White Paper on Lithium Batteries for Telecom Sites

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Preface

Building a high-quality and reliable battery infrastructure for telecom networks

In the digital era, lithium-ion batteries (lithium batteries for short) have become a crucial force in energy transition considering the advantages of high energy density, [1] long lifecycles, and easy deployment of intelligent technologies. Lithium batteries are widely used, from small-sized electronic devices to large-scale energy storage systems (ESSs). However, as lithium batteries have been extensively used, so safety issues have arisen and accidents have occurred frequently, causing severe losses. While lithium batteries are considered safe in most cases, issues such as short circuits and leakage still occur due to improper materials, inappropriate design or defective manufacturing. These defects, together with external environment factors, have caused fires or explosions, and have posed a serious threat to life and property.

In recent years, lithium batteries have been widely used as backup power supplies in telecom sites to mitigate unexpected power outages and ensure the continuity of telecom services. As critical infrastructure for information transmission, telecom sites must operate reliably to ensure environmental safety, economic development and social stability. Consequently, lithium battery safety is a key concern, as any minor faults may cause severe consequences. To maintain network reliability and stability, robust safety and performance standards must be implemented for lithium batteries in telecom applications.

Facing this challenge, the International Telecommunication Union (ITU), as a leading international standards body in the telecom industry, always stands at the forefront of technological advancements, closely monitoring and analysing emerging issues in lithium battery safety, and studies them in depth. To cope with the safety risks of lithium batteries in telecom sites, ITU conducts extensive research, has strengthened the formulation and amendment of lithium battery safety standards. ITU also collaborates with its members to propose the concept of "high-quality lithium battery" to lead the industry toward higher safety, reliability and efficiency through a series of scientific and rigorous standards and specifications.

To achieve higher levels of safety and reliability, and an a more efficient network, it is necessary to design, manufacture and use a "high-quality lithium battery".

Not only does this require excellent performance parameters for the battery, it also emphasizes the end-to-end battery safety features, including high-quality design (such as the intrinsic safety of cells), electrical, thermal and mechanical protection, high-quality testing, and high-quality production and manufacturing.

This white paper provides an overview for lithium batteries focusing more on lithium iron phosphate (LFP) technology application in the telecom industry, and contributes to ensuring safety across the entire lithium battery supply chain.

Focused on the theme of "building a high-quality and reliable battery infrastructure for telecom networks", this white paper discusses the safety of lithium batteries in telecom sites, analyses the terminology of "high-quality lithium battery," and contributes to promoting the safe, reliable and efficient application of lithium batteries in the telecom industry.

1 Energy density is measure as Wh/kg and it refers to gravimetric energy density.

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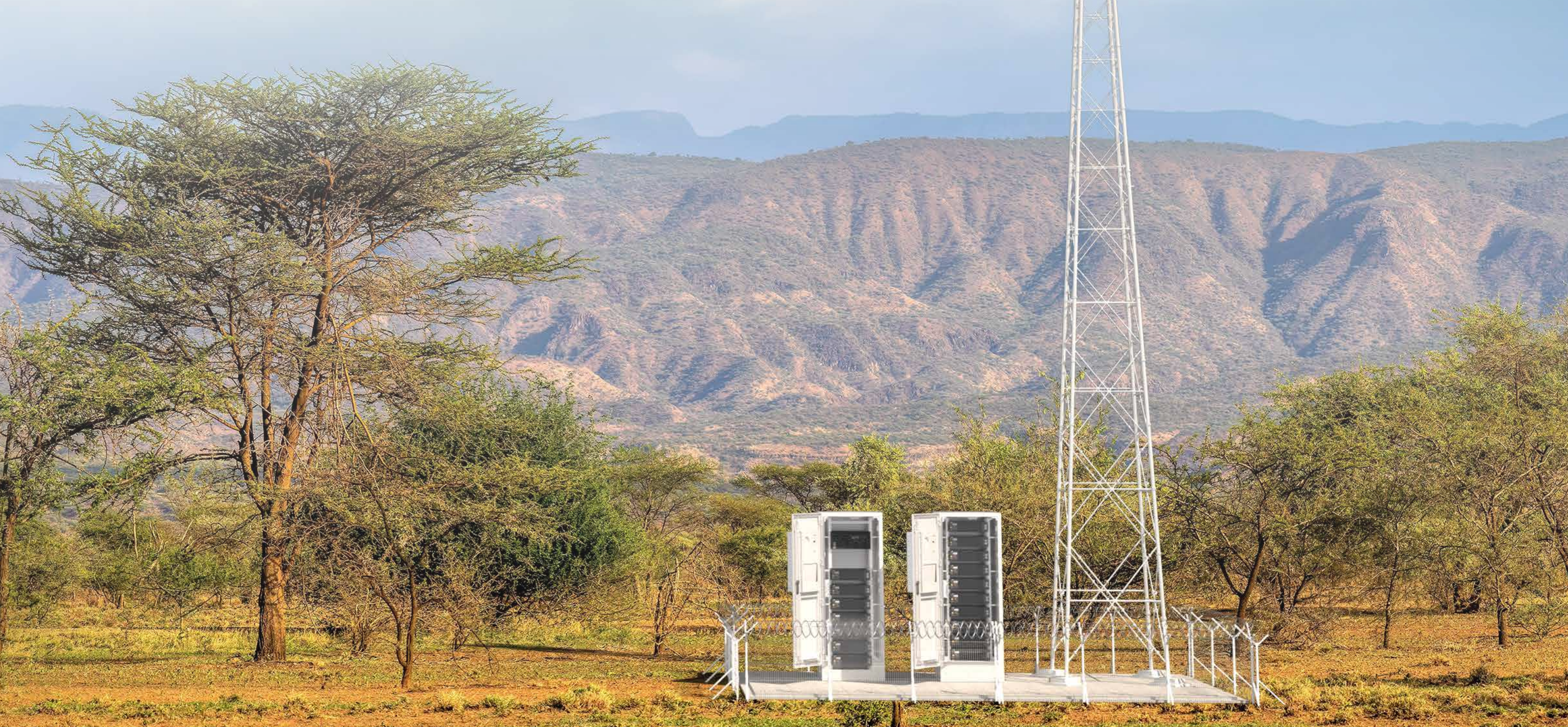


01

Development trends of batteries at telecom sites

1.1 Definition of batteries for telecom sites

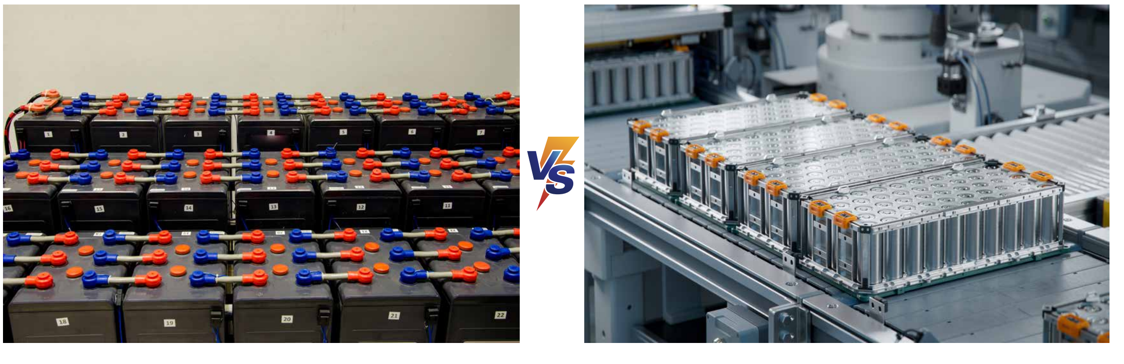
Batteries are indispensable for telecom sites. They function as “energy guardians” by providing backup power supplies in case of power outages to ensure uninterruptible communication at telecom sites. With the wide application of 5G and AI technologies and the continuous evolution of future telecom technologies, the importance and reliability requirements of these batteries are increasing. In addition, as telecom sites are gradually transforming into new service platforms such as virtual power plants (VPPs) to provide diverse services, higher requirements are posed on the safety of telecom sites and the reliability of energy storage systems (ESSs). The industry is continuously pursuing technological innovation and optimization of operation and maintenance (O&M) to meet increasingly complex and dynamic telecom demands.

Figure 1 Battery business panorama for telecom sites

1.2 Comparison of battery types at telecom sites

There are various types of batteries for telecom sites, including the lead-acid battery and lithium-ion battery. These types of batteries may differ in energy density, charge and discharge efficiency, as well as service life.

Figure 2 Lead-acid battery and lithium-ion battery

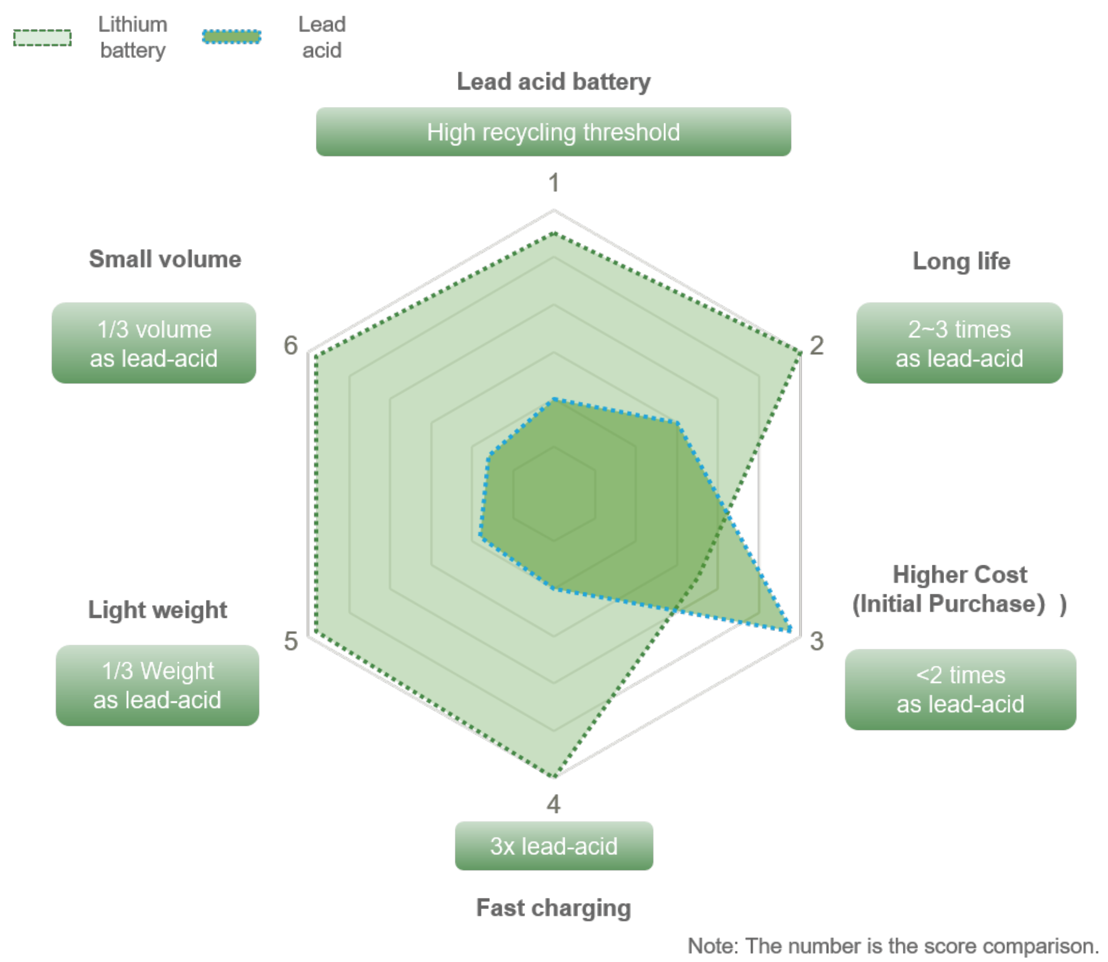


The following table shows the differences between a lead-acid battery and a lithium-ion battery.

Table 1 Differences between lithium and lead-acid batteries

Battery Type	Advantage	Disadvantage	Application Scenario
Lithium-ion battery	• Higher energy density and more energy stored in the same battery size • Longer service life and more charge and discharge cycles • Faster charge and discharge speed • Lower self-discharge rate and more environment-friendly • Easier to implement intelligent control • Lower maintenance costs	• Higher purchase costs • Degradation may be accelerated under high temperature conditions, and there is a risk of thermal runaway • Theft risks • Poor performance in low temperature • Fire protection within battery room (inside building) is needed	• ESSs • Telecom base stations • Data centres • Electric vehicles (EVs) • Consumer electronics
Lead-acid battery	• Lower purchase costs • Higher safety • Better performance at high and low temperatures, working temperature range of -40°C to +60°C	• Lower energy density • Shorter service life, requiring more frequent replacement • Made from harmful heavy metal (lead), polluting environments • Low recycling threshold • High theft risks	• Cost-sensitive backup power • Low-speed EVs

Figure 3 Example of lithium battery advantages: high energy density, long service life, fast charging speed, and anti-theft



In addition, there are multiple types of lithium-ion battery, including the lithium iron phosphate (LFP), lithium nickel-cobalt-manganese oxide (NCM), lithium cobalt oxide (LCO) and lithium manganese oxide (LMO). Among these, NCM and LFP are the most widely used in the market. Their major differences between NCM and LFP are as follows.

Table 2 Differences between NCM and LFP battery

Battery Type	Advantage	Disadvantage	Application Scenario
NCM battery	• Higher energy density • Better low-temperature performance • Wider range for charging and discharging power values	• Higher purchase costs • Higher safety management requirements • Shorter battery cycle in high temperatures • Possibility to thermal runaway at high temperatures	• ESS • Long-range EVs • Large scale renewable energy sources integrated ESSs
LFP battery	• Higher safety • Longer battery cycles • Lower purchase costs	• Lower energy density • Possibility to thermal runaway at high temperatures	• ESSs • Medium-low range EVs • Backup system for telecom sites or data centers

Featuring excellent performance, comprehensive capability and a high level of safety, LFP batteries are widely used across various sectors, while NCM batteries are mainly used in EVs.

In the 5G era, telecom sites consume a large amount of energy but tend to take up very little space; therefore, they have high requirements for energy density, charge and discharge efficiency, and intelligent control. In addition, telecom sites require extremely high standards of safety and reliability. Consequently, in actual applications, apart from some traditional base stations and sites with low reliability requirements, LFP batteries are increasingly widely used in 5G sites.

Figure 4 Typical application scenarios of batteries at telecom sites

Equipment room site

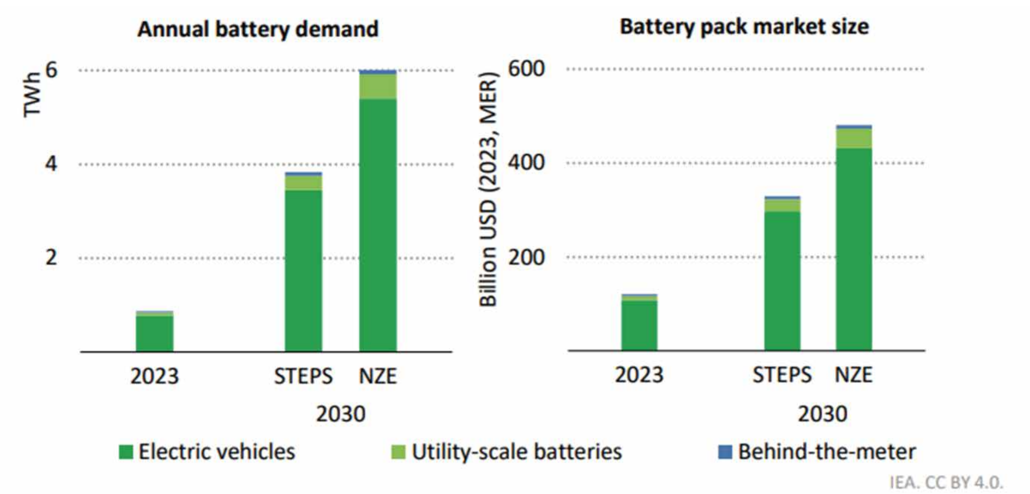
Outdoor site

Outdoor blade site

1.3 Capacity and growth trend of lithium batteries at telecom sites

In recent years, driven by the development of the electric vehicle (EV) industry, the global battery industry has experienced rapid growth. According to the report by the International Energy Agency (IEA), global battery production reached a new record in 2023, with total output hitting 800 GWh, marking a 45% increase compared to 2022. Progress on electromobility and renewable power generation through to 2030 is set to give a major boost to the battery pack market, driving global battery demand to exceed 3.8 TWh. Under the "Nearly Zero Emissions" (NZE) scenario, the global demand for lithium batteries alone is expected to surpass 6 TWh by 2030. The market size is anticipated to grow from $1.2 trillion in 2023 to $3.3 trillion by 2030, and under the NZE scenario, it could rise further to nearly $5 trillion.

Figure 5 Annual battery demand and battery pack market size by application and scenario, 2023 and 2030



Data source: Batteries and Secure Energy Transitions, IEA, 2024.05[2]

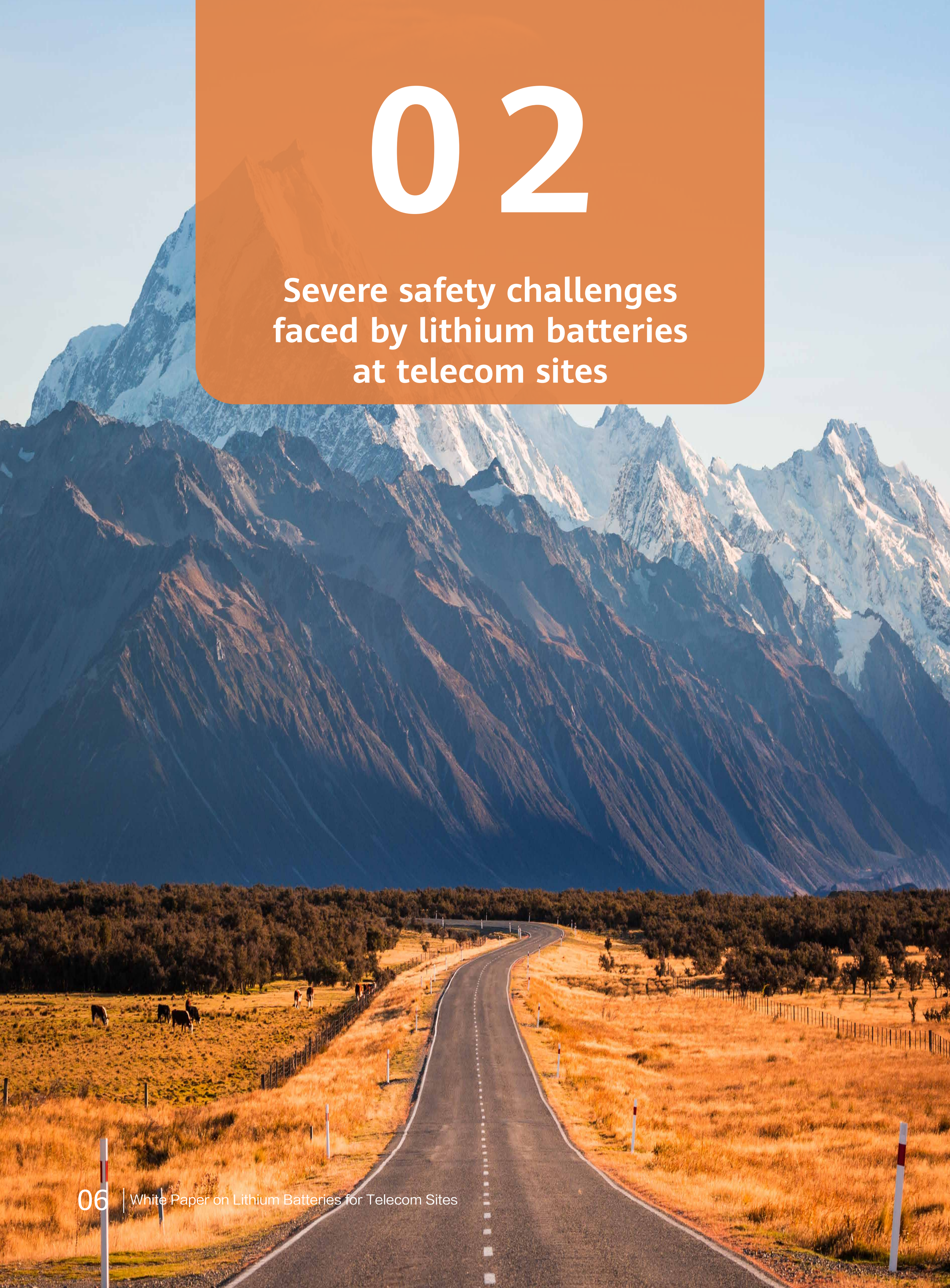
The expansion of lithium battery market has made their prices more affordable and highlighted their performance advantages, further driving the rapid growth of the global telecom lithium battery market. According to publicly available data, top-tier operators in Europe, the Middle East, and China are increasingly adopting lithium batteries for energy storage in their new sites.

While specific market data for telecom lithium battery installations is limited, forecasts of the global market share for telecom lithium batteries will continued growth.

2 IEA: Batteries and Secure Energy Transitions, https://www.iea.org/reports/batteries-and-secure-energy-transitions

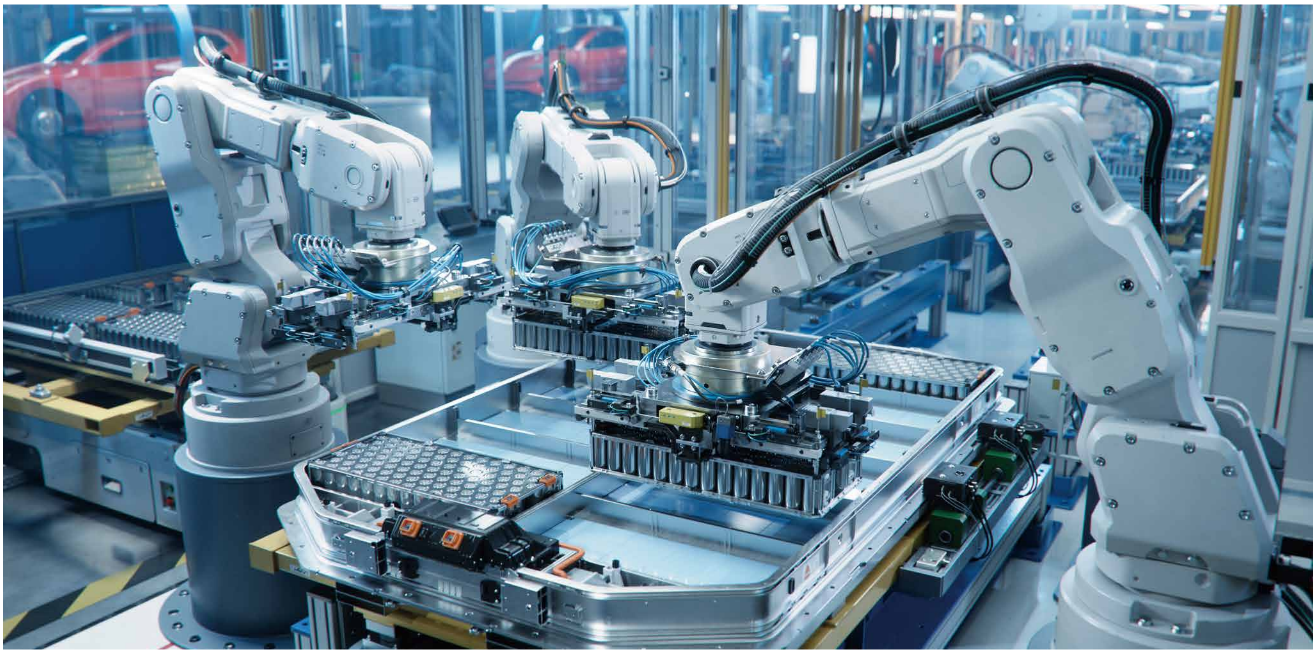
02

Severe safety challenges faced by lithium batteries at telecom sites



Lithium batteries are widely used and have become mainstream in energy storage. However, safety incidents involving lithium batteries have occurred frequently, and continue to raise social concerns. From the explosion of smartphones, the spontaneous combustion of EVs, to the fires at ESS plants, each incident has led to huge property losses and even casualties, which has attracted widespread attention worldwide. For example, in 2022, a lithium battery fire broke out in the data center of South Korea's SK Group, causing a large area of Internet breakdown across the country; In 2023, A data center in France operated by Maxnod has suffered a devastating fire, bringing the French facility offline and severely damaging infrastructure.

In response, governments and international organizations have developed and implemented various policies, regulations and standards to strengthen the safety supervision of lithium batteries and ensure the safety application of lithium batteries in various application scenarios. For example, the European Union (EU) has implemented its rigorous "Regulation (EU) 2023/1542", requiring battery manufacturers to pass stringent safety tests. The UL has published the UL 9540 "Standard for safety for Energy Storage Systems and Equipment", which specifies safety requirements for the design, installation and operation of ESS plants installed in USA.



2.1 Lack of specific safety standards for lithium batteries at telecom sites where low-quality lithium batteries are widely found

Although the need for lithium battery safety is a global concern, there has been scant attention with regard to its applications in telecom sites. As data hubs of the information society, many telecom sites use lithium batteries as backup power supplies. As show in section following, there are standards and regulations applicable to lithium battery. However, there are a lack of standards for lithium battery used in telecom sites. Additionally, there is a lack of stringent supervision of battery during its operation phase.

Compared to EVs and large-scale ESSs, the safety problems of lithium batteries are less overt but also more likely to be critical. Once an accident occurs, communications will be interrupted, affecting social operations and posing serious threats to the surrounding environment.

2.2 Complicated application environments expose safety risks of low-quality cells

2.2.1 Complex application scenarios of lithium batteries at telecom sites require high reliability

• Lithium battery system structure

The Lithium Battery System is an energy storage module, also called a Lithium Battery Pack. It consists of lithium battery cells, a battery management system (BMS), mechanical enclosure for electrical protection, and other auxiliary facilities.

The lithium battery cells are the core component of the Lithium Battery System. It consists of multiple cells connected in series and parallel. Energy is stored and discharged through conversion between electric energy and chemical energy.

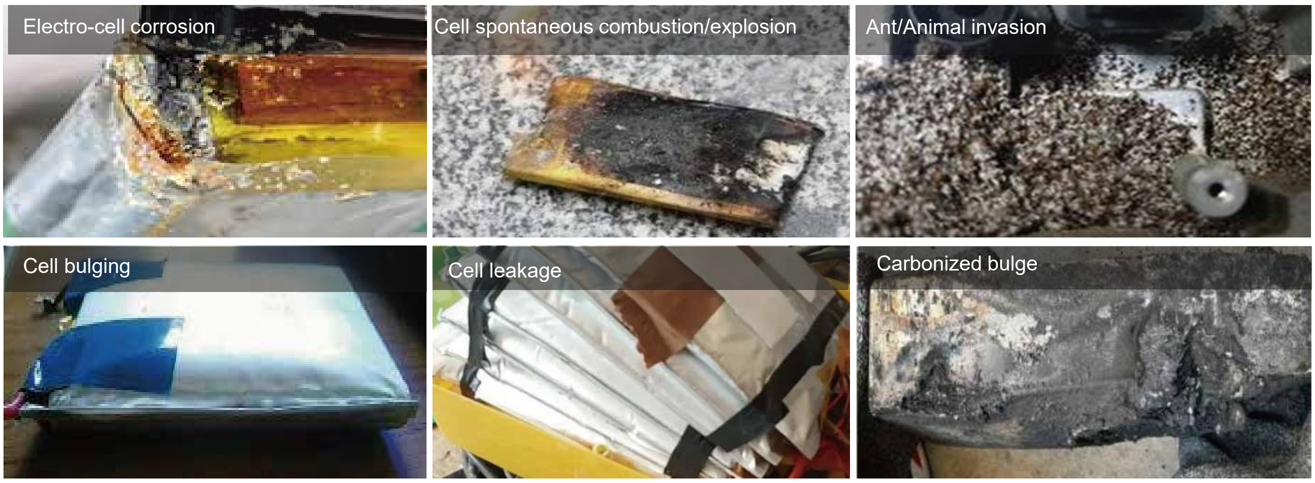
BMS is a general term for a circuit system that ensures healthy operation of cells and an entire battery system. The BMS collects parameters such as the total voltage of the lithium battery system, cell voltage, charge/discharge current, and temperature, detects the charge/discharge process of lithium batteries and provides effective protection and alarm functions.

Figure 6 Example of the lithium battery structure for telecom sites

• Complex Application Scenarios

Compared to a utility-scale ESS, a Lithium Battery System is used in a more variable and harsher telecom site. Telecom sites are usually distributed in remote areas or along urban edges, where they face multiple challenges such as mechanical shocks, biological intrusion, water intrusion, condensation and overtemperature. These environmental factors are important causes of lithium battery accidents. After low-quality lithium batteries have run for one to two years under these harsh conditions, they are prone to lithium plating, bulges, deformation, leakage, corrosion and short circuits, which may lead to more serious consequences such as fire and explosion, and may threaten the safety and stability of telecom networks.

Figure 7 Frequent quality accidents after one to two years of running of low-quality cells



2.2.2 Low-quality lithium batteries are the key to frequent safety accidents

The lack of unified lithium battery safety standards (especially in the fire protection and thermal runaway) in the telecom industry allows the entrance of lithium batteries into telecom markets that do not pass a high-reliability test or do not have a supervised production; this increases the safety risks of lithium batteries.

The quality of lithium batteries is reduced in order to lower costs; some substandard cells are used, and even repurposed retired batteries from vehicles are utilized as raw materials for new cell production without any strict control of the cells' conditions. Although the costs are reduced, these batteries cannot support long-term, stable running of telecom sites as backup power due to quality defects or safety risks. As a result, safety accidents are prone to occur.

1. Improper BMS design

As the "brain" of lithium batteries, the BMS is designed to ensure the safety and lifespan of the battery system. However, the current BMS in the industry still has limitations, including low indicator detection precision, poor heat dissipation performance and insufficient electrical protection design, and cannot accurately ensure the cells' health. In practical applications, if issues such as partial carbonization due to overtemperature and multiple electrical faults are not handled in a timely manner, the service life of lithium batteries will be shortened, and incidents such as short circuits or thermal runaway would be more likely to occur.

2. Insufficient safety protection for battery packs

As the physical support and protection barrier of the battery system, battery packs require high-quality design and manufacturing. As lithium batteries are designed to last for a long time, cells may experience bulging over time. During transportation and operation, batteries are inevitably exposed to external shocks, drops, moisture, condensation, and biological intrusion. Currently, lithium battery packs in the industry often suffer from issues such as poor sealing, insufficient mechanical strength, and poor safety protection. Therefore, they can hardly resist internal stress and external environmental influence, leading to frequent malfunctions and, in severe cases, fire or explosion hazards.

3. Defective manufacturing

Due to the lack of effective supervision mechanisms and laws and regulations, lithium battery manufacturing defects occur frequently. For example, screws are not tightened, foreign metal matter remains, and cables are in poor contact. These defects may cause battery fires and explosions.

2.3 Manufacturing high-quality and safe lithium batteries

Quality must not be compromised to reduce costs. Although some low-quality lithium batteries cost relatively little, the money saved during production will be paid during application. In practice, low-quality lithium batteries cannot meet the requirements for the long-term stable running of telecom sites. To ensure site safety, O&M personnel on the application side have to visit sites frequently to locate and rectify faults, so increasing the O&M costs of carriers. In addition, battery faults cause network interruptions, decrease the site utilization rate, and even affect social and economic activities, bringing immeasurable service losses, regulatory penalties, and even goodwill losses to mobile network operators.

Manufacturing high-quality lithium batteries is the only way to eliminate safety risks of lithium batteries at telecom sites. The telecom industry shall strengthen the supervision and control over the quality of lithium batteries and promote the development of dedicated safety standards and technical specifications. In addition, vendors shall be motivated to increase R&D investment, improve the cell quality and BMS design level, enhance the battery pack safety protection design and improve the manufacturing process. High-quality lithium batteries provide safe and reliable backup power for telecom sites and ensure the stable operation of telecom networks.

03

Using high-quality safe lithium batteries to build a robust network infrastructure

3.1 Definition of high-quality safe lithium batteries: comprehensive quality and safety across all dimensions and processes

High-quality lithium batteries are typically defined as those that are safe, reliable, have superior performance, and offer a long lifespan.

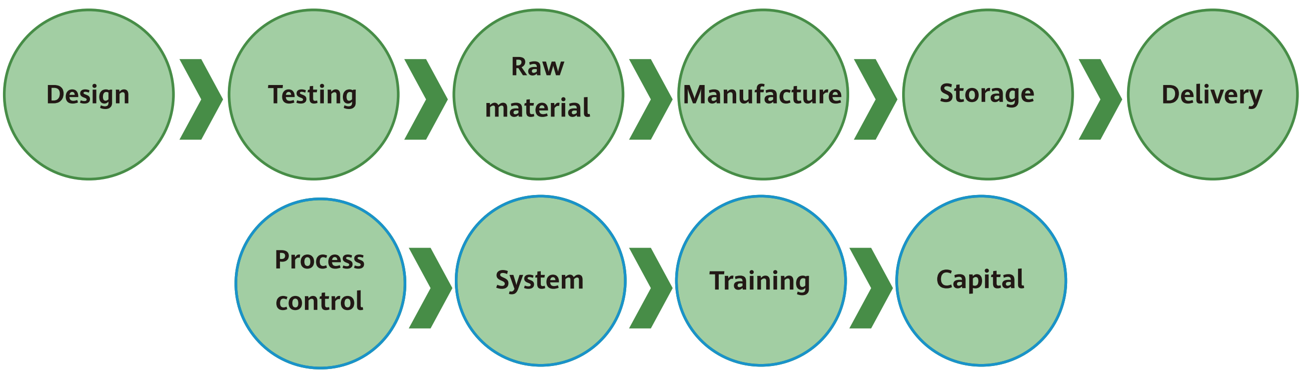
Superior performance: This usually manifests as high energy density and high-rate charge/discharge capability, meaning they can store more power and charge/discharge more quickly and stably given the same volume and weight.

Long lifespan: This means that in practical applications, the lithium batteries can maintain a high level of performance even after numerous charge and discharge cycles.

Safety and reliability: This entails adhering to safety standards across the entire chain of design, materials sourcing, manufacturing, storage, transportation, and delivery of lithium batteries. A comprehensive safety protection mechanism is employed to prevent risks such as leakage, fire, explosion, overtemperature and electric shock.

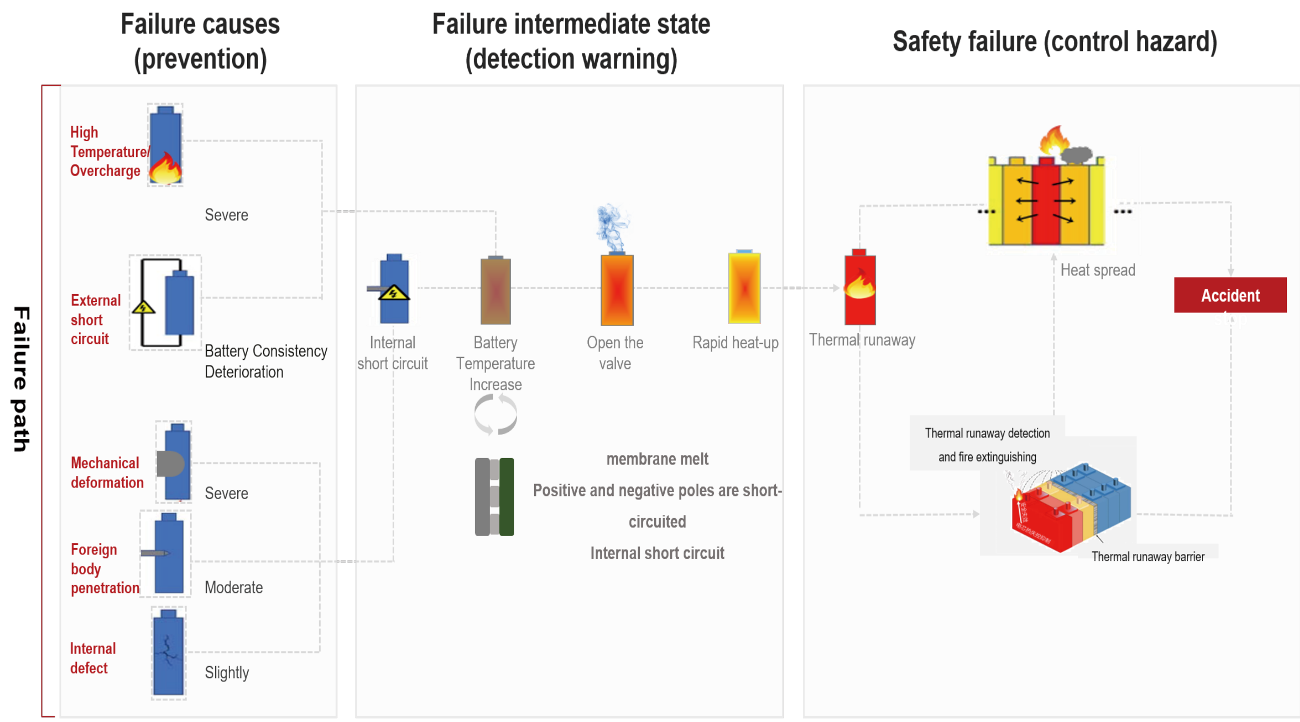
Selecting cell materials, designing mechanical architecture, electrical architecture, and thermal management systems, ensuring quality control during production, and detecting defective cells are all interrelated and essential components in creating high-quality safe lithium batteries.

Figure 8 End-to-end high-quality and safety system



3.2 Design and material selection for safety: design, key of high-quality lithium batteries

Figure 9 Lithium battery failure factors and general policies



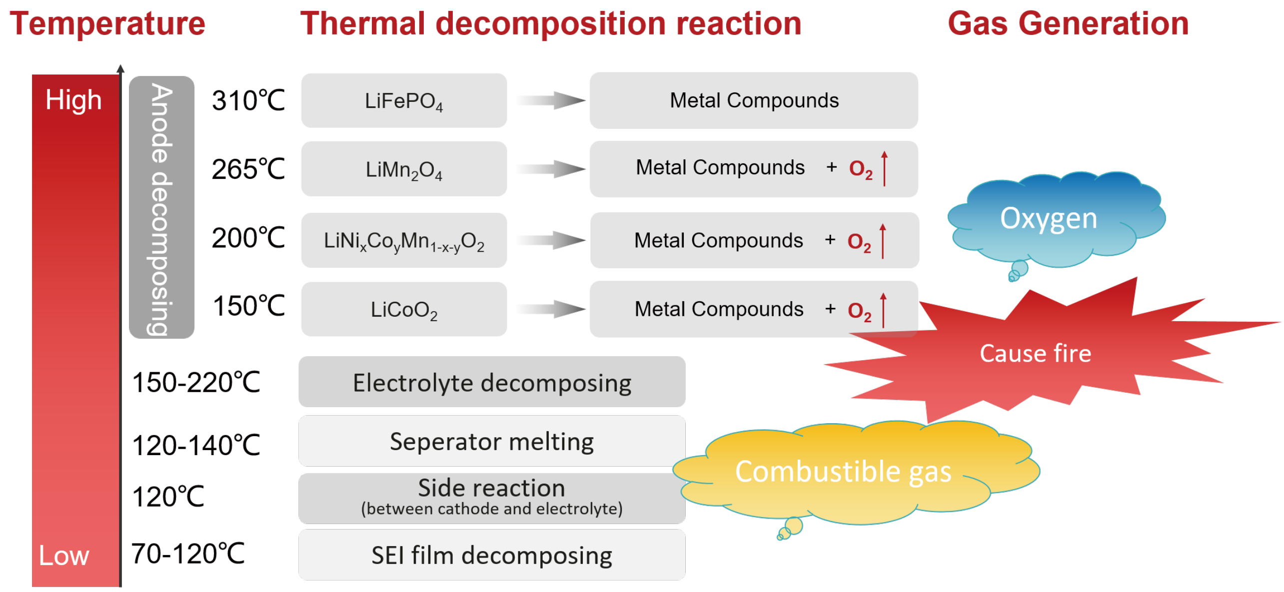
General strategy

Prior to: intrinsic safety	In-event: refined control	Post-event: system protection
■ Cell material selection ■ Insulation/Fire-retardant design ■ AI Predictive Maintenance ■ Mechanical protection ■ Manufacturing security	■ Leakage current detection ■ Overtemperature, overvoltage, overcurrent, and undervoltage faults ■ Call home ■ Short Circuit AI Predictive Maintenance ■ Fuse protection	■ In-room water fire protection ■ One-click EPO fault isolation ■ Module-level fire extinguishing ■ Establish a Warroom within 10 minutes.

3.2.1 Designing high-quality battery cells as the foundation for safe lithium batteries

A lithium battery cell consists of four key materials: positive electrode material, negative electrode material, separator, and electrolyte, along with the enclosure and terminals. Each part significantly impacts the quality of the lithium battery.

Figure 10 Thermal runaway development process



1. Positive electrode material

There are four main types of positive electrode materials available: lithium iron phosphate, lithium nickel-cobalt-manganese oxide, lithium cobalt oxide and lithium manganese oxide. Among these, lithium iron phosphate material is renowned for its high thermal stability, with a thermal decomposition temperature exceeding 300°C. Even upon decomposition, it does not generate oxygen, making it safer. Lithium iron phosphate batteries are less prone to thermal runaway even if damaged or improperly charged, and they have a longer cycle life. It is advised to use positive electrodes made of high-end lithium iron phosphate for high-quality lithium batteries as also required in ITU-T standard, Recommendation ITU-T L.1210. [3]

2. Negative electrode material

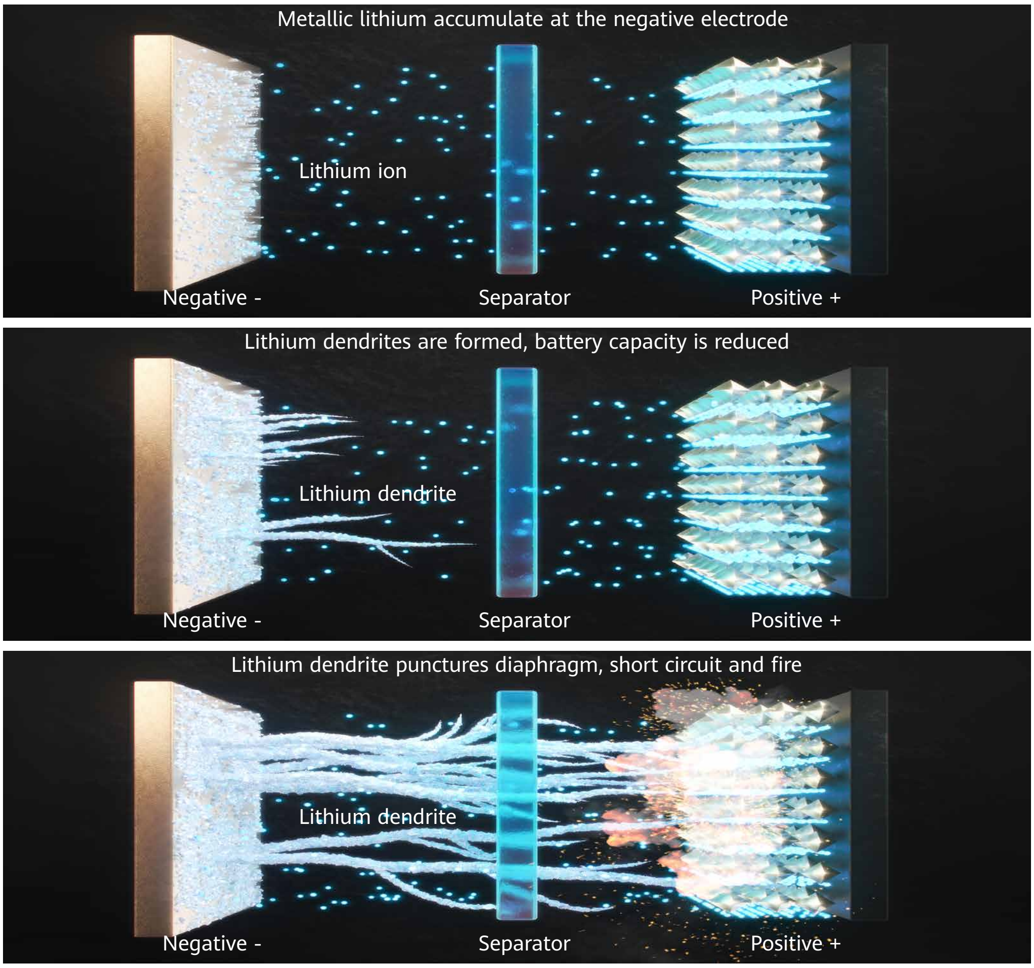
For negative electrode materials, options include artificial graphite, natural graphite, LTO and silicon-based anodes. Artificial graphite is preferred for its longer cycle life, better charge/discharge capabilities, higher tolerance to high/low temperature environments, and overall stability.

3. Electrolyte

Electrolyte is a crucial component in lithium batteries that significantly impacts their safety. If improperly selected, issues such as lithium plating and gas-induced bulges may occur. Lithium plating can cause internal short circuits in a battery, rapidly increasing the cell temperature. The expanded flammable gases function as fuel, and when mixed with oxygen, create the necessary conditions for combustion. High-quality lithium batteries should use highly safe and reliable electrolyte formulations to enhance the activity of Li+ ions, reduce side reactions, and prevent safety hazards such as lithium plating and gas-induced bulges. This helps ensure that the lithium batteries operate stably and efficiently during charge/discharge cycles, thus extending the batteries' lifespan and preventing fire accidents.

3 Recommendation ITU-T L.1210 (2019),) Sustainable power-feeding solutions for 5G networks.

Figure 11 Principle of lithium plating of a cell



4. Separator

The separator is an insulating medium in lithium batteries that prevents short circuits between the positive and negative electrodes. It is usually made of polymer materials such as polyethylene (PE) or polypropylene (PP). These polymer materials have poor heat resistance, with melting points generally below 200°C and shrinkage temperatures typically ranging from 60°C to 160°C. To improve heat resistance, engineers have developed composite separators by coating the base film with more heat-resistant materials such as ceramic powder or fluoroplastic, enhancing the separator's weather resistance.

5. Structure design

Besides the four key materials, the structural design of the batteries and their materials are equally important. Structurally, lithium battery cells can be prismatic, cylindrical or pouch-shaped. Prismatic and cylindrical cells typically use materials such as aluminium alloy or stainless steel for the enclosure, offering high structural strength to effectively resist external impacts and pressure, thus preventing a short circuit caused by leakage or polarizer damage. The electrolyte is toxic and highly corrosive; leakage can corrode equipment and cause electrolyte shortage inside the battery, leading to fire or explosion. Moreover, cylindrical batteries have slightly lower energy density and complex grouping, resulting in them being used mainly in consumer electronics and in the transportation sector at present.

High-quality cells should use good raw materials and comprehensive safety designs to prevent safety hazards and avoid fire/explosion accidents.

3.2.2 Designing high-quality BMS is an important means to ensure battery safety

The core task of a BMS is to monitor and manage various operational parameters of the batteries, ensuring the safe, stable and efficient operation of the battery system. The main components of the BMS include the battery management unit (BMU) and the battery control unit (BCU). The BMU is responsible for collecting and preliminarily processing basic parameters such as the voltage, current and temperature of the entire battery and individual cells, providing data support for the BMS, and handling internal and external communications, fault analysis, and more. Based on the data provided by the BMU, the BCU executes the battery control policies, including charge/discharge management, balancing management, cell state of health (SoH) prediction, and electrical hazard protection.

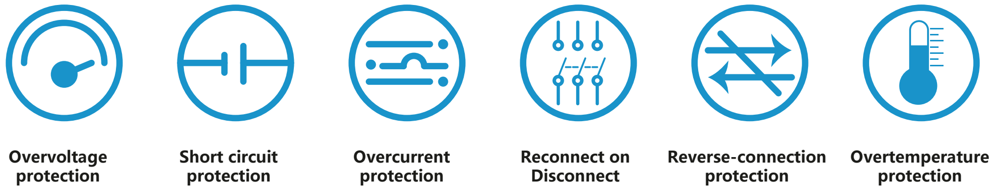
1. High-quality materials

The BMS integrates various electronic components such as chips, metal-oxide-semiconductor field-effect transistors (MOSFET transistors), passive components (resistors, inductors and capacitors), and sensors. Given the complex and diverse application scenarios in telecom sites, it is recommended that high-precision, high-quality electronic components be used to provide the BMS with more accurate basic data and a more sensitive response to faults.

2. Electrical safety protection

Electrical hazards are among the most frequent safety risks in communication lithium battery systems. During installation, lithium batteries may face abnormal conditions such as wiring errors, poor screw fastening, and foreign object invasion. During use, they may encounter environmental damage such as condensation, water ingress, and ant invasion. These factors can lead to electrical faults such as short circuits, overcurrent, overvoltage, open circuits, reverse polarity, and overtemperature. A well-designed BMS shall incorporate safety protection designs against common faults and anomalies at the electrical design stage, promptly shutting off or isolating fault points. The electrical protection design shall at least ensure that faults of BMS do not affect the safety of the cells, further ensuring the long-term stable operation of the device and reducing the failure rate of the BMS.

Figure 12 Common failure factors of the BMS



3. Thermal management design

Electronic components generate a certain amount of heat during operation, raising the temperature of the BMS. Research shows that the lifespan of electronic components shortens as temperature increases. In operating temperature range, according to Arrhenius equation, for every 10°C rise in temperature, the lifespan of electronic components is about halved. Therefore, efficient heat dissipation design is crucial. Currently, the maximum temperature rise during normal use for most industry lithium batteries' BMS is between 70°C and 100°C, while high-quality BMS can control the maximum temperature rise within 50°C to 65°C.

Additionally, good flame retardant design is equally important. The flame retardancy of BMS components shall meet the UL94-V0 standard. These designs effectively ensure that the BMS maintains stable performance during long-term, high-load operation, reducing the risk of thermal runaway.

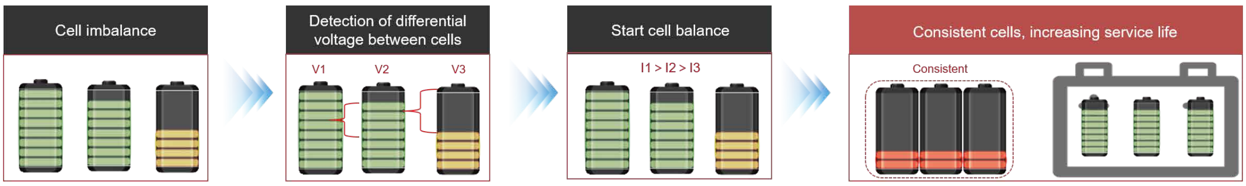
4. Intelligent multi-function applications

High-quality lithium batteries should meet intelligent multi-function applications. Generally, the BMS only needs to monitor the changes in the voltage and current of the battery cells in real-time and set end-of-charge/discharge voltage to prevent overcharging or overdischarging of the batteries. As telecom site power backup enters the intelligent era, application demands such as intelligent parallel, intelligent hybrid use, intelligent voltage boosting, and intelligent capacity measurement pose higher requirements on BMS intelligence. See ITU-T standards, Recommendations ITU-T L.1210 and ITU-T L.1382. [4]

5. Efficient balancing management

Battery equalization refers to the process of using power electronics technology to make the voltage distribution of all battery cells in a series circuit relatively consistent. In a series circuit composed of multiple cells, uneven grouping or inconsistent usage degradation can cause differences in internal resistance, capacity, and voltage among different cells. Without balancing management, like the "Cask Effect", the overall performance of system will be determined by the cell with the lowest capacity, highest internal resistance and shortest lifespan, leading to continuous deterioration of battery performance.

Figure 13 Battery balancing management process



Currently, the industry has two types of equalization efficiency management technologies: active equalization and passive equalization. Passive equalization relies on parallel resistors of the cells, releasing some excess energy in the form of heat. To prevent excessive temperature rise, the equalization efficiency is relatively low. Active equalization, through specific circuit design, can actively transfer energy from the cell with higher voltage to the cell with lower voltage, featuring low energy conversion loss, higher capacity utilization rate, and higher equalization efficiency. It is advised to use active equalization technologies for high-quality lithium batteries.

6. Cell status monitoring

During use, lithium battery cells gradually age, which can lead to problems such as capacity loss and increased internal resistance, affecting cell lifespan and system safety. The BMS has the capabilities of calculating SoC, SoH, and SoE, assessing the health status of the batteries, and adjusting charge/discharge policies promptly based on changes in SoH. High-quality lithium batteries should be equipped with an intelligent BMS that, through integrated intelligent algorithms and data analysis technology, achieves real-time monitoring and proactive warning of battery status.

7. Fault diagnosis and alarm

To improve the efficiency of solving safety issues in lithium batteries and prevent faults from occurring, the BMS should provide alarm functions when it detects any anomalies or potential faults such as short circuits, overcurrent, overvoltage, reverse polarity, overtemperature, single-point failures, cell aging, or abnormal humidity. It should preliminarily determine the fault type, position, and possible impact through data analysis and promptly upload the data to the cloud monitoring system.

4 ITU-T L.1382 (2020),) Smart energy solution for telecommunication rooms.

8. Intelligent cloud O&M and risk warning

The cloud monitoring system, with its powerful data processing and analysis capabilities, can analyse fault alarm information deeply. Based on multidimensional information such as historical data, device operating status, and environmental factors, it can accurately locate faults, produce diagnostic reports, and send them to the site O&M engineer promptly. This prevents fault escalation and ensures the safe and stable operation of the site.

This not only improves the operational efficiency of the system but can also issue early warnings before any battery abnormalities occur, allowing timely measures to avoid potential safety risks. With the support of AI, the BMS becomes more intelligent and efficient, providing strong assurance for the safe application of lithium batteries in telecom sites.

3.2.3 Designing high-quality battery packs to ensure high-quality battery application

A battery pack is a complex integrated system. To ensure system safety, a high-quality battery pack needs to address six aspects: mechanical protection, IP rating, thermal protection, environmental protection, secure connections, and anti-theft and anti-dismantling measures. These measures are vital to ensure that lithium batteries can withstand internal and external environmental risks over long-term use.

1. Mechanical protection: preventing structural deformation and enclosure damage

During transportation, installation and use, lithium batteries face risks such as collisions, crush and drops. Over time, lithium battery cells will also experience some internal expansion. High-quality lithium batteries should use high-strength enclosure structures and materials to maintain structural and external completeness under significant internal and external pressures. This protects the internal cells and the BMS from damage, so reducing safety risks caused by physical damage.

2. Enhanced Ingress Protection: protection against external dust and biological invasion

Ingress protection (IP) Code refers to the level of protection against dust and moisture for electrical devices. Currently, lithium batteries in the industry usually meet the IP20 standard (See IEC 60529[5] for more information), which blocks solid objects with a diameter greater than or equal to 12.5 mm. However, this protection level is clearly insufficient for practical application. During installation and use, metal particles, dust, gravel, ants, insects, and water in the environment can easily enter the battery pack, causing electrical system faults.

It is recommended that the protection level of the BMS be enhanced on the basis of the above protection level to protect the BMS from environmental foreign matter (e.g., metal welding slag, insects, and ants). This design is crucial to ensure the stable operation of the batteries in various environments.

3. Thermal protection: thermal diffusion prevention, heat insulation, and flame retardant

Studies have shown that when temperatures exceed 35°C, the cycle life of lithium batteries decreases with increasing temperatures; for every 10°C rise, the cycle life is halved. During charge/discharge, lithium batteries generate heat. The higher the charge/discharge rate, the greater the temperature rise.

Preventing thermal diffusion is a key aspect of thermal protection. High-quality battery packs should prevent thermal diffusion between adjacent cells and have good heat dissipation designs to promptly remove the heat generated by the cells. The operating temperature of the BMS is usually higher than that of the cells, so there should be thermal insulation between the BMS and the cells to lower the battery cabin temperature. The plastic components and wire harness insulation layers inside the battery pack should comply with international flame retardant standards.

5 IEC 60529:1989/AMD2:2013/COR1:2019, Degrees of protection provided by enclosures (IP Code).IPCode)

4. Environment protection: resisting environmental corrosion of external enclosures and internal components

During operation, transportation and storage, lithium batteries are easily affected by various environmental factors such as condensation, salt mist and electromagnetic interference. These factors can lead to performance degradation, failure or damage, and in severe cases, cause lithium battery fires or explosions. High-quality battery packs should adopt necessary environmental protection designs to prevent failures caused by condensation, avoid salt mist corrosion, and resist electromagnetic interference. These protective measures help ensure that the battery operates in optimal conditions, extend its lifespan, and reduce safety risks due to malfunctions.

5. Secure connection: providing safe fastening for internal and external components

Currently, most lithium batteries in the industry are primarily fastened using bolts and nuts, which carries a certain risk of loose or missing connections. It is recommended that the industry adopts necessary protective designs or manufacturing controls to mitigate these risks. Some high-quality lithium batteries have already adopted laser welding or ultrasonic welding for internal components, reducing the defects of loose or missing screws.

6. Anti-theft and anti-dismantling: reducing theft rates and protecting owners' legal rights

Lithium batteries, as inherent assets, still face a high risk of theft, causing property loss and business interruptions for owners. Due to varying economic and cultural development across different regions, theft rates can be as high as 15 per cent in some areas. It is recommended that lithium battery manufacturers adopt certain anti-theft or anti-dismantling designs to reduce the theft rate and protect the legal rights of battery owners. See Recommendation ITU-T L.1221[6] for more information.

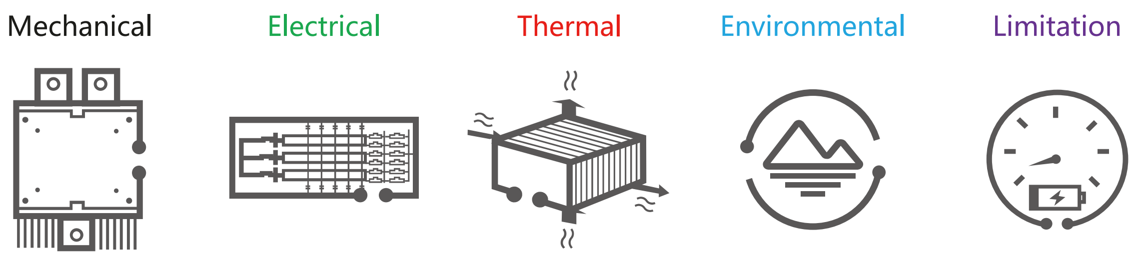
3.3 Comprehensive and in-depth verification and tests to ensure high quality and safety

In addition to design safety, verification and test safety are also crucial aspects of the safe application of lithium batteries. The safety requirements for lithium batteries need be high, and the environmental conditions at telecom sites are complex such as being prone to crush, electromagnetic interference, large temperature variations, high humidity, and biological invasion. To ensure the stable operation of lithium batteries, comprehensive, all-scenario tests shall be conducted, and lithium batteries shall pass various internationally recognized certification. See Recommendation ITU-T L.1221[6], which contains a description of information on possible stress tests and results.

3.3.1 Multi-dimensional full-scenario lithium battery tests

High-quality lithium batteries shall undergo comprehensive, all-scenario testing, including mechanical, electrical, thermal, environmental, and extreme condition tests.

Figure 14 Common test dimensions of lithium batteries



6 ITU-T L.1221(2018) Innovative energy storage technology for stationary use – Part 2: Battery

1. Mechanical test

This evaluates the safety and reliability of lithium batteries under various mechanical stresses, generally including:

- ♦ **crush test:** Simulates the safety performance of lithium batteries when subjected to mechanical crush. At room temperature, an individual cell is charged to full capacity, and a specific pressure is applied using extruder. High-quality lithium battery cells should exhibit no leakage, smoking or explosion during this test.
- ♦ **Nail penetration test:** Simulates the safety performance of lithium batteries when subjected to sharp object penetration. This is also an internal short circuit simulation test method to evaluate the lithium batteries' capability to withstand internal short circuit. At room temperature, an individual cell is charged to full capacity, and then a steel nail is used to penetrate the battery vertically. High-quality lithium battery cells should not catch fire or explode during this test.
- ♦ **Drop test:** Simulates the scenario where lithium batteries are accidentally dropped during user handling or assembly, assessing the batteries' impact resistance and stability. High-quality batteries shall be free of visible damage, leakage, smoking or explosion during this test.

Figure 15 Lithium battery nail penetration test:
(The left part of high-quality cells does not catch fire, and the right part of low-quality cells catches fire.)

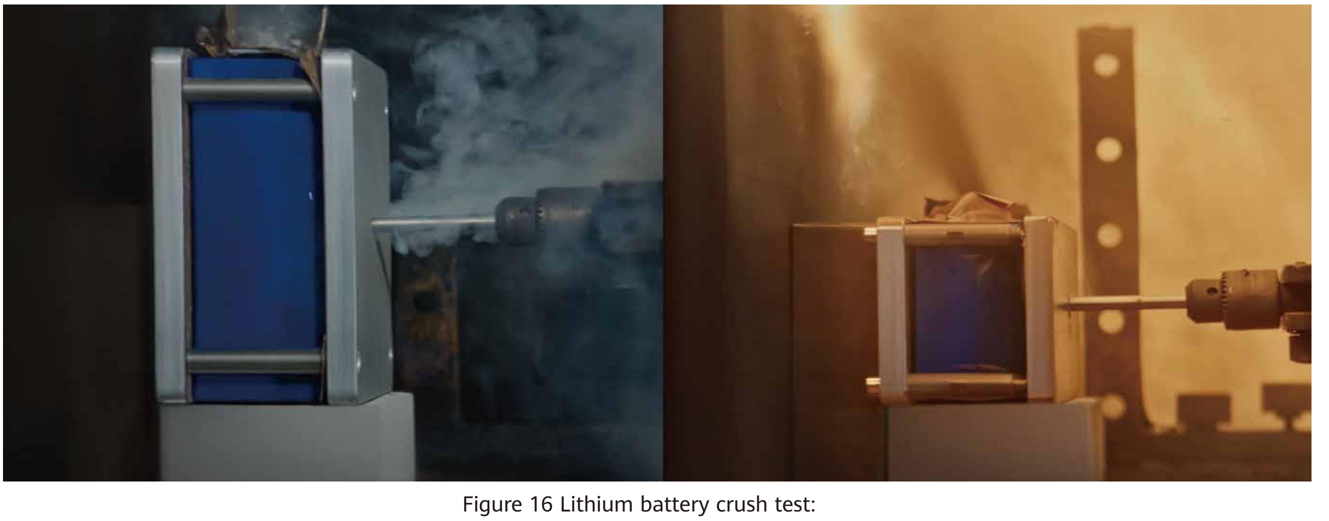


Figure 16 Lithium battery crush test:
(The left part of high-quality cell does not catch fire, and the right part of low-quality cell catches fire.)

2. Electrical test

This assesses the electrical features and safety of lithium batteries, typically including overcharge, overdischarge, short circuit, and insulation tests.

- ♦ **Overcharge/Overdischarge test:** Evaluates the safety performance of lithium batteries under overcharge/overdischarge conditions. Lithium batteries are charged and discharged at standard specified current until the preset termination conditions are reached. High-quality lithium batteries should not catch fire or explode under overcharge conditions. Additionally, battery temperature, gas generation and capacity should remain normal.

- ♦ **Short circuit test:** Simulates accidental short circuit scenarios to assess the batteries' capability to withstand short-circuit current. High-quality lithium batteries should not catch fire or explode during this process.

- ♦ **Insulation test:** Evaluates the insulation performance of lithium batteries to ensure that they do not cause accidental electric shocks during use.

3. Thermal test

This assesses whether lithium batteries will undergo uncontrolled heat release at high temperatures, potentially leading to fires or explosions. These tests provide insights into battery thermal stability, aiding in design optimization. Common tests include:

- ♦ **Thermal runaway test:** Triggers thermal runaway reactions through external heating or internal short circuits. High-quality lithium batteries should not catch fire or explode under test conditions.

- ♦ **Thermal shock test:** Involves rapidly transferring the batteries from extremely high temperature to extremely low temperature repeatedly. High-quality lithium batteries should exhibit no deformation, cracking, leakage, or other failures during this test.

4. Environment test

This ensures that batteries can operate safely under various extreme environmental conditions. High-quality lithium batteries shall pass environmental adaptation tests, typically including rain and earthquake tests.

- ♦ **Rain test:** Simulates a rain environment to check the battery enclosure's sealing ability, ensuring no water ingress that could cause short circuits. Tests are usually conducted according to international IP code standards. High-quality lithium batteries should show no short circuits or failures, and meet all specified indicators.

- ♦ **Earthquake test:** Simulates seismic vibrations to check the batteries' structural stability and safety under physical shocks, ensuring that the batteries remain stable and safe during vibrations.

5. Extreme condition test

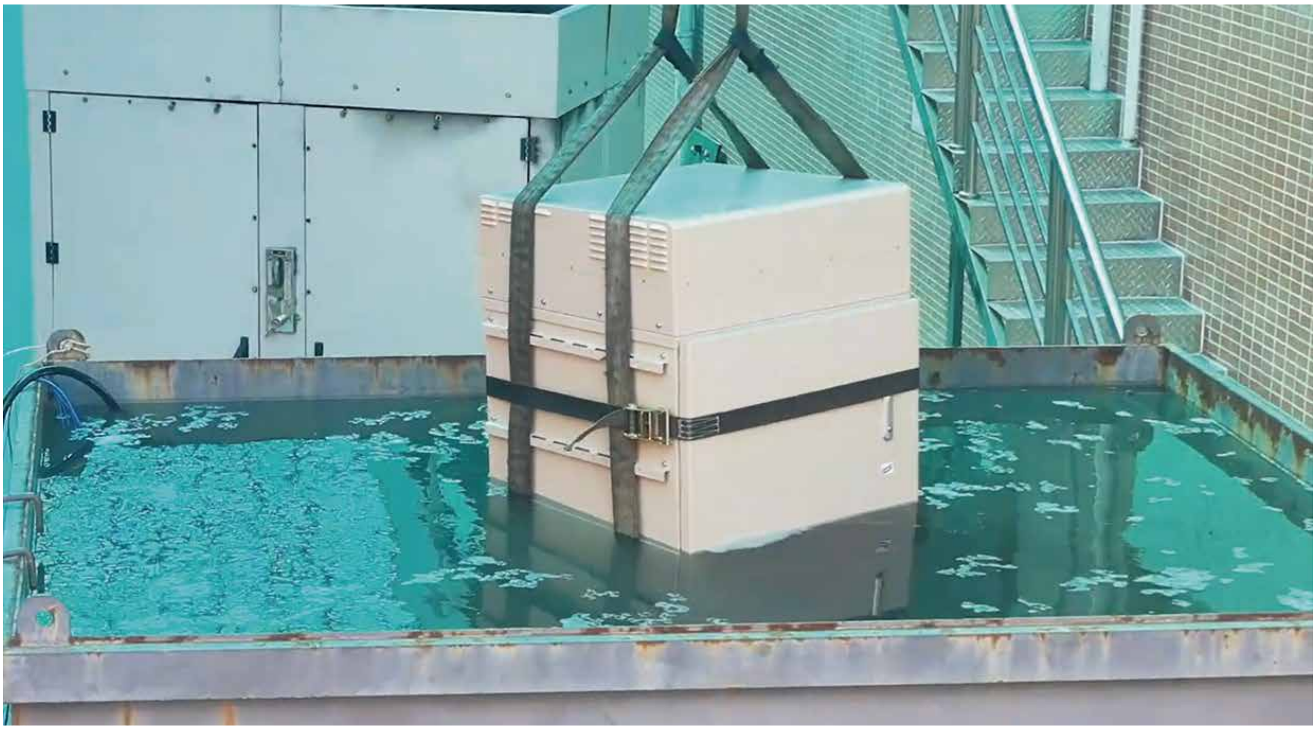
Lithium batteries may face various extreme conditions during application, and high-quality lithium batteries shall pass extreme condition tests, typically including:

- ♦ **Immersion test:** Involves fully or partially immersing the batteries in water to simulate use in humid or submerged environments, and observing for water leakage, short circuits, or other anomalies.

- ♦ **Leakage test:** Detects whether the batteries have electrolyte leakage through visual inspection or specialized devices, ensuring intact battery sealing with no electrolyte seepage.

- ♦ **Enclosure short circuit test:** Tests whether the batteries will short circuit when the enclosure is damaged or subjected to pressure, by simulating extreme conditions through penetrating batteries or applying pressure to ensure no abnormalities occur.

Figure 17 Lithium battery immersion test in seawater



3.3.2 High-quality and safe lithium batteries shall meet requirement of standards and regulations

High-quality lithium batteries need to obtain international standard certifications, which generally include:

International Electrotechnical Commission (IEC) standards, covering overall safety, electrical, mechanical and thermal such as IEC 62368-1 (safety standard for IT equipment can be used also for battery integrate in IT cabinet, e.g., radio base station), IEC 62485-5, IEC 62619, IEC 63056 and IEC 62620; UN transportation standards issued by the United Nations such as UN 38.3, IATA battery guidance document for air transportation related to the transportation of batteries, as well as IEC 62281.

European regulations: for example, CE certification refers to that lithium battery products comply with relevant EU directives and regulations. The standards include Low Voltage Directive (LVD), Electro Magnetic Compatibility (EMC), Battery Directive (EC) and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), and so on. In addition, the EU regulation 2023/1542, which imposes strict requirements on the entire lifecycle of battery products, from production to recycling. It should be also considered the implementation of the Digital Product Passport (DPP) for industrial batteries (>2kWh of capacity) that will be a legal requirement in February 2027; the first official standard for its implementation is DIN DKE SPEC 99100, which defines data attributes to be included in the digital battery passport based on requirements of the EU Battery Regulation.

UL certifications provided by Underwriters Laboratories (UL) in the United States, covering battery safety and combustion characteristics such as UL 94, UL 1642, and UL 1973.

And Chinese standards: such as GB 40165, GB 4943.1, YD/T 2344.1, and YD/T 3408, which outline various safety specifications for lithium batteries.

3.4 Manufacturing and delivery: ensuring high quality in every step

In addition to design and testing, the safety of lithium battery manufacturing and delivery is crucial. During manufacturing, it is essential to use high-quality raw materials, follow strict process standards, and conduct comprehensive quality inspections. In the delivery phase, batteries should be packaged, stored, transported and delivered safely. Safety shall be ensured in every step.

3.4.1 High-quality supply chain materials

It is recommended to use high-quality grade-A cells from top global manufacturers and conduct strict quality inspection on incoming materials. Only qualified materials should be stored to ensure the quality of lithium batteries from the source.

- **Top manufacturers' strong quality control:** Leading global lithium battery manufacturers usually have advanced manufacturing technology and stringent quality control capabilities. The cells they produce exhibit excellent performance, high consistency in terms of energy density, cycle life and safety, making them ideal raw materials for high-quality lithium batteries.

- **High-quality grade-A cells:** In the market, cells are categorized into grade-A, grade-B, and grade-C, based on quality. Grade-B or grade-C cells are products which are rejected by electric vehicle and energy storage manufacturers. They may have potential safety risks. High-quality lithium batteries should use higher quality, safer grade-A cells.

- **Strict incoming material quality inspection:** Each batch of raw materials should undergo rigorous inspections, including chemical composition analysis, physical performance tests, and electrochemical performance tests. Destructive testing should be conducted on the samples, and appropriately raise the acceptance criteria for lithium plating test.

3.4.2 High-quality intelligent manufacturing

The manufacturing process affects the quality of lithium batteries and needs to focus on several aspects, including:

- **Production process:** Precisely control parameters such as temperature, humidity, and pressure during production to ensure battery consistency. Use advanced packaging and processing techniques to accurately ensure battery design parameters. Implement a fully digital production system to monitor the quality of each battery in real time, ensuring the final product is high-quality and reliable.

- **Quality inspection:** Use high-precision quality inspection devices such as X-ray inspection and capacity testers, to conduct comprehensive battery inspection(including aging test), Implement stringent quality inspection processes, including incoming material and finished product inspection, to ensure high quality at every step.

- **Factory environment:** Use dust-free and anti-static workshops to avoid impurities and static interference. Regularly clean and maintain the production environment.

- **Quality system:** Establish a comprehensive quality management system such as ISO 9001 to manage the production process thoroughly and conduct regular audits.

3.4.3 High-quality safe storage

Lithium batteries are considered dangerous goods in transportation. To ensure safe handling and transportation, all lithium batteries must pass UN 38.3 tests. Key considerations for storage include:

- **Temperature and humidity control:** The storage environment for lithium batteries is recommended to be within 0–40°C. Higher temperatures accelerate capacity loss. Relative humidity should be between 5 per cent RH and 80 per cent RH to avoid prolonged exposure to extreme humidity. Avoid direct sunlight and keep a distance of greater than 2 meters from heat sources.

- **Storage requirements:** Use waterproof packaging for lithium batteries, store them in dry and well-ventilated areas, avoid contact with corrosive substances, and keep them away from flammable materials. Implement professional anti-crush designs to ensure stable stacking and avoid damage and leakage caused by external forces.

- **Safety management:** Provide good fire and explosion prevention facilities in warehouses to avoid safety accidents.

3.4.4 High-quality safety transportation

The transportation of lithium batteries should adhere to relevant standards such as UN 38.3, which generally includes the following aspects:

- **Dedicated transportation devices:** Different lithium batteries have different transportation requirements and risks, necessitating the use of dedicated devices to effectively reduce vibration and impact during transportation.

- **Proper packaging:** Use suitable and sturdy outer packaging such as wooden or metal boxes, along with insulated materials for isolation, and add some desiccant. Clearly label battery information such as type, voltage and capacity.

- **Transportation environment:** Avoid exposing lithium batteries to high temperatures and humid environments. If necessary, use thermal insulation and moisture-proof materials. Ensure the batteries are securely fastened during transportation with shock-absorbing foam and fixed brackets to prevent mechanical damage due to collisions or crush.

3.4.5 High-quality safety delivery

Safety should also be prioritized during the delivery process, including:

- **Professionals:** Assign qualified professionals to handle the batteries, and ensure that they wear ESD gear when working at the site.

- **Operation safety:** During installation, follow the country electrical rule for a correct and safe installation including electrical maintenance requirement, correct power-on sequence strictly in order to avoid safety hazards caused by operation errors, so ensuring a safe and smooth delivery process.

- **End of Life management:** In a correct EoL management it is important to reduce the environmental impact of the lithium battery. Recommendation ITU-T L.1035[7] describes sustainable management of used batteries from information and communication technology (ICT) equipment and their environmentally responsible management, including waste prevention, minimization, recycling, recovery and final disposal. Also provides information on best practices in recycling lithium batteries.

High-quality lithium batteries embody end-to-end safety, characterized by:

01 comprehensive high-quality product design: laying the foundation for excellent performance from the source;

02 rigorous testing and verification: covering various extreme conditions to ensure safety and reliability, with continuous design optimization;

03 stringent manufacturing and delivery controls, ensuring high-quality implementation at every step. By striving for perfection in every aspect, the batteries produced truly achieve high-quality status.

7 Recommendation ITU L.1035: "Sustainable management of batteries"

04

Conclusion

With the rapid expansion of network and the explosive growth of application, the demand for network stability and reliability is increasing. The ESS for telecom sites is a crucial infrastructure for the network, and its reliability is critical. High-quality and high-safety ESS is an inevitable trend. However, achieving high quality is not just about partial safety; it involves high-quality safety across the entire chain from raw materials, Strengthen the construction of safety regulations and standards.

While progress has been made in advancing and standardizing lithium battery technologies, several areas require further development:

- Enhancing safety requirements proposing additional testing requirements in ITU-T L.1221 is crucial to mitigating thermal runaway risks.
- Developing smart BMS (Battery Management System) protocols for real-time monitoring and predictive maintenance will improve efficiency.
- Strengthening sustainability regulations will promote responsible lithium battery disposal and recycling.
- Aligning national regulations with ITU standards and other global regulatory frameworks will ensure Implement safety measures for communication sites.

Ensuring high-quality lithium batteries for telecom networks requires a comprehensive, end-to-end approach, from material selection and design to manufacturing, testing, and deployment. By establishing a robust regulatory framework, these efforts will drive the adoption of high-quality lithium batteries across diverse applications, ensuring greater safety, sustainability and reliability.

As lithium batteries continues to advance, its applications in telecom infrastructure will expand beyond traditional backup power systems. With improved safety, high-quality lithium batteries can be leveraged in off-grid and remote telecom sites where reliability is crucial for:

- 5G-powered smart cities supporting Internet of Things (IoT) devices
- Virtual power plants (VPPs) that allow telecom sites to contribute to grid stabilization, and
- Hybrid renewable energy systems integrating solar and wind energy for sustainable power solutions.

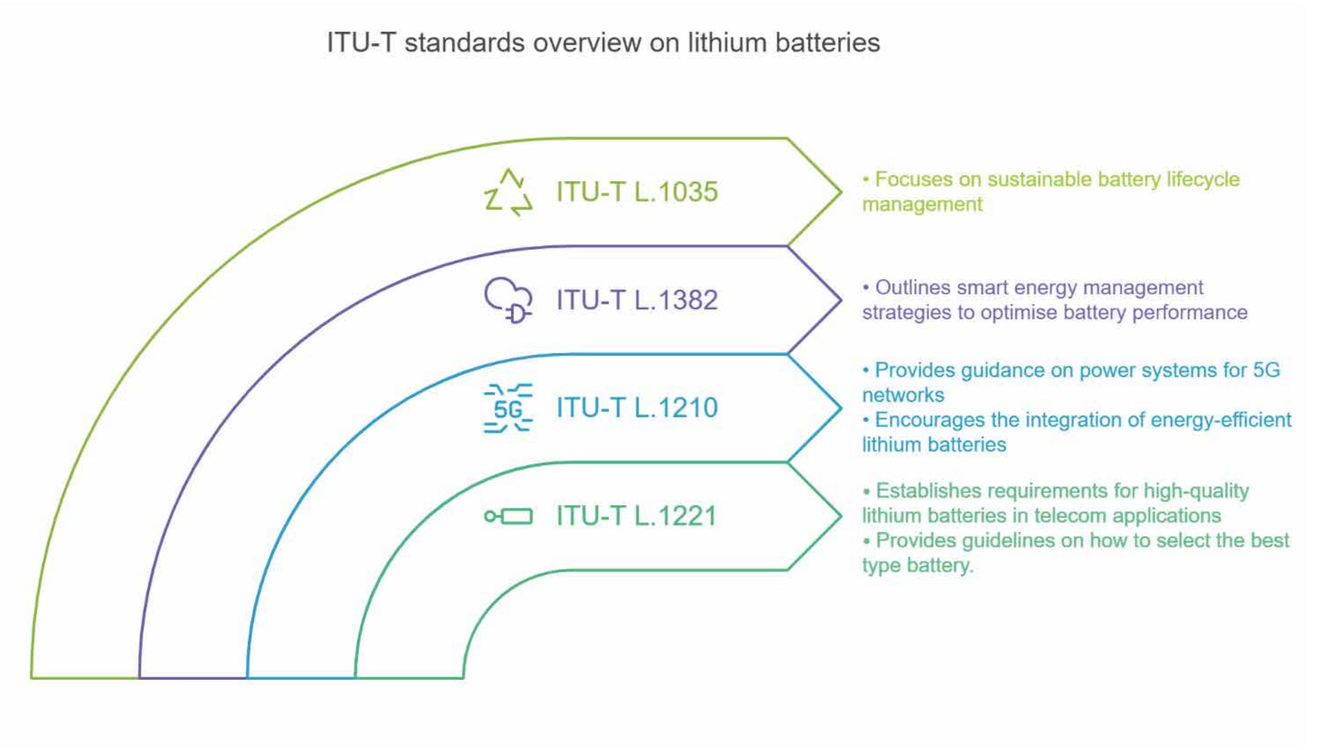
It is important to consider the following actions:

1. Promote the development of pilot projects for implementing Recommendation ITU-T L.1210 “Sustainable power-feeding solutions for 5G networks” in diverse climates, in collaboration with telecom operators.
2. Raise awareness among policymakers and relevant stakeholders on the importance of using international standards for high-quality lithium batteries.
3. Encourage the harmonization of standards by fostering partnerships between ITU, IEC, other SDOs, and regional organizations such as the EU Battery Alliance.
4. Develop a technical report within ITU-T SG5 on the use of lithium batteries by telecom operators.

Get involved in shaping global standards

The International Telecommunication Union Telecommunication, through its Standardization Sector (ITU-T), plays a pivotal role in shaping global standards for sustainable power solutions in the ICT sector. ITU-T Study Group 5 (SG5) "Environment, EMF, Climate Action and Circular Economy" is at the forefront of these efforts, driving the development of international standards that promote energy and resource efficiency, sustainable energy management, circular economy, e-waste management, and green data centres.

Figure 18 Overview of ITU-T Recommendations related to lithium batteries for the ICT sector



Moving forward, multistakeholder collaboration will be essential to achieving this vision. ITU Standards are developed through the collaboration of countries, industry leaders and academia, ensuring they reflect diverse perspectives and needs. Your expertise and insights can drive the development of standards that promote sustainability and innovation. Join ITU-T Study Group 5's efforts by contributing knowledge and helping to create a smarter, and more sustainable future. Be part of the change!