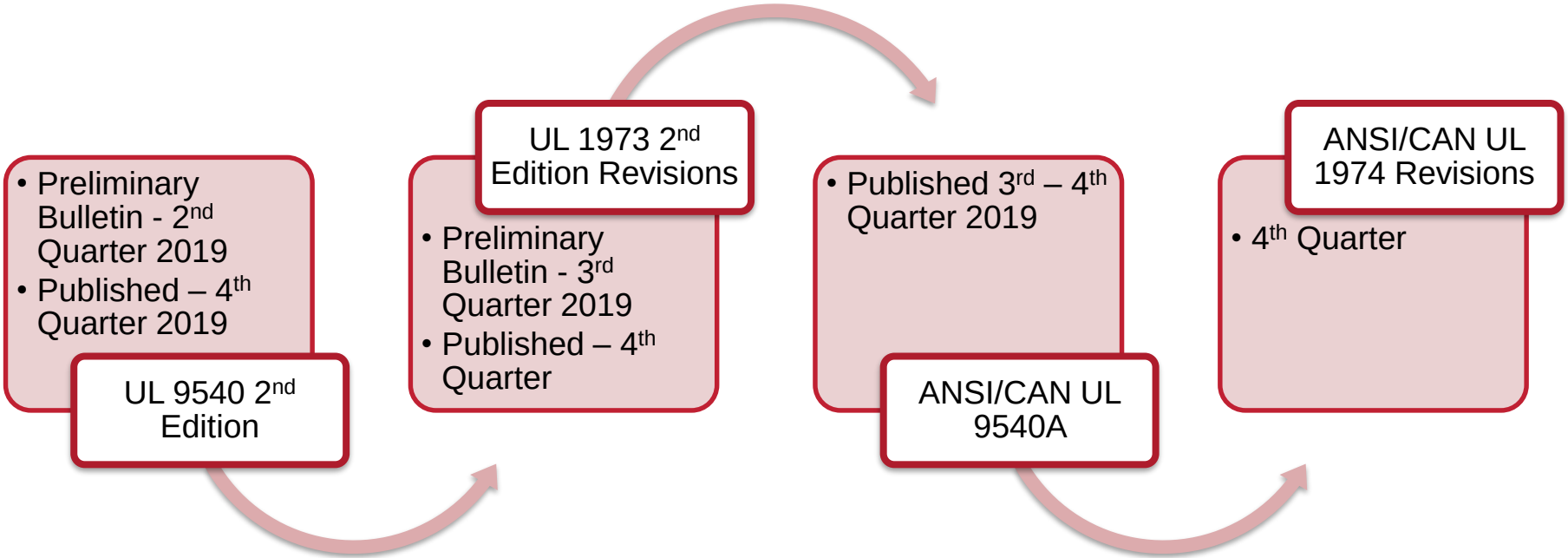
- How does UL 9540A fit into this hierarchy?
  - UL 9540A developed to address large scale fire testing requirements in the fire codes.
  - UL 9540A will be referenced in the bulletin for the 2nd edition of UL 9540
  - Compliance to UL 9540 would require UL 9540A test if required per the codes.

Battery Standards Hierarchy

UL 1974, Evaluation for Repurposing Batteries

- Process standard for batteries
  - Published in October 2018
  - Will be referenced in 2020 IFC and NEC
  - Registration program to be set up for UL 1974 manufacturers
  - Stationary batteries built from UL 1974 repurposed batteries will need to meet UL 1973

UL Standards Development Timeline



Laurie Florence

Principal Engineer
Stationary & Motive Batteries and Energy Storage Systems
laurie.b.florence@ul.com
1-847-664-3782

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