DOI 10.51558/2303-5161.2025.13.13.88 Review paper

EXPLOITATION OF CRITICAL RAW MINERALS IN THE CONTEXT OF MINING METHODS

Dr.sc Tihomir Knežiček[1]

[1]*Full professor, Faculy of Mining, Geology and Civil Engineering, University of Tuzla, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, tihomir.knezicek@untz.ba*

Summary

Mining methods of excavating and extracting critical raw minerals, where lithium ores belong, do not differ from the mining methods applied for metallic or non-metallic raw minerals. Each of the methods has variations and modalities that are applied depending on the ore body genesis and properties, and the applied digging or extraction mining mechanization. Globally, critical raw minerals are mined applying surface, underground and borehole - well exploitation mining methods, as well as a combination of surface and underground mining. The exploitation principles of critical raw minerals are identical to the principles of other solid mineral raw minerals exploitation, so the extraction of lithium ores, and other critical raw materials, must be considered exclusively from the perspective of mining practices and since only.
Key words: critical raw minerals, lithium, surface mining, underground mining, well exploitation.

1. INTRODUCTION

Mining is the essence of humanity's existence and progress. In today's time, absolutely everything that serves humanity, and that was made as a product of human activity, contains a mining component. Clothing, energy, communications, traffic, food, infrastructure, healthcare - it cannot function without mining products, primarily without metallic and non-metallic raw minerals. There is a wide spectrum of types of raw minerals and materials necessary for life functions, and this category also includes critical raw minerals, among which the metals lithium and boron are currently the most relevant. This "invisible" fact is rarely talked about, and mining is often seen as a difficult, dangerous and undesirable activity. And that is an activity that cannot be done anything without it. The logical sequence of the statement is that it is necessary to explore raw minerals, open mines, exploit raw minerals and in this way enable the functioning of humanity. BiH has significant reserves of various raw minerals and can build its prosperity on mining industry. In the context of the use of mineral resources, the EU believes that BiH has several opportunities for strategic partnership with the EU in the field of mineral resources, with the aim of promoting economic development and other areas, and therefore encourages BiH to identify sustainable projects, including potential in the field of critical raw minerals.

It is the fact that the exploitation of raw minerals – mining, may have a negative impact to the environment through soil degradation, soil and water pollution, disruption of biodiversity, reduction of forest areas and damaged ambient landscape. At the beginning of the 21st century,

the concept of controlling the extraction of raw minerals changed significantly, so new approaches to the use of mining equipment and the process of processing mineral raw materials were applied, as well as the application of strict environmental protection regulations. Mining facilities opened in the last 20 years in Bosnia and Herzegovina already respond to new concepts of control the mining operations and processing of raw minerals, but incidents that endanger or damage the environment still occur sporadically.

Prevention of threats for the environment are:
• compliance with the legislative framework (which foresees the recultivation and reuse of degraded areas resulting from the exploitation of minerals and form overburden dumps), monitored by the responsible mining inspections and
• the application of new technologies that prevent the negative impact of mining actions on the environment, and which provide increased safety for personnel and equipment in mining facilities, as well as safety in the raw mineral processing, especially in the area of industrial waste water treatment and percolation of overburden dump sites at open pit mines of metallic deposits.

Bosnia-Herzegovina mining works traditionally lean on the exploitation of ores of lead, zinc, barite, cobalt, gold, silver, bauxite, copper, iron, manganese, as well as the exploitation of coal, sand, gypsum, clay, salt, gravel and other raw minerals. Exploitation is based on surface and underground mining, as well as on well exploitation of salty water at the Tetima rock salt deposit near Tuzla. Bosnia and Herzegovina possess significant reserves of various metallic mineral raw materials, and exploitation is dictated by market needs, so new mines are opened, and financially unprofitable ones are closed (or conserved - sealed). Changes in the market prices of mineral raw materials or products based on raw minerals occur very frequently and often unexpectedly, which has a direct impact on mining, and thus on the effects of mining exploitation. The use of information taken from the Internet enables high-quality and efficient planning of the dynamics of mining operations, which can be adapted to changes in the market price of mineral raw materials. An example of the impact of the final product price on the mining industry is the example of the ArcelorMittal Zenica Steel and Iron Factory, where on 7 January 2024 began the process of restarting the blast furnace in order to continue the production that was interrupted in November 2023. Production was suspended on 11.11.2023 due to, as the management announced at that time, unfavourable status of the steel market. The ArcelorMittal corporation, apart from production in Zenica, also manages the largest regional iron open pit mine in Prijedor, which also suspended production during the period when the steel factory was not working. An example of internet information relevant to the raw mineral market is at the site https://markets.businessinsider.com/commodities/ , where the change in market conditions for each commodity can be monitor on a daily basis.

2. CRITICAL RAW MINERALS MINING METHODS

Availability of critical raw minerals is a condition for the global industry development of technological progress. The term raw material includes metal minerals, industrial minerals, building materials, wood and natural rubber. In 2011, the European Commission passed a

decision - the law on the official list of critical raw materials, and the list is updated every 3 years, therefore the number of raw materials that are considered critical also changes. Thus, in 2011, there were 14 raw materials on the list, 20 in 2014, 27 in 2017, 83 raw materials in 2020, and 87 candidate elements on the list in 2023. Raw materials are divided into three categories: strategic, critical and non-critical. Candidates in 2023 are 34 critical mineral resources, including 17 strategic mineral resources. Strategic mineral raw materials (and mineral products) for the EU are: aluminium/bauxite, lithium, light rare earth elements, heavy rare earth elements, silicon metal, gallium, manganese, germanium, natural graphite, bismuth, titanium metal, boron, group metals platinum, tungsten, cobalt, copper and nickel. Other critical minerals are coal (for households), phosphorus, antimony, feldspar, scandium, arsenic, magnesium, barite, strontium, beryllium, tantalum, hafnium, niobium, helium, rock phosphate and vanadium[1].

Bosnia and Herzegovina has not defined at any level of administration / entity what strategic mineral resources are for BiH, except the decision of the Government of the Federation of BiH (FBiH) that specifies that oil and gas are strategic mineral resources for FBiH.
Critical raw minerals are exploited in solid, liquid and gaseous state, and according to the aggregate state, a certain method of exploitation is applied. Raw minerals in a solid shape are usually exploited by classical methods of surface and underground mining, as well as by a combination of surface and underground mining. Raw mineral in liquid or gaseous state (oil, gases, mineral and thermal waters, lithium and boron in underground aquifers) are exploited by wells - boreholes. Well exploitation, i.e. hydro-dissolution also produces raw mineral that are in a solid aggregate shape, but which are dissolved by a liquid substance. Thus, salt rock, which is in a solid shape, is dissolved by water, which is extracted in the form of brine - salt dissolved in water. The dissolution of mineral raw materials in a solid shape is also done with chemical substances that are injected through wells, which dissolve e.g. lithium and boron ores that are in a solid shape, and are extracted by boreholes in the form of (hot) liquid concentrate.

The application of the excavation method, as well as the site location opening of the exploitation facility, depends on the genesis and geological deposit properties, the spatial location of the deposit, local conditions (water, climate, infrastructure), financial capacity of investors (land expropriation, procurement of equipment and personnel, obtaining permits) and security of materials supply needed for production processes.

2.1 surface mining of critical raw minerals

The surface mining of critical raw minerals is carried out according to the same concept as the surface mining of any raw mineral in a solid shape. It is characterized by an excavated area visible on the terrain that forms craters in the ground and overburden waste dumps in the nearby area. A crater is a formation of benches and other mining facilities that expands in surface (in all directions or in a certain direction - depending on the mining system) and down wording in

[1] European Commission, Study on the Critical Raw Materials for the EU 2023 – Final Report, Brussels, 2023.

depth during exploitation, up to the economically profitable pit bottom. In surface mining, the processes of drilling and blasting in hard rocks, digging, loading and transporting mineral raw materials are carried out. Waste material from the mine crater is disposed of in waste dumps, which belongs to the special mining facility. Overburden dumps can be internal or external. Internal dumps are the sites where overburden is deposited in an already excavated space within the pit mine contour - limits. The second type is external waste dump, where the overburden is deposited, and will remain permanently, at the sites where it was deposited outside the pit contour. Surface mining of critical raw minerals is often carried out by deep surface pit mines due to the nature of the mineral deposit. In the process of exploitation, the system of discontinuous mining system is most often applied, which includes the use of basic machinery: shovel excavators (rope or hydraulic) and trucks (dumpers). In addition to the basic mechanization, auxiliary mechanization is also necessary - bulldozers, draglines, graders, etc. In the last 20 years, developed countries have been applying automatization processes based on the satellite technologies for autonomic mining machinery management (machines without human crew). Surface mining has a negative impact on the environment from the aspect of soil degradation and eventual leaching of waste dumps on metallic deposits. In both cases, environmental protection measures can be undertaken by recultivation, conversion of excavated areas and waste dumps, and treatment of leachate from wasted dumps. Figure 1 shows the layout and size of Kathleen Valley, Liontown, Australia lithium open pit mine, and Figure 2 shows part of the discontinuous mining system of the backhoe – truck at the Greenbushes open pit mine, while the Figure 3 shows autonomous drilling rigs on lithium pit mine Greenbushes in Australia.

Figure 1. Lithium open pit mine Kathleen Valley, Liontown, Australia

Figure 2. Lithium ore truck loading by hydraulic excavator backhoe at Talison Lithium's Greenbushes in Australia

Figure 3. Drilled blastholes at Talison Lithium's Greenbushes in Australia

The impact on the environment of surface mining is primarily reflected in the large land degradation and the disturbance of the natural landscape. At the waste dumps of raw metallic minerals, leakage of water contaminated by metals can affect soil and water pollution in the vicinity of mining works, but also in remote sites where the soil and water are contaminated by polluted underground water inflow.

2.2 Underground mining of critical raw minerals

Underground mining of raw minerals is a way of extracting raw minerals by digging in underground spaces - mines. The concept and principle of mining critical raw minerals does not differ from the principle of mining metallic raw minerals applying underground hard rock mining methods.

Mining operations of digging and transportation take place in underground rooms / chambers, and the second part of the exploitation raw minerals takes place on the surface. Other elements

of the process are the transport and processing of raw minerals accompanied by supporting facilities and mine infrastructure. Several mining methods are applied in underground mining, depending on the type of raw minerals, the natural ore deposit properties and the machinery used. The production capacities are smaller compared to surface mining due to requirement to leave safety pillars, working conditions and other production influencing factors. Depending on the mining-geological conditions, mining machinery is used for digging the rock, the process of drilling and blasting, manual or mechanical loading of rock materials into the transport means and the transport of materials to the surface by conveyor belts, wagonettes, underground trucks or other means of transport . Since the beginning of the 21st century, digging and transport processes have been carried out by autonomous machinery without a human crew, i.e. processes are managed from monitoring stations located in the offices at the surface.

The lithium mine project in Jadar near Loznica, Serbia, envisages the construction and development of an underground mine with supporting infrastructure and equipment, including electric underground trucks, as well as the construction of lithium preparation and lithium carbonate production facilities.

Figure 4. Lithium underground mine Mt Marion in Goldfields region, Western Australia

Figure 5. Lithium underground mine Wolfsberg Project in Carinthia, Austria, obtained all required permits for the production in 2025

Figure 6. Lithium underground mine Wolfsberg Project in Carinthia, Austria officially starts production in 2025

The impact on the environment of underground mining is primarily reflected in the (small) possibility of land subsidence due to the formation of underground rooms - chambers (which are usually filled with solid or muddy material after the end of exploitation).

2.3 Combined mining methods of critical row minerals

Combined mining methods in mining industry generally are applied to generate maximum quantity of material to be extracted out of available ore deposit, and represent mining operations that take place in two ways.

The first combined mining method is applied in cases of simultaneous application of surface and underground mining methods. Simultaneous exploitation is, in most cases, realized by the construction of underground mining rooms starting from the area of pit crater, and the opening of underground rooms done from the bench level of the open pit mine. Thus, one spatial part of the deposit is exploited, in most cases, by a system of discontinuous mining machinery (excavator/shovel - truck), and the other part of the same deposit, which is outside the contour of the pit limits, is mined by one of the underground mining methods. In this concept, the transport of excavated raw mineral is carried out to the exit located on the of the surface mine bench where is the entrance to the deposit is, and the transport to the surface is carried out by trucks using the transport infrastructure in the contour of the pit mine - benches, berms, ramps. Another way of transporting mined raw mineral is vertical transport through a constructed shaft, which is used to transport wagonettes loaded by raw mineral and lifted to the surface. The second combined mining method is applied in cases of completion of surface mining with continuation of works applying underground mining methods. With the completion of the planned mining works in the open pit mine, the mine crater remains with the elements of the final pit contour. If the deposit of critical raw mineral has not been fully extracted (because the financial and operational unreasonableness of further deepening of the pit mine has been shown), then an underground mine is opened from the pit bottom or from one of the non-working pit benches. The opening takes place using the classic method of underground mining by creating a vertical entrance - shaft, with the subsequent development of underground mining rooms along the horizons. By advancing the works into the depth, it is possible to fully exploit the mineral deposit. The transport of excavated raw mineral is carried out by classic transport means in underground mines (chain conveyors, conveyor belts, wagonettes, mining trucks), and

upon exiting area of the surface mine, the transport to the surface is carried out by trucks using the transport infrastructure in the pit contour - benches, berms, ramps. Lithium ore in Whabouchi Lithium Mine, Quebec, Canada has been exploited by surface mining methods since 2020, and after exploitation of the deposit by surface mining (after 25 years), the opening of an underground mine is planned, which will be in operation for another 8 years.

Figure 7. Open pit mine Whabouchi Lithium Mine, Quebec, Canada

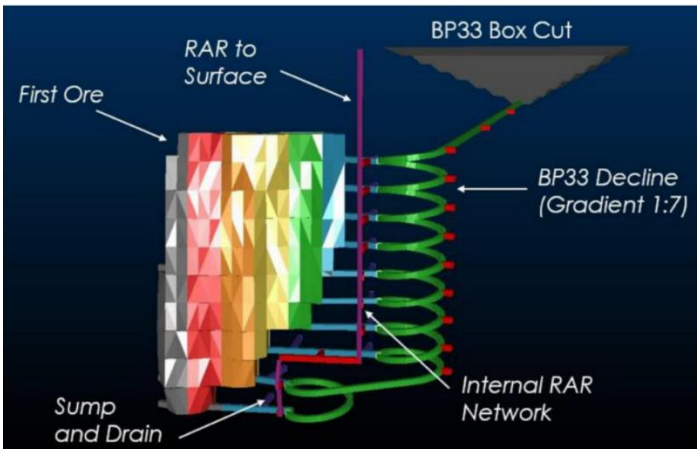

Figure 8. Projection of transfer from surface mining to underground mining in lithium mine

Figure 9. Combination of underground and surface mining with the opening of underground rooms from the pit crater floor level at open pit mine in Kathleen Valley, Australia

In the combined methods of exploitation of critical raw minerals, the processes of drilling, blasting, digging, loading, transportation, waste disposal and preparation of mineral raw materials are applied.

The impact on the environment of the combination of surface and underground mining is reflected in the combined harmful impact of soil degradation and the possibility of land subsidence due to the formation of underground empty spaces. In addition to the aforementioned key adverse impacts, there are adverse impacts caused by noise, air and water pollution, vibrations, disruption of biodiversity, removal of infrastructure for the advancement of mining operations, occurrence of landslides, and so on.

2.4 Well mining of critical raw minerals

Well (continental) exploitation is characterized by the exploitation of liquid and gaseous mineral resources, where the resource is extracted to the surface by pumping facilities and transported for further processing. Well - borehole mining is also the exploitation of solid raw minerals that are dissolved by means of a liquid medium and in the liquid form are pumped to the surface and transported for further processing.
Critical mineral resources, especially lithium and boron, can be exploited by well mining. The process of exploitation takes place by drilling vertical wells till the raw mineral deposit (injection well), drilling reversible vertical wells to the deposit (production well), cementing the wells, building an injection system, i.e. filling the wells with a concentrate of reagents that decompose and absorb lithium and accompanying minerals, installation of pumping systems for extraction of saturated liquid concentrate (brine) and directing the concentrate to further processing raw minerals.
This method of lithium extraction is considered to be the most economical and is widespread as a method in a number of countries.

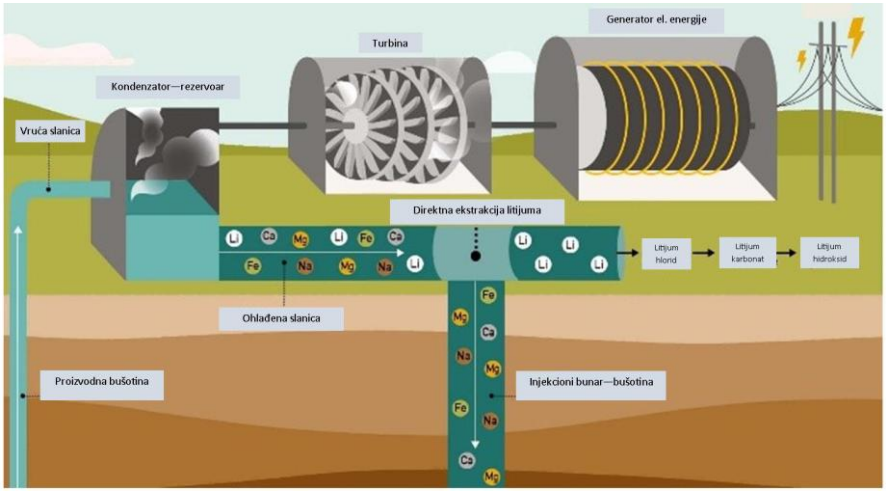

Figure 10. Borehole mining conception with concentrate injection

Figure 11. Pumping facility for injecting concentrate

With the development of technique and technology, various methods of critical raw mineral exploitation are invented and applied. Innovative methods are often an experimental works, and do not yet have mass application and often do not have proven efficiency and financial profitability of production processes. One of the new methods is the so-called "The method of direct lithium extraction"[2], and lithium is exactly the element that is obtained in different ways, depending on the natural circumstances of the environment that contains lithium and other critical raw minerals. The innovativeness of the method primarily refers to the use of evaporation basins and methods of raw mineral processing, and using basic exploitation tools - wells. Methods of lithium extraction from thermal waters, seawater, clay deposits and other natural resources are not the subject of this paper.

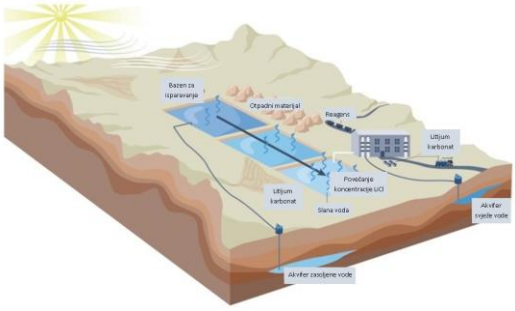

Figure 12. The concept of direct well mining for lithium extraction from saline aquifer

Figure 13. Well mining of lithium in Kachi Lithium Brine Project near Catamarca, Argentina

[2] https://lithiumharvest.com/knowledge/lithium-extraction/lithium-extraction-methods/

Figure 14. Direct well mining of lithium in The Smackover Formation deposit, Arkansas, US, which is a limestone aquifer with a high concentration of lithium

3. RECLAMATION MINING AREAS

The impact on the environment of borehole mining is reflected in the harmful effect of the concentrate containing aggressive acids that can affect the soil and water quality in the area of where of the deposit is mined, namely in the area below the wells or at least above the bottom of the well, considering that the wells are cemented (sealed), which prevents the impact of concentrates and acids to the ground where the wells are constructed.

Figure 15. Recultivated waste dump at Thacker Pass, Nevada pit mine

Elimination of the harmful effects of lithium ore exploitation is carried out by constant monitoring of production processes, processing and preparation of mineral raw materials, compliance with legislative frameworks and application of the concept of sustainable mine

development. The public often believes that the exploitation of lithium ores irreversibly devastates the environment, however, there are a large number of examples that prove the opposite. A common way of rehabilitating a devastated or degraded environment is the planned reclamation and reuse of devastated areas, such as the case of the Thacker Pass surface mine in Nevada, the Canadian-American company Lithium Americas, where after the end of each mining phase of lithium exploitation, the waste dump and the surrounding area are completely recultivated, which gives it a new value and purpose. The concept of reclamation is based on filling the craters of previously excavated areas with useless mine material (overburden or waste rock) that is created in active surface mines. In situations where this concept is inapplicable, a waste dump is formed after the mining life is first covered with soil suitable for the growth of grass and low vegetation, and then a plant cover is sown.

CONCLUSION

Lithium, like most other critical raw minerals, is exploited by various methods are applied in the mining industry. The most commonly applied methods are surface, underground, combined and well mining. Each of the methods has its own varieties, primarily in the choice of digging or extraction technique, the application of mining machinery and the execution of drilling and blasting works. The EU supports research and exploitation of critical raw minerals in BiH, and according to that strategy, it is necessary to direct and intensify the production of critical raw minerals in BiH. The intense need for lithium has caused public concern as lithium is being talked about in a negative light. Lithium ore exploitation, as well as exploitation of any other raw mineral, leaves negative impact to the environment, however, those impacts can be effectively reduced and mitigate by:

- applying regular monitoring of all mining processes,
- compliance with legal regulations,
- applying innovative techniques of lithium mining and extraction, processing and preparation of mineral raw materials and
- efficient reclamation and reuse of excavated or degraded mine sites.

LITERATURE

1. Assessment Report 94, Assessment method: Supplementary Environmental Report Finniss Lithium Project BP33 Underground Mine Core Lithium Ltd, april 2022.
2. Atlas Copco Rock Drills AB, Mining Methods in Underground Mining, Second edition, Örebro, Sweden, 2007.
3. European Commission, Study on the Critical Raw Materials for the EU 2023 – Final Report, Brussels, 2023.
4. European Lithium, Wolfsberg Project, European lithium fuelling the green energy revolution, Austria, maj 2022.
5. Knežiček T., Nurić S., Osnove površinske eksploatacije mineralnih sirovina, Tuzla, 2015.
6. Liontown Resources Limited, 2023 AGM Chair Address and Presentation, Australija, novembar 2023.

7. Lithium Power International Limited, ASX saopštenje, Drilling at Greenbushes lithium project, Australia, januar 2023.
8. María L. Vera, Walter R. Torres, Claudia I. Galli, Alexandre Chagnes & Victoria Flexer, Environmental impact of direct lithium extraction from brines, Nature Reviews Earth & Environment volume 4, str. 149–165, 2023.
9. Okubo S. i Yamatomi J., Underground mining methods and equipment, University of Tokyo, Japan, EOLSS On-line Virtual Library (nema datuma)
10. https://batteriesnews.com/lake-resources-kachi-lithium-brine-project-phase-one-definitive-feasibility-study/
11. https://systems.carmeuse.com/en/industries/lithium-extraction/
12. https://emag.directindustry.com/2022/11/03/lithium-what-are-the-main-mining-projects-in-europe/.