srk news
Battery Metals

Emerging prominence of battery metals

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Implementation of battery-powered equipment

Battery metals, a key component in the production of batteries for various technologies such as electric vehicles (EVs) and renewable energy storage systems, have become extremely critical as companies strive to achieve their greenhouse gas (GHG) emissions targets and minimize negative impacts to the environment.

While metals such as lithium, cobalt, and nickel typically garner the most headlines, there are a number of additional metals (e.g., manganese, aluminum, and zinc) that make up the chemistry of current batteries. Unless alternative chemistries are discovered, ensuring there is sufficient supply of these minerals will be essential in creating the technology required to achieve net zero emissions in the post-carbon economy.

Over the next decade, the demand for critical battery metals will continue to rise as the disruptive effects induced by the COVID-19 pandemic begin to recede and the pace of EV adoption accelerates. Government-mandated policies such as carbon taxes are forcing corporations and individual citizens to transform their ways of life, especially in Europe and North America. Recent forecasts indicate that some metals may be in a deficit as soon as 2024 and continue on that path unless new mines are commissioned or production expanded at existing operations. As new mines (and the downstream refining facilities required) take years to bring online, the deficit will impact both the raw material producers and their customers in the form of higher prices.

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Emerging prominence of battery metals *(continued)*

Alternatives to EVs, such as vehicles powered using hydrogen, light natural gas, or biodiesel carry either a lower GHG abatement potential or lower technology readiness level. Thus, EVs will continue to feature prominently in the near- to mid-term.

As with most minerals, worldwide in situ distribution of battery metals does not necessarily align with the consumption requirements of a specific country or region. Countries are increasingly developing strategies to protect national interests by limiting access to both the raw and refined versions of battery and other critical metals. Not only will this help minimize the reliance on imports (where feasible), but it can also provide internal economic boosts through job creation. Critics argue such strategies may be damaging if environmental regulations are loosened in order to expedite permitting; however, increasing sustainable production in jurisdictions with mature and well thought out mining regulations can remove so-called "conflict minerals" from the supply chain.

SRK provides expertise on battery metals, beginning from the exploration stage, through permitting and production, and finally into the closure and remediation of mine sites. This newsletter highlights a few of the topics SRK has assisted clients on in order to maximize their deposits of battery metals.

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Fully battery-powered dump truck

European battery metals: the state of play

Exploration in northern Sweden

Heavy investment in research and development, driven by the EV and renewable energy industries, is leading to an explosion in battery innovation. Europe is experiencing huge growth in the battery production space, with over 30 major battery factories either in construction or planned.

Metal has been mined in Europe for millennia and continues to be important to many European countries, but metal mining has been eclipsed by cheaper labour and energy, less stringent environmental legislation, and a higher tolerance for heavy industry in other parts of the world.

Does Europe have the potential to be globally competitive in the battery metals space? It certainly has the right geology. A long and complex geological history has endowed the continent with a wide variety of mineral deposits historically mined, including tin, copper, gold, silver, iron, and lead-zinc. Battery metals are also present: the often discussed battery metals/minerals are cobalt, graphite, lithium, manganese, and nickel, but other metals, such as aluminum, copper, iron, and tin are often required in significantly higher quantities. In addition, depending on battery chemistry, significant quantities of magnesium, phosphorus, sodium, titanium, vanadium, and zinc may be required. Most of these metals and materials exist within the reaches of Europe and are often found in existing mining districts; however, many key deposits are either not yet proven to be commercially viable, are at an early stage of exploration, or face barriers to permitting due to potential environmental and social impacts.

There has been some European lithium production on a small scale, but the deposits currently being explored are not due to be operational for many years. Many European copper and nickel deposits contain significant quantities of cobalt that are produced as by-products; however, growing demand is fueling cobalt exploration. Nickel is already key in the European mining industry in two main forms: nickel sulfide and nickel laterite. Graphite mines in Norway and Ukraine are both operational and well-positioned to provide graphite to European battery producers. Manganese is also available in significant quantities in Europe, and there are plans to re-process the tailings waste material that contains elevated levels of manganese.

Significant research is required to consider all economic and sustainability criteria. The proposed EU batteries regulation has many sustainability requirements that extend to miners, and each mine's carbon footprint and environmental and human rights impacts will have to be assessed.

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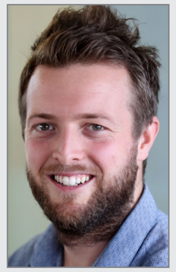

Ben is an environmental consultant with 13 years of international exploration and mining experience. Ben has recently transferred to the environmental, social and governance (ESG) team having formerly specialised in resource geology. As part of the ESG team, Ben works on environmental and social impact assessments along with audits and reviews of ESG studies as part of Mineral Resource and Mineral Reserve reporting.

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Lithium – the hard way

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Erik is a geologist with over 20 years of experience, specialising in resource geology, exploration and evaluation, resource estimation and geostatistics, mine and production geology, auditing, due diligence, and reporting of mineral resources. Erik has worked across North America, South America and Australia, from greenfields projects through open pit and underground operations. He is a Qualified Person for the purposes of NI 43-101, JORC Code, and SEC's S-K 1300 in several deposit types and commodities for exploration, geology and mineral resource estimation.

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Future generations will likely look back at this time and call it the "white gold rush". Companies and governments are scrambling to secure lithium production creating a historic run-up in lithium prices and many junior companies are adding "lithium" to their names. Historically, lithium was just another industrial mineral, mostly used in glass and ceramics, with minor usage in batteries. Annual global production was around 20 thousand tonnes per year (ktpa) of lithium carbonate equivalent (LCE) in 2010 (USGS, 2011), but started increasing around five years ago to 410 ktpa of LCE in 2020 and 540 ktpa in 2021 (McKinsey, 2022). Analysts believe global demand will increase by 30% per annum for the foreseeable future and the corresponding pricing has skyrocketed. For example, the battery-grade lithium carbonate EXW China price closed at $41,925 per tonne at year-end [2021], an increase of 485.8% year over year (S&P Global, 2022).

Given the current demand, pricing, and investment, everyone from large mining companies, junior explorers, and even car manufacturers are scouring the globe for sources of lithium for batteries to support energy storage and EV production. Lithium deposits can be broadly grouped into one of three categories: 1) brine or salar deposits, 2) lithium bound in lacustrine clays, or 3) as lithium-bearing minerals in pegmatites and granites. Due to a broader global abundance, many lithium-interested groups are focused on the hard rock pegmatite deposits. These types of pegmatites were often mined historically for tin, tantalum, and niobium and are common by-products produced today from operations like Greenbushes in Western Australia. Within lithium-bearing pegmatites, the common minerals of interest include spodumene, lepidolite, petalite, eucryptite, and amblygonite. Each requires good mineralogical and chemical characterization as there are material implications for grade, processing, and recovery between the various lithium-bearing minerals.

Advantages of lithium pegmatites are that mining is conventional, rather than in situ recovery characteristic of the brines, and processing often does not require expensive extraction as from low-grade clay deposits. Currently, lithium pegmatite operations are primarily open pit, but given the pricing and anticipated demand increases, the expectation is that more underground mines will become economically viable in the coming years. When spodumene is the primary lithium-bearing mineral, processing can be straightforward using well-proven technology. As lower grades and other minerals are considered for production, there are additional processing challenges or increased possibility of deleterious materials with iron and sulfur being among the main elements of concern.

Geologically, not all pegmatites are created equal. Pegmatites are defined as coarse-grained intrusives which are often present as dyke swarms associated with granitic intrusions. Chemistry, mineralogy, and geometry can vary greatly between deposits. Often with lithium pegmatites, there are generations of cross-cutting dykes with varying chemistries on a single property resulting in zones of lithium dilution, barren dykes, complex zonation, and thin dykes that present challenges for mining selectivity. Keys for assessing project viability and reducing resource risks for lithium-pegmatite deposits include focusing on structure (syn- and post-mineralization), multi-directional drilling to understand dyke thickness variations and sinuosity at depth, defining mineralogical zonation within dykes, identifying mineralogical and chemical continuity in both lithium-bearing minerals and potentially deleterious elements, and modeling both lithium-bearing and barren dykes to understand internal and external dilution.

Current global production is nearly all from Australia, Latin America, and China but with the current rush the expectation is that many other countries will join in production. As with any boom times, success will depend on diligent technical evaluation to address the many potential pitfalls of developing a hard rock lithium mine.

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McKinsey & Company, 2022. Lithium Mining: How new production technologies could fuel the global EV revolution, article 12 April 2022.
www.mckinsey.com

S&P Global, Snapshot: Lithium Cash Costs, S&P Global Market Intelligence, blog 19 August 2022.
www.spglobal.com

U.S. Geological Survey, 2011. Lithium Production. National Minerals Information Center, annual publications.

The Greenbushes hard rock lithium mine, Western Australia

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John Paul is an economic and exploration geologist with over 25 years' experience in grassroots to brownfields target generation and exploration, exploring for base and precious metal magmatic sulfide deposits, sediment-hosted and vein-hosted deposits, orogenic and placer gold, and mineralisation related to magmatic-hydrothermal systems, including iron oxide copper-gold (IOCG) type deposits.He has comprehensive experience in planning and executing exploration programs at all stages from target generation to evaluation and has been involved in numerous project reviews, due diligences and feasibility studies. He has worked extensively in sub-Saharan Africa and Scandinavia.

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Camilo is a Principal Consultant at SRK Argentina. He specialises in environmental geochemistry, hydrogeology, lithium-potassium brine exploration, exploration of pegmatites and applied mineralogy and petrology. His experience includes design and execution of comprehensive brine exploration programs, exploration of materials for brine processing and technical audits. He consulted on technical due diligences for four brine projects in Argentina.

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Southern Africa exploration targets battery minerals

The region could become a green energy hub

Southern Africa is a hotspot for mineral exploration to meet the global demand for battery minerals. With large deposits of cobalt, copper, graphite, lithium, nickel, manganese, rare earth elements and tin, the region could become a green energy hub. The region also boasts exceptional deposits of traditional resources like chrome, coal, diamonds, gold, platinum-group metals and uranium.

South Africa has the world's largest deposits of gold, platinum-group metals, chrome and manganese. There are numerous deposits of pegmatite, tin, nickel, copper, other base metals and industrial minerals such as ilmenite, rutile, zircon and mica. It also has some of the world's largest fluorite and iron ore deposits. New technology and improved geophysical methods can extend the life of existing projects.

Botswana remains attractive as there are several unexplored mineral deposits, particularly related to the recently described Kalahari Copper Belt, an extension to the well-known Central African Copper Belt. While further exploration is required to determine Botswana's fuller potential, exploration below the deep Kalahari sand is costly.

The Democratic Republic of the Congo (DRC) hosts world-class deposits of cobalt, copper, gold, lithium, and tin, but working in the DRC is extremely expensive and comes with many additional risks. Development is hindered by strict legislation, financial control, importation taxes, tax levies, corruption, and conflict.

Namibia is an attractive investment opportunity. The country hosts diamonds, gold, uranium, lithium, and tin pegmatite deposits. Although the gold concentration is lower grade than in other Southern African countries, some companies may find it viable to mine these deposits. Namibia also has deposits of oil and gas, with plenty of opportunity for renewable energy.

Zimbabwe, Zambia, and Angola should remain on the radar of exploration investors. Angola is expanding its minerals sector with cost-effective diesel and energy but diversifying by encouraging development of hard-rock minerals projects.

The Southern African region could become a superpower due to its rich mineral endowment and large mining potential. The region's long geological history provides a favorable foundation for a wide range of mineral deposits and commodities. Lithium, tin, nickel, cobalt, vanadium, and rare earths have all been discovered in Namibia, Botswana, Zambia, Zimbabwe, and South Africa, and many are being developed into sizeable projects. As a host region for battery minerals, Southern Africa could become more strategic to the Western world, given the uncertain global geopolitical environment. Graphite, for example, is a key material in lithium-ion battery anodes, and is currently being produced in Mozambique, Tanzania, and Madagascar.

To support mining endeavours, the region's governments will need to make changes, primarily to improving infrastructure. Much of Southern Africa's geological value cannot be realised due to insufficient infrastructure, including roads, rail, water, and electricity. The limited scale and lifespan of many projects often means they struggle to afford installing the necessary services if these are not already in place. If existing infrastructure was better, more of these deposits could be progressed from exploration stage to mining projects with fewer hurdles.

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Lithium brine exploration current trends

Soluble lithium deposits (lithium brines) include continental brines hosted in salars (salt flats), oilfield brines and geothermal brines. Currently, continental brines account for around 66% of the global lithium resource, excluding inferred resource, and have been the first source for lithium carbonate production since 2021. Continental brine is currently the most important source of soluble lithium as research on oilfield and geothermal brine production is relatively new and resources account for less than 7% of the global soluble lithium resource. Thus, since the discovery of economic soluble lithium in the Atacama salar (Chile) by the late 1960s, the start of systematic exploratory studies in the Argentinean salars in the 1970s and 1980s and production of lithium from brine in the Hombre Muerto salar (Argentina) in the 1990s, exploration programs and resource estimation techniques have been continually improving, with accelerated progress since 2010. The main challenge that has been triggering improvements in exploration techniques and resource and reserve estimation is the fact that lithium is a soluble dynamic resource in a liquid and thus grades change with time during production due to pumping extraction. The acceptable range for brine quality has recently widened together with the rapid progress of direct lithium extraction technologies: lower lithium grade brine with higher impurity contents (such as magnesium and boron) is now acceptable for classification as an exploration target.

The design of exploration programs should be aimed at collecting data to fully define brine chemistry and its variability, the potential volume of brine that can be drained (drainable porosity), hydraulic properties to assess brine extractability, sustainability of brine quality and brine levels and sustainable fresh-water availability during long-term pumping of both brine and water. Fresh-water is not only important as a source for industrial water but is also related to lithium reserve during production as lithium is soluble in water, and water ingress to the lithium deposit by fresh-water recharge is therefore the main source of dilution of the ore. Hence, exploration of both lithium in brine and fresh-water sources should start together and be part of the deposit exploration plan. Additionally, preliminary mapping of wetlands and collection of water samples from wetlands as well as other natural springs and streams related to the salar environment should be performed early in the exploration program to establish a basis for environmental monitoring. Simultaneously, a data quality assurance plan with strict QA/QC procedures should be applied for brine chemistry, drainable porosity, and hydraulic parameters.

Currently lithium brine exploration is not just a matter of building a geology and resource model. Soluble lithium must also be extractable by pumping and brine quality must meet process plant requirements throughout production, despite changes over time. Exploration of brine is a matter of collecting data for multi-disciplinary purposes.

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Lithium salar evaporitic crust

On the matter of snowflakes...

Snowflakes are single crystals of water that have achieved a sufficient size to fall through the Earth's atmosphere as snow. Each flake nucleates around a dust particle in supersaturated air masses by attracting supercooled cloud water droplets, which freeze and accrete in crystal form. Complex shapes emerge as the flake moves through differing temperature and humidity zones in the atmosphere, such that individual snowflakes differ from one another.

What has this to do with batteries you may ask?

Well, an important component of electric batteries is lithium and although categories can be placed on geological deposits of lithium, the reality is no two deposits are alike. This is particularly true of the lithium brine groups of deposits that occur as accumulations of saline groundwater that are enriched in dissolved lithium and other constituents. They are formed in closed basins in arid regions particularly in the salt flats (or puna) of Chile, Argentina, and Bolivia — often referred to as the "Lithium Triangle" that are estimated to contain more than three-quarters of the world's known available supply of lithium.

Despite the close proximity of these basinal deposits, variations in local geology and hydrogeology have led to variance in the stratigraphy of the basin infill and the location of the brine waters. In addition, the chemistry of the brine waters themselves is highly variable (Table 1). It is therefore essential to determine these variances in the evaluation of brine deposits, the main reasons being:

- It ensures a fair estimate of the resource by understanding deposit morphology
- It determines the most efficient locations for brine extraction and the rate of extraction to avoid dilution from surrounding waterways
- It informs the process required by determining not just economic components but also impurities that may form part of the final products

By doing this, SRK has been able to complete a number of feasibility studies for brine producers and provide a sustainable, economic and technically efficient solution to various projects.

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References: (1 Garrett, 2004; 2 Munk et al 2016; 3 Kesler et al., 2012; 4 Evans, 2014).

ROB BOWELL

Dr Rob Bowell is SRK's Corporate Consultant in Geochemistry & Geometallurgy with internationally recognised expertise in the geochemistry and geometallurgy of complex ores. For over 30 years he has specialised in applying geochemistry and mineralogy to diverse mining and engineering projects related to all stages of the mine life cycle. Rob has coauthored books on arsenic, gold, vanadium and uranium geochemistry as well as mine waste hydrogeochemistry. In 2018, Rob was appointed adjunct professor at Queen's University in Kingston, Ontario, where he continues to do research and teach

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Table 1: Typical Lithium Brine Chemistry in g/L

Elements g/L	Clayton Valley, USA[2]		Salar de Atacama, Chile[1]		Salar de Hombre Muerto, Argentina[4]		Salar de Rincon Argentina[2]		Zhabuye Salt Lake, China[3]	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Li	0.020	0.040	0.110	7.170	0.050	0.060	0.000	0.030	0.050	0.100
K	0.530	1.000	1.800	2.970	0.520	0.620	0.620	0.660	2.640	3.830
Mg	0.030	0.060	0.820	1.530	0.050	0.090	0.280	0.300	0.000	0.001
Ca	0.020	0.050	0.020	0.040	0.050	0.090	0.040	0.060	0.000	1.010
B	0.000	0.010	0.060	0.070	0.020	0.040	0.040	0.040	0.290	1.460
Na	6.200	7.500	1.030	9.100	9.790	10.300	9.460	9.790	10.660	10.810
Cl	10.100	11.700	2.030	18.950	15.800	16.800	15.800	15.800	12.160	12.310

Environmental aspects regarding brine extraction in lithium mining

Lithium deposits in the north of Chile

Lithium demand grows as lithium is an essential element for energy storage systems which reduce the exploitation of non-renewable and polluting energy resources for our planet.

Lithium is extracted by conventional mining methods from pegmatitic rocks, and from salt flat systems where the metal is contained in brines and extracted as a fluid.

Salt flat systems have a core formed by brines with high density and high concentrations of minerals (sulfates, nitrates, lithium, carbonates). Towards the borders of the salt flat, these brines coexist with lower-density fresh water from the upper areas of the basin. These two different density fluids collide at the borders of the salt flat where the brine pushes the water towards the surface. The contact zone generates a surface or mixing zone known as a salt wedge or salt interface. The marginal zone of the salt flat where the salt interface is observed is characterized as a sector of low permeability, and with local variations of topography where outcrops of fresh water appear, forming wetlands (vegas) or lacustrine systems. Unique, fragile ecosystems of native flora and fauna develop in these surface water systems.

Brine extraction through wells or ditches generates drawdown in the hydrogeological system that spreads to the borders, displacing and deforming the saline interface. These changes have an undesirable effect on the local flora and fauna which may be reduced or even disappear.

In this context, salt flat lithium extraction projects should consider detailed studies to examine the effect on salt flat borders. It is essential to have accurate groundwater and surface water data, detailed topography, water quality data, porosity and permeability of constituent units, lagoon bathymetry as well as geophysics and hydraulic conductivity profiles in wells to identify the geometry of the salt wedge. This information must be obtained over as long a period as possible in order to understand the seasonal evolution of the system. Furthermore, this monitoring should continue throughout the execution of the project in order to monitor possible changes in these systems and to detect in advance any variation in levels or quality that could bring undesirable consequences in the perimeter lacustrine systems.

At present, environmental regulations demand an understanding of these systems through detailed studies. These investigations are complex and challenge the use of hydrogeological conceptualization tools and numerical approaches to solve variable density systems, which are necessary to ensure the sustainability of lithium mining in salt flat systems.

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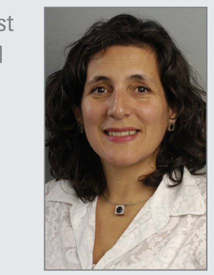

Beatriz is a geologist from the Universidad de Chile and has led the hydrogeology discipline of SRK Chile since 2007. She is proficient in supervision of well design and construction, hydraulic testing, and geophysical methods applied to hydrogeology. She is an expert in numerical groundwater modelling. Beatriz has developed water studies for obtaining environmental and sectorial permits and has participated in due diligences, NI 43-101s, peer reviews, and audits.

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Carolina is a civil engineer with 12 years of professional experience in conceptual and numerical modelling of hydrogeological and hydrological systems related to the mining industry. She has worked on projects involving saturated/unsaturated systems and studies considering variable density systems. Her experience includes simulation of filtrations in tailing dams, leach pads and water bodies. She has worked on hydrological analysis, surface water balance and design of hydraulic works.

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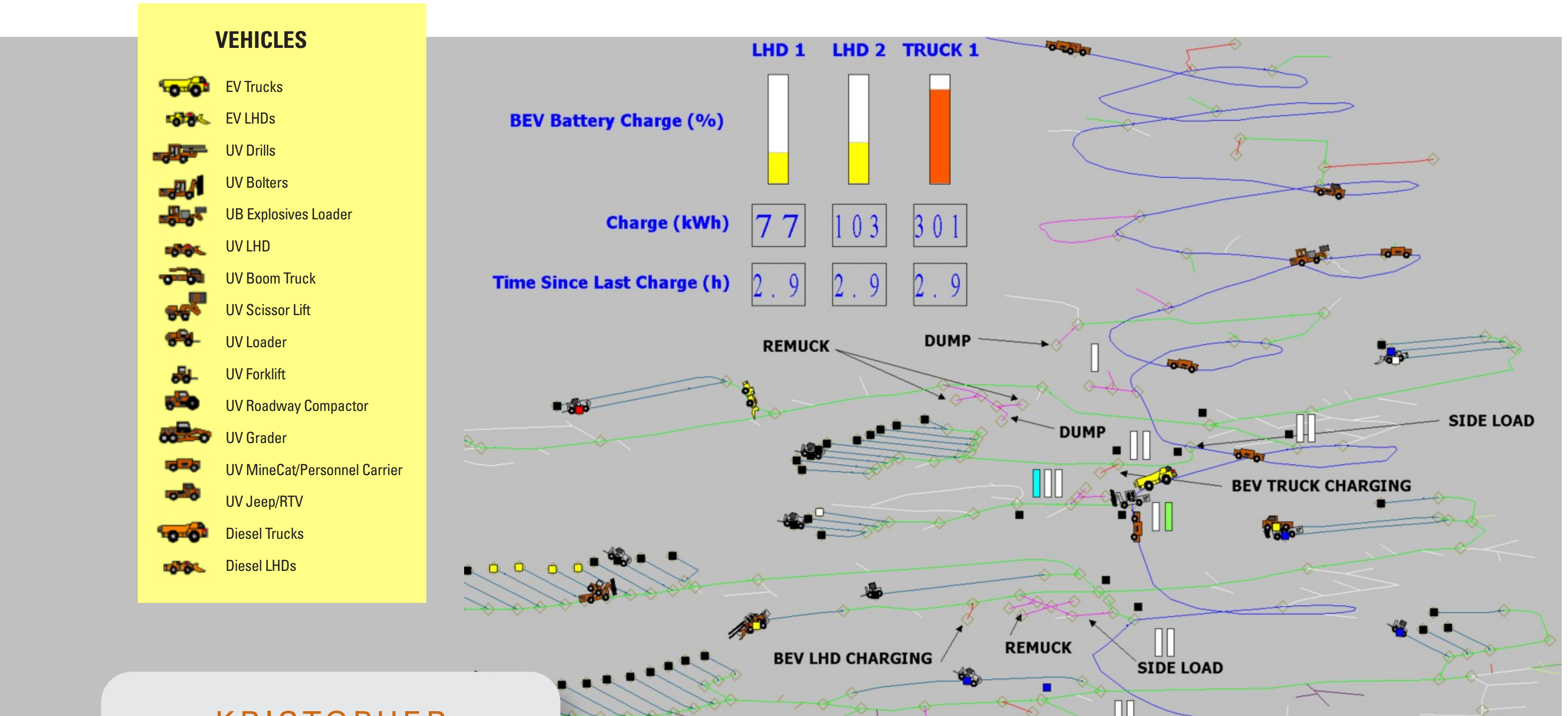
Mine simulation of diesel and BEV equipment



KRISTOPHER SHELSWELL

Kris is a consultant with over 10 years of experience in simulating surface and underground mining operations. He specialises in creating tailor-made discrete event simulation models that provide a holistic approach to understand mining systems. The models are designed to characterize interactions between critical system components for each specific operation, which provides a tool to evaluate mine designs, plan for future expansions, quantify the impact of operational practices, assess new methodologies, and identify process bottlenecks.

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The feasibility of transitioning from diesel-powered machines to battery-electric equipment is a key topic as mining companies embrace initiatives to decarbonize their operations. Many equipment manufacturers have committed to developing battery-powered versions of mining equipment fleets. Some companies even offer diesel-to-battery conversion kits for select equipment. Various trials are ongoing as mining companies transition to electrification, but there are still no best-fit guidelines and practices that can be applied across the board to allow any operation to convert to a battery-electric approach with ease.

Modelling and simulation allow us to replicate the proposed operating practices of a real system by using statistical descriptions of the activities involved. Traditional models include deterministic approaches for components of an operation, but fail to account for changes in operating conditions and interactions between equipment. Including random variability allows a model to simulate responses of the system to varying conditions over time. Discrete event models track the activity and behavior of each individual component of the dynamic system in response to specific events and activities.

Discrete event simulations are the preferred approach for modelling complex systems like mining operations because they capture the dynamic interactions between components of the system, including actual operating parameters like competition for resources, queuing, traffic, variable process times, random breakdowns, sporadic events, and changing operating conditions over time.

One of the main concerns is how battery-electric performance will compare to the established diesel approach. Simulations can be used to quantify the performance of both equipment types by defining the impacts of equipment parameters to predict fleet requirements. With battery-electric vehicles (BEVs), there is the additional consideration of recharging the battery. The impact of roadway grades and operating conditions on battery depletion ought to be evaluated to understand where to best place charging stations. Different operating configurations and strategies can be tested to determine the best strategy for leveling the power load required to charge batteries during a shift or day.

The overall goal of this simulation approach is to quantify the benefits of battery-electric technologies, identify opportunities for improvement and changes, mitigate bottlenecks, and improve financial forecasting. All factors can be tested without disrupting the existing mining sites or can be applied to future projects to make process and design decisions needed to implement battery-electric technologies.

Discrete event simulations are an ideal tool to test BEV concepts thoroughly and validate the proposed effectiveness of the system prior to decision making and implementation. No two mines are identical, and discrete event modelling provides a digitized study tailor-made for each operation. As the mining industry transitions into a new phase of battery-electric operations, simulation work allows us to determine how to best implement battery power.

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A summary of the 2022 Jackling lecture

Mining companies are working towards carbon neutrality, which requires lowering carbon monoxide emissions. One method of reducing emissions is by replacing internal-combustion engines (ICE) with battery electric vehicles (BEVs).

The drive for vehicle electrification will have significant impact on the metals required to produce BEVs, particularly nickel, copper, lithium, cobalt and molybdenum. Some estimates suggest that copper demand may be upwards of 3.7 Mt (4.1 million st) just for BEVs in the next 20 years. Combined with needs for renewable energy, BEV charging stations and energy storage facilities to feed power grids, the quantity of metals required for implementing BEVs at a large scale could easily outstrip current production.

The mining industry first investigated BEVs to help with ventilation and heat control in underground mines. A large impact on underground mines is diesel equipment's generated heat and emissions, such as carbon monoxide, nitrogen oxide and diesel particulate matter. Converting to BEVs eliminates exhaust, reduces heat, and reduces ventilation demand.

Numerous engineering studies have compared the benefits and disadvantages of swapping diesel equipment to BEVs. Risks include not meeting airflow requirements, less flexible operation, BEV fires and limits to haulage distances.

One significant risk is a BEV fire. Over 100 toxic gases can be released by lithium-ion batteries. Battery fires can be difficult to extinguish as the fire may be enclosed in the battery pack. CO2 or chemical extinguishers may suppress the fire, but may not cool the battery pack, while water sprays are effective at cooling but may trigger electrical faults or react with lithium to release hydrogen gas. To lower fire risk, BEV charging stations, parking stations and battery storage facilities will ideally be located near an exhaust and include gas sensors, fire doors and fire suppression systems. Mine operations will need to ensure proper handling and removal of excess batteries. A full understanding of the ventilation system is required so that in the event of a fire, mine rescue teams can access the area.

The risks need to be analyzed in a study that considers the types of BEVs on site, a vehicle tracking system, the location of charging stations and battery storage locations and the quantity stored at each location and proper training on BEV operation and firefighting. The risk study also must consider if the ventilation system will meet airflow requirements if the mine reverts to using some diesel machines.

It is projected that the use of BEVs for mining applications will continue to increase as more companies seek carbon neutrality. However, careful planning and risk assessment is required with BEVs to ensure operational flexibility, intentional placement of charging stations, and training of personnel in operating BEVs, BEV firefighting, and emergency planning.

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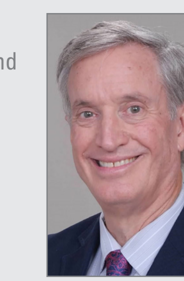

Keith has nearly 40 years of underground ventilation experience. Prior to merging with SRK Consulting in 2016, he was president and chief executive officer of Mine Ventilation Services, Inc. (MVS). He is currently a corporate consultant with the firm. He has published over 35 papers on various aspects of ventilation and was the editor of the 12th US/North American Mine Ventilation Symposium. He received the Howard Hartman Award for outstanding service in the field of Mine Ventilation Engineering in 2012 and the Daniel C. Jackling Award recognizing "Constant Achievement in the Advancement of Practical Mine Ventilation and the Elevation of Health and Safety in the Mining Community" in 2022.

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Don't lose it...reuse it...

Phosphyogypsum stack, Florida (USEPA)

The mining industry continues to face many challenges due to its potential environmental impacts. These challenges are becoming harder to overcome with growing social awareness, increasing regulatory pressure on suitable disposal options and the scarcity of available spaces for long term waste disposal. In addition there is growing pressure on the application of more sustainable approaches in mining.

Figure 1: Red mud discharge, bauxite processing facility

Historical mining waste and even process waste from many modern processes has potential to contain hidden "gems" of value that with a little effort could be unlocked. The different types of mine waste can include tailings, waste rock or process residues. During the life cycle of a mining operation, the various waste streams will show large variation both from different areas of the operation and over time and the most applicable methods of management may therefore also change over time. In addition, the re-evaluation of mine waste in light of a "circular economy" also seeks to find new uses for old materials, based on the idea that "mine waste is a commodity without a current use".

SRK has been involved in several projects that have identified efficient and effective solutions prior to mining commencing in operation and even for closed and abandoned sites. Typically such approaches require cross-disciplinary skills to valorise waste materials into market required resources. Some general information is given below.

A common issue lies with flotation tailings where recovery of fine-grained mineral particles became occluded originally by non-responsive gangue minerals during processing. Consequently, metal value was encapsulated within the waste and lost. A good example is the Wheal Maid tailings impoundment in Cornwall where historical mineral processing has left a legacy of heavily contaminated mine waste with high levels of metals in mine water. Copper, zinc, tin, silver, germanium and antimony as well as problematic metal(loid)s such as arsenic and lead occur in mine waste at concentrations similar to many modern mines (up to 3% copper and 2% zinc). These metals are associated with waste pyrite that could be recovered for sulfuric acid production and as inclusions of sulfide minerals in quartz. Recovery of this material may well involve regrinding the material or using modern sorters to selectively concentrate such phases and then process by conventional methods.

In some cases, the value is a surprise, or historically was not assessed. For example, in South East USA there are literally millions of tons of phosphogypsum mine waste that contain rare earth elements. These can be removed by regrind and leaching with an acidic leach. In other cases, the commodity has only recently been identified, for example the presence of high scandium concentrations in bauxite process residue, red muds (Figure 1).

In all these examples the critical link is achieving a better understanding of chemistry and mineralogy of the material to be processed and using this information to develop more sustainable mineral resourced.

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Flake graphite – bottleneck for meeting global energy supply demands

Named by a mineralogist in 1789 from the Greek word graphein, "write", graphite has played a significant role in the evolution of humanity from pencils to industrial lubricants, and now for conductors in batteries. There are two forms of graphite: naturally occurring flake graphite and synthetic graphite. Flake graphite has been used in industrial applications for crucible and refractory wares, lubricating compounds, and brushes. Today, flake graphite is an instrumental component in the construction and effectiveness of lithium-ion batteries, used to power EVs. This is due to its unique properties, notably its resistance to high temperature, oxidation and corrosion, its inertness and its high thermal and electrical conductivity. Today's EV lithium-ion batteries contain approximately two times more flake graphite than lithium and cobalt.

Recent graphite production has been dominated by China, Russia, India and Brazil. The United States Geological Survey reports that global mine production of graphite in 2021 was approximately 1.0 million tons with China, contributing roughly 80% of the global production. In contrast, countries like Canada and the United States that are leading the transition from fossil fuel vehicles to EVs contribute very little graphite to the global supply, even though graphite occurrences are known to occur in these countries.

There is no current substitute for flake graphite in the lithium-ion battery market and demand will only increase. Industry experts are estimating that an additional 4–5 million tons of flake graphite will be needed to meet the energy storage demands of the accelerating EV market and S&P Analytics is forecasting EV sales to rise by more than 400% by 2030. More countries should encourage exploration and development to meet this demand internally, rather than rely on imports that require material to be moved over large distances and which may not be reliable as demand grows.

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Scott is a geologist with over 15 years of experience in resource development, ranging from greenfields to advanced exploration to open pit and underground production. Scott's expertise includes executive-level mining and exploration, project management, generative exploration, geologic model development, resource estimates, and implementing data collection and database management systems. Scott has worked on a variety of mineralized systems, including bulk tonnage sediment-hosted gold, epithermal precious metals, carbonate replacement base metals, sedimentary exhalative zinc, and more.

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Mike has been involved in resource estimation for over 30 years, has written several papers on the subject and spent several years as joint course co-ordinator of an MSc in Mineral Resources at Cardiff University, and then as external examiner for the MSc in Metals and Energy Finance at Imperial College, University of London. At SRK he is now mainly responsible for managing feasibility studies, Competent Persons Reports, due diligence studies and project valuations on behalf of investment institutions and mining companies

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Electrification of the future mine

Of key importance in the transition to a "greener and cleaner" world economy is ensuring the production and refinement of battery metals is conducted in a manner that aligns with this thinking. To that end, mining companies continue to seek out means of reducing their dependence on fossil fuels in the extraction, comminution, and refining processes. Where open pit and underground mines are concerned, this is typically being achieved through "electrification", i.e., replacing diesel-powered equipment with equipment that derives its power from electricity.

Electric equipment has been a core component of modern mines for many generations. Historically this meant machinery such as belt conveyors, shovels/draglines, and rock drills. More recently, "going electric" at a mine often implies replacing diesel haul trucks and loaders with battery-electric variants or the implementation of in-pit crushing & conveying (IPCC) systems.

One of the ways in which SRK assists mining companies with their net zero pledges is by conducting analysis on mobile equipment that relies on battery-electric technology for power, rather than internal combustion engines. While fixed materials handling equipment can be used to transport broken material, mobile equipment is predominantly employed at both surface and underground mines to move ore and waste. While the numbers will vary depending on the size and geography of the mine, as well as the commodity being mined, diesel-powered mining vehicles are typically a significant contributor to the Scope 1 emissions at a given site.

As with our personal commuter vehicles, not all battery-electric mining equipment is created equal. For example, consider an underground haulage truck that may be sourced from either of two original equipment manufacturers. While the nominal payload capacity may be the same regardless of the equipment make, the trucks may differ in the size and number of traction and auxiliary motors, battery charging or changing methodology, and battery chemistry. This is a rapidly changing field and remaining up to date with the latest technology and trends is crucial. SRK works with clients to determine the best options available based on productivity and cost criteria, both at existing mine sites and greenfields projects.

Employing emission-free equipment at a mine is only one half of the equation, though; to be truly net zero requires the power source to be "clean" as well. Hydro, solar, and wind sources are currently in use at various sites worldwide with alternatives such as small modular reactors (nuclear) emerging. The extraction of battery metals can ultimately have a very circular pathway, as the refined materials are key components in mining EVs and the aforementioned renewable energy technology. Not only will the mines of the present (and future) play a large role in the battery metals story, but so will the equipment operated therein.

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The battery-electric TM3 BEV Transmixer

Risks rise as Indonesia nickel booms

As capital pours into nickel projects, companies face increasing challenges when attempting to develop nickel laterite mines or source offtake agreements in Indonesia.

Indonesia, the world's largest nickel producer, accounted for an estimated 48% of global nickel production in 2022, up from 37% the previous year, and has a 22% share of global reserves. It is forecast to deliver about half of global nickel production between now and 2025.

Two interrelated factors explain this growth. The first factor is surging demand for nickel and other critical minerals used in applications associated with the green energy transition, such as EV batteries. The second is strategic. As governments and multinationals rush to secure supply of critical minerals, this has ramifications for national and economic security, as well as global supply chains and production pipelines.

Indonesia is vital to nickel supply. However, breaking into the Indonesian nickel sector is becoming increasingly complicated.

China's significant investment in Indonesian nickel poses a major challenge. The country is pouring billions of US dollars into this sector, facilitating rapid expansion of China-backed projects. China's formulaic approach to asset development, coupled with its capacity to invest in large mines and infrastructure, solidifies its dominance in the industry.

From the perspective of the Indonesian government, which is trying to encourage processing and manufacturing of raw materials onshore and recently banned nickel exports, Chinese investments in its nickel-processing infrastructure are incredibly appealing. But this makes it extremely difficult for Western mining companies to get a foothold in the sector.

Nickel mining in Bahodopi Morowali, Indonesia

Processing technologies currently in use in the country include the well-established rotary kiln electric furnace (RKEF), which produces nickel pig iron, and the more recent adoption of high-pressure acid leaching (HPAL).

HPAL, a capital-intensive technology, has historically been associated with failed nickel projects in Australia and elsewhere. The technology has subsequently been applied to large HPAL facilities to recover nickel and cobalt from the low-grade limonite-nickel mineralisation that often overlies the saprolite mineralisation used as feedstock for the RKEF plants.

Another challenge to Western miners hoping to operate in Indonesia concerns the poor environmental practices and difficulties of obtaining social license to operate. In fact, the situation is bad enough that listed mining companies could find their ESG ratings impacted by Indonesia nickel projects unless they take steps to address these issues early in the mine development process.

In summary, China is moving faster, investing more, and driving up market-entry barriers. Therefore, Western companies looking to enter Indonesia's nickel sector need well-devised strategies.

Wait too long to enter and the rate of expansion and development will allow established players to dominate the strategic supply of Indonesian nickel. Move too quickly – or without expert advice – and companies face potentially costly complications and reputational risk.

Our experience in Indonesian nickel projects shows solutions can be found. However, no company should underestimate the growing competition in this sector.

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Scott has over 25 years' mining experience in both open pit and underground mining. He is a mining engineer who works in due diligence, project management and technical mine planning arenas. He has been responsible for delivering projects using multi-disciplinary teams, covering a diverse range of commodities and regions, including New Zealand, Australia, Asia, Africa, and Europe. Scott is a Chartered Professional and Fellow of the Australasian Institute of Mining and Metallurgy.

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Challenges of disposing lithium spent brine as part of direct extraction processes

The significant role of lithium in the continued development and expansion of renewable and clean energy has led to an increase in the demand for projects involving the extraction of lithium from shallow brines, particularly in the "Lithium Triangle" – Salar de Atacama in Chile, Salar de Uyuni in Bolivia and Salar de Hombre Muerto in Argentina.

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With this increased demand, several companies have developed direct extraction processes and new technology to recover lithium in brine. These direct extraction processes have emerged as an alternative to the conventional production processes that increase the concentration of lithium through solar evaporation in evaporation ponds. The advantages of direct extraction processes include lower costs, shorter ramp-up periods, and reduced dependence on favorable climate.

However, not everything that glitters is gold. Management of spent brine tailings can be a significant issue if inadequate planning is undertaken. Direct extraction processes generate large amounts of spent brine (brine with a reduced lithium concentration), which may affect the lithium-rich brine concentration. To prevent tailings disposal from affecting the lithium-rich brine, diligent engineering design is required.

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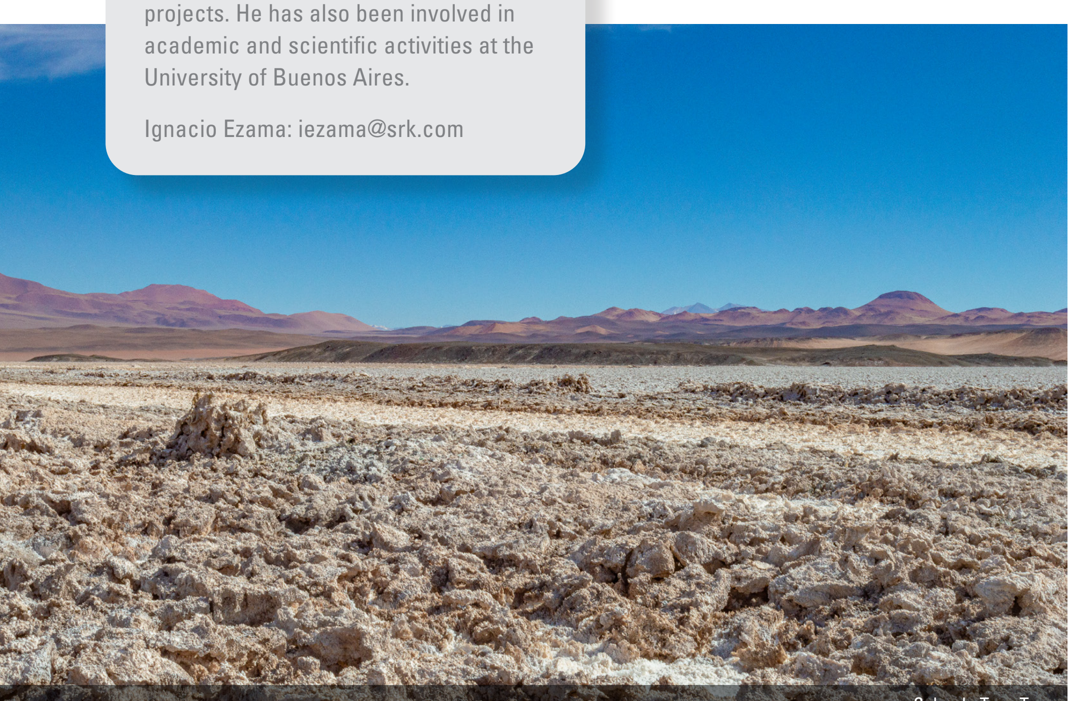

Salar de Taca Taca

Novel sources of lithium clay

The gently sloping hills of lithium-enriched clay of Bradda Head   Lithium's Basin East project area between Burro Creek (foreground) and the Grayback Mountains (background) in Arizona, USA

Demand for lithium, a key battery metal, is on the up. The largest brine (Salar de Atacama, Chile) and pegmatite (Greenbushes, Western Australia) lithium producers have been working up to double their production capacity to take up the slack in the short term, but that may not be enough to meet demand in the 2030s and beyond. Novel sources could help plug the gap – enter lithium clays.

These are sedimentary deposits where lithium is bound within clay minerals. While there are currently no lithium clay deposits in production, interest is ramping up, particularly in the USA where there is a push to find home-grown sources of the critical mineral.

The host rocks are varied and in SRK's experience include clay-altered ash tuffs, carbonate marls or carbonaceous siltstones. Common features are a lacustrine depositional setting and an association with rhyolite volcanism. The genetic model is still up for debate – low-temperature hydrothermal or hot-spring alteration of permeable basin sediments, diagenesis of fine-grained deposits containing lithium-rich ash or glass components, or a mixture of both? Faults are important, both as conduits for lithium-bearing fluids and by forming distinct fault-bound basins each having unique internal stratigraphy. Ultimately, the lithium content is controlled by underlying changes in the physical and chemical characteristics of the volcanic or sedimentary host; therefore, patterns in grade often closely reflect changes in internal stratigraphy.

The majority of lithium clay deposits benefit from being near surface, generally flat-lying, and having simple stratigraphy. They are also much softer than their hard-rock pegmatite cousins. This should facilitate mining with very low strip ratios and removes the need for expensive drilling and blasting during extraction. If the clay mineralogy is favourable (illite clays as opposed to smectite clays) we can also remove energy-intensive roasting from the processing (unlike the pegmatite deposits which need to break down spodumene through calcination).

While these clay deposits have the potential to be large – the top three lithium clay deposits in the Americas, Sonora (Mexico), Thacker Pass (Nevada), and Clayton Valley (Nevada) – each have contained lithium carbonate equivalent (LCE) resources similar to or larger than the Greenbushes pegmatite project (at least 7 Mt LCE) - they are generally lower grade. As such they may require proportionally large quantities of reagents to effectively leach and recover lithium. Similar to brines, the devil is in the detail – sediment chemistry, the types of clay species present, and the relative proportion of impurities, all have an impact and are unique to each deposit. To exploit lithium clays effectively, coming up with novel processing flowsheets is both an opportunity and necessity.

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Kirsty is a Senior Consultant in SRK's Cardiff office with 12 years' experience, who specialises in Mineral Resource estimation, 3D lithostructural modelling, and the interpretation of structurally complex mineral deposits. Kirsty has a PhD in Active Tectonics and Geophysics from the University of Cambridge, and at SRK has developed and presented Applied Structural Geology courses to mining professionals from all over the world. Kirsty has worked on a wide range of commodity types, including gold, base metals, and iron ore, and has worked on lithium clay deposits in the USA and Uzbekistan.

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Opportunity for Africa to fill the commodity gap

Simandou, Guinea

ANDREW VAN ZYL

Andrew specialises in valuing metals and minerals assets, including iron ore, manganese, chrome, copper, coal, gold and the platinum group metals. Andrew was elected chairperson of the South African Mineral Valuation Code (SAMVAL) committee in 2019, is a member of the International Mineral Valuation Committee (IMVAL) and on the council of the Southern African Institute of Mining and Metallurgy (SAIMM). Andrew has broad knowledge of a range of current interventions being pursued to reduce the carbon footprint of mining. He is currently managing the SRK team that is part of the EU Re-sourcing Project, an EU-funded project where SRK is facilitating stakeholder engagement in Asia and Africa on behalf of the project. He has also worked on a global SRK project to outline decarbonisation interventions in mining for a state fund.

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Forecasts suggest that the global economy is facing a 'commodity gap' in the near future as the demand for battery minerals could outstrip supply. Could Africa fill that gap?

There is certainly good reason to see Africa making a valuable contribution to future supplies of mined commodities from lithium, cobalt, nickel and graphite to manganese, iron, copper, chrome, uranium and aluminum.

While there are considerable resources of these minerals available in Africa and even currently being mined, there remain challenges which prevent their economic extraction. Gold mining has thrived in Africa because minimal infrastructure outside of the mine itself is needed to process and transport ore. By contrast, many of the in-demand commodities are bulk minerals that need extensive road, rail and harbour infrastructure.

Planning and developing such facilities requires more than capital. They rely on long-term government policies being implemented by well-resourced state bodies in collaboration with the private sector and international funding agencies. They also call for close working relationships between neighbouring countries to allow railways, powerlines and goods to pass over borders efficiently and at a low cost.

The African Continental Free Trade Agreement (AfCFTA), effective January 1, 2021, should address some of these concerns. Over time, the AfCFTA will eliminate import tariffs on 97% of goods traded on the continent, as well as address non-tariff barriers.

There are many opportunities for exploration and mining of battery minerals in West Africa. In Ghana, a significant lithium deposit is currently being investigated – the only one so far in West Africa. Interest in this region will grow if there are further positive developments linked to this project.

The impact of bulk mineral projects extends not just to physical infrastructure, but to a wider natural and human environment. For these projects to be sustainable in terms of environmental, social and governance considerations, developers need to navigate complex terrain related to regulatory compliance and social acceptance, which will require a high level of scientific and engineering skill to identify and mitigate the related risks as well as certainty in the expectations of the host country.

SRK is focusing on further improvement in Africa, particularly in the Democratic Republic of Congo and Zambia.

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Battery metal and mineral supply chains

Emerging commercial-scale battery applications, such as transportation and grid storage systems, offer potential low-carbon emissions energy sources and diversification of energy supplies. These prospects triggered global industry and government collaborations to develop and implement clean energy technologies. The design and implementation of clean energy technologies includes consideration of the raw material inputs required.

Battery metal inputs essential to current technologies include lithium, nickel, cobalt, and manganese. Combinations of these elements typically comprise the battery cathode. Graphite is used as the anode material. Rare earth elements are essential for permanent magnets used in EVs and wind turbines. Copper is essential for electricity-related technologies. Increased adoption of clean energy technologies across the globe will lead to increased demand for raw materials and to integrated supply chains for delivery.

Global copper and nickel supply chains are in place. These systems include raw material production and downstream processing. Increasingly, established producers now adopt responsible sourcing initiatives to differentiate their product and to meet the rising expectations of ESG focused customers. These supply chain initiatives apply to raw materials required by clean energy technology. The Global Battery Alliance describes this trend as a circular, responsible, and just (fair) battery value chain, illustrated above.

The circular elements of the value chain include the goals of incorporating renewable energy sources with mining, improving or substituting for processed materials and designing for recovery and recycling. Responsible sourcing aspects include conforming with international expectations related to ESG throughout the value chain. Finally, a just battery value chain recognizes ensuring safe and healthy working conditions and minimizing local environmental burdens.

The mining industry focuses on the raw and processed materials stages of the value chain. Most producers adopt sustainable development principles as a normal business practice. Such principles include decarbonization targets and water stewardship concepts, among other environmental and social goals. The future will require the producers of raw materials in this value chain to remain committed to these principles.

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Terry has over 29 years of professional experience dealing with environmental compliance activities that require engineered solutions at mining operations. His projects often require negotiations with regulatory agencies and other stakeholders to achieve client objectives. Terry's multi-disciplinary project teams address unique technical issues associated with mining, including permitting, design, construction and long-term monitoring of large-scale mine closure projects.

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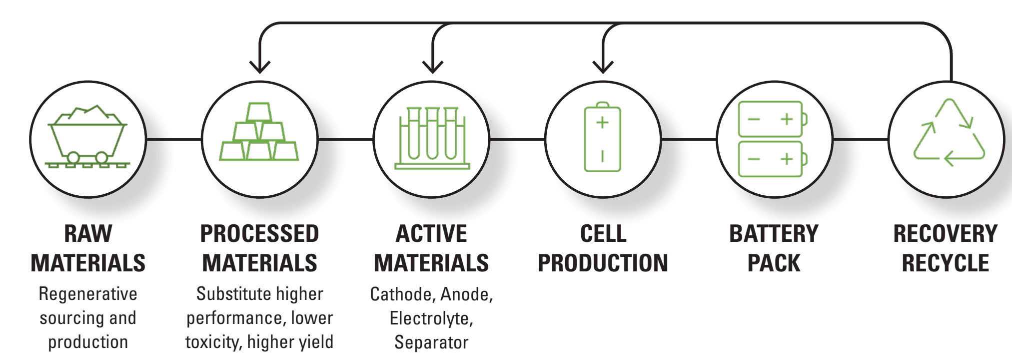

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