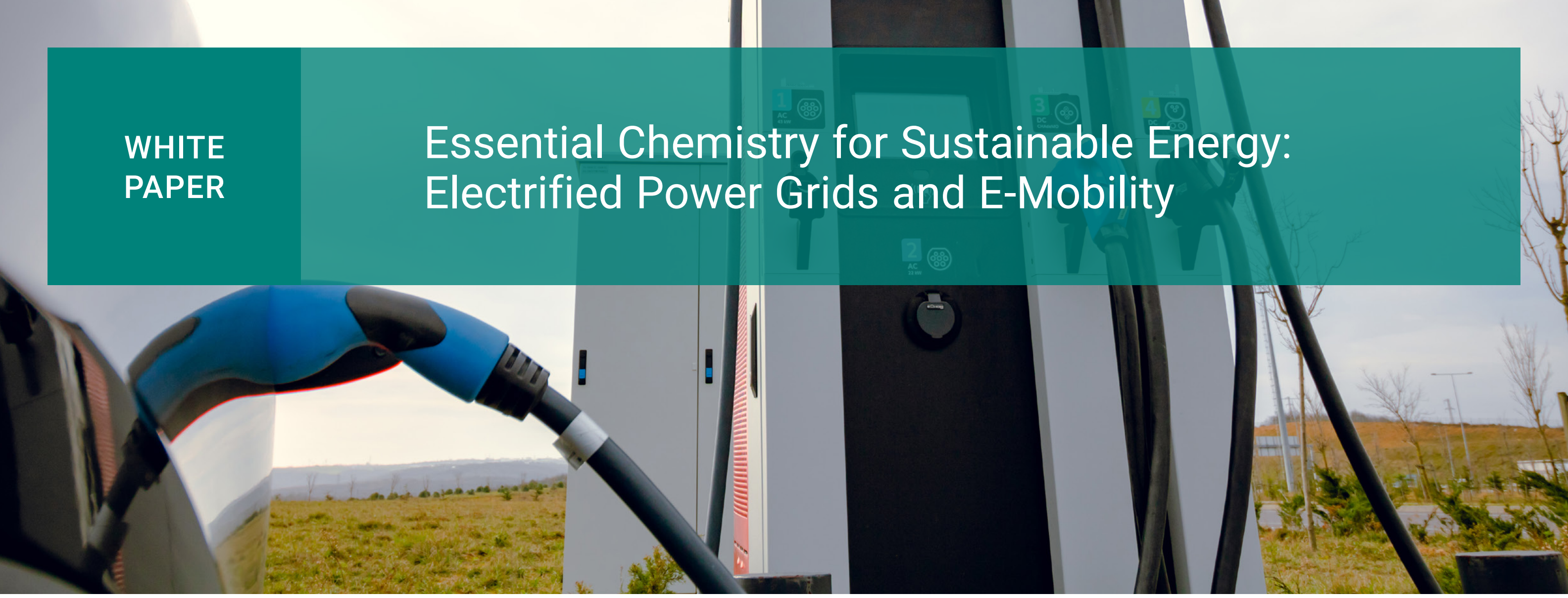
WHITE PAPER

Essential Chemistry for Sustainable Energy: Electrified Power Grids and E-Mobility



Introduction

Overall, coal and oil make up more than half of global energy sources. Natural gas contributes nearly another quarter.

Efforts continue worldwide to reduce carbon emissions with the goal of reaching net-zero by 2050. Fossil fuels are still the primary energy source globally, despite regional and national differences in energy source makeup. Replacing these carbon-based fuels with non-carbon-based, renewable sources will play a substantial role in reaching the net-zero carbon emissions goal.

Electrification of technology that still runs on petroleum-based fuel continues to be a major contributor to decarbonizing many economic sectors. The Energy Transitions Committee (ETC) projects that electricity's contribution to total energy supply will need to increase to 60% or more by mid century to meet the global net-zero emissions goal.[1]

Global Energy Profile

According to the International Energy Agency[2] global energy production in 2019 was 617 exajoules (EJ), more than double the production in 1971. The energy makeup has also changed over that timeframe with some fuels decreasing and others increasing, as detailed in Table 1.

Table 1: Global energy sources, 1971 and 2019.

Source	1971	2019
Coal	26.1%	26.8%
Oil	44.3%	30.9%
Natural gas	16.2%	23.2%
Nuclear	0.5%	5.0%
Hydro	1.9%	2.5%
Biofuels	10.8%	9.4%
Other Renewables	0.2%	2.2%

PerkinElmer®
For the Better

Electricity Production

Global electricity generation primarily relies on coal and natural gas as detailed in Table 2.[3]

Table 2: Global electricity generation by fuel type, 2019.

Fuel	Contribution
Coal	36.7%
Oil	2.8%
Natural gas	23.5%
Nuclear	10.3%
Hydro	16.0%
Wind	5.3%
Solar	2.6%
Biofuels and Biowaste	2.4%
Geothermal, Tidal, Other	0.5%

Currently, 35.4% of the global coal supply is used to generate electricity, with much of this use occurring in Asia.[3] The use of natural gas, a lower-carbon fuel, to produce electricity has steadily increased over the past decade, especially in the U.S.

The use of renewable resources—such as hydro, wind, and solar—to generate electricity has also picked up pace in the last decade. There is, however, great variation in how much each of these resources is used in different regions and nations.

Transportation Fuel Production

More than half of the global crude oil supply is used to make transportation fuels such as road vehicle fuel (49.3%) and aviation fuel (8.3%). Other uses of oil include residential heating, industrial processing, and so forth as detailed in Table 3.[4]

Table 3. Global oil use by sector, 2018.

Fuel	Contribution
Road Transportation Fuel	49.3%
Aviation Fuel	8.3%
Non-energy Uses	16.7%
Industry	7.2%
Navigation	6.8%
Residential	5.4%
Rail	0.8%
Other	5.5%

Biofuels such as ethanol and biodiesel are the predominant renewable fuels currently in use. Fuel ethanol is made from the starch of grains such as corn, sorghum, and barley. The fuel ethanol is then blended with gasoline and can be used in standard gasoline engines. Biodiesel is made from vegetable oils (chiefly soy oil), animal fats, waste oils, and greases. It can be used in standard diesel engines. Both biofuels help reduce the consumption of crude oil for transportation fuels.

These data clearly evidence the impact that decarbonization of electricity and transportation can have on the world and its citizens.

Power Grid Electrification

Power grids distribute electricity through a complex system of substations, transformers, and power lines that connect electricity producers and consumers. Most local grids are interconnected forming larger grids that enhance the coordination and reliability of the electricity supply.

The electricity distributed through power grids is used for a variety of purposes. The sectors leading in electricity consumption are:[5]

- Industrial (41.9%) – primarily for machine drives/motors, processes, and boiler heating
- Residential (26.6%) – primarily for space heating, space cooling, and water heating
- Commercial (21.2%) – primarily for computers and office equipment, refrigeration, space cooling, ventilation, and lighting

The makeup varies among different regions and nations of the world, but this snapshot provides a general understanding of global electricity usage.

The 2020 data show that 29% of global electricity was produced using renewable sources, up from 27% in 2019.[3] Wind and solar electricity generation are particularly susceptible to weather fluctuations. To continue increasing the use of renewables for power grid electricity, a highly efficient energy storage solution connected to the grid is needed to enable the continuous balancing of power generation and power demand.

Storage batteries are an attractive solution due to their modularization, adaptable installation, and rapid response to changing energy demand. Lithium-ion batteries (LIB) have attracted significant interest as grid power storage solutions because of several remarkable advantages, such as:[6]

- High energy storage density (up to 200 watt-hours per kilogram [Wh/kg])
- High efficiency (more than 95%)
- Long cycle life (3,000 cycles at deep discharge of 80%)

In the U.S., LIB are used in roughly 77% of electrical power storage systems used to balance grid supply and demand. Despite lingering operational challenges yet to be solved, LIB are a high-value market that will likely continue to grow, even while LIB alternatives like zinc and sodium are being researched and developed.

Vehicle Electrification

Increasing sustainably produced electricity for distribution via power grids will also support the continued electrification of the transportation industry.

According to IEA data, electric vehicle sales reached a record 3 million in 2020, up 40% from 2019. Add that to sales during the last decade and there are now more than 10 million electric cars on the road. The Net Zero Emissions by 2050 Scenario projects 300 million electric cars will be on the road by 2030, accounting for more than 60% of new car sales.[7]

Decreasing LIB costs helped drive the electric vehicle sales upward. If this trend continues, LIB vehicles are expected to reach cost parity with non-electric vehicles by 2030.[8] These projections rely heavily on the continuation of lower LIB costs, which itself is dependent upon raw materials availability and the absence of geopolitical flareups impacting trade and costs.

Lithium-ion Batteries

Lithium-ion batteries are used in countless applications, from laptop computers and refrigerators to power tools and electric vehicles. A few of the key characteristics that make LIB so useful and versatile include their light weight, high energy density, and ability to easily be recharged.

"Energy density" refers to the amount of energy that a system stores in proportion to its weight. Lithium batteries can be smaller and lighter than other types of batteries while holding the same amount of energy. In miniature-scale use, these characteristics make LIB excellent for small portable electronic devices. In larger-scale use, they are well-suited for electric vehicle batteries where they provide enough energy storage capacity to allow long-distance travel.

Lithium

Lithium is a soft, very light, silvery-white metal in the alkali metal group. It is very reactive and thus typically found in mineral compounds. When extracted and purified, lithium's high reactivity makes it an excellent conductor of heat and electrical charge.

BATTERY MATERIALS ANALYSIS

Learn more about analytical solutions for battery materials in the Application Notes:

- [High-Precision Analysis of Battery Materials with the Avio 550 Max ICP-OES]()
- [Determination of Impurities in Lithium Materials with the NexION 5000 ICP-MS]()

Rare Earth Elements

In addition to lithium, rare earth elements (REE) are also essential for several renewable energy technologies. REE exhibit many electrical and magnetic properties that play an irreplaceable role in renewable technologies, for example:[9, 10, 11]

- Neodymium and dysprosium are used in wind turbine magnets.
- Praseodymium, neodymium, samarium, and dysprosium are used in electric and hybrid vehicle motors.

WHAT ARE THE RARE EARTH ELEMENTS?

The rare earth elements (REE) consist of 17 metals—yttrium, scandium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. These 17 elements are also known as "rare earth metals."

Despite the group's name, REE are abundant in Earth's crust but not in concentrated, easily extractable deposits. Rather, they are diffuse components of other mineral deposits and must be painstakingly extracted from those deposits and thoroughly purified.

Lithium and REE Analytical Needs

As the electrification of global energy accelerates, so does the need for reliable analytical solutions that can accurately characterize and quantify lithium and REE content for improved and expanded renewable energy technologies. Analytical techniques such as inductively coupled mass spectrometry (ICP-MS) and ICP coupled optical emission spectroscopy (ICP-OES) are key solutions in this field. These technologies have capabilities that allow for rapid analysis of a wide variety of metals and sample types while effectively managing matrix interferences.

RESOURCES FOR LITHIUM AND REE TESTING

Interested in learning more about ICP-MS and ICP-OES capabilities for lithium and REE testing? Check out these resources:

- *App Note:* Analysis of Rare Earth Elements by Laser Ablation-ICP-MS with the NexION 2000 ICP-MS
- *App Note:* Using MSF to Resolve Difficult Interferences in Metallurgical Samples with the Avio 550 Max ICP-OES
- *Webinar:* Solving the Rare Earth and Other Element Challenges Using a Multi-Quadrupole ICP-MS
- *Video Presentation:* Accurate Rare Earth Element (REE) Analysis by ICP-MS

Lithium and REE Resources

Lithium and REE resources are found in diverse areas of the globe and equally diverse settings. The locations and volumes of known resources are discussed in this section.

Lithium Resources[12]

Global lithium production in 2021 was 100,000 metric tons (mt). The leading producers and their contributions are:

- Australia 55,000 mt
- Chile 26,000 mt
- China 14,000 mt
- Argentina 6.2 mt

Lithium reserves are estimated at 22 million mt in the following primary locations:

- Chile 9.2 M mt
- Australia 5.7 M mt
- Argentina 2.2 M mt
- China 1.5 M mt

REE Resources[13]

Global REE production in 2021 was 280,000 mt. China produced the majority of REE followed by three other primary producers:

- China 168,000 mt
- U.S. 43,000 mt
- Burma 26,000 mt
- Australia 22,000 mt

REE reserves are estimated at 120 million mt in the following primary locations.

- China 44 M mt
- Vietnam 22 M mt
- Brazil 21 M mt
- Russia 21 M mt

The amount of lithium needed for 2 billion passenger car LIBs would only be roughly 18% of current estimated resources. Similar estimates for REE and other key minerals also indicate no long-term constraints.[1]

Lithium and REE Extraction Methods

Lithium naturally occurs in three primary forms – brine, mineral ore, and clay. Currently, the majority of lithium is produced at five mineral operations in Australia, two brine operations in Argentina, two brine operations in Chile, and two brine operations and one mineral operation in China.[12] Clay extraction operations are limited, and effective methods are still under development.

GLOBAL LITHIUM OPERATIONS

Lithium sources and extraction locations in operation or under development in 2021.[12]

Mineral-based Sources	Brine-based Sources
Australia	Argentina
Austria	Bolivia
Brazil	Chile
Canada	China
China	United States
Congo (Kinshasa)	**Clay-based Sources**
Czechia	Mexico
Finland	United States

Lithium Brine Extraction[14]

To extract lithium from brine, drilling is used to access the underground brine deposits that lie beneath salt flats. The brine is pumped to surface ponds where it remains until water evaporation results in optimal lithium concentration. Utilizing solar evaporation alone can take months or even years, thus some operations use reverse osmosis to accelerate the concentration process.

The concentrated brine then undergoes a series of treatments to separate, purify, and prepare the lithium for sale as a stable lithium compound such as lithium carbonate, lithium hydroxide, lithium chloride, or lithium bromide. The remaining brine is reinjected into the underground brine reservoir.

Lithium extraction from brine can take a long time depending on the evaporation method used and site climate. It also has drawbacks related to groundwater resources, water quality, environmental impacts, and displaced or otherwise impacted local communities.

NEW EXTRACTION METHOD

Direct Lithium Extraction is a relatively new method of obtaining lithium from brine. The technology uses a special absorbent to directly extract the lithium without the need for evaporation ponds. More details are available from Ensortia Metals and International Battery Metals.

Lithium Mineral Ore Extraction

Five primary types of mineral ore are mined for lithium—spodumene, lepidolite, petalite, amblygonite, and eucryptite. The ores are obtained from hard rock formations using traditional mining techniques.

The process for recovering lithium from ore can vary based on the specific mineral deposit in question. In general, the mined ore is exposed to heat, crushing, chemical treatment, filtration, and concentration via evaporation. The wastewater generated by this process is treated for reuse or disposal.

Other lithium sources undergoing R&D for viable extraction methods include:

- Seawater
- Recycled brines from energy plants
- Recovered oilfield brine
- Recycled electronics

Environmental and social concerns related to lithium extraction are discussed more fully in the "Trends and Challenges" section.

REE Extraction Methods[15]

REE are found in a wide range of minerals including silicates, carbonates, oxides, phosphates and others. The economically feasible sources are primarily bastnaesite, monazite, loparite, and lateritic ion-adsorption clays. Commonly used methods for separating REE from these primary sources are:

- Physical separation – magnetic, gravity, and electrostatic
- Flotation and physical/flotation combinations – flotation, magnetic flotation, gravity-magnetic flotation
- Hydrometallurgy – acid leaching, sulfuric acid baking, roasting and hydrochloric acid leaching, caustic soda leaching, sodium carbonate roasting, solvent extraction

Historically, these extraction methods have been used at extremely large-scale using liquid-liquid methods that can be inefficient and generate large volumes of toxic waste. Recent R&D efforts have identified potential methods that are more sustainable by obtaining REE from waste streams and recyclates, such as:

- Coal and coal byproducts
- Iron ore and apatite
- Phosphate byproducts
- Cation adsorption clays

Other methods being investigated include bioleaching using microorganisms and biosorption using biomaterials.

BIOTECHNOLOGY FOR REE EXTRACTION

A bacterial protein may prove to be the newest breakthrough in environmentally-friendly REE extraction and separation. Learn more about it at Penn State College of Science.

Extraction Analytical Testing Needs

LIB manufacturers require lithium purity ranging from 99.5% to over 99.999%, depending on the chemistry of the battery being manufactured. This stringent criterion is becoming more crucial over time for minimizing LIB fire hazards, improving LIB efficiency, and maximizing LIB lifespan. Lithium extractors need a reliable, highly sensitive analytical solution to confirm and prove that their product meets this stringent purity level.

Lithium extraction operations that use toxic chemicals must also monitor waste streams and process materials for the presence and levels of potential contaminants. Brine operations must test waste streams, leftover brine that is to be reinjected to the subsurface, and pond leachate that could be unintentionally released to the surface or subsurface and impact water resources. Mineral ore operations must test waste streams such as spent ore and lithium processing byproducts.

REE must also meet extremely high purity levels (>90%) for use in LIB and other sustainable energy technologies. Waste streams generated during REE extraction and purification that must be monitored include spent ore, leachates, byproducts of baking and roasting, leftover secondary REE sources, and wastewater.

Trends and Challenges

LIB are under continuous scrutiny as researchers look for ways to improve battery design, safety, longevity, and sustainability. These efforts are driving several challenges and trends pertaining to LIB safety, analytical instrumentation, lithium and REE extraction methods, environmental and social concerns, and resource conservation.

LIB Safety

Lithium's high reactivity rate can result in fire safety concerns throughout the battery lifecycle, such as during:

- Battery construction
- Battery use
- Recycling operations
- Waste disposal

The presence of contaminants in lithium is the primary culprit in fires during battery use and they are also responsible for reduction in battery coulombic efficiency, or its ability to charge and discharge effectively. This realization is what drives the ultra-high purity requirements for lithium coming from the producer and at the battery manufacturing site.

Analytical Capabilities

To meet the ever-increasing purity level requirements, analytical instrument providers continuously conduct R&D to reach the next milestone for improved hardware and software for lithium (and REE) purity confirmation. In addition to purity requirements, the range of specifications for LIB continues to evolve and is becoming more and more customer specific. Analytical providers are developing solutions that are adaptable to meet the varying and growing needs of LIB manufacturers.

LIB ANALYTICAL TOOLS

Download our Li-ion Battery Guide to learn more about appropriate analytical testing tools that are critical to the LIB industry and others that rely on battery quality, safety, and technology advancements. Tools such as:

- FT-IR
- GC/MS
- ICP-OES
- ICP-MS
- Thermal Analysis
- Hyphenation

Resource Conservation

Although current lithium and REE resources seem vast, neither are infinite. Different strategies need to be undertaken to conserve these resources so they will last as long as possible. One strategy always on the mind of LIB designers is improving battery efficiency so that less lithium is required and the batteries have better storage capacity and longer life.

Looking even further down the road, exploration is underway for potential battery ion alternatives that are more abundant, easily obtained and recycled, and with better safety profiles. One such possibility being explored is a sodium-ion battery.

Even with their advanced chemistry and engineering, LIB have a finite usable lifespan, as do all batteries. Thus, increased LIB production will result in increased generation of spent LIB. Disposed batteries have the potential to release harmful chemicals to the environment where they may enter groundwater or waterways.

These concerns have prompted many corporate and government research teams to develop recycling methods that improve the recovery of lithium (and other chemicals) from LIB. As with mining operations, effective recovery and resale of lithium and REE from spent batteries must meet the stringent purity levels required by LIB manufacturers. Effective recycling methods provide multiple benefits including conservation of lithium and REE resources, decreased volumes of solid and hazardous wastes, and environmental protection, just to name a few.

Environmental and Social Concerns

In addition to the potential environmental impacts from LIB disposal, other concerns exist at lithium and REE extraction sites. The consumption of water and use of toxic chemicals in extraction processes are two specific issues.

Lithium brine extraction sites are almost exclusively located in salt flats such as the enormous areas found in Argentina, Bolivia, and Chile. The water resources in those areas are often scarce, so the use of available water for lithium extraction puts pressure on local populations and the environment. Consider the following to get a sense of the gravity of the situation:

- Roughly 500,000 gallons of water are used to produce one ton of lithium. That volume can provide potable water for 3,500 people for one year.
- Chile's Salar de Atacama is the world's largest lithium source. It is in a barren, salty desert where lithium mining activities consume 65% of the area's water, depleting the region's already scarce water resources.
- Toxic chemicals used in extraction and purification processes often leak from surface evaporation pools and enter local water supplies.

Such resource-impactful activities are causing serious problems for people living and working in these areas. Communities, farmers, and ranchers are being displaced due to water shortages or low water quality. Many of the displaced people are indigenous to those areas where they hold traditional or communal rights to land and natural resources.

Conclusion

Continued decarbonization of electricity will play a key role in meeting the goal of net-zero carbon emissions by 2050. Because of seasonal and weather-related variations in renewable energies such as wind and solar, an electricity storage strategy must be part of the solution.

The lithium-ion battery is a proven technology for energy storage that has been used in electric and hybrid vehicles for some time. LIB use in power grids is essential to balancing electricity production and demand and, therefore, providing a reliable and sustainable energy source to end users.

Lithium and REE are important and potentially limiting materials required for large-scale LIB success. Some of the challenges currently being addressed regarding these elements include environmental protection at extraction sites, improved battery efficiency and lifetime, improved recycling of LIB, and maintaining cutting edge analytical technologies that keep up with the changing LIB landscape. The solutions to these challenges will undoubtedly be found using the same ingenuity and perseverance that have brought us this far in the sustainability evolution.

References

1. ETC. 2021. Making Clean Electrification Possible: 30 Years to Electrify the Global Economy https://www.energy-transitions.org/publications/making-clean-electricity-possible/#download-form
2. IEA. 2021a. World Energy Balances: Overview. https://www.iea.org/reports/world-energy-balances-overview/world
3. IEA. 2021b. Global Energy Review 2021. https://www.iea.org/reports/global-energy-review-2021
4. IEA. 2018. World oil final consumption by sector. https://www.iea.org/data-and-statistics/charts/world-oil-final-consumption-by-sector-2018
5. IEA. 2021c. Electricity Information Overview. https://www.iea.org/reports/electricity-information-overview
6. Chen et al. 2020. Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems. https://doi.org/10.1007/s12209-020-00236-w
7. IEA. 2021d. Electric Vehicles. https://www.iea.org/reports/electric-vehicles
8. EY. 2021. Will you chart a course on e-mobility or be left behind? https://www.ey.com/en_us/emobility/e-mobility-will-you-blaze-a-trail-or-be-left-behind
9. Balaram, V. 2019. Rare earth elements: A review of applications, occurrence, exploration, analysis, recycling, and environmental impact. Geoscience Frontiers, Volume 10, Issue 4. https://doi.org/10.1016/j.gsf.2018.12.005
10. PV Magazine. 2021. Recycling rare-earth elements from dead lithium batteries. https://www.pv-magazine.com/2021/05/07/recycling-rare-earth-elements-in-dead-lithium-batteries/
11. USGS. 2019. Critical Mineral Commodities in Renewable Energy. https://www.usgs.gov/media/images/critical-mineral-commodities-renewable-energy
12. USGS. 2022a. Mineral Commodity Summaries – Lithium. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-lithium.pdf
13. USGS. 2022b. Mineral Commodity Summaries – Rare Earths. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-rare-earths.pdf
14. Samco. 2018. What Is Lithium Extraction and How Does It Work? https://www.samcotech.com/what-is-lithium-extraction-and-how-does-it-work/#
15. Peiravi et al. 2020. A Review of Rare-Earth Elements Extraction with Emphasis on Non-conventional Sources: Coal and Coal Byproducts, Iron Ore Tailings, Apatite, and Phosphate Byproducts. https://www.researchgate.net/publication/344445591_A_Review_of_Rare-Earth_Elements_Extraction_with_Emphasis_on_Non-conventional_Sources_Coal_and_Coal_Byproducts_Iron_Ore_Tailings_Apatite_and_Phosphate_Byproducts

PerkinElmer, Inc.
940 Winter Street
Waltham, MA 02451 USA
P: (800) 762-4000 or
(+1) 203-925-4602
www.perkinelmer.com

For a complete listing of our global offices, visit www.perkinelmer.com/ContactUs