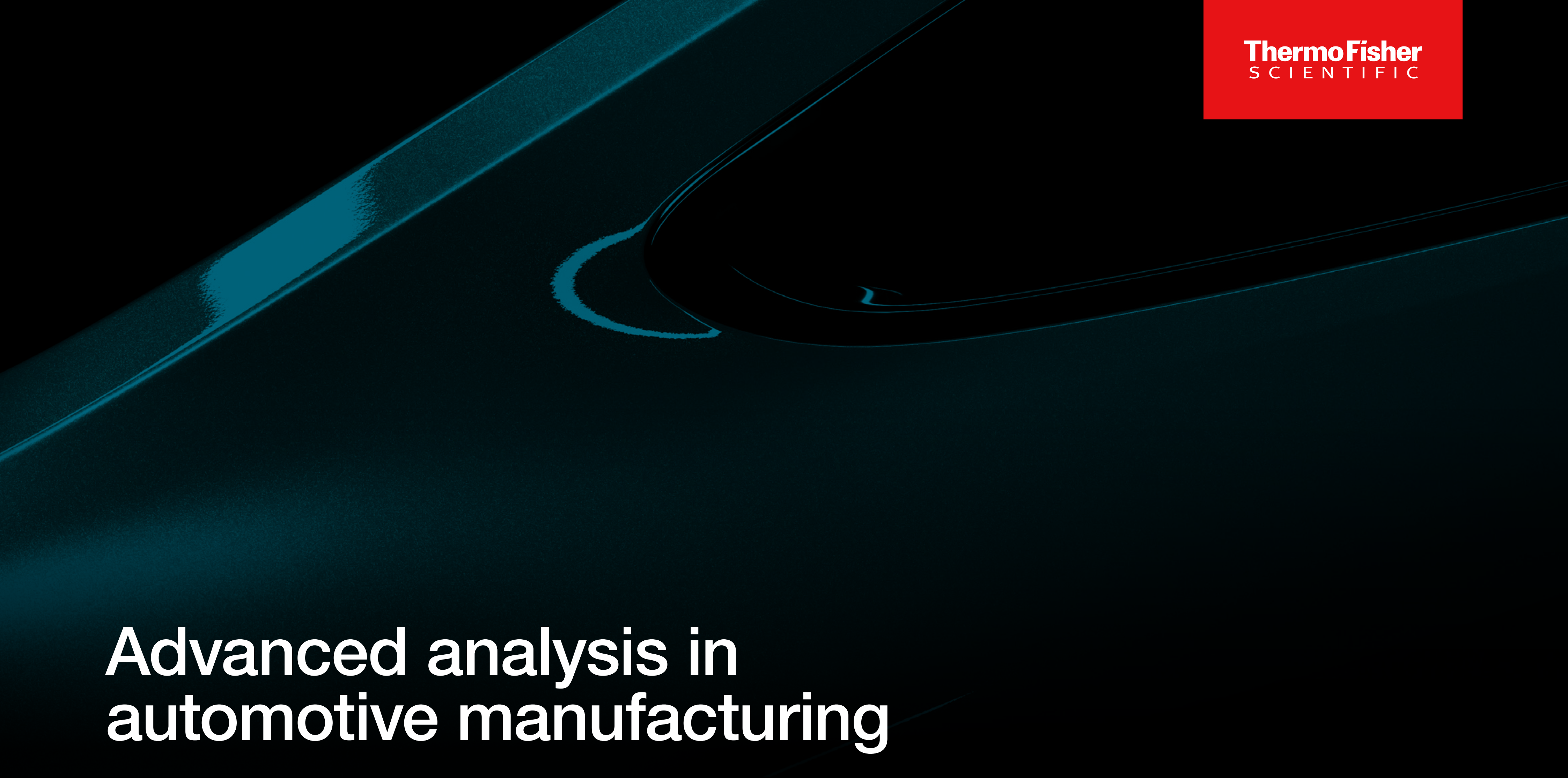
ThermoFisher SCIENTIFIC



# Advanced analysis in automotive manufacturing

## Creating next-generation vehicles with EM and XPS

thermo scientific

# Accelerating innovation with EM and XPS

The automotive industry is always evolving. Consumers and regulatory agencies alike expect continually greater fuel efficiency, lower emissions, higher performance, and, above all, enhanced safety. To meet these demands, manufacturers need detailed analysis, strict process control, and ongoing optimization across the entire product development process, from R&D and sourcing raw materials to assembling final vehicles.

Analytical techniques like electron microscopy (EM) and X-ray photoelectron spectroscopy (XPS) deliver a wide range of data that can help improve automotive components, including nanoscale images of material surfaces and insights into their chemical and structural makeup. Whether you're designing a brand-new vehicle, developing the latest generation of a trusted model, or creating new materials for a range of vehicles, EM and XPS can help you create new materials, improve manufacturing processes, analyze the quality of finished products, and accelerate innovation.

This eBook contains a selection of application notes that highlight how EM and XPS can support the automotive manufacturing process across four categories: material innovation, process optimization, quality control, and failure analysis.

Techniques like scanning electron microscopy and X-ray photoelectron spectroscopy deliver precise data that can lead to measurable improvements in vehicle components.

Surface coatings can extend component life by up to

**50%**

Lightweight materials can reduce vehicle component weight by up to

**70%**

Compared to traditional manufacturing methods, 3D-printed materials can reduce weight by up to

**80%**

A quality-improvement program that targets recalls can reduce quality costs by up to

**15%**

Cleanliness protocols help reduce contamination-related defects by

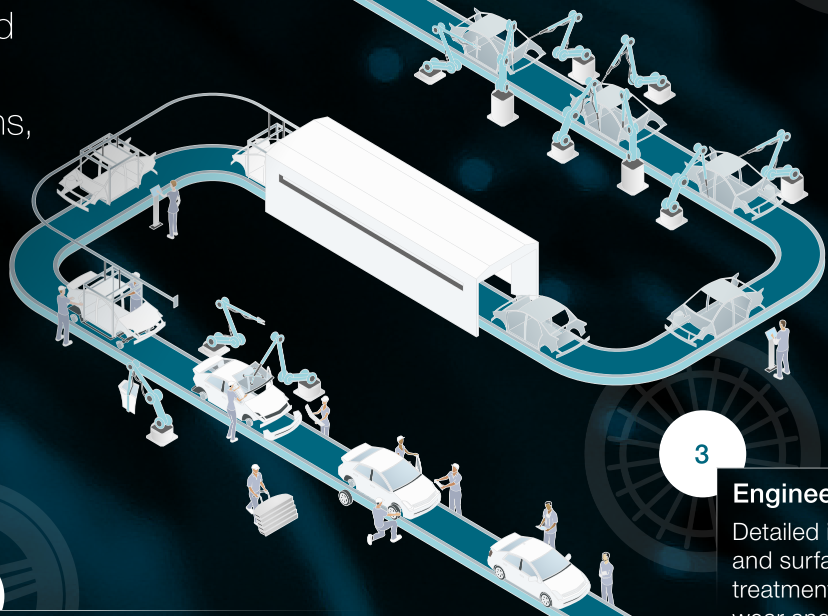
**40%**

High-resolution imaging techniques like SEM can image defects as small as

**1 nm**

# Advanced analysis across the automotive lifecycle

From raw material sourcing to vehicle maintenance, each stage of the automotive lifecycle requires detailed analysis, strict process control, and ongoing optimization to ensure the highest standards of quality, safety, and performance. EM and XPS techniques deliver high-resolution results across a broad range of applications, including nanoscale imaging, morphological and topographical analysis, and chemical and structural characterization.



1

**Sourcing raw materials**

High-resolution analysis of metals, alloys, composites, and materials for battery components can help you detect impurities and inconsistencies early in the supply chain.

2

**Forming and fabricating materials**

Chemical analysis helps you characterize microstructures and phase distributions, optimize fabrication methods, and confirm that material properties meet required specifications.

3

**Engineering and coating surfaces**

Detailed imaging and analysis of coatings and surface layers can help you optimize treatments that protect materials against wear and corrosion.

4

**Manufacturing and assembling components**

EM and XPS can help you identify microstructural defects, phase variations, and inclusions to ensure the integrity and reliability of components and assemblies.

5

**Testing and quality assurance**

Comprehensive failure analysis, root cause identification, and lifecycle testing can help you validate performance, safety, and regulatory compliance.

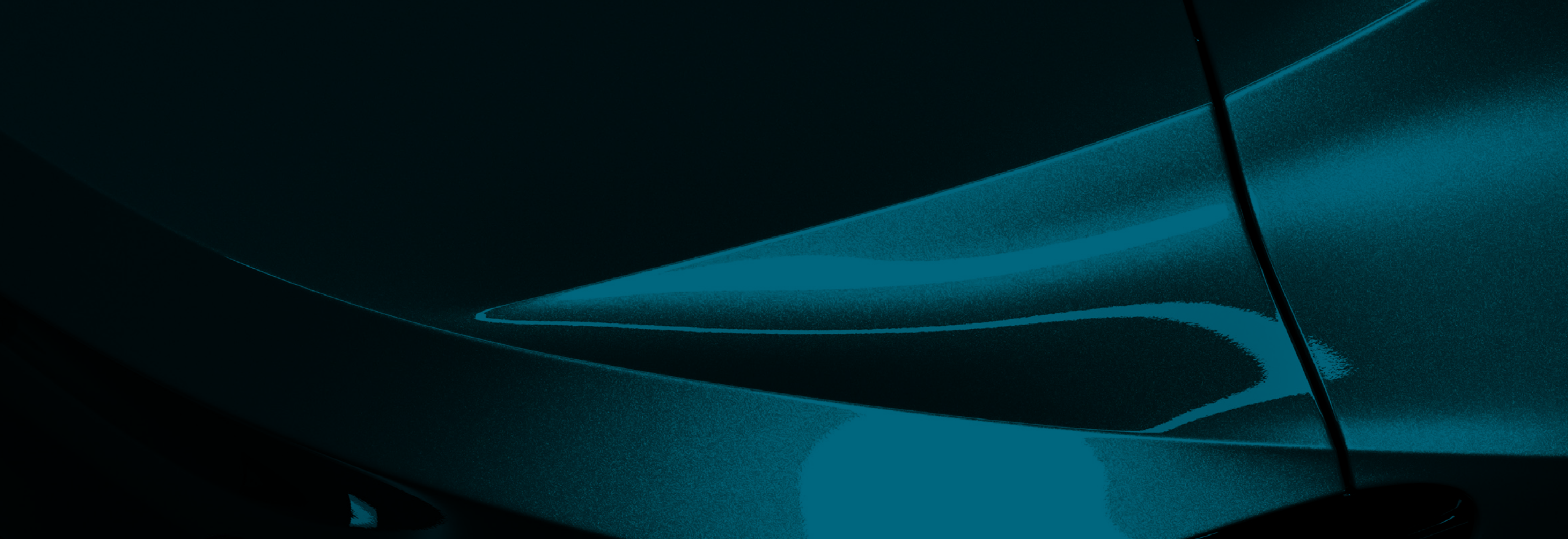
6

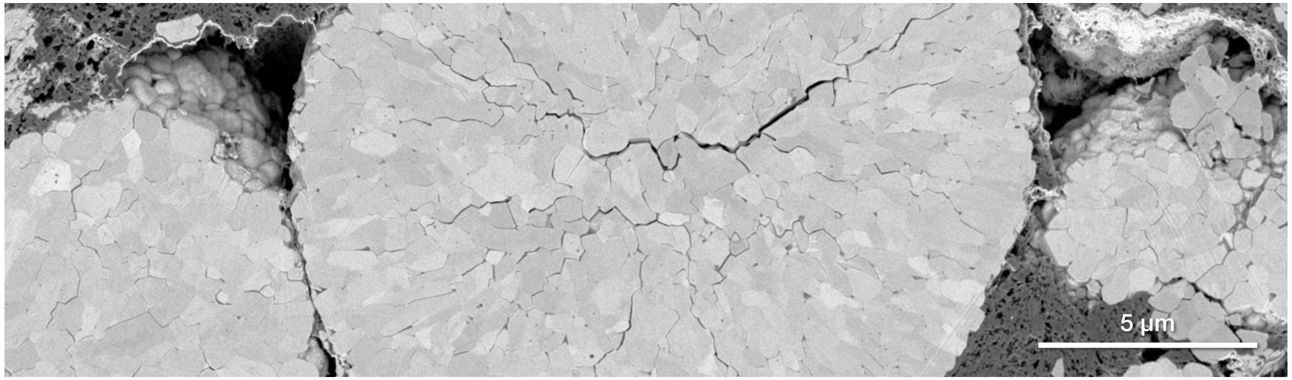
**Maintenance, repair, and overhaul (MRO)**

Advanced analysis can help you diagnose wear, fatigue, and failure mechanisms and provide crucial insights to extend the service life of components.

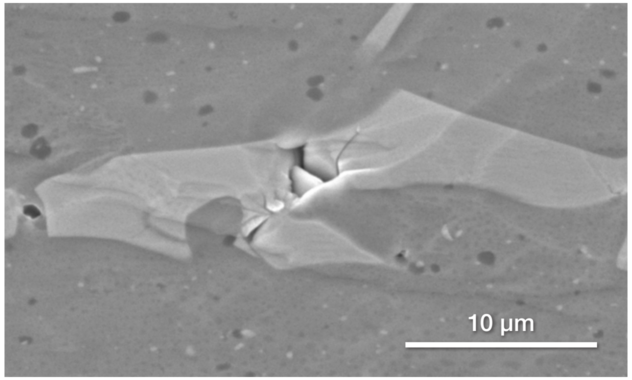
# Material innovation

The materials used in automotive components must meet stringent standards for performance, safety, and environmental impact. High-resolution analytical methods provide detailed insights into phase composition, grain structure, interfaces, and defect mechanisms—all of which are essential in establishing relationships between material structures and properties. This information helps remove the risk from innovation, precisely refine formulations, and accelerate the delivery of high-performance materials.






Polished cross section of a battery cathode showing a nickel-manganesecobalt (NMC) particle.




SEM image of an aluminum matrix showing microcracks. *Sample courtesy of the University of Science and Technology Beijing.*

## Analyzing cathode material in battery components

### Challenge

The composition and quality of cathode material significantly influence the overall performance and longevity of lithium-ion batteries. Several analytical methods, including EM and XPS, are used to investigate the microstructural and chemical properties of these materials to ensure that they meet stringent performance and safety standards.

### Solution

High-resolution scanning electron microscopy (SEM) is used to identify and analyze the fine structural details of cathode particles, including their morphology, size, and surface characteristics. This helps researchers understand how these microstructural features impact the electrochemical properties of the material.

XPS provides insights into the chemical state of elements on the cathode surface. It's particularly useful in detecting and quantifying residual lithium compounds such as LiOH and $Li_2CO_3$, which form due to the sensitivity of high-nickel cathodes like $LiNiO_2$-based materials to moisture and $CO_2$.

These residuals can impair the capacity retention and overall performance of the battery. Impurity analysis is also essential in identifying detrimental elements like copper, iron, and zinc, which can compromise the safety and durability of the battery. Similarly, energy-dispersive X-ray spectroscopy can collect elemental data of cross sections, which is used to create a three-dimensional map of elements spread throughout a sample.

With all of these analytical methods, it's important to protect battery materials from air exposure, which can cause degradation. An air-tight sample transfer system filled with inert gas is critical when moving these samples between instruments.

Learn more

## Analyzing 6000-series aluminum alloy for automotive panels

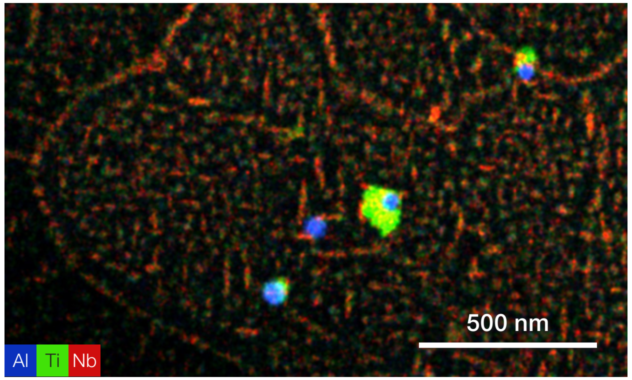
### Challenge

The 6000-series aluminum alloys commonly used in automotive applications often include iron-rich intermetallic particles, which can lead to microcracks that compromise mechanical integrity. A comparative study of a baseline aluminum alloy and a variant containing 0.03% nickel showed that adding nickel reduced the average particle size, which could reduce fracturing.

### Solution

In the study, automated scanning electron microscopy (SEM) enabled rapid, statistically significant analysis of particle size, shape, and composition. This method allows automotive manufacturers to optimize the material properties of aluminum components, to reduce the risk of microcracking.

Learn more




TEM-EDS overlays of Al, Ti, and Nb.

## Characterizing additively manufactured alloys (AMAs)

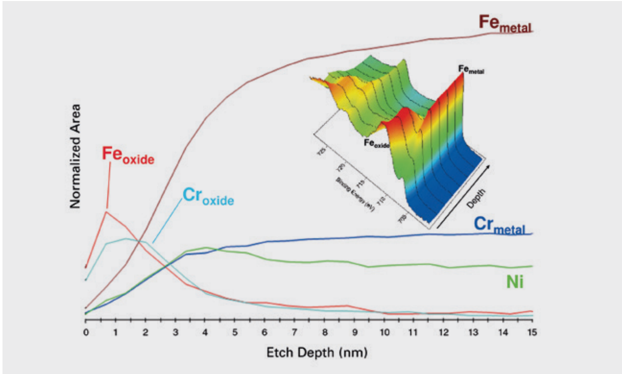
### Challenge

Additive manufacturing makes it possible to create complex metal components with tailored properties. However, the resulting microstructures often exhibit heterogeneity due to rapid thermal cycles and solidification rates, which can lead to anisotropic mechanical performance.

### Solution

Investigating these alloys with multiple techniques, including *in-situ* analysis, scanning electron microscopy (SEM), transmission electron microscopy (TEM), and electron backscatter diffraction (EBSD), at different scales delivers a more comprehensive and well-rounded perspective of the material's features, including phase distribution, grain orientation, and precipitate formation. This data helps optimize production processes, which can ultimately lead to better performance and extended lifetime.

Learn more




Sputter depth profiles of unpassivated and passivated steel surfaces.

## XPS analysis of the passivation layer on stainless-steel surfaces

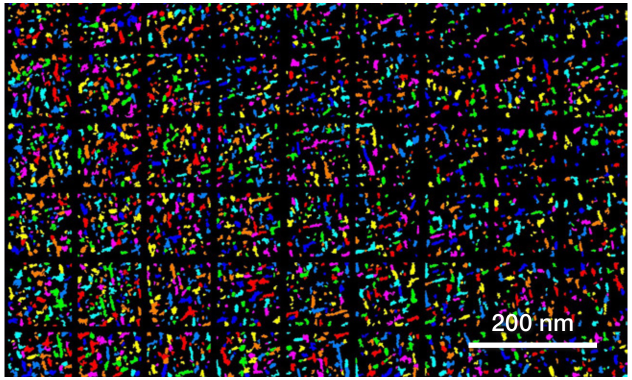
### Challenge

When manufacturing stainless-steel components, the passivation process helps protect against corrosion. The quality of the passivation layer is crucial when manufacturing automotive components that are exposed to harsh environments.

### Solution

X-Ray photoelectron spectroscopy can be used to evaluate the effectiveness of the passivation process and provides detailed insights into the metal species in the passivation layer, like chromium and titanium. These insights are helpful in improving passivation processes, which leads to longer-lasting components, reduced maintenance costs, and enhanced safety and performance.

Learn more




Wide-area automated TEM imaging, EDS mapping, and particle sizing.

## Micro- and nanoscale analysis of passivated stainless-steel landing gear

### Challenge

Passivated stainless steel is widely used in demanding applications due to its enhanced corrosion resistance and durability. To better understand its performance, researchers often use advanced analytical techniques such as X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM), and transmission electron microscopy (TEM).

### Solution

These methods highlight surface chemistry, microstructure, and precipitate formation in detail. For example, XPS reveals the distribution of chromium and titanium species in the passivation layer, while SEM and TEM provide high-resolution images of inclusions and precipitates. This multi-technique approach helps identify surface contaminants and assess material integrity, ultimately guiding the development of high-performance, corrosion-resistant alloys.

Learn more

Disc brake.

## Analyzing automotive disc brake pads with EDS

### Challenge

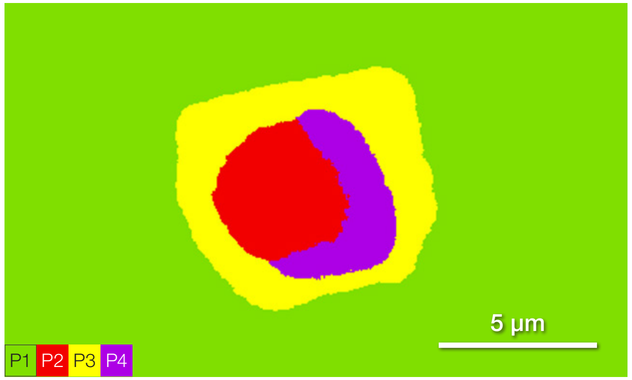
Automotive disc brake pads are complex materials composed of binders, reinforced fibers, friction performance modifiers, and padding. To analyze these materials at the micro- and nanoscale, you first must separate each of the many elemental phases. While traditional elemental mapping in X-ray microanalysis shows the elemental distribution, it does not provide a comprehensive understanding of the material's composition. This issue can be addressed by using a statistical approach that combines spectral imaging and principal component analysis through automated energy-dispersive X-ray spectroscopy (EDS) analysis.

### Solution

This method examines the spectra obtained using scanning electron microscopy and EDS, grouping statistically unique phases without regard to elemental composition. By applying this approach, researchers can identify and characterize distinct components within the brake pad material, such as iron oxide-rich phases, carbon-rich phases, and barium sulfate-rich phases, among others. This comprehensive analysis helps engineers understand wear characteristics and reverse engineer brake pads, ultimately helping them develop more reliable and efficient automotive braking systems.

# Process optimization

Advanced manufacturing methods like additive manufacturing and high-precision machining rely on precise material properties to achieve optimal component performance. Whether these processes are used for fabrication, coating, or surface treatment, electron microscopy can provide high-resolution imaging and chemical characterization to help optimize efficiency, reduce waste, and ensure production standards.



ChemiPhase analysis maps and phase area fractions of an inclusion.

## Automating SEM-EDS analysis and phase mapping of complex inclusions in steel

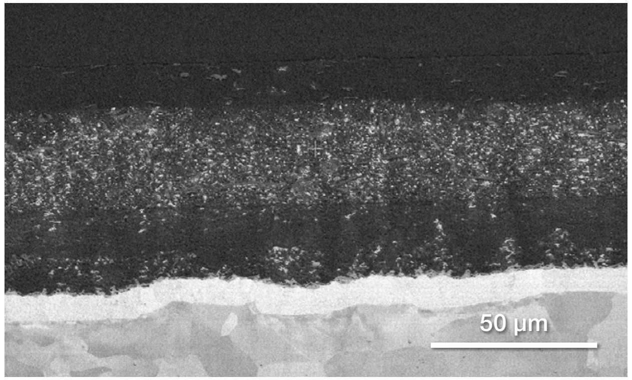
### Challenge

In steel production, controlling the formation of oxide, sulfide, and nitride inclusions is crucial as these micro-inclusions can significantly impact the material's mechanical properties and quality.

### Solution

Combining energy-dispersive X-ray spectroscopy with advanced software makes it possible to automatically analyze these complex inclusions, rapidly detect and classify particles, and map phases. This approach can help you better understand inclusion behavior and optimize steel quality through precise control of alloying elements and processing conditions.

Learn more



SEM backscattered electron image of an auto body coating cross section.

## Laser ablation for high-quality cross sectioning of auto body parts

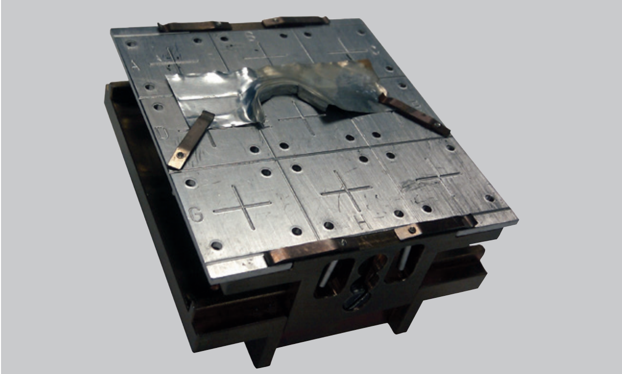
### Challenge

Automotive body coatings protect vehicles from corrosion and enhance their aesthetic appeal. These coatings have multiple layers—including an electrocoat, primer, base coat, and clear coat—that need to be precisely analyzed to ensure quality and performance.

### Solution

While traditional cross-sectioning methods are time consuming and may not produce the smooth surfaces needed for high-quality analysis, combining a femtosecond laser with scanning electron microscopy (SEM) and focused ion beam milling delivers rapid, high-quality cross sectioning, polishing, and imaging in a single instrument. This approach facilitates detailed structural and chemical analysis of paint layers with SEM and energy-dispersive X-ray spectroscopy, delivering a more efficient workflow and fast feedback during quality control.

Learn more


Aluminum sample mounted on the K-Alpha sample block.

## Identifying chemical differences on metal components

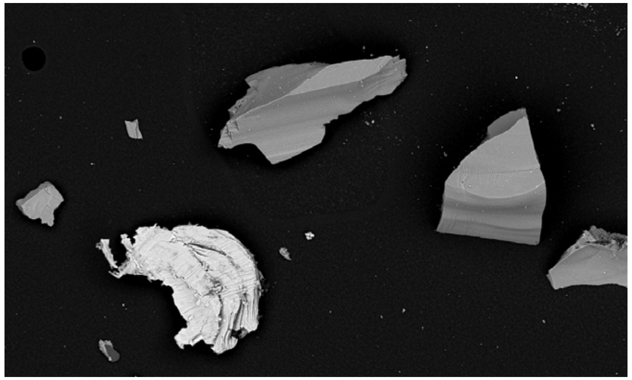
### Challenge

Tarnish on aluminum automotive components affects not only aesthetics but also functional quality.

### Solution

X-ray photoelectron spectroscopy makes it possible to identify and quantify the chemical differences between tarnished and non-tarnished areas, which helps manufacturers identify the source of the discoloration and guide improvements. This analysis can ultimately help manufacturers improve material processing techniques, surface treatments, quality, and visual appeal.

Learn more



$Al_2O_3$ and a pure aluminum particle on a carbon background clearly showing the difference in contrast.

## Understanding technical cleanliness

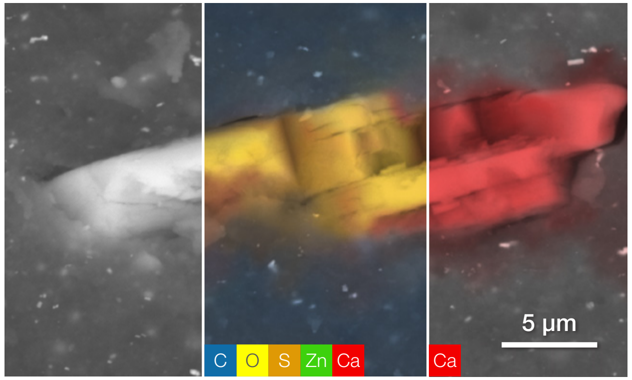
### Challenge

Removing unwanted particles from components is essential in modern manufacturing, especially in the automotive industry, where even small contaminants can cause severe and irreversible damage. To follow international standards like ISO 16232 and VDA 19.1, manufacturers must detect and analyze particle size, shape, and composition.

### Solution

Scanning electron microscopy and energy-dispersive X-ray spectroscopy enable fast, in-house analysis that can help you optimize quality control, reduce production time, and ensure compliance with cleanliness requirements. And with advanced software, you can automatically analyze and classify contaminants and then generate a report following ISO 16232 and VDA 19.1 standards.

Learn more




Layered filler. From left: BSE image, selected elements, and quantitative elemental image.

## Analyzing tires and fillers

### Challenge

Tires are complex, engineered composites made of multiple rubber compounds and various fillers that enhance performance characteristics such as grip, durability, and wear resistance.

### Solution

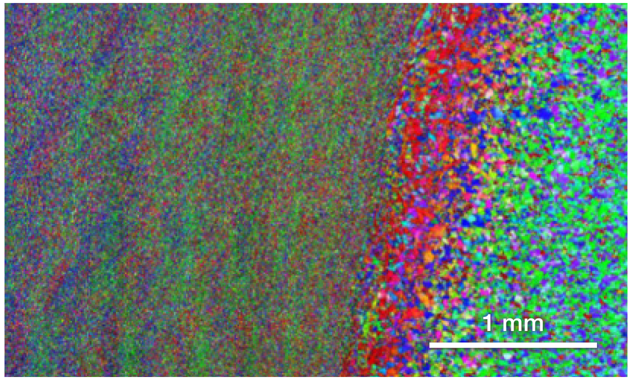
The uniform dispersion of these fillers—like carbon black, zinc oxide, aluminosilicates, calcium carbonate, and talc—is critical to tire quality and longevity.

Integrating live quantitative elemental mapping directly into the scanning electron microscopy workflow can help you identify and map the distribution of fillers in real time without altering imaging conditions between scanning electron microscopy imaging and energy-dispersive X-ray spectroscopy characterization. This approach delivers rapid, accurate failure analysis and quality control that can help you develop more reliable and higher-performing tires.

Learn more

# Quality control

In the automotive industry, quality control not only ensures that components meet stringent standards but also helps inform predictive maintenance strategies. High-resolution imaging makes it possible to detect microstructural defects like grain boundary irregularities, inclusions, voids, and phase separations that can compromise mechanical integrity and long-term performance. This information helps engineers analyze failures, monitor material behavior under stress, and validate manufacturing processes.




EBSD image of the weld, HAZ, and base metal regions. *Courtesy of WMG (Warwick Manufacturing Group), University of Warwick.*

## Analyzing aerospace aluminum alloy 2099 friction stir welds

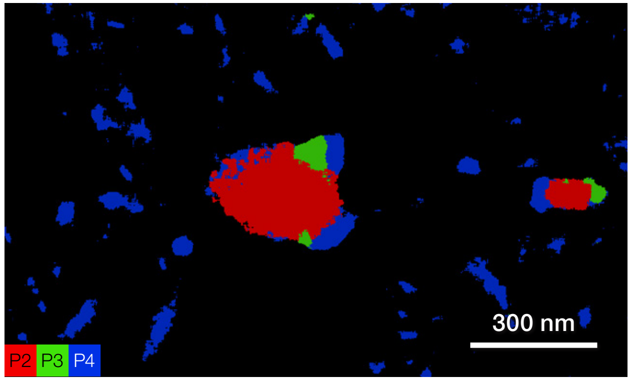
### Challenge

Friction stir welding (FSW) is a solid-state joining method for aluminum alloys that minimizes issues like solidification cracks and residual stresses. However, applying the technique to precipitation-hardened alloys like Al 2099 can result in challenging alterations to microstructure and mechanical properties.

### Solution

Advanced microscopy techniques like hardness mapping, electron backscatter diffraction (EBSD), site-specific liftout via focused ion beam (FIB), and transmission electron microscopy (TEM) can help you form a comprehensive understanding of microstructural changes and guide enhancements to welding parameters and post-weld treatments. In one study, hardness mapping revealed an 18% reduction in strength in the weld zone, EBSD showed significant grain refinement in the weld area, and TEM highlighted that strengthening T1 precipitates were replaced by less effective Tβ phases.

Learn more




ChemiPhase characterization of dispersoids in the AA2024-T6 sample.

## Characterizing aging-treated aluminum alloy AA2024

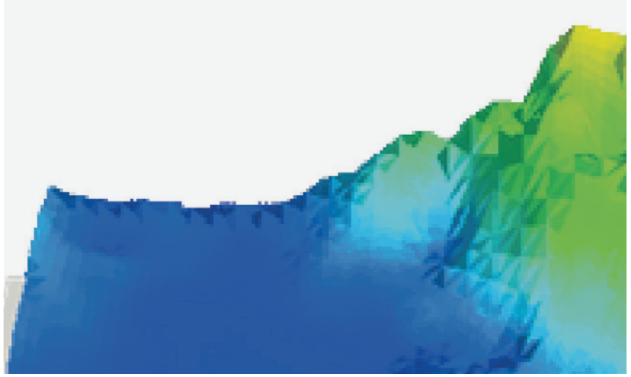
### Challenge

AA2024 aluminum alloy is widely used in aerospace and automotive industries due to its favorable strength-to-weight ratio and corrosion resistance. Its mechanical properties are significantly influenced by microstructural features such as precipitates and dispersoids, which form during various heat treatments. Understanding these microstructural changes is crucial for optimizing the performance of the final product.

### Solution

Advanced characterization techniques, including scanning electron microscopy, scanning transmission electron microscopy, energy-dispersive X-ray spectroscopy, and electron backscatter diffraction, can deliver real-time phase identification and quantitative elemental mapping. This approach can help you precisely identify precipitates and gain insight into grain structure and orientation, which is useful for tailoring heat treatment processes to achieve desired mechanical properties.

Learn more



Map of ratio of tin to total lead.

## Identifying stains on split steel bearings with XPS

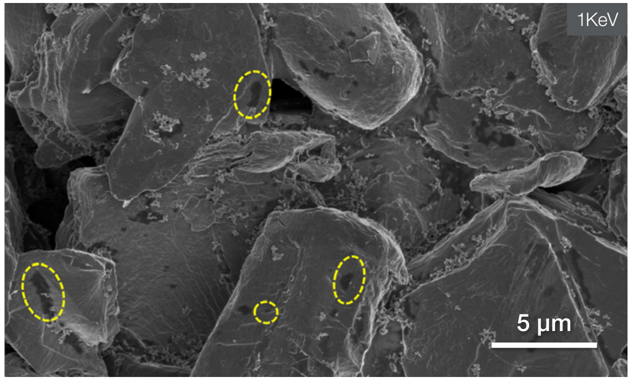
### Challenge

Stains on split steel bearings can decrease their performance and longevity. Understanding the root causes of staining helps manufacturers improve material processing and surface treatments, thereby enhancing the reliability and durability of critical automotive components.

### Solution

X-ray photoelectron spectroscopy analysis can reveal the differences between stained and unstained areas, identifying elemental concentrations in the stained regions. This analysis helps pinpoint possible causes of staining, such as issues with the eutectic before deposition, carbon-based contamination, or corrosion from loss of protective layers.

Learn more




Graphite and electrode surfaces imaged at low voltage using the Apreo ChemiSEM System.

## Quality control of battery components

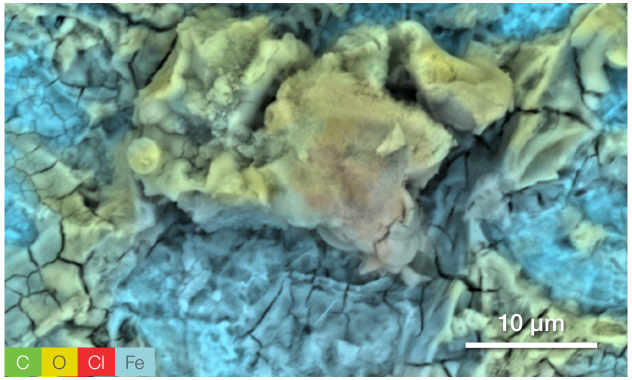
### Challenge

Quality control is a critical aspect of battery manufacturing that ensures that battery components meet specific standards and requirements for performance, safety, and longevity. It is a systematic process of monitoring and controlling various parameters throughout the production process, from inspecting raw materials to testing the final battery.

### Solution

Advanced imaging techniques like scanning electron microscopy and X-ray photoelectron spectroscopy are used to characterize the microstructure of battery materials and identify structural defects, elemental compositions, and chemical states. Integrating these techniques with automated quality control software can significantly enhance efficiency and accuracy by quickly analyzing particle sizes and compositions, generating detailed reports, and helping to maintain strict quality standards.

Learn more




Composition of a foreign object found in etched steel.

## Quality control of corroded steel surfaces

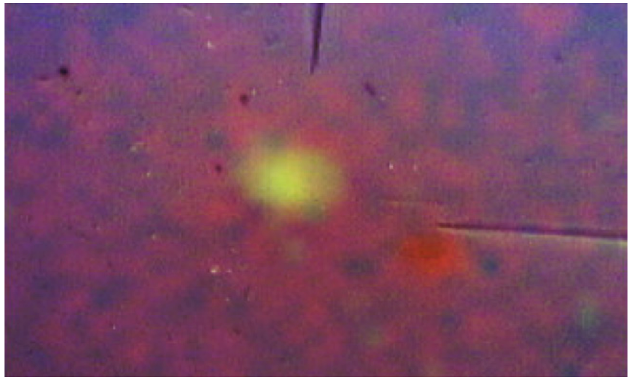
### Challenge

In steel manufacturing, pickling is a critical surface treatment process that removes oxide layers formed during hot rolling. This involves immersing steel in acid baths, typically hydrochloric acid, followed by thorough rinsing and drying. However, if residues from the pickling solution are not entirely removed, they can lead to surface contamination and corrosion.

### Solution

Investigating these stains with scanning electron microscopy and energy-dispersive X-ray spectroscopy can reveal the elemental composition of the stains, identify the source of contamination, and facilitate corrective actions to the pickling process that prevent future defects. In the study linked below, the analysis identified foreign particles on the steel surface containing elevated levels of chlorine and oxygen compared to clean areas, indicating the presence of residual hydrochloric acid. This finding confirmed that inadequate rinsing after pickling led to localized corrosion.

Learn more



Overlay of the XPS images and the live optical view. C1s(C-C) is red, Sn3d5 is green, and O1s is blue.

## Characterizing paint surface defects with XPS

### Challenge

Paint coatings not only make vehicles look good but also protect the underlying materials against corrosion. Any defects in these coatings can decrease the overall quality and longevity of automotive finishes.

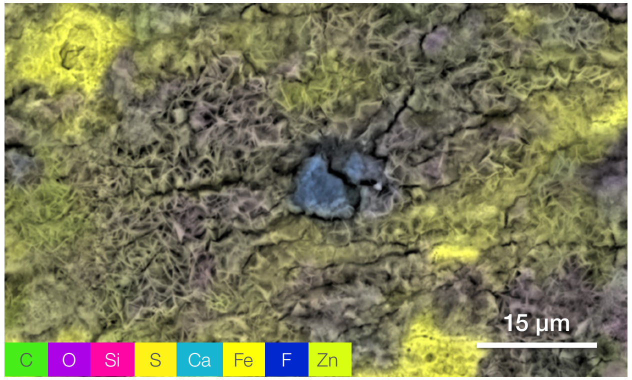
### Solution

X-ray photoelectron spectroscopy is an ideal technique for characterizing paint defects because it is nondestructive, highly surface sensitive, and able to quantify changes in chemical state. This information helps automotive manufacturers identify and mitigate issues that compromise the adhesion and quality of paint films.

Learn more

# Failure analysis

Failure analysis helps engineers identify the root cause of critical defects that can lead to early failure and decrease the lifespan of automotive components. High-resolution imaging techniques help them investigate fractures, corrosion, and stress-induced damage, which in turn provides the data needed to improve product design, optimize manufacturing processes, and ultimately enhance overall reliability.




Elements in a sample (all activated and shown in this view) and their distribution.

## Failure analysis of metal production parts

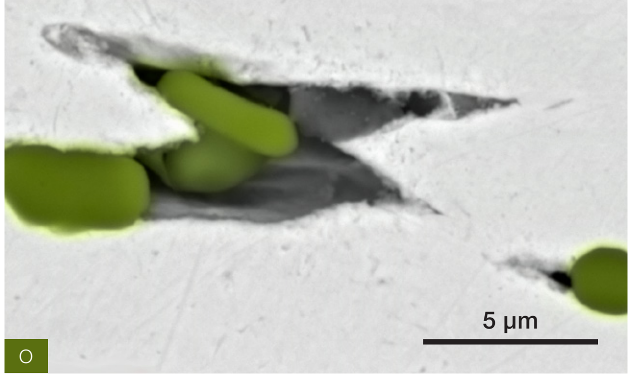
### Challenge

Steel automotive parts rely on protective coatings to prevent corrosion and ensure long-term durability, especially under harsh operating conditions. These coatings typically include layers like electrogalvanized zinc, phosphate treatments, and primer coatings. When defects such as peeling or flaking occur, they can signal deeper issues with material processing or surface treatment.

### Solution

Scanning electron microscopy and X-ray photoelectron spectroscopy can help you quickly identify the root causes of coating failures, such as contamination or insufficient adhesion, providing a way to improve coating performance across production batches.

Learn more




Higher-magnification view of inclusions in a stringer and overlay showing O distribution.

## Bend failure mechanism of high-strength steel

### Challenge

High-strength low-alloy (HSLA) steels are designed to combine strength with ductility, making them suitable for applications that require bending and forming. Despite this ductility, bend tests during quality control occasionally reveal fractures.

### Solution

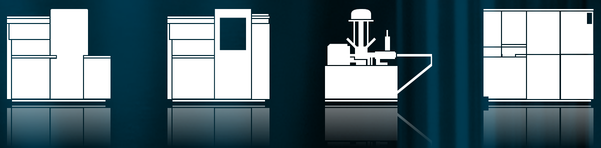
Performing particle analysis with a combination of scanning electron microscopy and real-time energy-dispersive X-ray spectroscopy can uncover the cause of the observed failures, facilitating targeted improvements in the steel production process to prevent similar issues in the future. In the study linked below, this analysis uncovered a subsurface inclusion stringer composed primarily of aluminum oxide, with traces of magnesium and calcium. These inclusions, likely introduced during steelmaking and elongated during hot rolling, acted as stress concentrators and led to the observed failure.

Learn more

# Thermo Scientific EM and XPS instruments

Thermo Scientific EM and XPS instruments are designed to meet the unique requirements of automotive manufacturers and suppliers, with tailored configurations that optimize performance for specific production needs. From enhancing quality control in research and development to helping you ensure precision in mass production, our flexible instruments integrate seamlessly into each stage of the manufacturing process.

Learn more about EM



Learn more about XPS

# How can we help?

## NanoPorts

The teams at our four NanoPorts around the world provide tailored solutions for your applications and on-site or remote demonstrations, plus they act as research collaboration centers. The NanoPorts also help R&D, factory, and field service teams provide optimized outcomes and improved solutions.

Learn more

## Global service logistics and field service assistance

We maintain an extensive network of central warehouses, regional hubs, and local stock locations to fulfill your needs more quickly. From installation services to on-site and remote maintenance agreements, our team of experts is here to support you at every step.

Learn more

## Application support

After your system is installed, our team of applications experts can help you quickly get up to speed. From training and documentation to troubleshooting and more, we're with you every step of the way to help your research succeed.

Learn more

# About Thermo Fisher Scientific

We are the world leader in serving science. Our Mission is to enable our customers to make the world healthier, cleaner and safer.

**Learn about the mission of Thermo Fisher Scientific. Duration 1:23.**

Our innovative solutions for electron microscopy, surface analysis, and microanalysis help materials science researchers advance their sample characterization to gain deeper insight into the physical and chemical properties of materials from the macroscale to the nanoscale. Our multiscale, multimodal solutions cover a broad range of applications across dozens of industries and research fields, serving customers in academia, government, and industry. Our TEMs, DualBeam™ FIB-SEMs, comprehensive portfolio of SEMs, XPS, and microanalysis solutions, combined with software suites, take customers from questions to usable data by combining high-resolution imaging with physical, chemical, elemental, mechanical, and electrical analysis across scales and modes.

## Financial and Leasing Services

At Thermo Fisher Scientific, we will not let budgetary constraints stand between you and your next great discovery.

We are your one-stop partner for the best laboratory products and analytical technologies available, plus the unique financing options you need to accelerate success in science or industry.

Cost-effective financing designed for each individual customer is key to any successful capital equipment solution.

We understand not just your advanced technology and application requirements, but the business challenges you face when financing your critical equipment assets. For decades, we have worked closely with businesses, hospitals, universities, and municipalities to provide flexible financing terms to support their successful operations.

If you are looking for off–balance sheet financing, accelerated ROI, technology protection, or cash flow management, our innovative financing options can help meet your company's budgetary needs and bottom-line goals.

**Explore equipment leasing and financing options**

We also offer instrument maintenance and training services.

Learn more at **thermofisher.com/em-materials-science**

thermo scientific