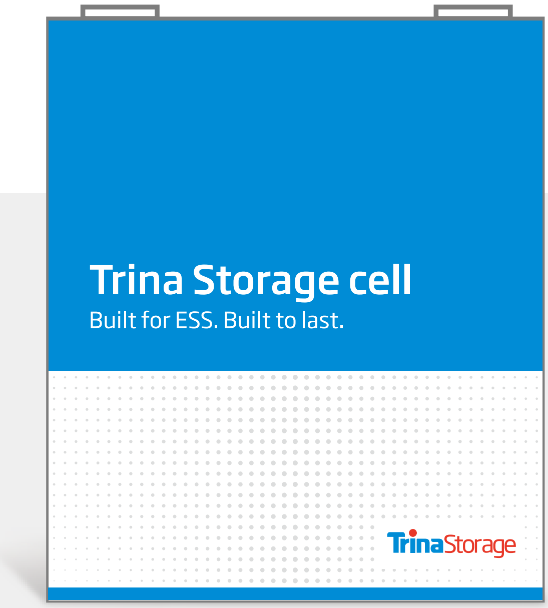
WHITE PAPER

Advanced Battery Cells for Energy Storage Systems

Unlocking Performance and Reliability

Trina Storage cell Built for ESS. Built to last.



2024-11-25

Introduction

Energy storage battery cells are the foundation of modern energy storage systems, providing critical support for the transition to renewable energy. This white paper delves into the specialized features and evolving trends of energy storage battery cells, offering insights into their development roadmap and emerging technologies. Trina Storage takes center stage with its full-stack self-research capabilities, pioneering material and structural innovations, and a commitment to ultimate reliability.

By integrating advanced manufacturing, a robust supply chain, and comprehensive after-sales service, Trina Storage builds a seamless ecosystem that ensures quality at every stage. The paper highlights how self-developed battery cells enhance safety, efficiency, and customer value, providing a reliable foundation for utility-scale energy storage applications. Through this exploration, Trina Storage reaffirms its role as a leader in redefining the standards of performance, sustainability, and economic value in the global energy storage industry.

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1

Characteristics and Development Trends of Energy Storage Cells

1.1 Specialized Features and Advantages

An energy storage cell is an electrochemical device that stores electrical energy and releases it as needed. As the smallest functional unit in an energy storage system, it consists of a positive electrode, negative electrode, electrolyte, and separator. Energy storage cells can be categorized based on their material composition into types such as lead-acid, nickel-metal hydride, lithium-ion, sodium-ion cells (Figure 1). Additionally, they can be classified by their packaging form into three categories: prismatic, cylindrical, and pouch cells (Figure 2). Different types and capacities of cells through different forms of series and parallel to form a coarse energy system to form a variety of energy storage solutions, which are applied to residential, industrial and commercial scenarios, and developed into utility-scale energy storage power stations at the source-grid interface.

The cells is the most important component in battery energy storage system (BESS), and also accounts for a significant portion of the overall system cost. As the primary medium device for energy storage and conversion, the performance, lifespan, and cost-effectiveness of the cell directly influence the overall efficiency and competitiveness of the BESS. For the client, BESS providers, which have full stack self-research and production capacity from the cell, is more advantage for ensuring control in quality, supply chain management, and cost optimization. Full stack self-research ability also can enhance BESS providers` performance and financial sustainability.

Figure 1 (Source: Internet)

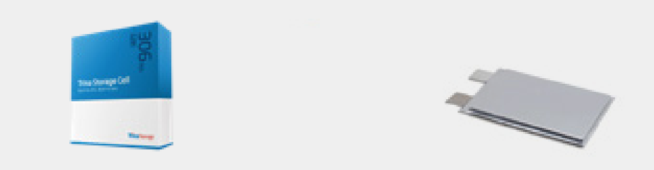


Figure 2 (Source: Internet)

The Levelized Cost of Storage (LCOS) remains the most objective indicator of an energy storage system's economic value. Driven by customer demands and the expansion of application scenarios, energy storage cells are now characterized by the following features:

— Extended Cycle Life

With the rapid adoption of wind and solar power combined with energy storage, the demand for longer battery cycle life has intensified. This trend, particularly evident in integrated PV-energy storage systems, calls for cells that can match the operational lifespan of renewable energy systems, ensuring efficient and sustainable performance.

— High Consistency

Achieving high consistency across energy storage cells significantly improves the battery system's reliability, stability, and energy conversion efficiency. Cells with high consistency effectively minimize capacity loss and slow the increase in internal resistance over time, extending the battery system's lifespan and enhancing its overall stability. Additionally, enhanced conversion efficiency boosts energy throughput, effectively reducing LCOS over the system's life cycle.

— Enhanced Safety

Safety is paramount in energy storage systems, especially in light of the surging global demand and the rise in fire incidents at energy storage power stations across the world. Between 2018 and 2022, nearly 40 incidents were reported worldwide, underscoring the growing concern over system safety. The intrinsic safety of cells is the foundation for the overall safety of the energy storage system. Ensuring this intrinsic safety is critical for the secure operation of new types of power systems, a key factor in achieving China's "dual-carbon" goal of carbon peaking and carbon neutrality.

— Large Capacity

As China develops more 100 MW-scale energy storage projects, the demand for large-capacity energy storage systems and cells is growing. Large-capacity cells improve the power density of individual cabinets, reduce project footprints, and lower investment costs. Furthermore, they minimize the number of series-parallel connections required, which helps reduce the "weakest link" effect that leads to capacity degradation. This ultimately extends the battery's life and enhances returns on investment.

1.2 Technology Roadmap for Energy Storage Cells

The primary purpose of energy storage is to address the imbalance between continuous power generation and fluctuating power demand. Energy storage technology decouples power generation from consumption across both time and location, eliminating the need for real-time alignment between production and demand. This breakthrough enables energy to be stored for use when required, fundamentally transforming grid operations, dispatch, and planning by addressing the historical challenge of electricity's non-storable nature. Large-scale energy storage is applicable across all stages of the power system—generation, transmission, distribution, and consumption—helping to reduce short-term power disruptions, ease peak power demand, delay or reduce grid investments, and improve the grid's ability to integrate renewable energy. It also ensures more flexible and stable power system operations across the generation, grid, and user sides. Energy storage-specific cells are therefore a strategic cornerstone of new energy infrastructure. Their development must prioritize safety and cost-effectiveness. The advancement of energy storage cell technology will continue to prioritize safety and cost reduction as core objectives. A full life cycle cost analysis reveals that features such as large capacity, long lifespan, high energy density, high energy efficiency, and tolerance to extreme temperatures will further enhance the economic viability of energy storage systems.

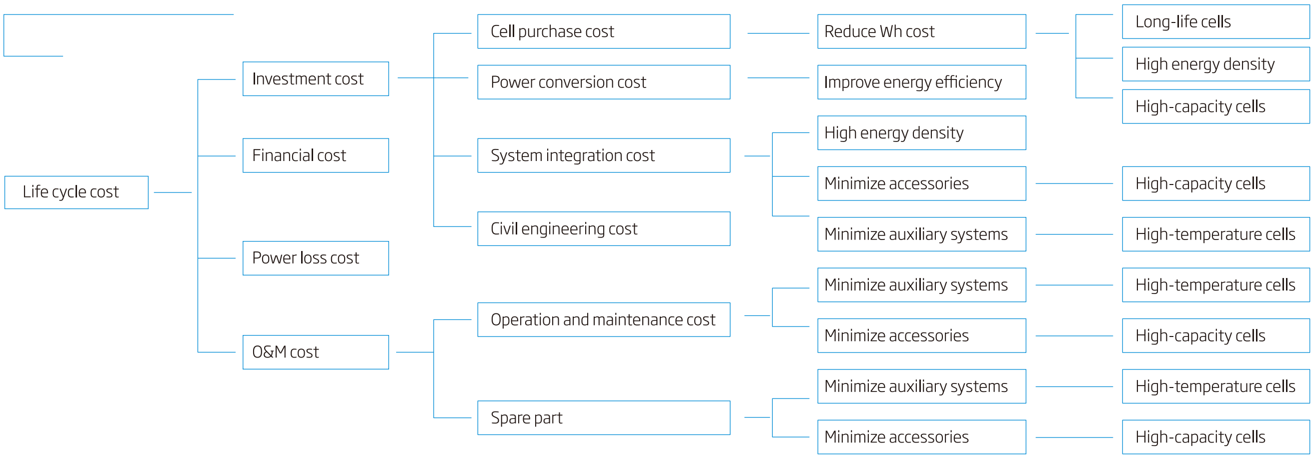


Figure 3 Cost Structure of Energy Storage Across Its Full Life Cycle and Economic Strategy

— High Safety: The Cornerstone of Energy Storage Development

As the scale of energy storage power stations continues to grow and the deployment of energy storage cells expands rapidly, public awareness of energy storage safety has intensified. In response, safety regulations for energy storage systems have become increasingly stringent. The national safety standard, Lithium-Ion Batteries for Electrical Energy Storage, which took effect on July 1, 2024, marked a significant advancement in safety requirements for energy storage cells. Among the various electrochemical systems, lithium iron phosphate (LFP) cells have been particularly recognized for their superior intrinsic safety.

Among the various electrochemical systems, lithium iron phosphate (LFP) cells are particularly noted for their superior intrinsic safety. Compared to nickel manganese cobalt (NMC) cells, LFP exhibits a significantly lower intensity during thermal runaway events, leading to reduced fire risks. This is because LFP cells feature higher thermal stability, delaying the onset of exothermic reactions and making them less likely to ignite under abuse conditions.

Additionally, in the event of electrolyte evaporation, LFP cells release fewer and less flammable gases compared to NMC cells. This directly impacts the design and performance of BESS safety systems, as the mitigation measures required for LFP systems are less complex and costly. These attributes reinforce the preference for LFP technology in large-scale energy storage systems, where safety is paramount.

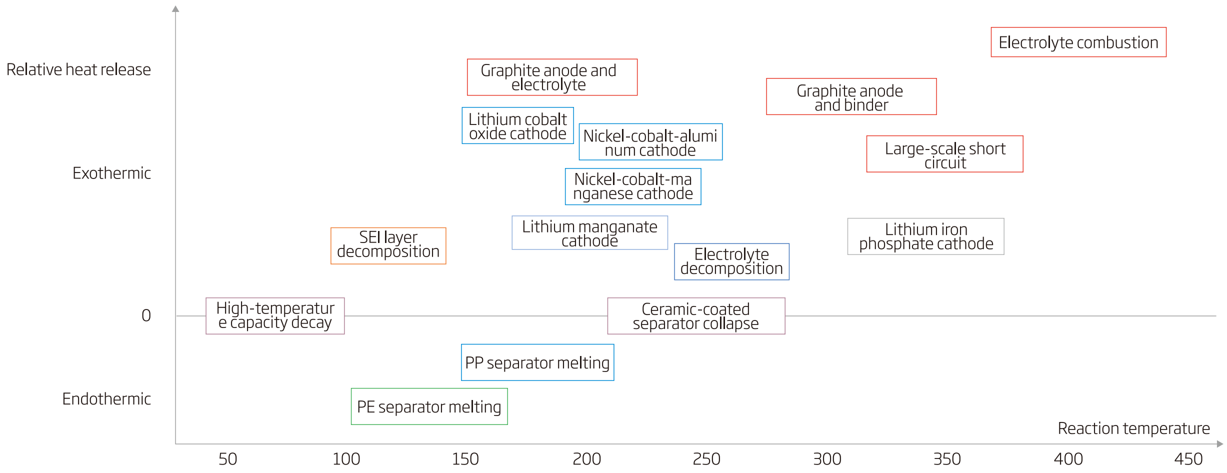


Figure 4 Heat Release of Various Lithium-Ion Battery Components during Thermal Runaway

— Large-Capacity Cells: Driving Significant Cost Reduction

Large-capacity cells offer a significant opportunity for cost savings by reducing the number of structural components required per unit of energy (Wh). This design optimization results in more efficient space utilization and lower bill of materials (BOM) costs. In manufacturing, large-capacity cells enable higher production efficiency without requiring additional labor or energy, leading to better economies of scale. On the system integration side, the reduced number of cells and connectors required improves consistency across the system and lowers operational and maintenance (O&M) costs. In addition, large-capacity cells minimize the physical footprint of the system and simplify construction processes.

— High-Temperature Cells: Driving Extreme Cost Reductions

Conventional energy storage systems rely on temperature control mechanisms to maintain a stable internal environment, typically around 25°C. High-temperature cells, however, can operate efficiently in much hotter conditions, which reduces both the upfront investment and the ongoing operational costs associated with temperature control systems. High-temperature cells also offer greater energy efficiency by minimizing heat-related energy losses.

— Longer Lifespan Cells: Reducing LCOS and Aligning with the 10,000 to 18,000 Cycles Lifespan of Renewable Energy (Wind and PV) Power Stations

Energy storage plays a critical role in the development of the smart grid. The expected lifespan of energy storage cells is increasingly being aligned with the lifespan of key power station components. Table 1 illustrates the lifespan of energy storage cells in various types of power stations. For 2-hour energy storage applications, where the battery is fully charged and discharged once per day, cells for wind and PV power stations typically last between 8,000 and 10,000 cycles. In applications where the battery undergoes two cycles per day, the lifespan extends to between 15,000 and 18,000 cycles. Similarly, for 4-hour energy storage applications, the lifespan ranges from 8,000 to 10,000 cycles.

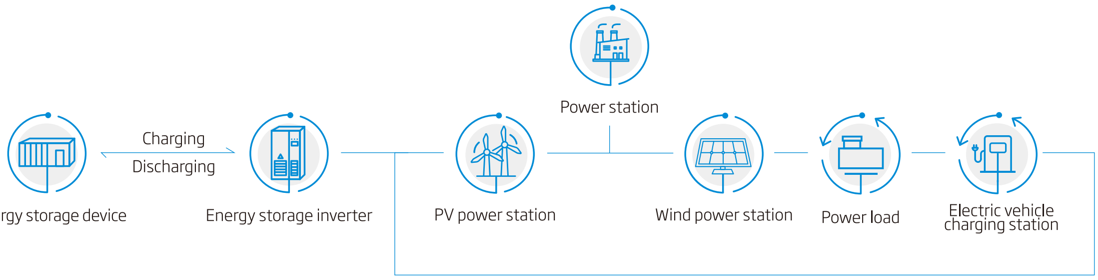


Figure 5 Smart Grid and Energy Storage System

Table 1 Lifespan of Energy Storage Cells in Corresponding Power Stations

Power Station Type		Thermal Generator	Hydro Generator	Nuclear Power	PV Module	Wind Turbine Generator
Design Life of Power Station (Years)		15~30	20~40	30~40	20~25	20~25
Energy Storage Cell Lifespan	1 cycle/day	5,475~10,950	7,300~14,600	10,950~14,600	7,300~9,125	7,300~9,125
	2 cycle/day	10,950~21,900	14,600~29,200	21,900~29,200	14,600~18,250	14,600~18,250

— The analysis of end-use electricity consumption characteristics reveals that energy storage durations of 1 to 4 hours are the most economical

With the rapid advancement of smart grids, an extensive amount of power data has been accumulated within distribution networks. This data contains rich user information, enabling precise analysis of electricity consumption patterns. By employing data mining techniques to examine user consumption behavior, we can generate valuable insights for applications such as load forecasting, demand-side response, and personalized tariff formulation. Effectively leveraging this user data can drive the development of energy storage technologies, ensuring that energy storage systems effectively enhance the security of electricity supply for consumers. User behavior is influenced by various factors, including daily and seasonal variations. A common analytical approach involves extracting patterns from load curves to swiftly and accurately identify concealed consumption trends. Grid operators are tasked with continuously balancing electricity generation and demand within a given region. Typically, electricity demand is lowest during the early morning hours when most individuals are asleep and many businesses are closed. As the day progresses, demand begins to rise in the morning as people wake up and businesses open. This demand remains elevated throughout the day, reaching a peak in the evening as people return home and residential electricity usage surges, before declining again late at night. Globally, peak electricity consumption tends to persist for 1 to 2 hours, with high-demand periods extending for 2 to 3 hours, according to available statistics.

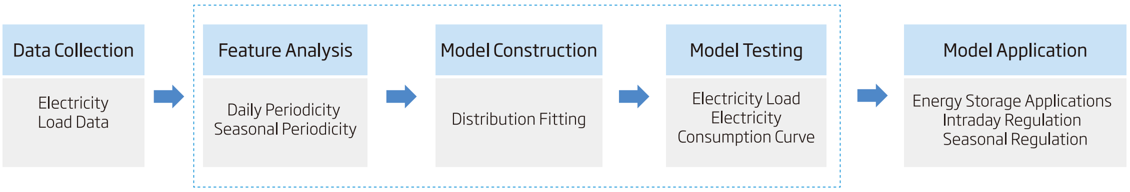


Figure 6 Construction and Application of the Electricity Load Model

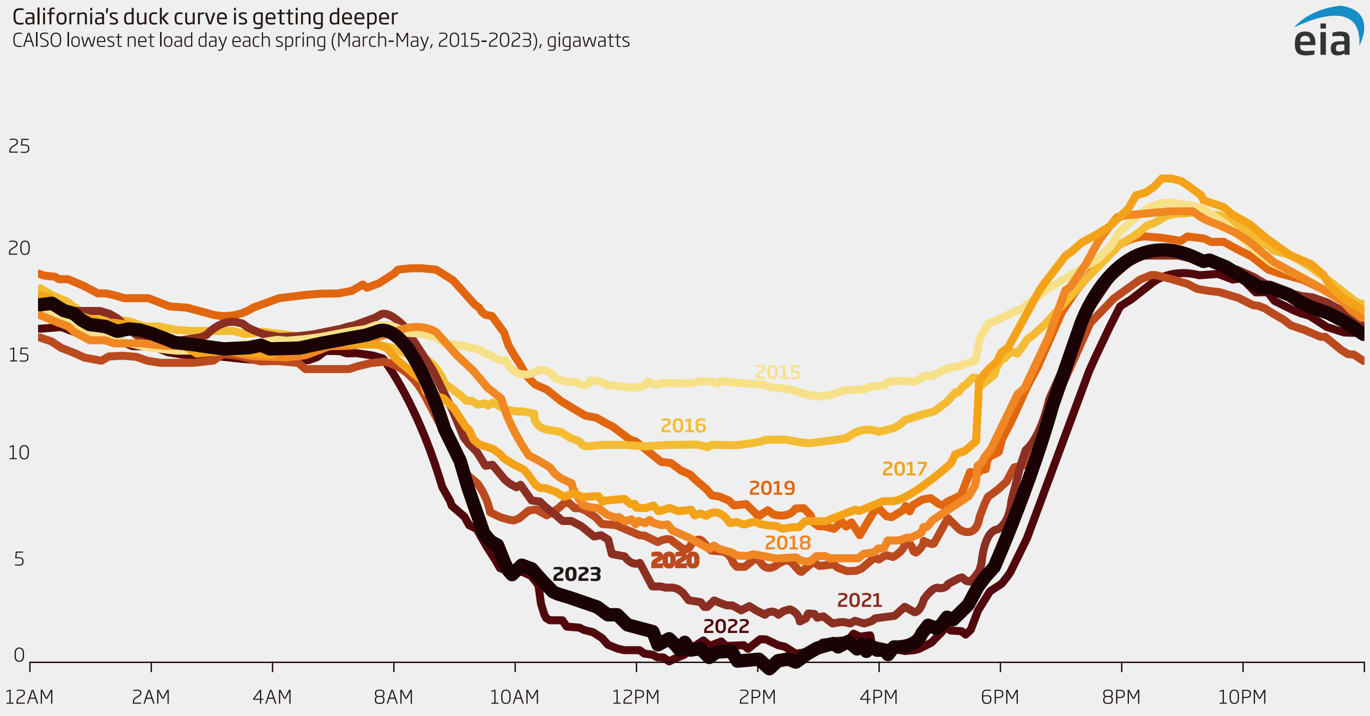
Table 2 Characteristics of General Electricity Peak Hours

Time Period		Peak Period	Peak Load Period	Flat Period	Valley Period
Morning	Time	10:30-11:30	8:30-10:30	7:00-8:30 11:30-12:00	-
	Duration (h)	1	2	2	-
Afternoon	Time	-	-	11:30-18:00	-
	Duration (h)			6.5	
Evening	Time	19:00-21:00	18:00-19:00 21:00-23:00	-	23:00-7:00
	Duration (h)	2	3	-	8

— Looking ahead to 2030, energy storage durations of 2 to 4 hours are expected to dominate in PV applications

A sustainable grid should provide both environmental and economic benefits in energy production, consumption, and trading. As fossil fuel shortages become more pressing and environmental pollution intensifies, the deployment of wind and solar energy technologies is rapidly increasing worldwide. However, these renewable sources face inherent challenges, such as "no wind during heatwaves" and "no sunlight during evening peaks", resulting in reverse peak pressures of 15% to 30% on the grid. The "duck curve" illustrates that during extreme weather events—such as heatwaves, cold snaps, or extended cloudy periods—maintaining grid stability and ensuring power quality will necessitate even greater demands for peak-shaving and frequency regulation from conventional energy sources as renewable energy penetration increases. In this context, energy storage systems provide an effective solution to address these challenges.

The "duck curve" presents two challenges associated with the increasing reliance on solar energy. First, it exerts pressure on the grid, as conventional power plants must respond to sharp fluctuations in electricity demand from midday to late evening. During these times, energy demand remains high even as solar generation diminishes, compelling conventional power plants (such as natural gas facilities) to rapidly ramp up production to meet consumer needs. This rapid response complicates the task for grid operators to balance supply and demand in real time. Additionally, when solar energy production exceeds the grid's capacity, operators may need to curtail solar generation to prevent overproduction. Conversely, the "duck curve" also creates opportunities for energy storage. Large-scale battery storage systems can capture surplus solar energy generated during the day and release it after sunset. By storing solar power throughout the day, the "belly" of the curve is flattened, and by discharging stored energy at night, the "neck" is shortened, thereby smoothing the "head" of the duck. The duration of energy storage during the "belly" spans 4 to 8 hours, while discharge durations in the "neck" and "head" range from 2 to 3.5 hours. The duck curve phenomenon is not limited to California; it is increasingly observed across the United States and other regions globally where solar energy adoption is rising. According to forecasts by IHS, energy storage durations of 2 to 4 hours will likely become the predominant configuration by 2030.


California's duck curve is getting deeper
CAISO lowest net load day each spring (March-May, 2015-2023), gigawatts

Source: California ISO

Figure 7 Duck-shaped Curve of Electricity Load Demand in California, USA

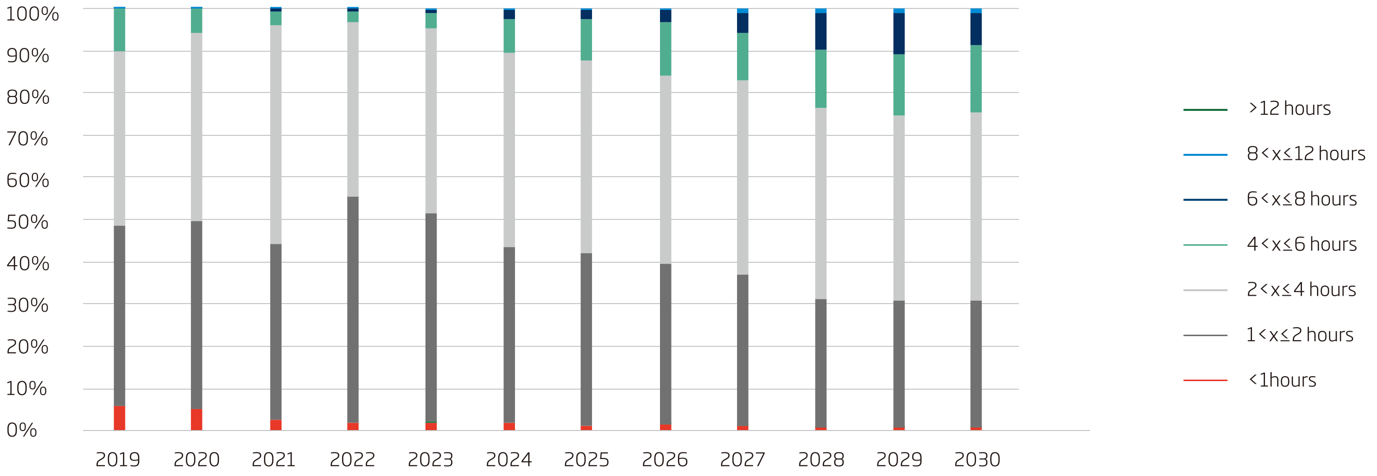


Figure 8 Analysis of the Share of Global Installed Capacity with Different Energy Storage Durations from 2023 to 2030

The global energy storage landscape is shifting toward longer durations, driven by the demand for 24/7 clean energy solutions, especially in key markets like Chile and the USA. Current trends show that 4-6 hour systems dominate installations. However, this is expected to increase toward 8-12 hours by 2030 as developers aim to integrate Solar+BESS configurations for cost-efficient, round-the-clock energy delivery. Batteries, as the most economical and mature technology, remain pivotal for managing diverse P-rates and durations, including long-duration storage critical for energy arbitrage and shifting.

Based on the analysis above, we outline the technology pathways for energy storage cells designed to effectively maximize their commercialization potential.

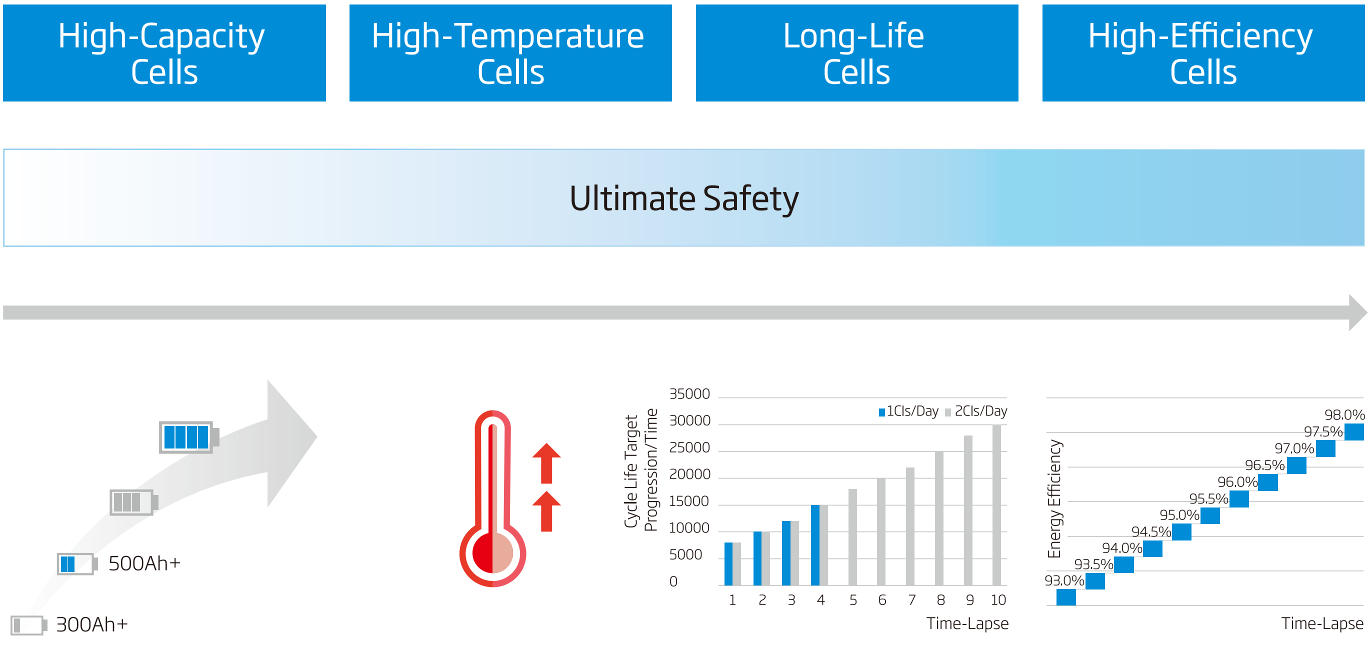


Figure 9 Development Pathways for Key Technologies in Energy Storage Cells

2

Trina Storage Cell’s Technology Innovation

2.1 Full-Stack Self-Research Capability

Trina Storage is dedicated to independent research and development, mastering the core technologies essential for the development, testing, and validation of cells. By leveraging deep insights into integrated solar and energy storage application scenarios, Trina Storage transforms these insights into optimal solutions that meet the technical requirements, cost constraints, and overall performance expectations of energy storage-specific cells. The Advanced Energy Storage Battery Research Institute at Trina Storage, led by an intelligent R&D center, has established nine platforms: forward-looking innovation, mechanism research, material pre-study, process R&D, equipment development, model simulation, product development, testing and certification, and project management. Additionally, a comprehensive R&D database support platform has been implemented to cover mechanisms, materials, processes, and cell research while proactively laying out future technology. This closed-loop system of “computing + validation” enhances the safety, efficiency, and cost-effectiveness of cell designs. Through full-stack self-research on cells, Trina Storage utilizes cutting-edge technologies to deliver high-quality solutions that provide exceptional value to customers.

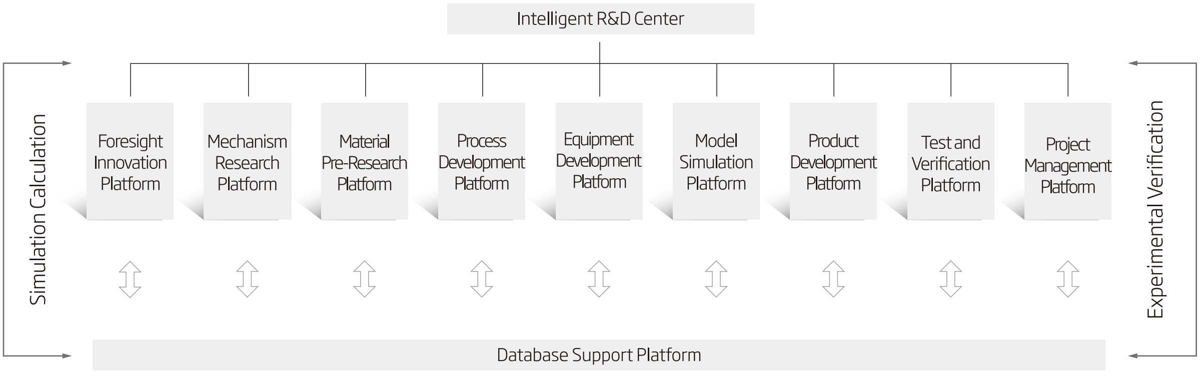


Figure 10 Full-Stack R&D Capability

2.2 Material Innovation

Currently, lithium-ion batteries–especially lithium iron phosphate ($LiFePO_4$) batteries–dominate the electrochemical energy storage market. Lithium iron phosphate features high energy density, excellent safety, superior cycling performance, low production costs, and environmental friendliness. Furthermore, China possesses abundant upstream resources for lithium iron phosphate, and the development outlook has significantly improved in recent years.

The main materials used in lithium iron phosphate batteries include positive electrode materials, negative electrode materials, electrolytes, separators, binders, current collectors, casings, and covers. The properties of these materials are directly linked to the performance of lithium iron phosphate batteries.

2.2.1 Application and Innovation of Positive Electrode Materials for Energy Storage

Positive electrode materials are crucial components of lithium batteries, undergoing lithium ion's intercalation and deintercalation during charging and discharging processes. These materials significantly influence energy density, power density, cycling performance, and safety in lithium-ion batteries.

Common lithium-ion positive electrode materials include ternary layered oxides such as lithium cobalt oxide, lithium iron phosphate, and lithium manganate. Given safety considerations and the demand for extended cycling longevity, lithium iron phosphate has been chosen as the positive electrode material for energy storage cells. This material is recognized as one of the safest options among lithium-ion battery cathodes, characterized by a stable crystal structure, excellent thermal stability, low cost, and the absence of harmful heavy metal ions, making it environmentally friendly.

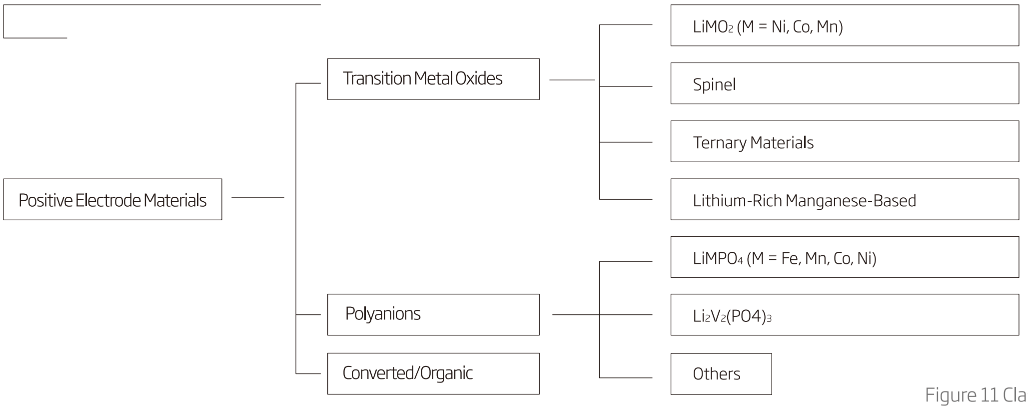


Figure 11 Classification of Positive Electrode Materials

Lithium iron phosphate has a theoretical specific capacity of 170 mAh/g and operates within a voltage range of 2.5V – 3.6V, outperforming other materials in safety and cycling longevity. However, it has limitations, including a low lithium-ion diffusion rate and electronic conductivity, which restrict its application in high-rate and low-temperature environments. Additionally, its lower true density results in comparatively low energy density when measured against other materials. Consequently, our focus on positive electrodes aims to enhance the capacity utilization and packing density of lithium iron phosphate materials. This involves optimizing particle size distribution to increase packing density while controlling the size of smaller particles to ensure cycling stability. Furthermore, through doping modifications, we aim to maximize specific capacity and energy efficiency, enabling the material to achieve both high compaction and optimal energy efficiency.

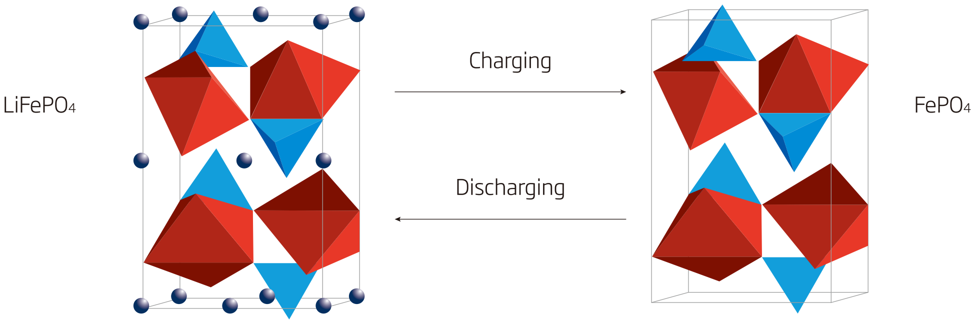


Figure 12 Structure of Lithium Iron Phosphate

To align with the PV lifecycle, the current requirements for battery cell cycling and storage have been extended to a lifespan exceeding 20 years. Although lithium iron phosphate (LFP) currently offers the longest cycle life among battery materials, substantial challenges remain. To address these problems, two primary solutions are in development: 1. Enhanced Coating for Longevity: To improve both storage and cycling performance, an advanced carbon-based coating has been applied. This innovative coating enhances conductivity, minimizes side reactions involving iron and lithium, and significantly extends the battery's lifecycle. 2. Pre-Cycle Performance Stabilization: LFP cells often exhibit rapid degradation in the initial cycling stages. To mitigate this and enhance user experience, the lithium supplement agent is added to reduce early-stage degradation. By fine-tuning the amount of this agent, initial decay is controlled, allowing for a custom-designed cycle life that meets specific application requirements.

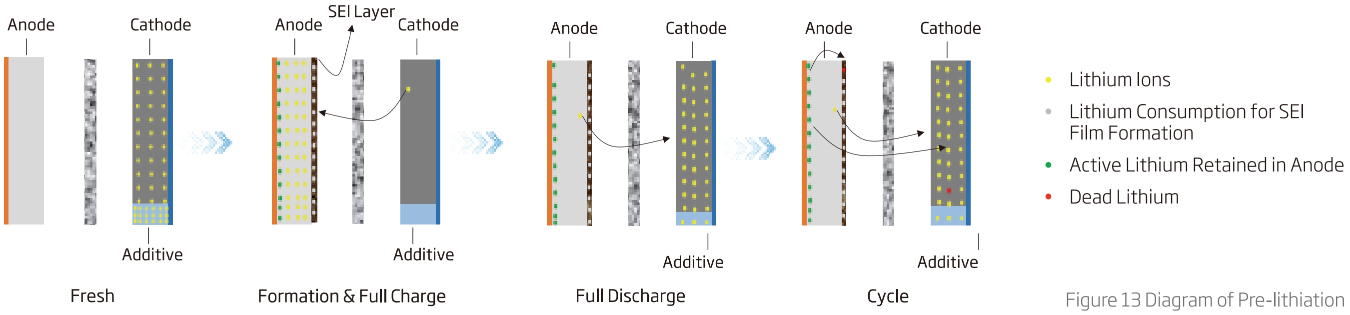


Figure 13 Diagram of Pre-lithiation

2.2.2 Application and Innovation of Negative Electrode Materials for Energy Storage

Negative electrode materials play a critical role as lithium-ion carriers within the charging and discharging cycles of lithium-ion batteries, enabling efficient energy storage and release. For use in energy storage cells, negative electrode materials must meet several essential requirements: Low and stable lithium insertion potential; structural stability throughout charge-discharge cycles; high specific capacity; high electronic/ionic conductivity with minimal charge transfer resistance; simple production process, environmentally friendly, and resource abundant.

Negative electrode materials fall into two primary categories based on composition: carbon-based and non-carbon-based, as illustrated in Figure 14.

To support energy storage cells that are cost-efficient, long-lasting, and safe, research on negative electrode materials is progressing along two main paths: enhancing extreme long-cycle performance and reducing costs.

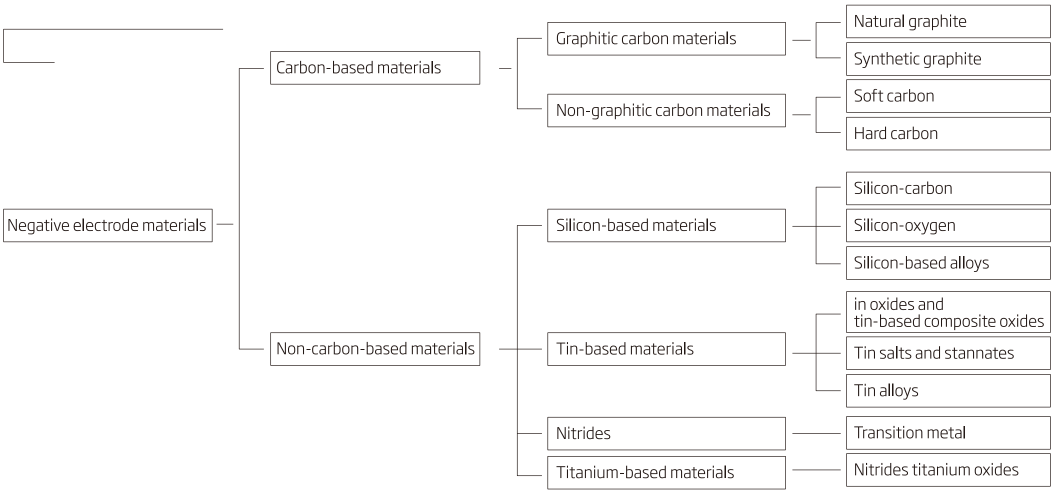


Figure 14 Classification of Negative Electrode Materials

Long-Cycle Performance Studies on graphite cycling have shown that capacity degradation primarily stems from the depletion of active lithium. This loss occurs at the graphite level due to several factors: 1. Increased polarization due to insufficient kinetics. 2. Loss of active lithium through side reactions caused by defects. 3. Active lithium consumed to repair the Solid Electrolyte Interphase (SEI) film, which ruptures due to particle expansion. Trina Storage's approach to long-cycle graphite development focuses on enhancing "high kinetics," "low defect levels," and "minimal expansion". Key methods include: 1. Selecting low-defect raw cokes. 2. Optimizing particle structures. 3. Reducing graphitization levels. 4. Customizing raw material coke sources.

Cost Reduction An analysis of cell costs indicates that graphite in negative electrode materials accounts for approximately 8% of the total cell cost. Within the negative electrode materials' cost structure, raw materials (such as needle coke, petroleum coke, and pitch coke) represent about 41%, while graphitization processing makes up about 51%. Therefore, cost-control efforts for negative electrode materials focus on these two areas.

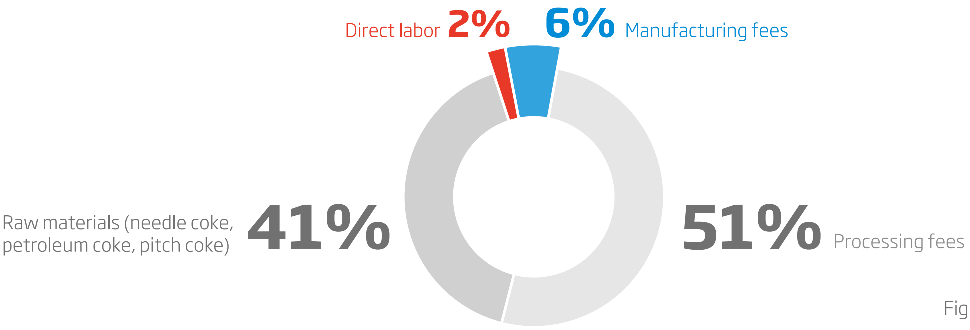


Figure 15 Cost Breakdown of Artificial Graphite

Through partnerships with raw material suppliers and graphite negative electrode material manufacturers, Trina Storage has independently developed customized, low-cost, long-cycle cokes (including petroleum, needle, and pitch cokes). Additionally, in collaboration with negative electrode material producers, Trina Storage has validated cost-effective graphitization furnaces—such as compartment-type, continuous, and large-capacity crucible furnaces—creating a fully integrated cost-reduction chain from raw material coke to graphite and, ultimately, to cells.

2.2.3 Application and Innovation of Electrolytes for Energy Storage

Serving as the lifeblood of cells, electrolytes critically affect battery lifespan, power, energy density, safety, and overall performance. An ideal electrolyte should exhibit high ionic conductivity, strong electronic insulation, a broad electrochemical stability range, exceptional chemical stability and safety, and be both environmentally friendly and non-toxic. Comprising solvent, lithium salt, and additives, the electrolyte typically consists of approximately 80% solvent, 10–15% lithium salt, and 5–10% additives, with each component's characteristics directly influencing the electrolyte's overall performance.

Trina Storage has developed a proprietary electrolyte formulation tailored specifically for energy storage cells. The solvent system is precisely adjusted to meet each cell's operational demands, optimizing both viscosity and dielectric constant. Employing a dual-salt strategy, the lithium salt combines the benefits of traditional commercial lithium salts with those of novel lithium salts to improve thermodynamic stability, mass transfer capacity, and adaptability across a wide temperature range. The additive package is built upon conventional additives, such as VC and FEC, and further enhanced with advanced sulfur-based film-forming agents, acid and moisture scavengers, anti-corrosion agents, and wetting agents. This comprehensive additive formulation improves compatibility with energy storage cells by addressing interface film structure, degradation mechanisms, and system integration, thereby boosting Trina Storage cells' energy efficiency, long-cycle stability, and high-temperature storage performance. Additionally, Trina Storage has optimized the use of traditional film-forming additives by analyzing their consumption rates over the cell's lifespan. Through refined injection protocols and calibrated additive configurations, Trina Storage maintains the SEI layer's integrity during extended cycles, thus alleviating high-impedance issues associated with high film-forming additive content. This approach mitigates the risk of rapid performance declines in Trina Storage cells over prolonged cycles.

Regarding safety, Trina Storage cell's electrolyte design incorporates stability across three critical dimensions: intrinsic electrolyte stability, beneficial external factors, and interface interaction stability. By assessing thermodynamic and electrochemical stability, gas production thresholds, electrode interface thermal resilience, and exothermic reaction rates, Trina Storage has optimized the electrolyte composition to comprehensively enhance the safety of cells. This focus on stability and mitigation of degradation-related risks enables Trina Storage cells to meet rigorous domestic and international energy storage safety certifications with top-rated safety performance.

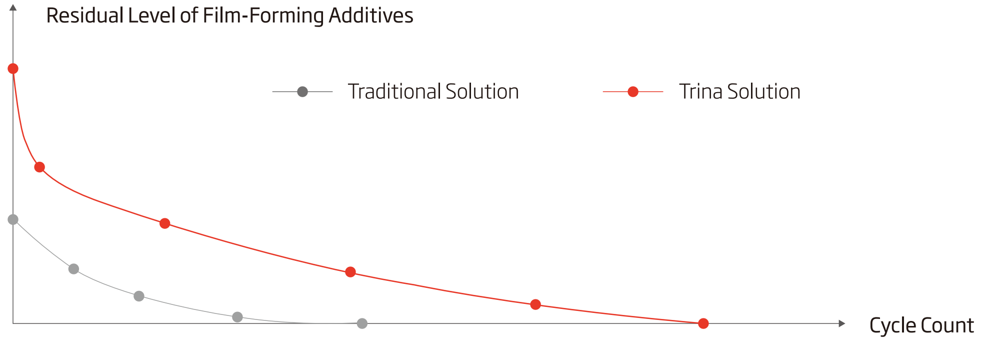


Figure 16 Life Cycle Additive Consumption

2.2.4 Application and Innovation of Separators for Energy Storage

The separator is a vital component in lithium-ion battery production, with its complex network of interconnected micropores facilitating the free movement of electrolyte ions to form a charge-discharge circuit. Under conditions of overcharge or elevated temperatures, the separator's pore-closing functionality isolates the battery's positive and negative electrodes, preventing direct contact that could lead to short circuits, interrupting current flow, and significantly reducing risks of overheating or explosion.

Currently, energy storage batteries primarily employ either wet- or dry-process separators. Wet-process separators, typically made from PE, are valued for their uniform pore distribution, high tensile strength, and excellent performance across applications. In contrast, dry-process separators, generally produced from PP, offer higher melting points than PE and are more cost-effective, though they do exhibit lower lateral strength. As safety requirements increase for energy storage applications, manufacturers are focusing on advancements in separator manufacturing processes to enhance performance. This has led to coating technologies that apply specialized materials to the base separator, effectively altering its properties to meet varied performance needs. These coatings enhance the separator's thermal stability and mechanical resilience. Trina Storage applies an inorganic and organic coating technique to improve the separator's thermal stability and mechanical strength, helping prevent unwanted contact between electrodes caused by separator shrinkage. Additionally, the coating stabilizes the electrodes, counteracting deformation from anode expansion and contraction during charge-discharge cycles and significantly extending battery cycle life. To further enhance cell energy density, Trina Storage utilizes thinner, high-temperature-resistant coatings, which increase energy density without sacrificing thermal resistance. In efforts to reduce separator costs, Trina Storage is exploring the use of thinner dry-process single-pull separators as alternatives to coated wet-process separators, while addressing the wrinkle challenges dry separators may present during electrolyte injection, ultimately lowering overall cell costs.

2.2.5 Application and Innovation of Binders for Energy Storage

Binders, classified by their dispersing medium as either oil-based or water-based, are essential for maintaining battery stability. Common oil-based binders include polyvinylidene fluoride (PVDF), while water-based binders encompass styrene-butadiene rubber (SBR) emulsion and carboxymethyl cellulose (CMC), along with polyacrylic acid (PAA), polyacrylonitrile (PAN), and polyacrylate, each of which has a specific market presence. Binders play a crucial role in maintaining electrode integrity and adapting to volume changes in active materials during charge and discharge cycles. They prevent the detachment of active materials, enhance cycling stability, and improve electrolyte wetting, facilitating efficient lithium-ion transport across electrode interfaces.

As a widely used binder for positive electrodes, Trina Storage has optimized the PVDF binder by increasing the polymer's molecular weight to enhance adhesion performance. Additionally, Trina Storage has fine-tuned the polymer chain branching to further improve dispersion capability.

For negative electrode binders, Trina Storage has refined the core-shell structure and adjusted the monomer composition of SBR latex particles. These modifications effectively control particle size, prevent SBR flotation during high-speed coating, and expand the processing window. Additionally, functional monomers are added to enhance lithium-ion affinity, boosting product kinetics. Trina Storage's flexible PAA formulation incorporates flexible monomers and advanced topology for increased flexibility, ensuring high adhesion, low swelling, and excellent dynamic tensile strength, thereby enhancing long-cycle performance. To ensure slurry stability, Trina Storage has chosen high-viscosity CMCLi, a selection that supports high energy density while enhancing kinetic performance and energy conversion efficiency.

2.2.6 Application and Innovation of Current Collectors for Energy Storage

The current collector in lithium-ion batteries aggregates and conducts current generated by the active materials. Key selection criteria include conductivity, chemical stability, and cost.

In energy storage applications, aluminum foil is generally used as the positive electrode collector, while electrolytic copper foil serves as the negative electrode collector. To further increase cell energy density, Trina Storage applies thinner copper and aluminum foils, which require advanced processing techniques and equipment. Trina Storage meets these demands through continuous refinements in technology and manufacturing processes. For positive electrode collectors, the relatively low conductivity of lithium iron phosphate is offset by Trina Storage's application of functional coatings on aluminum foil, reducing contact resistance and enhancing adhesion to improve both energy efficiency and cycling performance. In addition to conventional copper and aluminum foils, composite current collectors—consisting of aluminum-plastic or copper-plastic films—are gaining prominence. These composites feature an inner layer of polymers such as polypropylene, polyester, or polyethylene and an outer layer of metals like copper or aluminum. Compared to traditional metal foils, composite collectors offer significant gains in energy density and safety. Trina Storage is actively investigating the use of composite collectors in its energy storage solutions to further advance performance and efficiency.

Figure 17 Copper Foil, Carbon-Coated Aluminum Foil

2.3 Structural Innovations

2.3.1 Trends in Innovation and Evolution

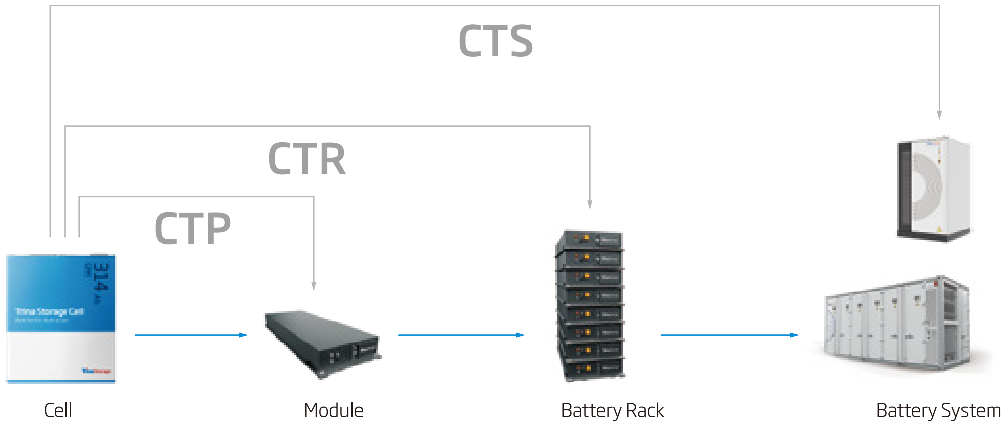


Figure 18 Packaging Method

Increasing the energy storage density per unit area can lower the lifecycle electricity costs of energy storage systems by minimizing fixed, one-time land investment expenses, all while maintaining other key performance metrics of the system. As single-cell technology advances, product quality has reached levels that support large-module or even module-free designs. These innovations reduce internal components, improve packaging efficiency, and optimize battery volume energy density.

2.3.2 Trina Storage's Selection

Among cell formats—prismatic, cylindrical, and pouch—Trina Storage has strategically chosen prismatic cells for energy storage, following a thorough evaluation of assembly efficiency, long-term reliability, manufacturing productivity, and cell performance. This focus has enabled Trina Storage to make significant strides in both technological and performance benchmarks.

Figure 19 Trina Storage's 280Ah and 314Ah Cells

— 280Ah Series Capacity Enhancement

Building on the established 280Ah cell, Trina Storage has expanded its portfolio with the proprietary 314Ah and 306Ah cells. The Elementa 2 flexible liquid-cooled battery system, powered by these advanced cells, offers significant energy capacity enhancements. The 306Ah cell delivers an impressive 4.073 MWh per container with a good balance between capacity and cycle life, while the 314Ah cell increases capacity to 5.015 MWh—a 103% jump compared to the previous generation's 2.2 MWh. These advancements demonstrate Trina Storage's commitment to driving innovation in energy storage solutions, meeting diverse demands with higher efficiency and capacity.

The Elementa2's single-cabinet energy capacity has now reached 5 MWh, effectively reducing land use and infrastructure costs, which translates to a marked improvement in users' return on investment.

Trina Storage Elementa 2

| Next-Generation Flexible Energy Storage Battery Cabinets

4MWh & 5MWh Platform

20ft Standard Cabinet

306Ah & 314Ah Trina Storage Cell

Unique Pack Design

Figure 20 Trina Storage's Elementa 2 Product Line

— 500Ah+ Cells

After meeting current demands for high-capacity cells, Trina Storage is exploring advanced technological pathways for even larger-capacity cells. Starting with customer requirements, Trina Storage is defining the ideal system capacities and refining cell specifications to pave the way for 500Ah+ cell development.

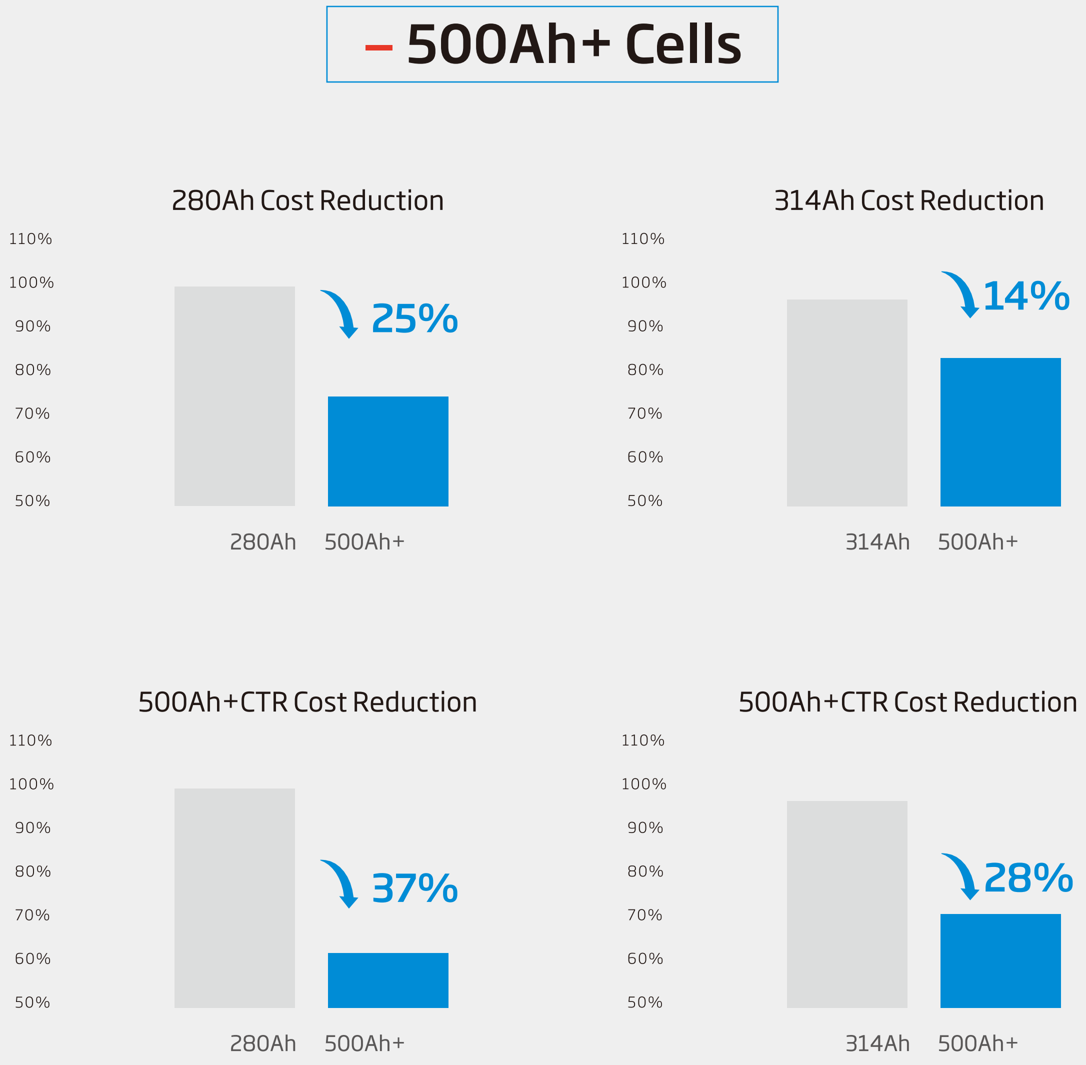


Figure 21 Cost Comparison for Large-Capacity Cells

3

Reliability Assurance

3.1 Testing Capabilities Expansion

Since achieving CNAS accreditation, Trina Storage's test center has earned additional certifications from CQC, UL, TÜV Süd, and IEC-accredited laboratories. As the first globally recognized CQC energy storage cell witnessing laboratory, the test center provides extensive testing services compliant with standards such as IEC62619, IEC62620, GB/T36276, UL1973, UL9540A, and GB38031.

The center has established a robust infrastructure, comprising six specialized labs for material synthesis, physical and chemical analysis, mechanical testing, electrical performance, safety and reliability, and system testing. With over 11,000 square meters of space, advanced testing equipment, and a dedicated team, the facility delivers comprehensive, one-stop testing and analysis services to clients.

Figure 22: Laboratory at Trina Storage's Test Center

To enhance lab management and efficiency, Trina Storage has developed a proprietary digital platform for cell testing, integrating real-time data capture and automated display. This platform enables seamless, end-to-end data retrieval and analysis, meeting the demands of "big data" storage and processing. The center's proprietary Laboratory Information Management System (LIMS) enables comprehensive digital lifecycle management, covering everything from order initiation, approval, sample delivery, and collection to scheduling and data processing. Key features include automated workflow execution, data export, anomaly detection, and automated report generation. This ensures full traceability, secure data storage, and robust encryption, substantially enhancing data security and operational efficiency throughout the lab.

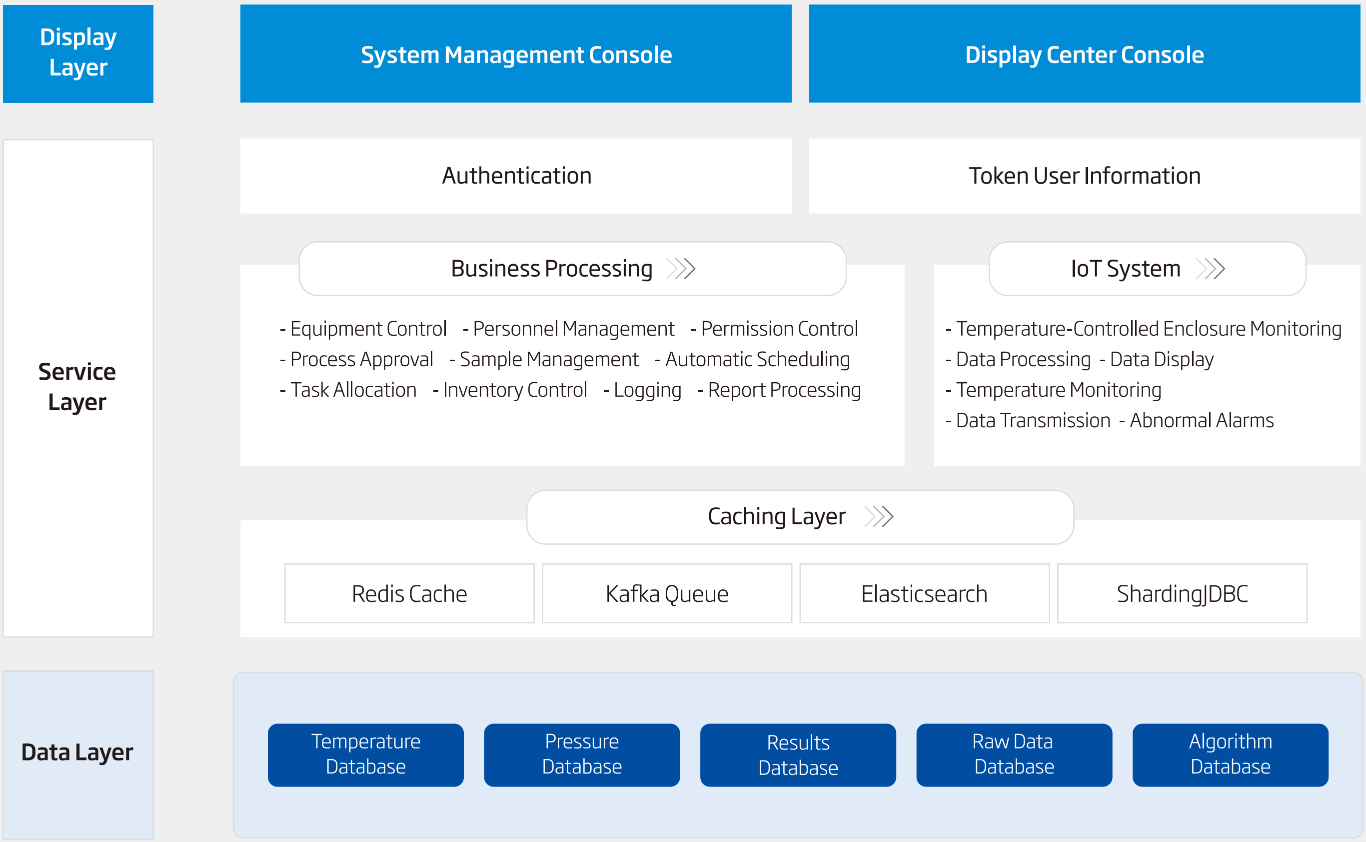


Figure 23 LIMS System Architecture

The center possesses comprehensive testing and development capabilities, enabling it to independently conduct over 30 unique tests, including high- and low-temperature energy efficiency, calendar life, terminal and explosion-proof valve airtightness, puncture, thermal runaway, and short-circuit tests. Additionally, it has developed a complete suite of gas generation testing methods, as well as in-situ expansion force (constant pressure/constant displacement) testing, volume testing, and water-cooled test fixtures. Notably, the in-situ expansion force test in constant gap mode achieves high precision, maintaining core expansion thickness within ±1 μm. The dual-channel constant pressure mode allows for the simultaneous testing of two cells, accurately assessing expansion consistency across parallel samples, thereby setting an industry-leading benchmark.

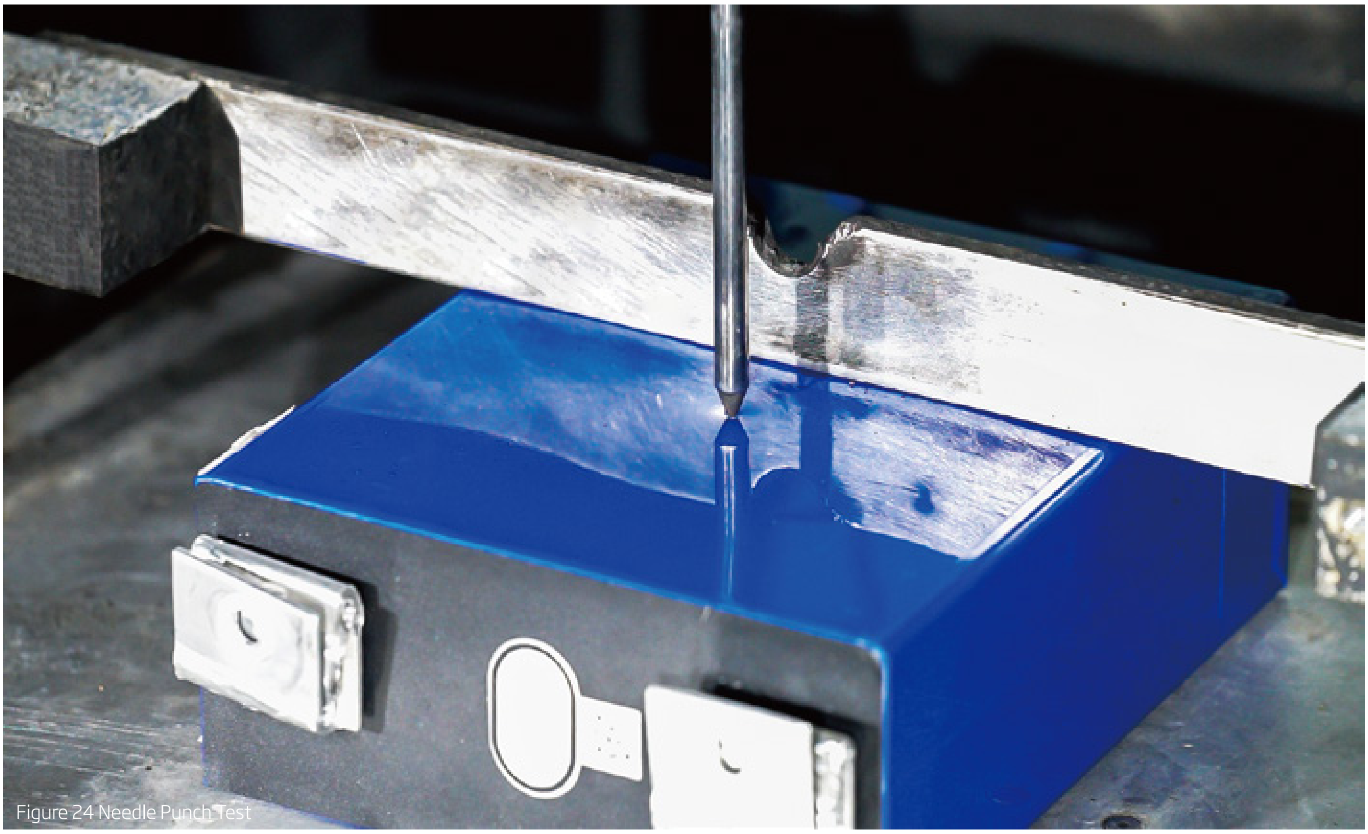


Figure 24 Needle Punch Test

Trina Storage's test center is dedicated to advancing technical capabilities, strengthening operational precision, and continuously optimizing laboratory efficiency and productivity. These efforts contribute to enhancing product safety and reliability, providing robust support to the energy storage industry.

3.2 Ultimate Reliability Assurance

Reliability represents a product's ability to fulfill specified functions under designated conditions over a given period, encompassing aspects of safety, applicability, and durability. Guided by a comprehensive understanding of energy storage cells' reliability demands, Trina Storage has established three pillars of reliability assurance: safety reliability, environmental adaptability, and lifespan reliability, each fortified by detailed assessments of potential failure modes.

3.2.1 Safety Reliability Assurance

Rooted in its customer-centric philosophy, Trina Storage prioritizes the highest safety standards for its energy storage cells, addressing users' top safety concerns. Consequently, Trina Storage has placed the utmost priority on achieving ultimate safety in cell design. To ensure outstanding safety and reliability, Trina Storage's R&D and manufacturing teams have implemented rigorous standards and processes at every stage—from product development and mass production to final delivery.

Trina Storage's cells have successfully achieved multiple international and domestic certifications from respected institutions like TÜV SÜD, including UL 9540A, UL 1642, UL 1973, UN 38.3, IEC 62619, and GB/T 36276. In exhaustive safety tests—spanning overcharge, over-discharge, overload, external/internal short circuits, crush, drop, impact, needle punch, and adiabatic temperature rise—Trina Storage cells have consistently demonstrated non-flammable and non-explosive performance, earning widespread client recognition globally.

Figure 25 Authoritative Testing and Certification of Trina Storage Cells

To further improve product safety at its core, Trina Storage emphasizes meticulous material selection and cell design optimization. Recognizing the electrolyte as a primary source of gas and heat during side reactions, Trina Storage applies in-situ DSC-MS technology to precisely control the cell's high-temperature exothermic and gas-generating behaviors. For enhanced thermal stability, Trina Storage utilizes lithium iron phosphate, known for its high thermal decomposition threshold under inert conditions, alongside high-stability materials that can endure elevated temperatures. Advanced interface control technology further stabilizes materials in high-temperature, reducing gas environments. Trina Storage's ultra-stable, inert interface control technology significantly minimizes oxygen release during thermal runaway, reducing heat and combustible gas generation. Through this refined material system, Trina Storage has achieved a maximum cell temperature below 300°C in UL 9540A certification thermal runaway tests, with combustible gas overpressure kept under 0.69 MPa, 5% below industry standards. This achievement provides an exceptional safety margin, protecting personnel in extreme scenarios. According to international overpressure standards for casualty prevention, Trina Storage cells provide the maximum safety distance, ensuring personnel safety during extreme accidents.

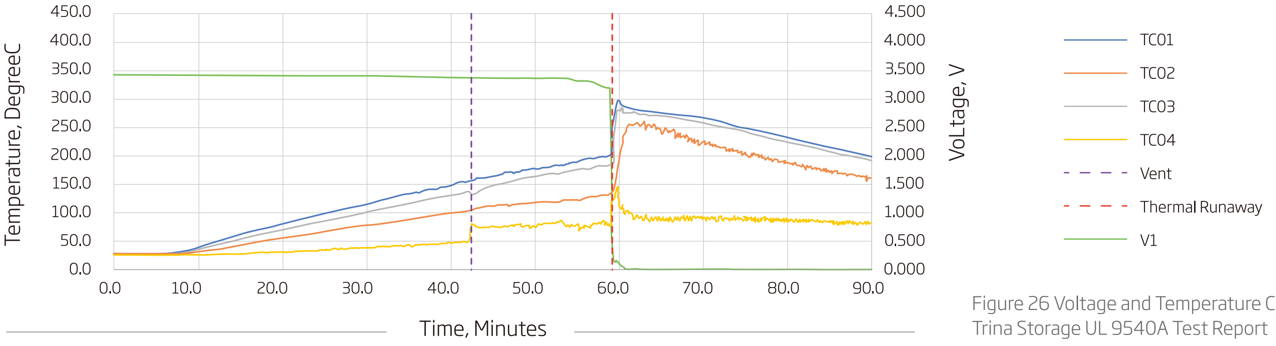


Figure 26 Voltage and Temperature Curves from Trina Storage UL 9540A Test Report

3.2.2 Environmental Adaptability Assurance

Energy storage cells are often exposed to diverse application environments, including high-altitude, tropical, frigid, and coastal regions. Lithium batteries, known for their high-performance energy storage capabilities, are particularly sensitive to environmental conditions. In challenging environments, they may face performance degradation or accelerated aging, potentially impacting their ability to meet client requirements effectively. To address this, Trina Storage conducted extensive studies on environmental conditions at both user sites and transport routes, evaluating potential impacts. Comprehensive environmental reliability testing was conducted at the battery level, covering high- and low-temperature energy efficiency, extreme temperature discharge, low-temperature lithium precipitation, salt spray corrosion, and vibration tests. Beyond meeting national standards, Trina Storage cells also meet criteria from third-party testing authorities, ensuring robust environmental adaptability that supports a broad spectrum of customer business models.

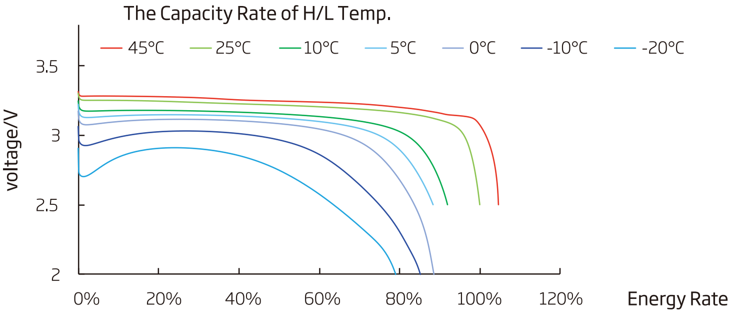


Figure 27 High- and Low-Temperature Discharge Test Flow and Results Display

3.3 Lifetime Reliability Assurance

The battery's function within energy storage products is to store and release electrical energy reliably throughout its expected lifecycle. Structurally, a battery consists of an internal core and an external casing, with its overall lifespan dictated by the durability of these components. The principle of the "weakest link" applies here: failure in any component can reduce the battery's life. Trina Storage assesses battery lifespan through two primary dimensions: auxiliary material longevity and electrical performance durability. This approach shifts reliability from a focus solely on product use to a comprehensive lifecycle reliability framework, maximizing customer value.

3.3.1 Auxiliary Material Longevity

The core's materials include primary and auxiliary components. While primary materials have been extensively researched, auxiliary materials—subject to slower degradation and harder-to-assess longevity—have received less focus. As industry standards for battery lifespan in energy storage advance, addressing auxiliary material aging is becoming essential. Building on insights into fatigue mechanisms of various auxiliary materials, Trina Storage has developed specific testing methods for assessing their fatigue lifespan.

For example, accelerated temperature cycling tests replicate decades of daily thermal fluctuations to evaluate the adhesion reliability of binder materials between electrodes and collectors. Using the Coffin-Manson fatigue failure model, Trina Storage predicts adhesion deterioration due to thermal cycling, ensuring bond integrity at the cell's end-of-life (EOL). To enhance auxiliary material reliability, Trina Storage uses extensive data to optimize design and manufacturing processes, reducing risks of lifespan degradation for end-users and supporting project economic objectives.

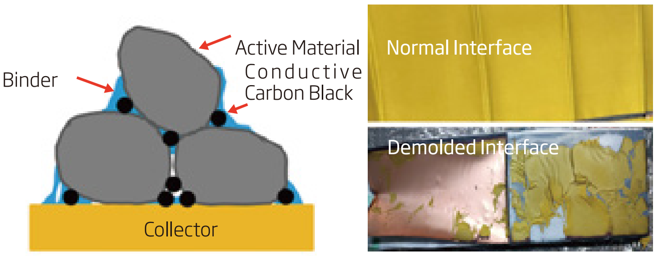
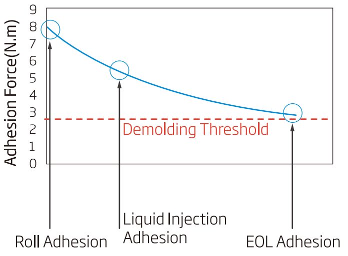


Figure 28 Mechanism of Binder Action and Normal vs. Demolded Interface



Coffin-Manson Model

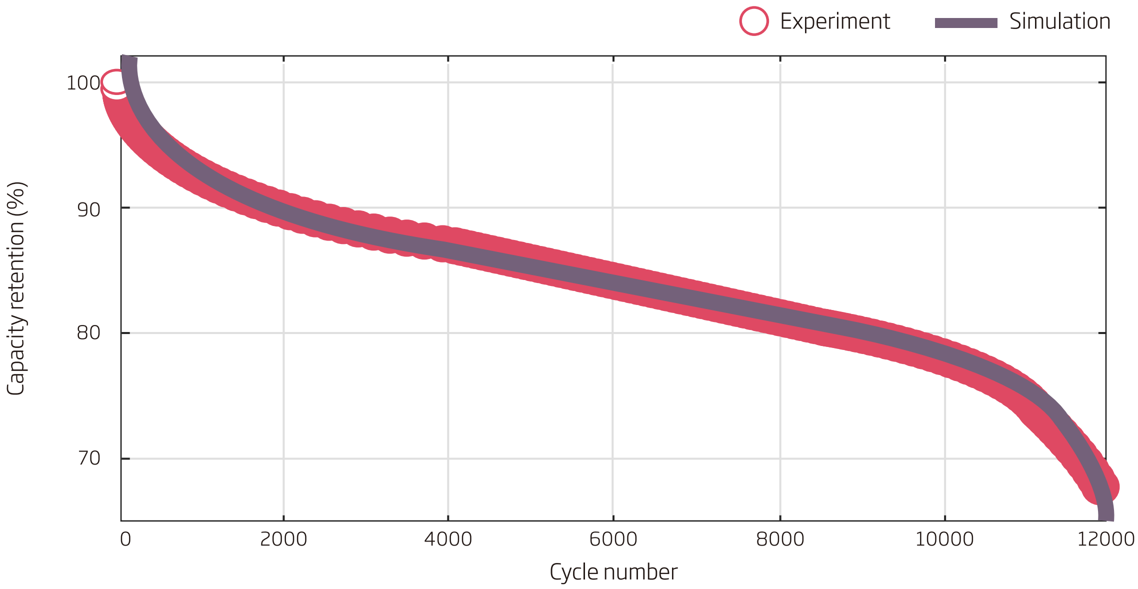
$$AF = \left(\frac{\Delta T_1}{\Delta T_f}\right) \times \left(\frac{f_f}{f_1}\right) \times EXP\left[\frac{E}{R} \times \left(\frac{1}{T_{\max f}} - \frac{1}{T_{\max 1}}\right)\right]$$

AF: Acceleration Factor
ΔT_1: Laboratory Temperature Difference
ΔT_f: Market Temperature Difference
f_1: Laboratory Temperature Frequency
f_f: Market Temperature Frequency
T_{max1}: Maximum Laboratory Temperature/k
T_{maxf}: Maximum Market Temperature/k
E: Activation Energy, R: Boltzmann Constant

Figure 29 Adhesion Degradation Model Framework

3.3.2 Electrical Performance Durability

For customers, the battery's electrical performance lifespan–defined as the time until capacity drops to 70% of state-of-health (SOH) under specified conditions–is of utmost importance. During R&D, Trina Storage conducts high-temperature cycling and stress tests at boundary conditions such as low state-of-charge (SOC) storage. This data informs Trina Storage's various lifespan prediction models, including semi-empirical, data-driven, and electrochemical simulations, which produce lifespan curves tailored to clients' power usage profiles. Further analysis of aged batteries allows Trina Storage to identify risks of accelerated capacity decline in later usage stages, informing proactive improvements in battery design. Ensuring mass-produced batteries meet expected lifespans also poses challenges. Trina Storage addresses these by accounting for production line variations, batch differences, and environmental factors, implementing on-line reliability tests (ORT) and a comprehensive anomaly assessment system to detect and prevent defective units from reaching the market.



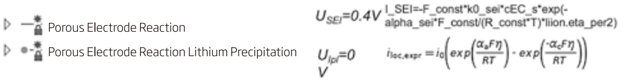
SEI Growth and Lithium Precipitation Equation

—Reaction Equation

$$j_{SEI} = -aFk_{0,SEI}c_{EC}^{s} \exp\left(-\frac{\alpha_{c,SEI}F}{RT}\left(\phi_s - \phi_e - \frac{j_{tot}}{a}R_{film} - U_{SEI}\right)\right)$$

$$j_{lpl} = -ai_{0,lpl} \exp\left(-\frac{\alpha_{c,lpl}F}{RT}\left(\phi_s - \phi_e - \frac{j_{tot}}{a}R_{film}\right)\right)$$

—Model Setup



U_{SEI}=0.4V I_SEI=-F_const*k0_sei*cEC_s*exp(-alpha_sei*F_const/(R_const*T)*liion.eta_per2)

U_{lpl}=0 V $i_{loc,expr} = i_0\left(exp\left(\frac{\alpha_a F\eta}{RT}\right) - exp\left(\frac{-\alpha_c F\eta}{RT}\right)\right)$

Realization of Current Equations for Lithium Ion Diffusion in SEI Membranes

—Control Equation

$$-D_{EC}\frac{c_{EC}^{s} - c_{EC}^{0}}{\delta_{film}} = -\frac{j_{SEI}}{F} \rightarrow C_{EC}^{s}(t) = Ki_{loc}(t)\delta_{film}(t)$$

两边对t求微分

—Model Setup

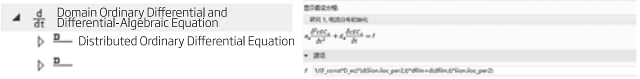


Figure 30 Electrochemical Simulation Model for Predicting Battery Life Reference: X.-G. Yang et al., Journal of Power Sources 360 (2017) 28-40

With customers' rising standards and heightened focus on product quality, reliability has become essential for competitive products. Trina Storage has established a robust reliability framework, integrating advanced management tools, methodologies, and a dedicated team to deliver highly secure, dependable lithium battery solutions to customers.

4

Building a Full-Chain Ecosystem

4.1 Advanced Manufacturing Technology

Trina Storage has deployed a comprehensive smart manufacturing strategy that combines automation, digitalization, and intelligent manufacturing to establish an industrial internet system and user-centric "lighthouse factory". Guided by specialized teams in process, quality, equipment, and manufacturing, Trina Storage continually refines technology to achieve efficient, precise, flexible, and sustainable production. This approach enhances product quality and production efficiency while reducing costs.

4.1.1 Intelligent Manufacturing for Product Empowerment

4.1.1.1 Automated Production Line and Intelligent Manufacturing System

Trina Storage has developed a fully automated production line featuring high-efficiency pulping and dispersion processes with three-stage demagnetization technology. This ensures uniform and stable distribution of electrode materials, conductive agents, and binders, providing a robust foundation for premium products. Precision coating technology achieves micron-level accuracy at speeds of 60m/min, while high-speed strip rolling, laser die-cutting, and multi-lug winding further optimize product performance, precision, and efficiency. Through the use of efficient contact-type vacuum baking technology, Trina Storage achieves robust energy recycling, markedly enhancing energy utilization efficiency. High-efficiency vacuum formation technology effectively resolves cell interface inconsistencies, promoting greater cell uniformity, safety, and formation efficiency, thus safeguarding product quality. An MES system enables real-time traceability and full lifecycle management of battery cells, while ERP-MES integration oversees over 2,100 process checkpoints, allowing millisecond-level interactions between equipment and systems.

Figure31 Automated Mechanical Equipment

4.1.1.2 Flexible Production

Trina Storage's production line design anticipates future product diversification, incorporating key workstation flexibility and multi-size jigs to facilitate rapid transitions between battery specifications. This adaptability extends beyond equipment adjustments, encompassing intelligent optimization of the entire production process. Focused training and cross-departmental collaboration ensure smooth transitions from design to production, maximizing overall production efficiency.

4.1.1.3 Intelligent Energy Management

By the end of Q2 2024, Trina Storage achieved a production capacity of 25GWh across energy storage batteries, DC battery cabinets, and AC/DC products. The production base prioritizes clean, stable energy, improving efficiency through real-time, precise energy monitoring, smart scheduling, and optimized distribution. This energy management framework supports environmental protection and carbon reduction, aligning with ESG principles.

4.1.1.4 Preventive Maintenance and Health Management

Reliable equipment performance is vital for uninterrupted production. Trina Storage utilizes an intelligent, digital equipment management system that automates maintenance, repair, and upkeep across equipment lifecycles, reducing unplanned downtime and boosting consistent production and efficiency.

4.1.2 Quality Control for Consistency

4.1.2.1 Quality Management System

Trina Storage employs a standardized, systematic quality management framework to ensure product consistency. Through IPD and NPI processes, Trina Storage addresses quality at the design stage. Supplier audits and automotive-industry-standard PPAP processes guarantee that incoming materials meet quality standards. During production and shipment, MES, QMS, and other systems enforce stringent quality and consistency benchmarks. After-sales support is managed by cloud-based, big-data-driven monitoring systems, which provide early warnings and proactive quality management, offering customers greater assurance and satisfaction.

4.1.2.2 Digital Quality Control

Trina Storage's smart factory generates over 15 production traceability reports, supporting detailed product and process analyses. The system collects and assesses hundreds of thousands of in-process data points during capacity ramp-ups, allowing real-time capacity and yield inquiries to align data with actual production. Diverse monitoring tools and reports assist in managing inventory, on-site consumption, and product analysis, providing production, quality, and lineside teams with accurate, immediate material verification capabilities.

4.1.3 Intelligent Delivery

Trina Storage achieves full digital control of its production chain through seamless integration of MES and ERP for plan management, and MES with WMS/ERP for on-site material management. This comprehensive connectivity spans from material procurement, warehousing, and distribution, to production, finished goods warehousing, product delivery, and account processing. The result is a streamlined production planning process, efficient logistics, and well-regulated manufacturing that enable stable system operations, intelligent delivery, and full traceability of information.

ISO

ISO 9001: Quality Management System
ISO 14001: Environmental Management System
ISO45001: Occupational Health and Safety Management System

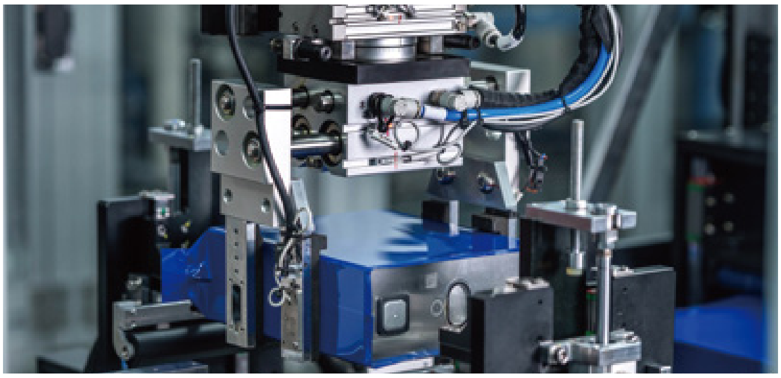


Figure 32 Automatic Film Wrapping Machine

4.2 Supply Chain Assurance System

4.2.1 Building an Efficient, Collaborative Global Supply Chain

The evolving external landscape and rising internal demands bring new challenges, underscoring the need for digital transformation to mitigate supply chain uncertainties. External globalization-driven complexities increase risks, while internally, consumer preferences shift toward smaller, customized orders, adding operational pressures.

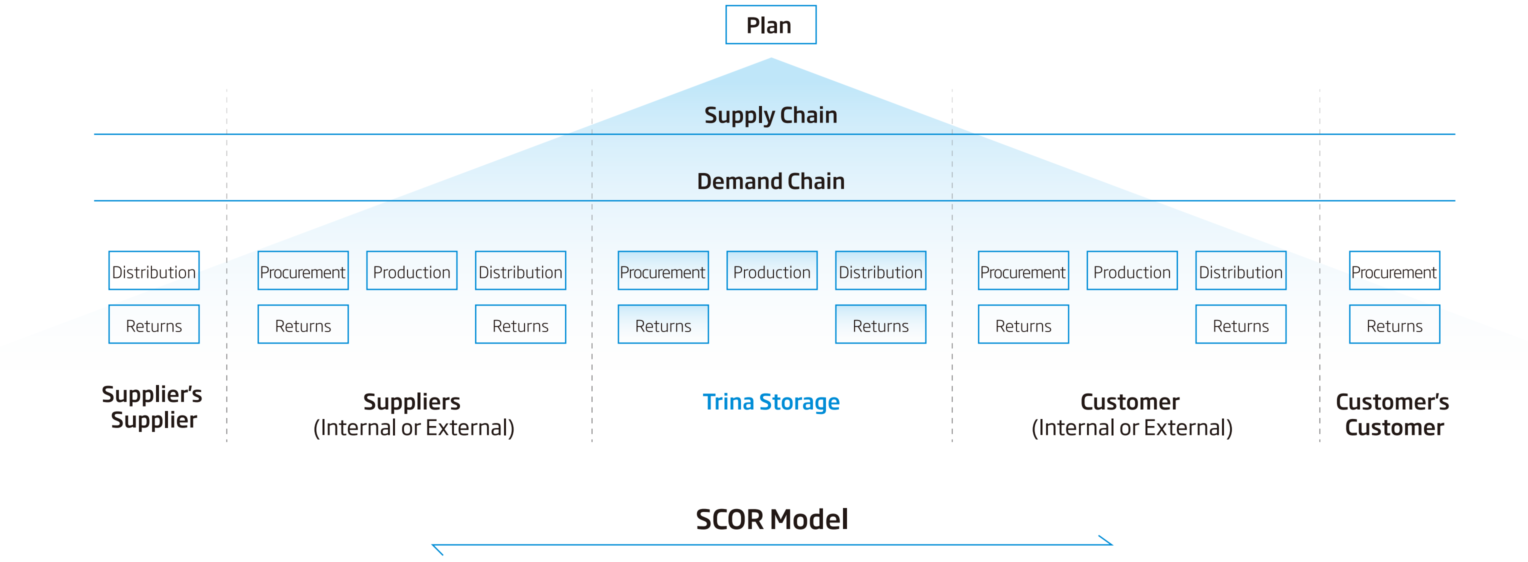


Figure 33 SCOR Model

Trina Storage responds by implementing a digital, customer-focused supply chain system that synchronizes planning, procurement, manufacturing, delivery, logistics, and warehousing. Utilizing the SCOR model (Supply-Chain Operations Reference model) and best practices in change management, Trina Storage orchestrates global production, supply, and marketing planning. Supplier management is organized through a structured tiering system, covering onboarding to exit, with supply-specific strategies that ensure robust internal and external connectivity throughout the supply chain.

4.2.2 Comprehensive Device Control for Flexible Production

To ensure a flexible supply, Trina Storage employs a BOM-centered strategy to maintain a stable material flow for production, emphasizing both cost efficiency and quality. This approach is supported by annual framework agreements and rigorous quality assurance protocols, ensuring cost-effectiveness alongside superior product quality.

The supply chain structure and procurement processes are crafted to manage risks comprehensively. This includes an early-stage intervention in procurement to proactively address and mitigate design-related supply risks. A robust supplier certification process ensures rigorous screening, while a cost-optimization approach keeps expenses under control across all product lines. Additionally, Trina Storage enhances supply reliability by expanding and refining its supplier base through scenario-based certifications that minimize lead times, streamline workflows, and strengthen supply dependability.

Through digital enhancements, Trina Storage's supply chain resilience is reinforced across supply-demand optimization, relationship management, and quality improvement. In supply-demand alignment, we enhance efficiency and quality in matching, making supplier selection more streamlined. Our relationship management fosters strong, mutually beneficial ties with suppliers, while continuous collaboration in quality drives supplier innovation, improving product standards and elevating the overall supply chain structure.

4.3 After-Sales Service System

— Customer Service Platform

Trina Storage has developed a 24/7 multi-channel customer service platform centered on prompt responsiveness to customer needs. Through hotlines, email, and official accounts, Trina Storage ensures quick and effective handling of all customer inquiries.

— After-Sales Technical Support and Maintenance

Trina Storage provides comprehensive lifecycle service and technical support, offering prompt and professional assistance for inquiries regarding product information, technical support, usage guidance, and general consultations. With a rapid response mechanism in place, Trina Storage guarantees a 24-hour response for domestic requests and a 48-hour response for international inquiries, enhancing overall customer satisfaction.

— Spare Parts Management

Trina Storage has established a dedicated spare parts center managed by a digital information system, allowing for precise planning and efficient control of global spare parts inventory. This system enables a quick response to client needs, ensuring minimal downtime.

— Global Training Center

To continually enhance the skillset of its service team, Trina Storage operates a professional training center led by industry experts. Regular training sessions increase the technical capabilities of after-sales engineers, while specialized client training programs equip customers to understand and maximize product benefits.

Rapid Response Resolution Mechanism

24h Domestic — **48h** Overseas

5

Self-Developed Cells: Enhancing Customer Value

Leveraging Trina Group's extensive experience in the new energy sector and three decades of manufacturing expertise, Trina Storage tailors its products to meet diverse customer needs in the photovoltaic market. Driven by customer demand, Trina Storage has carefully developed energy storage solutions extending across the industrial chain, ensuring ongoing enhancement and innovation in its proprietary cells. Trina Storage aims to exceed customer expectations by delivering superior products and fostering sustainable growth within the energy storage market.

— Safety and Reliability

Quality Assurance Trina Storage's proprietary cells are developed under stringent quality control measures from raw material selection to production and quality checks, ensuring exceptional reliability and product stability.

Traceability Each cell features a comprehensive traceability management system, monitoring all materials and production stages to facilitate rapid identification and resolution of any potential safety issues.

— Economic Efficiency

Capacity Assurance Trina Storage's strong supply chain ensures consistent production capacity, preventing shortages that could disrupt project delivery and supporting customers' long-term operational needs.

Optimized Performance Long-life, high-efficiency batteries extend system cycles and enhance throughput, optimizing system value, improving power station efficiency, and reducing overall lifecycle electricity costs.

— Reliability and Peace of Mind

Rapid Response With a global after-sales network, Trina Storage has established a robust support system for timely and effective customer service.

Technical Support A dedicated technical team offers full-spectrum consulting and support, helping customers optimize the usage, safety, and efficiency of their products.

Unified Interfaces Trina Storage's full-stack self-developed product lineup ensures end-to-end after-sales support, eliminating the complexities of multi-manufacturer coordination and providing customers with seamless service from core components to entire systems.

> In its pursuit of seamless integration of solar and energy storage technologies, Trina Storage upholds a commitment to innovation, focusing on high-performance, long-lasting energy solutions. Our dedication lies in providing safe, reliable, and highly efficient energy storage products and solutions, engineered for extended lifespans and intelligent functionality. Through continuous technological advancement, we aim to propel the energy storage industry forward, support the transformation of modern power systems, and collaboratively lead the way in smart solar energy solutions for a net-zero future.

BNEF Energy
Storage Tier 1 List

Tier 1

BNEF Storage
Providers & Integrators
Bankability

Global Top-level

TrinaStorage

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