BESS 101

Battery Energy Storage Systems (BESS): Essentials, risks and safety protocols

An introduction and overview into Battery Energy Storage Systems, its risk management and insurance considerations

Crawford®

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Executive Summary

Battery Energy Storage Systems (BESS) play a crucial role in energy systems by providing grid stability, energy reliability as well as integrating renewable energy.

In this report, we discuss the key aspects of BESS, from fundamental chemistry to operational challenges, emerging trends and standards. A thorough understanding of these factors will help to navigate energy industry and optimize the potential of battery storage system.

KEY FINDINGS

- The increasing adoption of renewable energy sources has led to a significant increase in the need for energy storage solutions.
- Li-ion remain dominant technology but alternative chemistries such as flow batteries or solid-state batteries are emerging as potential solutions.
- BESS installations face risks such as electrical faults, degradation and thermal runaway. Stringent safety protocols and international standards can help mitigate risks.
- As of 2024, China leads in battery deployment with 36GW, followed by the US with 13GW, Europe with 10 GW and Australia with 2GW.

KEY STATISTICS

- In 2023, global Li – ion battery cell production surpassed 1 TWh, with 52% of the output being LFP batteries.
- In 2024, the average storage duration increased by 33% to 2.4 hours, compared to 1.8 hours in 2020.
- The root causes of BESS failures are mainly attributed to system defects (72%), cell defects (15%) and module defects (13%).

The need for Battery Energy Storage Systems (BESS):

Battery Energy Storage Systems (BESS) are devices that connect to power grids to capture excess electrical energy and discharge it during periods of peak demand.

Due to the inherent intermittency of renewable energy sources – such as wind, solar, tidal, and geothermal – it is essential to incorporate energy storage into electrical grids. BESS is one technology that helps ensure a consistent and stable electrical energy output.

Excess energy can be stored during surplus periods, preventing the need to curtail renewable sources during high-demand times. Additionally, BESS provides voltage support and helps stabilize power grid fluctuations.

In the past, the use of BESS often resulted in higher costs per kilowatt-hour (kWh) because the price of electricity included storage expenses.

The high cost of energy storage previously made it more economical to construct additional generation facilities. However, recent reductions in energy storage costs, coupled with growing environmental concerns, have spurred an increase in energy storage projects.

As of November 2024, the race for large-scale battery energy storage is gaining momentum, with California's Edwards & Sunborn project leading the way at 821 MW/ 3280 MWh. The United States is home to ten of the twelve largest BESS installations (over 300 MW), while China leads in total capacity.

Despite these ambitious developments, the industry has yet to see a 1 GW system become operational.

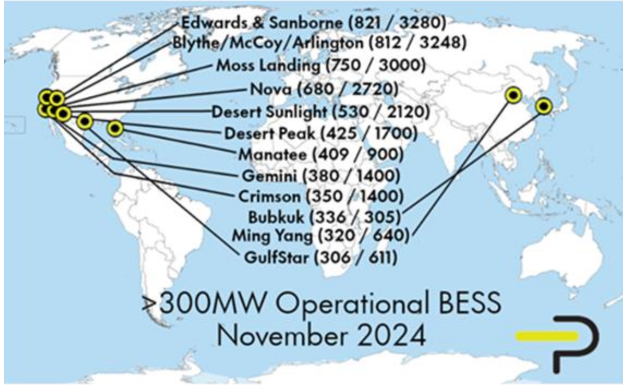


FIG. 1 Operational BESS Projects in the world (as of November 2024). Reproduced from [1].

Integration and Operation of Energy Storage Systems (ESS)

Energy Storage Systems (ESS) are designed to store excess energy generated from renewable or conventional sources and release it when needed. Their primary purpose is to balance the electrical grid and improve energy efficiency and stability.

Integrating ESS with renewable energy systems, such as solar and wind, is crucial for achieving net-zero emissions, as it allows for the storage of clean energy, ensuring a continuous and reliable power supply.

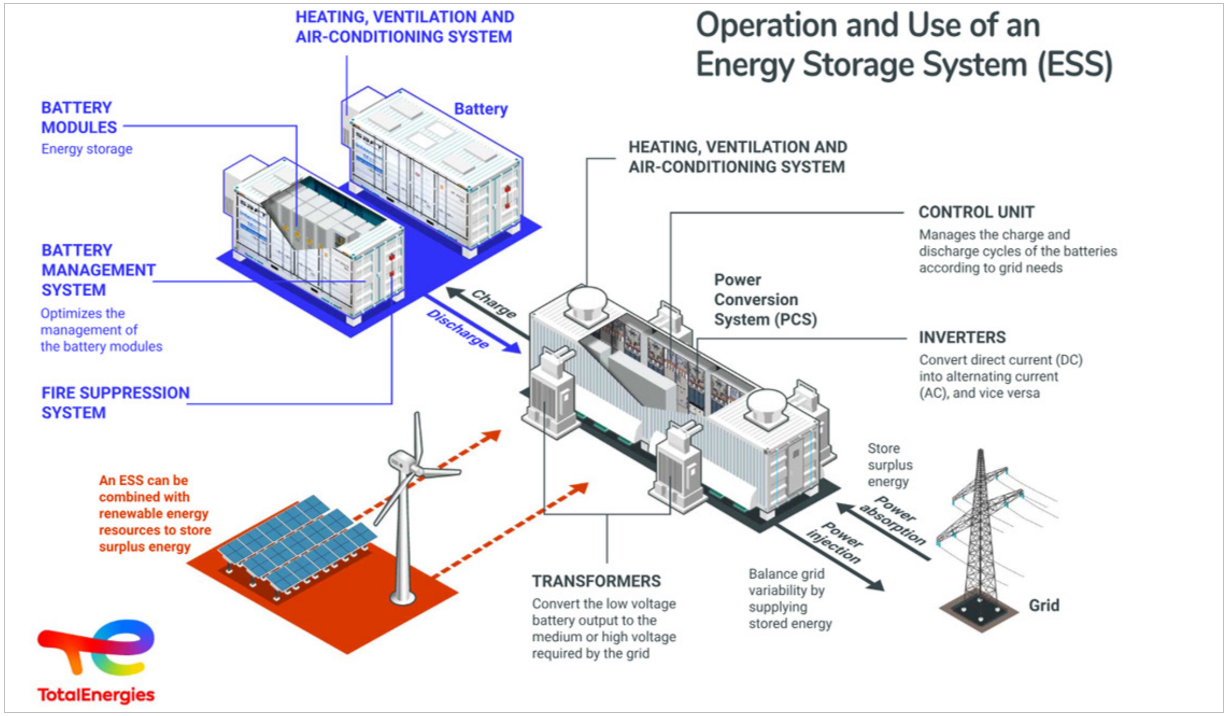


FIG. 2 Schematic representation of ESS Operation. Reproduced from [2].

Integration and Operation of Energy Storage Systems (ESS)

An ESS consists of several key components, each playing a crucial role in energy storage distribution:

- **Battery cells:** These are the core of the ESS system. Multiple cells are combined to form a battery module, optimizing voltage and capacity. Several modules are assembled into a battery pack or rack, allowing for scalable energy storage. Finally, multiple packs work together to store and deliver energy efficiently to the grid or end users.
- **Battery Management System (BMS):** The BMS optimizes and monitors the performance of the battery modules. These systems utilize several sensors monitoring internal and external temperature, state of charge, voltage, and charging current. It ensures efficient charging and discharging, prevents overcharging and protects against overheating and other faults.
- **Fire Detection and Suppression Systems:** These are integrated into the system to detect fires and provide relevant signals to the BMS, which shuts off if fire activity is detected. Some systems also include suppression systems, which may consist of liquid, powdered, or gaseous extinguishing media. Systems may also include a “dry pipe,” allowing emergency responders to flood the compartments with water from an external standpipe without opening the container. While extinguishing lithium battery fires can be challenging, these systems aim to prevent and mitigate potential hazards caused by overheating or other failures.
- **Heating, Ventilation and Air Conditioning System (HVAC):** The HVAC system regulates the temperature inside the battery enclosures to prevent overheating. The HVAC system within each BESS module must be designed considering external heating loads, such as the exhaust from adjacent containers.

Integration and Operation of Energy Storage Systems (ESS)

- **Power Conversion System (PCS):** PCS is responsible for energy flow between the battery modules and the grid, managing charging and discharging processes for smooth energy transfer.
- **Inverters:** Since batteries store energy in Direct Current (DC), inverters are essential for converting DC into Alternating Current (AC) for integration with the power grid.
- **Transformers:** These devices convert the low-voltage output from inverters to the medium or high voltages required for grid integration and long-distance transmission.

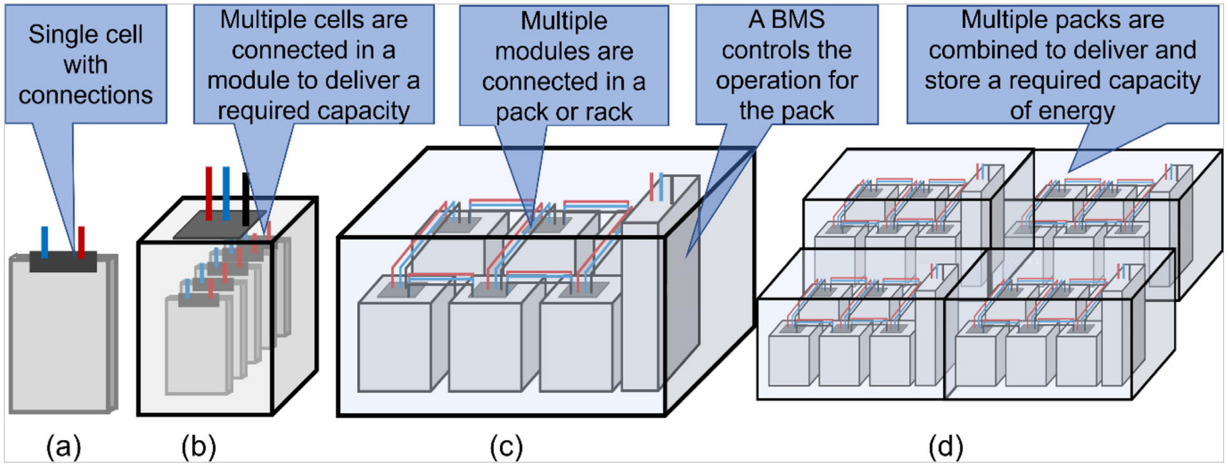


FIG. 3 Cell - to - pack configuration in BESS System. Reproduced from [3].

Introduction to Battery Chemistry

Electrochemical batteries are preferred for utility-scale energy storage due to their high conversion efficiency, considerable energy density, and ability to respond to demand almost instantly. This rapid response is essential for managing fluctuations in the electricity grid.

A battery functions by converting chemical energy into electrical energy through electrochemical reactions. Each battery cell consists of four key components:

1. **Anode:** The anode is the negative (-) electrode where oxidation (the loss of electrons) occurs. Typically made from materials like graphite or silicon, the anode plays a significant role in determining the battery's energy density, cycle life, and charging rate.
2. **Cathode:** The cathode is the positive (+) electrode where reduction (the gain of electrons) takes place. Made from materials such as lithium cobalt oxide (LiCoO2) or nickel-manganese-cobalt (NMC), the cathode affects the battery's capacity, voltage, and thermal stability.
3. **Electrolyte:** The electrolyte, often containing lithium salts like lithium hexafluorophosphate ($LiPF_6$), facilitates ion transport between the electrodes while ensuring the battery's stability and safety. Various types of electrolytes – solid, liquid, polymer, aqueous, and composite – differ in performance, safety, and energy density. The choice of electrolyte depends on the operating conditions and electrode materials.
4. **Separator:** This is a porous membrane that prevents short circuits while allowing ions to flow between the anode and cathode.

Additionally, the design of the battery cell – which includes factors like electrode thickness, packing density, and thermal management – is crucial for optimizing performance, efficiency, and safety.

Operation Principles

A battery cell operates through electrochemical reactions during both charging and discharging.

In discharge mode, the anode undergoes oxidation, releasing electrons that flow through an external circuit to power a device. Meanwhile, positive ions move through the electrolyte to the cathode, where a reduction reaction occurs.

During charging, an external power source forces electrons back to the anode, restoring the battery's chemical energy. This process continues until the battery is depleted, at which point the cycle begins again when it is recharged.

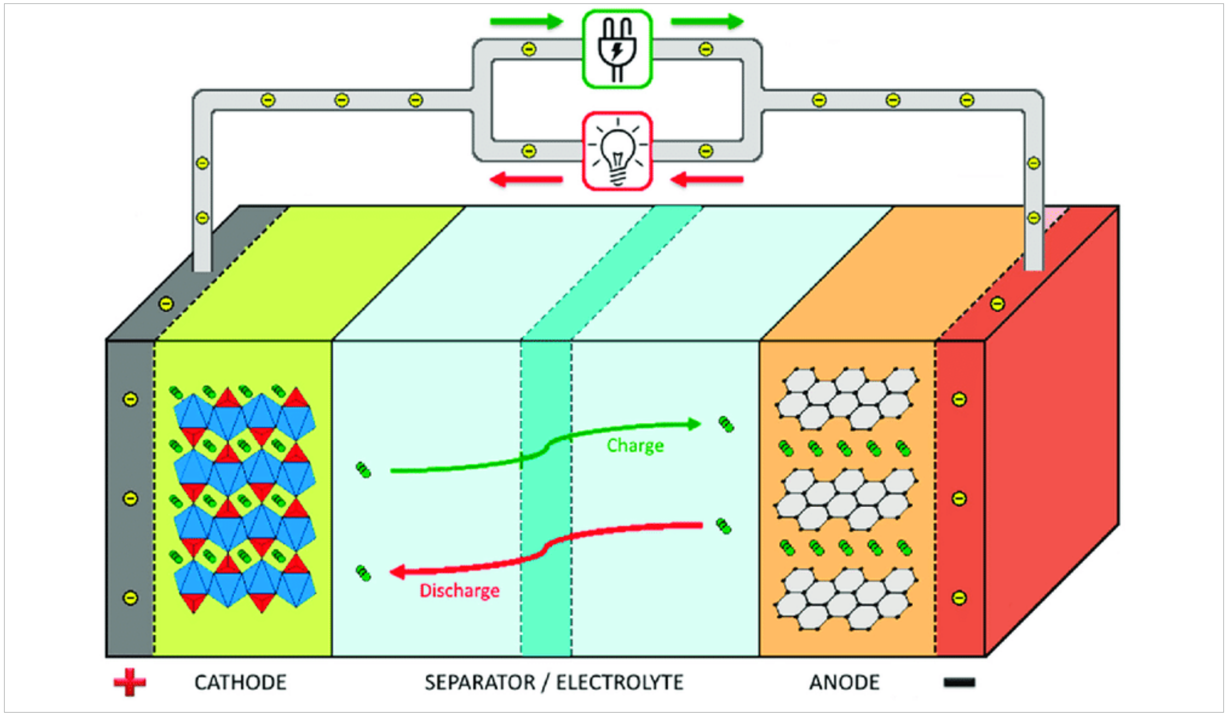


FIG. 4 Schematic representation of Battery cell operation. Reproduced from [4].

Common Cell Types

Battery cells are often named based on their cathode material. Currently, the most dominant battery chemistries in the market are:

1. **Lithium-Ion Batteries:** Lithium batteries offer remarkably high energy densities due to the high reactivity of Lithium (Li), long cycle life, and low self-discharge rate. However, issues such as dendrite growth on the anode during cycling can lead to electrical shorts, escalating temperatures, and potential damage. Several different lithium chemistries are available, and many have been commercialised since the early 1990s.
2. **Lithium iron phosphate (LFP)** batteries are one of the most common Li-ion chemistries used in grid-scale energy storage due to their cost-effectiveness, safety and long lifecycle compared to other chemistries. However, they have lower energy density than Nickel-Manganese-Cobalt (NMC) and Nickel Cobalt Aluminium (NCA) Batteries.
3. **Lithium Nickel Cobalt Manganese Aluminium Oxide (NCMA)** batteries represent the next-generation development in Li-ion batteries, combining NCA and NCM features.
4. **Lithium Polymer (LiPo)** batteries are another variation of Li-ion technology, using a polymer electrolyte instead of a liquid electrolyte.
5. **Nickel-Manganese-Cobalt (NMC) Batteries:** NMC batteries offer high energy density, high voltage, and low-temperature performance with strong battery supply chain and recycle value, e.g. Li- NMC is one of the most common cathode chemistries in electric vehicles. However, there are several disadvantages, particularly in terms of safety. High thermal release and dangerous side reactions during cycling pose significant risks, along with issues such as off-gassing, cell swelling, and high cost of metals and processing. Moreover, Cobalt (Co) makes the technology hazardous if the cells are ruptured.
6. **Nickel-based Batteries:** An improvement from the earlier Nickel-Cadmium batteries, this chemistry was the dominant type of battery technology in portable systems before the widespread use of Lithium-ion batteries. Nickel-Metal-Hydride is one of the most common Ni-based batteries.
7. **Lead Acid Batteries:** These are among the oldest rechargeable battery technologies, invented in 1859. These consist of a negative lead electrode paired with a lead dioxide positive electrode immersed in a sulphuric acid solution as the electrolyte. Although they have high power output, their low energy density, short life cycle capabilities and toxicity of lead make these batteries less advantageous.

Alternative Battery Chemistry

1. **Flow Batteries** store energy in liquid electrolytes, typically using Vanadium, Zinc, Bromine, or iron-chromium chemistries. Flow batteries have a long lifespan (up to 10,000 cycles) and offer large-scale storage, as the electrolyte can be stored in large tanks. On the other hand, they have lower energy density. While they generally are a non-polluting technology, small installations are typically more expensive than other established battery storage techniques, as the systems require pumps and other mechanical equipment.
2. **Sodium-based Batteries:** Sodium sulphur (NaS) and Sodium Ion (Na-Ion) are emerging alternatives to Li-based technologies. NaS chemistry has high energy density compared to other non-lithium chemistries, competitive conversion efficiency, and low degradation over time. However, it requires high temperatures, and there are safety implications due to Na's high reactiveness. Na-ion batteries operate similarly to Li-ion but use Na ions for charge transport. They are advantageous due to the use of abundant material and have good performance in moderate temperatures. However, they have lower energy density than Li-ion technology.
3. **Metal Air Batteries:** These batteries are emerging as alternatives to Li-based technologies and are currently under development. They use Mg, Zn, or Li as the anode and oxygen from the air as the cathode, offering a more sustainable and cost-effective solution. They also provide high energy density, such that Li-air batteries offer extremely high theoretical energy density.
4. **Solid-state Batteries:** They replace the liquid electrolyte with a solid material, offering significant advantages like higher energy density than Li-ion, improved safety toward thermal runaway, longer cycle life, and faster-charging potential. However, due to their early-stage commercialization, they have high manufacturing costs and challenges with scalability and compatibility.

Other emerging technologies currently under development are Magnesium-ion batteries, Aluminium-Ion batteries, and Graphene batteries, which promise faster-charging rates and cheaper alternatives.

Battery Development and Evolution

The evolution of battery technology from 2000 to the anticipated advancements by 2030 has involved significant improvements in cathode, anode, electrolyte, and separator materials.

Early cathodes, such as Lithium Cobalt Oxide (LCO), were succeeded by nickel-manganese-cobalt (NMC), nickel-cobalt-aluminium (NCA), and lithium iron phosphate (LFP). More recent developments include high-voltage lithium nickel manganese oxide (LNMO), sodium-ion (Na-Ion), and sulphur-based cathodes.

Anodes have transitioned from using graphite and hard carbon to soft carbon, lithium titanate (LTO), graphite/silicon composites, and silicon and lithium metal, all aimed at achieving higher energy densities.

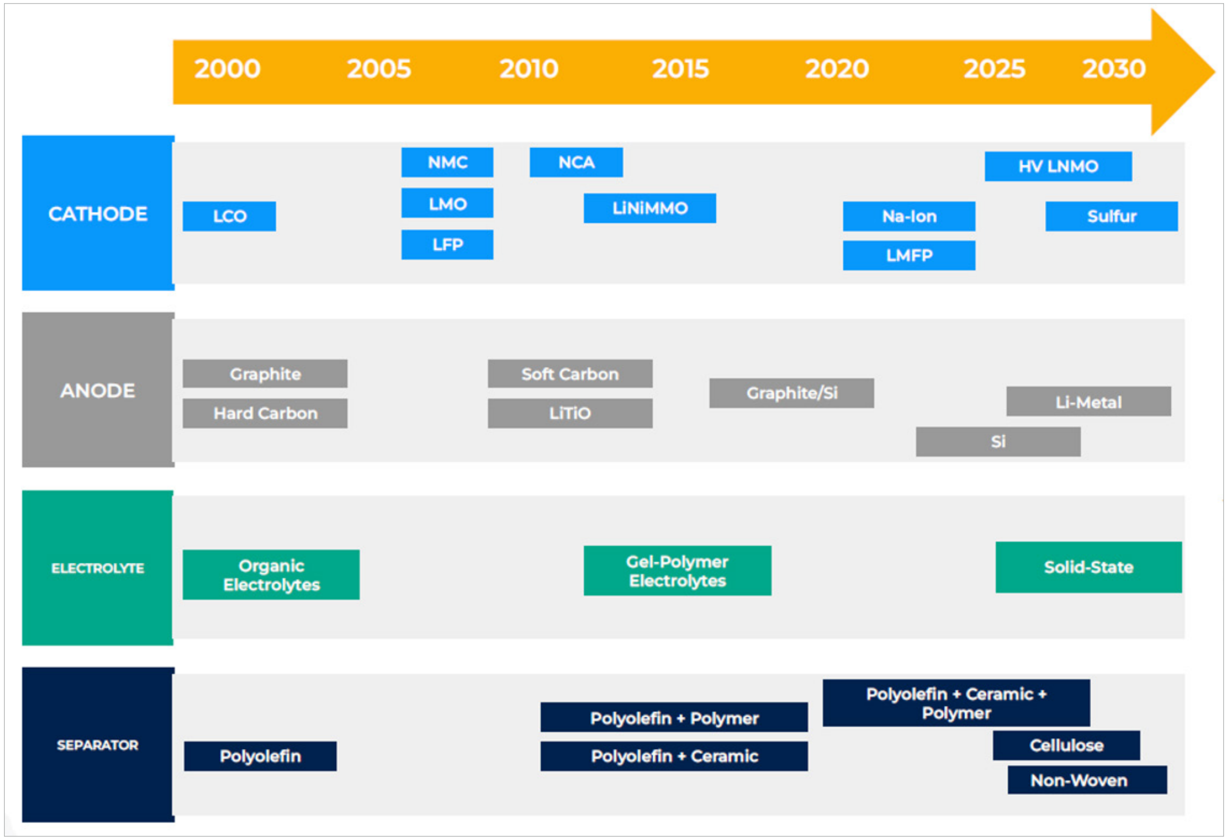


FIG. 5 Battery cell chemistry and timeline of its development- Volta Foundation [1].

Battery Development and Evolution

Electrolytes have evolved from organic formulations to gel-polymer options and, more recently, solid-state electrolytes, which focus on enhancing performance and safety.

Initially, separators consisted mainly of microporous polymer membranes. Recent advancements have introduced ceramic-coated separators and composite materials designed to improve thermal stability and prevent short circuits.

Presently, the most prevalent types of battery technologies in BESS are lithium-ion batteries. In 2023, global Li – ion battery cell production surpassed 1 TWh, with 52% of the output being LFP batteries.

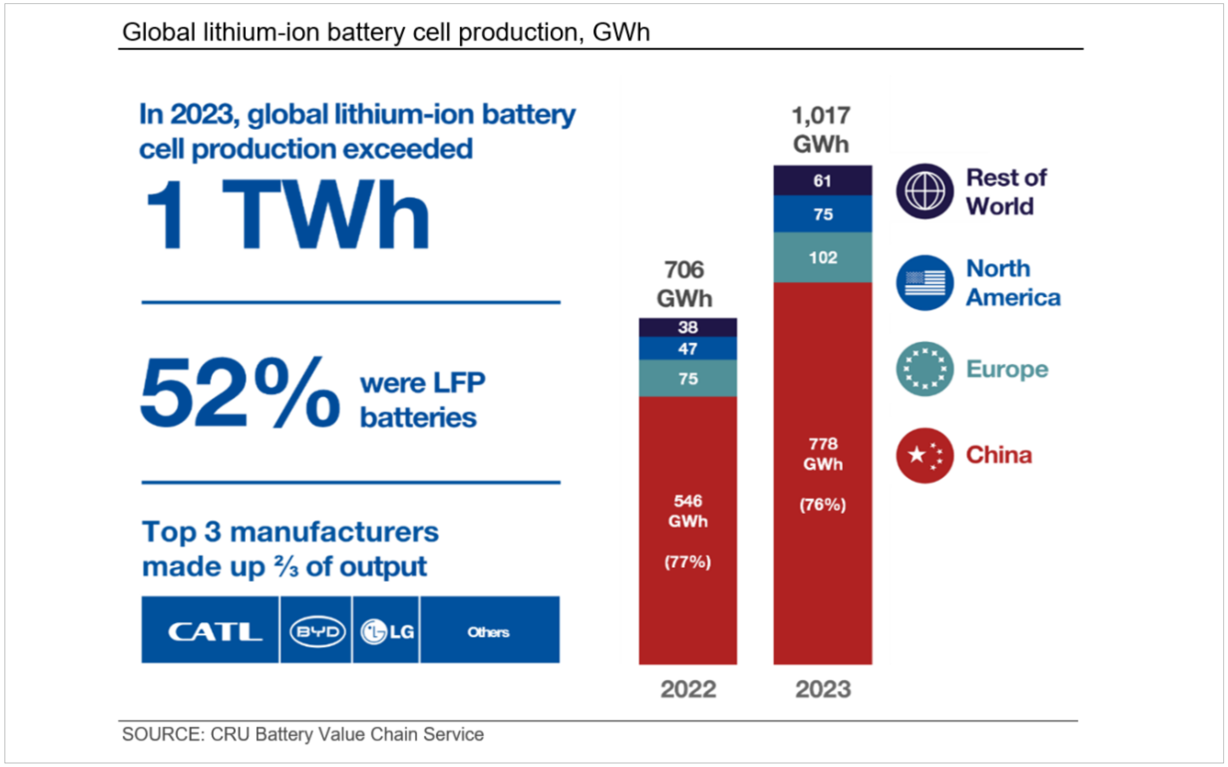


FIG. 6 Cathode share percentage in BESS chemistry. Reproduced from [5].

Introduction to Battery Terminology

BESS relies on several key terminologies, and understanding these terms is essential for evaluating its performance, efficiency, and longevity in applications such as grid stabilization, renewable energy integration, and peak shaving such as:

- **Battery Capacity:** It is the total amount of electrical charge a battery can store and deliver. It indicates “how long” a battery can supply a current before being fully discharged.
- **Battery Life Cycle:** It refers to the number of charge and discharge cycles it can complete before losing performance. For example, NMC batteries can achieve 1000-2000 charge-discharge cycles, while LFP batteries can handle 3000 cycles or more.
- **Depth of Discharge (DoD):** DoD is the percentage of a battery’s total energy capacity that can be used without degrading its lifespan. The higher DoD, the more battery capacity before recharging it.
  - Many Li-ion batteries have DoD of 80% which means the battery may be discharged to 20% of its full capacity without causing internal damage.
- **C-rate:** Defines the rate at which a battery charges or discharges relative to its maximum capacity. The higher the C-rate, the faster battery is charged or discharged e.g. low C-rate C/100, means 100 hours to fill to capacity; high C-rate 10C, means 1/10 of an hour to fill to capacity.
  - The faster the battery is charged the more electric current is fed into the battery for chemical reactions which causes the cell to heat up. Moreover, it might cause Lithium plating or thermal runaway which causes the battery failure.
  - To calculate the C-rate two parameters are needed: Battery capacity and current, either for charge or discharge.

C-rate (Hours)

=

Battery capacity (mAh) / Current (mA)

Introduction to Battery Terminology

- **State of charge:** It refers to the percentage of the remaining energy in the battery of its maximum capacity.
- **State of Health (SoH):** It represents the battery's overall condition in terms of aging and performance.
- **Energy Density:** The amount of the energy a battery can store per unit of weight or volume.
- **Power Density:** This is the amount of power a battery can deliver per unit mass or volume, which means that "how quickly" the energy will be released. High power density can lead to deliver a large amount of power in a short time.
- **Current Density:** This is the amount of current flowing through a cross-sectional area.
  High current density typically leads to higher power output as the large current flows through a small area of the electrode. However, it may cause heat generation or electrode degradation.
- **Round-trip Efficiency:** It refers to the ratio of the electricity output from the storage device to the electricity input to the device during one charge/ discharge cycle, considering losses during the charging/ discharging.

Common Risks Associated with BESS

Like any technological system, Battery Energy Storage Systems (BESS) offer several advantages but also present potential hazards. These hazards can affect the operational efficiency of the systems and pose significant safety risks.

The Electric Power Research Institute's (EPRI) 2024 report, titled "Insights from EPRI's Battery Energy Storage Systems (BESS) Failure Incident Database," provides a thorough analysis of the risks associated with BESS. Currently, the most common risks identified within BESS include the following:

- **Thermal Runaway and fire hazards:** Thermal runaway is a situation in which the battery self-heats uncontrollably. This condition is occurring when the heat internally generated exceeds the ability of the cell's dissipation capability. This can lead to the emission of flammable and toxic gases, causing a chain reaction of the same issue withing adjacent cells.

  Thermal runaway may lead to the release of toxic and ignitable gases including hydrogen. When introduced to oxygen these can ignite and cause an explosion.

  Lithium battery fires can be difficult to extinguish as the burning battery cells generate their own combustion and oxidation gasses.

- **Toxic Gas Emissions:** Some battery chemistries produce toxic or combustible gases, including carbon monoxide, carbon dioxide, hydrogen methane, ethane and other hydrocarbons.
- **Stranded Energy:** This is usually a form of post event damage leading to the BESS being unable to discharge its stored energy leading to electrocution risks.

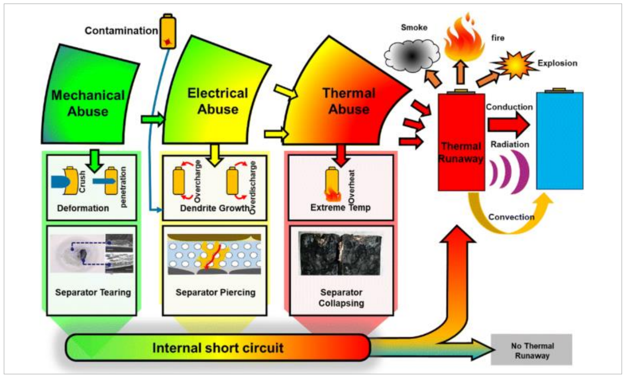


FIG. 7 Schematic representation of thermal runaway and its propagation. Reproduced from [6].

Typical Root Causes of BESS failures

Incidents are mainly attributed to issues in design, manufacturing, integration, assembly, construction, and operation. Failures typically occur in components such as cells, modules, control systems, or other specific elements.

The root causes of BESS failures are mainly attributed to system defects (72%), cell defects (15%) and module defects (13%).

The leading root cause of incidents is integration (wiring, coolant systems, safety mechanisms), assembly and construction issues followed by design, operation and manufacturing incidents often occur early in project's lifecycle; during construction, commissioning or withing first two years of operation.

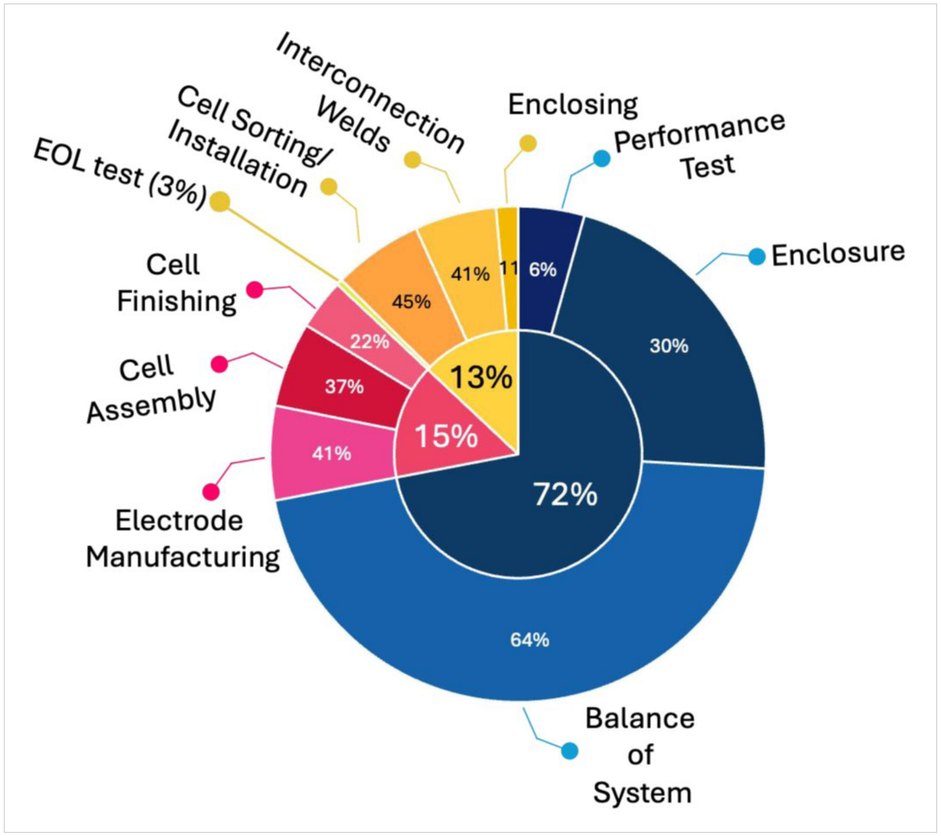


FIG. 8 Breakdown of failures and quality risks in BESS - Clean Energy Report 2023, from [1].

Typical Root Causes of BESS failures

The chart below illustrates EPRI's analysis of battery energy storage system (BESS) failure incidents from 2011 to 2023, detailing identified root causes as well as those that remain unexplained. A notable increase in failures began in 2018, peaking around 2019 and again in 2023, which aligns with a rise in deployments. During this same period, the overall rate of incidents fell. However, a significant number of incidents each year lack clear explanations, underscoring the challenges associated with failure analysis.

The typical root cause of the risks discussed above can be usually traced to the following factors:

- **Thermal Maloperation:** arises from external factors leading to overheating. Adjacent overheated battery cells, elevated ambient temperatures, or other external heat sources can cause the BESS to operate outside of the design temperature range.
- **Electrical Maloperation**: occurs when a battery is subjected to a short circuit, overcharged, charged too swiftly, or outside of prescribed voltage parameters.
- **Mechanical Damage**: Physical damage, such as being crushed, dropped, or distorted by mechanical forces, can compromise the integrity and function of cells.
- **Internal Faults:** Sometimes, the issue can be intrinsic, originating from flaws during the manufacturing phase, the employment of substandard or contaminated materials or even design inadequacies.
- **Environmental Impacts**: While rare, the increasing incidence of natural disasters, including seismic activity and floods, can cause BESS installations to fail. Notably, as highlighted by the Financial Times, insurers have seen a rise of USD 50 billion in losses this year alone due to NatCat losses. Furthermore, placing systems next to marine environments or deserts can accelerate the corrosion of a system due to salinity or sand abrasion.

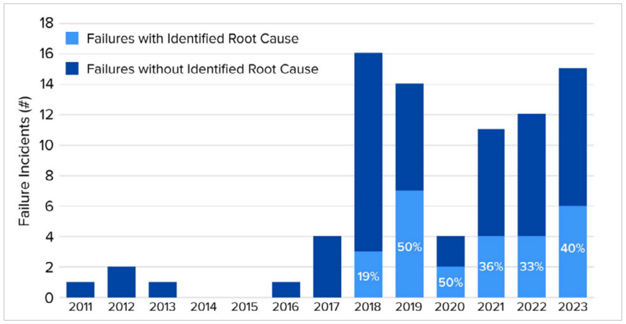


FIG. 9 Failure statistics for identified and unidentified root causes between 2011-2023 - EPRI White Paper (2024) [7].

Typical Risk Management & Safety Protocols

When planning a BESS facility, it is important to enforce a set of safety protocols to prevent malfunctions, potential hazards and to safeguard human life. These can include the following:

- **Thermal Runaway Detection:** Incorporating devices specifically approved for detecting and controlling thermal runaway can preventing uncontrolled heating which may lead to fires.
- **Design Certification:** Utilising certified components which comply with recognized industry standards typically improves the likelihood that they operate safely under varying conditions.
- **Non-combustible Housing:** Encasing battery systems in non-combustible housings can help to minimise the risk of fire propagation.
- **Choice of Location:** Positioning BESS installations away from other critical infrastructure can mitigate the risk of personal injury, especially considering potential toxic gas emissions that may be released. This is an important consideration since placing BESS installations in proximity to sensitive areas like schools and hospitals can improve the reliability of the electrical supply.
- **Adequate Ventilation:** Ensuring proper ventilation for battery systems can help to disperse any accumulated toxic gases and maintain the correct operating temperature.
- **Smoke Detection Systems:** Implementing advanced smoke detection mechanisms can provide early warnings, enabling swift action in the event of a malfunction.
- **Firefighter Training:** Equipping local firefighting units with the knowledge and tools to effectively combat BESS-related incidents and minimise harm to personnel and property.
- **Regular Maintenance:** Instituting periodic inspections and maintenance routines to confirm that all BESS components function correctly and efficiently.
- **Thermal conditioning systems:** Utilizing thermal management systems to maintain internal temperatures within design requirements.
- **Data Acquisition System:** The BESS should have a comprehensive data monitoring system that: monitors electrical power and operational metrics, sounds alarms during potential safety threats and signals when preventive maintenance is due.

Typical Risk Management & Safety Protocols

- **Protection Mechanisms:** BESS should be equipped with protective relays, circuit breakers, and fuses for protection against internal electrical faults.
- **Labelling:** All electrical devices and containers should be clearly marked, aligning with the final design blueprints.
- **Fire Systems:** Necessary fire detection and suppression systems should be installed, as dictated by regulations or manufacturer guidelines.
- **Emergency Guidelines:** Detailed instructions should be available onsite for essential tasks, like emergency shutdowns.
- **Wildfire:** Contractors should manage the vegetation around the BESS in order to mitigate fire hazards.

ROOT CAUSE	FAILED ELEMENT	MITIGATIONS AND RECOMMENDATIONS
Design	Controls, BOS	• Compliance with relevant codes and standards (UL, NFPA). Latest revisions have incorporated lessons learned from past failures. • Site-specific hazard assessments to consider all risks and failures. • Robust sensing and monitoring to provide early alert for design failures.
Integration/Assembly/ Construction	BOS, Controls	• Workforce training and quality checks during energy storage commissioning and installation. • System-level failure analysis, especially for interfaces between components.
Manufacturing	Cell/Module, Controls	• Increased manufacturing quality controls. • Supplier quality verification. • Robust system specifications. • Factory acceptance testing.
Operation	Controls	• Battery monitoring and analytics to augment BMS operation, generating trends and predictive analyses to identify potential failures early.

FIG. 10 Root causes and risk mitigation recommendations- EPRI White Paper (2024) [7].

Typical Risk Management & Safety Protocols

Despite a significant increase in global BESS deployments (from 1GW in 2018 to 65GW in 2023), the overall incident rate has declined dramatically. This suggests that lessons from earlier installations have been incorporated into newer sites, and safety measures have improved broadly.

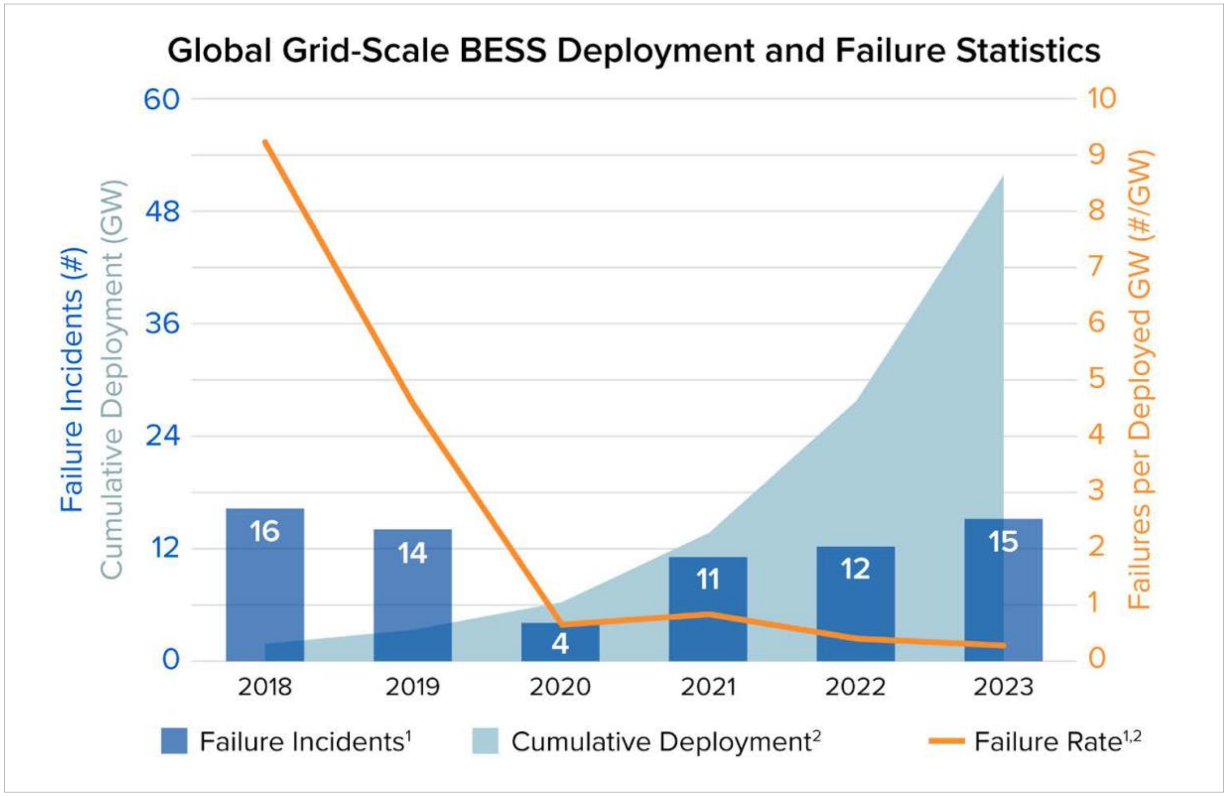


FIG. 11 Global grid-scale BESS deployment and failure statistics - EPRI White Paper (2024) [7].

Emerging Trends in BESS

Recent advancements in BESS are significantly enhancing the efficiency and integration of renewable sources into the power grid. The surge is driven by falling costs, technological advancements, and increased demand for renewable energy integration. Improved supply chains, declining Lithium prices, and increased market competition have significantly reduced storage costs, making BESS more accessible and scalable.

A notable trend is the substantial reduction in costs for solar panels and battery systems over the past two years, with decreasing prices by 66% and 58%, respectively. [9] In 2024, storage costs dropped by 40%, reaching $165 per kWh, less than half of 2019 ($375/ kWh) [1].

Overall, the value of the BESS market exceeded $90B, reflecting 20% financial growth compared to the 2023 market value of $75B [1].

The Volta Foundation's 2024 Battery Report highlights rapid growth in Battery Energy Storage Systems over the past year. Global BESS installations increased by 55% year-on-year, adding 69GW/ 169GWh of capacity, with Li-ion batteries comprising 98% of these deployments.

China's ambitious energy transition is evident in its battery storage deployment of 36GW which is followed by the US (13GW), Europe (10 GW) and Australia (2GW).

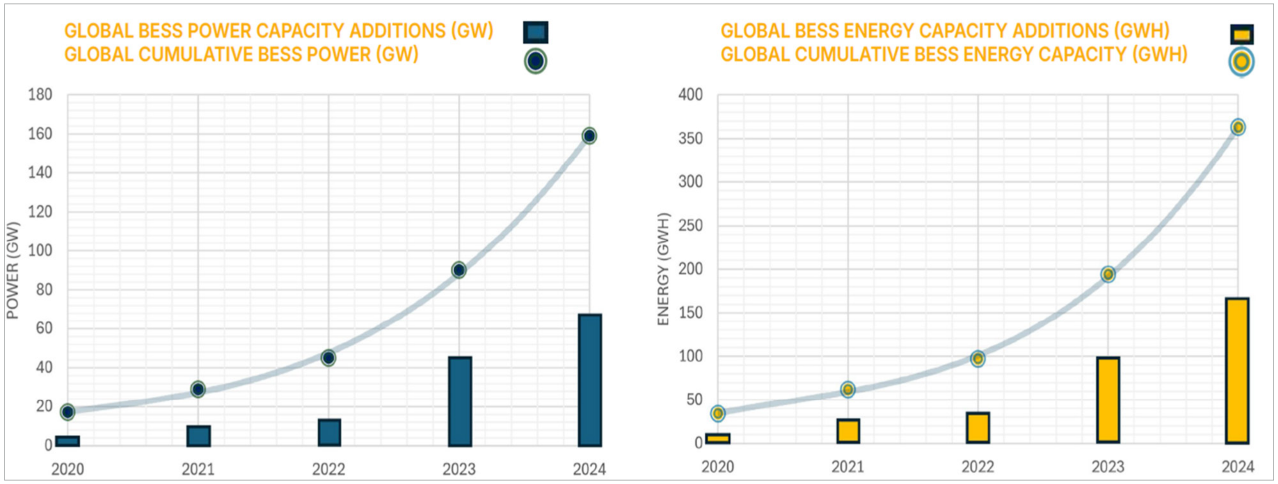


FIG. 12 Global Cumulative BESS Energy Capacity - Volta Foundation. Reproduced from [1].

Emerging Trends in BESS

The transition from Nickel Manganese Cobalt (NMC) to Lithium Iron Phosphate (LFP) batteries has contributed to longer storage durations and enhanced system stability. In 2024, the average storage duration increased by 33% to 2.4 hours, compared to 1.8 hours in 2020.

With energy storage becoming cheaper and more efficient, how soon will we see a fully renewable-powered grid? The trends suggest that future is closer than we think.

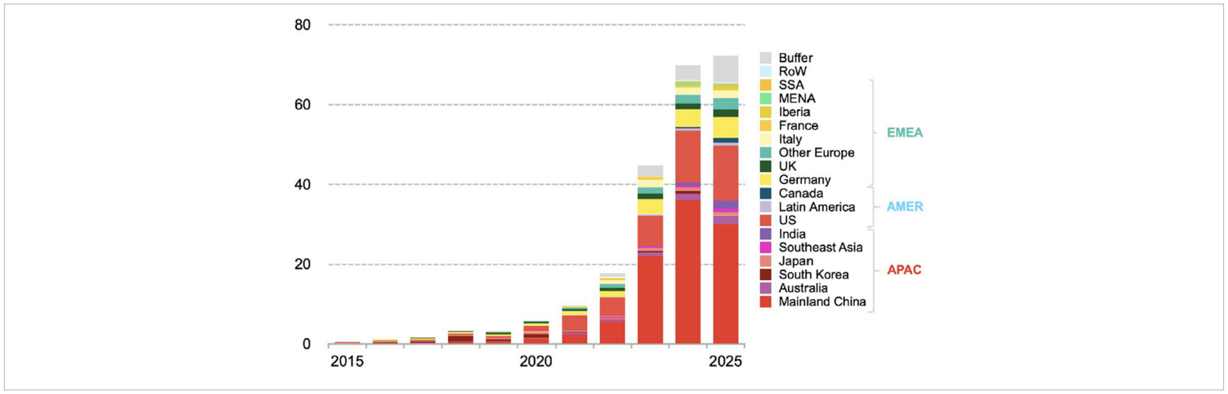
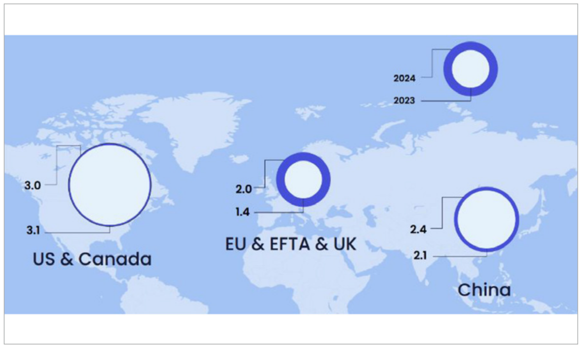


FIG. 13 Global BESS Energy Capacity by Region- Volta Foundation. Reproduced from [1].



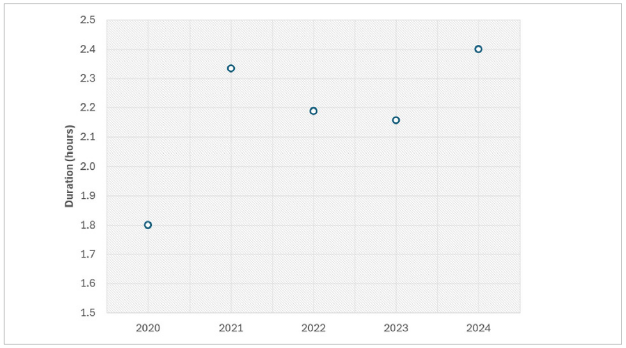


FIG. 14 & 15 (left))Average BESS Duration (hrs) by Region [10] (right) Global Average Duration (hrs) – Reproduced from [1].

International Standards

Battery Energy Storage Systems (BESS) international design standards cover aspects like electrical design, fire safety, environmental impact, and performance. Below are key international standards:

1. **Safety & General Design Standards**

   IEC 62933 series – International Electrotechnical Commission (IEC) standards for electrical energy storage systems, covering:

   IEC 62933-1 – Terminology

   IEC 62933-2-1 – Safety considerations

   IEC 62933-3-1 – Planning and performance aspects

   IEEE 2030.2.1 – Guide for design, operation, and maintenance of BESS in power systems.

   NFPA 855 – National Fire Protection Association (NFPA) standard for stationary energy storage system installations.

   UL 9540 – Safety standard for energy storage systems and equipment.

   UL 9540A – Fire test method for evaluating thermal runaway propagation in BESS.

2. **Battery Cell & Module Safety**

   IEC 62619 – Safety requirements for rechargeable lithium-ion batteries in industrial applications.

   IEC 62133 – Safety testing for secondary cells and batteries containing alkaline or non-acid electrolytes.

   UL 1973 – Safety standard for batteries used in stationary and motive applications.

   IEEE 1725 & IEEE 1625 – Battery safety standards, mainly for portable and lithium-ion systems.

3. **Fire Protection & Thermal Management**

   NFPA 70 (NEC) – National Electrical Code, covering electrical safety and wiring requirements for BESS.

   NFPA 69 – Standard for explosion prevention in energy storage installations.

   NFPA 72 – Fire alarm and detection systems related to BESS.

   FM Global 5-33 – Fire protection requirements for energy storage systems.

4. **Grid Integration & Performance**

   IEEE 1547 – Standard for interconnecting distributed energy resources (DER), including BESS, with electrical power systems.

   IEC 61427 – Performance testing for lead-acid and lithium-ion batteries used in renewable energy applications.

   IEC 61850 – Communication protocols for BESS integration with power grids.

International Standards

IEEE 2030.5 – Smart energy profile standard for communication and control of energy storage.

5. **Environmental & Transportation Standards**

   IEC 60721 – Classification of environmental conditions for BESS components.

   UN 38.3 – UN transportation testing for lithium-ion batteries to ensure safety during shipping.

   ISO 14040/14044 – Life Cycle Assessment (LCA) standards for environmental impact evaluation.

6. **Structural & Seismic Considerations**

   IBC (International Building Code) – Structural safety standards for BESS enclosures and installations.

   ASCE 7 – Seismic design requirements for BESS installations in earthquake-prone areas.

Conclusion, Summary & Recommendations

Battery Energy Storage Systems (BESS) play a crucial role in promoting renewable energy and achieving decarbonization. Their integration into electrical grids helps turn the vision of a sustainable future into a reality. However, while these systems generally exhibit low failure rates, it is important to recognize the significant risks they can pose when failures do occur.

Historical data and case studies provide valuable lessons. Although system failures are rare, they can lead to substantial financial liabilities, extensive property damage, and prolonged business interruptions when they happen.

Recommendations:

To ensure a sustainable energy future, it is essential to have a thorough understanding of BESS safety and potential failure mechanisms. Safety standards are necessary for the safe operation and handling of BESS and guide the industry towards best practices. As the field of BESS continues to evolve, these safety standards must also progress, adapting to the changing landscape of energy storage.

The following recommendations are suggested:

- Ensure adequate spacing between modules
- Ensure appropriate HVAC and partitioning is considered during design
- Early detection and fire suppression systems
- Regular inspections and maintenance of fire detection and suppression systems
- Compliance with safety standards and codes
- Establishing an emergency response plan and comprehensive workforce training on fire safety protocols and quality checks
- Ensure compliance with UL 9540 / UL 9540A for management of Thermal Runaway risk

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Appendix – Standards and Guidance

As technology within BESS is rapidly advancing, their testing standards also are evolving. Organisations, including the ISO, IEC, SAE, UL, SAC, and MIIT play important roles in battery industry safety, they have created many standards for BESS safety testing of cells, packs, and modules.

The main causes of BESS thermal runaway are broadly categorised as mechanical, electrical, or thermal mis operation. Therefore, safety tests are aligned with these categories, including mechanical tests (such as drop tests, vibration tests, and mechanical shock tests), electrical tests (such as external short circuit tests, overcharge tests, and over discharge tests), and environmental tests (such as thermal shock cycle tests, damp heat cycle tests, and external fire tests).

UK Government Advice on Lithium-Ion Batteries (Li-On).

No specific UK government advice has been published to date on Li-On cells and packs.

There has been general guidance published by the HSE relating to the safe use of lead acid and Li-ion batteries as follows:

- Trying to prevent any physical damage – impacts such as dropping, striking, or being struck.
- Protecting the batteries from exposure to high or low temperatures.
- Preventing over-charging and consequently reducing the risk of short circuits.
- Eliminating the use of lithium-ion batteries if they have been damaged in any way.

Official UK standards are believed to be coming out next year.

National Electric Code (NEC):

The current National Electric Code dictates that all installed equipment must be tested and approved by either the Underwriters Laboratories (UL) or another nationally recognised testing facility.

This includes the National Fire Protection Association (NFPA), Institute of Electrical and Electronics Engineers (IEEE) standards, American National Standards Institute (ANSI) standards, United Nations (UN) standards on transportation, Alternative International Electrotechnical Commission (IEC) standards, and American Society of Civil Engineers (ASCE).

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Relevant Certifications

Microgeneration Certification Scheme:

Battery Storage Standard (MIS 3012) outlines the installation requirements for MCS certified Installers involved with the supply, design and installation of electrical energy (battery) storage systems.

National fire protection association (NFPA)

The NFPA has enhanced testing criteria to include specific tests for various types of BESS. These tests encompass systems like indoor floor-mounted BESS, outdoor ground-mounted BESS, indoor wall-mounted BESS, and outdoor wall-mounted BESS. Each of these system types now has dedicated installation requirements, in alignment with the latest iterations of the International Fire Code (IFC), NFPA 1, and NFPA 855

- NFPA 70: This guideline dictates that all electrical circuitry associated with stationary energy storage systems must be housed within weather-resistant containers. These containers must meet specific environmental ratings to ensure they withstand different climatic conditions. The standard also includes other requirements relating to equipment grounding, conductor sizing, and fire propagation.
- 2018 IFC and NFPA 1 Fire Code: Introduced in 2018, these codes delve into the specifics concerning the size (or the electrical capacity) of a unit. They dictate separation guidelines and set the maximum allowable quantity, which pertains to the total electrical capacity allowed within a particular space. The purpose of these directives was to mitigate uncertainties related to thermal runaway and the consequent fire propagation in BESS.
- NFPA 855: Standard for the Installation of Stationary Energy Storage Systems: This is a newly developed standard by the NFPA. It serves as a comprehensive guide, covering various aspects of the design, construction, installation, commissioning, operation, routine maintenance, and even the decommissioning of BESS. While the scope is broad, there's a particular emphasis on traditional battery systems, such as the ones utilities commonly use.

National Electrical Manufacturers Association (NEMA):

NEMA establishes manufacturing and usage standards for electrical components. Including for electrical enclosures. These enclosures primarily act as protective shields for BESS and their related equipment, providing safety and longevity.

Underwriters Laboratory Standards:

In essence, the UL standards provide a robust framework ensuring the safety, functionality, and reliability of electrical and energy storage systems across different applications.

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UL standards relating to battery modules include:

- UL 1642 Standard for Lithium Batteries: This standard has traditionally been the certification basis for battery cells, predominantly associated with lithium-ion batteries, its focus has been portable consumer applications. However, it does not address the additional requirements required for motive applications or large stationary installations.
- UL 1973 Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications: Provides requirements for battery systems used as energy storage in various stationary applications, including photovoltaic (PV) systems, wind turbine storage, and uninterruptible power supply (UPS) systems.
- UL 9540 Energy Storage Systems and Equipment: This standard sets forth the requirements for energy storage systems intended to store and supply electrical energy to power systems, ranging from local setups to extensive utility grids.
- UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems: A comprehensive test method designed to assess and measure the potential risks and behaviours of battery energy storage systems during thermal runaway scenarios.

UL grid interconnection standards include:

- UL 1741 Standard for Static Inverters and Charge, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources: This standard provides a framework for the requirements of various electrical components like inverters, converters, and charge controllers. These components can be used in both standalone systems (those not connected to the grid) and or grid-connected systems.

Institute of Electrical and Electronics Engineers (IEEE):

The IEEE standards offer a comprehensive blueprint for the seamless, efficient, and safe integration of electrical systems, energy resources, and storage solutions in the broader electrical infrastructure.

- IEEE 1547: The technical specifications for, and testing of, the interconnection and interoperability between utility electric power systems (EPSs) and distributed energy resources (DERs) It includes aspects like performance, operation, safety, and maintenance of these interconnected systems.
- IEEE 2030.2 Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure: Serving as a guide, this document elucidates the integration guidelines for both discrete and

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- hybrid energy storage systems (ESSs) with the broader electric power infrastructure. It covers diverse scenarios, including different end-use applications and load considerations.

United Nations (UN):

In essence, these regulations ensure that lithium batteries are transported under stringent safety protocols, minimizing potential hazards.

UN 38.3 Certification for Lithium Batteries (Transportation): The UN, recognising the potential risks associated with the transportation of lithium batteries, has established specific guidelines for their safe transit. This certification stipulates the necessary requirements for lithium battery transportation testing.

Additionally, organisations such as the International Air Transport Association (IATA) and the U.S. Department of Transportation (DOT) emphasise the importance and enforcement of these UN standards.

American National Standards Institute (ANSI):

American National Standards Institute (ANSI) C12.1 electricity metering: The current edition of this provides a comprehensive framework for electricity metering. It outlines the performance criteria that new types of alternating current, watthour meters, demand meters, demand registers, pulse devices, and auxiliary devices must adhere to. It also sets standards for the in-service performance levels of meters and related devices used for revenue generation purposes.

A significant portion of the standard delves into the testing and installation protocols of these meters. It considers various challenges that meters might face throughout their lifecycle.

International Electrotechnical Commission (IEC):

These standards, aim to ensure the safety and durability of lithium batteries, especially considering the potential risks associated with their mishandling or accidental drops.

IEC 62619:2022: specifies requirements and tests for the safe operation of secondary lithium cells and batteries used in industrial applications, including stationary applications.

IEC 63056-2020: This contains drop test height specifications for different weight classes pf batteries.

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Local Fire Fighters Involvement:

Design Consultation and Approval:

It's imperative for the Contractor overseeing the BESS project to actively engage with the local fire marshal or other fire protection authorities. Their involvement ensures the design meets fire safety standards and receives necessary approvals. The Contractor should also align the design with established guidelines, such those set by the International Association of Fire Fighters and the most recent edition of NEC code.

Training and Awareness:

Local firefighters should be offered training sessions, orchestrated by the Contractor, detailing the operation of BESS. Essential topics include BESS shutdown procedures, and the formulation of a fire suppression plan tailored to the specific system. This equips first responders with the knowledge required to take swift and safe actions during crises.

Safety Markings and Setback Requirements:

The Contractor, in coordination with the fire marshal, should identify optimal locations to display permanent instructions and mandatory safety markings on the BESS. These instructions are crucial for immediate reference during emergencies. Additionally safe distances should be maintained from potential hazards. The emphasis is on safety, ensuring that first responders have clear guidelines and easy access during emergency operations.

ASTM E681-09(2015):

Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapours and Gases). This standard provides a test method to ascertain the concentration limits concerning the flammability of chemicals, especially those with sufficient vapor pressure. It helps in determining the formation potential of flammable mixtures in the ambient atmosphere.

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