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Trusted Answers

Powering the Future: A Buyer's Guide to Elemental Analysis Instrumentation for Unearthing Battery Minerals

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Introduction

Over the past decade, there has been unprecedented growth in the lithium-ion battery market, primarily driven by an increased demand for electric vehicles (EVs) and renewable energy storage. This exponential growth has subsequently led to a surge in the demand for lithium, cobalt, and other elements used in the production of these batteries. As we navigate through a world increasingly reliant on sustainable energy sources, it's crucial to consider the evolving landscape of lithium production and the potential challenges that lie ahead.

The rising demand for lithium and other elements

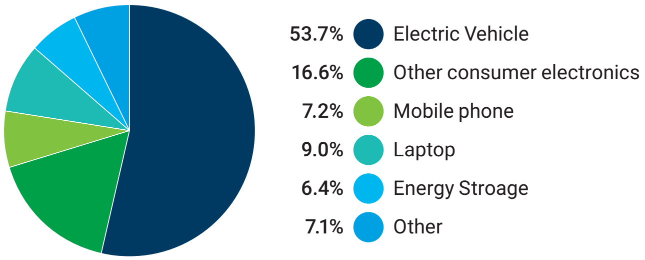
Lithium, cobalt, nickel, and manganese are among the key elements required to produce lithium-ion batteries. Among these, lithium and cobalt have drawn the most attention due to their crucial role in battery efficiency and energy density.

Global Li battery Market Size (B$)

The global lithium ion battery market is growing rapidly and is forecast to reach USD94.4 billion by 2025 (Source: ASKCI, Markets and Markets).

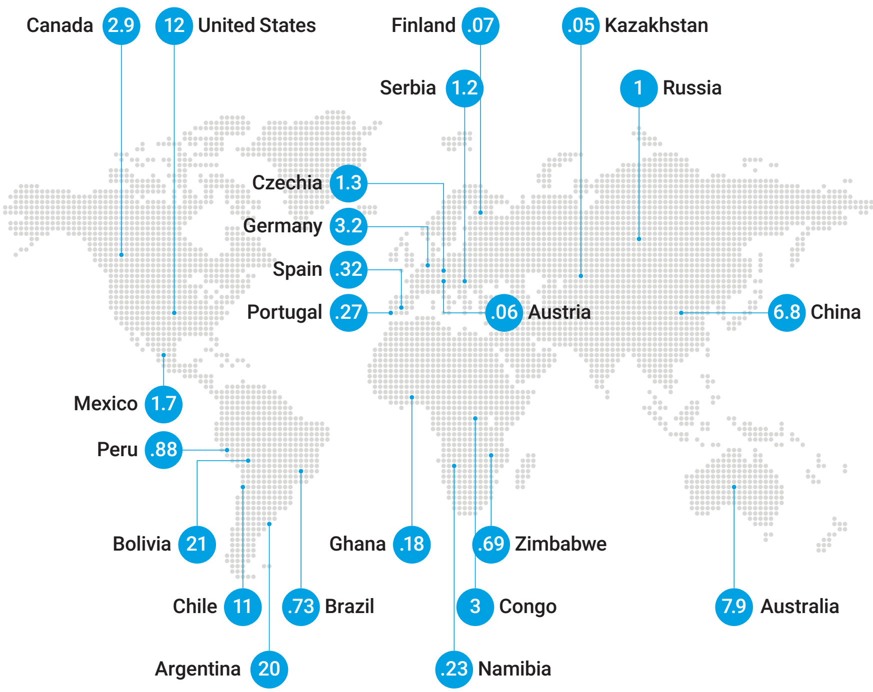
Lithium production has been scaling up to meet this demand. As of 2021, worldwide production of lithium was about 82,000 metric tons. However, experts suggest that to keep pace with the expected demand from the EV and renewable energy sectors, lithium production will need to increase significantly. Some projections suggest that the world will need over 1.3 million metric tons of lithium per year by 2030, which represents an almost 16-fold increase in less than a decade.

End market of global Li battery in 2020



The electrification of vehicles is driving the growth in the lithium battery industry (Source: CCID).

This growing demand has led to an increase in lithium mining activities, particularly in countries like Australia, Chile, USA, Bolivia, and Argentina, which hold the majority of the world's lithium reserves. However, ramping up production to the necessary levels will be a significant challenge, requiring substantial investment and potentially leading to environmental concerns.



Known lithium reserves (millions of tons) in 2023 (Source: U.S. Geological Survey, Mineral Commodity Summaries, January 2023).

Cobalt, another crucial element in lithium-ion batteries, is facing similar challenges. Around 60% of the world's cobalt supply comes from the Democratic Republic of Congo, a country with a concerning record on human rights and environmental issues. As demand for lithium-ion batteries continues to grow, so does the pressure on these cobalt-rich regions.

The exploration of mineral resources is a critical component of the mining industry. The focus of exploration is not only to locate a resource but also to quantify its economic potential. The discovery of mineral deposits such as spodumene (Li), cobaltite (Co), limonite (Ni), and pyrolusite (Mn) is guided by a rigorous process of data collection, analysis, and interpretation. In this respect, analytical measurements are crucial to this endeavour. They provide comprehensive data regarding the presence, concentration, and distribution of these minerals in a given geological formation.

Sources of Battery Minerals

As the global demand for batteries continues to soar, mining exploration companies are intensifying efforts to uncover new sources of lithium, manganese, nickel, cobalt as well as other electrification minerals.
Accurate and reliable analytical measurements are integral to these exploration efforts. These measurements not only identify potential deposits, but also inform feasibility studies and ensure that the exploitation of such resources is economically viable and environmentally responsible.

Lithium sources and exploration

Lithium, the lightest metal and least dense solid element, is often extracted from two main sources: hard-rock mining (primarily from spodumene) and lithium brine deposits. The majority of the global lithium production, greater than 60%, is produced from brines while lithium ores account for the remaining production (Ebensperger et al., 2005). Each source presents unique challenges and requires specific analytical methods for effective exploration.

Hard rock lithium exploration

When exploring for lithium in hard rock formations, geochemical surveys are conducted using surface and subsurface rock samples. These samples are evaluated using a combination of techniques including X-ray fluorescence (XRF), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), and Atomic Absorption Spectroscopy (AAS).

- XRF is a non-destructive technique used to determine the elemental composition of materials. It provides a reliable analysis of major and trace elements, not including lithium.
- AAS is a technique that measures the concentrations of specific elements by analyzing the absorption of light. It is instrumental in lithium exploration as it provides highly sensitive and selective measurements.
- ICP-OES is more sensitive than XRF and AAS and is used when speed and precision is required, particularly in detecting trace elements. The technique uses a plasma to excite the sample, producing light emissions at discrete wavelengths, which are used to determine the elemental composition of the sample.
- ICP-MS is the most sensitive of the analytical techniques, being able to measure elements at parts-per-trillion levels. It uses a high-energy plasma source to ionize atoms from the sample, which are then separated and quantified based on their mass-to-charge ratio.

Lithium brine exploration

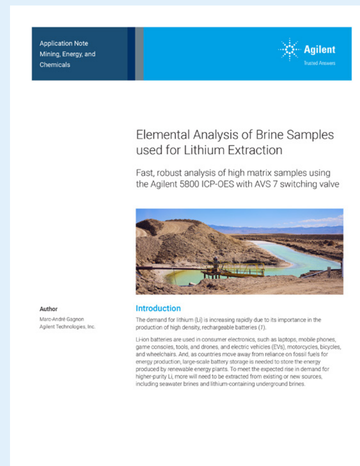
Lithium brines are found in salt pans and playas, often at high altitudes or in arid environments. The composition of these brines can vary significantly, making their analysis complex.

Most exploration companies will use a combination of geophysical methods to detect brine deposits, such as seismic, magnetic, and gravity surveys. These techniques can provide a detailed understanding of the subsurface, helping to pinpoint the location and extent of lithium-bearing brines.

Once potential deposits are located, samples are collected and analyzed using techniques such as Flame AAS, ICP-OES, ICP-MS and Ion Chromatography (IC). IC, in particular, is used to analyze anions and cations in the brine, providing a comprehensive chemical profile that includes lithium concentration.

Other elements used in batteries

Nickel, cobalt, and manganese are also crucial to battery performance, longevity, and energy density. Exploration for these critical elements typically requires the analysis of rock, soil or sediment samples using flame AAS, ICP-OES or ICP-MS. These 3 techniques can detect and quantify these battery-critical elements, as well as identifying other elements present in the samples.



Download this application note which details the method used and typical results for the analysis of lithium in brine samples.

Testing Needs at Mines

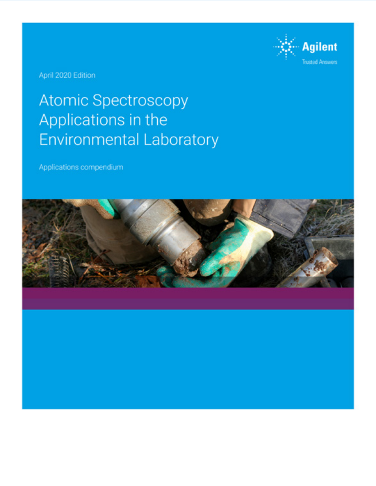
Mineralogy and metallurgical testing

Once lithium is detected, further testing is needed to determine the extractability of the lithium. Techniques like X-ray diffraction (XRD) are used to identify the specific lithium-bearing minerals present. For example, spodumene might be present in hard-rock deposits, while various lithium salts may be present in brines.

The next step is to conduct metallurgical testing to establish how easily lithium can be extracted and processed from the ore. Various techniques such as flotation, roasting, and hydrometallurgical methods are evaluated to understand the most efficient method for lithium extraction.

Environmental monitoring

As part of responsible resource development, mining exploration companies also need to conduct environmental assessments. These analyses examine potential impacts on air, water, and soil quality, as well as the local biodiversity. Techniques such as ICP-MS, ICP-OES, FAAS, gas chromatography-mass spectrometry (GC-MS), and various microbiological assays may be used in this context.



Download this applications compendium listing methods for a wide range of environmental tests, from drinking water to soils, sludges, and air filters.

Sampling Techniques

A crucial step for successful mining ventures is the collection and subsequent elemental analysis of geological samples. These exploratory endeavors seek to discover, define, and eventually extract valuable mineral resources hidden beneath the Earth's surface. The processes of sample collection, preparation, and elemental analysis are methodically conducted to ensure accurate representation of a mineral deposit's potential value. Let's delve into this intricate process to better understand its importance in the mining exploration industry.

Sampling collection

Mining companies use various sampling techniques, each suited to different terrains, minerals, and stages of exploration. The type of sample collected typically depends on the geological setting, target mineral(s), and exploration phase. Examples of sample types include rock chip and grab samples, soil samples, drill core samples, and bulk samples.

- Rock chip and grab samples involve the collection of small pieces of rock from the surface or slightly below.
- Soil samples are taken from the uppermost layer of the Earth's crust.
- Drill core samples are obtained through drilling into the Earth to collect cylindrical sections of rock, offering a view of the layers beneath the surface.
- Lastly, bulk samples are large samples, often several tons, collected to evaluate the feasibility of an ore deposit for mining.

Sample preparation

Samples undergo rigorous preparation before being sent for elemental analysis. The objective of this phase is to produce a homogeneous sample that is representative of the initial material.

Samples are logged, catalogued, and carefully packaged to avoid any contamination or alteration during transit. For solid samples, such as rock chips or drill cores, they are typically crushed to a fine powder in a process known as pulverization. This allows for a more representative sample for subsequent testing. Soil and sediment samples, on the other hand, may be dried and sieved to achieve a uniform particle size.

Elemental Analysis to Support Exploration and Mining Operations

With mine sites often being in remote locations, setting up and running an onsite laboratory has many challenges, including:

- Accessing utilities such as water, gases, and electricity
- Obtaining and storing chemicals and consumables
- Finding suitably qualified and experienced lab technicians willing to work at remote sites
- Accessing technical support, parts and supplies for instrumentation
- Selecting instrumentation that will be suited to temperature extremes and dusty environments, or providing air conditioning to control the climate in the lab
- Disposal of chemical waste
- Providing a safe working environment

Tips for selecting instrumentation for a mine site

With elemental analysis often being a critical part of a mine's workflow, having onsite analysis capabilities reduces the time it takes to get the results needed to make decisions. When selecting elemental analysis instrumentation, consider the following:

- How much electricity and gas is used to measure each sample? Selecting an instrument that measures samples quickly will reduce the consumption of both electricity and expensive gases, such as argon. There may be optional accessories, such as a switching valve, available that also helps in this area.
- How fast is the measurement? Exploration samples might number hundreds per day, with a lower number of samples likely during mining operations. You'll need the match the instrument's throughput capabilities with the number of samples you'll have each day.
- What is the lead time on consumables? Consider the stock you need to have on hand to reduce any instrument downtime due to shipping delays.
- If the mine location is remote, will you need a backup instrument in case of failure?

- Where is the nearest service centre? Do they offer video-based technical support? If a technician is required to come onsite, how long will it take and how much will it cost for them to visit? Are others in your region happy with the service provided by the vendor?
- How easy is the instrument to use? With the right instructions in place would it be possible for someone without experience to operate the instrument without help? Does the vendor supply standard operating procedures or video-based help to guide an operator?
- Will you have to air condition the lab and/or install air filtration systems to keep dust out of the lab? Some instruments have their own dust filters and can cope with dirty environments.
- Flame atomic absorption spectrometers (FAAS) have an open flame, so cannot be left unattended.
- Exhaust vapours will need to be extracted from the room and flammable chemicals stored safely.
- What analyses will the instrument be used for? If you want to cover a range of applications – from mining samples to environmental samples to trace impurity analysis after mineral processing, ensure the detection limits of the instrument are suitable for all applications. It might be preferable to do the higher concentration analyses onsite and send the trace-level testing to a specialist lab, where the testing can be done in a more controlled environment.

Agilent instrumentation for exploration and mining

Instrument	Applications	Notes
Flame Atomic Absorption Spectrometer 	Quantifying ~60 elements in exploration or mined samples	FAAS instruments are relatively low cost to purchase and are ideal for measuring lithium concentrations in 100-200 samples per day. The technique is long established and simple to use. It cannot be left unattended and requires a supply of acetylene gas. The Agilent FAAS instruments were designed for the mining industry and have a large installed base. The instruments have no cooling fan to suck in acid vapor and components are protected from dust. PROMT mode, available on Agilent FAAS instruments, increases sample throughput by allowing the operator to select the result precision for each element in a sample, perfectly achieving desired precision whilst simultaneously speeding up sample throughput. The Agilent SIPS accessory automates calibration, sample dilution, standard preparation, sample spiking, standard addition calibrations, and the addition of ionization suppressants.
Inductively Coupled Plasma Optical Emission Spectrometer 	Quantifying ~70 elements in over 2000 exploration or mined samples-per day elements at ppm to % levels Quantifying the elements present at each stage of ore beneficiation Determining what is present in the gangue material that could be of commercial value Monitoring discharges to the environment	ICP-OES instruments are ideal for labs with heavy workloads. An ICP-OES instrument can measure more than 70 elements at 10 ppb to % levels in up to 2500 samples per day. The instrument can be left unattended, so can operate 24/7 with the use of an autosampler. Argon gas is required for operation. The Agilent ICP-OES instruments have several features that make them ideal for mine sites or centralized mining labs: – Speed and built-in intelligence: Fast sample-to sample measurement time increases the number of samples you can measure in a day and reduces the cost of gas and power per sample. The instruments can check their own health and have smart algorithms to remove the need for highly experienced operators. – Intelliquant: this function can be used to screen samples – quickly identifying which elements are present and the approximate concentration of each. It can also help with selecting analytical wavelengths during method development and helps with troubleshooting problematic results. – Agilent ICP-OES instruments have a built in dust filter, making them ideal for mining labs. An integrated switching valve minimizes the exposure of instrument components (such as the plasma torch) to deleterious group 1 metals such as lithium, so they'll last longer. The switching valve also minimizes the volume of sample required for measurement, thus reducing laboratory waste. With the high level of dissolved solids in mining samples, the switching valve also reduces the frequency of cleaning of the sample introduction components that might otherwise be required.
Microwave Plasma Atomic Emission Spectrometer 	Determining what is present in the gangue material that could be of commercial value Monitoring discharges to the environment	MP-AES instruments are relatively low cost to both purchase and operate. The biggest benefit of the MP-AES for remote mine sites is the fact that they don't need special gases and can be left unattended. Only nitrogen gas is required, which can be extracted from the air. A switching value can be fitted. This minimizes the exposure of instrument components (such as the plasma torch) to corrosive group 1 metals such as lithium, so they'll last longer. The switching valve also minimizes the volume of sample required for measurement, thus reducing laboratory waste. With the high level of dissolved solids in mining samples, the switching valve also reduces the frequency of cleaning of the sample introduction components that might otherwise be required. The Agilent MP-AES features application-specific software applets, allowing operators of any experience level to simply walk up, click an icon to open the method and start the analysis. Even novice users can make accurate and reproducible measurements without training.
Inductively Coupled Plasma Mass Spectrometer 	Quantifying ~70 elements in over 1000 exploration or mined samples per day at <1 ppt to 1000 ppm levels Quantifying very low levels of elements present at each stage of ore beneficiation	ICP-MS instruments are ideal for measuring trace and ultratrace levels of elements in a central lab servicing the mining industry. Able to measure down to parts-per-trillion, these sensitive instruments are not suitable for dusty environments and require higher skilled operators. An ICP-MS instrument can measure >70 elements at <1 ppt to 1000 ppm levels in up to 1200 samples per day. The instrument can be left unattended, so can operate 24/7 with an autosampler. The Agilent ICP-MS instruments have several features that are prized by contract labs analyzing mining samples: – Low detection limits: Concentrations of high value elements, such as precious metals or rare earth elements can be measured down to parts-per-trillion. – Robustness: The ability to handle a wide range of samples, from high concentration process samples, immediately followed by low concentration samples. – Collision Reaction Cell: Removes the interferences common with this technique, allowing accurate measurements.

Agilent instrumentation for exploration and mining

Comparing the different techniques across a range of areas.

	FAAS View products	MP-AES View products	ICP-OES View products	ICP-MS View products
Battery elements that can be measured*	Li, Co, Ni, Mn, Mg, Al, Sn, Ta, V, and more	Li, Co, Ni, Mn, Mg, Al, Sn, Ta, V, and more	Li, Co, Ni, Mn, Mg, Al, Sn, Ta, V, and more	Li, Co, Ni, Mn, Mg, Al, Sn, Ta, V, and more
Relative Price	$	$ $	$ $ $	$ $ $ $
Relative Cost per sample	$ $	$	$ $	$ $ $
Relative Sensitivity	🔍🔍	🔍🔍	🔍🔍🔍	🔍🔍🔍🔍🔍
Reviews	SelectScience	SelectScience	SelectScience	SelectScience
Maximum samples per day[1]	100 to 200 (6 elements)	300 to 400 (10 elements)	2000 to 2500 (50+ elements)	1200 (50+ elements)
Dynamic range of measurement[2]	100 ppb to 1000 ppm	100 ppb to 1000 ppm	10 ppb to 10,000 ppm	<1 ppt to 1000 ppm
Relative sample volume required	💧💧💧	💧💧💧	💧💧	💧💧
Relative tolerance of solids in sample	🧪🧪	🧪	🧪🧪🧪🧪	🧪🧪🧪
Element measurement	Sequential	Sequential	Simultaneous	Simultaneous
How many elements can be measured?	67	70	74	86
Relative routine maintenance requirements	🔧	🔧	🔧🔧🔧	🔧🔧🔧🔧
Relative operator skill required	🎓	🎓	🎓🎓	🎓🎓🎓
Can be left unattended	✗	✓	✓	✓

** These elements are currently used for batteries. The instruments can measure many more.*

	FAAS View products	MP-AES View products	ICP-OES View products	ICP-MS View products
Specifications				
Relative operational power use	⚡	⚡ ⚡	⚡ ⚡	⚡ ⚡ ⚡
Dimensions (mm – width x depth x height)	790 x 580 x 590[3]	960 x 660 x 660	625 x 740 x 887	730 x 600 x 595
Weight	75 kg	73 kg	90 kg	100 kg
Gas requirements	Compressed air and 99.0% pure acetylene and/or 99.5% pure N_2O (depending on elements measured)	99.5% pure Nitrogen[4]	99.99% pure Argon Optional: Nitrogen, Oxygen	99.99% Argon 99.999% Helium
Exhaust venting requirements	2.5 m^3/min	2.5 m^3/min	2.5 m^3/min	5 to 7 m^3/min
Warranty[5]	12 months	12 months	12 months	12 months
Accessories				
Autosampler	Optional	Optional	Optional	Optional
Water cooling system	Not required	Not required	Required, not included	Required, not included

1. The ICP-OES and ICP-MS instruments must be fitted with a switching valve to achieve these sample numbers
2. Dynamic range of the instrument only, with no sample introduction devices that enhance sensitivity
3. Height depends on the model selected
4. The MP-AES requires only nitrogen, which can be extracted from ambient air by a nitrogen generator. Alternatively, a nitrogen cylinder or dewar can be used.
5. Agilent has various extended warranty and support options

How to choose the right atomic spectroscopy technique

This ebook describes how each technique works, which elements can be measured and which can't, how the techniques compare to each other and guidance on how to select the right instrument for your needs.

Download the ebook

Pre-prepared Methods

Agilent has a wealth of application notes that detail common analyses used in the mining industry. The application notes include details on sample preparation, instrument settings, method setup, and show typical results.

They include:

5994-6112EN	Determination of Elemental Impurities in Lithium Carbonate Using ICP-OES
5994-6011EN	Lithium content in pegmatite ores by FAAS
5994-5590EN	Determination of Elemental Impurities in Silicon-Carbon Anode Materials for Lithium-Ion Batteries by ICP-OES
5994-5341EN	Quantifying trace-levels of 64 elements in Lithium Ion Battery raw materials using ICP-MS/MS
5994-5149EN	Elemental Analysis of Brine Samples used for Lithium Extraction using ICP-OES
5994-4492EN	Analysis of Rare Earth Elements in Base Metal Ores by ICP-OES
5991-9340EN	Determination of Gold, Palladium, and Platinum in Noble Metal Ores Prepared by Fire Assay
5991-8120EN	Determination of metals in base metal ores using Agilent MP-AES
5991-7914EN	Analysis of Four Elements (Ca, Mg, Si, Sr) in Brine Using the Agilent 5100 ICP-OES
5991-7786EN	Determination of rare earth elements in geological samples using the Agilent SVDV ICP-OES
5991-7103EN	Rapid determination of gold in geological samples
5991-5932EN	Ultra-fast determination of base metals in geochemical samples using ICP-OES
5991-6406EN	Ultra-trace analysis of metals in mineral reference materials using ICP-MS
5994-1520EN	The Fastest and Smartest Way to Analyze Water Samples by ICP-OES
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5994-2307EN	Analysis of Soils, Sediments, and Sludges by ICP-OES per US EPA 6010D
5994-3906EN	Analysis of Environmental Waters by ICP-OES per Standard Method
5991-5921EN	High Throughput, Low Cost ICP-OES Analysis of Sludge Samples According to US EPA Method 6010C
5991-6239EN	Analysis of domestic sludge using the Agilent 4200 MP-AES

Related journal articles

V Balaram	Microwave plasma atomic emission spectrometery (MP-AES) and its applications – a critical review
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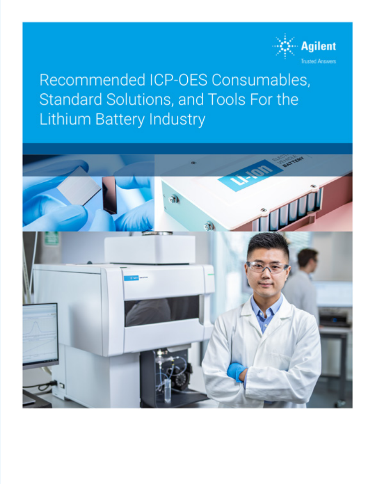
J Shehu	Investigation of the solid mineral deposits in Kano states Shhist belt using geochemical analysis

Recommended Accessories and Consumables

Whether in raw material testing or scientific research work, accurate and effective tolerance accessories are matched to the different needs of the sample introduction system to meet the durability and data quality requirements of different users. Agilent offers a supply of calibration solutions, instrument parts, and consumables suitable for the specific demands that elemental analysis of lithium-ion battery materials have. This includes lithium salt-tolerant sample introduction components and components that allow the direct analysis of organic samples containing hydrofluoric acid. Calibration solutions for the elements commonly used in batteries are also available.



Download the [Agilent guide] to consumables and tools for the lithium battery industry.

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