# TREATMENT AND RECOVERY POSSIBILITIES OF SOLID WASTE FROM MINING AND REFINING METALS USED IN BATTERY INDUSTRY

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# ABSTRACT

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**Treatment and recovery possibilities of solid waste from mining and refining metals used in battery industry**

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There is an international trend of $CO_2$ emissions reduction and electrification of machines is one of the main parts in many countries' strategies. However, batteries, that keep electric vehicles going, require raw materials that should be extracted from the earth. The process of mining and refining generates billions of tons of waste worldwide, creating environmental threats like water and soil pollution.

The main goal of this thesis is to identify possible uses of tailings, that were formed during metal mining. Extraction of precious materials was left out from this work, keeping focus on treatment and recovery possibilities of solid waste, that otherwise would be considered useless.

Based on the literature review, ten methods of recovering nickel and lithium tailings were found. According to the current knowledge, no cobalt tailings treatments were observed. Out of ten discovered methods, one was chosen for application on Finnish and Russian realities. Calculations showed that production of bricks from lithium mine tailings and glass wool waste has a great potential for both case countries. Monte Carlo analysis was performed to find most possible profits and prices of one brick for both Finland and Russia.

# ACKNOWLEDGEMENTS

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*In Lappeenranta, 1st of December 2021*

Polina Petrova

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# 1. Introduction

Mining drives the economy from ancient times. The search for minerals and metals, their excavation, brought wealth to civilizations. The process of extraction and processing of metals has been developing since the Bronze Age. Prehistoric people extracted copper and tin from ores, using fire-setting or crashing. (Schibler et al. 2011, 1259-1260)

Nowadays, with the help of policies and governments, our world is moving towards sustainability. We witness a rapid growth in a demand of the electric vehicles (EVs). International Energy Agency (2021) stated that despite COVID-19, the market of EVs grew by 40% in 2020 and is expected to expand even more in the future.

However, such a rapid transition to sustainability has put a toll on raw material extraction. The linear model of materials' consumption becomes resource-intensive and other solutions are needed. Recycling and re-use of mining waste will be an option as it will lead to the increase in resource efficiency and reduce waste accumulation. (Matinde E. 2018, 840)

## 1.1 Objectives and research questions

The hypothesis of this paper is the following: it is possible to find an economically profitable way to use solid waste after mining. The reuse of solid waste can be economically beneficial for companies and countries. The understanding of how to properly recycle the waste can be exploited in the mining and metal refining industries.

The study has an impact, as there is a limited amount of research found on mining and refining industries in Russia and Finland. Most papers are concentrated on the effects, but not on what actions should be done in order to achieve better sustainability. The findings, made in this thesis project, could lead to the development of the recycling process of waste and by-products during mining and refining metals for battery industries.

The study is mainly focused on a thorough literature review, so the reliability of the data is crucial for the research. Data for this work is collected from various sources. In addition to researching relevant articles reporting the investigation of aspects summarized in research questions below, Keliber and Nornickel companies were contacted to gain more information. The material and data provided by mining sites, located in Finland and Russia, were also utilized to create a feasible solution.

The main goal is formulated from the hypothesis: to suggest a way of efficient recycling of waste and by-products left from mining metals, needed in the battery industry. Therefore, the following three main research questions and one sub-question are answered:

1. What can mine waste be used for?
2. How can we lower the amount of waste sent to landfill?
3. What could be the financial benefit of its recovery?
    - How these calculations can be applied to Russia and Finland?

## 1.2 Structure and boundaries

This thesis consists of two main sections: theoretical and empirical. The theoretical part is the focus of the study. It aims to provide a comprehensive background on which the empirical part is written. This section consists of a thorough literature review on the most efficient practices that are applied to reduce the environmental impact of solid mining waste. The theoretical part also describes the percentage of waste, that can be recovered and the impacts of the process. Pre-conditions of the practices, their requirements, and levels of maturity are also taken into consideration.

The empirical part is based on theoretical sections. The aim of it is to see how relevant those ideas could be for the case countries: Finland and Russia. The empirical part includes calculations and application of the solutions in case countries. Calculation’s part describes the difference in prices between common brick production and brick from tailings manufacturing. The application section describes the relevancy and further possible development. Lastly, conclusions will be drawn based on the outcomes of the findings.

The structure of the work is visually represented in Figure 1. First three boxes represent the theoretical part of the research. During the background information research, the analysis of the context was done. The aim of this part was to identify the knowledge gaps that exist in the topic of solid waste from mining and refining. The formation of research questions is also included in this section. During the methodology part, research method was chosen. Data collection describes the literature review, that has been done.

The empirical part of the research is divided into two boxes. The first one explains how to apply chosen technologies to Finnish and Russian realities, the last one presents the results of the research.

Figure 1. Structure of the thesis work.

In this study, only metals, that are mostly used in battery manufacturing are taken into consideration: cobalt, nickel, and lithium. Information about those metals can be found in Chapter 2. Also, only Finland and Russia cases are explored in this paper.

# 2. Literature review

This chapter presents a literature review that covers various topics connected to battery production. First, battery types and their shares on the market are presented. Then, the development of mining industry in case counties is discussed. Moreover, metals, which are used in the production of batteries are explored. Lastly, types of waste from mining activities and their possible treatment and recycling ways are reviewed. The main goal of this chapter is to present a background for the study and to choose the most applicable and potentially economically beneficial way of solid mining waste management.

## 2.1 Battery

Batteries have a wide area of application, from alarm clocks to electric and hybrid electric cars. The last application mentioned requires a suitable battery system, that would be both safe and efficient choice for the operation.

### 2.1.1 Market

Nowadays, the interest in electric vehicles is growing. According to Virta Global research (2021), even despite the COVID-19 pandemic, the EV market grew by 41% from 2019 to 2020, numbering 10 million units of EV cars. Europe had the largest increase in sales, 1,4 million cars, the second was China with 1,2 million cars. In Europe, Germany had the biggest market share with 295 000 cars. Norway has the highest number of EV cars per capita. Now almost every citizen is making a choice towards EV models. (Dyhr 2021) Policies played a big role in switching towards e-models. The tax system makes it cheaper to buy EVs. Even though the import price of EVs could be higher, holders of EVs do not pay $CO_2$ tax, $NO_x$ tax, 25% VAT, and weight tax. Saving on taxes could be around 12 000 euros and more. (Norsk Elbilforening)

Figure 2 demonstrates the number of new cars registered globally. The drastic increase happened in 2020. Such a big increase can be explained by the registrations that European Union has introduced.

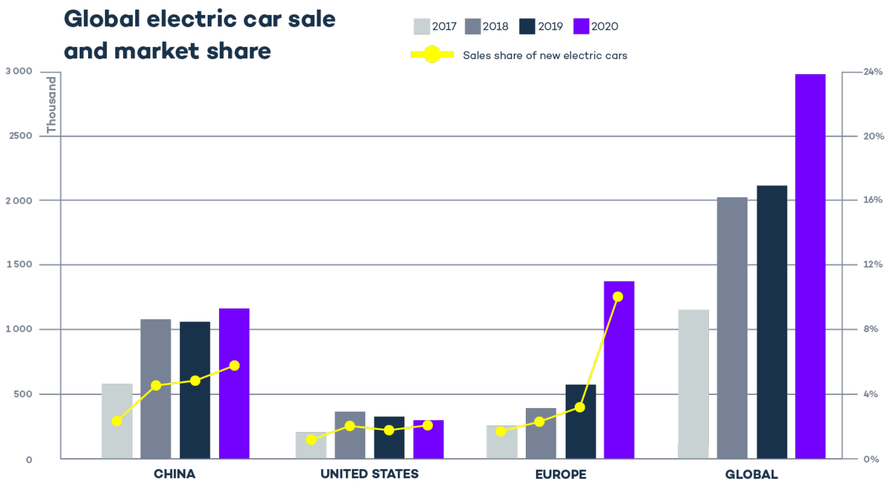


Figure 2. Global EV market (Virta Global 2021).

In July 2021 European Commission suggested corrections in policies to meet the previously set ambition of reducing greenhouse gas emissions by 55% compared to 1990 by 2030. In order to achieve set goals, European Commission suggests introducing stickier $CO_2$ standards for cars and vans. Those policies assume that the average $CO_2$ emissions of new cars should go down by 50% by 2030 and by 100% by 2035. An infrastructure for charging should be made. (European Commission 2021)

On the 6th of May, the Finnish government has presented the roadmap to achieve a 55% reduction by 2030. The roadmap is divided into three steps. The first step introduces subsidies for not using fossil fuels. The second step will access the effects of remote work and new transport services. This assessment will be ready by Autumn 2021. The last step includes a decision of corrective measures if they are needed. The ambition of the Finnish government is to have 700 000 electric cars on roads by 2030, where at least half would be fully electric. In 2020 there were more than 9500 EV. (Ministry of Transport and Communication 2021) Valmet has been producing EV cars in Finland since 2009 and in 2022 in collaboration with Dutch start-up Lightyear, they are planning to release a new car, Lightyear One. (Lightyear 2021)

In Russia, the EV market is also growing. EV sales doubled from 2019 to 2020, from 353 to 687 respectively. The Russian government is planning to invest around 10 billion euros into the development of electric cars. It was claimed the goal is to reach 1,5 million EVs on roads by 2030. (The Moscow Times 2021a) Policies on the no-tax import of EV to Russia came into force in 2020. (Kireeva 2020) Currently, there is no factory site in Russia that would develop EV cars. Therefore, Ford claimed to release an electric van Transit in 2022 on the first Russian factory site. (The Moscow Times 2021b)

### 2.1.2 Battery types

There are several types of battery systems that can be used in EVs. Each of them has its own positive and negative sides. Figure 3 represents different a time of batteries that have been used in EVs throughout time.

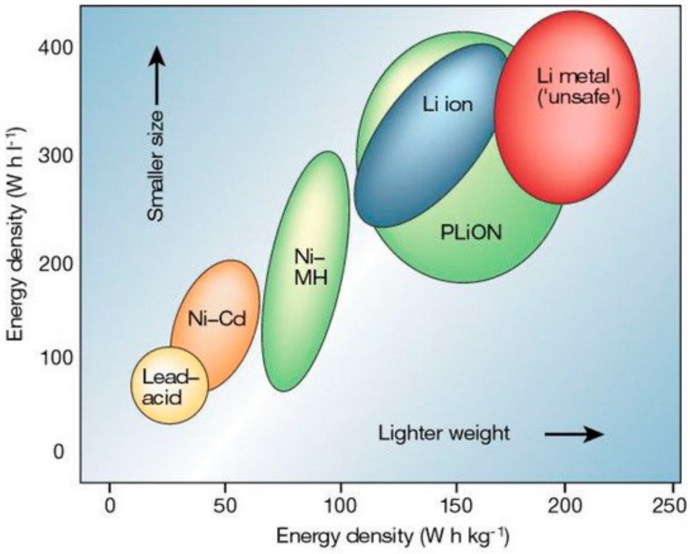


Figure 3. Battery technologies used in EV (Miao et al. 2019, 2).

Lead-acid has been developed in 1859. It was the first rechargeable battery that was invented and since those times it is still in use, due to its low cost and good recharge efficiency. Most frequent applications include scooters and electric bicycles. However, lead-acid batteries did not gain big popularity in EV technologies as they have a short service life and low energy density. Due to those factors, in EVs lead-acid is used only as a supplement to the main battery. (Jung et al. 2015, 3-4) The lead-acid battery is based on the reaction between the positive electrode, lead dioxide ($PbO_2$), and negative electrode, spongy lead (P), in an aqueous sulphuric acid electrolyte. (EASE 2016a) This process is demonstrated in Figure 4.

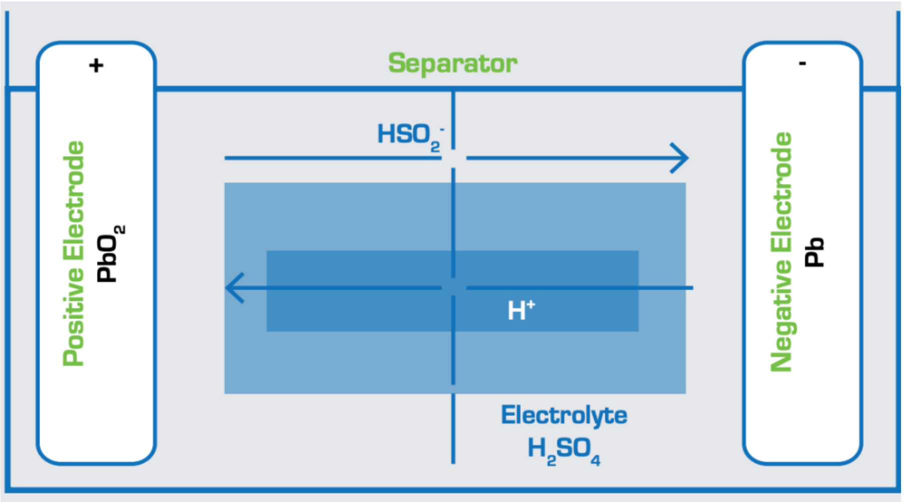


Figure 4. Lead-acid battery (EASE 2016a).

The chemistry of lead-acid depends on the reaction between lead dioxide ($PbO_2$) positive electrode and lead (Pb) negative electrode in sulfuric acid solution. The positive electrode is responsible for performance and life cycle, while the negative electrode establishes the work of the battery in cold temperatures. (Jung et al. 2015, 3-4) Electricity is generated, when the difference in potentials on electrodes is formed. (Pavlov 2017, 29-31) Process formula is the following (Jung et al. 2015), where the left side is the product of charge, and the right side is the product of the discharge:

$$Pb + PbO_2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_20 \qquad E = 2.0V \qquad (1)$$

After Lead-acid, Nickel-Cadmium, or Ni-Cd, was developed. The capacity has increased but voltage problems have been occurring. (Miao et al. 2019, 2) Such an issue is called the “memory effect” and it happens, when the battery is charged before being fully discharged. This decreases the working voltage and makes the battery lose its initial capacity. (Sasaki et al. 2013, 569) The principle of working is similar to a lead-acid battery, however, in this case, the reaction takes place between nickel oxide-peroxide as a positive electrode and metallic cadmium as a negative electrode. Figure 5 is a visual demonstration of the process. (EASE 2016b)

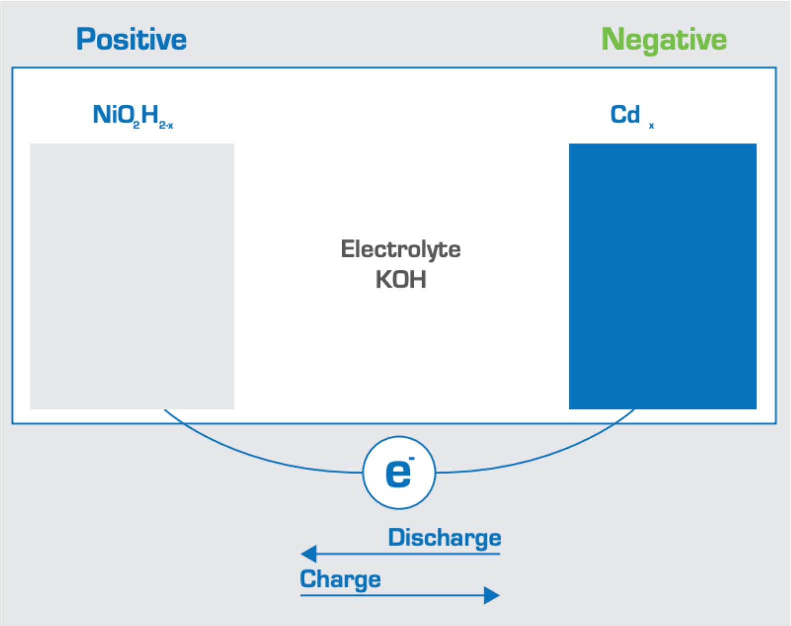


Figure 5. Nickel-Cadmium battery (EASE 2016b).

The overall reaction of the process is presented below (GP Batteries, 4). Reading the formula from left to right means a charge, while from right to left – a discharge:

$$2Ni(OH)_2 + Cd(OH)_2 \leftrightarrow 2NiOOH + Cd + 2H_20 \qquad (2)$$

As in Ni-Cd batteries, Ni-MH (Nickel-Metal Hydride) batteries also have nickel oxide-peroxide as a positive electrode. However, the negative electrode is different and consists of a hydrogen-absorbing alloy. (EASE 2016c) The process can be seen in Figure 6. Different anode makes Ni-MH batteries have higher energy density and lower “memory effect”. (Revankar 2019) They also have longer lifetime, if compared with lead-acid batteries. Despite the benefits, Ni-MH is considered to be expensive and also unsatisfactory in terms of self-discharge rates. (German 2004)

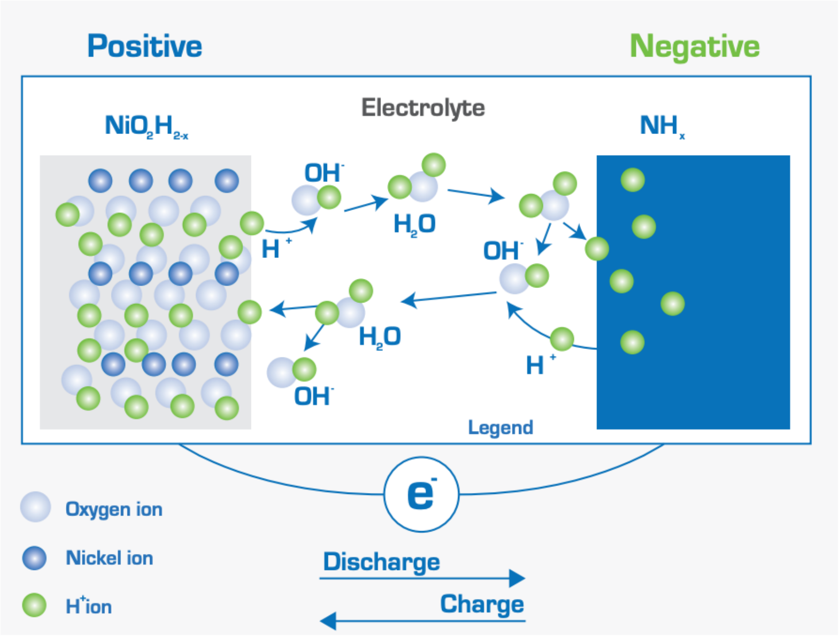


Figure 6. Nickel-metal battery (EASE 2016c).

The formula of the overall process is shown below. (Tarabay, Karami 2015, 24)

$$M + Ni(OH_2) \leftrightarrow MH + NiOOH \qquad (3)$$

At the same time, Li-Ion (Lithium-ion) batteries were in development. The first battery was made in 1980 and Sony started to manufacture them in 1991. (Zhang et al. 2018, 1) Li-Ion batteries are one of the most popular types and their production is growing exponentially since the time it was introduced to the public for the first time. It is not surprising as the benefits of Li-Ion batteries include declining cost, low weight, and high energy storage. (Horiba 2014) However, there are some disadvantages to Li-Ion batteries too. Iclodean et al. (2017, 9) in their research found that Li-Ion is not the best choice in terms of safety due to high functioning temperatures. Potential harm is also discussed in the study of Stephens et al. (2017, 2-31). It is stated that when malfunctioning Li-Ion batteries can pose a potential danger by producing toxic and volatile chemicals. Nowadays research is being done on choosing non-flammable electrolytes in Li-Ion production. The paper shows that the efficiency of improved batteries does not go down. (Zeng et al. 2018, 681)

Figure 7 shows how Li-Ion batteries work. The reaction happens between a positive electrode, which consists of some lithiated metal oxide, and a negative electrode, which contains carbon. During the charging process, lithium ions from the positive electrode move towards the negative electrode and stay in the carbon layers. During the discharge process, ions travel back. (EASE 2016d)

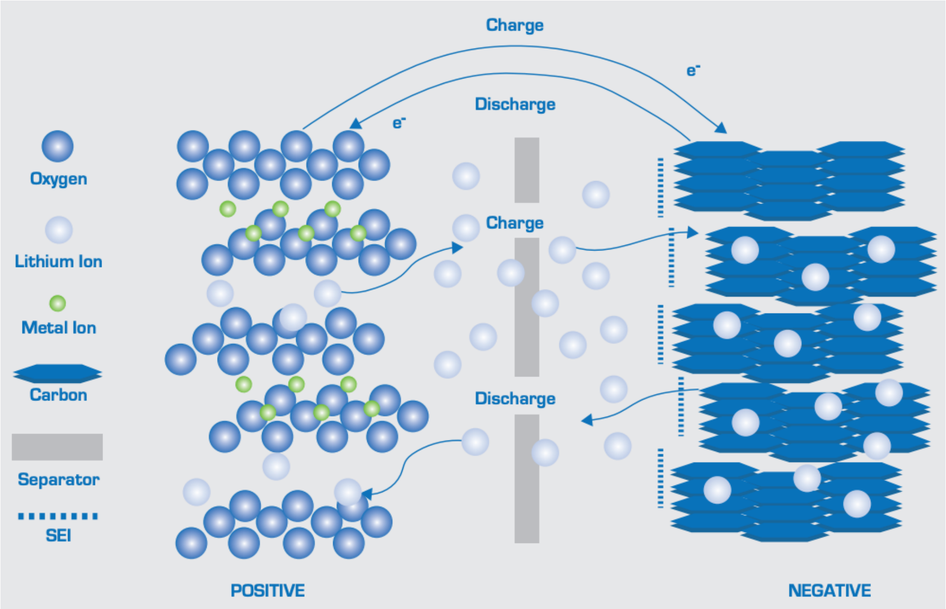


Figure 7. Li-Ion battery (EASE 2016d).

There are different technologies by which Li-Ion battery is produced. Each technology can enhance the performance or increase safety, but it also can be more expensive or has a short life span. Depending on the needs or the budget, the right type is chosen. However, the market of Li-Ion batteries is also not separated equally. The visual representation can be seen in Figure 8. The biggest part is taken by the nickel manganese cobalt oxide (NMC) battery. Examples of EV producers, that use NMC batteries are BMW, Audi, VW e-Golf, and so on (Bratosin et al. 2021, 2). In 2030 the second largest battery choice is expected to be the lithium iron phosphate (LFP) battery. The third one is lithium nickel cobalt aluminum oxide, or NCA. Both of those batteries are actively used in Tesla cars. Elon Musk, the chief executive officer of Tesla, claimed to switch from NCA to LFP due to its better price and non-dependency on scarce materials. (Wayland 2021)

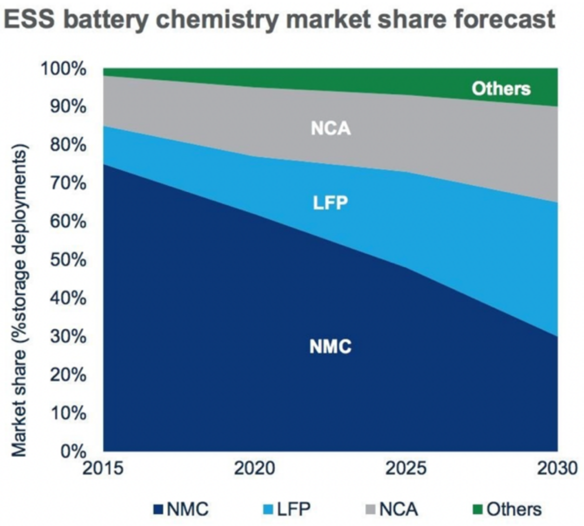
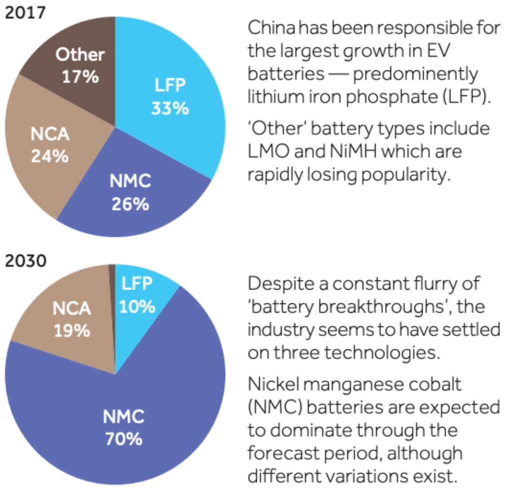


Figure 8. Li-ion battery share (Wood Mackenzie 2020).

Figure 9 represents the possible separation of different batteries on the market. Yugo and Soler (2019, 25) report that in 2017 LFP batteries had the highest share, 33%. NMC and NCA were almost equal, NMC being more popular just by 2%. The company predicts that in 2030 NMC batteries will take over 70% of the whole market. However, the paper highlights that the future can be different. It could be true as Tesla could become a trigger for other companies to also switch to NCA.



China has been responsible for the largest growth in EV batteries — predominently lithium iron phosphate (LFP).

'Other' battery types include LMO and NiMH which are rapidly losing popularity.

Despite a constant flurry of 'battery breakthroughs', the industry seems to have settled on three technologies.

Nickel manganese cobalt (NMC) batteries are expected to dominate through the forecast period, although different variations exist.

Figure 9. Market predictions (Yugo & Soler 2019, 25).

Based on Figure 8 and Figure 9 most promising Li-Ion battery types are chosen for further research and are discussed below.

LFP is considered to be one of the safest types of Li-Ion batteries. Its short word stands for lithium iron phosphate technology, which was developed in 1996 by Texas researchers. (Miao 2019, 2) Phosphate in the battery not only helps to keep it from overcharging but also gives a wide temperature range – from +60 C to -30 C. (Hannan et al. 2018) One of the drawbacks of the LFP battery is its high self-discharge rate. (Miao 2019, 13)

NMC is believed to be the most successful technology of lithium-ion batteries due to the combination of nickel and manganese. (Hannan et al. 2018) Manganese helps to stabilize nickel, while nickel gives high specific energy to the battery. (Miao 2019, 5)

Lithium Nickel Cobalt Aluminum Oxide, or NCA, was invented in 1999 and is chosen in electric vehicles for its high specific power and long-life cycle. However, the production of NCA can be costly and is not as safe as the two other types, which were discussed below. (Miao 2019, 10)

Li-Ion battery types can be compared by different criteria. Table 1 presents the differences in the cycle life, nominal voltage, operating conditions, and energy density. As it can be seen, LFP has the highest number of cycles and widest operating conditions range, however, its energy density is significantly lower than NCA. Table 1 also describes the metals, which are used in the production. Lithium, nickel, and cobalt are used in two of three of these batteries' types.

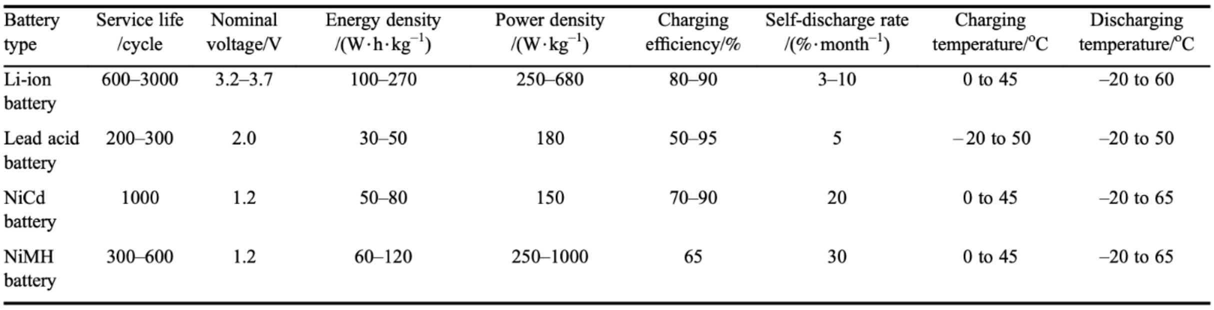
Table 1. Comparison of Li-Ion batteries (Adapted from Koniak and Czerepicki 2017, 2-3, 5-6 and EFORE 2020, 2)

| Type | Number of cycles before capacity drops to 80% | Nominal voltage | Operating conditions | Energy density | Metal used |
|---|---|---|---|---|---|
| LFP | 3600 | 3,2 V | -30 C – +55C | 130 Wh/kg | Lithium, iron, phosphate |

| | | | | | |
|---|---|---|---|---|---|
| NCA | 500 | 3,6-3,7 V | -20 C – +60C | 240 Wh/kg | Lithium, nickel, cobalt, aluminium |
| NMC | 3000 | 3,6-3,7 V | -20 C – +55C | 150 Wh/kg | Lithium, nickel, manganese, cobalt |

The comparison between characteristics of EV batteries can be seen in Table 4. From the table, it can be seen that some types of Li-Ion batteries have a drastically longer service life, up to 3000 cycles, higher energy density, and better charging efficiency. The lead-acid type has a service life of a minimum of three times fewer cycles and two times lower power density.

Table 2. Information on popular battery types (Lei et al. 2019).



| Battery type | Service life /cycle | Nominal voltage/V | Energy density /(W·h·kg$^{-1}$) | Power density /(W·kg$^{-1}$) | Charging efficiency/% | Self-discharge rate /(%·month$^{-1}$) | Charging temperature/°C | Discharging temperature/°C |
|---|---|---|---|---|---|---|---|---|
| Li-ion battery | 600–3000 | 3.2–3.7 | 100–270 | 250–680 | 80–90 | 3–10 | 0 to 45 | –20 to 60 |
| Lead acid battery | 200–300 | 2.0 | 30–50 | 180 | 50–95 | 5 | –20 to 50 | –20 to 50 |
| NiCd battery | 1000 | 1.2 | 50–80 | 150 | 70–90 | 20 | 0 to 45 | –20 to 65 |
| NiMH battery | 300–600 | 1.2 | 60–120 | 250–1000 | 65 | 30 | 0 to 45 | –20 to 65 |

Shares of battery type are unequal on the market. Figure 10 represents the share of each battery that is used in EVs. From the figure, it can be seen that Lithium-Ion batteries have had the biggest part since 2014 and are forecasted to have around half of the market in 2025. The second most common battery type is Lead-Acid. However, as it was stated above, in EV Lead-Acid batteries are mostly used as supplementary batteries.

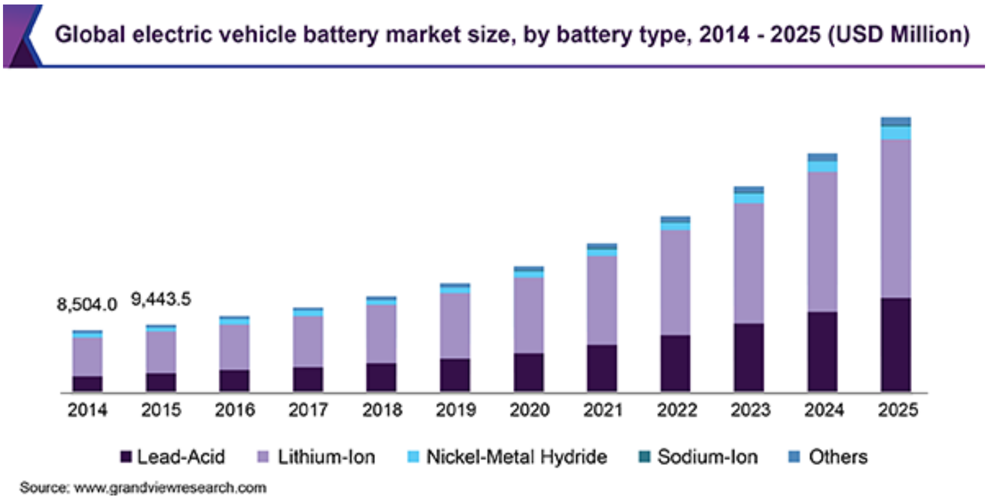


Figure 10. Global EV battery market size (Grand View Research 2019).

Taking into account the future of batteries, which were discussed above, and the amount of metal needed in production, nickel, cobalt, and lithium were chosen as main metals.

## 2.2 Metals

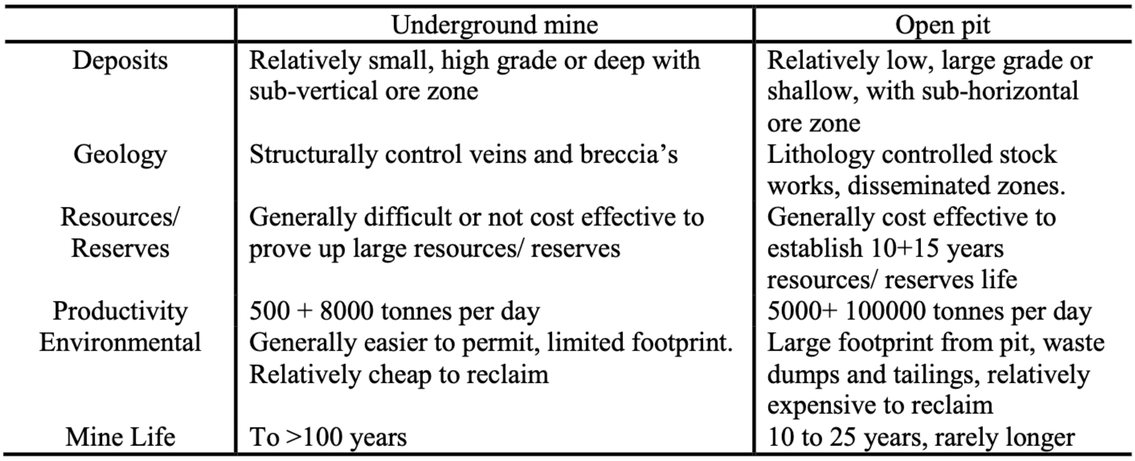
In Russia and in Finland metals are mined from ores. Ore is defined as a “natural aggregation of one of more solid metals that can be mined, processed and sold at a profit”. (Hustrulid et al. 2013, 1) The same source explains profit in this definition as a difference between revenues and costs.

According to the best environmental practices, which were described by Kauppila et al. (2011, 12) , the life cycle of the mine is separated into four stages: exploration, construction, production, and rehabilitation.

The first phase, exploration, is determined by investigating the site and searching for minerals. Several methods of exploration include outcrop mapping, which stands for observation of rock type and structure, boulder perspective, as in the usage of ice to locate ore-bearing bedrock, exploration trenches, and bedrock drilling. The construction phase starts when mining activities are proved to be profitable. To identify whether there are benefits in opening the mine, several guidelines, including National Instrument 43-101 and the JORC code, are used. (Kauppila et al. 2011, 17) National Instrument is a Canadian instrument, while JORC was written by the Australian Joint Ore Reserves Committee. Such Finnish mines as the Pahtavaara project and Osikonmäki support either one or both tools. (Rupert Resources 2021) Waste, that will be formed from mining, should already be discussed at this stage and future storage should be taken into consideration.

The production part may vary, depending on the type of mine. Types, which are the most common in case countries are underground mines and open pits. Therefore, a comparison would be written between those two types. Table 3 represents the difference between open pit mining and underground mining. It can be noticed that each of the mine types has its own situation, where the technology would be best applied. As an example, an underground mine has almost ten times less productivity, however, it is having a much longer mine life and cheaper reclamation costs. Mine can also be a combination of the underground mine and the open pit.

Table 3. Comparison of open pit mining and underground mining (Rajak et al. 2018).



| | Underground mine | Open pit |
|---|---|---|
| Deposits | Relatively small, high grade or deep with sub-vertical ore zone | Relatively low, large grade or shallow, with sub-horizontal ore zone |
| Geology | Structurally control veins and breccia's | Lithology controlled stock works, disseminated zones. |
| Resources/ Reserves | Generally difficult or not cost effective to prove up large resources/ reserves | Generally cost effective to establish 10+15 years resources/ reserves life |
| Productivity | 500 + 8000 tonnes per day | 5000+ 100000 tonnes per day |
| Environmental | Generally easier to permit, limited footprint. Relatively cheap to reclaim | Large footprint from pit, waste dumps and tailings, relatively expensive to reclaim |
| Mine Life | To >100 years | 10 to 25 years, rarely longer |

### 2.2.1 Metals mined in Finland

Finland has a long history of mining activities, accounting for more than 130 years. (Nurmi 2020, 149) Throughout the years the demand is growing, therefore the number of mines is growing. During the past years, a noticeable number of new mines were opened. (GTK 2010, 14) The location of the mines can be seen in Figure 11.

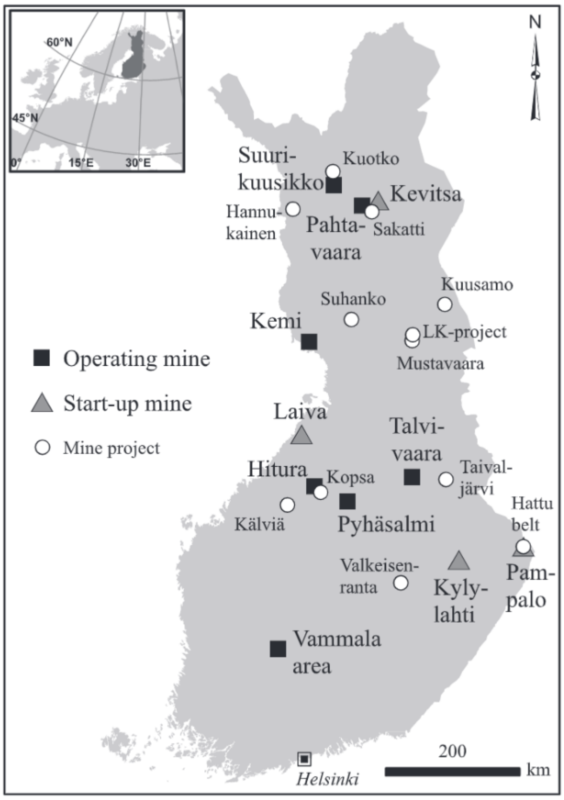


Figure 11. Finnish mines (Tuusjärvi et al. 2014).

The rates of extraction are also growing. The number of metal ores and waste rock extracted grew from less than 10 Mt in 2004 to 80 Mt in 2016. (Ministry of Economic Affairs and Employment of Finland 2018) This dynamic can be seen in Figure 12.

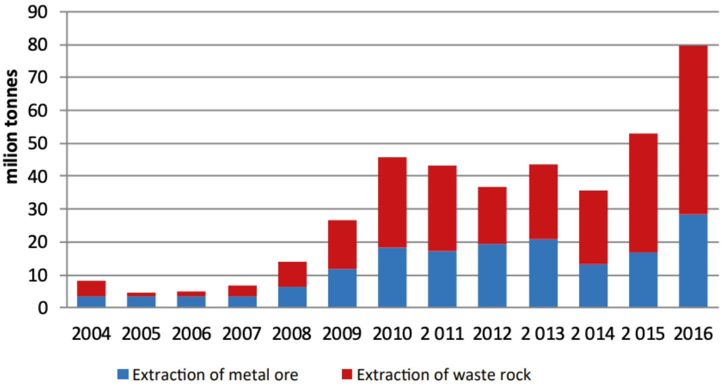


Figure 12. Extraction of metal ores and waste rock (Ministry of economic Affairs and Employment of Finland 2018, 18).

Table 4 shows the capacity of mines and metals, that are needed in the production of EVs. Processing type is also mentioned.

Table 4. Finnish mines (adapted from Tuusjärvi et al. 2014). OP stands for open pit and UG for underground mining.

| | Location | Mine | Metals (annual capacity | Mine type and processing type |
|---|---|---|---|---|
| Operating mines | Talvivivaara | Talvivaara Mining Company | Ni (50kt),<br>Cu (15kt),<br>Co (1,8kt) | OP, heap leaching |
| | Hitura | Belvedere Mining Oy | Ni (2,5kt),<br>Cu, Co | UG, flotation |
| Start-up mines | Kevitsa | First Quantum minerals Ltd | Ni (10kt),<br>Cu (20kt) | OP, flotation |
| | Kylylahti | Altona Mining Ltd | Cu (8kt) | UG, flotation |
| Mine development projects | Suhanko | Gold Fields Arctic Platinum Oy | Ni, Cu | OP, flotation (and hydrometallurgy?) |
| | Sakatti | Anglo American Exploration B.V. | Ni, Cu | UG(?) |
| | LK-project | Finore Mining Inc | Ni | OP |
| | Valkeisenranta | Altona Mining Ltd | Ni, Cu | UG |
| | Kuusamo | Dragon Mining Oy | Co | OP, flotation |

The future of the mining industry in Finland has been discussed. Finland was one of the first European countries to release a mineral mining strategy (Nurmi 2020, 150). In this paper, GTK released a vision for 2050. In this vision, GTK explains three objectives for the development: solution for global mineral chain challenges, promoting domestic growth and prosperity, and mitigation of environmental impact. To achieve the first goal, GTK plans to be aware of the local and global trends and see the arising environmental challenges and increased demand as business potential. To accomplish the second goal, GTK intends to include the utilization of mineral resources into regional mapping and optimization of logistics. For the last achievement, an increase in the amount of sustainably mined raw materials is needed. (GTK 2010)

### 2.2.2 Metals mined in Russia

Mining is considered to be one of the main industries in Russia. Financial benefits, that are gained from the extraction and export of raw materials and refined products, are a large share of Russia's budget. (Dikunov 2021, 42) Map, which is shown in Figure 13, presents Russian mines, where the deposits of several minerals are. Some of the mines were closed, but companies are planning to open them again. As, for example, the Zavitinskoe deposit is going to be re-opened by "Atomredmedzoloto". (NANGS 2019)

Figure 13. Russian mines (Spank 2019, 4).

In Russia, the rate of metal ore excavation can be considered stable. Rosstat (2021) reports that in May 2021 the index of metal ore extraction decreased by 0,2% compared to the amount excavated in May 2020 but grew by 7,3% compared to April 2021. The same source also shared the statistics on factors, that limit production growth. In mining organizations, the most important factors turned to be the uncertainty of the economic situation, insufficient demand in the domestic market, and high taxes.

COVID-19 pandemic helped Russian mining companies to implement a process of digitalization. The new approach helped to save money and manage risks as fewer offices were needed, and more local resources were used. (Dikunov 2021, 43) However, even though positive results were shown, Dikunov (2021, 43) claims that investors may not support the switch to new technologies as they may not see the need in changing operational ways that are working. Moreover, the transition requires resources. Environmental sustainability is another trend in mining. Nornickel published that by 2025 they are planning to place 100% of the waste of ecologically safe objects and by 2030 - to collect and recycle 100% of their waste. (Nornickel 2021)

### 2.2.3 Nickel

Nickel is important for nowadays infrastructure. It is essential to produce stainless steel, electroplating, and recycle batteries. It is considered that Earth's crust has a limited amount of nickel, therefore, its mining is unsustainable, and recycling is preferred. (Mudd 2010) However, recycling cannot meet the need. Elshkaki et al. (2017) in their work explored the percentage of nickel demand that was met by the secondary production. Figure 14 represents the results. On the figure, the fraction of global secondary nickel did not go higher than around 35%.

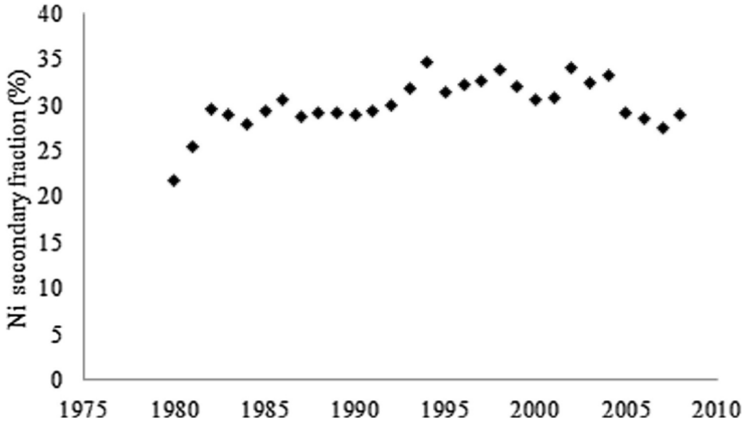


Figure 14. Nickel global secondary production (Elshkaki et al. 2017, 302).

The demand for nickel is expected to grow. The increase can be seen in Figure 15. Elshkaki et al. (2017) investigates the demand in four possible scenarios: MW, or market world, represents the idea of people, who recently acquired wealth, are buying as much as people, who have been wealthy for a long time, TW, or towards resilience, shows the same future, however with more respect towards renewable energy government, SF, or security foremost, is about a decrease in international trade and EW, or equitability world, draws a picture of the inclusive and collaborative world. Despite the scenario, the difference in demand between 2010 and 2050 is noticeable.

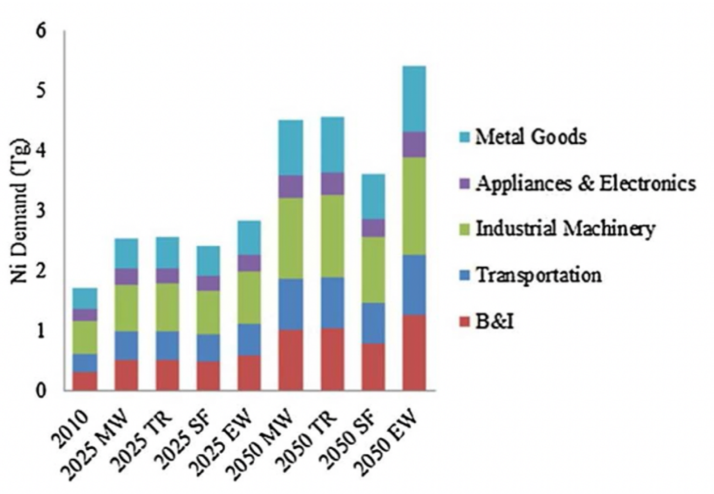


Figure 15. Nickel demand (Elshkaki et al. 2017, 306).

GTK data corresponds that the largest active mine in Finland is the Talvivaara mine. It has 3,8 Mt of nickel as a resource. The second biggest deposit In Finland is the Kevitsa mine with around 0,8 Mt of nickel. (GTK)

In Russia, the biggest deposits of nickel are located in the ores of Norilsk and Pechenega groups. (Talovina et al. 2017) Nornickel is the biggest company in Russia, that is responsible for nickel production. It has nine mines, which probable and proven reserves are 6,5 Mt. (Nornickel 2021)

### 2.2.4 Cobalt

Cobalt is a silver-grey metal. In rechargeable batteries, it is used as a cathode. (Slack et al. 2017) Cobalt is usually found in ores together with nickel and copper, alone it is extracted only in Morocco or Canada. The Republic of Congo is responsible for around 70% of cobalt production.

Demand for cobalt is investigated in the report of Alves Diaz et al. (2018). Through their papers, it is clearly seen that cobalt is largely needed for the battery chemicals and the sector of EV batteries is equal to 9%. This demand can be seen in Figure 16.

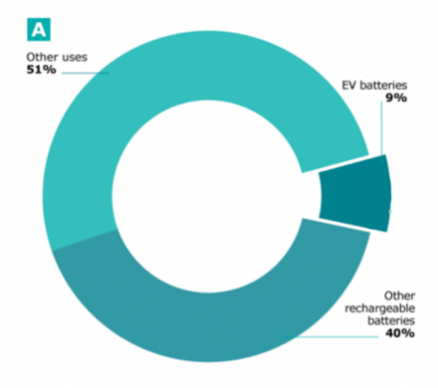


Figure 16. Cobalt demand (Alves Diaz et al. 2018, 16).

The trend is expected to only rise and increase by around 20% from 2020 to 2030 (Alves Diaz et al. 2018), which is demonstrated in Figure 17. Only the sector of rechargeable batteries is presented in the figure.

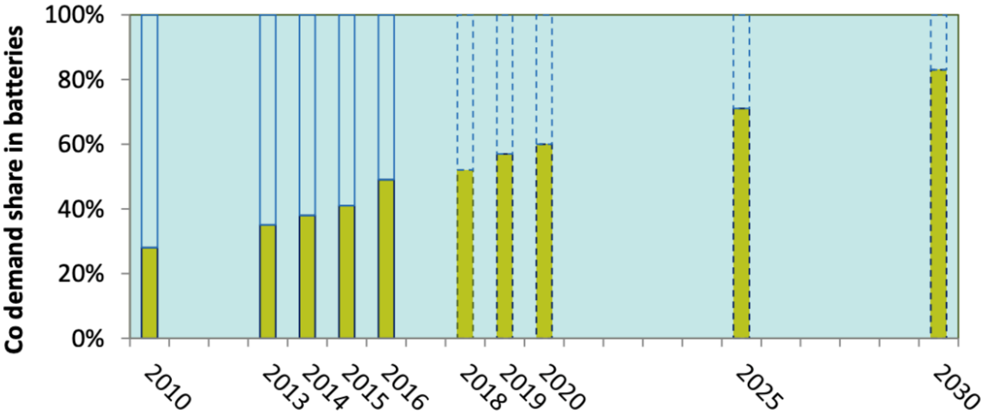


Figure 17. Cobalt demand 2010-2030 (Alves Diaz et al. 2018, 14).

In Finland, the biggest deposit of cobalt is located in Talvivaara, around 28 Mt. Cobalt is mined through open-pit mining. Two large deposits are also located in Haarakumpu with 7769 t of cobalt and Hautalampi, which has a total resource is 5671 t. (GTK 2021)

Russia is in second place and is accounted for 5% of the global share. Norilsk Nickel is the only producer that extracts cobalt in Russia and their ambition is to increase the global share of Russia up to 8%. (Gerden 2020)

### 2.2.5 Lithium

Lithium is a metal, which is widely distributed in trace amounts in rocks, soils, and oceanic and sea waters, and only a fraction of identified lithium resources is in theory economically feasible for extraction. However, around a quarter of the global lithium reserves cannot be developed due to political and technical issues. The biggest amount of lithium can be found in Argentina, Bolivia, and Chile. Lithium can be sourced from hard rock mines (in Australia and China, for example) or from the surface of dried lakes (Chile, Argentina). There are several places in Russia, where lithium can be found. However, none of them are actively working, Russian companies are mostly investing in mines, located in Argentina or Australia. Glazyrina and Latyshova (2021) found through SWOT analysis, that Russia will benefit from restoring lithium mines, located in Zabaikalskii krai. The researcher also suggests that local lithium mines will present an opportunity to promote the economy and living conditions in this area. In Finland, company Keliber is currently planning to start the construction phase of the mine by 2022 in the Kaustinen and Kokkola municipalities. The reserves that were found are considered to be one of the most notable ones in Europe. (Keliber 2021)

McKinsey (2018) presented a report on lithium. In this study, the company says that the demand for lithium metal will grow by 318% from 2017 to 2025, which can be seen in Figure 18. While in 2017 the demand was equal to 214 kt, lithium carbonate equivalent (LCE), in 2025 it will be 893 Kt LCE, in an aggressive scenario and 669 Kt LCE in a base scenario. However, according to McKinsley, lithium has a mining capacity, that exceeds these numbers. In 2017 capacity was equal to 447 Kt LCE, in 2025, if latent capacity and new entrants are included, the number was 1 206 Kt LCE.

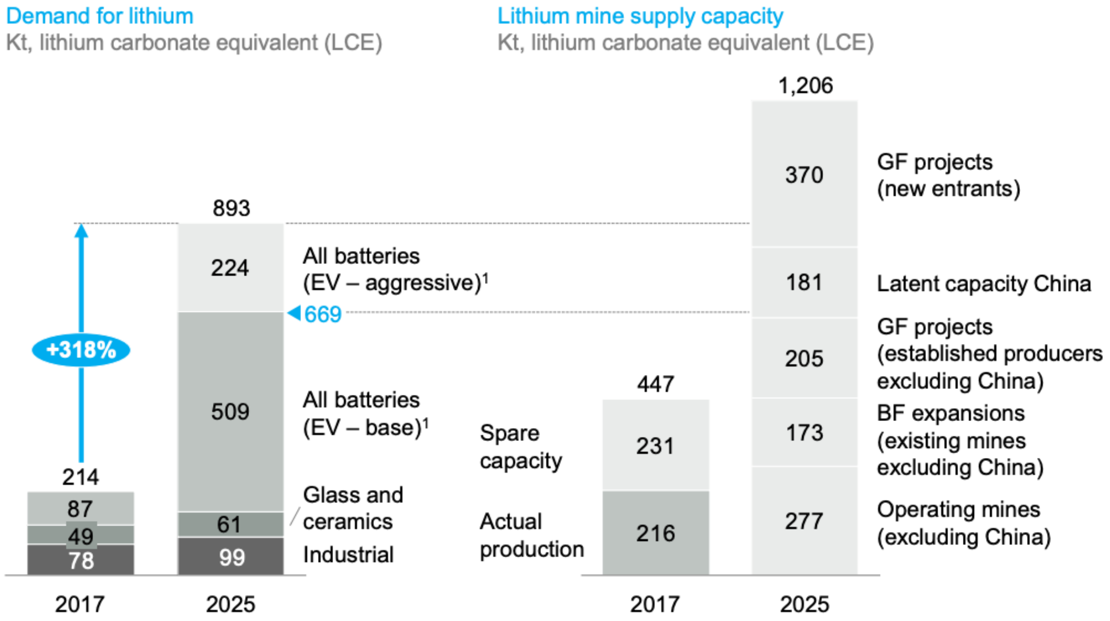


Figure 18. Lithium demand. (McKinsley 2018, 12).

According to the same source, out of 669 Kt LCE that is expected in 2025 in a base scenario, 76%, 509 Kt LCE, will be allocated to battery production and 160 Kt LCE to other uses, which is demonstrated in Figure 19.

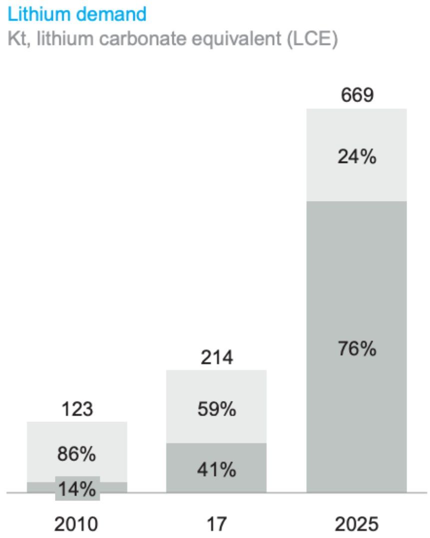
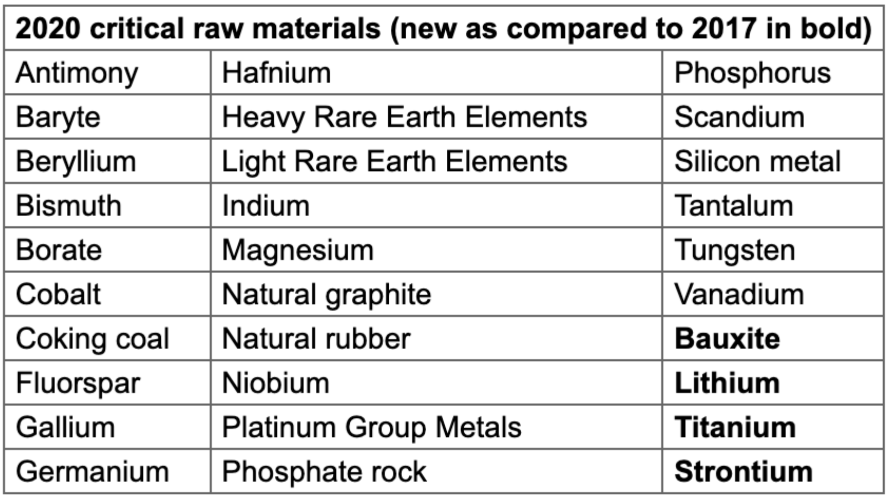


Figure 19. Percentage of lithium demand (McKinsley 2018, 8).

The question of lithium’s circular economy is important, as lithium was included in the critical raw materials list, published by European Commission (2020). As it can be seen from Table 5, lithium was recently added.

Table 5. Critical raw materials (European Commission 2020).



| **2020 critical raw materials (new as compared to 2017 in bold)** | | |
|---|---|---|
| Antimony | Hafnium | Phosphorus |
| Baryte | Heavy Rare Earth Elements | Scandium |
| Beryllium | Light Rare Earth Elements | Silicon metal |
| Bismuth | Indium | Tantalum |
| Borate | Magnesium | Tungsten |
| Cobalt | Natural graphite | Vanadium |
| Coking coal | Natural rubber | **Bauxite** |
| Fluorspar | Niobium | **Lithium** |
| Gallium | Platinum Group Metals | **Titanium** |
| Germanium | Phosphate rock | **Strontium** |

## 2.3 Waste

Battery technologies are mature enough to electrify more than 75% of the vehicles in Europe by 2030 and drastically decrease greenhouse emissions (McKinsey 2021). With such a high demand more raw materials are needed and, therefore, more waste is produced during extraction.

It is stated that for each ton of extracted metal, from 2 to 12 tons are removed as waste. Over 1,2 billion tons of waste as mine tailings are stored in the European Union every year, while the global rate is 5 – 14 billion tons per year. (Kinnunen and Kaksonen 2019) Generally, during mining, around 71% of ore is disposed of further as waste. (Espo et al. 2019)

Espo et al. (2019) report, that in the year 2017, around 124 million tons of excavated material were generated from mining activities, from which only 1 million tons are recycled. 23 million tons are sent for further processing, 88 million tons are backfilled, and 12 million tons are for internal use, which includes the construction of mines and backfilling of the mine. These shares can be seen in Figure 20.

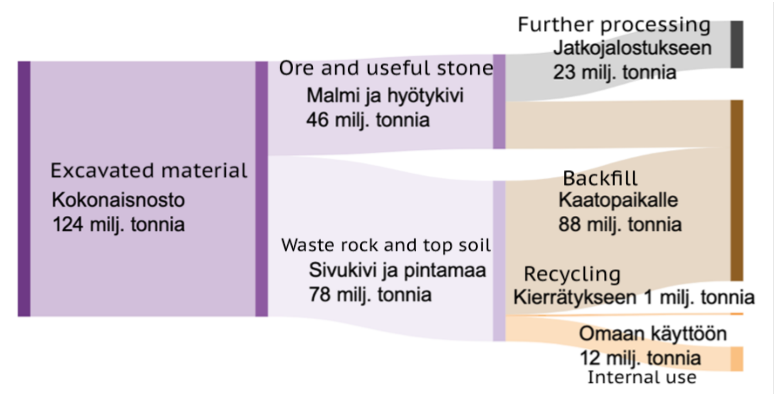


Figure 20. Waste generation in Finland (Espo et al. 2019).

As extraction processes are more active in Russia, the number of wastes is also bigger. According to Gulyaeva (2021), waste that is generated from the extraction is equal to 7,2 billion tons every year. Out of these 7,2 billion tons, 85% is an overburden. Ministry of Natural Resources and Environment reports that over a century the amount of waste is equal to 100 billion tons (Nevskaya et al. 2019). FinExpertiza (2020) reports, that 1,6 billion tons are formed during metal mining. In contrast, 5,2 billion tons of waste come from coal mining and 0,4 billion tons – from other excavations.

In the mining industry, materials, that do not contain ore metals, fuels, or minerals or their concentration is so low, that it is not economically profitable to extract them, are called mine waste. Various waste can be generated during metal mining. Types of solid waste, which stand out the most due to big volumes are waste rock and tailings. Waste rock is formed while blasting or drilling, then it is moved to a stockpile. (Hitch et al. 2009)

Visual representation of mining activities such as underground mines and open pits with waste, that is generated, can be found in Figure 21. From the figure, it can be seen that during the excavation phase, such a by-product as a waste rock is formed. From the processing or separation, as it is called on the figure, tailings are generated. The waste from metal extraction is called slag.

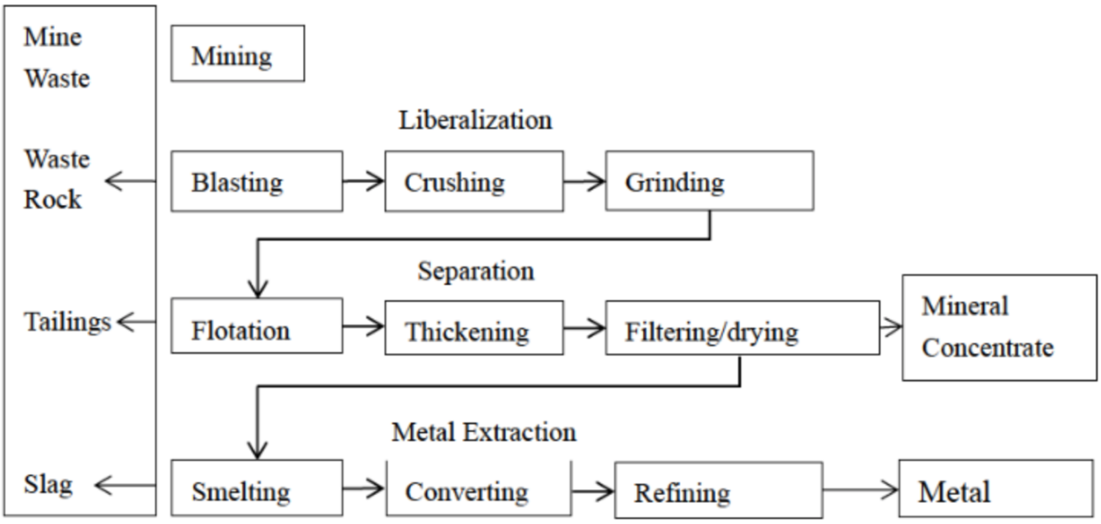


Figure 21. Waste from mining activities (Gou et al. 2019, 449).

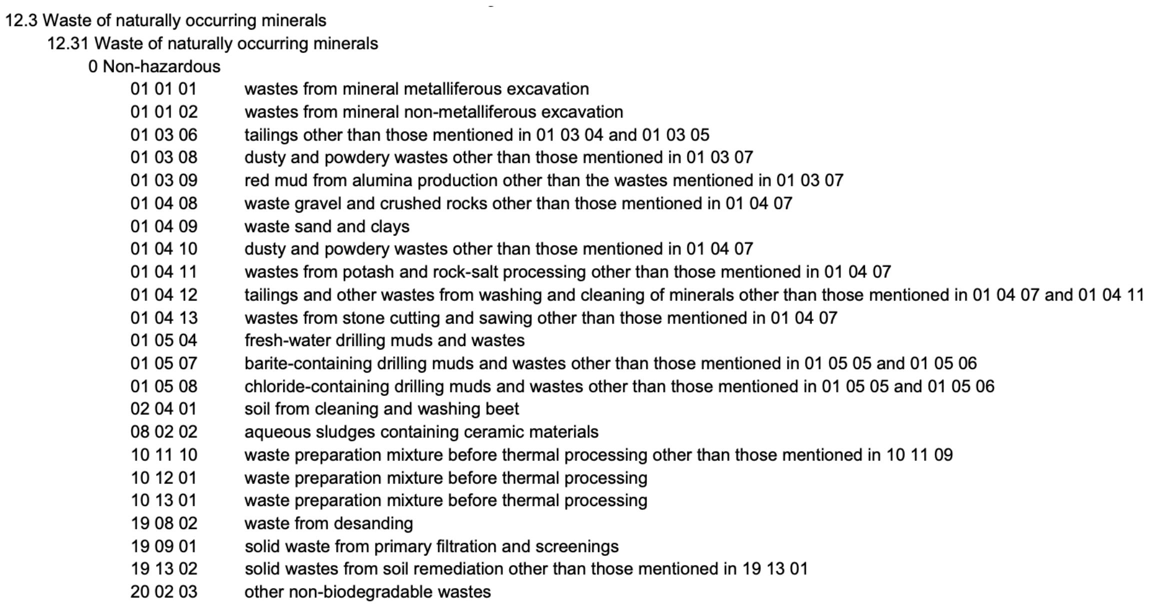
The main leftovers from mining activities are tailings and waste rock. (Gorakhki & Bareither 2017) Tailings are explained as a by-product, which was created during mining activities and does not have any economic value. (Wang 2018) Tailings are usually produced by crushing and grinding. Due to these processes bulk density is low, so it is not uncommon for tailings to collapse during rainy seasons. (Sun et al. 2018) While tailings have a fine structure, waste rock is usually more gravel-sized. It is also more water-resistant than tailings. (Gorakhki & Bareither 2017) Slag is defined as a result of metal ores processing. (Male et al. 1997)

### 2.3.1 Waste legislation in Finland

Waste classification exists to make waste collection easier. In 2006 European Commission released the Extracted Waste Directive. By the European Commission, the waste is explained as “any subject or object which the holder discards or intends or is required to discard” (Waste Framework Directive 2008/98/EC)

European Waste Code separates all kinds of waste into 20 chapters. Each waste has a six-numbered code, formed as three paired numbers. The first pair of numbers describes the activity that formed waste (waste from the leather, fur, and textile industries) or its state (oil waste and liquid fuels). The second pair brings more description to the waste. The last pair shows the individual number. Asterisk in the end demonstrated that the waste is hazardous. (Commission of the European Communities 2010)

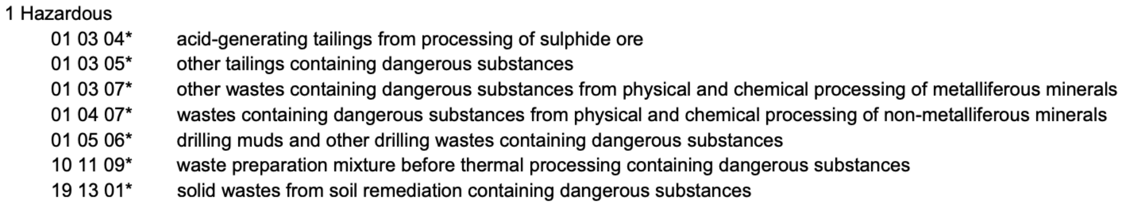
In EWC most of the waste from the mining industry starts with 01. Figure 22 shows examples of non-hazardous waste, while Figure 23 presents the hazardous types.



12.3 Waste of naturally occurring minerals
12.31 Waste of naturally occurring minerals
0 Non-hazardous

| | |
|---|---|
| 01 01 01 | wastes from mineral metalliferous excavation |
| 01 01 02 | wastes from mineral non-metalliferous excavation |
| 01 03 06 | tailings other than those mentioned in 01 03 04 and 01 03 05 |
| 01 03 08 | dusty and powdery wastes other than those mentioned in 01 03 07 |
| 01 03 09 | red mud from alumina production other than the wastes mentioned in 01 03 07 |
| 01 04 08 | waste gravel and crushed rocks other than those mentioned in 01 04 07 |
| 01 04 09 | waste sand and clays |
| 01 04 10 | dusty and powdery wastes other than those mentioned in 01 04 07 |
| 01 04 11 | wastes from potash and rock-salt processing other than those mentioned in 01 04 07 |
| 01 04 12 | tailings and other wastes from washing and cleaning of minerals other than those mentioned in 01 04 07 and 01 04 11 |
| 01 04 13 | wastes from stone cutting and sawing other than those mentioned in 01 04 07 |
| 01 05 04 | fresh-water drilling muds and wastes |
| 01 05 07 | barite-containing drilling muds and wastes other than those mentioned in 01 05 05 and 01 05 06 |
| 01 05 08 | chloride-containing drilling muds and wastes other than those mentioned in 01 05 05 and 01 05 06 |
| 02 04 01 | soil from cleaning and washing beet |
| 08 02 02 | aqueous sludges containing ceramic materials |
| 10 11 10 | waste preparation mixture before thermal processing other than those mentioned in 10 11 09 |
| 10 12 01 | waste preparation mixture before thermal processing |
| 10 13 01 | waste preparation mixture before thermal processing |
| 19 08 02 | waste from desanding |
| 19 09 01 | solid waste from primary filtration and screenings |
| 19 13 02 | solid wastes from soil remediation other than those mentioned in 19 13 01 |
| 20 02 03 | other non-biodegradable wastes |

Figure 22. Non-hazardous examples from EWC code (Commission of the European Communities 2010, 70).



1 Hazardous

| | |
|---|---|
| 01 03 04* | acid-generating tailings from processing of sulphide ore |
| 01 03 05* | other tailings containing dangerous substances |
| 01 03 07* | other wastes containing dangerous substances from physical and chemical processing of metalliferous minerals |
| 01 04 07* | wastes containing dangerous substances from physical and chemical processing of non-metalliferous minerals |
| 01 05 06* | drilling muds and other drilling wastes containing dangerous substances |
| 10 11 09* | waste preparation mixture before thermal processing containing dangerous substances |
| 19 13 01* | solid wastes from soil remediation containing dangerous substances |

Figure 23. Hazardous examples from EWC code (Commission of the European Communities 2010, 71).

According to the Environmental Protection Act (82/2000), in order to start the construction phase, permits are required. Such license gives a company or a natural individual permission to utilize organic and inorganic surface materials, minerals, and waste that is associated with mining activities. The permit is valid for the fixed time or until further notice. Mining operators should obey such directives as Mining Act and Government Decree on mining activities. (TUKES, 2021) According to the law (TUKES, 2021), after the permit is expired, the site should be restored in two years.

Mining activities, including exploration, are mainly regulated by the Mining Act (503/1965) and the Mining Decree (663/1965). The Nature Conservation Act (1096/1996) and the Nature Conservation Decree (160/1997) are taking care of nature safety, as well as the Act on Wilderness Reserves (62/1991). The Act on Environmental Impact Assessment Procedure (468/1994) and the Decree on Environmental Impact Assessment Procedure (268/1999) are needed for the environmental impact assessment of the mine. The Land Use and Building Act is one more regulation that is needed to be kept in mind.

The company, that decided to start the mining activity, should pay 0,15% of the extracted minerals to the owner of the land as well as the common income tax. For now, no special mine tax is introduced, however, Finnish Government is aiming to introduce a separate mining tax in 2023 (Boreneus 2021)

### 2.3.2 Waste legislation in Russia

In the mining industry, Russia defines waste as enclosing or overburdening rocks that are formed during mining activities. Waste, formed from the activities, can be divided into three groups: solid, wastewaters, and air pollution. Solid waste is divided into waste rocks and tailing. During the metal refining process through pyrometallurgical methods, slag is formed.

According to the Directive, every waste has a six-numbered code. The first number shows the origin of the waste (animal, vegetative, chemical, mineral, or a household), its aggregate state, formation of raw materials, and environmental hazard from 1 to 5, where 1 is the most dangerous. (FKKO 2021) Sometimes letters are used to describe the hazard. Waste from mining and refining are put in the mineral waste category. Table 6 shows how FKKO presents most of the waste from mining activities.

Table 6. FKKO classification of most of the mining waste (Adapted from FKKO 2021).

| | |
|---|---|
| 300000 | Mineral waste |

| | |
|---|---|
| 310000 | Mining waste (including metal waste) |
| 312000 | Metallurgical slags, scrap and dust |
| 314000 | Other solid mineral waste |
| 316000 | Mineral slag |
| 340000 | Mining waste |
| 350000 | Metal and alloy waste |
| 353000 | Scrap and waste of non-ferrous metals |
| 355000 | Metallurgical slags |
| 390000 | Other mineral waste |
| 399000 | Other mineral waste and waste from processing |

Researchers claim that the Russian mining tax should be changed, as the tax system that exists now is imperfect (Utkina and Marchenko 2000, Kimelman 2011). Umaev (2011, 65) reports that one of the reasons for excessive tax is that the object is not defined correctly, and companies should pay a tax, that is based on the expenses, rather than on the income. Utkina and Marchenko (2000) suggest that discounts and subsidies are necessary for poor ores mining.

Taxes in Russia are separated into three groups: federal taxes, Russian Federation subject taxes, and local taxes. (Utkina and Marchenko 2000) Table 7 separates taxes that should be paid by the mining company according to these three groups.

Table 7. Russian taxes (adapted from Utkina and Marchenko 2000)

| Federal taxes | Russian Federation subject taxes | Local taxes |
|---|---|---|
| Value added tax (VAT) | Tax on property | Land tax |
| Taxes on certain types of mineral raw materials | Real estate tax | Local license fees |
| Tax on profit of organizations | Road tax | |
| Tax of capital income | Transport tax | |
| Personal income tax | Sales tax | |

| | | |
|---|---|---|
| Contributions to social funds | Regional license fees | |
| State tax | | |
| Customs duties and customs fees | | |
| Tax on subsoil use | | |
| Tax on the reproduction of the mineral resource base | | |
| Tax on additional income from hydrocarbon production (when oil is extracted) | | |
| Environmental tax | | |
| Federal license fees | | |

Table 8 presents two taxes that concern only mining companies: tax on subsoil use and on the reproduction of the mineral resource base. Fees that should be paid to these taxes are regulated by the "Law on fossil resources (Zakon o nedrah)". (Utkina and Marchenko 2000) Some of the payments are paid one time, others are continuous. The environmental tax focuses on three areas: air pollution, water pollution, and waste relocation. ("Law on environmental protection (Ob ohrane okruzhaushei sredy)")

Table 8. Taxes on subsoil use and on the reproduction of the mineral resource base (adapted from Utkina and Marchenko 2000)

| Fees that depend on the subsoil type | Fees that do not depend on the subsoil type |
|---|---|
| Fee for the right to participate in the auction | Payments for the right of prospecting and appraisal, exploration and production of minerals |
| Fee for issuing a license | Deductions for the reproduction of the mineral resource base |
| Payment for the right to use a land plot | Excise taxes |

| | |
|---|---|
| Payment for the right to use geological information | Payments for the right to use subsoil for purposes not related to the extraction of minerals |
| | Payments for the right to use the water area and sections of the seabed |

Payments for the right to use a land plot, where tailings will be, is 0,01% - 2% from the market price. (Yastrebinskiy & Bekrenev 2012)

At the end of 2021, the Russian government plans to publish corrections to the “Law on fossil resources (Zakon o nedrah)”. With the help of this correction, utilization of tailings and some other mining waste will be more possible, as nowadays there are many laws that forbid the use of waste. (RIA 2021)

### 2.4 Treatment and recovery possibilities

Social awareness and an increased need for depleting metals lead to the development of various technologies, that could help to close the material loop. Better recovery of raw metals will decrease the need for waste treatment and possibly reduce the amount of extraction needed. (Blengini et al. 2019) Kinnunen and Kaksonen (2019) found in their research that the technology readiness is low, as well as the knowledge gap is high. Their paper also stresses the need for testing new methods, that could be difficult in current realities. In the authors’ opinion, it is also crucial to communicate during the very beginning of mine processing, as the way that mining waste is treated defines whether this waste can be used in the future.

Tailings are frequently used in building roads, construction on the site, or backfilling. (Kauppila et al. 2011) However, there could be other options, which are discussed below for each of the chosen metals.

#### 2.4.1 Waste from nickel mining

Hefni and Hassani (2020) published a work that described the production of a new backfill material – foam mine fill. In contrast with average backfill, air penetrates the material and makes it less heavy, highly fluid, and suitable for civil applications. (Hefni et al. 2015a) The density of the new material is also significantly lower. While the average number for some concrete is 2400 kg/m$^3$, for foam mine fill it is 300 - 1600 kg/m$^3$. Foam with the lowest density can be used in thermal and acoustical insulation. For the process, copper-nickel tailing was needed, and the mixture consisted of tailings, Portland cement, foaming agent, foaming generator, and water. (Hefni et al. 2015b) The necessary volume of tailings needed is 70% of the weight, with a medium sample size of $149 * 10^{-6}$ m. Portland cement takes up to 8% of the weight, the recommended percentage of entered air is up to 20%. The compressive strength of foam mine fill would be 2,72 MPa when the amount of air in the foam is 10%. (Hefni & Hassani 2020)

Yang et al. (2014) described the process of turning copper-nickel tailings from a Jinchuan mine to a filling cementing material. The number of tailings, that were added, was 85% and the strength of the body varies between 2,9 and 6,3 MPa. Characteristics were good enough to prove that the new method is safe and can replace conventional cement for filling.

Russian mine Oktyabrskoe has the same type of tailings – copper-nickel tailings. According to the current knowledge, there are no articles yet, that would use mine tailings from Oktyabrskoe in foam mine fill production or as a filling cement material, however, there could be a potential.

### 2.4.2 Lithium

Much more articles on the usage of lithium tailings and lithium slag in production can be found. One of the possible applications of lithium mines is cement.

The demand for cement is rising and this can be seen in Figure 24, taken from the research of Taylor et al. (2006). The same trend can be seen in the papers of Chatziaras et al. 2016. According to their research, world cement demand in 2010 was around 2750 Mtons, while in 2020 it was prognosed to be 3000 Mtons. Because of such high demand, the cement industry is in need of new, sustainable technologies, which would lower $CO_2$ emissions. (Schneider et al. 2011)

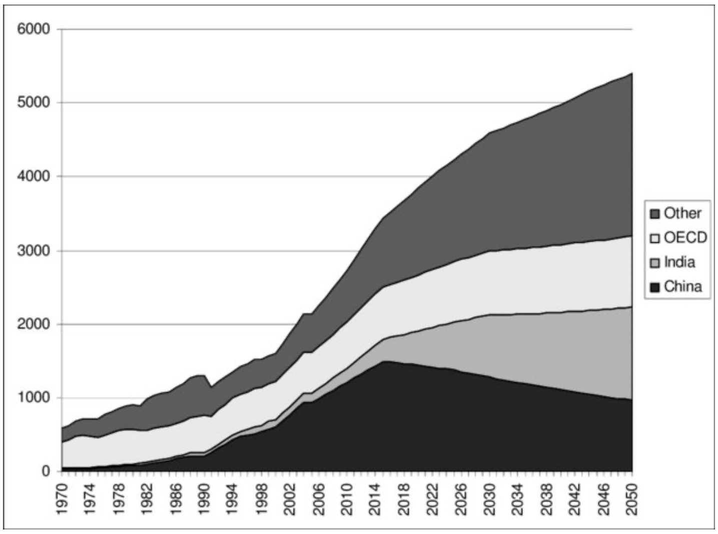


Figure 24. Cement demand (Taylor et al. 2006, 3).

Lithium tailings are one type of mining waste that can be used for further cement production. Betolar, Keliber and JA-KO made a statement on their collaboration, in which JA-KO and Betolar are planning on using Keliber's side stream as a raw material for cement production. (Betolar 2021) Geoprime is the technology that Betolar uses to reduce the carbon footprint up to 80%, compared to current production. (Geoprime, 2021)

Lithium slag, one of the waste streams of lithium extraction, can be used as a raw material for cement production. He et al. (2019) described a process, in which a mixture of lithium slag of pH 5,6, fly ash and ordinary Portland cement was used in efficient cemented fine tailings backfill. The ratio, which brought the biggest result was 1:1:2 respectively, so for the production 800g of water, 600 g of Portland cement, 300 g of lithium slag, and 300g of fly ash were recommended. The compressive strength of the sample rose according to a number of days cured. For 7 days it was 29,46 MPa, for 28 days – 38,42 MPa, for 56 days – 52,63 MPa. The particle size of a lithium slag was $30 * 10^{-6}$ m. (He et al. 2019)

Porous ceramics is another application that can be found for leftovers, that was generated after lithium extraction. Porous ceramics are widely used in filters, heat and sound isolation, or as an energy conservation component in solar energy devices. (Chen et al. 2021) The research of Lemougna et al. (2021), basing their findings on the sample from Keliber mine. Table 9 shows the mixture contents. The paper says that compressive strength is reducing from 15wt% glass wool, therefore mixtures, where these number is lower, are included in Table 9. According to the research, these mixtures might be used in high buildings.

Table 9. QFS, glass wool waste, silica carbonate and water. In the table QFS stands for quartz feldspar sand, or lithium tailings. (Adapted from Lemougna et al. 2021)

| Sample | QFS, g | Glass wool, g | Silica carbonate, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|---|
| 10wt% glass wool | 100 | 10 | 0,1 | 24 | 950 |
| 5wt% glass wool | 100 | 5 | 0,1 | 24 | |
| 0wt% glass wool | 100 | 0 | 0,1 | 22 | |

Lemougna et al. (2020) also described an experiment, in which QFS was used as a raw material for metakaolin geopolymer composites. Samples from the same Keliber mine were acquired for the research. As in previous papers, several sample mixtures were tested, however, 12,5% wt showed the best results. The compressive strength, that was reported, is equal to 45 MPa. However, this number differed post-heating, depending on the particle size. (Lemougna et al. 2020) The graph can be seen in Figure 25. Table 10 represents the mixture that was chosen as the most efficient.

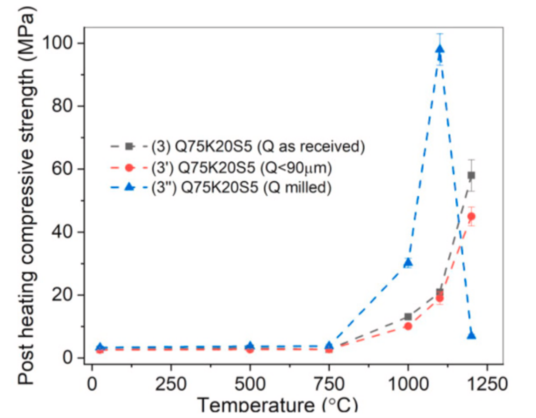


Figure 25. Geopolymer (Lemougna et al. 2020).

Table 10. QFS, metakaolin, sodium metasilicate and water (Adapted from Lemougna et al. 2020)

| Sample | QFS, g | Metakaolin, g | Sodium metasilicate, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|---|
| 12,5%wt | 67,5 | 20 | 12,5 | 25 | 750, 850, 950 |

Porcelain could also be created with QFS. Lemougna et al.'s (2019b) research proved that such porcelain could replace conventional porcelain. Two types of porcelain have been created, one with 50 grams of lithium mine tailings, another with 41 grams, other raw materials stayed the same. The properties of the porcelain also turned out to be close to each other. First porcelain had a compressive strength of 85 MPa, second – up to 90 MPa. Density and particle size were the same for both experiments, 2,5 g/cm$^3$ and around $10 * 10^{-6}$ m accordingly. The mixture components are demonstrated in Table 11.

Table 11. QFS, kaolin and water (Adapted from Lemougna et al. 2019b)

| Sample | QFS, g | Kaolin, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|
| P1 | 50 | 50 | 38 | 1050, 1100, 1150, 1200 |
| P2 | 41 | 50 | 38 | |

Bricks production could be another method of mining waste recovery. Lemougna et al. (2019a) described the process of turning lithium mine tailings, or quartz-feldspar sand, QFS, into a low-temperature ceramic. For this method lithium tailings, ladle slag, water, and sodium hydroxide as a fluxing agent. Sodium carbonate was also used in the study, however, samples with it showed lower compression strength and higher water absorption. During the process, the temperature does not exceed 900°C as it does in standard ceramics. On contrary, the temperature is kept at 700-900°C. Several mixtures were described in the article, however, bricks, that were created with 3-7%wt NaOH, also meet the requirements of the ASTM C62-99, standard specification for building brick, and could be used in weathered conditions. (Lemougna et al. 2019a) Mixture content of these specimens can be seen in Table 12. Particle size of QFS was $10{,}70 * 10^{-6}$ m, the particle size of ladle slag was $12{,}34 * 10^{-6}$ m. A sample from Keliber mine was taken for the research. (Lemougna et al. 2019a)

Table 12. Case 1. QFS, ladle slag, NaOH and water. (Adapted from Lemougna et al. 2019a)

| Sample | QFS, g | Ladle slag, g | NaOH, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|---|
| 3%wt NaOH | 90 | 10 | 3 | 24 | 700, 800, 900 |
| 5%wt NaOH | 90 | 10 | 5 | 24 | |
| 7%wt NaOH | 90 | 10 | 7 | 24 | |

Another way of using lithium tailings is mixing them with glass wool waste. Bricks, created this way, also satisfy the ASTM C62-99 norms and can be used in construction. Materials, used for the described study, were taken from the same company, Keliber, as in the case, described above. In Lemougna et al.'s (2020) study, the mixture consisted of QFS, glass wool, liquid sodium silicate, and water. Table 13 shows mixtures, that were recommended by the study. However, sample with 40 g of glass wool waste required less energy during sintering. Samples were dried on temperatures 750°C, 850°C, and 950°C. (Lemougna et al. 2020)

Table 13. Case 2. QFS, glass wool waste, liquid sodium silicate and water. (Adapted from Lemougna et al. 2020)

| Sample | QFS, g | Glass wool waste, g | Liquid sodium silicate, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|---|
| 10 g of glass wool waste | 100 | 10 | 1 | 28 | 750, 850, 950 |
| 20 g of glass wool waste | 100 | 20 | 1 | 31 | |
| 40 g of glass wool waste | 100 | 40 | 1 | 38 | |

The process of ceramic production from QFS is also described by Adediran et al. (2021). Same samples as in the examples above were used in the study. Mixtures that were prepared with QFS can be seen in Table 14.

Table 14. Case 3. QFS, glass wool waste, $R_2O$ and water. (Adapted from Adediran et al. 2021)

| Sample | QFS, g | Glass wool, g | $R_2O$, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|---|
| 10wt% glass wool waste | 90 | 10 | 0,09 | 25 | 750, 850, 950 |
| 0wt% glass wool waste | 100 | 0 | 0,08 | 25 | |

The sample with 10wt% glass wool waste gained compressive strength of 32 MPa and 55 MPa at 750°C and 850°C respectively and then increased its number up to 117 MPa at temperature 950°C.

Ceramics in construction was also discussed in the article of Lemougna et al. (2019). For the production, QFS was mixed with kaolin in different proportions. Mixtures can be seen in Table 15. With the research, Lemougna et al. (2019a) stated, that tailings, left from lithium mining, are a viable source of ceramics.

Table 15. Case 4. QFS, kaolin and water. (Adapted from Lemougna et al. 2019a)

| Sample | QFS, g | Kaolin, g | Water, g | Sintering temperature, °C |
|---|---|---|---|---|
| S1 | 80 | 20 | 30 | 1050 |
| S2 | 90 | 10 | 25 | |

Comparison of these four methods can be seen in Table 16. As it can be seen from the comparison, case 2 requires the most tailings, it has medium compressive and the biggest flexural strengths and it could be used in decoration, as when glass wool waste content is equal to 40 g, a brick can have round edges. (Lemougna et al. 2020)

Table 16. Comparison. Ceramics.

| | Tailings + ladle slag, case 1 | Tailings + glass wool waste, case 2 | Tailings +glass wool waste, case 3 | Tailings + kaolin, case 4 |
|---|---|---|---|---|
| Tailings needed | 90 g | 100 g | 90 g | 80 – 90g |
| Compressive strength | 55 MPa | 90 MPa | 117 MPa | 67 - 69 MPa |
| Flexural strength | 14 MPa | 25 MPa | 20 MPa | 16,5 – 17,5 MPa |
| Water absorption | 4 – 19% | 0 – 25% | 2 – 19% | 6,3 – 6,8% |
| Apparent density | 1,65 – 2 g/cm$^3$ | 1,5 – 2,1 g/cm$^3$ | Around 1,6 – 2,1 g/cm$^3$ | 2,05 – 2,07 g/ cm$^3$ |
| Particle size | 10,70 $* 10^{-6}$ m | Around 10 $* 10^{-6}$ m | 10 * $* 10^{-6}$ m | 10 $* 10^{-6}$m |
| Size of the brick | 80 x 20 x 20 mm | | | |
| Temperature | 700 – 900°C | 750 – 950°C | 750 – 950°C | 1050°C |
| Comments | | Could be used in decoration | | Highly suitable for structural applications |

Because of high compressive and flexural strengths, case 2 has been chosen for calculations in both case countries, Finland and Russia.

# 4. Economic calculations of case studies

This chapter presents economic calculations of case studies. The main aim of this chapter is to explore, whether the chosen way of tailings' recycling is financially profitable for the chosen counties. Because of uncertainty in prices on the market, Monte Carlo analysis was used to see the most probable annual profit and the most probable price for one brick.

In order to achieve the goal of the chapter, several assumptions have been made for the calculations:

1. The production of the bricks is happening 30 days per month, 360 days per year. The factory is producing bricks 75% of this time. The factory works in 3 shifts, each shift lasts 8 hours. The capacity of the factory is 28 000 bricks per day. Production of bricks can be calculated as

   $$Production = capacity\ per\ day * number\ of\ days * 0{,}75 \qquad (4)$$

   Monthly production of the factory in both case countries is 630 000 bricks, yearly production is 7 560 000 bricks.

2. Several machines are needed for production. Types of machines, that were mentioned, are taken from the research (Lemougna 2020), and conveyer belts, mechanical loader, and overhead-type crane are added to automize the process. Prices for the equipment were taken from the internet. An interest rate of 11% (Sberbank 2021) in the case of Russia is added, considering that money will be taken from the bank. The interest rate of 12% (OPR Vakuus 2021) is added in the Finnish case. Total price of machines can be calculated as

   $$Total\ price\ of\ machines = (1 + interest\ rate) * price\ of\ machines \quad (5)$$

   Total price of machines in Russia is 698 234 euros, in Finland is 713 348 euros.

3. Office equipment is evaluated to be 2000 euros per month in Russia and 2600 euros per month in Finland, basing the evaluation on personal experience. The area of 600 $m^2$ will be rented for the production site. The price of the Russian production site is based on a medium of real-life advertisements in Chita city, taken from the Avito.ru website (2021). Finnish price is based on a statistical price of industrial $m^2$ taken from the Statista.com website (2019) multiplied by the area needed. Rent price per month can be calculated as

$$Rent\ per\ month = price\ per\ m^2 * area\ needed \qquad (6)$$

$$Rent\ per\ month_{Russia} = 4{,}5\ euros * 600m^2$$
$$Rent\ per\ month_{Russia} = 2700\ euros$$

$$Rent\ per\ month_{Finland} = 6{,}7\ euros * 600m^2$$
$$Rent\ per\ month_{Finland} = 4000\ euros$$

4. According to the article (Lemougna, 2020), four raw materials are needed for manufacturing the brick: lithium mine tailings, glass wool waste, water, and liquid sodium silicate. The price of the lithium mine tailings was calculated as the price of transportation from the mine to the factory. The price of lithium tailings can also be a difference between transportation costs and the costs of the tailings dam construction. However, the information of correlation between tonnage of tailings and the area that the tailings would take was not found. Therefore, in the case of Finland, the distance of 100 km is calculated from Keliber Oy mine to the south, on the way to Saint-Gobain Finland factory, as glass wool waste will be produced there. This route is shown in Figure 26. In the Russian case, the distance of 100 km is taken from the Zavitinskoe deposit towards Chita city, where bricks will be sold. The map can be seen on Figure 27. Truck is expected to be full, with the tonnage of 23,5 tons. Its diesel consumption is considered to be 40 l/100 km. (Webfleet Solutions) The price of gasoline is 0,6 euros per liter in Russia (Global Petrol Prices) and 1,6 euros per liter in Finland (Autotraveler).

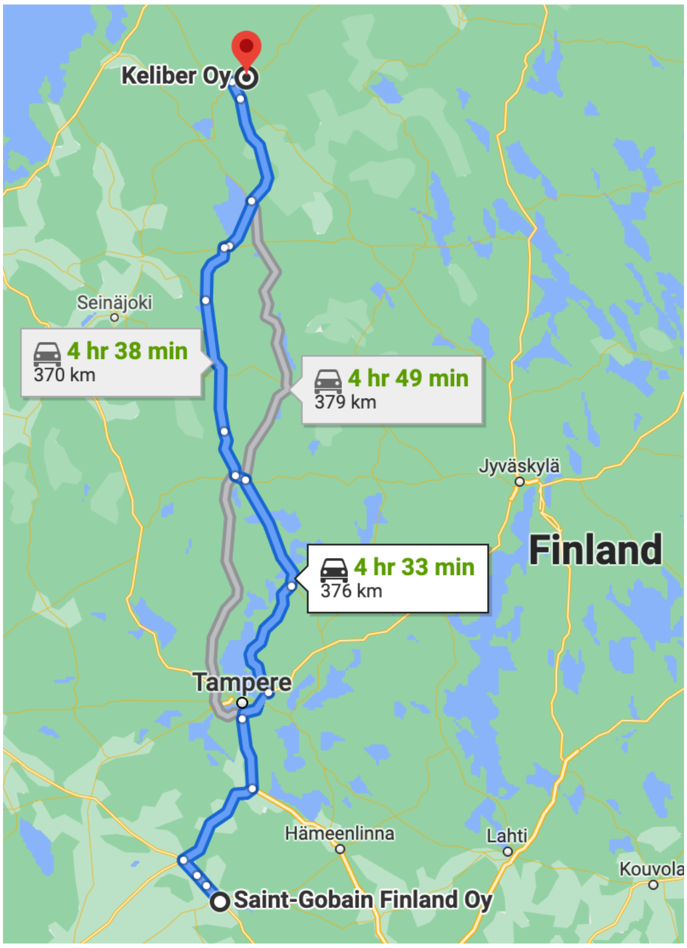


Figure 26. Finnish case (Google Maps 2021a).

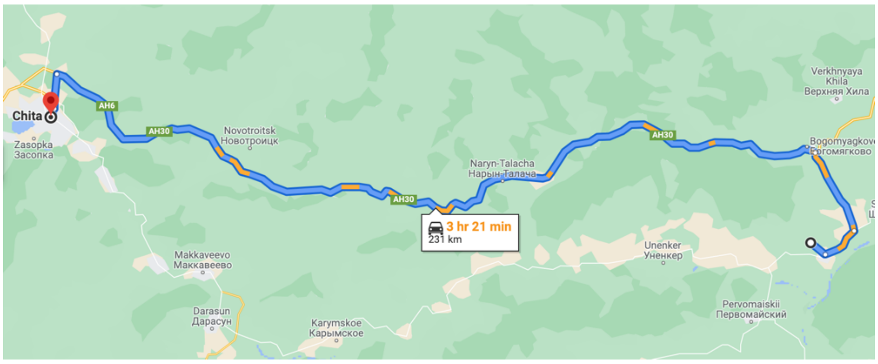


Figure 27. Russian case (Google Maps 2021b).

In the case of Finland, bricks will be sold to the closest city, Vaasa, which is 116 km away from the probable factory. The way can be seen in Figure 28. In Russian case, the city is Chita, which is 131 km away. Figure 26 demonstrates the road.

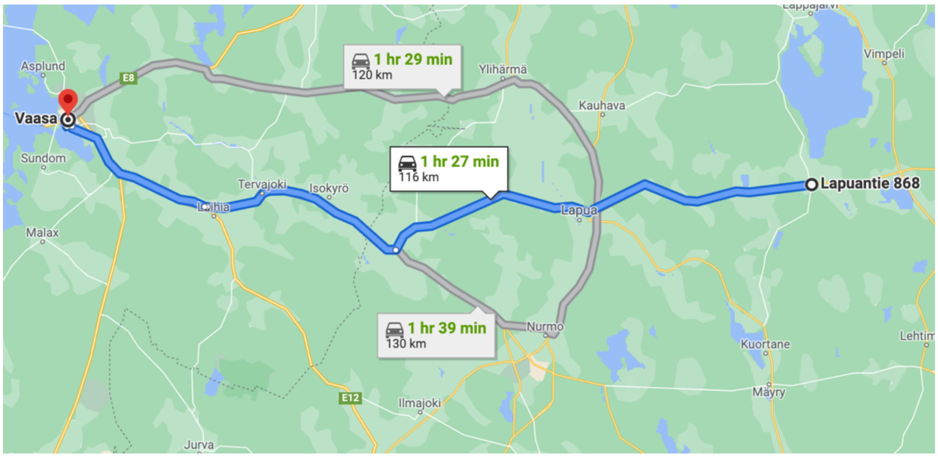


Figure 28. Finnish case, Vaasa (Google Maps 2021c).

5. The price of glass wool waste is calculated as the difference between the transportation costs and the price, that would be otherwise spent on correct waste management. The price for glass wool waste utilization in Finland is taken from Lounais-Suomen Jätehuolto (2021) and the distance from Saint-Gobain to the factory is 270 km. Same truck parameters are used in the calculations. In the Russian case, utilization of glass wool waste would have a cost starting from 3000 rubles per ton (Omega 2021), or 36,41 euros per ton. The distance is taken as 120 km, proposing that the factory of glass wool production will be located in Chita. In reality, to the best of our knowledge, the closest factory will be constructed by Saint-Gobain in 2023 in Kemerovo, which is 2765 km away. (Interfax Russia 2021) Such a big difference drastically changes the results of the calculations and proposes that the price of the Russian brick would be 0,44 euros, or 36 rubles if the glass wool waste is transported to the factory with the same truck. The stated price will not be competitive on the market.

6. The price of the water for the production is taken from the official sources. No separate information for Kokkola water was found, therefore prices for Hämeenlinna are used. In the Finnish case, the price of water is 1,49 euros/m$^3$ (HS-Vesi), in the Russian case, the price of water in Chita is 0,56 euros/m$^3$, or 46,21 rubles. (Vodokanal 2020)

7. The price of liquid sodium silicate is taken from the Internet. In the Finnish case, the same liquid sodium silicate was found, which costs 1750 euros per 250 kg. (Sigma

Aldrich 2021) In the Russian case, liquid sodium silicate was found on the Leroy Merlin website (2021) with the price of 8 euros per 45 kg. It is expected that the price for the production will be lower than the stated numbers, therefore the Monte Carlo analysis was used to show the possible difference in the prices.

8. It is believed that 15% of weight from all materials will be a loss during production. To calculate the extra cost of the materials, following formula can be used:

$$Loss\ costs = total\ material\ price * (1 + 0{,}15) \qquad (7)$$

9. Several employees are needed for the factory to function. Salaries for Finland were found on the SalaryExplorer.com website (2021), for Russia – Trud.com website (2021), searching for Chita region. To find the cost of salaries for the employees, social payments like pension contribution and social interests are added. In Russia social payments include pension fund (22%), medical insurance (5,1%) and social insurance (2,9%). (1C Start 2021) In Finland social payments are pension fund (16,95%), employment accident insurance (0,7%), unemployment insurance (1,42%), group life insurance (0,06%), employer's social security contribution (1,53%) and monthly cost for annual bonus and holiday pay (15,9%). (Business Finland)

10. Average prices for energy calculations were also taken from the Internet. Finnish average price per 1 kWh was found on the Lumo Energia website (2021), then electricity tax was added. Prices for the Russian case calculation was found on Chita official website. (Official portal of Zabaikalskii krai 2021). Due to the lack of information, precise number of kWh needed was not calculated but was estimated. The price of water, needed for office functioning, was taken from the same sources as for water in brick production. However, this time price of water includes both prices for getting water to the factory and removing it. The price is 3,84 euros per $m^3$ for Finland (HS-Vesi) and 1,29 euros per $m^3$ for Russia (Vodokanal 2020). Water consumption was taken as the average of office water consumption. U.S. Department of Energy (2010) reports that one employee consumes 68 liters of water per day. In

calculations 17 employees work, from which 5 employees work 23 days per month. Unskilled workers in the amount of 8 people, technicians and watch men work in two shifts, 15 days each. Driver was excluded from water calculations as he does not work on the factory. In this situation water consumption is 20600 liters.

$$Water\ cost\ per\ month = water\ price * consumption\ per\ month. \quad (8)$$

$$Water\ cost\ per\ month_{Russia} = 0{,}00129\ euros/l * 20600\ l$$

$$Water\ cost\ per\ month_{Russia} = 25{,}88\ euros$$

$$Water\ cost\ per\ month_{Finland} = 0{,}00384\ euros/l * 20600\ l$$

$$Water\ cost\ per\ month_{Finland} = 77{,}03\ euros$$

11. Other costs include marketing expenses, maintenance, insurance and telephone. They are added with average numbers. Depreciation of machines and office furniture are added to the calculations table. In the case of machines, depreciation is 10%, furniture – 2%. The margin for the bricks is 42%.

Monte Carlo analysis was chosen to find the most probable profit and the selling price per one brick. Results from 500 simulations were drawn as a graph for a visual representation. Annual profit for Finland can be seen in Figure 29. Profit was calculated with the following formula:

$$Profit = (Revenue - expenses - depreciation) * tax \quad (9),$$

Where:

$$Expenses = land\ rental + materials + salaries + utilities + other\ costs \quad (10)$$

Tax for the profit is also deducted in calculations. Invest in Finland reports that Finnish companies should pay value added tax (VAT) of 24% and corporate tax of 20%. Electricity tax of 0,703 cents per kWh is also added to the utility price. (Invest in Finland)

Each of the parameters has its own expected value, which was taken from the calculation table, and its standard deviation was calculated as the difference between worst case scenario and best case scenario, divided by two.

As it can be deducted from Figure 29, the most probable profit in the Finnish case is between 103 000 euros and 147 000 euros. Profit in this range was predicted in 94 simulations. In 86 simulations the profit was between 147 000 euros and 191 000 euros. In 43 simulations, or in 8,6%, the profit was negative.

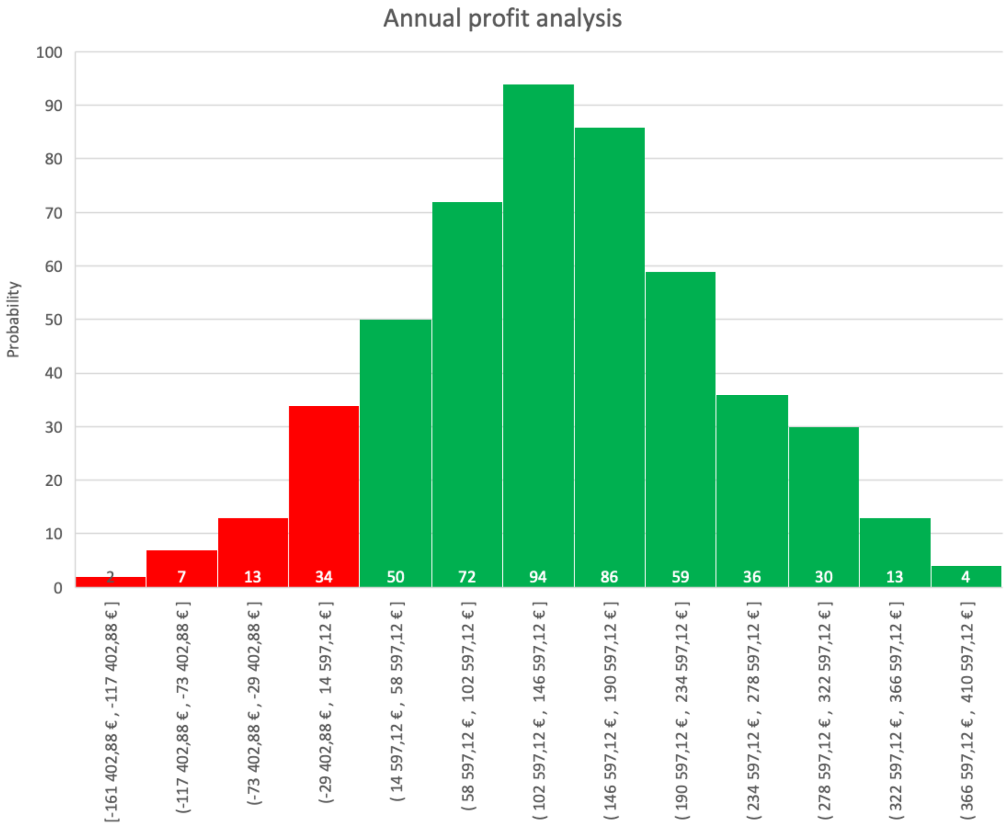


Figure 29. Annual profit for the Finnish case

Selling price of one brick was deducted with the following formula:

$$Price\ per\ brick = (expenses + depreciation\ costs) * \frac{margin}{amount\ of\ bricks\ per\ year} \quad (11),$$

Where:

$$Expenses = land\ rental + materials + salaries + utilities + other\ costs \quad (12)$$

Figure 30 represents the probabilities of costs of one brick. As it can be seen from the figure, the price between 0,24 euros and 0,25 euros was calculated in the biggest number of simulations.

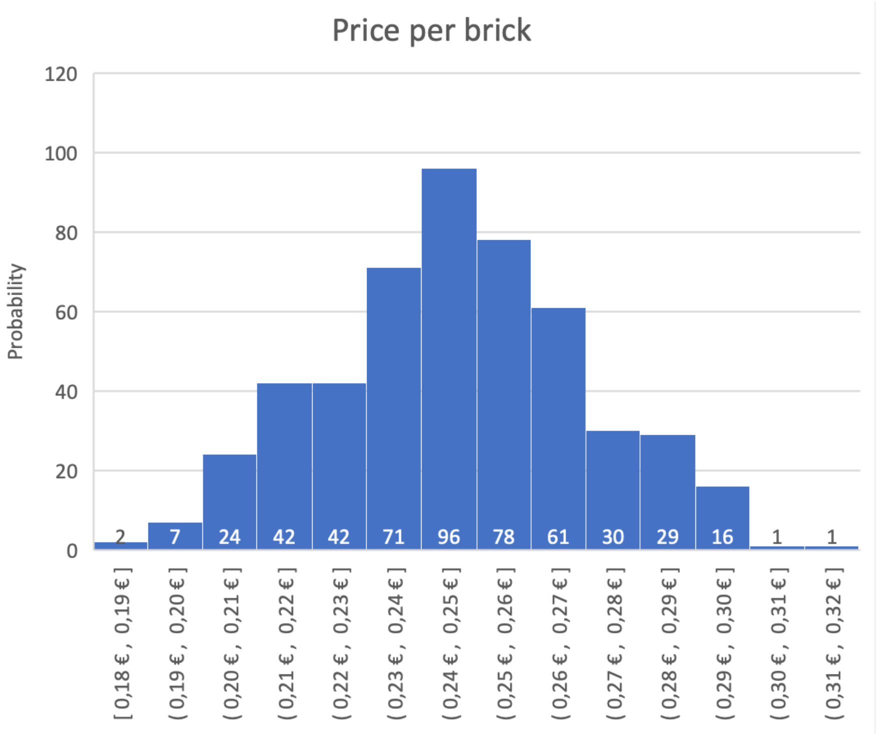


Figure 30. Price per one brick in Finland

In the Russian case, same formulas were used. However, standard deviations were different due to different expected numbers.

Taxes that are paid in Russia by companies are also different. It is expected that the company has a USN tax system as its income does not exceed 200 million rubles per year and it has less than 130 employees. (Tinkoff) In the calculation, tax of 6% is removed from the profit.

Figure 31 shows the most possible annual profit in the Russian case. As it can be seen from the figure, the most possible annual profit is in the range between 161 000 euros and 204 000 euros, or between 13 300 000 rubles and 16 900 000 rubles. In 23 simulations, or in 4,6%, the profit was negative.

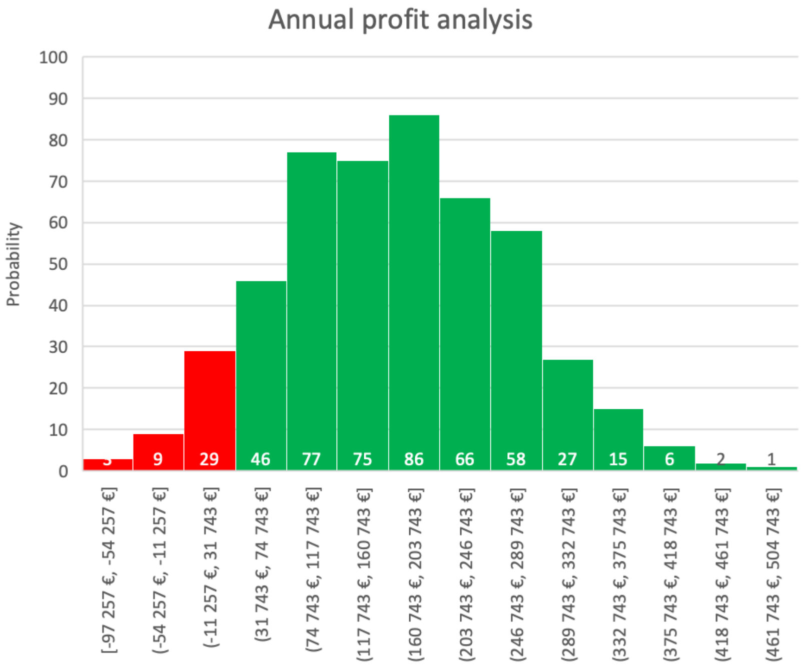


Figure 31. Annual profit for the Russian case

The price per brick in the Russian case can be seen on Figure 32. The figure shows the price in rubles as the difference between the prices in euros is not as notable. In the biggest number of simulations, or in 87 simulations, the price of the brick was between 6,64 rubles and 6,83 rubles, which is around 0,08 euros per brick.

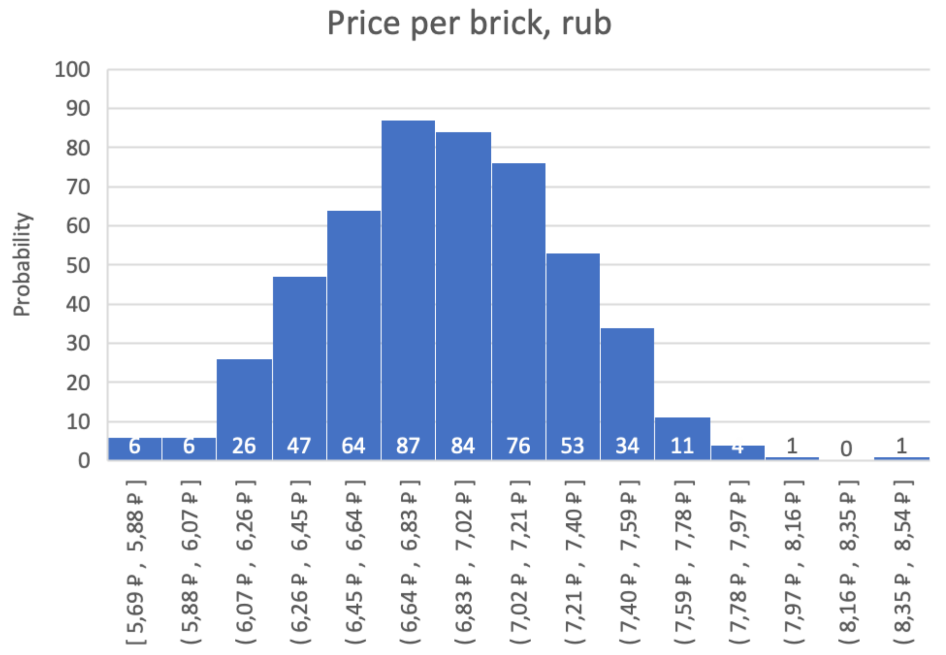


Figure 32. Price per one brick in Russia

A pie chart in Figure 33 demonstrates the impact on the final cost of each cost parameters in Finland, Figure 34 shows the impact of cost parameters in Russia. It can be noticed that expenses on salaries are significantly affect the price in both case countries and take almost a half of the contribution to costs in Finland and almost 40% in Russia. The second most significant parameter in Finland is the costs of materials and the third one is other expenses, which include marketing costs, insurance, maintenance and telephone. In Russia the second most significant parameter is other expenses and the third one is depreciation costs.

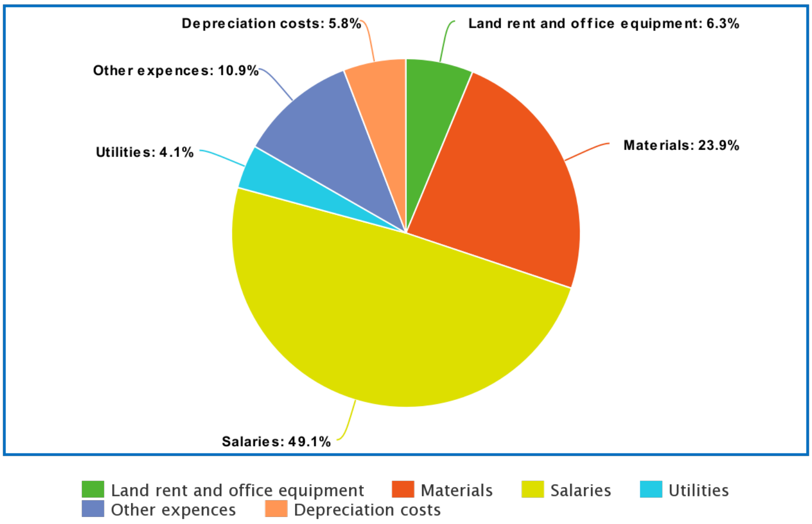


Figure 33. Contribution of cost parameters in Finland.

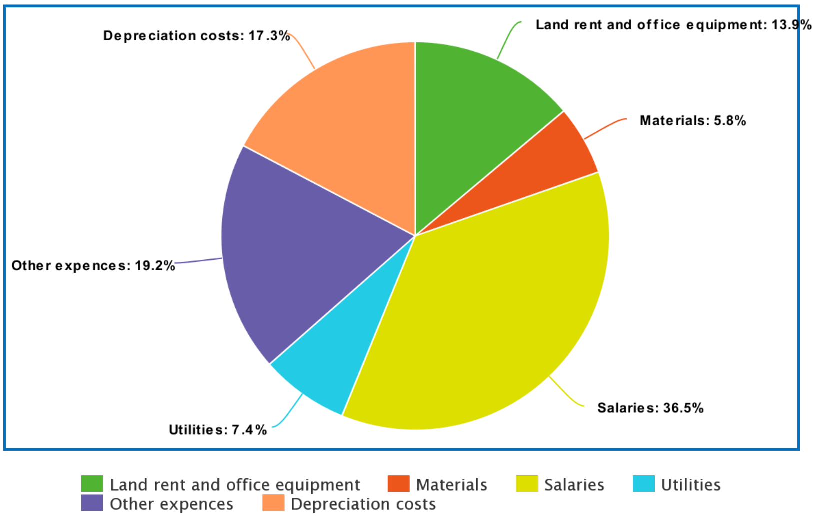


Figure 34. Contribution of cost parameters in Russia.

Through the calculations, it can be suspected that the building of brick factories and using lithium mine tailings as it was described in Lemougna et al.'s (2020) research, can be beneficial for both Finnish and Russian cases, as prices for the bricks from tailings are lower than the prices for average bricks. Finnish and Russian prices can be seen in Table 17 for a comparison. It can be stated that the price of an average brick is 3-4 times higher in Finland and around 2 times higher in Russia than the price of the brick from tailings.

Table 17. Price comparison

| Finland | Russia |
|---|---|
| 1,05 euros (Taloon.com 2021) | 19 rub per piece (0,23 euro) (Vorotynskiy kirpich 2021) |
| 0,85 euros (Taloon.com 2021) | 8 rub per piece (Zabor bez zabot 2021) |

# 5. Conclusions

Electrification of transport is important for sustainable development of the world. As the interest in electric vehicles is growing, mining industry is facing a challenge. From a large number of excavated materials only a small part can be used for the production of batteries. Therefore, it is important to involve solid waste in circular economy and find new ways of its valorization.

Through the literature review, two of research questions were answered. It was discovered that mine waste can be used for several purposes in construction and decoration and to lower that amount of waste sent to landfill, it is possible to explore suggestions of the researchers that were mentioned in the literature review and test applicability for each of mines. Applications, that were found, involve the production of geopolymer, porcelain and foam mine fill.

Calculation part has answered the last research question. With the help of calculations, it was found that the production of bricks from lithium tailings and glass wool waste can be a feasible option for Finland and Russia, as the price of a brick, which was made from waste materials, is lower than the price of the brick made from clay. In calculations, that were performed, salaries and materials were in top three cost parameters that affected the price the most. It also should be noted, that in both case countries there is a probability that annual profit is below zero. However, this percentage is rather low.

Another important factor in cost formation is the location of the future factory. It should be close enough to the mine and to the city, where bricks will be sold. In the Finnish case, Vaasa could be a city of interest. For Russia, this city could be Chita.

In the Russian case, this paper brings another benefit to the renovation of the lithium mine in Zabaikalskii krai. However, construction of the factory will help in reducing the amount of lithium tailings and promote jobs in both countries.

For future research, prices for the machines and their needed amount can be regulated. Taxes and costs of using land for backfilling could be added with minus costs to raw materials to see a clearer picture. Even though bricks are commonly used in construction, it would be beneficial for the research to study the demand and construction needs in cities, that were mentioned in the calculations. It is also important for the Russian case to find a local source of glass wool waste, as factories that can be found now, are too far away and drastically affect the price. Moreover, the correct solution of liquid sodium silicate should be stated to correctly calculate the costs of raw materials.

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# Appendix 1: Calculations for Finland

| | | | Product | | | | | |
|---|---|---|---|---|---|---|---|---|
| 75% | | Machine efficiency | 75% | | | | | |
| | | Number of shifts | 3 | | | | | |
| | | Hours/shift | 8 | | | | | |
| | | Days | | | | | 30 | 360 |
| | | Machine capacity pcs/day | 28000 | | | | 630000 | 7560000 |
| | | | Capacity Pcs/min | | | | | Total € |
| Capex | | Grinder | | | 2 | € 12 070,00 | | € 24 140,00 |
| | | Dry-grinding mill | | | 2 | € 48 000,00 | | € 96 000,00 |
| | | Bunker for mixing | | | 4 | € 60 000,00 | | € 240 000,00 |
| | | Two-roll mixer | | | 2 | € 9 600,00 | | € 19 200,00 |
| | | Conveyer belt | | | 6 | € 7 200,00 | | € 43 200,00 |
| | | Pressing machine | | | 2 | € 20 500,00 | | € 41 000,00 |
| | | Oven | | | 3 | € 20 000,00 | | € 60 000,00 |
| | | Mechanical loader | | | 2 | € 18 100,00 | | € 36 200,00 |
| | | Propeller-driver conveyer belt | | | 4 | € 4 200,00 | | € 16 800,00 |
| | | Overhead-type crane | | | 1 | € 12 000,00 | | € 12 000,00 |
| | | Truck | | | 1 | € 64 450,00 | | € 64 450,00 |
| | | | | | Total | | | € 652 990,00 |
| | | | | | With loan 12% | | | € 731 348,80 |
| | | | | | | | Total €/month | Total €/year |
| | | Land & building rental | | | | | € 4 000,00 | € 48 000,00 |
| Land/building | | Office equipment | | | | | € 2 600,00 | € 31 200,00 |
| | | | | | Total | | € 6 600,00 | € 79 200,00 |
| | | Description | | kg/product | | Rate €/kg | Total €/month | Total €/year |
| | | Lithium mine tailings | | 3,8 | | 0,005 | € 11 970,00 | € 143 640,00 |
| Raw material | | Glass wool waste | | 0,38 | | -0,014 | -€ 3 351,60 | -€ 40 219,20 |
| | | Water | | 0,084 | | 0,00149 | € 78,85 | € 946,21 |
| | | Liquid Sodium Silicate | | 0,003 | | 7 | € 13 230,00 | € 158 760,00 |
| | | | | | | | | |
| | | | | | | subtotal | € 21 927,25 | € 263 127,01 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | Wastage | 15% | € 3 289,09 | € 39 469,05 |
| | | | | | Total | | € 25 216,34 | € 302 596,06 |
| | | | | | | | | |
| | Item | | | | | | Total €/month | Total €/year |
| | Work Manager | | | | 1 | € 3 200,00 | € 3 200,00 | € 38 400,00 |
| | Accountant | | | | 1 | € 3 480,00 | € 3 480,00 | € 41 760,00 |
| | Secretary | | | | 1 | € 2 130,00 | € 2 130,00 | € 25 560,00 |
| | Cleaner | | | | 1 | € 2 000,00 | € 2 000,00 | € 24 000,00 |
| | Unskilled workers | | | | 8 | € 1 200,00 | € 9 600,00 | € 115 200,00 |
| | Driver | | | | 1 | € 1 430,00 | € 1 430,00 | € 17 160,00 |
| | Logistics | | | | 1 | € 3 000,00 | € 3 000,00 | € 36 000,00 |
| | Mechanical and electrical technician | | | | 2 | € 3 000,00 | € 6 000,00 | € 72 000,00 |
| | Watchman | | | | 1 | € 2 146,00 | € 2 146,00 | € 25 752,00 |
| Labour costs | Total | | | | | | € 32 986,00 | € 395 832,00 |
| | Pension contribution (16,95%) | | | | | | € 5 591,13 | € 67 093,52 |
| | Employment accident insurance (0,7%) | | | | | | € 230,90 | € 2 770,82 |
| | Unemployment insurance (1,42%) | | | | | | € 468,40 | € 5 620,81 |
| | Group life insurance (0,06%) | | | | | | € 19,79 | € 237,50 |
| | Employer's social security contribution (1,53%) | | | | | | € 504,69 | € 6 056,23 |
| | % | Monthly cost for annual bonus and holiday pay (15,9%) | | | | | € 5 244,77 | € 62 937,29 |
| | Total for employer | | | | | | € 45 045,68 | € 540 548,18 |
| | | | Overheads | | | 15% | € 6 756,85 | € 81 082,23 |
| | | | | | | Salaries | € 51 802,53 | € 621 630,41 |
| | | | | | unit | €/unit | Total €/month | Total €/year |
| | Power | | | kWh | 60500 | 0,07 | € 4 235,00 | € 50 820,00 |
| Utilities | water | | | litres | 25500 | 0,00311 | € 79,31 | € 951,66 |
| | | | | | | Total | € 4 314,31 | € 51 771,66 |
| | | | | | | | | |
| | Marketing | | | | | | € 3 000,00 | € 36 000,00 |
| | Insurance | | | | | | € 1 500,00 | € 18 000,00 |
| Other | Misc expenses | | | | | | € 2 000,00 | € 24 000,00 |
| | Maintenace | | | | | | € 1 500,00 | € 18 000,00 |
| | Telephone | | | | | | € 500,00 | € 6 000,00 |
| | Transport | | | | | | € 3 000,00 | € 36 000,00 |
| | | | | | | Total other expences | € 11 500,00 | € 138 000,00 |
| | | | | | | Overall total | € 99 433,18 | € 1 193 198,13 |
| | Depreciation on machines | 10% | | | | | | € 73 134,88 |
| | Depreciation on office furniture | 2% | | | | | | € 624,00 |
| | Total | | | | | | | € 1 266 957,01 |
| | Production/product | | | | | | €/product | € 0,17 |
| | Margin | 42% | | | | | | 532121,943 |
| | Total | | | | | | | € 1 799 078,95 |
| | | | | | | | €/product | 0,237973406 |

# Appendix 2: Calculations for Russia

| | | | | Product | | | | |
|---|---|---|---|---|---|---|---|---|
| 75% | | Machine efficiency | 75% | | | | | |
| | | Number of shifts | 3 | | | | | |
| | | Hours/shift | 8 | | | | | |
| | | Days | | | | | 30 | 360 |
| | | Machine capacity pcs/day | 28000 | | | | 630000 | 7560000 |
| | | | Capacity Pcs/min | | | | | Total € |
| Capex | | Grinder | | | 2 | € 12 070,00 | | € 24 140,00 |
| | | Dry-grinding mill | | | 2 | € 48 000,00 | | € 96 000,00 |
| | | Bunker for mixing | | | 4 | € 60 000,00 | | € 240 000,00 |
| | | Two-roll mixer | | | 2 | € 9 600,00 | | € 19 200,00 |
| | | Conveyer belt | | | 6 | € 7 200,00 | | € 43 200,00 |
| | | Pressing machine | | | 2 | € 20 500,00 | | € 41 000,00 |
| | | Oven | | | 3 | € 20 000,00 | | € 60 000,00 |
| | | Mechanical loader | | | 2 | € 18 100,00 | | € 36 200,00 |
| | | Propeller-driver conveyer belt | | | 4 | € 4 200,00 | | € 16 800,00 |
| | | Overhead-type crane | | | 1 | € 12 000,00 | | € 12 000,00 |
| | | Truck | | | 1 | € 40 500,00 | | € 40 500,00 |
| | | | | | Total | | | € 629 040,00 |
| | | | | | Debt 11% | | | € 698 234,40 |
| | | | | | | | Total €/month | Total €/year |
| Land/building | | Land & building rental | | | | | € 2 700,00 | € 32 400,00 |
| | | Office equipment | | | | | € 2 000,00 | € 24 000,00 |
| | | | | | | Total | € 4 700,00 | € 56 400,00 |
| | | Description | | kg/product | | Rate €/kg | Total €/month | Total €/year |
| Raw material | | Lithium mine tailings | | 3,8 | | 0,002 | € 4 788,00 | € 57 456,00 |
| | | Glass wool waste | | 0,38 | | -0,034 | -€ 8 139,60 | -€ 97 675,20 |
| | | Water | | 0,084 | | 0,00056 | € 29,64 | € 355,62 |
| | | Liquid Sodium Silicate | | 0,003 | | 0,56 | € 1 058,40 | € 12 700,80 |
| | | | | | | | | |
| | | | | | | subtotal | -€ 2 263,56 | -€ 27 162,78 |
| | | | | | Wastage | 15% | € 339,53 | € 4 074,42 |
| | | | | | | | -€ 1 924,03 | -€ 23 088,36 |
| | | | | | | | | |
| | Item | | | | | | Total €/month | Total €/year |
| Labour costs | Work Manager | | | | 1 | € 443,00 | € 443,00 | € 5 316,00 |
| | Accountant | | | | 1 | € 408,00 | € 408,00 | € 4 896,00 |
| | Secretary | | | | 1 | € 410,00 | € 410,00 | € 4 920,00 |
| | Cleaner | | | | 1 | € 225,00 | € 225,00 | € 2 700,00 |
| | Unskilled workers | | | | 8 | € 475,00 | € 3 800,00 | € 45 600,00 |
| | Driver | | | | 1 | € 839,00 | € 839,00 | € 10 068,00 |
| | Logistics | | | | 1 | € 394,00 | € 394,00 | € 4 728,00 |
| | Mechanical and electrical technician | | | | 2 | € 502,00 | € 1 004,00 | € 12 048,00 |
| | Watch man | | | | 2 | € 374,00 | € 748,00 | € 8 976,00 |
| | | | Total | | | | € 8 271,00 | € 99 252,00 |
| | | | | Pension fund (22%) | | | € 1 819,62 | € 21 835,44 |
| | | | | Medical insurance (5,1%) | | | € 421,82 | € 5 061,85 |
| | | | | Social insurance (2,9%) | | | € 239,86 | € 2 878,31 |
| | | | | Total for employer | | | € 10 752,30 | € 129 027,60 |
| | | | Overheads | | | 15% | € 1 612,85 | € 19 354,14 |
| | | | | | | Salaries | € 12 365,15 | € 148 381,74 |
| | | | | | unit | €/unit | Total €/month | Total €/year |
| Utilities | Power | | | kWh | 60500 | 0,041 | € 2 480,50 | € 29 766,00 |
| | water | | | litres | 18700 | 0,00129 | € 24,12 | € 289,48 |
| | | | | | | | € 2 504,62 | € 30 055,48 |
| | | | | | | | | |
| Other | Marketing | | | | | | € 1 000,00 | € 12 000,00 |
| | Insurance | | | | | | € 1 000,00 | € 12 000,00 |
| | Misc expenses | | | | | | € 2 000,00 | € 24 000,00 |
| | Maintenace | | | | | | € 1 000,00 | € 12 000,00 |
| | Telephone | | | | | | € 500,00 | € 6 000,00 |
| | Transport | | | | | | € 1 000,00 | € 12 000,00 |
| | | | Total | | | | € 6 500,00 | € 78 000,00 |
| | | | | | | Total Opex | € 22 145,74 | € 265 748,86 |
| | Depreciation on machines | 10% | | | | | | € 69 823,44 |
| | Depreciation on office furniture | 2% | | | | | | € 480,00 |
| | Total | | | | | | | € 336 052,30 |
| | Production/product | | | | | | €/product | 0,044451362 |
| | Margin | 42% | | | | | | € 141 141,96 |
| | Total | | | | | | | € 477 194,26 |
| | | | | | | | €/product | 0,063120934 |