ThermoFisher SCIENTIFIC

Potential, realized

Move forward faster with advanced solutions for every step of the battery supply chain

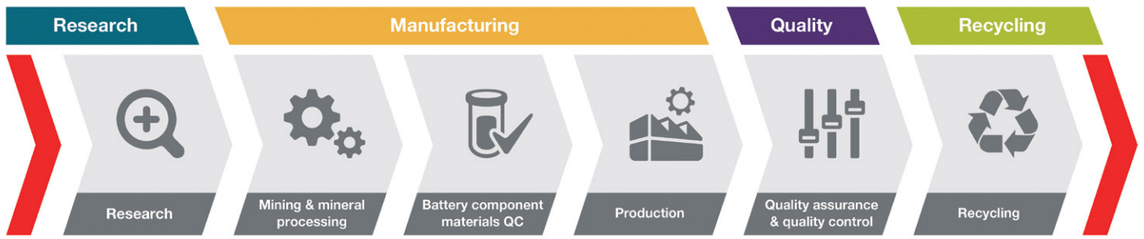
Research | Manufacturing | Quality | Recycling

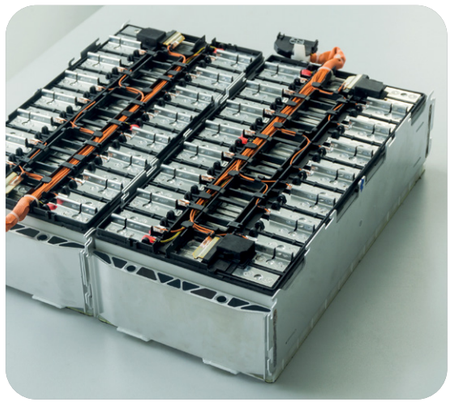
Building better batteries for the transition to clean energy

Offering global partnership and integrated analytical solutions for higher performance and greater sustainability, from research to production.

Improvements in lithium-ion battery technology and manufacturing lie at the heart of society's transition to clean energy. Making affordable batteries that pack more power, last longer, charge quickly, and are safer is essential for the pivot towards electrified vehicles and renewable energy storage.

Thermo Fisher Scientific offers integrated analytical solutions and advanced metrology to support and strengthen activities across the battery manufacturing lifecycle.





We help:

- Researchers develop next-generation battery technology
- Materials processors achieve greater efficiency and a lighter environmental footprint
- Cell manufacturers reduce waste, maximize throughput, and improve profitability

Whatever your role in the battery supply chain, and wherever you work within it, we can provide the material insights you need to succeed.

Turning analytical data into process decisions

Battery manufacturers produce millions of cells every day. From development to delivery, battery cells and the materials used in them, undergo thousands of quality control analyses. Bringing data from these tests together in a way that facilitates actionable insights is a challenge every battery manufacturer faces.

Through informatics platforms that empower rapid data processing, interpretation, reporting and management, we enable you to easily access and share valuable insights from your analyses. By bringing all your data together, our software can help you uncover hidden trends and comprehensively characterize your sample. It also boosts productivity by aiding sample preparation, streamlining workflows, and facilitating customization.

Use our range of easy-to-use, intuitive software solutions to present your data in compelling, easy-to-understand formats, for example, to quickly create detailed 2D and 3D images, zoom in on areas of interest and/or slice through structures to examine critical features.

Laboratory Information Management System (LIMS) solutions for traceability, repeatability, and workflow efficiency

The Battery Solution for Thermo Scientific™ SampleManager™ LIMS Software provides a comprehensive suite of tools and capabilities for efficient lab, data and workflow management of the complete battery production process. In ways that a traditional MES can't, the software enables increased compliance, productivity, and traceability across your business, helping to reduce scrap rate, rapidly upscale production, and drive consistency and continuous product quality improvements. SampleManager LIMS makes it straightforward to comply with The Battery Passport regulation, by creating a digital representation of your battery for effective lifecycle management.

Use it to:

- **Establish exemplary traceability**
- **Improve sample, data, instrument and lab productivity and scalability**
- **Drive and demonstrate compliance with regulatory standards**

Stamping Battery Passports with authenticity

From January 2026, the EU Battery Regulation Amendment will require EV and industrial batteries in the EU to comply with new regulations, at which point a digital passport will become essential for market listing. The Battery Passport was conceptualized by the Global Battery Alliance (GBA) in 2019 with the aim of bringing transparency to the market, to support greater sustainability. Ultimately, The Battery Passport program will support "a global reporting framework to govern rules around measurement, auditing, and reporting of ESG parameters across the battery value chain."

Such goals are vital as the industry expands but create a requirement for rigorous tracking across the battery supply chain. LIMS software can help. Not just in streamlining data gathering and collation, from the lab to the production line, but also with respect to demonstrating data integrity. By providing comprehensive lab, data and procedural workflow management, a LIMS can provide the complete traceability and authentication that battery manufacturers now need.

Unique material insights for the development of battery technology

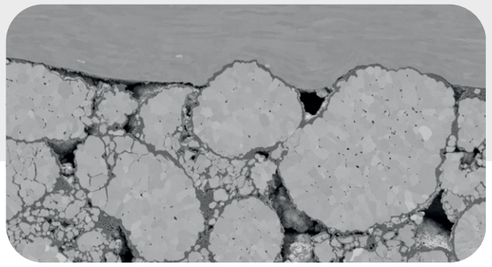
To accelerate the development of new battery technologies, researchers investigate candidate materials, characterizing them from the millimeter to the atomic level. Chemical, structural, and molecular information for materials in their native state builds a core understanding of new battery chemistries, helping to establish critical structure-performance correlations. Gathering precise and relevant data for all types of material, as quickly and efficiently as possible, accelerates knowledge-led progress toward improved performance.

A powerful portfolio for battery research

Researchers characterizing battery materials demand elemental composition and impurity analysis and quantification in order to ensure the quality and performance of the finished products. Understanding material microstructure is also critical: particle size, porosity, cracking, connectivity, and tortuosity are all important parameters that need to be evaluated. Our electron microscopy and surface analysis solutions deliver rapid, accurate 2D and 3D imaging and chemistry analysis, from the microscale down to the atomic level.

Spectroscopy solutions add complementary insight to microscopy, by enabling the determination of crystallinity and phase composition. Meanwhile, chromatography, mass spectrometry, and elemental analysis technologies quantify major elements, such as lithium, nickel, manganese, iron, and phosphorus, accurately detecting trace-level impurities and measuring a wide range of organic and inorganic components.

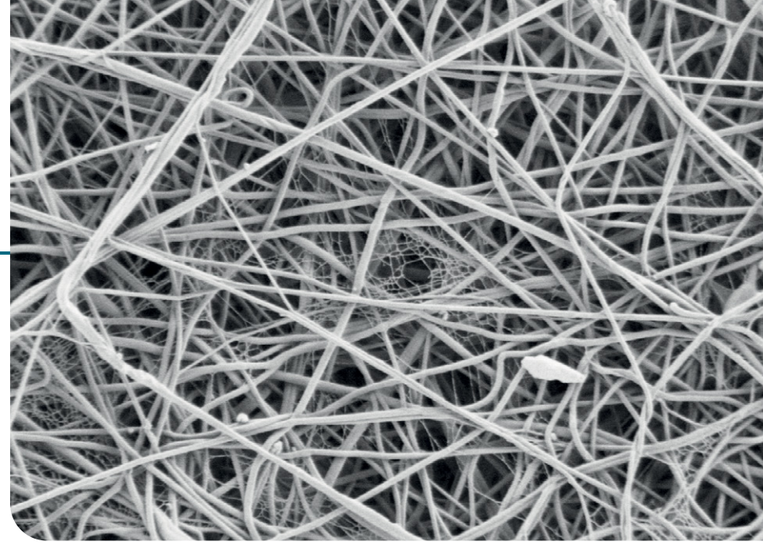
Rotational rheometers provide high-resolution insight into the viscoelastic behavior, non-Newtonian behavior, and structure of electrode slurries to guide formulation.

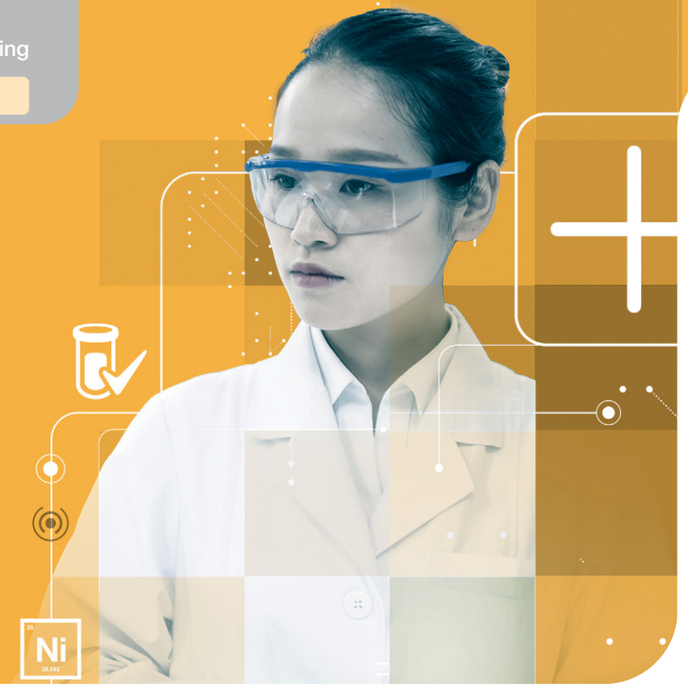


Use these products to:

- **Visualize the spatial distribution of components and phases on electrode surfaces and at the electrolyte interface, including in operando during battery cycling**
- **Learn how lattices and crystal structures change with charging and discharging**
- **Investigate problematic issues such as dendrite growth**
- **Identify elemental and molecular components and impurities associated with routine operation, battery degradation and/or failure**
- **Study the crystallinity, stability, texture, and reactivity of different battery materials and cell chemistries, in normal operation and following failure**
- **Develop electrode slurry formulations that combine high stability with excellent coating performance**

Our analytical solutions allow users of all skill levels to confidently obtain reproducible, high-quality results: efficient workflows ensure representative data and high productivity. Advanced software accelerates measurements while at the same time presenting quantitative data in an accessible visual format. The results allow battery researchers to solve analytical challenges efficiently and effectively, to access the information needed to drive progress.





Real-time data for efficient, sustainable metal extraction

Mining companies and mineral processors delivering metals for battery production face exponentially growing demand: the essential requirement for extracting battery metals in an environmentally sustainable way and the need to ensure maximum extraction efficiency with minimum waste add to the challenge of meeting it. Optimally processing minerals in the face of natural variability is a defining goal and relies on having timely information to drive process control decision-making. The need is for robust, high-availability systems that work reliably in harsh environments to deliver the information needed to maximize efficiency while simultaneously driving up throughput.

Robust, established technology for process monitoring and control

Our market-leading process elemental analyzers utilize prompt gamma neutron activation analysis (PGNAA) or x-ray fluorescence (XRF) spectroscopy to deliver dependable real-time elemental composition analysis of bulk materials, from mine to smelter. X-ray diffraction systems add complementary insight into ore crystallinity while innovative sampling systems ensure representative and reliable measurement for every stream, in an appropriate timeframe. Real-time particle size data help to maximize the throughput of grinding circuits, while simultaneously minimizing energy consumption.

Use these products to:

- Implement bulk ore sorting to extend quarry/mine lifespan, make lower grade ores economical to process, increase plant throughput, and minimize the loss of valuable material to waste
- Establish robust Metallurgical Accounting (MA) to track saleable metals through the process, identify where value is lost, and improve process economics
- Optimize the control of grinding circuits, ensuring consistent operation in the ‘sweet spot’ that maximizes metal recovery within the constraint of avoiding excessive energy consumption and downstream inefficiencies
- Respond effectively to changes in ore mineralogy, feed rate, pulp density, and particle size to minimize reagent use in froth flotation circuits while maintaining separation performance
- Determine ore values and the nature of contaminants/impurities for efficient mine operation, from stockpile management to the manipulation of processing parameters, for the cost-efficient production of the high-value feedstocks

Shaped by decades of working with the mining industry our proven technology can increase asset utilization, lifespan, and profitability, helping operators to produce critical metals such as lithium, nickel, cobalt, manganese, iron, and aluminum cost-efficiently and with less environmental impact.

XRF / XRD spectroscopy

PGNAA elemental analysis

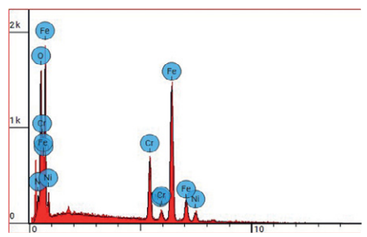
Bulk ore sorting

Timely and accurate material analysis

The manufacture of quality batteries begins with high-purity raw material feedstocks; lower-grade materials lead to batteries with poor or inconsistent performance, and, potentially, safety issues. Controlling the proportions of each element in the feedstock is crucial to ensure consistent battery performance, with each new batch of raw material necessarily subject to rigorous physicochemical QC. The requirement is for lab quality analysis at the point of need to facilitate robust and rapid decision-making. Ensuring that material composition and impurity levels are consistently within specification through timely analysis can help to safeguard quality, reduce scrap, enhance productivity, and increase profitability.

Easy-to-use, near-line technology for feedstock assessment

Our chromatography, mass spectrometry, and elemental analyzer solutions quantify the composition and purity of lithium salts and other raw materials used in the manufacture of cathodes, anodes, and electrolytes. Handheld XRF analyzers enable non-destructive, instantaneous elemental measurement, robustly quantifying key elements such as nickel, manganese, cobalt, copper, and zinc. Scanning electron microscopy systems offer complementary near-line detection capabilities for impurities and contaminants in separator, anode, and cathode materials. Routine rheological testing assesses the flow properties of electrode slurries.



Reference EDS spectra collated from x-ray generated by scanning electron microscopy

Use these products to:

- **Streamline contaminant detection via the combined application of particle morphology and composition data**
- **Robustly identify and control elemental contaminants that can adversely impact battery performance**
- **Check electrode and electrolyte material composition in real-time prior to commissioning equipment or tools**
- **Verify effective cleaning and the absence of cross contamination from equipment such as blender paddles or coating machine rollers**
- **Confirm the homogeneity of raw cathode active materials, at-line, prior to application and coated cathode active materials, off-line, on the electrode**
- **Certify the purity of refined lithium (and other metal) salts, graphite, silicon and other elements used in the production of cathode, anode and electrolyte materials**
- **Ensure the consistency of electrode slurry viscosity for superior coating performance**

Designed for trouble-free, daily use within the production environment, our solutions for battery component material QC provide the information needed to establish a secure foundation for consistent battery manufacture to the highest standards.

Smart solutions for electrode manufacturing

Consistent, uniform electrode coatings are critical for the manufacture of high-power batteries, with uneven coating and defects detrimentally affecting performance characteristics; detecting increasingly small defects in a timely way is becoming progressively more critical. Calendering helps to ensure uniformity by reducing porosity and improving particle contact. Electrode thickness and weight control is also crucial and must be carefully controlled. The same is true for separators with the performance of increasingly sophisticated multilayer films reliant on thickness uniformity. The need is for rapid measurement and high levels of coverage to enable responsive process control and rapid, cost-effective remedial action.

Our Battery Customer Experience Centre in Korea, including a demo lab of our advanced in-line metrology solutions

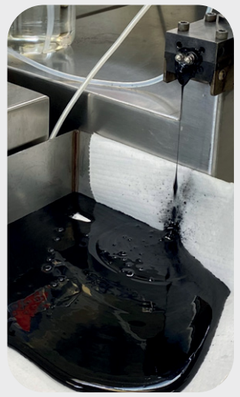
Robust, effective, in-line metrology for battery manufacturing

Our in-line metrology solutions deliver precise thickness and coating weight measurement for electrode coatings, calendered electrodes, and separator films. Innovative sensor technology, measurement methodologies, reporting and remote instrument health monitoring capabilities ensure continuous, robust measurement and exemplary uptime. These in-line solutions provide manufacturers with a secure platform for the responsive process control needed to make high-performance batteries with speed and efficiency.

Use these products to:

- **Reliably measure electrode coating weight with leading edge precision**
- **Access unmatched streak resolution and electrode coating edge defect detection**
- **Measure at fast scan speeds for greater coverage in a process relevant timeframe**
- **Apply ultra-precise confocal laser thickness measurement with excellent repeatability regardless of surface roughness, reflectivity, and electrode material**
- **Automate separator extrusion die control, for both wet and dry systems, for every membrane composition**

These in-line metrology solutions benefit from highly effective remote monitoring, near real-time critical issue reporting and extensive process analytics and data recording/reporting options. Rely on them for high process uptime and use the resulting data to produce high-quality batteries, achieve high yield and at the same time minimize waste.



Looking ahead: Solvent-free electrode processing

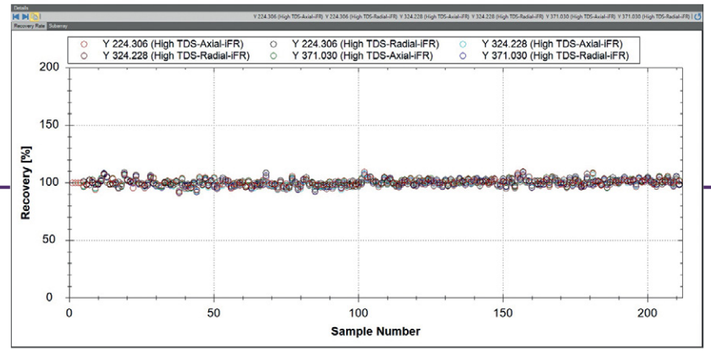
Solvent-free processing is an appealing prospect for battery manufacturers. Solvent-free electrode coating would eliminate the energy consumption associated with solvent evaporation in later process steps, speeding up processing while at the same time reducing health and safety concerns. A downside is the need for high shear. Conventional planetary mixers are limited with respect to energy input and expensive to run under high shear conditions; screw extruders are a superior option.

We offer a range of twin screw extruders for the cost-efficient, continuous production of highly dispersed battery slurries, helping manufacturers to embrace lower solvent processing. With a material requirement as low as 50g/h our small footprint, high performance family of extruders share strictly comparable geometry allowing battery manufacturers to develop and optimize in the lab and then to scale up, easily and reliably.

Testing for QC, investigating failure

Measuring the critical characteristics of batteries as they flow from the production line is crucial for effective QC. Both partly assembled and complete batteries require examination, the most robust approach being 100% measurement of the finished product; measuring a statistically meaningful proportion of the product flow is the minimum requirement. By rapidly detecting mechanical defects such as poor electrode alignment, overhang, and sub-optimal tab positioning, battery manufacturers can ensure rapid and effective remedial action and consistent delivery to demanding specifications, thereby safeguarding reputation.

When batteries do fail it's vital to understand why, since this is an essential precursor to improving performance and aging characteristics. Elucidation relies on detailed, multifaceted material characterization taking account of the potential to destroy vital evidence by exposing samples to air or moisture.



Internal standard stability in battery material samples

Rapid measurement for QC, detailed characterization for failure analysis

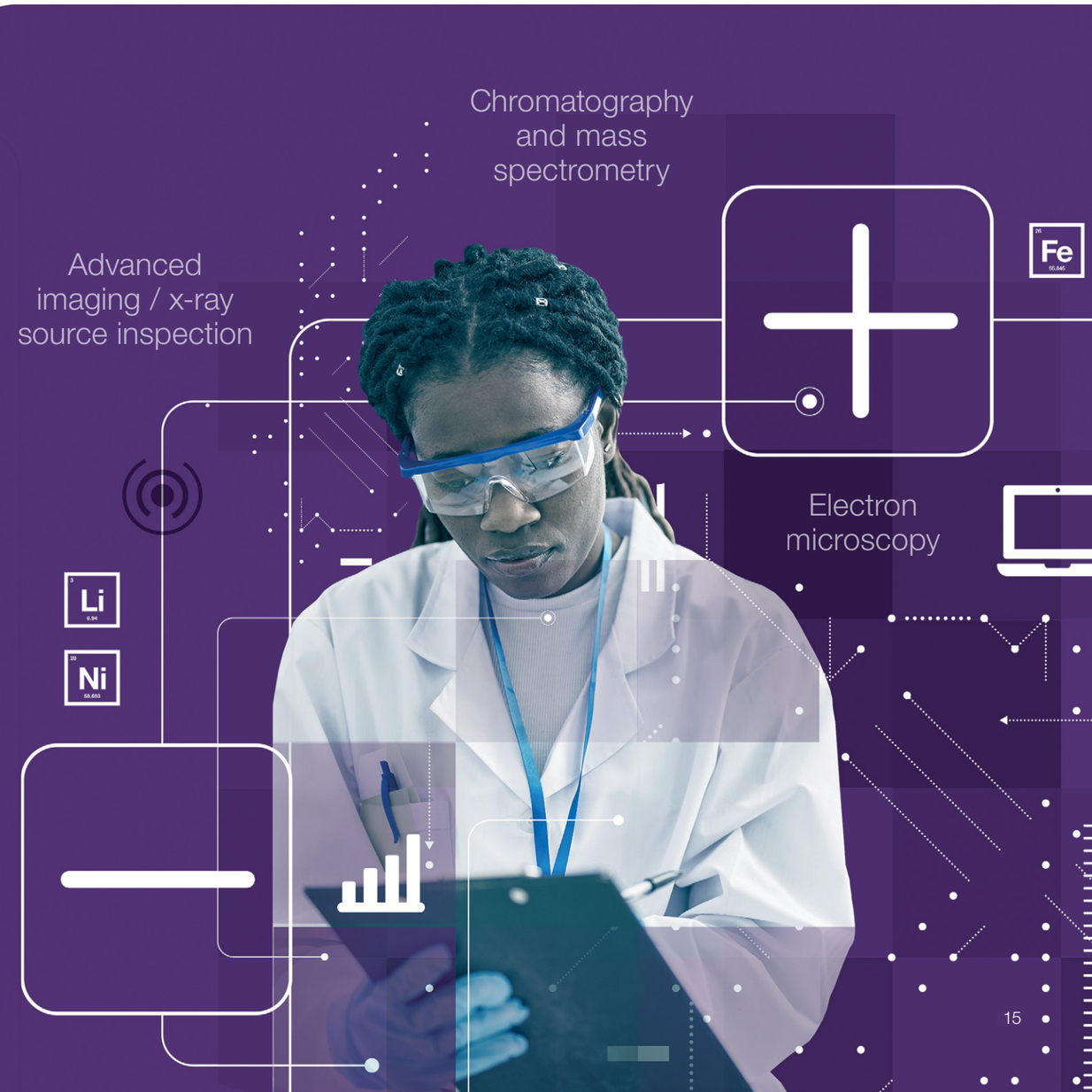
Our X-ray sources provide power and resolution for robust battery inspection. Integrated into automated at-line systems or positioned directly into the production line for continuous measurement, they produce 3D images that capture the detail that battery manufacturers need to safeguard quality. High reliability and long uptimes are combined with high stability for excellent image resolution.

Our chromatography and mass spectrometry systems allow investigators to apply ultra-trace analysis to detect elemental impurities and metal-based degradation products and comprehensively investigate electrolyte degradation, for efficient failure analysis. Our microscopy solutions characterize defects via imaging and elemental analysis enabling both 2D and 3D characterization for a deep understanding of failure mechanisms. Inert Gas Sample Transfer (IGST) workflows preserve evidence for more relevant analysis.

Use these products to:

- **Inspect representative batches of product, at-line, at speeds of less than one minute per battery**
- **Measure up to 100% of the production output at multiple angles for complete quality assurance**
- **Carry out a detailed analysis of electrolyte composition, of the structure of degradation products and of the gases associated with processes that cause swelling**
- **Dig deep through the structure of a cell or electrode, at different length scales, down to the microstructure of individual cathodes and anodes to reveal the imperfections associated with failure and/or elucidate how cycling erodes structural integrity**
- **Prepare high-quality site-specific cross-sections for detailed defect characterization**
- **Implement inert gas sample transfer workflows that preserve sample integrity and data relevance**

Via effective battery QC manufacturers can rapidly detect problems, protecting quality and at the same time, minimizing waste. Investigating how batteries age and fail generates unique insights that support progress towards next generation batteries that combine higher performance with enhanced reliability.



Ramping up understanding for effective recycling

Within the decade, large scale recycling will become essential as batteries from the exponentially growing electric car fleet reach end-of-life in appreciable numbers. Optimizing bulk recycling and recovery strategies is vital whether addressing the scrap rate in production, the reuse of spent batteries or developing ‘urban mining’ capabilities.

Disassembling, crushing, shredding, and processing used batteries produces a waste stream referred to as ‘black mass’. Regulations associated with Extended Producer Responsibility (notably in the EU) and high demand for the scarce metals in black mass make it increasingly important, and profitable, to process this material effectively. Screening black mass, tracking the recycling process and certifying maximum impurity levels in the final recycled products are all critical tasks. The need is for analytical techniques that can help to differentiate waste streams with regards to value and optimal processing route.

An analytical toolkit for battery recycling

Our handheld XRF analyzers provide real-time elemental analysis for rapidly screening and separating incoming material by cathode chemistry type, to optimize the recycling process. Spectroscopy solutions quantify the elemental content of wet, dry, and powdered recycled materials, providing insight into the structure in which elements of interest are held; they can also be used to determine moisture levels. Chromatography and mass spectrometry solutions add complementary, high sensitivity composition and impurity measurement to support the optimal processing of recycled material streams.

Use these products to:

- **Determine the chemical make-up, molecular structure, and economic value of black mass**
- **Assess the relative merits of alternative processing routes, e.g. pyrometallurgical vs. hydrometallurgical**
- **Optimize the recycling workflow for every batch**
- **Prevent unwanted material entering a recycling process**
- **Confidently trace and monitor sources of problematic contaminants**

Our analytical solutions for black mass and other recycled materials are helping battery recyclers to learn how best to process different streams and optimize metal recovery, both of which are vital tasks for the long-term sustainability of the industry.

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The battery industry presents unique challenges. There are considerable performance gains still to be made, the rate of growth is exceptional, societal demand is pressing, and sustainability is a crucial concern.

Our contribution is to provide leading analytics, informatics and metrology, that generate reliable information from development through to QC, from mine to line. With the scale, longevity and reputation required for global partnership we're already helping battery manufacturers across the world to innovate, make feedstocks and batteries of exemplary quality, and improve production efficiency.

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Battery community

Learn more at **thermofisher.com/battery-solutions**