



LITHIUM ORE PROSPECTING, MINING, BENEFICIATION AND THE EXPECTED CONTRIBUTIONS TO THE NIGERIAN ENERGY SECTOR

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Abstract

Because of its particular use in the field of sustainable energy and its many applications, lithium ore is one of the most sought-after minerals of the twenty-first century. Lithium usage and needs are constantly rising because to the rapid advancement and expansion of electronic devices, small-scale power storage, the new energy sector, and electric cars. It has been determined that Nigeria is endowed with an abundance of mineral resources, with lithium ore found in at least five of the nation's states. An overview of the different quantities, locations, and methods of characterisation and beneficiation that can be applied to Nigerian lithium ore is provided in this study. This report includes a section on the relationship between lithium and the expansion of Nigeria's renewable energy sector. It confirms that Nigeria's energy problems may be resolved by the exploitation, exploration, beneficiation, and processing of this significant resource.

This study also discusses the significance of value addition for other mineral ores that Nigeria exports in addition to lithium ore. A review has been conducted on the different beneficiation and characterisation techniques that are appropriate for lithium ore mining. The study has devoted a part to this topic because of the difficulties Nigeria has previously encountered as a result of mining-related environmental concerns that were disregarded. Many researchers are forced to transfer samples overseas for analysis since the equipment in many of the nation's analytical laboratories is unable to perform the majority of the studies needed for the industry. Accordingly, the study suggested that Nigeria should either enhance its current analytical laboratories or establish new ones specifically for the mineral sector. To this aim, a list of the tools that form the basis of these studies has been supplied.

1. Introduction

In order to meet the needs for metal and energy for various industrial uses, there is a greater need than ever to utilise additional natural resources due to the world economy's rapid rise. According to the United States Geological Survey (2015), there is a 10% yearly growth in the predicted

demand for lithium, which is increasing rapidly. The use of lithium is growing quickly due to the development of technologically advanced devices and the new energy sector. According to estimates, lithium ranks as the twenty-fifth most abundant element in the crust of the planet (Meshram, Pandey and Mankhand, 2014). According to the British Geological Survey's (2013) Risk Level Report, the crustal abundance was 16 ppm, meaning that it is classified as medium-risk globally (British Geological Survey, 2016).

The name lithium, which means "stone" in Greek, refers to a highly soft, silvery-white metal that sizzles and flames when wet (RSC, 2024). A bar of lithium will float on water because it is so light. It is the element with the highest heat capacity and melting point of all. As a result, it finds application as a coolant in certain nuclear reactors, as well as in lubricating grease, air conditioners, industrial dryers, batteries, glass, medications, and nuclear bombs. Lithium compounds, including lithium carbonate, hydroxide, and bromide, are utilised in the production of aluminium, glass, ceramics, lubricants, and greases to enhance their resistance to extreme temperatures. They are also employed as catalysts in the rubber and pharmaceutical industries, as well as in air conditioning and dehumidification systems (Ebensperger *et al.*, 2005, Peiro *et al.*, 2013). But the demand for lithium minerals has increased due to the recent use of lithium-ion technology in electric vehicles (Ebensperger *et al.*, 2005, Peiro *et al.*, 2013).

The pressing need to ensure a low-carbon future is driving up demand for essential minerals. Rare earth elements and essential minerals are becoming more and more necessary for countries to meet their climate obligations. One of the main points of the 2015 Paris Climate Agreement is that non-renewable materials should not be used to generate electricity. An alternative to the energy transition economy is offered by renewable energy sources. High demand for essential minerals for use in climate-friendly technology is the result of this significant change (Huang and Zhai, 2021). By 2040, the World Bank predicts that the demand for these minerals will have tripled. Without a doubt, there will be a considerable long-term intensity to the deployment of essential minerals for a clean energy transition. Nigeria is richly endowed with a variety of natural mineral deposits, but over half of these reserves, including lithium, remain undeveloped. This has been a significant cause for concern as Nigeria, despite its wealth in minerals (it currently has about 44), lacks sufficient plans for how these resources can benefit the country. Furthermore, these minerals have been allowed to be mined illegally in areas where environmental safety and public health are completely ignored because the government has been more focused on the exploration, processing, and sale of crude oil (Aniobi *et al.*, 2021).

Lithium does not exist in elemental form in nature because of its reactivity. Though only a small number of these are presently regarded as viable sources of lithium, there are more than 100 recognised minerals that may contain the element. The bulk of lithium minerals are found in lithium-cesium-tantalum pegmatites, which are huge intrusive igneous rocks that incorporate lithium and have coarsely crystalline granites as a result of the magma's delayed cooling process. But only a small number of them—lepidolite, spodumene, petalite, amblygonite-montebrazite, and zinnwaldite—occur in magmatic crystalline rocks and have the potential to be used commercially or industrially (Filippov, 2022).

Lithium can be economically obtained from brines and hard rock ores. More than 60% of the lithium produced worldwide comes from brines, with the remainder output coming from lithium ores (Ebensperger *et al.*, 2005). Two minerals, spodumene and lepidolite, are known to be

economically connected with lithium metal. As an element, lithium is found in adequate concentration in the two minerals lepidolite and spodumene in nature. If not, it will be distributed among minerals, but not to a significant enough degree to be economically significant. They are typically found in specialised rocks such as greisens and pegmatites that contain rare metals. These rocks must be the focus of the hunt for viable lithium resources (Filippov, 2022).

Manufacturing industries have a significant demand for lithium. Seven years ago, greases, metallurgical powders, polymers, and other industrial uses accounted for almost 35% of lithium demand, while glasses and ceramics accounted for 35%. For batteries, less than 30% was used. But 95% of demand is anticipated to be met by batteries by 2030. Although lithium-ion batteries are more costly overall, they perform better and are quickly replacing other technologies (Garba, 2022).

Up to 35 industrial minerals are abundant in Nigeria and, if properly utilised, might increase the country's ability to generate cash. Lithium ore, found in various lithium-bearing pegmatites, is one of these minerals. Nigeria produced 50 metric tonnes of lithium overall in 2019; however, it was not good grade. In comparison, Zimbabwe produced 1,200 metric tonnes in the same year, thus this is tiny. In Nigeria, the broad band of rare metal-bearing rock types known as pegmatite is known to contain lithium minerals (spodumene and lepidolite) that are connected with cassiterite, columbite-tantalite (coltan), and other rock types (Nwaobi and Nzene, 2023). These rock pegmatites extend from the north central Wamba area of Nasarawa State, via the north central Egbe-Isanlu of Kogi State, the south-central Ondo-Ekiti States, to the south west Ife-Ilesa of Osun State. The rare metal-bearing pegmatites are known to be found in another belt in the western part of Nigeria, which stretches from Zamfara and Kaduna States in the north west, through Niger and Kwara States in the north central region, and Oyo State in the south west (Nwaobi & Nzene, 2023). Additionally, several have been discovered in Obudu, Southern Nigeria's Cross River State. Numerous instances of the uncommon metal-bearing pegmatites are known to exist in these belts, and some of them are thought to include minerals including lithium. But no recognised or developed commercially viable deposits exist as of yet. This is true even though a lot of explorers have recently expressed interest in responding to the demand for lithium around the world. Hard-rock lithium deposits, or migmatite lithium deposits, can include tantalum, niobium, tin, and lithium, among other elements. Additionally, preliminary findings indicate that the grades of lithium-bearing ores from Nigeria are equivalent to those found in lithium-producing mines worldwide. The lithium was classified as high grade by the Geological Agency due to its 1% to 13% oxide content. Typically, exploration starts around 0.4% of a level. The grade, expressed as a percentage, indicates the amount of lithium present in the minerals and/or rocks. Therefore, the economic viability increases with the grade. For metals like lithium, higher grades are extremely uncommon (Nwaobi and Nzene, 2023).

2. Lithium Ore Deposit and Mineralization in Nigeria

There are lithium ore deposits in several African nations, including Zimbabwe, Namibia, Ghana, the Democratic Republic of the Congo, Mali, and others. These deposits are often found in low concentration in igneous rock, but if properly explored, they might represent a viable source of lithium concentrate (MMSD, 2022). Nigerian lithium ore can be found in regions including Kogi, Nasarawa, Kwara, Oyo, Plateau, Bauchi, Gombe, and Adamawa, which are located in both the country's northern and southern halves. In Nigeria, spodumene, petalite, amblygonite, kunzite, and lepidolite are the most prevalent forms of lithium ore. The export of lithium ore in its raw form,

without any additional value added, lowers the nation's mining and mineral industry's earnings (Goodenough, 2021). The locations of lithium ore deposits in Nigeria are displayed in Table 1 (Abdulfattah et al, 2023).

Table 1. Lithium ore deposits in Nigeria (MMSD, 2022)

Deposits	State	Associated Minerals
Panda	Nasarawa	Pegmatite
Wamba	Nasarawa	Quartzite
Kabba	Kogi	Quartzite
Kushaka, Birnin Gwari	Niger	Pegmatite/Petalite
Isanlu Egbe	Kogi	Pegmatite
Ilesha	Osun	Pegmatite
Ijero Aramoko	Ekiti	Pegmatite
Arikyia Tsauni	Nasarawa	Pegmatite and Quartzite
Kafin Maiyarki	Nasarawa	Granite
Itakpe Area	Kogi	Quartzite and Pegmatite
Oke Ogun	Oyo	Quartzite
Ago Iwoye	Ogun	Pegmatite
Hong	Adamawa	Lepidolite/Kunzite
Zuru	Zamfara	Petalite
Kafanchan	Kaduna	Spodumene/Kunzite
Lere	Kaduna	Petalite
Jos- South	Plateau	Quartzite/Lapidolite
Ganjuwa	Bauchi	Lithium Oxide/ Lithia
Gidan Boda, Baruten	Kwara	Spodumene
Keffi	Nasarawa	Lepidolite

The Benue Trough's rotational stresses appear to be connected to the pegmatitic belt and the orientation of the units inside it. From a worldwide standpoint, this pattern most likely represents the Brazilian pegmatite belt's northern expansion, which stretches from Rio Grande del Sul to Rio Grande del Norte. The Nigerian lithium deposit's pegmatite field is a component of the late Pan African granitic pegmatites that include uncommon (specialty) metals (Jacobson and Webb, 1946; Wright, 1976). Quartz-feldspar-muscovite pegmatites host the major mineralization of tantalum, niobium, tin, beryllium, and lithium (Kinnaird, 1984).

3. Characterization and beneficiation of lithium ore

Appropriate characterization and lithium recovery—a value-adding technique that adds value to minerals and boosts revenue from selling concentrate for industrial use—are required in order to determine the potential deposit of lithium ore in Nigeria. Lithium ore has been the subject of numerous studies conducted recently throughout the world as a result of the growing market for energy storage. The desire to reduce greenhouse gas emissions has made research on the characterization and beneficiation of lithium ore as a substitute sustainable energy source more well known. It is possible to characterise suspected lithium-bearing pegmatites using a variety of techniques, including XRD, SEM-EDS, QEMSCAN, EDS-XRF, AAS, and other methods (Abdulfattah et al, 2023). Several beneficiation processes, including magnetic separation, gravity concentration, electrostatic separation, leaching, and flotation, can be used to recover lithium from lithium-bearing pegmatite ore (Filippov, 2022). A high-grade lithium concentrate can be produced by combining the beneficiation process.

Grammatikopoulos *et al.* (2020) conducted a mineralogical analysis of Zoro lithium ore using XRD and QEMSCAN techniques. Spodumene (10.5%), quartz (29.3%), plagioclase (29.0%), K-feldspars (21.3%), micas (5.1%), tourmaline (2.9%), and Fe-Mn-phosphates (0.1%) are all present, according to the data. However, the average Li content was found to be 3.7% in spodumene, 2196 ppm in micas, 1001 ppm in tourmaline, and 115 ppm in K-feldspars, according to electron probe micro-analyses and LA-ICP-MS. Additionally, the study reveals that 96% of the total lithium in Zoro Pegmatite is found in spodumene, the main lithium mineral. According to the research, the rejection of iron silicate minerals can result in the production of a high-grade (nearly 6% Li₂O) lithium concentrate through the use of Heavy Liquid Separation (HLS) in conjunction with magnetite separation for the beneficiation of the lithium ore deposit (Grammatikopoulos *et al.*, 2020).

Reverse and direct flotation are two commonly used methods of recovering lithium from lithium-bearing pegmatite ores (Bhappu and Fuerstenau, 1964). Using the changes in surface properties between the two types of minerals, it is used to separate valuable minerals from unwanted gangue minerals (Sahoo, Suresh, and Varma, 2021; Wills and Finch, 2015). In order to separate minerals with varying surface wettability by attachment or detachment from bubbles, a combination of chemicals is used in this process, including pH modifiers, collectors, frothers, and activators/depressants (Wills and Finch, 2015; Sahoo, Suresh, and Varma, 2019; Sahoo Suresh, and Varma, 2020; Tabelin *et al.*, 2021).

Choi *et al.* (2012) used AF65 as a frother and stearyl trimethyl ammonium chloride (STAC), one of the quaternary ammonium salts, as a collector to work on the flotation of lepidolite without the need for any depressants. The bulk of the ores extracted from the Boam mine in Uljin, South Korea, consist of the minerals lepidolite, muscovite, quartz, calcite, and albite. By changing the pH of the solution, the zeta potentials of the minerals were evaluated. The findings indicate that the lepidolite's zeta potential was less than 2, and the values of the isoelectric point (IEP) for silica, albite, and calcite were found to be approximately 2.5, 2.3, and 9.7 pH, respectively. They recovered 76.3% of lepidolite with a concentrate grade that was 3.8 times higher Li₂O than feed by using a three-stage flotation process to separate the minerals calcite, albite, and quartz (Abdulfattah *et al.*, 2023).

Additionally, by flotation of spodumene-rich pegmatite from Lanttä (Finland) and lepidolite-rich pegmatite from Gonçalo (Portugal), respectively, Sousa *et al.* (2019) obtained concentrate with a grade of 5.20 % Li₂O and 4.58% Li₂O. Optical microscopy, X-ray diffraction (XRD), scanning electron microscopy-energy dispersive x-ray (SEM-EDX), and Raman spectra were used to characterise the lithium ores samples. It was discovered that in the Gonçalo lepidolite, micro-inclusions of quartz and albite were found, while in the Lanttä, spodumene occurs with fine quartz intergrowths and is partially crosscut by fine albite and K-feldspar. (Sousa *et al.*, 2019). In the Pilbara region of Western Australia, the primary minerals in the Spodumene concentrate were identified and quantified by Fosu *et al.* in 2021. X-ray diffraction (XRD), mineral liberation analysis (MLA), XRF, ICP-OES, and scanning electron microscope energy dispersive spectroscopy (SEM-EDS) were used in the characterization process. The lithium concentration was found to be 2.14 weight percent based on the elemental composition of the concentrate as oxides obtained from XRF and ICP-OES. As a result, the calculated concentrations of lithium oxide and spodumene were 4.61 weight percent and 57.39 weight percent, respectively, which is in close agreement with the MLA's indication of 60.21 weight percent spodumenes and the

spodumene's 3 weight percent Li content. The primary minerals discovered in the concentrate's XRD spectra include spodumene, mica (muscovite and biotite), quartz, feldspars (orthoclase, albite, and anorthite), and amphiboles. These minerals are characteristic of the spodumene ore found in the Pilbara (Fosu *et al.*, 2021).

To determine whether there was a lithium deposit in any suspected areas of the nation, the Ministry of Mines and Steel Development in Nigeria carried out an initial investigation into the mining, extraction, and processing of lithium. Table 2 displays the outcome of the chemical characterisation performed using ED-XRF.

Table 2. Results of energy dispersive x-ray fluorescence spectrometer (ED - XRF) chemical analysis of sourced lithium ore at different deposits within Nigeria (Dele-Yaro, 2023)

Sample Locations	SiO ₂ wt. %	Al ₂ O ₃ wt. %	Na ₂ O wt. %	K ₂ O wt. %	TiO ₂ wt. %	P ₂ O ₅ wt. %	MgO wt. %	Li ₂ O wt. %	MnO wt. %	CaO wt. %	Fe ₂ O ₃ wt. %	L.O.I wt. %
Panda	73.8	3.21	2.14	0.12	2.14	1.04	0.26	9.53	0.06	2.36	4.31	0.01
Wamba	74.23	3.08	1.06	0.13	2.06	1.21	0.18	8.69	0.05	2.21	3.98	0.03
Kabba	82.86	2.14	1.05	2.10	0.06	0.03	0.50	8.69	0.01	0.16	2.07	0.01
Kushaka	94.08	0.06	0.03	0.12	0.18	0.002	0.05	3.51	0.01	0.14	2.04	0.01
Isanlu Egbe	78.4	2.63	2.01	0.25	3.14	0.001	0.05	9.336	0.37	1.05	1.29	0.02
Ilesha	85.51	1.01	2.01	3.62	0.21	0.002	0.43	4.379	0.089	0.96	1.93	0.01
Ijero	87.21	1.86	1.05	0.34	0.069	0.006	0.061	6.102	0.42	1.71	1.16	0.03
Aramoko												

According to the elemental ED-XRF analysis, lithium is present in the chosen pegmatite ore deposit in the range of 3.52 to 9.53%, with Panda in Nasarawa State having the greatest concentration of lithium oxide in the pegmatite that contains lithium (Goodenough, 2021). Additionally, the froth-flotation process was used to beneficiate the found deposit in order to provide a better lithium concentrate (Goodenough, 2021). According to Table 3, the ore's ED-XRF results demonstrate a notable improvement in lithium, which varies from 31.79 to 37.9% Li₂O, and a decrease in silica as an impurity, from 54.21 to 66.00% SiO₂.

Table 3. Results of ED - XRF chemical analysis of beneficiated lithium ores using froth flotation processing method (Dele-Yaro, 2023)

Sample Locations	SiO ₂ wt. %	Al ₂ O ₃ wt. %	Na ₂ O wt. %	K ₂ O wt. %	TiO ₂ wt. %	P ₂ O ₅ wt. %	MgO wt. %	Li ₂ O wt. %	MnO wt. %	CaO wt. %	Fe ₂ O ₃ wt. %	L.O.I wt. %
Panda	60.46	0.21	1.14	0.10	0.14	0.01	0.09	37.96	0.03	1.31	1.11	0.001
Wamba	58.21	3.08	0.68	0.13	0.96	0.11	0.08	36.86	0.05	0.21	1.78	0.001
Kabba	66.00	0.24	0.45	0.90	0.06	0.03	0.08	34.69	0.01	0.09	0.97	0.001
Kushaka	65.02	0.06	0.03	0.09	0.09	0.002	0.05	34.51	0.01	0.07	0.44	0.000
Isanlu Egbe	54.21	1.53	0.81	0.08	1.54	0.001	0.05	33.31	0.37	0.51	0.69	0.001
Ilesha	65.51	0.91	0.91	1.21	0.09	0.002	0.231	31.79	0.089	0.49	0.43	0.001
Ijero	63.72	0.76	0.85	0.14	0.05	0.006	0.061	32.11	0.42	0.64	0.66	0.001
Aramoko												

Thirty lepidolite samples were obtained from the Ijero-Aramoko Pegmatite Field in southwest Nigeria, and Akinola *et al.* (2014) conducted study on the physical-chemical features of these samples using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). The

analysis's findings show that Li, Be, Cs, and Rb levels are highly prevalent; for Oke-Asa, Oke-Igbo Aba, and Ijero Ekiti, respectively, average Li values of 1859 ppm, 1778 ppm, and 1656 ppm were noted. The study concluded that Nigeria's Ijero-Aramoko pegmatite deposit may be a possible supply of lithium ore.

Agaku *et al.* (2020) investigated the hydrometallurgical extraction of lithium from polyolithionite ore that was produced from the Keffi pegmatite field in Nassarawa State, North Central, Nigeria, as well as its qualitative characterization. Therefore, the study demonstrated that the hydrometallurgical extraction of lithium using chloride roasting additives (NaCl and CaCl₂) is efficient, less energy-intensive, and cost-effective because the fractions of the lithium extraction process that the chloride additives were rationed in (1:0.6:0.4 ore, NaCl, and CaCl₂) produced significant optimal lithium extraction efficiency of 89.90% under the optimal conditions. The lithium-rich rock's chemical composition was determined by energy dispersive x-ray fluorescence (EDXRF) and flame atomic emission spectroscopy (FAES). The results showed that Li₂O and 3.25 weight percent Li were found in the rock.

4. Lithium and renewable energy

Energy is frequently a driving force behind technical and economic progress. The world has directed its efforts towards the development of renewable energy sources in order to guarantee that the environment will continue to support human survival. As a result, discussions about renewable energy emphasise the importance of using sustainable energy sources. Lithium satisfies many requirements in the real context of climate change risks in order to provide a more sustainable and greener solution (Dele-Yaro, 2023). As a result, there is a mad rush to harvest this natural resource in the locations where it is discovered in order to fulfil the always increasing demand for it. Lithium supply is therefore essential for the expansion of energy sustainability in countries.

Nigeria is among the nations that are intensifying their efforts to adopt more environmentally friendly energy and climate policies. Large-scale rollouts of renewable energy technologies will be necessary to achieve net zero objectives embraced by energy-intensive economies. This will help to decarbonise the world's manufacturing and transportation sectors, which are heavily dependent on fossil fuels, and eliminate emissions from power generation. The Nigerian mining industry should be well-positioned to take advantage of two crucial opportunities, given the commitment of numerous governments worldwide to an electric vehicle (EV) future: first, to establish itself as a major regional leader in the production of sustainable EV batteries; and second, to assist the domestic and international automotive sectors in building strong EV manufacturing capabilities. In addition to being necessary for Nigeria's transition to a carbon-free energy future, which includes doing away with internal combustion engine cars, a sustainable mining sector offers a special chance to advance the circular economy by reimagining the vital mineral value chain.

One of the main forces for a more sustainable future is the mining sector. It will need focused investment, clever public-private partnerships, and the adoption of cutting-edge, environmentally friendly business practices and ideas to seize that opportunity. The exploration and mining of critical minerals must therefore be expedited. This includes addressing the dearth of active lithium mining operations, utilising government programmes to train and hire a skilled workforce from start to finish, developing a robust domestic exploration-to-electrification value chain, and building

out domestic infrastructure to support operations. Nigeria can mine the gap to success with creative thinking and investment that is goal-focused.

The bulk of the energy in the world still originates from fossil fuels, despite the fact that renewable energy supplies are expanding quickly (Scrosati and Garche, 2010). The use of fossil fuels raises a number of problems, such as increased oil consumption, oil resource depletion, political unrest and insecurity in oil-producing nations, greenhouse gas emissions, and concerns about climate change (Grosjean *et al.*, 2012, Scrosati and Garche, 2010). As an engineering material, lithium is essential to mitigating the problems associated with the use of fossil fuels. For instance, it is anticipated that the use of lithium ion batteries in hybrid and electrical vehicles will reduce the possible environmental harm caused by emissions from conventional automobiles (Grosjean *et al.*, 2012). Additionally, power from renewable energy sources like solar and wind power is anticipated to be stored in lithium ion batteries (Scrosati and Garche, 2010). The primary global end-use usage of lithium is found in the production of batteries, glass, and ceramics (US Geological Survey, 2018). According to analysts, there may not be enough mining capacity available globally to extract the minerals needed to produce enough batteries to fulfil the anticipated demand for electric vehicles. Therefore, this is a fantastic time for nations to set themselves up for the windfall that will come from investments in nations that have improved their mining capacities for these raw minerals.

According to analysts at Rystad, a global energy research company with headquarters in Oslo, by 2024, there will be a shortage of high-grade nickel due to increased demand. While supply is expected to rise steadily year over year to 3.4 million tonnes (Mt) in 2024 from 2.5 Mt in 2021, the experts pointed out that rising demand, partly due to the energy transition, will result in a deficit in less than two years, with a production of 3.2 Mt. By 2026, this difference will have grown to a 0.56 Mt deficit (IPCC, 2022; RYSTADENERGY, 2023).

Ensuring access to and management of essential natural resources, such as minerals and metals, which are crucial inputs into numerous clean energy and digital solutions, is a crucial strategic priority. Therefore, the Nigerian government ought to:

- Take advantage of the growing demand for vital minerals like lithium around the world;
- Establish Nigeria as the go-to sustainable global supplier; and
- Fund projects that increase Nigeria's competitiveness.

In a very short amount of time, a lot more minerals will be needed as the globe moves towards a green economy. This holds true for lithium as well. The fact that the process of extracting minerals is carried out in a sustainable and responsible manner should be understood right away.

5. Use of lithium

Lithium and its derivatives have numerous applications. Acton (2013) lists the following as examples of these:

1. Electrolytes and electrodes for batteries made of lithium are thin and effective. They consist of:
 - a. Battery made of lithium-cobalt oxide. It finds usage in electric vehicles as well as consumer electronics. It is affordable.
 - b. A more recent and improved battery chemistry is lithium-nickel-manganese-cobalt. Though it was primarily created for the electronic car business, its growing cost-effectiveness is causing it to find more applications.

- c. The safest technology, lithium iron phosphate, is somewhat pricey yet performs relatively well. Although it is quite well-liked in China, in the long run, lithium-nickel-manganese-cobalt is probably going to surpass it; and
 - d. Known for its good performance and affordable price, lithium-nickel-cobalt-aluminum oxide was created to lower cobalt use. Outside of China, it is gaining popularity as well.
 - e. Electronics, computers, energy storage devices, mobile phones, and electric cars all employ lithium-ion batteries. It is predicted that within the ensuing decades, they will control the lithium market. On the other hand, a wide variety of lithium-ion battery types are available for various purposes.
2. Lithium compounds are employed in medicine because they contain anti-manic agents, which are intended to treat and prevent bipolar disorder, a kind of mental illness.
 3. To process silica and lower the material's melting point and viscosity, lithium oxide is utilised as a flux.
 4. Lithium hydroxide, which is additionally useful for creating the primary component of all high-temperature lubricating greases can typically be lithium soap.
 5. Lithium compounds are added to the foundry during the iron casting process to minimise veining.
 6. Acts as an additive during the melting of aluminium, lowering the melting point and raising electrical resistance.
 7. During soldering or welding, metallic lithium enhances the fusing of metals.
 8. Due to their hygroscopic properties, lithium bromide and chloride are employed as desiccants in gas streams.
 9. Because lithium fluoride is transparent, clear, and crystallised, it is most frequently utilised in specialty optics.

6. The Mining Process

The process of extracting valuable resources from the ground is called mining. There are three primary phases to the mining process: 1. Exploration 2. Production, 3. Mine closure. The process of locating an ore deposit and turning it into a mine is referred to as exploration. Production is the amount of time ore is extracted from the mine during this period. The term "mine closure" describes the time after which the mine is shut down and no more ore is extracted. Each of the three phases is covered in further detail in the sections that follow. The mining process's exploration phase is given more attention. This is due to the fact that exploration happens at the start of the value chain and that a healthy pipeline of exploration projects is necessary for a mining industry that can survive. Moreover, many more exploration proposals are studied than are developed into production.

6.1 Challenges of the mining industry

Securing enough raw materials for the shift to green energy is one of the major difficulties facing the mineral exploration and mining business, which makes it challenging to construct new mines to supply raw materials for society. Nowadays, the process of locating, developing, and running a mine is more costly and technically challenging (Bryant, 2015). Additionally, obtaining a social licence to operate, or SLO, is getting harder. As a result of public protest, numerous projects end up being shelved or having their permits revoked. Rio Tinto's proposed Jadar Lithium Mine in Serbia is one example of this. Due to public opposition in the area, its mining licences were cancelled earlier this year (De Launey, 2022).

Due to the increased cost of exploration activities resulting from longer lead times, all of this leads to longer lead times—about 15 years—from discovery to mine (Schodde, 2014; Wilburn and Karl, 2018; Enders and Saunders, 2011). For investors, this means a worse return on investment. The exploration sector has shifted from adding value to destroying value during the previous fifteen or more years. Only 49 cents of value were produced by the sector for every dollar invested in exploration between 2010 and 2019 (Schodde, 2020). These issues need to be resolved at a time when new materials are needed more quickly than ever to enable a responsible and successful energy transition.

The social, environmental, and economic pillars of sustainability are all lacking in the mining exploration sector. Industries with characteristics like top-down hierarchical structures, linear and sequential thinking, risk intolerance, process inflexibility, and managing of its own assets are at risk for business model innovation, according to a study on breakthrough business models (Volans, 2016). This is the reason why a closer examination of the business models of exploration corporations is conducted.

7. Lithium Mining World Estimates

Along with other high-value metallic minerals like tin, niobium-tantalum (columbite-tantalite), and uranium (in pyrochlore), lithium and the majority of its minerals are mined. The world's largest hard-rock lithium mine is called Greenbushes Mine, and it is located in Western Australia. After a second processing unit was completed in 2019, the mine's yearly output capacity more than doubled to 1.34 million tonnes of lithium concentrates. In 2021, the production of lithium mines worldwide reached a new high of 100,000 tonnes, up 21% from 82,500 tonnes in 2020 (Garba, 2022).

As most nations develop plans to gradually phase out fossil fuel vehicles and transition to zero emission electric vehicles, the demand for lithium has surged due to the increased interest in sustainable energy (Azevedo *et al.*, 2022). It is anticipated that the underlying demand for lithium will increase in direct proportion to the number of vehicles produced and sold. Global lithium output increased to 86,000 metric tonnes in 2019 from 28,100 metric tonnes in 2010 (Garba, 2022). Getting enough lithium onto the market will be a difficulty.

Approximately 86% of the lithium in the world is mined in three countries: Australia (40,000 tonnes), Chile (20,600 tonnes), and China (14,000 tonnes). As per 2020 data, the remaining countries are Portugal (900 tonnes), USA (900 tonnes), Zimbabwe (1,200 tonnes), Argentina (6,200 tonnes), Brazil (1,900 tonnes), and Zimbabwe (1,200 tonnes). The US, Belgium, China, Japan, and South Korea are the top importers of lithium. According to Garba (2022), the average price of lithium per metric tonne increased from US\$2,000 in 2002 to US\$18,000 in 2018.

As of right now, the discovery in Nigeria only indicates the pegmatites there may contain lithium. Complete investigation will be required prior to the original ore's concentration. In terms of the rate at which lithium is growing in other industries, the battery has emerged as the first-largest application field in light of recent changes in the many uses of the metal. Approximately 140,000 tonnes of lithium carbonate are needed worldwide at the moment. It is anticipated that the increasing demand for new energy vehicles and consumer electronics worldwide will sustain an average yearly growth rate of 15% to 20% for lithium carbonate. More than 300,000 tonnes will

be consumed annually, and from 9.7% in 2012 to 37.8% in 2018, new energy vehicles will use more lithium carbonate (Ying, 2023).

7.1 Market potentials for lithium

Global lithium reserves were estimated by the USGS to be 16 Mt Li (85 Mt LCE) in 2018. Additionally, the USGS reported lithium resources of 53 Mt Li (282 Mt LCE), of which 60% came from continental brine deposits. The average annual rise in mine output since 2000 has been 10% annually; in 2017, 360 256 t LCE of lithium were produced. The total mine capacity worldwide was approximately 375 000 LCE in 2017. By 2022, this is expected to rise to 950 000 tpy, and by 2027, it is expected to reach 1.15 Mtpy. In order to keep up with demand growth later in the decade and into the 2030s, considerable amounts of additional capacity will be needed by the mid-2020s, notwithstanding projects that are already underway and being expanded (US Geological Survey, Mineral Commodity Summaries, January 2021).

The industry for rechargeable batteries has been the main driver of consumption growth, with growth of 19.3% pp between 2000 and 2017. In 2017, the industry for rechargeable batteries accounted for 45% of the total lithium usage. The most commonly used product is lithium carbonate, which is used in aluminium, glass, ceramics, glass-ceramics, rechargeable batteries, and other products. Since 2011, the demand for battery-grade lithium carbonate has grown by 22.0% each year (Yang *et al.*, April 2021). In 2017, the combined consumption of battery-grade hydroxide and carbonate accounted for 44% of total product consumption, indicating the market share of rechargeable batteries in the larger lithium market. With around 40% of the world's lithium usage in 2017, China is the biggest user, followed by South Korea and Japan, with 14% and 19% of the global lithium market, respectively. Lithium is a mature commodity in both North America and Europe, where growth has stalled since the early 2010s. According to Yang *et al.* (April 2021) India, Russia, and the CIS are still comparatively minor markets.

Lithium consumption has a promising short-, medium-, and long-term prognosis, with overall growth expected to reach 14.7% py by 2027. Forecasts indicate that the market will grow to exceed 831 600 t LCE in 2027, 1 Mt LCE in 2029, and 1.5 Mt LCE in 2032. The lithium consumption is expected to remain primarily driven by the rechargeable battery industry, which is expected to expand at a rate of 19.6% per year through 2032, ultimately reaching 1.4 million litres of lithium. Battery-grade lithium carbonate and hydroxide demand could rise by 14.6% and 28.9% annually, respectively, through 2027 and from 2027 to 2032 to reach approximately 600 000 t LCE and 785 000 t LCE, respectively, in line with the expansion in rechargeable battery lithium consumption. Asia, especially China, Korea, and Japan, is predicted to exhibit the largest increases in lithium consumption until 2032 because the region accounts for the majority of the world's intermediate supply for rechargeable batteries (STATISTA, Feb 21 2024).

According to Roskill's base-case prediction, lithium consumption will rise by 13.1% every year until 2032 to reach 1.556 Mt LCE in 2017, a seven-fold increase. In the near future, it is anticipated that the production of mineral concentrate will surpass the demand for refined lithium and the requirements of converters. This will lead to a period of stockpiling and eventual rationalisation of mineral capacity and/or supply in 2019/20. Strong demand increase is anticipated after 2021 to cover higher mine supply requirements for mineral operations (GREENCARCONGRESS, 25 November 2020). The supply of lithium hydroxide and carbonate is anticipated to keep up with demand. An excess of lithium carbonate is not anticipated, despite the possibility of a brief glut of

lithium hydroxide in 2019 or so. Production of carbonate derived from brine may rise in the early 2020s, although a sharp increase in output is not anticipated due to the sluggish ramp-up of brine assets (Tay, July 2021). Similar to most other raw materials, lithium product prices are influenced by changes in supply, demand, and the perceived supply/demand balance as well as by costs and economic variables. Mineral concentrate, lithium hydroxide, and lithium carbonate are the three final products that are most frequently sold. The producer (or agent/trader) and the customer negotiate the terms of the transaction to fit their specific needs. There is no exchange where lithium is traded.

Spot costs in China seem to demand a premium over technical-grade (>99.0% Li₂CO₃) lithium carbonate for battery-grade (>99.5% Li₂CO₃). But there have been years when technical-grade carbonate has been marketed at a premium over battery-grade. Contract pricing for technical-grade lithium carbonate are anticipated to mirror those of battery-grade. Although a decline in pricing is anticipated from 2019 to 2022, average yearly prices are predicted to increase to US\$15 000/t by 2025 and US\$20 000/t by 2032 (KELIBER June 14 2018).

Because most producers need to go through the purification and/or micronizing processes, battery-grade lithium carbonate is often slightly more expensive than technical-grade, costing between US\$500 and US\$1,000 per t CIF. This isn't always the case, though. It is anticipated that the new floor for average annual contract pricing will be US\$12,000/t, assuming that demand growth stays strong and higher-cost supply and capacity expansion are required. According to KELIBER's June 14 2018 estimate, the nominal price of battery-grade lithium carbonate is expected to rise from USD11,000/t in 2020 to USD19,000/t in 2032. During the production of lithium, numerous by-products are produced, including analcime sand and quartz-feldspar sand, both of which may have commercial significance. Analogime sand has the potential to be utilised in water treatment, construction, and land fill applications. Experiments have been conducted on the use of quartz-feldspar sand as a raw material for foam glass and geopolymer brick manufacture, as well as a filler in concrete, mortar, plaster, and asphalt. It is possible to explore the use of waste rock that has been crushed and graded as aggregate in building projects.

8. The quality of lithium found in Nigeria

Nigeria's economy, while one of the biggest in Africa, is heavily reliant on oil exports. Despite having massive mineral deposits, the nation only achieved a pitiful N496 billion from solid minerals in 13 years, according to the latest audit report from the Nigeria Extractive Industries Transparency Initiative (NEITI) (MONEYINAFRICA, 2024). But while investors pound on doors in the US and China, as well as in Africa, Zimbabwe, and the Democratic Republic, Nigerian raw materials are largely unexplored, and in those cases, little thought is given to producing them in large quantities for export. Critical raw material (CRM) consumption is expected to rise by a factor of four for graphite, five for cobalt, and eighteen for lithium by 2030; by a factor of thirteen for graphite, fourteen for cobalt, and nearly sixty for lithium by 2050, according to a report published in October by Carnegie Endowment International (Eleanya, 2021). Africa and Nigeria stand to gain from the anticipated need for CRMs, which could displace Asian supply chains.

Owing to sustained investment and robust local and domestic demand for its lithium-ion batteries, China continues to dominate the ranks of the lithium-ion battery supply chain. Eighty percent of the world's battery cell production capacity is currently located in this Asian country, and in the next five years, capacity is predicted to more than double, producing enough battery cells for

almost 20 million electric vehicles (Bloomberg NEF Report, 2021). Although the Nigerian Geological Survey Agency (NGSA) has explored lithium to some extent in Nigeria, experts believe further study must be done on par with that of developed nations (Olade, February 2024).

Nigeria's mining industry faces numerous difficulties, including low technical competence among all parties involved, a lack of a unified fiscal framework that permits problems like double taxation at the federal and state government levels, and a host of other issues. The majority of stakeholders in the industry have a poor understanding of solid minerals and the mining ecosystem. First and foremost, it should be noted that the discovery is not the same as a commercial find. Actually, it should only be viewed as the beginning of the long road towards becoming recognised as a deposit with commercial viability—one that can be mined and extracted and then transformed into a product that can be sold to customers. In actuality, just a handful of these hundreds of "discoveries" (finds)—after undergoing numerous phases of exploration and development—may turn out to be mines. A value can only be attributed to such a finding at that point. A small to medium sized deposit may require five to ten years to completely investigate and bring it to production (THECONVERSATION, 2022). Assuming no unanticipated financial, technical, or other difficulties arise. We should only anticipate a shorter time frame in an extremely rare and highly feasible set of circumstances.

Many elements have the power to enhance or detract from the development process. The expense of extraction technologies, market dynamics, attractive fiscal and regulatory frameworks, demonstrating the economic grades and volumes (or tonnages) of the mineral ores, and other logistical and sociopolitical challenges are some of these. The beneficiation and extraction of lithium from ores must be optimised and improved in order to meet the growing demand for the metal. Like most minerals, lithium ore is processed first through a process called beneficiation, which comes before the compounds are extracted in subsequent steps. Through a variety of beneficiation techniques, lithium minerals are transformed into lithium concentrates and hydroxides along the lithium supply chain. In extractive metallurgy or the mining sector. Any procedure that eliminates the gangue minerals from the ore to produce a higher-grade product (ore concentrate) and a waste stream (tailings) is referred to as beneficiation.

8.1 The Importance of Value Addition

The Federal of Nigeria rejected *Tesla's* offer to buy raw lithium from the nation, according to Olamilekan Adegbite, the former Minister of Mines and Steel Development. This is because the Federal of Nigeria no longer wants foreign companies to mine the country's mineral resources and ship them out without adding local value (THE NATION, August 22, 2022). TESLA had proposed to invest in the mining industry in Nigeria in order to export high-quality lithium from the nation for use in the production of batteries for electric vehicle batteries, but the Nigerian government had turned down the offer. The government's stance was that TESLA and other foreign companies with similar interests should establish an industry and manufacture batteries in the nation. The Nigerian government now holds the view that all mining in Nigeria must give value to the nation. The Federal Government also held the view that, rather than exporting these mineral resources, foreign investors ought to be urged to establish manufacturing facilities here and utilise the resources as raw materials for domestic production in order to boost employment and the GDP of the country. Future mineral exploitation must be linked to sustainable development. The current worldwide emphasis is on creating a low-carbon economy that makes use of future mineral

resources.

Driven by the growing need for battery materials, it is now projected that over the next 20 years, electric vehicles and battery storage would make up around half of the energy minerals demand. Copper, cobalt, lithium, nickel, and platinum group minerals make up the majority of the minerals used in battery storage. Lesser amounts of aluminium, chromium, graphite, manganese, rare earth elements, and zinc are also included. According to Azevedo *et al.* (2022), the demand for minerals from electric vehicles and battery storage is expected to increase tenfold to thirtyfold by 2040.

Nigeria needs to participate in the international effort to exploit its enormous reserves of these material resources. To recover from the low level of electricity output, the government must take significant action to explore its lithium ore resources and diversify the nation's energy mix to include more renewable sources. Nigeria is forced to enter the global competition to improve the value chain for vital minerals. According to Bloomberg's growth estimates, the percentage of sales of electric vehicles is expected to increase from 2% in 2018 to 35% by 2030 (BLOOMBERG, 2023). However, robust supply chains—which depend on a stable and sustainable supply of raw resources, particularly minerals and metals, the majority of which are abundant in Nigeria but terribly underutilized—will be necessary for the expansion. Large commercial quantities of lithium ore, nickel ore, and cobalt are discovered in various states in Nigeria. These three raw materials are needed to make batteries that power electric vehicles.

8.2 Environmental Impact of Mining Activities

Mining can have a variety of effects on the environment, most of them unfavourable. These effects might include a decrease in regional and global biodiversity as well as an escalation of climate change. The range of distinct species of creatures that can be found in a certain location—which could be anywhere on Earth—is referred to as biodiversity. Mining operations can have a lot of harmful effects. Climate change, pollution, soil erosion, deforestation and habitat degradation, conflicts between humans and wildlife, and biodiversity loss are a few examples. Here are a few of these instances in more detail.

8.3 Deforestation/habitat destruction

Large tracts of land are frequently needed for mine construction, and these areas are frequently home to natural habitats that were previously undisturbed. enormous tracts of habitat—typically forests—are destroyed in order to develop the mine, and this has additional detrimental effects due to the enormous number of people who live, work, and migrate around the mine. Other detrimental effects include wildlife poaching, excessive fishing in rivers and wetlands, and an increase in conflicts between people and wildlife, especially in places with high concentrations of large predatory species (such as crocodilians and big cats). Conflict miners who are aggressive also frequently have a negative impact on the local indigenous human populations.

8.4 Pollution

Numerous of these mines release waste products into nearby river systems, which may have extensive and long-lasting effects later on. These waste materials contain hazardous chemicals that find their way into rivers, lakes, and wetlands downstream that are used by people for drinking water and fishing. These pollutants include arsenic, lead, and mercury. These dangerous substances accumulate in fish tissue through a process known as biomagnification, which then affects higher-ranking species (like humans) that eat fish. The term "biomagnification" describes

the increased accumulation of a poison or toxins in organisms that progressively move up the food chain. An estimated 180 million tonnes of toxic pollutants are released into water bodies globally each year by mining, causing extensive harm to fish species and tainted drinking water (Bashir, 2020).

8.5 Loss of Biodiversity

In certain regions of Nigeria, illicit sand mining operations are posing a serious threat to the environment and public safety. Sand mining is a lucrative industry there. The degree of biodiversity in the area could be significantly impacted by the mining operations. Furthermore, between 2020 and 2022, an estimated 418 individuals lost their lives as a result of violence with sand miners, sometimes known as the "sand mafia" (STUDYSMARTER, 2024).

8.6 Climate Change

The fact that coal mining gives people access to cheap fossil fuels is likely the reason that 40% of the world's population today uses coal-powered electricity. There are also terrible effects of coal mining and use on biodiversity, the environment, and human health. But the effect of coal on Earth's climate is the one that is most well-known. Burning coal contributes greatly to human climate change and now accounts for roughly 40% of carbon dioxide emissions worldwide (WEFORUM, 2022).

8.7 Positive Impact of Mining on the Environment

Although the majority of mining's effects on the environment are detrimental, a few beneficial effects have also been identified. The most often cited benefits of mining are how they lessen their negative effects on the environment by generating jobs and enhancing local communities' infrastructure. In actuality, though, this is rarely the case because mining frequently lead to the unsustainable exploitation of the surrounding area and incite conflict. On the other hand, mines can have some very advantageous effects. Particularly, abandoned mines frequently provide vital homes for a number of species, including some that are in danger of going extinct. Actually, 64% of the bat species found in the United States use abandoned mines as a home for roosting, nursing, hibernating, and foraging/hunting. Amphibians, birds, reptiles, and rodent species are among the other creatures that make use of abandoned mines.

8.8 Ways to Reduce the Environmental Impact of Mining

Mines may be made more sustainable and ecologically friendly in a few different ways. First and foremost, issues in some places may be significantly reduced by tighter enforcement of mining legislation and the cessation of illicit mining activity. Nonetheless, some of the worst violators are big international companies involved in mining that, although it is "legal," causes considerable harm to the environment. For this reason, laws need to be upheld and amended. Even while mines are in operation, they can provide as a natural habitat for a variety of species if the right laws are observed.

Managing and maintaining mine sites properly is also essential to boosting sustainability. First things first: before mining is done, environmental impact surveys should be carried out by biologists to identify the species and habitats that may be impacted. Limits on the amount of resources that can be extracted should be put in place during actual mine operations, and every attempt should be made to recycle as much waste as feasible. It is imperative to neutralise any leachate resulting from the mining process to enable the elimination and oxidation of any harmful

compounds prior to their introduction into the ecosystem. Leachate is a liquid that has been tainted by the substances it has come into contact with. Following the end of mining, the region needs to be returned to its natural form. Mine reclamation is the term used to describe this post-mining restoration, which may include replanting the old mine area or even the reintroduction of wildlife species. Replanting and restoring an area with trees and vegetation is known as reforestation.

9. Mineralogy of lithium bearing minerals

Pegmatites, which are hard rock complex aluminium silicate deposits, are frequently found in lithium ores (Bale and May, 1989, Colton, 1957). According to Colton (1957), pegmatites are intrusive igneous rocks mostly made of interlocking grains of mica, spodumene, feldspar, and quartz. Lithium minerals including spodumene, petalite, lepidolite, and amblygonite are present in the lithium pegmatite ores (Bulatovic, 2015). There have also been reports of other lithium minerals, including eucryptite, triphylite, and zinnwaldite.

9.1 Lithium from brine lake deposits compared with hard-rock deposits

Brine lake deposits are less expensive to generate lithium from than hard-rock resources, and up until recently, brines accounted for the majority of lithium production (Sahoo *et al.*, 2020). But during the past several years, as demand has surged, so too has lithium output from hard-rock mines. In 2020, hard-rock resources accounted for more than half of the world's lithium production (5 operations in Australia and 1 in China). According to the United States Geological Survey (2015), the remaining amount was derived from brine activities in China (2 operations), Chile (2 operations), Argentina (2 operations), and the United States (1). Brine deposits are less costly to run, but new research indicates that they have a big environmental impact. Two orders of magnitude more water must be evaporated during the lithium extraction from brines procedure than during the processing of hard-rock deposits (Bhappu and Fuerstenau, 1964; Grammatikopoulos *et al.*, 2020). This is because each tonne of lithium carbonate generated during the process requires half a million litres of water to evaporate. A number of businesses are creating ecologically friendly methods for removing lithium from brines. But industrial use of these methods has not yet occurred (Sahoo, Suresh and Varma, 2021).

It is thought that the world has enough lithium reserves to meet future demand, but this is dependent on the availability of brine and hard-rock deposits (Wills and Finch, 2015; Sahoo, Suresh, and Varma, 2021). Canada is home to about 2.5 percent of the world's lithium reserves, which are almost exclusively found in hard-rock occurrences in the Northwest Territories, Quebec, and Manitoba (Jacobson, 1946). A cooperative action plan to enhance the security of vital metals, such as lithium, was announced by the governments of Canada and the United States in 2020 (Sahoo, Suresh, and Varma, 2019). The development of Canada's hard-rock deposits is essential to securing a competitive domestic supply of lithium; projects must be financially feasible, adhere to strict environmental rules, and, most importantly, be supported by the local community. The technical methods for increasing productivity and lowering energy consumption in the concentration of lithium-bearing minerals from Canadian hard-rock sources are the main topic of this article.

9.2 Beneficiation of lithium ores

Nine minerals that contain lithium are thought to be commercially advantageous for recovery. The most important of them is spodumene ($\text{LiAlSi}_2\text{O}_6$), which is found alongside other silicate gangue minerals such quartz, micas, and feldspars (Gibson, 2021). The three main methods for

beneficiating lithium materials are froth flotation, magnetic separation, and gravity separation (DMS). In recent years, sorting has also gained recognition as a viable technique. Although this technique is typically utilised for coarse gangue rejection, dense media separation can also be used to extract lithium concentrations from high-grade ores. When processing feed with fine particle sizes and high-grade ore, flotation is employed.

1) Hand selection method

The distinction in colour and appearance between gangue and lithium minerals is the basis for the hand selection method of sorting. The typical selective particle size ranges from 10 to 25 mm, with the economic benefits determining the lower bound of the particle size. The oldest mineral processing technique in the history of lithium mine production was hand selection. Apart from spodumene, lithionite, petalite, and amblygonite are the other materials from which lithium concentrates are selected by hand. Because of the hand selection method's high labour effort, low production efficiency, and significant resource waste, flotation or other processes have largely replaced it.

(2) Flotation method

Flotation was previously used in the industrial synthesis of spodumene concentrate. Spodumene is floated using two different processes: positive flotation and reverse flotation. The principle of positive flotation, or preferential flotation of spodumene: The spodumene is immediately floated by adding fatty acid or its soap as a collector after the finely crushed ore has been concentrated, vigorously stirred, and repeatedly washed and de-sludged in an alkaline medium created by sodium hydroxide or sodium carbonate. (Filippov, 2022).

The reverse flotation method uses a cationic collector to float the silicate-like gangue material as a foam, inhibiting the spodumene in an alkaline medium adjusted for lime and regulated using dextrin and starch as a regulator. The product in the tank is a concentration of spodumene. Spodumene is primarily selected by hand selection and flotation. Spodumene concentrate is produced using a variety of additional techniques, including thermal cracking, magnetic separation, and gravity separation (Filippov, 2022).

(3) Thermal cracking beneficiation method

Around 1100°C is the temperature at which natural spodumene's crystals switch from α to β type, and its volume increases and readily breaks into powder. Spodumene and gangue minerals can be separated by producers using grinding and screening (JXSCMACHINE, 2024).

(4) Heavy medium separation (HMS / DMS)

For the process of spodumene ore, gravity separation techniques including jigging, spiral beneficiation, and shaker beneficiation are not appropriate because the density difference between spodumene and related gangue minerals is not great. For spodumene ore, heavy liquid beneficiation or heavy medium separation is an efficient technique. Lithium mines in North Carolina and South Dakota have been produced using the heavy medium separation technique (JXSCMACHINE, 2024).

(5) Magnetic separation method

A common supplementary technique for raising the quality of spodumene concentrate is magnetic separation. For instance, the spodumene concentrate made in North Carolina, USA, through

flotation is limited to chemical grade sales due to its high iron content. Iron is extracted from the facility using magnetic separation in order to satisfy the demands of the ceramic sector. Furthermore, magnetic separation can be the primary technique for generating iron-lithium mica concentrate due to the mica's weak magnetic characteristics (JXSCMACHINE, 2024).

10. Types of Analysis for Lithium Compounds

1. XRD Analyses

Samples' X-ray diffraction (XRD) patterns are obtained at room temperature using a CuK α radiation D2 Phaser Bruker diffractometer that features a LYNXEYE detector operating at 30 kV and 10 mA. The non-oriented flat plates of the powdered samples are used for the analyses. At a scan step of $2\theta = 0.02^\circ$ and a step exposure length of 1 s, XRD patterns are collected between $2\theta = 2.5^\circ$ and $2\theta = 70^\circ$. Using the International Centre for Diffraction Data's PDF2 database in conjunction with the EVA© software, semi-quantitative relative abundances of the phases are determined. Based on the relative heights of the pattern and the I/I_{cor} values, semi-quantitative studies are carried out under the assumption that all crystalline phases are recognised and that their sum equals 100% (BRUKER, 2024).

2. SEM-EDS Analyses

Samples are prepared using two methods prior to analysis. Initially, a thin layer of carbon is applied to the surfaces of graphite supports onto which powdered samples have been adhered. In the second, the powdered sample is poured into epoxy resin and left to stand until it solidifies. To obtain a highly polished finish, the surfaces of the hardened materials are polished and ultrasonically cleaned using deionized water. A tiny layer of carbon is applied to the surfaces of the samples made using the two methods. During analysis, the coating is intended to improve good electrical conductivity.

3. Mineral Liberation Analysis

For its measurements, Mineral Liberation Analysis (MLA) combines point-generated X-ray signals and BSE pictures with contemporary image and pattern recognition (Fosu *et al.*, 2021; LaBranche *et al.*, 2023). The unprocessed concentration is let to stand in resin to harden, and then the samples' surfaces are polished. The MLA is then applied to the prepared samples. When grain particles come into contact with one another as a result of their settling mode in the resin, DataView's online programme software package detects them. The shadow/boundary identification process is then used to separate the grains from one another. In order to prevent potential interference that could result in mistakes in liberation results and mineral phase identification, this is done to make sure that all of the grain particles in the sample are well separated from one another. By comparing elemental composition X-ray analysis with a standard database, mineral phase identification is accomplished. In this case, the concentrate particles (found in the resin) are separated into their distinct mineral grains, with the borders between them marked by the average BSE grey level. The apparatus carries out a methodical point X-ray elemental map that is connected to particular grains according to variations in the grey level from the composite particles' BSE map. To identify each mineral, the resulting X-ray elemental map is compared to its associated average atomic number (AAN). When there are doubts about the identity of a mineral because of overlaps in grey levels or similar AAN minerals, the area X-ray analysis finds these anomalies and uses X-ray mapping to help distinguish and identify the

minerals. After that, the minerals-related data are saved and shown using the MLA DataView programme (Fosu *et al.*, 2021; LaBranche *et al.*, 2023).

4. X-ray Fluorescence (XRF) Microscopy and Inductively Coupled Plasma—Optical Emission Spectrometry (ICP-OES)

To perform the bulk assay, the sample's major components and minor components are determined using XRF and digestion/ICP-OES, respectively.

5. Bulk Chemical Analysis

The elemental composition of the concentrate as determined by the oxides acquired using XRF and ICP-OES.

6. Determination of Lithium in Lithium Minerals

Two analysis techniques are examined: solution-flame photometric and spectrographic. Spark and arc spectrographic methods were briefly investigated in the lab, but the results seemed too unpredictable for routine lithium analyses in the expected range. In contrast, flame photometry showed greater promise, and efforts are now being directed towards creating a process that would meet the requirements.

A Beckman spectrophotometer with a 9200-flame attachment, Model DU, is the tool employed for the experiments. The sensitivity control is almost at maximum, the wave length dial is set at 671 milliseconds, and the selector switch is set at 0.1 to run the machine. With each new burner used, the oxygen and hydrogen pressures are adjusted to achieve the maximum intensity of the lithium flame. To bring the instrument readings to predefined values, the unit's slit width is modified. A red-sensitive cesium cell provided by the manufacturer serves as the detector. The readout in every instance was the percent transmission; in this study, "relative intensity" refers exclusively to the instrument reading for the emission of the lithium 671 millimicron line (BECKMAN, 2024).

7. Particle Size Analysis

One of the main areas of study is the development of affordable lithium-ion battery cathode materials that offer a long-life cycle, high safety performance, and outstanding capacity. These efforts are rapidly progressing and have emerged as the primary focus of the battery industry. According to statistics, at the beginning of January 2021, lithium-ion battery production in the automobile industry was operating at full capacity, and year-end orders had grown astronomically (AZOM, 2024). As a result, there was a lack of upstream, high-performing raw materials, especially for the cathode materials used to make lithium-ion batteries. High concentrations of lithium carbonate, lithium cobalt oxide, lithium iron phosphate, and nickel ternary compounds are frequently found in lithium-ion battery cathode materials.

The size and distribution of all the cathode material particles have an immediate impact on the charge and discharge performance of these batteries. Therefore, it is very important to measure the particle size distribution of the materials used in the cathode of lithium-ion batteries when developing and manufacturing these batteries. In lithium-ion batteries, lithium iron phosphate is frequently utilised as the cathode material. The processing and application performance of lithium iron phosphate in lithium-ion batteries is determined by its particle size distribution. The particle

size distributions of five specimens of lithium iron phosphate are quantified using the Bettersizer 2600 laser particle size analyzer (Better Size Instruments, 2024).

11. Mineral Analysis Laboratory

A typical Mineral Analysis laboratories comprise analytical instruments and preparation facilities in the following areas:

- Mass spectrometry;
- Geochemical clean labs;
- Electron microscopy;
- Elemental analysis;
- Optical microscopy facility;
- Sample preparation facilities.

11.1 Mass Spectrometry

11.1.1 Solution ICP-MS

The complete range of trace elements, from lithium to uranium, can be analysed using Agilent 7500 and Agilent 8800 ICP-QQQ devices in a variety of geological and environmental samples (rock digests, soils, and waterways) (AGILENT, 2024).

11.1.2 Laser ablation ICP-MS

A Photon Machine Analyte G2 193 nm excimer laser system with a HelEx II 2-volume cell can be connected to ICP-MS instruments. With this configuration, the apparatus may simultaneously load nine grain mounts or four regular glass slides plus three grain mounts into the laser cell (Pullen *et al.*, 2018).

11.1.3 Ar/Ar and Noble gas mass spectrometry

Two Infra-Red fibre lasers, a 193nm excimer laser from Photon Machines, and a CO₂ laser system are among the mobile laser units that are fully compatible with the MAP 215-50 and Nu Instruments Noblesse mass spectrometers. When combined, this enables the examination of numerous materials (NU-INS, 2024).

11.2 Geochemical Clean labs

PicoTrace Clean-Air workstations (class E XIV air supply) with electronically controlled PTFE hotplates should be located within a metal-free clean room suite. Weighing rooms with five or more balances should be made available, and each lab should have access to a clean water supply (>18.2 MΩ).

11.2.1 Electron Microscopy

a. Electron Microprobe Analyser (EMPA)

The Cameca SX100 equipment can test most element concentrations at ppm concentration and beyond and is capable of both WDS and EDS analysis. For best analysis, the holders can hold six 1-inch mounts or four thin sections (CAMECA, 2024).

b. Scanning Electron Microscope (SEM)

High resolution imaging, large-area mapping, EDS chemical analysis, EBSD, and CL methods are among the applications for SEMs (THERMOFISHER, 2024).

11.3 Elemental analysis

11.3.1 ICP-OES

A range of aqueous samples can be elementally analysed using an inductively coupled plasma atomic/optical emission spectrometer (ICP-AES / ICP-OES), which can report both major and trace element contents. It is primarily utilised for the identification of trace metals in environmental materials, including water samples, soil extracts, mixed chemical analyses, and projects for commercial purposes. This instrument's strengths include reporting numerous elements at once, auto-sampling, good repeatability, and high precision. According to AGILENT (2024), this device is utilised for both commercial and scientific purposes.

11.3.2 XRF

The elements contained in solid rock samples, sediments, and powders can be measured in the field or in a lab using the Niton XL3t handheld XRF instrument. Elements as light as Mg, Si, and S can be analysed by the device, and it can also trace elements like Pb, Mo, and V. For the majority of elements examined, detection limits are significantly lower than the average crustal composition (THERMOFISHER, 2024).

11.4 Optical Microscope Facilities

11.4.1 Microscope facilities

It is recommended that dedicated microscope facilities have both petrographic and reflected microscopes for examining thin layers of rock, as well as microscopes for micropalaeontological examination (palynomorphs, foraminifera, insects, and diatoms). In addition, the facility should have a six-figure microbalance for weighing small samples, an image analysis system for assessing the size of microscopic shells, and an inverted microscope and micromanipulation system for quickly selecting palynomorphs and other microfossils.

11.4.2 Virtual Microscope

Rock collections already housed in museums, academic institutions, and other organisations worldwide are now more widely accessible thanks to the Virtual Microscope. Without the need for expensive microscopes and equipment for thin section production, users of the virtual microscope can study and explore minerals and microscopic characteristics of rocks, assisting in the development of classification and identification abilities (Virtual Microscope, 2024).

11.5 Sample Preparation Facilities

11.5.1 Thin section laboratory

The plant should be able to create standard and larger-sized thin sections of a variety of materials, including grains, single crystals, clay, meteorites, rock, pottery, and coal.

11.5.2 Rock crushing and mineral separation facilities

With a rock splitter, jaw crusher, milling equipment, heavy liquid facilities, and a Frantz magnetic separator, the facility should be fully equipped to crush and separate minerals from rocks.

11.5.3 Sedimentary/paleontology preparation

Sediment core splitters, walk-in refrigerators for storing cores, freezers, extractor hoods for HF acid digestion of samples, centrifuges, ovens, precision balances, water baths, hot plates, and pure water supplies should all be part of a dedicated suite of laboratories for the storage, preparation, and analysis of sedimentary and paleontological samples.

11.6. Geodata Surveying Equipment

Modern geodata should all be surveyed using precision or hand-held GPS devices.

11.7 Mineral Processing and Metallurgical Testing

A procedure for the beneficiation of the pegmatite spodumene deposits and the subsequent processing of the spodumene concentrate to create battery grade lithium carbonate as the final, marketable product has been developed through a series of metallurgical test programmes. Figure 1 depicts a typical process flow diagram, which is divided into three sections: hydrometallurgical process, conversion, and mineral processing.

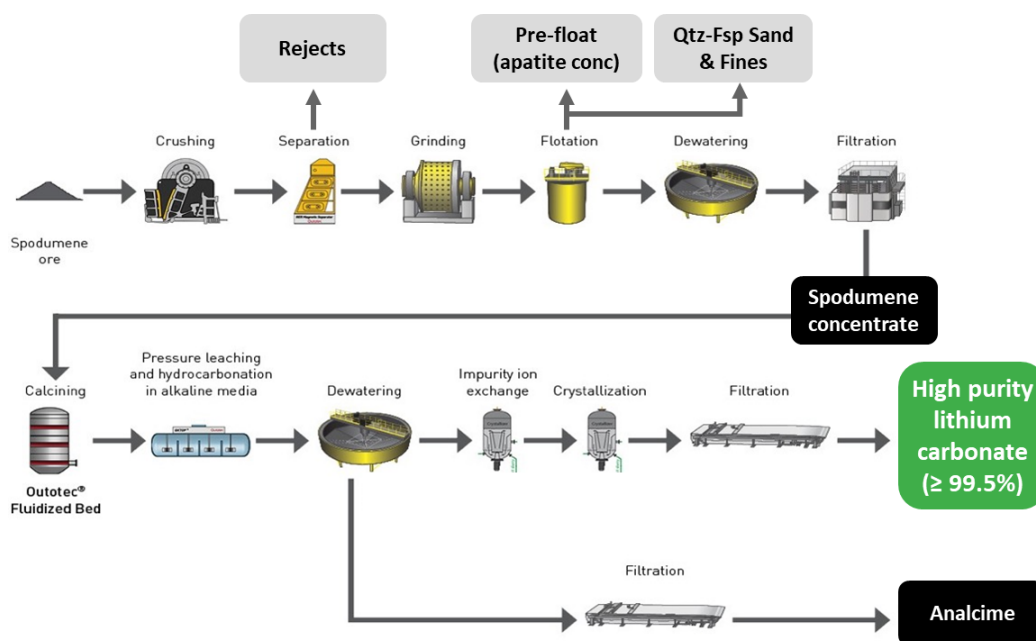


Figure 1. Simplified flowsheet of the KELIBER process route (KELIBER, 2018)

The synthesis of spodumene concentrate for the subsequent step is the purpose of the mineral processing circuit.

12.1 Overview of the Treatment Route to Produce Lithium Carbonate

Extensive test work forms the basis of the treatment pathway used to convert spodumene into lithium carbonate. The overall flowsheet that was chosen includes a soda pressure leach method

to make lithium carbonate, a rotary kiln for converting alpha to beta spodumene, and a traditional spodumene concentrator. Figure 2 shows a streamlined process block flow diagram.

The soda pressure leach process (in continuous mode) is not yet in commercial operation, but the process flowsheets that have been designed are based on unit operations that have been proved in the chemical and mineral processing industries. Nonetheless, a pilot plant has validated the overall procedure (Bishimbayeva, 2018).

12.2 Key Mining Project Criteria

The following are the main requirements for a normal mining project (STOCKHEAD, 2024):

1. Establishing the nominal ore throughput: For instance, a plant with a design value of 650 000 tpa and a nominal ore throughput of 600 000 tpa.
2. The rate of yearly manufacturing of lithium carbonate: For instance, with the chosen nominal throughput rate, the yearly production rate of lithium carbonate will be 11,000 tonnes.
3. Over the course of the mine, the head grade of the spodumene ore will be 1.04 Li₂O%.
4. The targeted Li₂O content: As an illustration, the spodumene concentrate's goal Li₂O content is 4.5% and 99.5% Li₂CO₃ of the finished product.
5. The minerals processing plant will be available. For instance, it will manufacture lithium carbonate with an 85.6% quality level and 91.3% efficiency.
6. Given the relative complexity of the flowsheet, a high degree of automation will be used; g. Equipment will be chosen for dependable performance and ease of maintenance; and h. In order to decrease building costs, layout engineering will guarantee that all equipment is easily accessible for maintenance and operation while maintaining a small footprint.

13. Typical Recoveries in the Lithium Carbonate Production Process

Table 3 summarises typical lithium recovery values for the various phases of the manufacturing of lithium carbonate.

13.1 Typical Reagents and Consumables needed in a lithium carbonate plant

The consumables and reagents for the lithium carbonate plant include:

1. Water – process and de-mineralised water
2. Steam – high and mid pressure steam
3. Flocculant
4. Sodium carbonate
5. Calcium hydroxide
6. Magnesium hydroxide
7. Sodium hydroxide
8. Sulphuric acid
9. Carbon dioxide.

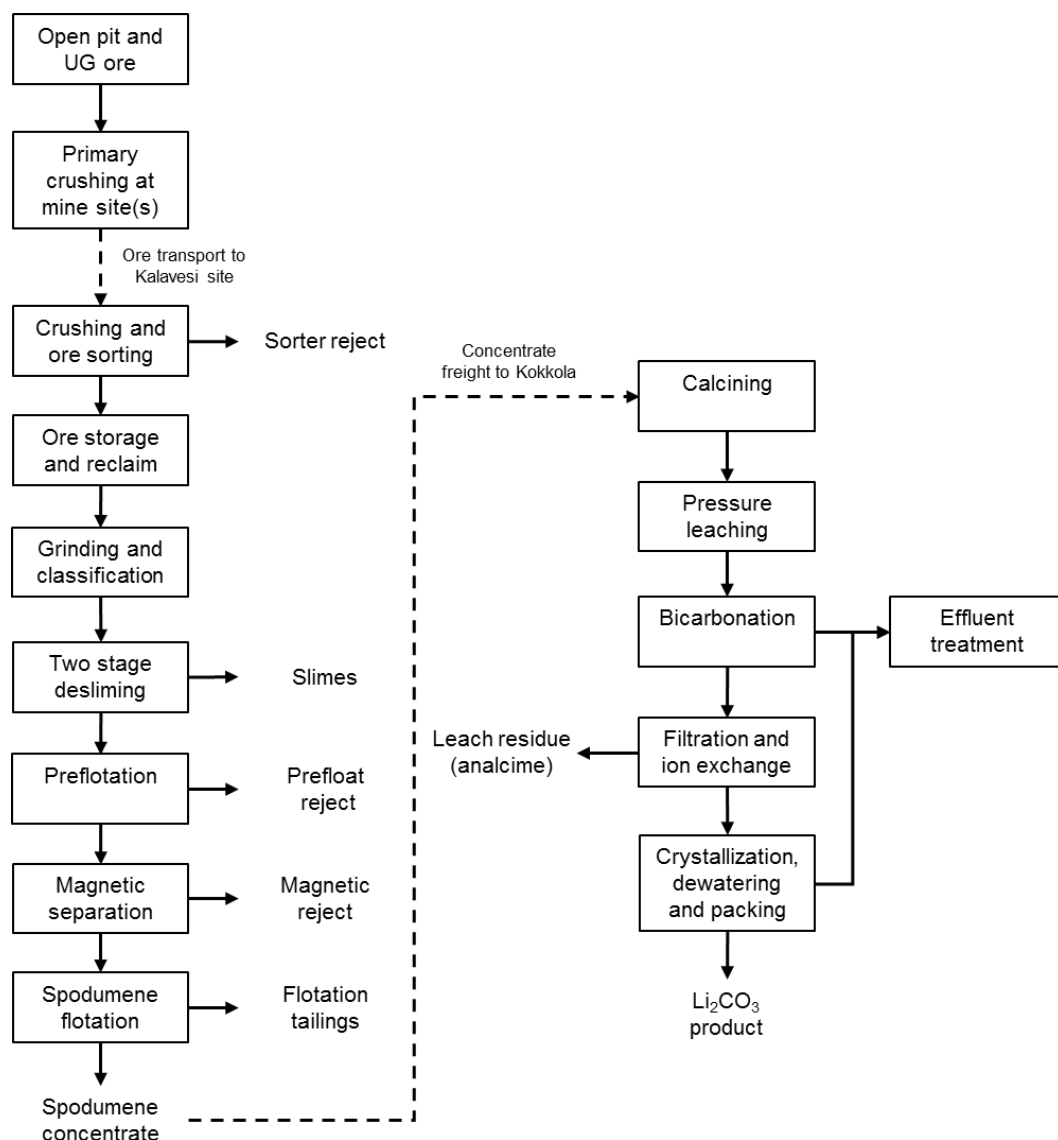


Figure 2. Simplified overall process block flow diagram to produce lithium carbonate (KELIBER, 2018)

13.2 Typical Project Infrastructure

The major infrastructure for the project are presented in Table 4.

14. Feasibility Studies Processes

A feasibility study is a thorough examination that takes into account every important factor associated with a proposed project in order to assess the project's chances of success. Assessing a plan or project's viability is called a feasibility study. A feasibility study evaluates a project's viability to ascertain the likelihood of success for the endeavour. The purpose of the study is also to pinpoint prospective concerns and issues that might come up when the project is being pursued.

Table 3. Recovery figures in the lithium carbonate production (KELIBER, 2018)

Area	Concentrate grade%	Recovery %	Basis
Minerals Processing	4.5%Li ₂ O%,2.09%Li	87.3%	Flotation test work in laboratory and pilot scale. Recovery varies by deposit and this is a typical average value
Conversion	4.5%Li ₂ O, 2.09%Li	>95.0%	Metso Minerals pilot test 2017
Leaching yield	4.5%Li ₂ O, 2.09%Li	89.0%	Average value from Outotec test work 2017
From concentrate to Li ₂ CO ₃ product		83.9%	Outotec engineering estimate
Overall recovery from ore to Li ₂ CO ₃ product		73.2%	Average calculated value. Varies from one deposit to another due to differences in recovery in mineral processing

A Definitive Feasibility Study is required for any mining project (DFS). Among these methods are (GOSSELIN MINING, 2024):

1. Estimates of mineral resources and ore reserves that outline the process treatment path and adhere to the JORC Code of 2012.
2. In order to evaluate the project economics, capital and operating expenses have been established, and a discounted cash flow model has been created. Most mines have a 13-year lifespan, however many projects can extend that to 20 years by buying spodumene concentrates from outside sources for roughly 7 years after the mines' existing resource constraints are met.
3. The necessity of a project's definitive feasibility study (DFS). This study outlines the process treatment method and provides estimates of mineral resources and ore reserves that adhere to the 2012 edition of the JORC Code. To evaluate the project economics, capital and operating costs should be established, and a discounted cash flow model should be created.
4. The project's environmental components are significant and have undergone extensive research to guarantee that the project's impact is minimal and that all Finnish environmental laws, permits, and international recommendations are fully complied with. The project's environmental and community components need to be handled in order to fully comply with all Nigerian environmental rules, permits, and international norms, as well as to ensure that the project's good effects are recognised and any potential negative effects are mitigated.
5. To portray the cost structure and the economic evaluation of the project as a stand-alone entity, the project's economics should be assessed using a real-basis financial model. It is necessary to evaluate the project cash flows throughout the ensuing 25 years. Future cash flows should

be estimated using the financial model, and the project's net present value (NPV), internal rate of return (IRR), and payback period should be considered while evaluating it.

Table 4. Major infrastructure for the lithium project (KELIBER, 2018)

S/No	Infrastructure
	<i>Mines</i>
1	The access roads from the mines to the concentrator
2	power transmission lines to mine sites
3	Mobile crushing unit
	<i>Concentrator</i>
1	Raw water pumping station, piping and water treatment plant
2	power transmission lines from the supplier substation
3	Required infrastructure for the concentrator and equipment:
4	crushed ore pile
5	Screening
6	secondary crusher, sorting and tertiary crusher
7	conveyors and ore silo
8	grinding, flotation and dewatering
9	concentrate storage
10	Tailing ponds: Two tailing ponds process residues and one water pond
11	Small power plant to produce heat
	<i>Chemical Plant</i>
1	Required infrastructure for conversion and hydrometallurgical plant and equipment:
2	concentrate storage
3	conversion plant
4	hydrometallurgical plant
5	Effluent treatment plant
6	Liquefied petroleum gas (LPG) storage and handling facilities
	Auxiliary facilities all at sites
1	Main switch station and electricity distribution at each site
2	Main gate, area fencing and weighbridges
3	Pipe bridges for pipelines
4	Office, laboratory and service / storage facilities.

Table 5 summarises the usual post-tax-free cash flow over the duration of a lithium ore mining project. The financial analysis should look at how sensitive the IRR is to the three primary project-affecting factors: development money up front, operating expenses, and battery grade lithium carbonate.

15.0 Business Models in Lithium Exploration

A business model describes how an organisation generates, distributes, and retains value. It can also refer to a company's strategy for turning a profit. According to Forbes Business Development Council (2021), a company generates value by producing a good or service for its clients, distributing that value to them, and then collecting value in the form of profit from those sales.

The firm outlines its target market, the goods or services it intends to offer, and any projected costs. Both new and existing businesses need to have solid business models. They support young, emerging businesses in luring capital, hiring skilled personnel, and inspiring leadership and employees. All well-established companies must periodically adjust their business models in order to stay ahead of emerging trends and obstacles. Business models also assist employees in understanding a company's future and investors in assessing organisations that catch their attention.

The transition from an economy based on fossil fuels to one with zero emissions is a problem facing the entire planet. As a result, the number of minerals needed for technologies like solar panels, wind turbines, and electric cars increases multiple times, and recycling cannot meet this enormous demand. This challenge is made more difficult for Europe by the ongoing Russian crisis in Ukraine and the realisation that we must not only decarbonise the European economy but also become self-sufficient in terms of energy and minerals from Russia. For these crucial technologies, a large number of raw materials are needed, and the quicker this shift happens, the more minerals must be mined (Azevedo *et al.*, 2022).

Mineral deposits have to be found during the exploration process before mining can start. Less than one mine is successful out of every 1000 exploration initiatives, and it might take decades for a project to go from discovery to producing mine. Furthermore, we are currently looking for lower-grade deposits, which are harder to locate and require more technical expertise to extract. All of this is happening at a time when environmental laws are getting harsher, the mining sector needs to decarbonise, and getting a social licence to operate is getting harder. This seemingly insurmountable undertaking calls into question the viability of exploration companies' business models in order to assess if business model innovation can contribute to the development of a more socially, ecologically, and economically sustainable industry.

Presently, the mineral exploration sector is not functioning in a sustainable manner concerning the social, environmental, and economic facets of sustainability. This is a major challenge for supply chains worldwide at a time when more minerals are needed more quickly than ever before. Although there isn't much research on business models in the mining and mineral exploration sectors, there is a lot of potential to improve the sustainability and efficiency of companies.

Following an analysis of several lithium mining businesses, eight innovation categories were determined (Henderson, 2022). Social, Environmental, Economic, Circular, Collaborative, Lean, Value Chain, and Technology Innovators are the categories of innovation. The lithium exploration sector now uses seven different business models. In addition to the Traditional (non-innovator) business model, the various business models were categorised as Economic, Circular, Collaborative, Lean, Value Chain, and Technology innovators. Since social and environmental innovation helped projects and companies gain a competitive edge, it is regarded as a business strategy rather than a model (Henderson, 2022).

The truth is that most businesses use a linear business model, or 'take, make, and waste,' as opposed to a regenerative one. Regenerative business, also referred to as the circular economy, aims to fundamentally alter how business is done in both our individual and collective lives as individuals and as a society. However, it is a continual journey rather than an end point, which is the fundamental idea of circularity.

Table 5. Financial evaluation summary (KELIBER, 2018)

Description	Unit	Value	
LOM (total life of operations)	Years	13 (20)	
Total Ore Tonnes Mined	Mt ore	7.41	
Annual Mine Production	ktpa average	570	
Total Spodumene Concentrate Produced	Mt conc	1.48	
Annual Spodumene Concentrate Production	ktpa average	112	
Total Spodumene Concentrate Purchased (years 14-20)	Mt	0.62	
Total Battery Grade Lithium Carbonate Sold	t Li ₂ CO ₃	214 898	
Battery Grade Lithium Carbonate Sold from Mine Spodumene Concentrate Production	t Li ₂ CO ₃	137 898	
Battery Grade Lithium Carbonate Sold from Purchased Spodumene Concentrates	t Li ₂ CO ₃	77 000	
Annual Battery Grade Lithium Carbonate Sold	tpa average	10 745	
Revenue	\$M	2,463	
OPEX (Operational Expenditure)			
Mine OPEX	\$M	228	
Unit Mine OPEX	\$ / t ore	30.78	30.78
Concentrator	\$M	126.36	126.36
Unit Concentrator OPEX	\$ / t concentrates	85.32	85.32
Conversion & Hydrometallurgical Plants OPEX	\$M	713.88	713.88
Unit Conversion Plant OPEX	\$ / t Li ₂ CO ₃	3323.16	3323.16
Other Fixed Costs and G&A	\$M	60.48	60.48
Unit Other Fixed Costs and G&A OPEX	\$ / t Li ₂ CO ₃	282.96	282.96
Total OPEX	\$M	1129.68	1129.68
Unit Total OPEX (over total life of project)	\$ / t Li ₂ CO ₃	5255.28	5255.28
Unit Total OPEX	\$ / t Li ₂ CO ₃	4781.16	4781.16
EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization)	\$M	1310.04	1310.04
CAPEX (Capital Expenditure)			0
Direct	\$M	221.4	221.4
Indirect	\$M	54	54
Total CAPEX	\$M	275.4	275.4
Permit Application Fees	\$M	1.08	1.08
Sustaining Capital	\$M	27	27
Closure Costs	\$M	12.96	12.96
Royalties	\$M	10.8	10.8
Pre-Tax NPV (Net Present Value) @ 8%	\$M	318.6	318.6
Post-Tax NPV @ 8%	\$M	243	243
Pre-Tax IRR (Internal Rate of Return)	%	24	
Post-Tax IRR	%	22	
Pre-Tax Payback Period	Years	5.5	
Post-Tax Payback Period	Years	5.7	

By maximising a product's value before recycling or reusing it, a circular strategy can assist lower waste, energy consumption, and environmental effect. This strategy can assist us in reaching goals and benchmarks while guaranteeing that we are utilising our resources sustainably, whether that means recovering parts from items that are nearing the end of their useful lives or producing goods in a fundamentally different method.

To encourage particular behaviours or activities, however, new business models must be developed. Whole operations must then be reorganised around these behaviours or activities. For instance, it could entail providing incentives to customers for returning goods when their useful lives are ended so that materials and components can be recovered, repurposed, or recycled. Above all, the circular economy may help us achieve net zero worldwide, nationally, and even inside our own organisations if we satisfy our carbon reduction commitments. Transitioning to renewable energy will only handle 55% of global emissions, according to the Ellen MacArthur Foundation, a worldwide think tank. The remaining 45% will need to come from altering how we produce and utilise materials, food, and products (Ellen MacArthur Foundation, 2024).

Circular models centred on reverse logistics and take-back programmes are already beginning to take shape. Even though these models could appear easy or simple in reality, they actually involve a lot of cooperation from all stakeholders throughout the value chain, including new approaches to supply chain visualisation and a change in the perspective of the customer.

16. Conclusion

An overview of the different locations, quantities, and methods of characterisation and beneficiation that can be applied to Nigerian lithium ore has been provided in this paper. This article includes a section on the relationship between lithium and the expansion of Nigeria's renewable energy sector. It was determined that this significant mineral's exploitation, exploration, beneficiation, and processing may help Nigeria's energy problems be solved. This article discusses the significance of value addition for several mineral ores that Nigeria exports, in addition to lithium ore. A review has been conducted on the different beneficiation and characterisation techniques that are appropriate for lithium ore mining. The study has devoted a part to this topic because of the difficulties Nigeria has previously encountered as a result of mining-related environmental concerns that were disregarded.

It was noted that not much research had been done on the characterisation and beneficiation of lithium, despite Nigeria having a lithium deposit. For the extraction and processing of lithium in Nigeria, there is an obvious need to take full advantage of this knowledge gap. It has been shown that most analyses cannot be performed by the equipment in many analytical facilities, forcing researchers to transport samples overseas. It is necessary to conduct an extensive investigation into the characterisation and beneficiation of Nigeria's lithium-bearing pegmatite ore. Since the ecologically friendly provision of mineral-based feedstock for a competitive manufacturing sector makes minerals beneficiation a complement to important national development goals.

As a result, the paper emphasises the necessity for Nigeria to establish a specialised analytical laboratory for the mineral industry and offers a list of the essential tools for this kind of facility. This paper has taken a closer look at a number of studies on the beneficiation and characterisation of lithium ore. The study demonstrates the progress made worldwide in the characterisation and beneficiation of lithium ore.

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