Accelerating Sustainable Battery Manufacturing with Confidence

Powering purity in battery elemental testing

As demand for lithium-ion batteries surges across electric vehicles, renewable energy storage, and mobile technologies—quality and sustainability have never been more critical. Trace elemental impurities—even at parts-per-billion levels—can compromise performance, shorten battery life, and introduce serious safety risks.

Agilent's ICP-OES solutions empower laboratories at every stage of the battery value chain:

- The **Agilent 5800 VDV ICP-OES** with IntelliQuant Screening and fitted background correction (FBC) identifies unknowns and mitigates spectral overlaps—from lithium brines to black mass recycling.
- **Single-vendor automation**, integrating the AVS 6/7 switching valve and ADS 2 reduces carryover, eliminates manual errors, and maximizes productivity in high-throughput environments.
- Specialized **sample introduction supplies** like the V-groove nebulizer, which can handle challenging samples up to 30% total dissolved solids (TDS)—eliminating filtration steps across aggressive acids and high-matrix materials aggressive acids and high-matrix materials.

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Overview

As the global shift towards clean energy and electric mobility accelerates, the demand for lithium-ion batteries (LIBs) is rising rapidly—from electric vehicles and energy storage systems to mobile devices and industrial tools. Meeting this demand requires both expanded production capacity and strict quality assurance. High-purity materials and tight process control are essential to maximize battery performance, ensure safety, and minimize environmental impact.

Elemental impurities—even at trace levels—can affect electrochemical behavior, shorten battery life, and introduce safety risks such as thermal runaway. Elemental analysis, particularly using inductively coupled plasma optical emission spectroscopy (ICP-OES), is critical throughout battery production and recycling. Offering simultaneous multi-element detection, wide dynamic range, and fast throughput, ICP-OES is ideal for routine high-volume sample testing.

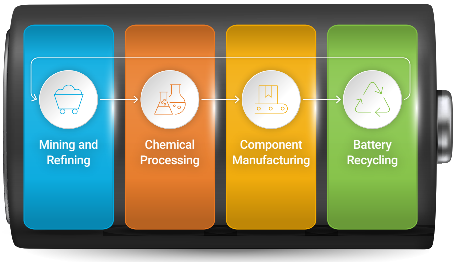

Figure 1. The four key stages in the battery value chain—mining and refining, chemical processing, component manufacturing, and battery recycling.

From mining, refining, and chemical processing to component manufacturing, and battery recycling, Agilent ICP-OES solutions are trusted by laboratories worldwide to deliver accurate, reproducible results in even the most complex matrices. These matrices include high concentrations of lithium salts, fluoride-containing compounds, and organic solvents typical of battery materials. To address these challenges, the Agilent 5800 Vertical Dual Mode (VDV) ICP-OES has advanced features that improve confidence, reduce downtime, streamline method development and increase productivity:

- The 5800 VDV ICP-OES, offers flexibility between viewing modes to avoid interferences, enhancing the sensitivity and the linear dynamic measurement range
- Fitted background correction (FBC) automatically handles sloping baselines and complex spectral backgrounds for cleaner signal interpretation
- IntelliQuant Screening provides real-time heat maps and semiquantitative scans, helping users identify unknowns, streamline method development, and avoid spectral interferences.
- The Neb Alert system delivers early warnings of nebulizer clogs or leaks, helping to protect instrument uptime and data integrity in high-throughput environments.
- Early Maintenance Feedback (EMF), utilizes over 100 sensors that monitor and track instrument health, alerting the analyst when maintenance is needed, overcoming common reasons for service calls, reducing expense and wasted time.

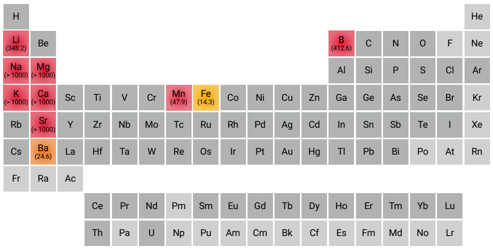

Figure 2. IntelliQuant periodic table heatmap. The information helps with selection of the best analyte wavelengths to use in the quantitative method for the analysis

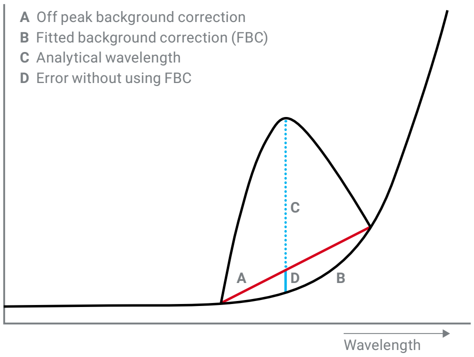

Figure 3. Fitted background correction calculates the true background signal, improving accuracy.

Beyond the technology, Agilent brings deep application knowledge and ongoing collaboration with leading battery manufacturers, research institutions, and recyclers. This teamwork ensures that our solutions evolve alongside the industry—supporting emerging chemistries, stricter purity requirements, and sustainability goals.

Whether verifying cathode stoichiometry, ensuring electrolyte cleanliness, or supporting efficient materials recovery during recycling, Agilent's elemental analysis solutions empower battery innovators to move faster, reduce waste, and maintain quality from mine to module.

Key Resources:

A Practical Guide To Elemental Analysis of Lithium Ion Battery Materials
Agilent Solutions for the Lithium-Ion Battery Industry
Battery Analysis by ICP-OES
Elemental Analysis of Lithium Ion Batteries

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Mining and Refining

The first stage in the lithium-ion battery (LIB) value chain is the extraction and refining of raw materials such as lithium (Li), nickel (Ni), cobalt (Co), manganese (Mn), and copper (Cu). These elements are fundamental to battery chemistries, especially for cathode formulations like nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP). As global production capacity expands to meet the surge in demand for electric vehicles and renewable energy storage, so does the need for reliable, high-purity sources of these critical materials. Extracting them efficiently and refining them to battery-grade standards requires robust analytical tools that can keep pace with process complexity and production scale.

Lithium is primarily sourced from two feedstocks–hard rock (spodumene) and lithium-rich brines. Brine extraction, particularly through direct lithium extraction (DLE) techniques, is becoming increasingly popular for its efficiency and reduced environmental impact. However, brine matrices present unique analytical challenges due to the presence of interfering elements such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), boron (B), and silicon (Si). These elements, along with residual impurities from leaching and concentration steps, must be tightly monitored to ensure optimal recovery and downstream processing.

Figure 4. Salt flat with evaporite formations, a common source of lithium-rich brines used in battery raw material extraction

The Agilent 5800 VDV ICP-OES is engineered to meet the demands of this upstream environment. High-matrix-tolerant sample introduction systems and corrosion-resistant components provide durability and reliable performance, even with aggressive or high-solid-content samples. The VistaChip III detector allows for simultaneous detection of both high-concentration target elements like lithium and low-level contaminants such as arsenic (As), cadmium (Cd), and lead (Pb) in a single analytical run. Paired with IntelliQuant Screening and FBC, labs can quickly identify unknowns, mitigate spectral overlaps, and ensure method accuracy without excessive rework.

Figure 5. The Agilent ICP-OES automation system: Agilent 5800 VDV ICP-OES with integrated AVS 7 switching valve (left), Agilent Advanced Dilution System ADS 2 (middle), and Agilent SPS 4 autosampler (right).

In lithium brine operations, reducing sample-to-sample carryover and minimizing analysis time are essential for throughput. Agilent addresses these needs with the Advanced Valve System (AVS 6/7), which provides short rinse times and enables precise, repeatable analysis while maximizing productivity. To further streamline workflows, the Agilent Advanced Dilution System (ADS 2) automates calibration and sample dilutions—eliminating manual preparation, reducing dilution errors, and improving analytical results across high-matrix brine samples. These capabilities are especially valuable in DLE workflows, where fast, reliable elemental data is critical for real-time process optimization.

Beyond analyzing raw materials, ICP-OES is used extensively for monitoring metal recovery rates during leaching and refining. Tracking key performance indicators—such as lithium recovery efficiency, contaminant removal, and reagent consumption—enables process engineers to fine-tune operations for greater yield and lower environmental impact.

As global environmental and regulatory standards become more stringent, accurate elemental analysis plays a vital role in ensuring compliance. Wastewater generated from extraction and refining must be characterized before discharge, and solid residues often require elemental certification before they can be disposed of, reused, or sold. Agilent's solutions help mining and refining operations meet these obligations confidently, while also supporting broader environmental, social, and governance (ESG) commitments.

Key Resources:

[Elements in Brines Produced by Direct Lithium Extraction (DLE)]

[Elemental Analysis of Brine Samples used for Lithium Extraction]

[Determination of Elemental Impurities in Lithium Hydroxide Using ICP-OES]

[Determination of Multiple Elements in Lithium Salts using Autodilution]

Click here to find out more

Chemical Processing

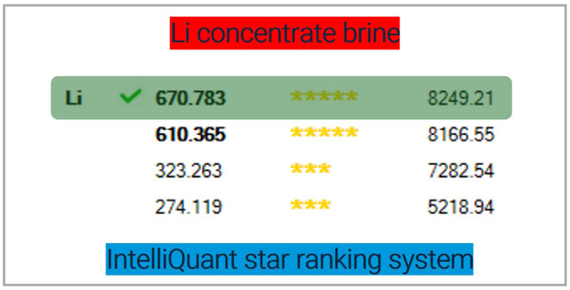
After refining, battery-grade metals such as lithium (Li), nickel (Ni), cobalt (Co), and manganese (Mn) are converted into high-purity chemical compounds essential for electrode production. These compounds include lithium carbonate (Li_2CO_3), lithium hydroxide (LiOH), lithium chloride (LiCl), nickel sulfate, and cobalt sulfate—critical precursors for cathode materials like NMC (nickel manganese cobalt oxide) and LFP (lithium iron phosphate). For anodes, purified graphite and silicon-carbon composites are engineered to meet strict purity and particle-size requirements, supporting high-capacity retention and cycling stability.

At this stage, the precise stoichiometry of cathode materials is established. Deviations in Ni:Mn:Co ratios, for example, can affect electrochemical performance and battery longevity. ICP-OES is widely used to monitor these ratios in real time, enabling prompt adjustments to maintain batch consistency.

The Agilent 5800 VDV ICP-OES is robust to meet the demands of chemical processing. Samples often contain aggressive acids like hydrochloric or hydrofluoric acid, organic binders, and high total dissolved solids (TDS) — all of which can interfere with analysis or damage sample introduction components. Agilent mitigates these risks with specialized lithium-ion battery sample introduction kits including recommended torch, spray chamber, nebulizer, peri-pump tubing, and sample tubes, ensuring a reliable and efficient system for analysis.

Figure 6. Lithium-ion battery sample introduction kits suitable for Agilent 5000 series ICP-OES instruments. The kit includes the recommended torch, spray chamber, nebulizer, peri-pump tubing, and sample tubes.

Controlling trace elemental impurities in processing samples is equally critical. Low levels of sulfur (S), phosphorus (P), iron (Fe), aluminum (Al), sodium (Na), calcium (Ca), copper (Cu), and zinc (Zn) can interfere with crystal growth or trigger unwanted reactions. Agilent's IntelliQuant Screening accelerates impurity detection by identifying unknown elements and recommending optimal wavelengths—streamlining method setup and reducing rework.



Li concentrate brine

Li	✓	670.783	*****	8249.21
		610.365	*****	8166.55
		323.263	***	7282.54
		274.119	***	5218.94

IntelliQuant star ranking system

Figure 7. IntelliQuant star rating system for Li showing 670.783 received a five star rating.

Beyond precursor analysis, ICP-OES is vital for monitoring the purity of process reagents—such as acids, rinse water, and solvents. Cross-contamination from equipment or incoming raw materials can introduce transition metals or halides that affect product quality. ICP-OES supports in-process control with short analysis times, high sensitivity, and integration-ready automation features.

As production scales up, continuous monitoring becomes essential. Agilent ICP-OES instruments are optimized for 24/7 workflows and real-time decision-making, helping manufacturers improve yield, reduce downtime, and meet the demanding purity requirements of today's lithium-ion batteries.

Key Resources:

Determination of Multiple Elements in Lithium Salts using Autodilution

Determination of Elemental Impurities in Silicon-Carbon Anode Materials

Determination of Elemental Impurities in Graphite-based Anodes

Determination of Elemental Impurities in Lithium Carbonate Using ICP-OES

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Component Manufacturing

Component manufacturing and cell assembly represent the most intricate and quality-sensitive stages in the lithium-ion battery value chain. At this point, purified materials—including cathodes, anodes, electrolytes, separators, and current collectors, are integrated into complete battery cells. Even the smallest trace contaminants—often at the parts-per-billion level—can impact battery performance, thermal stability, and overall safety.

ICP-OES plays an essential role in ensuring that all components entering the assembly process meet strict purity and compositional standards. One of the most critical applications is the verification of the purity of lithium salts used in electrolytes, such as lithium hexafluorophosphate ($LiPF_6$). Trace impurities, particularly transition metals like iron (Fe), copper (Cu), and zinc (Zn), can act as catalysts for unwanted reactions, leading to electrolyte decomposition, gas formation, or thermal runaway —compromising battery performance and safety. Electrolyte solvents—commonly ethylene carbonate (EC), dimethyl carbonate (DMC), and diethyl carbonate (DEC), must also be screened for metal contaminants. These solvents are typically stored and transferred through metal pipes and containers, which can introduce trace levels of corrosion products. ICP-OES ensures that these potential impurities are identified and quantified before solvents are introduced into production lines.

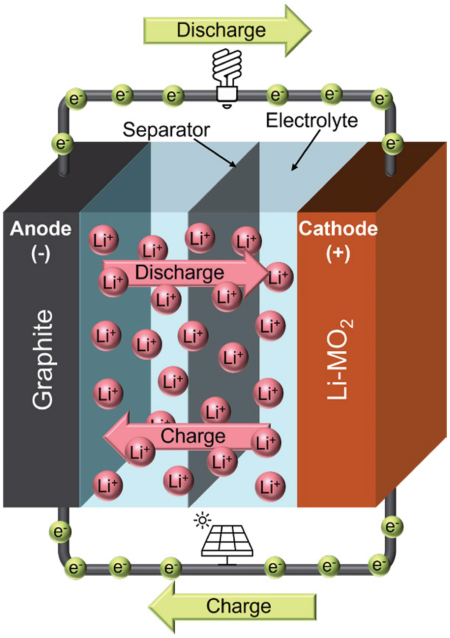

Figure 8. Lithium-ion battery schematic.

Similarly, separators (polyethylene or ceramic-coated films) and electrode coatings must be tested for surface contamination. Manufacturing equipment, human handling, and ambient environmental exposure can all contribute to particulate contamination. Surface leaching followed by ICP-OES analysis allows quality teams to assess cleanliness and take corrective measures if contamination thresholds are exceeded.

Dry rooms used in battery assembly require constant environmental monitoring to ensure airborne metal particulates or volatile compounds do not enter the cells during assembly. Air filter sampling and surface wipe tests analyzed by ICP-OES provide valuable feedback for maintaining ISO-classified cleanroom environments.

In a production environment where precision and speed are non-negotiable, ICP-OES gives manufacturers the insight needed to identify risks early, ensure product uniformity, and meet the increasingly strict purity standards required for next generation lithium-ion batteries.

Figure 9. Battery assembly production line.

Key Resources:

Rapid Analysis of Elemental Impurities in Battery Electrolyte by ICP-OES
Elemental Impurities in Lithium Iron Phosphate Cathode Materials
Elements in Ternary Material Nickel-Cobalt-Manganese Hydride
Elemental Impurities in Silicon-Carbon Anode Materials

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Battery Recycling

As global adoption of lithium-ion batteries accelerates, so does the need for effective end-of-life recycling solutions. Recycling recovers valuable metals—such as lithium (Li), cobalt (Co), nickel (Ni), and copper (Cu)—while reducing environmental risk and dependence on primary resources. With growing regulatory pressure and material demand, battery recycling is now a strategic priority for both industry and governments.

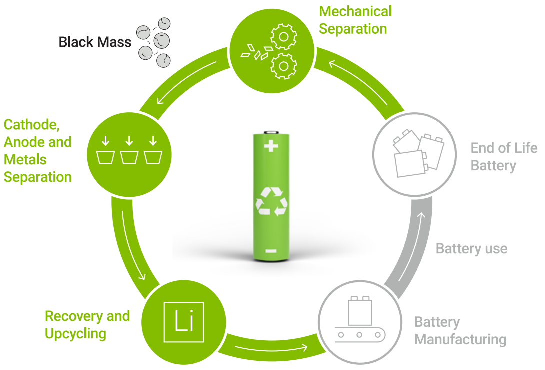

Figure 10. Lithium-ion battery recycling infographic highlighting the main stages of the battery recycling process.

A key step in modern recycling is the analysis of black mass—a complex, powdered material produced by shredding spent batteries. It contains cathode and anode particles, binders, electrolyte residues, and conductive additives. Because battery chemistries (for example, NMC and LFP) and degradation states vary, accurate elemental analysis is essential.

ICP-OES plays a central role in quantifying black mass composition, including lithium (Li), nickel (Ni), cobalt (Co), manganese (Mn), copper (Cu), and impurities like iron (Fe), aluminum (Al), calcium (Ca), and silicon (Si). This data supports process decisions and helps estimate recovery value.

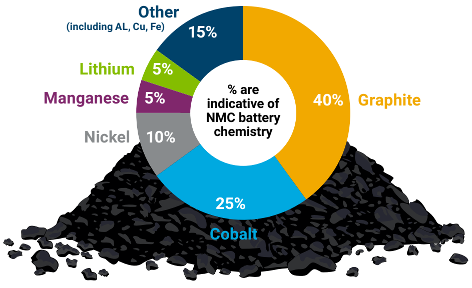

Figure 11. Black mass contains a mixture of valuable metals essential for manufacturing new batteries.

In pyrometallurgical workflows, black mass is heated to extract metals as alloys or oxides. ICP-OES monitors melt and slag compositions to ensure efficient recovery and control impurities. In hydrometallurgical recycling, acid leaching, and solvent extraction are used to isolate battery-grade compounds. ICP-OES enables multi-element analysis across key process streams—leachates, eluates, and residues—to optimize separation and control.

Following recovery and purification, the resulting materials—such as lithium carbonate or nickel sulfate—must meet strict specifications to be reused as battery metal feedstock for new batteries. ICP-OES is critical at this stage for verifying purity and regulatory compliance.

The Agilent 5800 VDV ICP-OES is optimized for this type of complex analysis. Features like IntelliQuant Screening, short rinse times, robust plasma stability, and the optional Advanced Dilution System (ADS 2) and AVS 6/7 switching value allow for high-throughput, accurate analysis in even the most demanding recycling environments. The Agilent inert V-groove nebulizer further enhances performance by allowing routine analysis of unfiltered acid-digested black mass samples with up to 30% TDS and suspended particles as large as 350 µm. Its clog-resistant design eliminates the need for filtration, reduces sample preparation time, and ensures consistent performance across challenging matrices.

In addition to material characterization, recycling facilities must also address environmental and workplace safety. ICP-OES supports compliance with regulations like RoHS, REACH, and WEEE by measuring toxic metals such as lead (Pb), arsenic (As), and cadmium (Cd) in wastewater, solid residues, and stack emissions. It is also used to monitor air filters and surface swabs for metal particulates generated during processing—critical for maintaining safe and compliant working conditions.

By enabling accurate, efficient, and scalable elemental analysis, the 5800 VDV ICP-OES system empowers recyclers to recover high-purity battery metal feedstock, minimize waste, and support the circular economy. As recycling practices evolve, Agilent remains at the forefront with hardware, software, and application expertise that drives cleaner, smarter battery manufacturing.

Key Resources:

Determination of Metals in Recycled Li-ion Battery Samples by ICP-OES
Elemental Analysis of Lithium-Ion Battery Black Mass Recycling Material
Elemental Analysis of Intermediate Feedstock Chemicals for Li-Ion Batteries
Sustainable Battery Recycling: Recovery of Metals in Green Solvents
Workplace Air Monitoring: Multi-Element Analysis of Air-Filters using ICP-OES
Analysis of Waste Samples According to US EPA Method 6010D
Enhanced RoHS Compliance Testing with Agilent 5800 ICP-OES

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