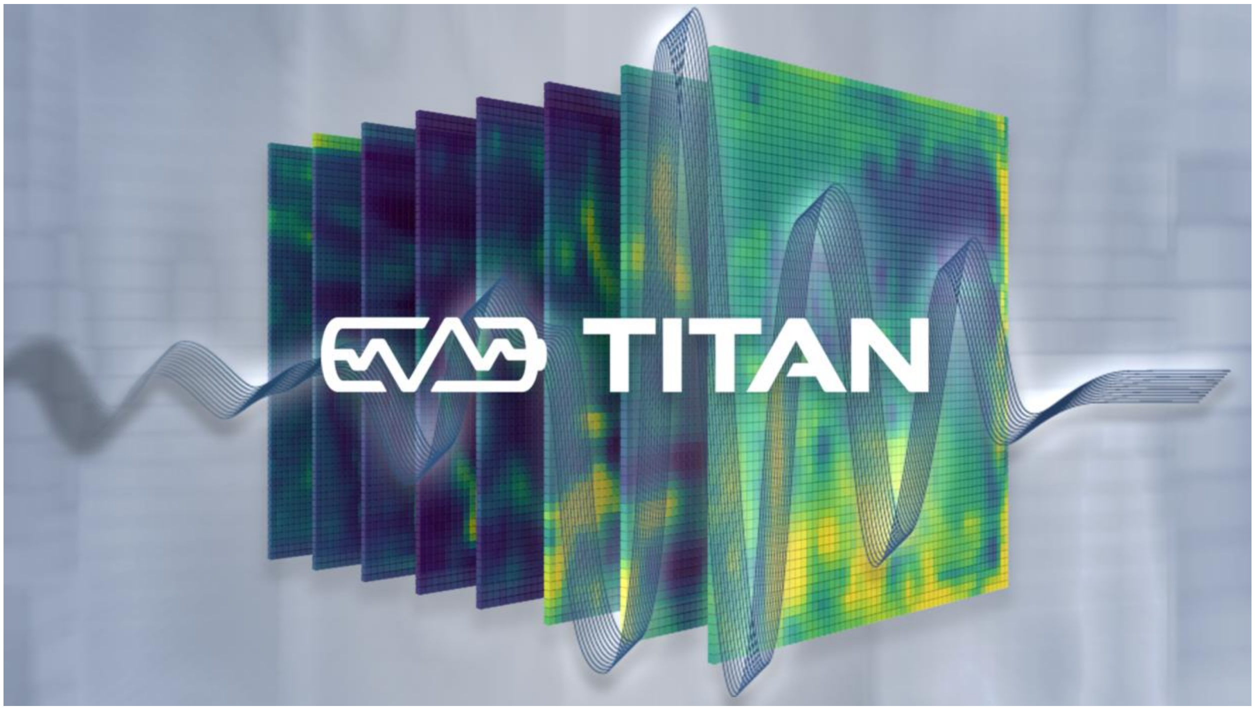

Digital Teardowns Are Here:

An Opportunity for Battery Quality and Economics

Executive Summary

Scaling lithium-ion battery production to meet market demand presents a critical challenge: ensuring the quality and safety of every cell while hitting aggressive economic targets. Conventional quality control, relying heavily on electrical tests, leaves a dangerous gap. Our data confirms that **an average of 3-5% of commercially available cells contain hidden internal anomalies, despite having passed state of the art electrical QC —**flaws like electrode tears, delamination, or early lithium plating, that are outside of design intent. Such issues can directly lead to reduced performance, field failures, and catastrophic safety events. Manufacturers must set aside a substantial warranty reserve, as the looming potential for billion-dollar recalls represents unacceptable risks. In turn, downstream customers who are left to rely on quality metrics and assurances provided by battery makers are unshielded from direct financial losses and reputational detractions caused by integrating potentially faulty cells into their products.

This white paper introduces Titan's IonSight™ ultrasound platform, enabling a **Digital Teardown of every cell produced**. This non-destructive inspection technology operates inline, at production speed, enabling battery manufacturers to gain unprecedented visibility inside the battery cell. IonSight™ detects the critical defects missed by other methods *before* the product is shipped to customers. In addition, OEMs and pack integrators who want to have better control of their products' components, now have access to the same testing methodology, with hardware and software tailored to their specific needs.

Implementing a Digital Teardown of every cell delivers immediate, quantifiable value IonSight:

- **Eliminates Quality Escapes:** Directly reduces warranty liabilities and drastically minimizes recall risk by catching hidden flaws. Each 1% of reserve reduction can unlock $100M+ for large facilities.
- **Accelerates Profitability:** Provides rapid real-time feedback (vs. weeks of waiting for teardowns) to optimize processes faster, significantly improving yield, reducing scrap, and shortening the crucial ramp-up time to reach target capacity and positive cash flow.
- **Enhances Control:** Offers continuous data for process stabilization and advanced AI-driven quality improvements.

For manufacturers striving to scale confidently, protect their brand, and achieve operational excellence, 100% internal cell inspection is now a viable and essential practice. IonSight's Digital Teardown provides the essential capability to de-risk production and secure a competitive advantage in the demanding battery market.

The Quality Challenge in High-Volume Battery Manufacturing

Meeting Demand Without Compromising Safety or Performance

The lithium-ion battery industry faces exciting growth, driven by strong demand for electric vehicles (EVs), grid-scale energy storage, and advanced consumer electronics. This surge compels manufacturers to dramatically scale production capacity. However, this rapid expansion cannot come at the expense of the stringent performance, safety, and cost standards the market demands.

Successfully navigating this growth presents critical challenges:

- **Quality Consistency at Scale:** As gigafactories ramp up to produce tens of thousands of cells daily, even statistically small defect rates translate into significant numbers of potentially hazardous units. Ensuring cell-to-cell uniformity and preventing defects—which can lead to thermal runaway, reduced lifespan, or poor performance—becomes exponentially more difficult at high volumes.
- **Integrating Process & Material Innovation:** The relentless pursuit of higher energy density and faster charging requires adopting new materials (e.g., silicon anodes) and evolving manufacturing processes. These innovations often introduce new, less understood defect types and process sensitivities, complicating quality control during crucial scale-up phases.
- **Navigating Stricter Regulatory Landscapes:** High-profile battery safety incidents have intensified global regulatory scrutiny. Manufacturers face increasingly stringent compliance requirements and the severe financial and reputational consequences of quality escapes and recalls.

These interconnected factors—scale, innovation, and regulation—demand a fundamental competency: **ensuring the quality and safety of every single cell produced.** Traditional quality control methods struggle to keep pace. Meeting today's demands requires a transformational leap in quality assurance, validating process stability and product integrity amidst the complexities of rapid growth and technological change.

The High Cost of Hidden Defects

Defects originating during lithium-ion cell manufacturing carry significant consequences, directly impacting battery performance, safety, and longevity. Even seemingly minor internal imperfections—often undetectable by standard electrical tests early on—can degrade efficiency, shorten operational life, or critically, trigger catastrophic thermal runaway events. The financial and reputational costs associated with these "hidden" defects are immense.

These costly defects typically fall into several categories:

- **Electrochemical Issues:** Subtle deviations like early-stage lithium plating or localized electrolyte degradation compromise a battery's energy storage and delivery, often preceding obvious electrical failure signatures.
- **Process-Related Variations:** High-volume production inevitably introduces inconsistencies like minor electrode misalignment or overhang, coating thickness variations, incomplete wetting, or improper electrolyte filling. These create latent weaknesses affecting uniformity, performance, and safety.
- **Mechanical Flaws:** Physical imperfections such as microscopic separator tears, electrode delamination, folding, cracking, or foreign metallic particles compromise the cell's structural integrity and internal safety barriers, posing significant safety risks.

Many of these varied defects begin as subtle physical anomalies before manifesting themselves as clear electrical failures. Detecting all of them is an ongoing challenge. The financial and reputational costs of allowing these hidden defects to escape production (resulting in reduced yield, costly warranty claims, damaging recalls, or severe safety incidents) underscores the urgent need for more comprehensive quality assurance.

Limitations of Conventional Inspection

Electrical Testing: Necessary but Insufficient

Electrical testing is the cornerstone of quality control in cell manufacturing, verifying fundamental performance characteristics. Standard procedures like high-potential (Hi-Pot) testing, capacity checks, internal resistance measurements (DCIR), and self-discharge analysis are essential for identifying cells with immediate electrical failures or significant performance deviations. However, **these methods primarily measure bulk electrical properties and often fail to detect localized physical or structural defects** that can lead to problems later in the cell's lifecycle.

Consider the limitations of key electrical tests in detecting physical root causes:

- **High-Potential (Hi-Pot) Testing:** Performed before electrolyte filling, Hi-Pot detects gross insulation weaknesses or shorts. While catching some critical defects (e.g., major metallic contamination or separator damage incurred during assembly), it misses issues related to electrode alignment, coating quality, or problems arising *after* cell activation.

- **Capacity Testing:** Conducted during/after formation, this verifies charge storage (Ah). It's crucial for grading but offers no insight into internal structure. A cell might meet initial capacity specs despite containing defects like minor electrode misalignment or poor wetting that compromise long-term safety or cycle life.
- **Direct Current Internal Resistance (DCIR):** Measured post-formation/aging, DCIR indicates overall cell resistance. While sensitive to issues like poor welds or widespread wetting problems, it typically averages resistance across the entire electrode surface. **Small but critical localized defects**—minor delaminations, particle contamination, small separator wrinkles—often don't significantly alter the bulk DCIR reading and pass undetected.
- **Self-Discharge Testing (via OCV Monitoring):** Monitoring Open Circuit Voltage (OCV) drop during aging helps detect internal shorts or side reactions. However, achieving sufficient sensitivity requires lengthy test periods (days/weeks), creating substantial work-in-progress (WIP) inventory and associated costs, making it impractical for high-throughput screening. It also reveals little about mechanical integrity or subtle physical flaws not causing immediate leakage current.

The fundamental limitation remains: **electrical tests measure symptoms, not necessarily the underlying physical conditions.** They provide snapshots of electrical behavior but struggle to identify the subtle structural anomalies or localized inconsistencies within electrodes, separators, or interfaces that often precede failure.

This gap creates significant risk. Based on Titan's experience scanning commercially produced cells equivalent to over five Gigawatt-hours, **we consistently find that an average of 3-5% of cells passing all standard electrical quality checks possess internal anomalies detectable by ultrasound.** These include critical flaws such as electrode buckling, electrode tears, and early-stage lithium plating, alongside other structural issues like delamination, separator damage, or gas pockets from poor wetting. These "passed-good" cells with hidden defects represent critical quality escapes, potentially leading to field failures or safety events.

Furthermore, when electrical tests *do* flag a cell, diagnosing the physical root cause often requires time-consuming offline analysis, delaying corrective actions on the production line. This slow feedback loop hinders rapid process optimization, crucial in high-volume environments. Relying solely on electrical testing leaves manufacturers exposed to undetected risks and impedes process improvement.

CT Scanning: Powerful but Impractical for 100% In-line Inspection

Computed tomography (CT) scanning offers high-resolution, non-destructive 3D visualization, making it invaluable for R&D and detailed failure analysis. It excels at identifying certain macroscopic defects like significant electrode misalignment or casing deformities.

However, CT is unsuitable for comprehensive quality assurance in high-volume manufacturing due to critical limitations:

- **Speed and Cost:** CT scans typically take minutes per cell, far too slow for production lines processing cells per second. The high capital expenditure (CAPEX) also restricts widespread deployment.
- **Sampling Inadequacy:** Consequently, CT is used for offline analysis or minimal sampling, inspecting only a tiny fraction of production. This statistical sampling creates significant risk. As illustrated by the challenge of detecting low-PPM defects (Figure 1), reliably catching defects occurring at rates common in scaled manufacturing (e.g., 100-1000 PPM) requires inspecting tens of thousands of cells per batch—impossible with CT sampling. <u>Resorting to small sample sizes statistically guarantees that critical defects will bypass inspection.</u>
- **Material Contrast:** CT relies on X-ray absorption contrast. While good for dense metallics (foils, collectors), it struggles to clearly visualize lower-density materials like the polymer separator, assess electrolyte wetting uniformity, or detect gas bubbles—all critical for safety and performance.

Therefore, while CT is a powerful diagnostic tool, its inherent slowness, cost, inability to scale beyond small samples, and material contrast limitations make it impractical for ensuring the internal quality of **every cell** on a high-throughput manufacturing line. It leaves a critical quality assurance gap, allowing potentially dangerous hidden defects to proceed undetected towards pack assembly and end-use.

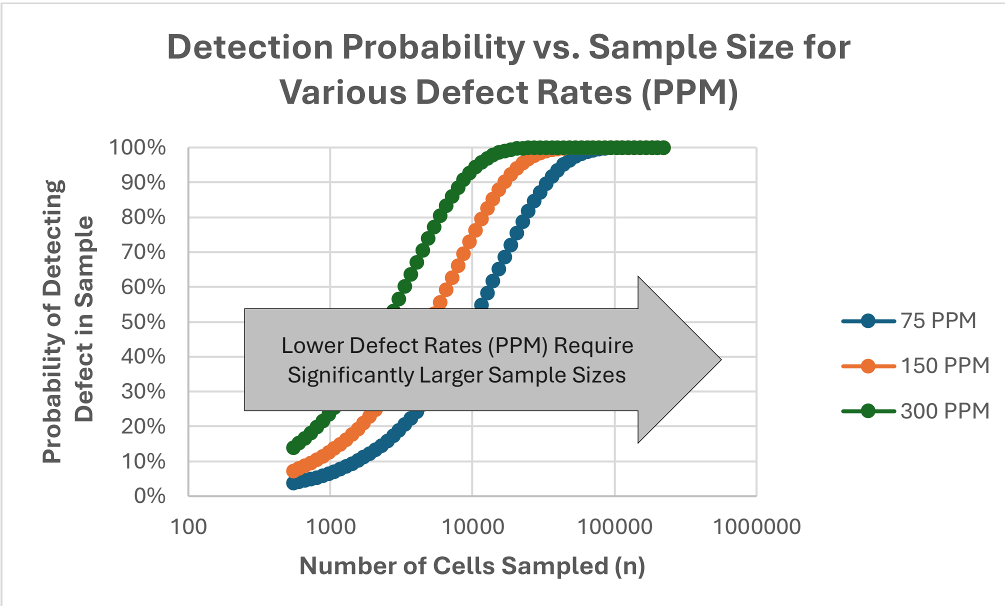

*Figure 1. **The Challenge of Detecting Low-PPM Defects with Sampling Inspection.** This chart illustrates that achieving a high probability of detecting a defect present at a low parts-per-million (PPM) rate requires inspecting a very large sample of cells. For example, reliably catching defects occurring at rates below 300 PPM necessitates sampling tens of thousands of cells, rendering sampling-based methods like offline CT impractical for comprehensive quality assurance in high-volume production.*

Introducing IonSight's Digital Teardown: Ultrasound Tomography for 100% Cell Insight

Seeing Inside: Ultrasound Tomography Principles for Batteries

Ultrasound is a well-established non-destructive testing (NDT) technique, trusted for decades in demanding fields like medical imaging and materials science to visualize internal structures without damage. Recent advancements in high-frequency transducers, rapid signal processing, and sophisticated reconstruction algorithms have enabled the application of this proven technology to the unique challenges of lithium-ion battery inspection. This allows manufacturers to visualize the internal quality of finished cells comprehensively and non-destructively.

The fundamental principle involves transmitting high-frequency acoustic waves into the battery cell. As these waves propagate, they interact with the various materials and interfaces within—including electrode layers, the separator, current collectors, and electrolyte. At each boundary or change in material properties, the sound waves are partially reflected, scattered, or attenuated (weakened). By precisely capturing and analyzing the returning echoes and transmitted signals from multiple positions, a detailed acoustic map of the cell's interior is constructed.

This acoustic map directly reveals critical details about the cell's internal morphology—its physical structure and composition. Key insights include:

- **Layer Integrity and Alignment:** Visualizing anode, cathode, and separator layers to detect misalignment, wrinkling, folding, delamination, or variations in spacing.
- **Electrode Quality:** Identifying defects within electrode coatings, such as density variations, cracks, poor adhesion to the current collector, or surface irregularities.
- **Separator Condition:** Assessing separator integrity, crucial for identifying tears, punctures, or folds that could lead to internal short circuits.
- **Wetting and Gas Presence:** Detecting anomalies like gas pockets or regions of poor electrolyte wetting that significantly impact performance, safety, and formation efficiency.
- **Foreign Particles:** Locating metallic or other contaminants that compromise safety.

Understanding this internal morphology is vital because **subtle physical deviations often precede measurable electrical failures** and directly influence cell performance, safety, and lifespan. Issues like minor electrode buckling, early-stage delamination, or small separator defects might not immediately alter capacity or resistance measurements but represent significant latent risks. By providing a detailed, layer-by-layer view of the internal structure, ultrasound tomography enables the early detection of these critical flaws. This offers actionable data for real-time process control, rapid root cause analysis, and ultimately, ensuring the quality and reliability of **every cell** produced.

IonSight: Enabling High-Throughput Digital Teardowns

IonSight™ is Titan's inspection platform, engineered specifically to bring the power of ultrasound tomography into the high-volume battery manufacturing environment. This fully automated, in-line system (Figure 2) enables manufacturers to perform a **"Digital Teardown"—**a comprehensive internal quality assessment—on **100% of the cells** they produce, without interrupting production flow.

*Figure 2. **Titan's IonSight™ inspection platform.** This rendering illustrates Titan's most recent system engineered to perform automated, in-line 'Digital Teardowns' of battery cells using advanced ultrasound tomography.*

At its core, IonSight utilizes arrays of custom ultrasonic transducers. During inspection, these sensors interrogate each cell by emitting and receiving focused ultrasound pulses at tens of thousands of unique locations, generating an unprecedented level of acoustic detail about the cell's internal state (conceptualized in Figure 3).

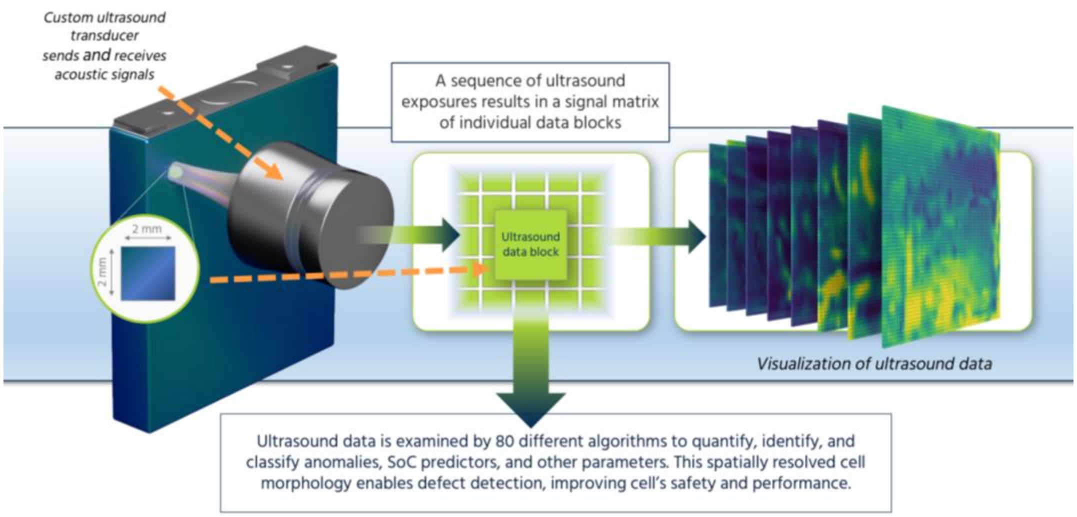

Figure 3. ***IonSight Ultrasound Data Acquisition, Processing, and Visualization.*** *Custom ultrasound transducers send and receive acoustic signals at thousands of discrete locations on the cell. This sequence of exposures generates a rich signal matrix (data blocks). Sophisticated algorithms analyze this data to identify and classify anomalies and other parameters. The spatially resolved data is then visualized as cross-sectional "slices," providing a detailed view of the cell's internal morphology for defect detection and quality assessment.*

Sophisticated Digital Signal Processing (DSP) analyzes the received ultrasound signals from each point, extracting key features like signal attenuation, time-of-flight, and scattering patterns. As shown in Figure 3, this processed data is then fed into a suite of advanced algorithms, including AI/ML models trained on battery-specific defect signatures. These algorithms automatically identify, classify, and quantify internal anomalies with high precision, enabling the **direct detection of defects often missed by electrical testing.**

This systematic, point-by-point interrogation generates a comprehensive acoustic dataset—a spatially resolved signal matrix representing the cell's internal characteristics (Figure 3). This forms the foundation of the **Digital Teardown.** The data is computationally reconstructed into virtual cross-sectional images or "slices" (also depicted in Figure 3), revealing the internal structure and potential defects layer by layer. This detailed internal view empowers manufacturers to confirm structural integrity, pinpoint subtle flaws, and gain actionable quality insights for **every cell** before it progresses further in manufacturing or leaves the factory.

Detecting the Undetectable: Identifying Defects Missed by Electrical Tests

IonSight's ultrasound tomography provides a direct, non-destructive view of a battery cell's internal physical structure, revealing characteristics and anomalies that electrical measurements alone cannot capture. While the underlying physics of ultrasound interaction is established, IonSight's unique strength lies in its ability to **rapidly generate high-resolution acoustic maps at production speeds**. This enables consistent, automated detection of internal defects and quantitative assessment of cell-to-cell uniformity across entire production volumes.

This section showcases specific examples of internal defects identified by IonSight within commercially produced battery cells. These examples represent precisely the types of flaws that can compromise long-term performance or safety, yet **critically, often go undetected by standard end-of-line electrical testing.** The validity of IonSight's findings is rigorously confirmed through comparative analysis, typically involving high-resolution CT scanning and/or meticulous physical teardowns, as shown in the following figures.

The examples presented utilize 100 Ah prismatic LFP cells intended for energy storage system (ESS) applications, sourced from the open market (Figure 4a). **Crucially, all cells shown in these examples had successfully passed their original manufacturers' standard electrical quality control checks** and were deemed commercially acceptable based on those tests. This underscores the critical quality assurance gap that IonSight's **Digital Teardown** capability addresses—providing essential physical insights beyond electrical screening.

Figure 4a. 100 Ah Prismatic LFP cell.

Before examining defective cells, establishing a visual baseline using a "good" cell exhibiting expected internal uniformity is essential. Figure 4 presents such an example.

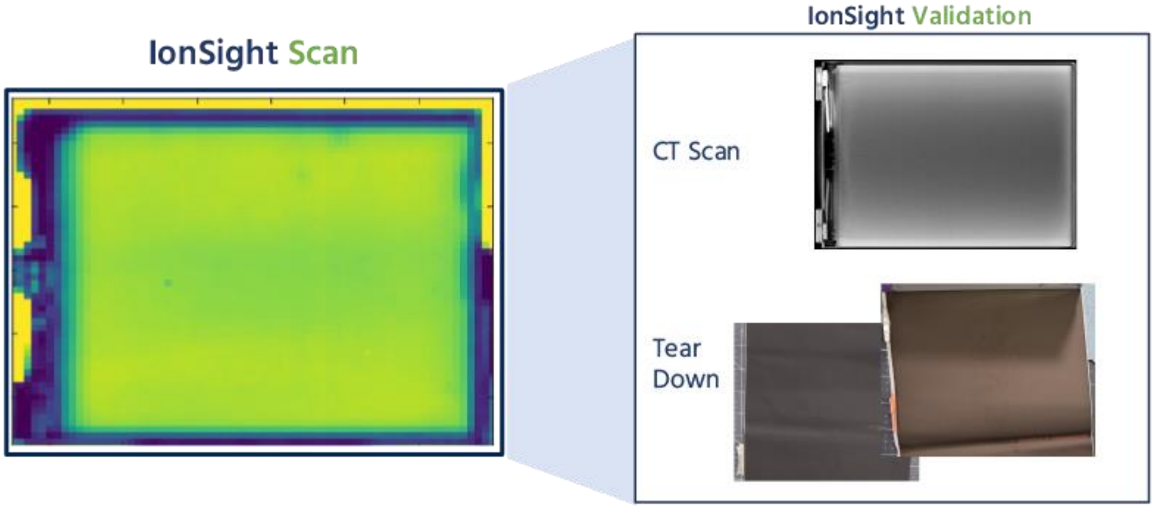

*Figure 4b. **Baseline Uniformity in a "Good" Cell.** The IonSight scan (left) of a 100 Ah LFP cell shows high acoustic uniformity. This finding is validated by the uniform appearance in the CT scan (top right) and the physically intact electrode stack observed during teardown (bottom right), establishing the visual signature of a high-quality cell.*

The IonSight scan (left panel, Figure 4b) displays a highly uniform acoustic response across the bulk of the electrode stack. This uniformity typically indicates consistent electrode adhesion, uniform electrode density, and proper electrolyte wetting—key attributes associated with reliable performance and long cycle life. This interpretation is validated by the corresponding CT scan (top right panel), which also shows good structural uniformity, and by the physical teardown image (bottom right panel), confirming intact and uniform electrode layers were present within the cell. This clear baseline signature of a high-quality cell serves as a reference point for identifying deviations linked to defects in the subsequent examples.

In distinct contrast to the uniform baseline cell (Figure 4b), the IonSight scan of the cell in Figure 5 reveals significant internal non-uniformity.

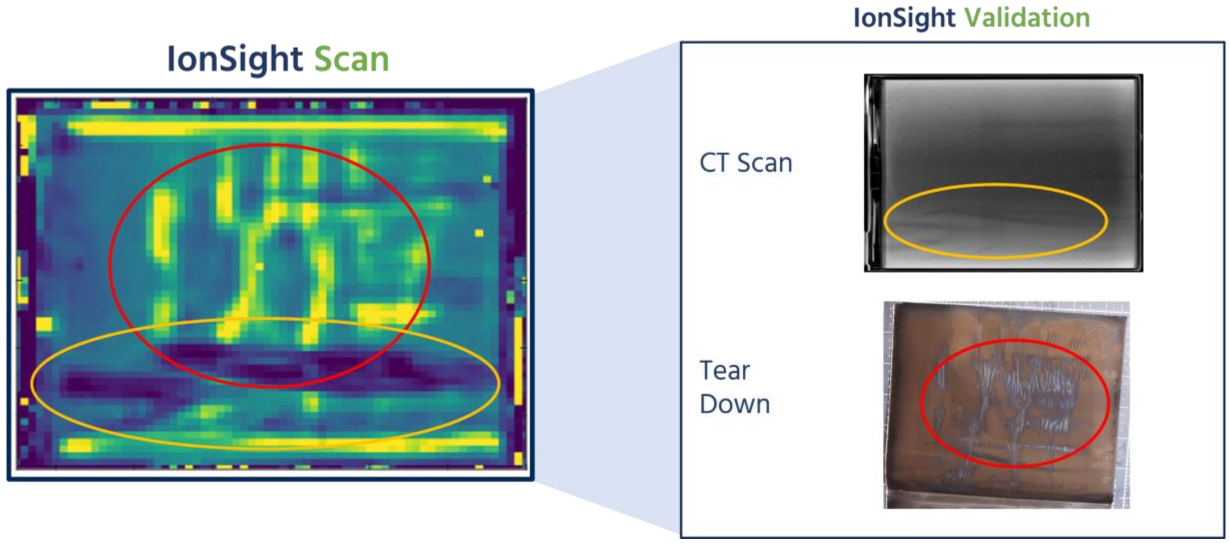

Figure 5. ***Electrode Buckling and Side Reactions.*** *IonSight scan reveals internal non-uniformity correlated with buckling (circled orange) and potential side reactions (circled red). CT and teardown confirm physical wrinkling and residue. In-field expectation: Lower capacity and reduced cycle life.*

The acoustic pattern strongly indicates **electrode buckling** (circled orange). This type of structural defect can arise from factors like over-compression of the electrode stack within the cell casing, leading to localized pressure gradients.

Such pressure variations are detrimental for several reasons:

- They create mechanical stress concentration points, increasing the risk of electrode cracking over extended cycling.
- They can disrupt uniform ionic transport pathways within the electrolyte, leading to uneven current distribution and accelerated degradation.
- This unevenness can promote **unwanted secondary reactions** at the electrode surfaces, consuming active lithium and electrolyte components, thereby reducing capacity and cycle life.

Notably, the IonSight scan not only visualizes the structural buckling but also shows **acoustic signatures consistent with the early stages of these detrimental secondary reactions** (circled orange).

The validation images confirm these findings. Both the CT scan and the physical teardown clearly show the physical **wrinkling** of the electrodes. Furthermore, the teardown reveals

residue on the anode surfaces, characteristic of the byproducts from secondary reactions which are only visible in IonSight's scan data.

Crucially, despite possessing these internal structural defects and early signs of degradation pathways—flaws directly linked to reduced performance and potentially compromised long-term safety—**this cell passed standard electrical QC.** IonSight's **Digital Teardown** identified these hidden issues, providing critical quality insights missed by conventional methods.

This next example highlights IonSight's ability to detect severe mechanical damage within the cell structure, defects that pose significant safety risks.

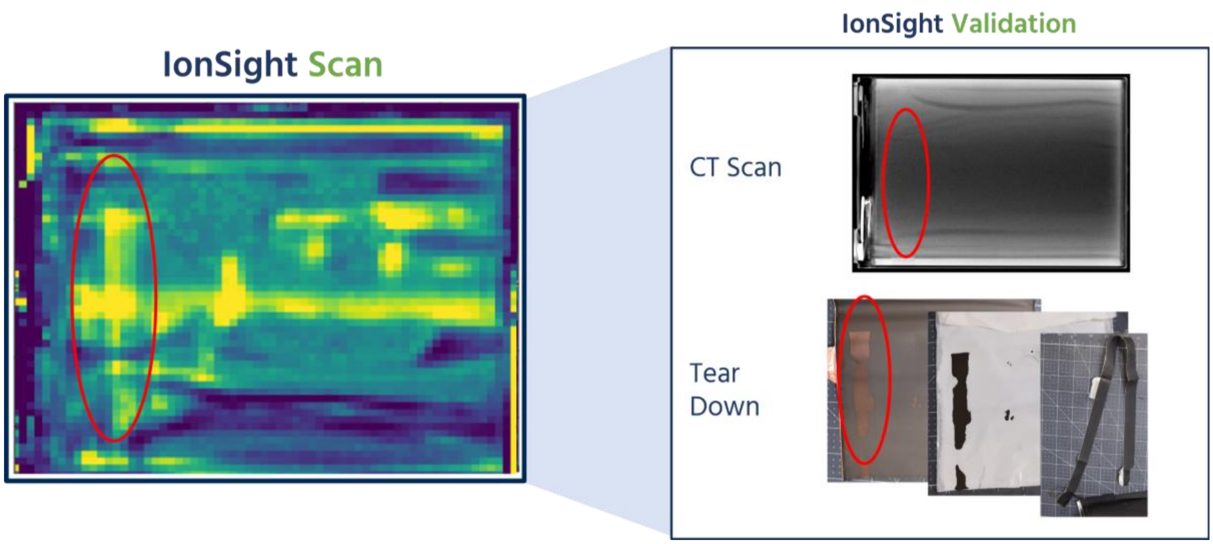

*Figure 6. **Anode Delamination and Missing Cathode Material.** IonSight scan indicates delamination and layer anomalies (circled region). Teardown confirms anode delamination and a significant tear resulting in a missing cathode section. In-field expectations: Lower capacity, potential for internal short circuit leading to thermal runaway.*

The IonSight scan reveals acoustic anomalies (circled) suggesting **anode delamination** and **significant layer irregularities**, indicative of tearing or missing material. Such mechanical defects drastically compromise cell integrity, reducing capacity and critically increasing the risk of internal short circuits and thermal runaway.

Physical teardown confirmed both **anode delamination** and a **major tear resulting in missing cathode material**, directly correlating with the IonSight findings.

Despite containing these hazardous structural flaws, **this cell passed standard electrical QC.** IonSight's ability to identify this type of hidden, critical damage provides essential safety assurance beyond electrical screening.

This final example showcases IonSight's sensitivity to electrochemical anomalies like lithium plating, which are often invisible to other non-destructive inspection methods, including CT scanning.

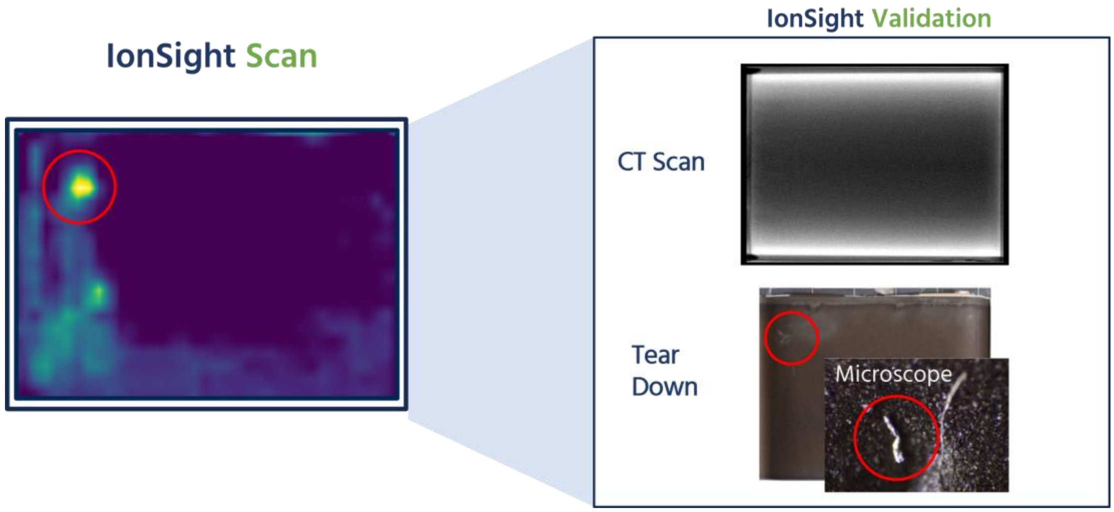

*Figure 7. **Lithium Plating Detection.** IonSight scan (left) reveals an anomaly (circled) indicative of lithium plating, which is **not visible** in the corresponding CT scan (top right). Teardown and microscopy (bottom right) confirm metallic lithium plating in the identified region. In-field expectation: Accelerated capacity fade, increased risk of internal short circuit.*

Figure 7 illustrates a critical capability: the IonSight scan clearly identifies a localized acoustic anomaly (circled), while the corresponding CT scan of the *same cell region* appears uniform and defect-free.

The distinct signature detected by IonSight is characteristic of **lithium plating,** the hazardous deposition of metallic lithium onto the anode surface. Plating irreversibly consumes active lithium, reducing cell capacity and cycle life. Critically, plated lithium can form sharp, needle-like dendrites that may eventually penetrate the separator, potentially causing internal short circuits and catastrophic thermal runaway.

Validation through teardown, followed by microscopic examination of the suspect area, confirmed the presence of **metallic lithium plating**, precisely correlating with the anomaly detected by IonSight.

This case powerfully demonstrates IonSight's ability to detect early-stage lithium plating—a critical defect posing significant performance and safety risks—that was **undetectable by both standard electrical QC (implied context) and even high-resolution CT scanning.** This capability provides an essential layer of quality and safety assurance otherwise unavailable through conventional inspection techniques.

Actionable Intelligence: From Scan to Process Improvement

The true value of IonSight's Digital Teardown extends beyond identifying rejectable defects; it lies in transforming comprehensive scan data into actionable intelligence for **process optimization and control.** While the previous examples focused on discrete flaws, the detailed acoustic maps also reveal subtle but critical variations in internal cell morphology that are directly linked to process parameters.

For instance, **electrolyte wetting uniformity**, a crucial factor for performance and safety, creates distinct acoustic signatures detectable by IonSight but is notoriously difficult to assess reliably with CT due to low density contrast. By monitoring characteristics like wetting patterns, electrode alignment consistency, or coating density variations across 100% of production, manufacturers gain unprecedented visibility into their process stability.

This rapid, granular feedback loop is invaluable during production ramp-up. As validated by IonSight's deployments in multiple battery factories globally, this **real-time process insight** helps manufacturers quickly identify and correct deviations, stabilize production, and accelerate the transition to high-volume manufacturing with higher yields. Instead of relying solely on delayed electrical feedback or infrequent destructive analysis, IonSight provides immediate physical context for process adjustments.

Furthermore, recognizing that each cell design and manufacturing line has unique sensitivities, Titan collaborates with manufacturers to develop **customized analysis algorithms and insights** tailored to their specific needs. Beyond standard defect classification, this can include generating insights into capacity potential based on internal structure, providing data to optimize electrolyte filling, soaking, and aging protocols, or even enabling early prediction of potential degradation pathways based on subtle morphological precursors.

By translating detailed internal cell data into actionable process insights, IonSight empowers manufacturers not just to remove defective cells, but to proactively improve their manufacturing processes, enhance overall quality, reduce scrap, and ultimately scale production with greater confidence and speed.

Scaling with Confidence: The Economic Imperative for 100% Inspection

The Ramp-Up Dilemma: Increased Risk During Production Scaling

Scaling lithium-ion battery production from pilot lines to gigafactory volumes is a high-stakes endeavor. While the goal is to reach nameplate capacity and profitability quickly, manufacturers face a critical **"ramp-up dilemma."** This phase is characterized by inherent process instability as equipment is commissioned and parameters are optimized. Early production runs often suffer from lower yields and higher variability, leading to significant scrap costs and delayed timelines—all under intense pressure to meet market demand and achieve financial targets. There is enormous economic value in accelerating this learning curve and reaching stable, high-yield production faster.

A core challenge lies in the **limited visibility** into the battery cell's internal state once assembly is complete. Batteries become "black boxes" early in the process, especially after sealing and during crucial formation and aging steps. While manufacturers strive to follow frameworks like Quality by Design (QbD)—linking process parameters to critical quality attributes—the inability to easily *see* the internal results of process variations creates a major bottleneck.

Key obstacles during ramp-up include:

- **Delayed Root Cause Analysis:** When quality issues inevitably arise (e.g., inconsistent performance, electrical failures), the primary method for investigation is often

physical teardown. This process is slow (typically taking weeks to provide feedback), labor-intensive, and destructive. This significant delay cripples the ability to make rapid, informed adjustments to the production line.

- **Difficulty Correlating Issues:** With slow feedback loops, identifying the specific process step or parameter causing an internal defect becomes extremely difficult, especially when multiple process changes or minor issues overlap—a common scenario during scaling.
- **Inadequate Data on Rare Defects:** Pilot lines or early low-volume runs may not produce statistically significant numbers of certain defect types, particularly rare but critical ones. This lack of data hinders the development of robust control strategies before full-scale production begins.

This combination of limited visibility and slow feedback creates a high-risk environment during ramp-up. It prolongs the time needed to stabilize processes, increases scrap rates, delays time-to-market, and heightens the chance of undiscovered systemic quality issues propagating as volume increases. Resolving this situation requires a fundamental shift towards faster, scalable, non-destructive methods for gaining insight into the internal quality of **every cell** during the critical scaling phase.

Digital Teardown of Every Cell: De-risking Production and Preventing Quality Escapes

By integrating high resolution, sensitivity, and speed, IonSight enables a paradigm shift: the **Digital Teardown of every cell produced.** This capability fundamentally transforms quality control from a reactive, sample-based approach to a proactive, comprehensive system, directly addressing the risks inherent in scaling production.

This shift dramatically accelerates process learning and optimization, particularly during critical ramp-up phases. Key benefits include:

- **Rapid Root Cause Identification:** Instead of waiting weeks for teardown results, IonSight provides immediate, non-destructive internal visibility. When repeatable defects occur, manufacturers can quickly correlate acoustic signatures with specific upstream process parameters—such as calendaring pressure, electrolyte fill variations, or degassing protocol. This allows for targeted, data-driven corrective actions, minimizing trial-and-error.

- **Closing the Feedback Loop:** The ability to analyze **every cell** creates a rich dataset linking process inputs to internal quality outcomes. Over time, sophisticated AI/ML algorithms applied to this comprehensive data can identify subtle trends, predict potential issues before they escalate, and radically shorten the quality control feedback loop, enabling significantly faster process stabilization and scale-up compared to traditional methods.
- **Preventing Quality Escapes:** Perhaps most critically, inspecting every cell ensures that units with hidden internal flaws—like those demonstrated earlier which passed electrical tests—are identified and removed *before* they leave the factory. This directly de-risks production by preventing potentially hazardous cells from reaching pack assembly or the end customer.

The impact of implementing effective corrective actions, enabled by faster feedback and 100% inspection, translates directly to improved manufacturing economics, **as visualized in Figure 8.** Faster problem-solving and reduced defect rates increase the Rolled Throughput Yield (RTY) —the probability that a unit passes through all manufacturing steps without defects. Higher RTY means lower scrap and rework, directly reducing the Cost of Quality (COQ) and boosting the factory's Gross Margin (GM).

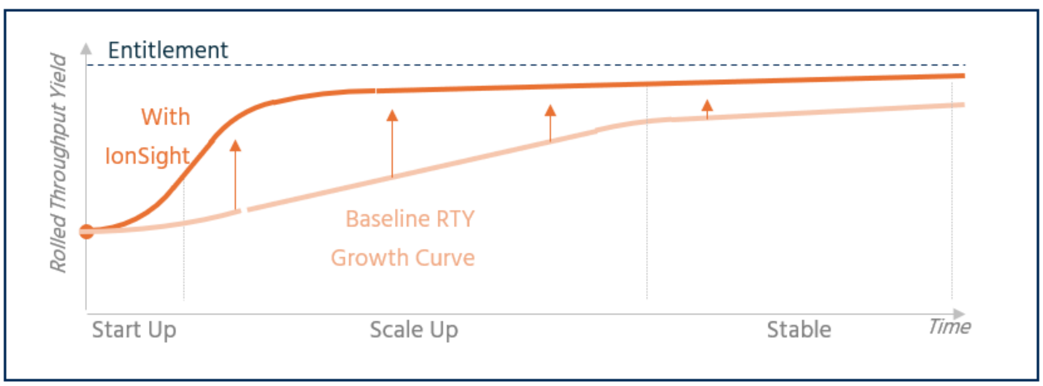

*Figure 8. **Accelerating Yield Improvement with IonSight.** The Digital Teardown enables faster process learning and stabilization, leading to a steeper Rolled Throughput Yield (RTY) curve during ramp-up and a higher sustained yield in stable production compared to baseline methods relying on delayed feedback from sampling or electrical tests alone.*

Quantifying this impact is crucial. According to Argonne National Labs' BatPaC 5.1 cost modeling tool, even incremental improvements in yield have a substantial effect at scale.[1] For a representative 40 GWh factory, **increasing RTY by just 1% each year over a 5-year period is projected to reduce annual scrap costs significantly and increase the overall Gross Margin by approximately $116 million over that timeframe.** IonSight's Digital Teardown provides the critical visibility needed to achieve and sustain such accelerated yield improvements (Figure 8), making 100% inspection an economic imperative for competitive battery manufacturing.

Quantifying the Value: Tailored Economic Impact Analysis with Titan

While the industry benchmarks and high-profile recall costs illustrate the significant financial risks associated with quality escapes, understanding the precise economic impact of implementing IonSight within a *specific* manufacturing environment requires a more tailored approach. Recognizing this need, Titan has invested considerable effort in developing a **proprietary value quantification framework**, built upon deep insights gathered from direct engagements and data analysis across more than 20 lithium-ion battery manufacturing operations globally.

This sophisticated framework allows us to move beyond generic estimates. By collaborating with your team, we can integrate **your factory's specific operational and financial parameters** into our model. Key inputs typically include factors such as:

- Production capacity (current and planned GWh)
- Existing baseline yield rates (RTY) and scrap levels
- Cell cost structures and pricing models
- Current quality control workflows and associated costs
- Specific process sensitivities and known defect challenges
- Warranty reserve policies and field return data (if available)

Leveraging these inputs alongside IonSight's proven defect detection capabilities, our framework generates **tangible financial projections tailored to your unique situation.** The outputs provide data-driven insights into areas such as:

[1] Argonne National Laboratory, *Electrochemical and Chemical Technoeconomic Analysis (TEA)*, accessed March 31, 2025, https://www.anl.gov/cse/electrochemical-chemical-TEA.

- Projected improvements in RTY
- Quantifiable reductions in scrap volume and associated costs
- Estimated savings in warranty reserves and claim expenses
- Financial impact of mitigating recall risk (based on probability reduction)
- Value generated through accelerated ramp-up timelines
- Overall Return on Investment (ROI) and impact on Gross Margin (GM)

This collaborative analysis provides the concrete financial justification needed for strategic investment decisions. It allows your organization to clearly visualize the economic benefits of implementing IonSight's Digital Teardown service, moving from industry trends to **actionable ROI data specific to your production lines and business goals.** Engaging with Titan provides access not only to leading inspection technology but also to this unique analytical capability, ensuring the value proposition is clearly understood and validated within the context of your manufacturing reality.

Seamless Integration: Implementing Ultrasound Inspection in Existing Production Environments

Implementing IonSight's Digital Teardown capability is designed for straightforward integration into existing high-volume battery manufacturing lines or incoming material quality assurance workflows for OEMs. The physical system is engineered to interface with standard cell conveyance and automation systems, minimizing the need for major line alterations. Required modifications to the production workflow are typically minimal, primarily involving the allocation of space and standard connections for power and data. Operator training focuses on system monitoring and basic maintenance, leveraging intuitive interfaces, while flexible implementation plans allow for phased rollouts aligned with specific production schedules and goals.

Figure 9. IonSight Atlas 1.0 deployed at a gigafactory

Data connectivity is a core aspect of the integration strategy. IonSight systems are built to readily integrate with factory Manufacturing Execution Systems (MES) and overarching quality management platforms. Utilizing standard communication protocols (e.g., OPC-UA, Modbus TCP) and offering well-defined APIs, the rich inspection data from every cell—including defect classifications, acoustic signatures, and trend analyses—can be seamlessly incorporated into the factory's central data infrastructure. This ensures that the actionable intelligence generated by the Digital Teardown is immediately available for real-time process monitoring, quality traceability, and continuous improvement initiatives without creating data silos.

For OEMs and inbound customers—including automotive, ESS, and pack integrators—implementations of IonSight hardware exist in smaller form factors, with software provisions made for ingesting product data delivered by battery manufacturers and interfacing ultrasound inspection with existing cell sorting and pack balancing systems.

Conclusion: Embracing the Digital Teardown for Future-Proof Battery Manufacturing

The lithium-ion battery industry faces immense pressure to scale production rapidly while simultaneously guaranteeing unprecedented levels of quality, safety, and performance. Meeting these demands requires moving beyond the limitations of traditional quality control methods, which struggle to provide comprehensive insight into the internal condition of every cell produced at gigafactory speeds. Electrical testing misses critical physical flaws, and while CT scanning is valuable, it remains impractical for 100% inline inspection.

Titan's IonSight™ platform, delivering the **Digital Teardown of Every Cell** through high-speed ultrasound tomography, represents the necessary evolution in battery quality assurance. By providing detailed, non-destructive visualization of the internal morphology of **every single cell**, IonSight™ enables manufacturers to detect hidden defects often missed by electrical tests—flaws that can compromise safety and performance downstream. This unprecedented visibility transforms quality control from a reactive necessity into a proactive driver of value.

Implementing the Digital Teardown delivers tangible benefits: it accelerates process learning and ramp-up, improves rolled throughput yield, reduces costly scrap and warranty claims, and critically, reduces the risk of potentially catastrophic safety incidents and recalls. It provides the actionable intelligence needed to optimize manufacturing processes in near real-time. For manufacturers of batteries and battery-powered products striving for world-class quality, efficiency, and market leadership, comprehensive cell inspection is essential—it's the foundation of economic viability and operational excellence in today's fiercely competitive landscape.

ABOUT TITAN ADVANCED ENERGY SOLUTIONS

Titan Advanced Energy Solutions, headquartered in Salem, MA, develops revolutionary, ultrasound-based battery cell inspection systems. Using non-destructive, high-resolution, high-speed ultrasound technology, Titan's IonSight analyzes cell morphology to detect critical manufacturing anomalies, directly addressing safety concerns and in-field risks. The novel in-line technology integrates into existing cell manufacturing processes to optimize quality yield, accurately classify cell quality grades, and evaluate lifetime performance and safety characteristics. As a science and engineering organization, Titan is diligent in its intellectual property strategy. Currently Titan holds 6 granted patents in the U.S. and 20 patent applications pending, as well as exclusive world-wide licenses. Additionally, Titan's intellectual property is also expressly protected worldwide, including China, Japan and Taiwan in the form of patent extensions granted by respective national agencies. The scope of Titan's IP covers applications of ultrasound to battery interrogation and cell handling.

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