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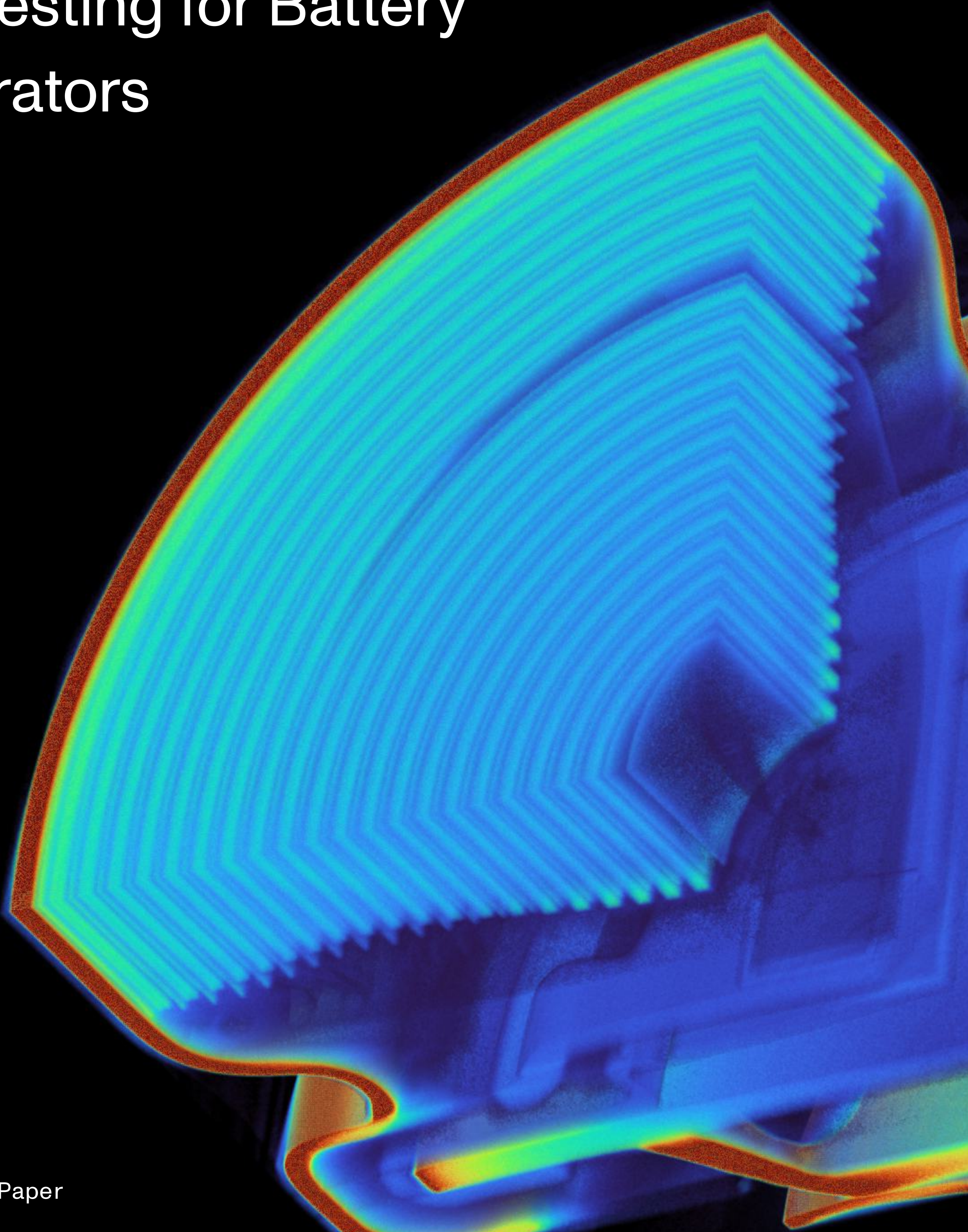
Streamlining Validation and Testing for Battery Integrators



Lumafield White Paper

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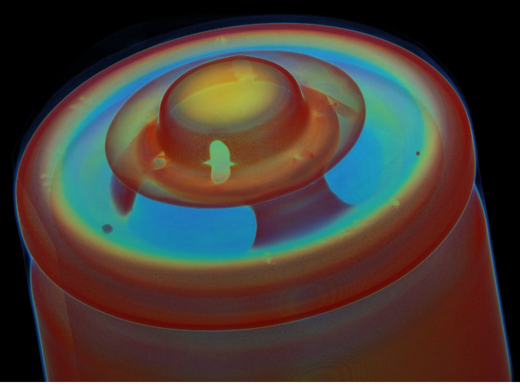
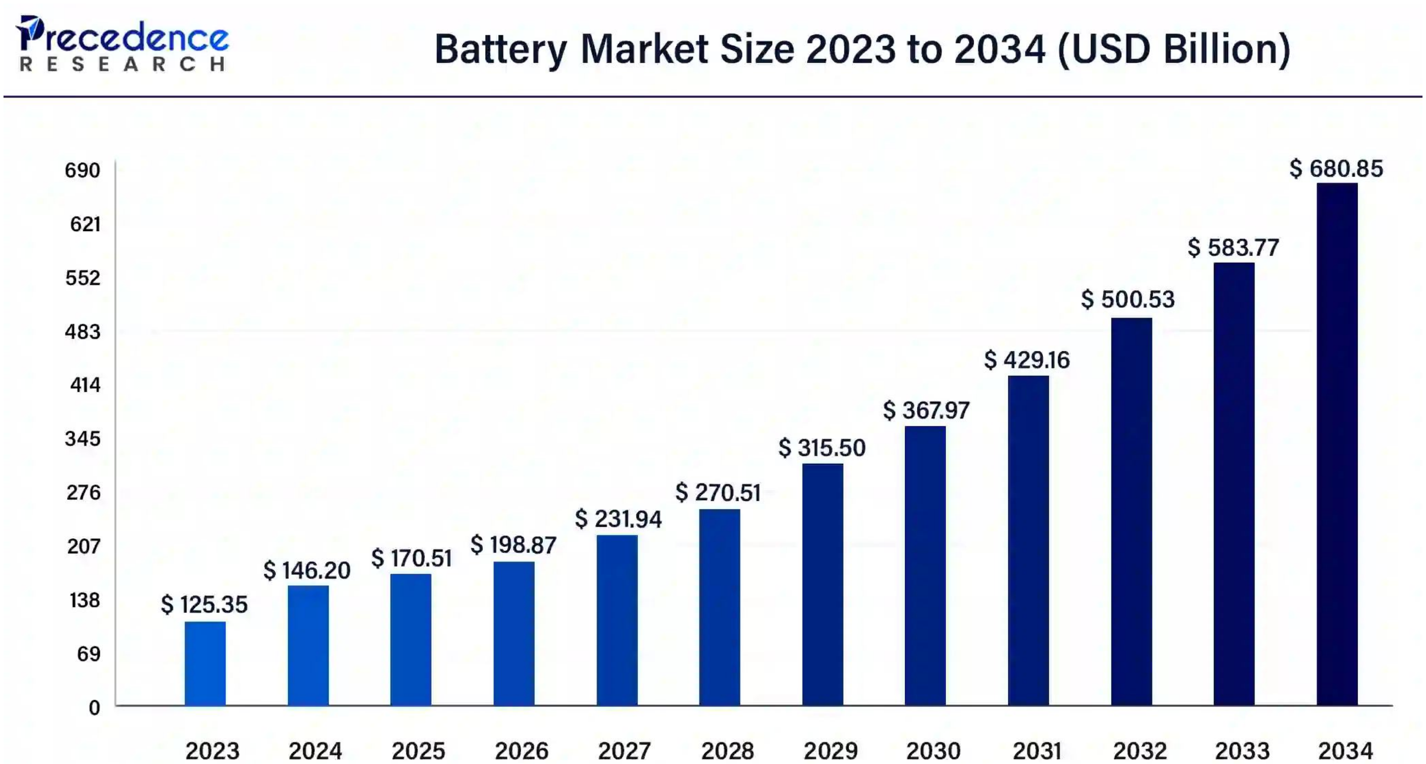


Streamlining Validation and Testing for Battery Integrators

Introduction

Battery integrators play a critical role in bridging the gap between cell manufacturers and end-use industries, such as electric vehicles (EVs), energy storage, and consumer electronics. As demand for battery systems continues to surge, driven by growth in sectors like renewable energy and EVs, integrators face the growing challenge of ensuring that the batteries they assemble are both reliable and safe. The global battery market is projected to exceed $300 billion by 2030, intensifying the need for robust testing and validation processes to mitigate risks associated with defective batteries, which can lead to fires, explosions, and costly recalls.[1]

The stakes of battery safety could not be higher, and integrators are at the forefront of ensuring that cells, modules, and packs meet stringent quality standards. Traditional testing methods, such as electrochemical tests, provide valuable data on battery performance metrics like capacity and voltage stability. However, these methods often fall short in detecting internal physical defects that may compromise the battery's integrity. Industrial Computed Tomography (CT) scanning, a non-destructive imaging technology, is emerging as a critical tool for integrators, offering data-rich insights into the internal structure of batteries. By providing high-resolution, 3D images of cells, CT scanning allows integrators to detect defects early, ensuring safer and more reliable battery systems throughout their lifecycle.[2]



Supplier Validation: Verifying Incoming Cells

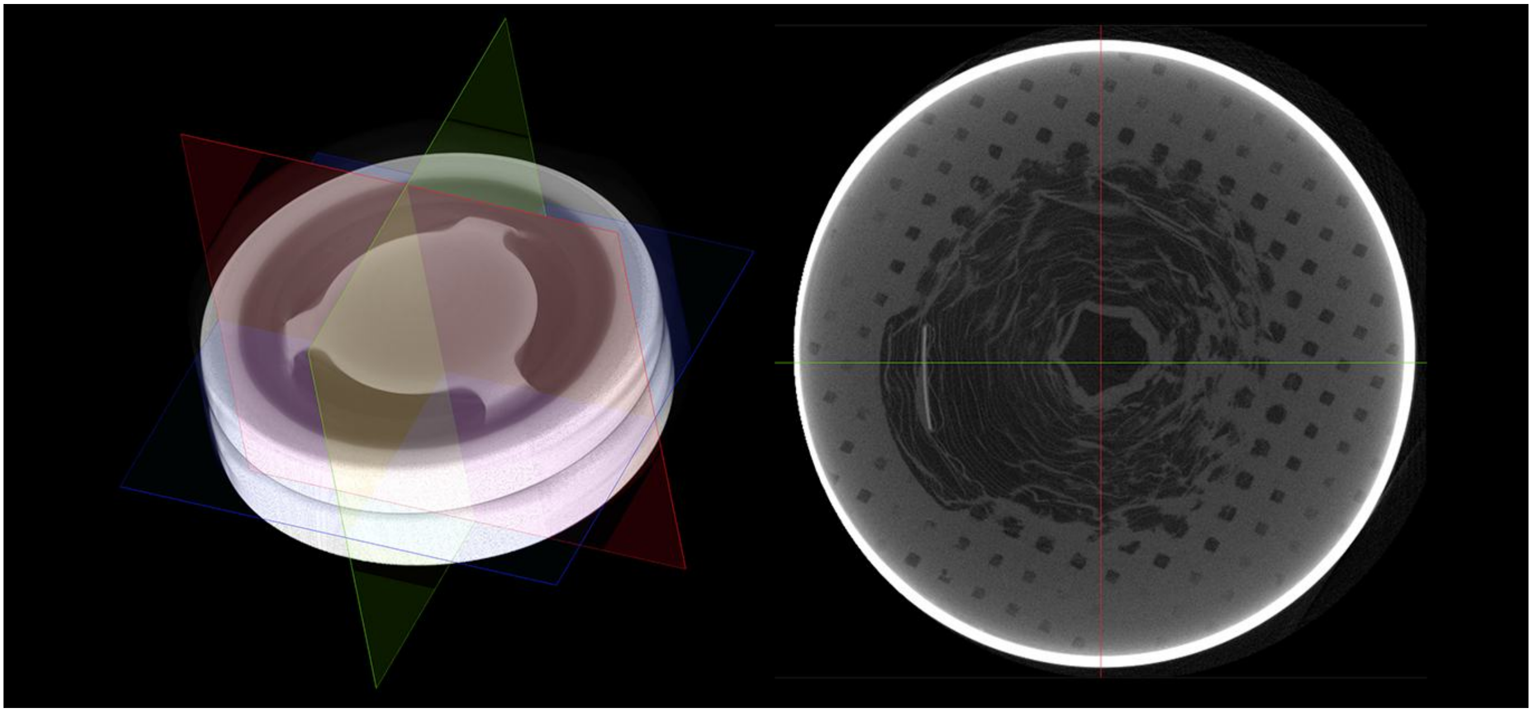
In a highly competitive market, battery integrators must balance the need for thorough testing and validation with the pressures of reducing costs and accelerating production timelines. CT scanning offers a cost-effective solution by helping integrators catch defects early in the production process, thereby reducing the risk of costly failures, warranty claims, or recalls later on.

Supplier validation is the first crucial step for integrators, as even small defects in incoming cells can lead to significant performance issues later in the battery's life cycle. Traditional electrochemical testing methods are useful for evaluating the electrical properties of a cell, but they do not offer insights into its internal structure. This leaves a gap in quality control, where physical defects—such as misalignments, internal voids, or improper layering—may go undetected. Such issues can compromise the safety and reliability of battery systems, especially in high-stakes industries like automotive and aerospace.

CT scanning bridges this gap by offering a non-destructive method for inspecting the internal structure of battery cells. Through high-resolution 3D imaging, integrators can detect issues like delamination, poor alignment of anode and cathode layers, or contamination by foreign particles.[3] These types of defects can lead to dangerous conditions, such as short circuits, thermal runaway, or premature aging of the battery.

For example, misalignment between the anode and cathode layers can cause lithium plating, which leads to capacity loss and safety risks. CT scanning has been proven to detect such critical defects at the earliest stages of production, preventing defective cells from being integrated into larger systems.[4] This is especially important as the internal structure of lithium-ion cells is intricate, with thin, closely-packed layers. Even minor defects can compromise performance.

▼ This industrial CT scan of a 21700 battery highlights the polyolefin separators—likely made of polyethylene (PE) and polypropylene (PP)—which are visible as concentric layers between the electrodes. CT allows for the detection of potential defects, such as wrinkles, tears, or misalignments in these separators, which could lead to uneven ion flow, reduced battery performance, or short circuits.



Advanced Testing: Inspecting for Changes After Thermal or Use Cycling

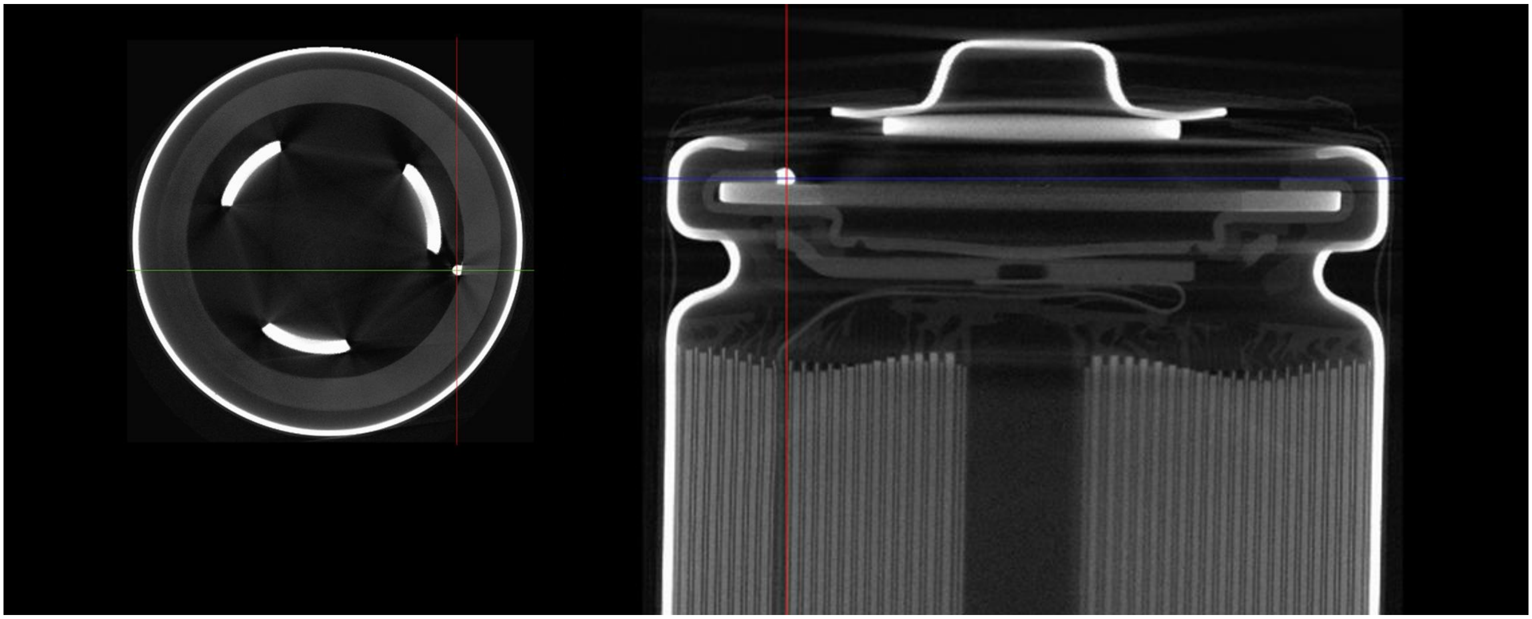
After verifying the quality of incoming cells, integrators must also ensure that batteries can withstand real-world operating conditions. Thermal cycling and use cycling tests are designed to simulate the environmental and operational stresses that batteries will face during their lifecycle. Thermal cycling subjects batteries to rapid temperature fluctuations, while use cycling involves repeated charge and discharge cycles. Both tests are essential for identifying how a battery's internal structure might degrade over time.

CT scanning plays a critical role in post-cycling testing by providing detailed insights into how a battery's internal components change under stress. Traditional testing methods, such as electrochemical analysis, cannot detect physical changes like delamination, cracking, or swelling that may occur after thermal or use cycling.[5] These internal defects can lead to significant performance issues, such as reduced capacity or even catastrophic failure.

Incorporating CT scanning into the post-cycling testing process allows integrators to detect these hidden issues before they manifest as failures in the field. For instance, studies have shown that CT scanning can reveal early signs of delamination in lithium-ion cells after thermal cycling, an issue that would otherwise go unnoticed until it leads to battery failure.[6] By detecting such defects early, integrators can make data-driven decisions about the reliability of their batteries, preventing costly failures and improving overall product quality.

Furthermore, CT scanning supports long-term reliability by allowing integrators to refine their supplier selection and manufacturing processes based on data gathered from post-cycling tests. This proactive approach ensures that only the highest-quality cells make it into production, reducing the risk of costly recalls or warranty claims later on.[7]

▼ In this 18650 battery, CT reveals debris along the edge of the gasket. Identifying foreign particles like these is critical, as they can lead to internal short circuits or compromise the battery's long-term reliability and safety. Industrial CT allows for non-destructive detection of such contaminants, ensuring defects are caught early in the production process to prevent performance issues or failures.



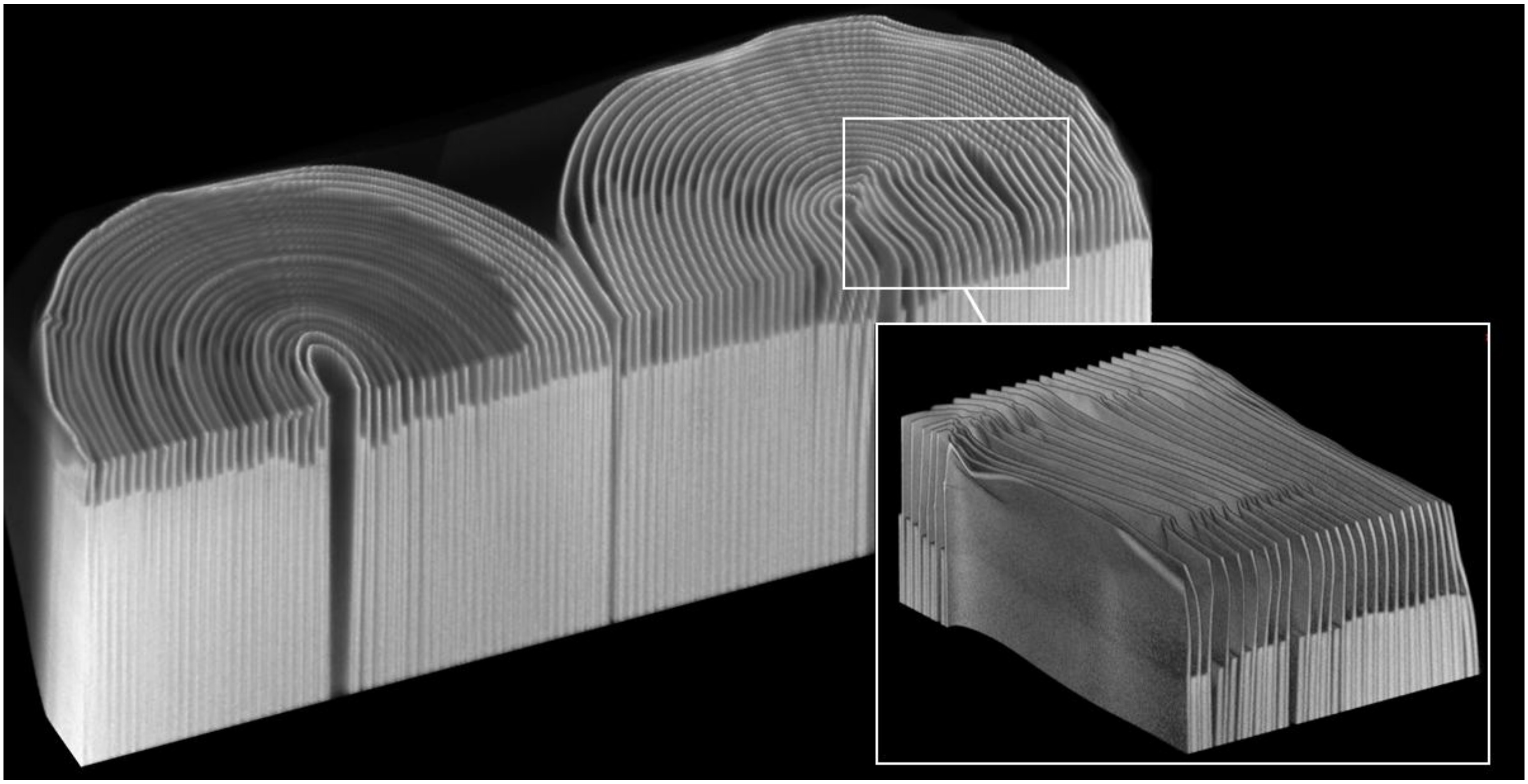
Integration Challenges and Solutions

As battery cells move from validation to assembly into modules or packs, battery integrators face new challenges. Ensuring that cells are properly aligned, mechanically stable, and securely connected is critical to optimizing battery performance and safety. Misalignments, voids in resin filling, or improper electrical connections can lead to long-term failures, including uneven wear, mechanical stress, or catastrophic short circuits. CT scanning provides a non-destructive solution that enables integrators to identify these issues during and after the assembly process, ensuring that battery packs meet strict quality standards.

Industrial CT plays a crucial role in ensuring that electrical connections and mechanical fits meet tight tolerances. In applications such as EVs or renewable energy storage, even small deviations from the design specifications can lead to significant performance losses or safety risks. CT scans can verify the integrity of welds and connectors, ensuring that no gaps or inconsistencies are present, which could compromise the electrical performance of the entire pack.[8] This level of precision is especially important in industries where safety standards are strict, and failure is not an option.

Furthermore, by incorporating CT scanning into the assembly process, integrators can reduce the need for post-production rework. Catching defects early, such as poor alignment or material contamination, saves time and resources, preventing costly recalls or repairs after the battery packs are deployed.[9] Overall, CT scanning helps integrators ensure that their battery modules and packs are reliable, safe, and compliant with industry standards.

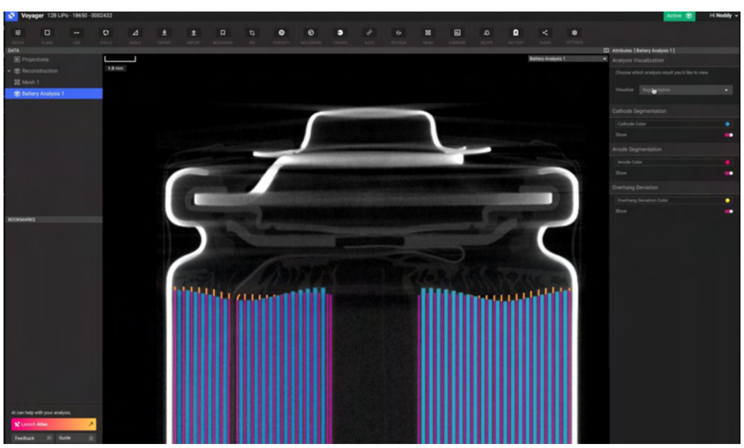
▼ This industrial CT scan of a prismatic battery cell shows a detailed view of the jelly roll, where layers of electrodes and separators are tightly wound to form the internal structure of the battery. The highlighted section reveals wrinkles that may have resulted from misalignment, uneven compression, or manufacturing inconsistencies during the winding process. Such defects can negatively impact the ion flow and mechanical stability of the battery, leading to reduced efficiency, capacity fade, or even safety risks like short circuits over time.



Ensuring Compliance with Regulatory Standards

Battery systems, particularly those used in high-risk industries like automotive and aerospace, must adhere to strict regulatory standards designed to guarantee safety and reliability. Key standards, such as ISO 26262 for automotive safety and UL 1973 for stationary energy storage systems, set rigorous requirements for battery performance, durability, and safety. Meeting these standards is not only essential for market access but also critical for reducing the risks associated with battery failures, which can lead to fires, explosions, and costly recalls.

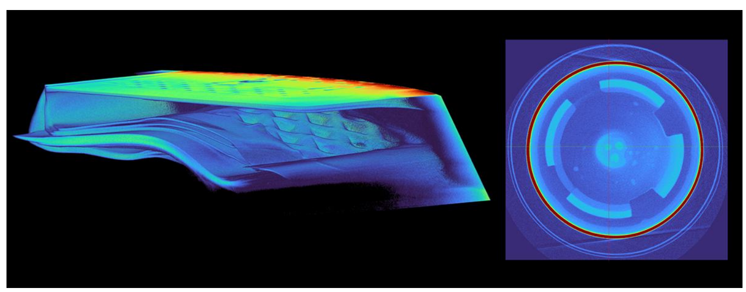
CT scanning plays a pivotal role in helping battery integrators meet and exceed these regulatory requirements. By providing a non-destructive method for inspecting the internal structure of battery cells and modules, CT scanning ensures that potential defects—such as delamination, misalignment, or contamination—are detected before they lead to failures in the field. This level of inspection is essential for demonstrating compliance with regulations that require detailed quality control documentation and traceability.[10]



▲ Advanced inspection software like Lumafield's Voyager allows for segmentation of battery anode (shown in pink) and cathode (shown in blue) layers, providing a detailed view of the internal alignment. The overhang deviation is also tracked (marked in yellow), allowing for precise measurements of Anode-Cathode Overhang (ACO).

For example, ISO 26262, which governs the functional safety of electric vehicles, requires that all critical components, including batteries, undergo extensive testing and validation to ensure they can operate reliably in a range of conditions. CT scanning allows integrators to gather the necessary data to verify that their battery systems are free from defects that could compromise safety, providing the evidence needed for certification and audit processes.[11] This data can also be stored for future reference, offering a clear record of compliance in case of future recalls or investigations.

Incorporating CT scanning into the validation process not only helps integrators meet regulatory requirements but also enhances the overall quality and reliability of the battery systems they produce. By ensuring that every module and pack meets the highest standards of safety and performance, integrators can reduce the risk of costly compliance failures and build trust with both customers and regulatory bodies.



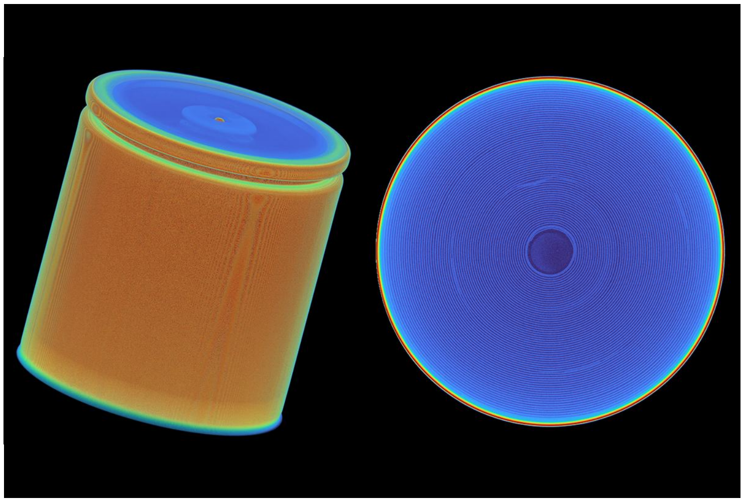
▲ These industrial CT scans highlight the tab welds in both prismatic (left) and cylindrical (right) cells, allowing for early detection of potential defects like voids, cracks, or incomplete fusions. By identifying these issues, CT scanning ensures the structural integrity and electrical reliability of the welds, critical for battery performance and safety.

Sustainability and Lifecycle Management

As sustainability becomes a core focus for the battery industry, particularly with the growth of electric vehicles (EVs) and renewable energy storage, CT scanning offers valuable insights into battery recycling and second-life management.

While CT scanning itself does not directly assess the chemical recoverability of materials like lithium or cobalt, it plays a critical role in evaluating the structural integrity of used batteries, particularly in their potential for second-life applications and guiding recycling processes.

For instance, CT scanning can help identify physical defects such as delamination, cracks, and other forms of internal degradation, which are essential for determining whether a battery is suitable for further use or if it should be recycled. These assessments are particularly relevant in second-life applications, where batteries are repurposed for less demanding uses like stationary energy storage. By ensuring the structural soundness of a battery through non-destructive testing, CT scans help minimize unnecessary waste and extend the lifecycle of batteries.



▲ This CT scan shows a 4680 cylindrical battery, a larger format commonly used in electric vehicles for its higher energy density and improved thermal management. The 2D slice on the right highlights the internal jelly roll structure, with the layers of anode, cathode, and separator wound tightly. Industrial CT allows for non-destructive inspection of critical features like layer uniformity and potential defects such as wrinkles or voids in the winding, which could compromise performance or safety.

The Fraunhofer Institute's research into synchrotron CT goes a step further, offering ultra-high-resolution imaging that enhances the precision of recycling by allowing for the accurate sorting of materials. This can help prevent mixed recycling streams, which often degrade the quality of recovered materials, ensuring that batteries are handled in a more sustainable and closed-loop manner. However, the actual extraction of valuable raw materials from batteries remains the domain of chemical and metallurgical processes, beyond what CT scanning alone can achieve.[12]

Overall, CT scanning supports sustainability by aiding in the assessment of battery integrity for reuse and by optimizing recycling workflows through detailed structural insights. This process plays a vital role in the broader effort to move toward a circular economy in battery production and end-of-life management.[13]

Conclusion

In the rapidly evolving world of battery technology, manufacturers must continuously innovate while maintaining high standards of quality and safety. CT scanning has proven to be an indispensable tool for battery manufacturers across all phases of the product lifecycle—from R&D to high-volume production. By enabling non-destructive, detailed internal inspections, CT technology accelerates material development, refines new chemistries, and ensures that battery designs are robust before they are scaled up for mass production.

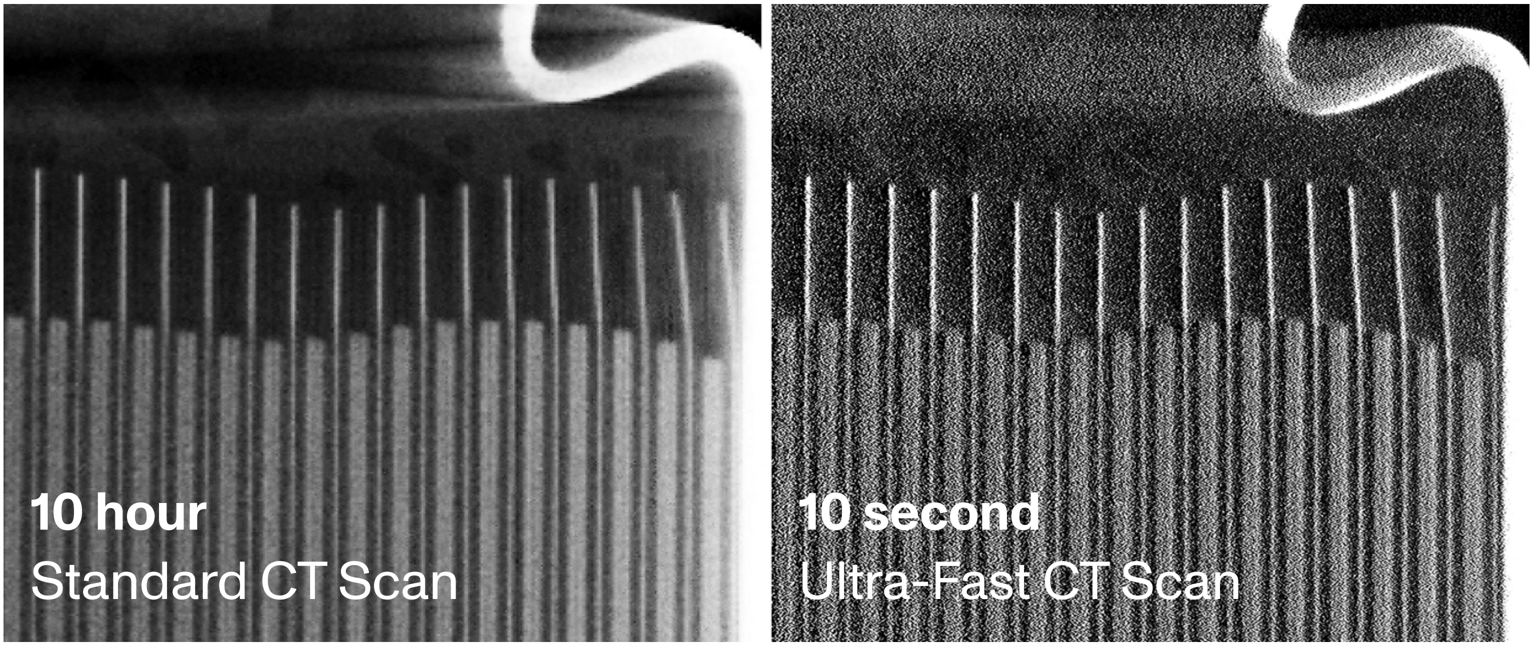
In the pre-production and scale-up stages, CT scanning plays a crucial role in identifying early-stage defects that could potentially escalate in mass production. By catching these issues before they lead to large-scale failures, manufacturers not only reduce the risk of costly recalls but also improve the overall reliability of their products. CT scanning

Ultra-Fast CT Scans in as Little as 0.1 Seconds

Lumafield's Battery Analysis Module is a fully-integrated solution designed to streamline battery inspection across various formats, including cylindrical, pouch, and prismatic cells. As part of the Voyager platform, it automates critical tasks like Anode-Cathode Overhang (ACO) measurement, defect detection, and the assessment of material integrity. This allows battery manufacturers to evaluate quality, identify foreign debris, and detect potential issues like delamination or current collector defects with ease. The module is particularly useful for both R&D and high-volume production, reducing human error and accelerating the inspection process.

The Battery Analysis Module's browser-based interface provides seamless access to inspection data, enabling engineers to begin gathering actionable insights without the steep learning curve that legacy systems often impose. With its intuitive design, the system facilitates rapid adoption and empowers teams to share results effortlessly across departments. By integrating Voyager Studies, the module also allows for high-level trend analysis and statistical process control (SPC), helping manufacturers track product quality over time and make continuous improvements to their processes.

▲ Lumafield's Battery Analysis Module automatically takes precise anode-cathode overhang (ACO) measurements within cells, presenting the results through intuitive color-coded visualizations. In this image, green values indicate ACO within acceptable limits, while red and yellow mark deviations from specifications. This detailed analysis helps manufacturers easily identify potential misalignments or overhang issues, which could impact cell performance or safety.

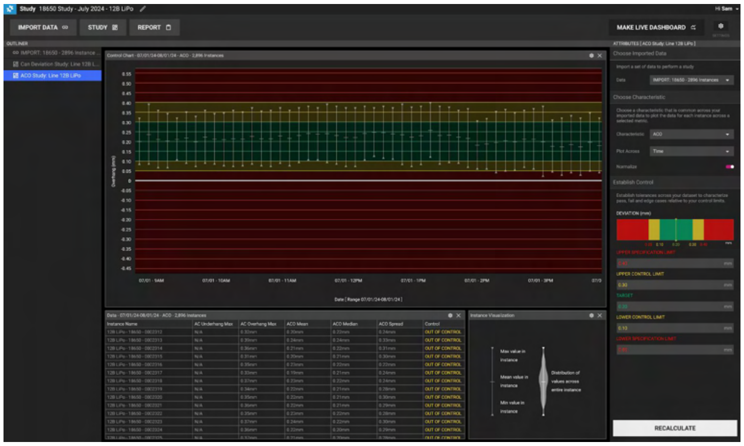


▲ Lumafield's Ultra-Fast CT can capture high-resolution scans of internal features in as little as 0.1 seconds. This extremely high-speed X-ray imaging technology enables comprehensive assessment of internal structures 100x faster than conventional CT.

With the introduction of Ultra-Fast CT, Lumafield takes inspection speed to a whole new level, reducing scan times by over 99%. Ultra-Fast CT can capture high-resolution internal scans of batteries in as little as 0.1 seconds, making it practical for real-time, high-volume production environments. This technology is a game-changer in industries like electric vehicles (EVs) and renewable energy, where rapid, precise inspection is critical to avoid performance failures or costly recalls.

Traditional CT scanning systems have long been hindered by the trade-off between speed and accuracy, but Ultra-Fast CT eliminates this compromise. By delivering 100x faster scans without sacrificing image quality, Lumafield's advancement ensures manufacturers can now adopt industrial CT for 100% inspection of all parts, even at scale.

Ultra-Fast CT integrates seamlessly with the rest of Lumafield's Voyager platform, including Voyager Studies, to provide real-time trend data for long-term quality management. Manufacturing teams can track how specific defects evolve over time and use this data to fine-tune processes for greater efficiency. This capability makes Ultra-Fast CT not only a valuable tool for production but also a strategic asset for driving continuous improvement and innovation cycles.



▲ Manufacturing managers have access to actionable, real-time trend data through Voyager Studies, enabling them to track battery quality metrics across multiple scans and projects over time. Here, control limits are visually represented, with data points in green, yellow, and red indicating whether ACO measurements are within acceptable ranges. The chart provides detailed instance-specific data, flagging cells that fall out of control, allowing manufacturers to pinpoint and address deviations early.

Technology	Volumetric Data	Dimensional Measurements	Internal Features	Accessible	Fast Acquisition
Visible Light 3D Scanning	✗	✓	✗	✗	✗
Contact Metrology	✗	✓	✗	✗	✗
Ultrasonic Inspection	✓	✗	✓	✗	✗
AXI	✗	✗	✓	✗	✓
Legacy CT	✓	✓	✓	✗	✗
Lumafield CT	✓	✓	✓	✓	✓

Until now, industrial CT has been too slow and expensive for production applications. Lumafield's automated Triton scanner can now run thousands of CT scans per shift, unlocking countless production applications. By combining the speed of Ultra-Fast CT with Lumafield's flexible and cost-effective subscription model, battery manufacturers can finally deploy CT scanning technology at massive scales.

Footnotes

[1] "Using CT to Detect Defects in Lithium-Ion Batteries." SAE International. 2021. https://www.sae.org/news/2021/05/ct-detects-battery-defects.

[2] "Industrial CT Scanning Various Battery Types." Haven Metrology, June 23, 2021. https://www.havenmetrology.com.

[3] "CT Scanning Benefits for Battery Manufacturing." Waygate Technologies. https://www.bakerhughes.com.

[4] "Inspection of Battery Cells and Modules with X-ray / Computed Tomography." ZEISS. Webinar. 2023. https://www.zeiss.com.sg/metrology/knowledge/webinars/2023/inspection-of-battery-cells-and-modules-with-x-ray-ct.html.

[5] SAE International, "Using CT to Detect Defects."

[6] Haven Metrology, "Industrial CT Scanning Various Battery Types."

[7] Waygate Technologies, "Advanced NDT Solutions for Battery Manufacturing."

[8] Haven Metrology, "Industrial CT Scanning Various Battery Types."

[9] SAE International, "Using CT to Detect Defects."

[10] ZEISS, "Inspection of Battery Cells and Modules."

[11] Waygate Technologies, "Advanced NDT Solutions for Battery Manufacturing."

[12] Fraunhofer IIS, "Synchrotron CT: From Brilliant Images to Innovative Approaches for Battery Development and Recycling," accessed September 18, 2024, https://www.iis.fraunhofer.de/en/focal-topics/battery-research.html.

[13] RSC Advances, "A Gradient Screening Approach for Retired Lithium-Ion Batteries Based on X-ray CT," accessed September 18, 2024, https://doi.org/10.1039/D0RA03602A.

An Integrated Inspection Platform

Neptune

Industrial CT scanner

+ EVERYDAY ENGINEERING TOOL

With a easy-to-use touchscreen interface and AI-driven scan configuration, Neptune can work for your entire team—no dedicated technician required.

+ FAST INSIGHTS

Avoid time-consuming destructive testing and inspect anything from single parts to complex assemblies in a matter of minutes.

+ AT HOME IN YOUR WORKSPACE

Neptune is designed to be used as a frontline tool in an office or workshop environment. It's just 6 feet wide and runs on a standard 120V outlet.

Triton

Production-scale CT

+ AUTOMATE INSPECTION

Triton quickly loads, scans, and exchanges your part, while fully automating decision-making, to nearly eliminate human error.

+ ULTRA-FAST CT

Capture high-resolution scans of internal features in as little as 0.1 seconds.

+ EASY TO USE

Monitor quality on Triton's live dashboard and scale complexity up or down with a fully configurable and user-friendly UI, allowing for seamless switching between scan tasks.

Voyager

Analysis software

+ LEVERAGE THE WORLD'S ENGINEERING EXPERTISE

Visualize scans in Voyager, Lumafield's browser-based analysis software. Quickly pinpoint issues and share bookmarks and notes with collaborators. Voyager includes Atlas, our generative AI engine equipped with encyclopedic engineering knowledge to empower your teams.

+ MEASURE THE INVISIBLE

Take dimensions for hidden features and apply automated check gauges to ensure quality inside and out.

+ BETTER PRODUCT DECISIONS

Use Voyager on your production line to automate go/no-go decisions and catch small defects before they become big problems.