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About lithium and lithium in Serbia

Abstract: This paper summarizes basic information about lithium, its physical and chemical characteristics and its occurrence in different minerals, especially in jadarite. A review of different types of application of lithium and their compounds in different industries, especially in medicine, is presented here. Also, the review of literature data on lithium occurrence in water and various food and its influence on humans is described. The role of lithium in warfare is also mentioned. Detailed data on different types of lithium batteries, including the new type of lithium batteries with solid electrolyte is given. Data on lithium production and lithium demand, including the increase of lithium demand in the near future is summarized in this article. In the part related to the Serbian Jadar project, some basic data on this project is given; that includes the technological procedure of lithium production, solid and liquid waste and landfill for waste deposition, especially in regard to the environmental protection. The part of beginning with the subtitle "Shouting and shame about lithium in Serbia" contains critical review on numerous nonsensical claims, misinformation and lies about lithium and Jadar project, especially about sulphuric acid and lithium toxicity that were spread across Serbia in the past four years, becoming an object of intimidation of Serbian citizens. Aiming to show how nonsensical and false these claims are, the data from valid and credible verifiable sources were cited. The final part of the text contains proposals about things that should be done in relation to the Jadar project.

Keywords: lithium, occurrence and production, application, Jadar project

About lithium

Lithium is the third element in the periodic system of elements, and belongs to the group of alkali metals. Its chemical symbol is *Li*. Its name is derived from the Greek word for stone (*lithos*). Even though it is one of the three elements produced in the Big Bang, there is very little of it in the universe, and is not found in a free state in nature. It is very scarce in the universe (0.0007% in the Earth's crust), even

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though it is one of the three elements, along with hydrogen and helium, which were created at the very beginning of the universe. According to this theory of origin, the universe should contain three times as much lithium as is calculated from the oldest stars (in cosmology this is the problem of “lithium deficiency”) (Fields, 2011). It was discovered in 1790 in the mineral petalite ($LiAlSi_4O_{10}$), based on the carmine red colour it exhibited in a flame (Figure 1). For this reason, lithium is also used in the manufacture of pyrotechnics.

Figure 1: Carmine red colour of lithium in a flame.
Source: Wikipedia

Lithium has an atomic number of 3 and an atomic mass of 6.941. It is a silvery-white metal, very soft. It has a hardness of 0.6 on the Mohs scale, which means it is softer than talc, which has a hardness of 1. It occurs in the form of 10 isotopes, of which 2 are stable in nature, the most abundant being Li-7 (92.5% natural abundance) and Li-6 (7.5% natural abundance). It has the lowest density of all metals, 0.534 g/cm^3, which, together with a redox potential of -3.04 V, makes it very suitable for use in lithium-ion batteries. Lithium has the highest melting point (182 °C) and boiling point (1,342 oC) of all alkali metals. It also has the highest specific heat capacity, which is 3,570 J/kg K. (Specific heat capacity is the amount of heat required to raise the temperature of 1 kilogram of a substance by 1 °C and for water it is 4,185.5 J/kg K). At very high pressure (400,000 atmospheres) lithium becomes superconductive (Rumble, 2017). Like all alkali metals, lithium is reactive and flammable and releases hydrogen with water, which is why it is not found in nature in its free state. Pure lithium must be stored in a vacuum, in an inert atmosphere, or under an organic liquid (kerosene, mineral oil).

Occurrence

So far, 124 minerals are known to contain lithium (Edward, 2020), and it is most commonly found in the following minerals: *amblygonite, cookeite, elbaite, eucryptite, faizievite, Finniss Lithium Project, fluor-liddicoatite, hectorite, jadarite, lepidolite, lithiophilite, lithiophosphate, nambulite, neptunite, petalite, pezzottaite, saliotite, spodumene, sugilite, tourmaline, triphylite, zabuyelite, zektzerite, zinnwaldite.*

In Serbia, in the valley of the Jadar River, about ten kilometres southwest of Mount Cer, the mineral jadarite (Stanley et al., 2007), which contains lithium and boron, was discovered in 2004. It is a monoclinic silicate mineral with the chemical formula $LiNaSiB_3O_7(OH)$ or $Na_2OLi_2O(SiO_2)_2(B_2O_3)_3H_2O$. The International Mineralogical

Association recognised the new mineral under this name (2006–36) (Jadarite Mineral Data).

Jadarite, named after its location in the Jadar River valley (about ten kilometres southwest of Mount Cer), is a monoclinic silicate mineral. Its chemical composition is sodium lithium boron silicate hydroxide ($LiNaSiB_3O_7(OH)$ or $Na_2OLi_2O(SiO_2)_2(B_2O_3)_3H_2O$). Based on the chemical formula, the authors (Stanley et al, 2007) calculated the percentage content of individual components: Li_2O 7.3%, Na_2O 15.0%, SiO_2 26.4%, B_2O_3 47.2%, H_2O 4.3%, a total of 100.2% by weight. Webmineral (Jadarite Mineral Data) lists the following composition of jadarite: Li_2O 7.28% (Li 3.38%), Na_2O 14.96% (Na 11.1%), SiO_2 26.30% (Si 12.29%), B_2O_3 47.12% (B 14.63%), H_2O 4.31% (H 0.48%). Jadarite occurs in the form of small crystals (5 -10 mm). When it comes to the average composition of lithium and boron in jadarite, the average content of Li_2O is 1.8% and B_2O_3 is 13.1%.

Seawater contains approximately 0.17 mg/l, rivers generally only 3 mg/l, while mineral waters can contain 0.05 – 1 mg/l (Lenntech). Larger amounts of lithium are found in the water of Carlsbad, Marienbad and Vichy (Kavanagh et al., 2018). Lithium is found in solutions only in the form of the Li^+ ion. Groundwater can contain significantly higher amounts of lithium, even more than 500 mg/L (Kavanagh et al., 2017), but the lithium content in these waters is generally between 0.5 and 19 mg/L (Figueroa et al., 2012). In northern Chile, however, the lithium content in drinking water, but also in food, is 100 to 10,000 times higher than in rivers in North America (Figueroa et al., 2012).

Soil contains an average of about 20 mg/kg of lithium (Kavanagh et al., 2018).

Application of lithium

Lithium does not react with oxygen. In humid air, lithium reactions with nitrogen and other gases in the air are slow, forming lithium nitride (Li_3N), lithium hydroxide (LiOH), and lithium carbonate (Li_2CO_3). It reacts with halogen elements to form the corresponding halides (lithium fluoride, lithium chloride, lithium bromide, and lithium iodide). Lithium hydrides (LiBH, LiAlH) are reagents widely used in organic synthesis. Lithium reacts with acids to produce lithium sulphate, lithium nitrate, and lithium chloride.

Metallic lithium is produced by electrolysis from molten salts of lithium chloride and potassium chloride.

Some lithium compounds, such as lithium chloride and lithium bromide, are highly hygroscopic (absorb moisture), and are used in industrial gases drying. Lithium hydroxide and lithium peroxide (Li_2O_2) are used to remove carbon dioxide and purify the air in confined spaces, such as spacecraft and submarines. Lithium hydroxide was also used in the Apollo space missions, as it absorbs carbon dioxide and forms lithium carbonate. Lithium peroxide also reacts with carbon dioxide in the presence of moisture, forming lithium carbonate, while releasing oxygen. An “oxygen candle”, or lithium perchlorate, releases oxygen and is used in submarines.

Lithium and its ores have long been used in glass production and ceramic industries, and until recently, they were the most widely and frequently used. Lithium ores (spodumene, amblygonite, lepidolite, and petalite) are used to reduce the viscosity and lower the production temperature of glass and ceramics, thereby reducing production costs. Lithium has a low coefficient of thermal expansion, so when added to molten glass it reduces the thermal expansion and fluidity of the glass. Adding 0.17% lithium oxide (Li_2O) to glass reduces the melting temperature by 25 °C, thereby saving 5-10% energy. The addition of lithium creates pyroceramic products, i.e. products resistant to high temperatures, which are used to make furnaces for insulating materials with extended service life, resistant to temperature shocks, with enhanced mechanical properties and increased surface tension. Lithium fluoride crystals are used to make special optical parts, which are used for ultraviolet (UV) and infrared (IR) optics, which is especially useful in the construction of telescopes with enhanced properties.

Lithium is widely used in steel industry, especially in the production of aluminium, where lithium carbonate significantly reduces energy consumption (in 1996, about 40% of all lithium in the United States was spent on aluminium production). In addition, it is used to make many alloys, since it is the lightest metal, and light alloys with improved strength are obtained (alloys with aluminium and magnesium for the production of light but strong parts for aircraft).

Lithium is also used for the production of special glasses (pyrex) resistant to temperature, for the production of touch screens, in the pharmaceutical industry, the production of fibreglass, special glasses for glass-ceramic stoves and for induction furnaces.

Numerous organic lithium compounds are used in the chemical industry, as catalysts, in polymerization, as reducing agents, and for the production of special lubricants (lithium stearate) resistant to high temperatures.

Application in medicine

Lithium is also widely used in medicine. It has beneficial neurological effects, and has been used for a long time, since the time of ancient Rome, to treat neurological diseases. Soranus of Ephesus, a Roman physician, discovered that patients who drank alkaline water (with an increased lithium content) had better health (Thomson, 2007). Even without knowledge of lithium, Soranus discovered an improvement in health for bone pain, as well as for the treatment of manic symptoms.

Lithium has been used as early as 1845 to treat gout because it was established that a solution of lithium salts dissolved uric acid crystals in the urine, which formed gout (Schrauser, 2002, Kaill, 1999). It was assumed that an "imbalance of urate" (uric acid salts) lead to many diseases. It is also known that uric acid is a psychoactive substance, so it was assumed that lithium treatment, which would reduce uric acid levels, would help in the treatment of patients with acute mania (Oruch et al., 2014). Thus, in the 1920s, lithium became known as a miracle nerve-protecting agent, and for a time it was added to some soft drinks, such as "*Lemon-Lime Soda*", the predecessor of the *7-up* soda (where lithium was the original "*up*" ingredient), and "*Lithia Water*" (Davis, 1987). In some parts of the world, lithium chloride was used as a substitute for table salt (sodium chloride), especially for people who had a diet low in sodium. The wide application of lithium in the diet or in soft drinks could lead to harmful effects due to excessive amounts of lithium, so the use of lithium in soft drinks was prohibited. Since 1880, lithium has been used to treat patients with acute mania, as well as those prone to suicide. The increased use of lithium (lithium carbonate) for the treatment of mental illness began in 1940, when Australian psychiatrist Dr. John Cade, while treating such patients, found that lithium carbonate had a calming effect on patients. Lithium carbonate, as well as lithium acetate, lithium aspartate, lithium citrate, lithium borate, lithium orotate, and lithium sulphate, were used to treat bipolar disorder (manic depression), which resulted in a decrease in suicides (Kaill, 1999). Lithium salts (most commonly lithium carbonate) are also used to treat schizophrenia and addiction. Lithium interacts with neurotransmitters (stimulant transmitters) and receptors in the human brain, increasing serotonin levels and decreasing norepinephrine (a hormone and neurotransmitter) production in the brain. It is a very complex process that has not been fully studied, although there are already nine theories about it and further research is forthcoming.

Figure 2. Lithium is also used in medicine to treat neurological diseases.
Photo: Shutterstock

Therapeutic doses of lithium prescribed for the treatment of the aforementioned mental disorders and diseases range from 600 to 2,400 milligrams/day (Mayo Clinic, Minddisorder).

Lithium efficacy in the management of acute mania was approved by the *US Food and Drug Administration (FDA)* in 1970. Other conditions that have been treated with lithium include headache, high blood pressure, diabetes, epilepsy, arthritis, dementia (Timmer et al., 1999, Kessing et al., 2010), and even tooth decay.

No cases of the stated acute or chronic poisoning from natural sources of lithium have been reported in the literature. In humans, ingestion of more than 5 g of lithium chloride can result in fatal toxicity (Shahzad et al., 2017, Aral et al., 2008). Another estimate for the lethal dose is up to 90 mg/kg body weight of lithium, which means about 6,300 mg (6.3 grams) of lithium for an average weight of 70 kg, according to Koen van Deun et al (Van Deun et al., 2021).

Lithium in water and food and its impact

Lithium in small concentrations is useful in human nutrition, and no data in literature indicates any physiological symptoms of a diet that lacks in lithium. A study done in Texas (US) in 1990 records beneficial effects of lithium. Over the span of more than ten years, a reduction in the number of suicides had been recorded, as well as home homicides and rapes in the area where lithium concentration in the drinking water was in the range of 0.07 – 0.160 mg/l (Bluml et al., 2013). This study also confirmed beneficial effects of lithium on the reduction of violence and the number of suicides, even at concentrations found in drinking water (Schrauzer et al., 1990, Giotakos et al., 2013, Liaugaudaite et al., 2017). Similar studies have been done in Japan, Austria, in the East of England, and they have shown that the number of suicides declined in places where the concentration of lithium in drinking water had been increased.

Due to its exceptional effects as a protector of the nervous system, lithium is also used in medicine in pretty high dose (600 to 2,400 milligrams per day), especially in psychiatry, for treatment of various forms of manic, schizophrenic, and bipolar disorders. This is why comprehensive studies looked into possible effects of significantly smaller doses of lithium on people, as seen in drinking water or in foodstuffs (Szklarska et al., 2019). The confirmed results regarding the reduction in the number of suicides, domestic murders, addiction-related diseases, and crime have prompted many scientists to seriously investigate the effects of small concentrations of lithium on humans, such as those found in drinking water or food products. Such studies have also emerged from the need to determine whether the global suicide rate, which is around 800,000 per year, can be reduced (WHO, 2017). A large number of suicides is most common in highly developed countries, as confirmed by the example of Europe (Kovess-Masfety et al., 2011). Suicides are most often committed due to a diagnosed illness or due to bipolar disorder (Phillips, 2010). One of the objectives of these studies is to determine the smallest dose of lithium, introduced through water or food, which has a positive effect on reducing crime and the number of suicides and domestic murders (Schrauzer et al., 1990). Numerous papers have highlighted the justification for such research (Schrauzer et al., 1990, Young, 2009, Ohgami et al., 2009, Kapusta et al., 2011, Sugawara et al., 2013, Giotakos et al., 2013, Liaugaudaite et al., 2017).

Daily lithium intake differs in various parts of the world and depends on the availability of lithium in the environment and foodstuffs, and its concentration ranges from several micrograms to several thousand micrograms a day. Schrauzer proposes that the daily lithium intake should be around 1,000 µg (1 mg)/day for adults weighing 70 kg (14.3 µg/kg) (Schrauzer, 2002). Due to uneven distribution of lithium in Earth's surface, its concentrations differ in various parts of the world, but it is known that the ones in Europe are among the lowest. And so, data states that the intake of lithium in Poland is only 10.7 µg/day, and 8.6 µg/day in Belgium.

The main sources of lithium in the diet are cereals, potatoes, tomatoes, cabbage, some mineral waters, and certain spices, although the intake through spices is negligible. The average lithium content is 4.4 µg/g of dry matter in cereals, 3.1 µg/g of dry matter in fish, 0.19 µg/g of dry matter in mushrooms, 2.3 µg/g of dry matter in vegetables, 0.5 µg/g of dry matter in dairy products, 8.8 µg/g of dry matter in nuts, and only 0.012 µg/g of dry matter in meat. Bottled water in Europe contains an average of about 0.94 µg/l, while tap water contains an average of 0.54 – 0.64 µg/l. From these data, it is clear that it is almost impossible to reach the recommended daily intake of lithium, which is about 1,000 µg, through food alone.

Numerous studies have shown the importance of lithium's effects, which is found in water, on the reduction of suicides, even though such doses are significantly smaller than the ones used in treatment of bipolar disorders, which are the most frequent cause of suicide (Schrauzer et al., 1990). These results were obtained from studies conducted in the US, Japan, Austria, Greece, Italy, Lithuania, and Denmark. It is assumed that a very small intake of lithium causes worsened mood, impulsivity, and anxiety (Sher, 2015). Such results partially confirm the assumption about the increase in violence and the number of suicides and domestic homicides in people living in areas with small concentrations of lithium in drinking water (0 - 12 μg/l). For this reason, it has been suggested that lithium be introduced through dietary supplements, similar to how iodine is added to table salt.

Lithium in warfare

Lithium is used in the production of so-called hydrogen (thermonuclear) bombs. The lithium isotope, *Li-6*, and the hydrogen isotope, *H-2* (deuterium), absorb neutrons and decay into helium and tritium (a hydrogen isotope), releasing enough energy to initiate a nuclear fusion (combination) reaction, which results in the formation of two helium atoms. These bombs release an enormous amount of energy and have a yield of millions of tons of TNT (trinitrotoluene, a classic explosive).

Lithium hydride and lithium aluminium hydride are used as high-energy additives in rocket fuel. The production of rocket weaponry also requires materials that are resistant to high temperatures and have low thermal expansion, so lithium salts are used in the creation of such composite materials (Kunasz, 2006). In addition, lithium batteries are used in many electronic devices essential for modern warfare.

Lithium batteries

Lithium batteries can be primary (non-rechargeable), and these are typically button-shaped or cylindrical batteries used in calculators, wristwatches, and early digital cameras. Compared to traditional alkaline batteries, lithium batteries have a higher energy density, are lighter, and have a longer lifespan.

Figure 3. Primary lithium batteries.
Photo: Shutterstock

Another type of lithium battery is the secondary (rechargeable) lithium-ion battery, which is used in mobile phones, laptops, numerous small electronic devices, various power tools, electric cars, and other vehicles, and more recently, for energy storage.

These batteries also have a higher energy density, lower mass (weight), and a longer lifespan. To produce 1 kWh (kilowatt-hour), 0.16 – 0.18 kg of lithium carbonate is required. Energy density, expressed in Wh/kg, is the amount of energy that can be stored in a unit of mass. Power density, expressed in W/kg, is the amount of power that can be generated from a unit of mass. A lithium-ion battery for newer mobile phones contains about 3 grams, a battery for a laptop computer contains 10 – 30 grams, a battery for power tools contains about 40 – 60 grams, and a battery for cars and trucks contains 40 – 100 kilograms of lithium carbonate.

Figure 4. Secondary lithium batteries.
Photo: Shutterstock

A lithium battery consists of several individual cells connected together. Each cell is made up of a positive electrode (cathode), a negative electrode (anode), a separator that separates the cathode from the anode, and an electrolyte (which can be liquid, gel-like, or solid). Since lithium is extremely reactive in its elemental form, lithium-ion batteries do not contain elemental lithium, but rather an oxide, such as lithium cobalt oxide. These batteries are rechargeable, meaning that the cycles (discharges and recharges) can be repeated hundreds (or thousands) of times. Lithium-ion batteries have the highest charge density compared to any other type of battery.

There are six types of lithium-ion batteries.

1. *Lithium-cobalt-oxide,* $LiCoO_2$ ***(LCO)*** battery, where lithium oxide is the cathode and graphite is the anode. Its operating voltage is 3.6 V, specific energy is 150-200 Wh/kg, energy density is 400 Wh/l, and the number of charge/discharge cycles is 500-1,000. They are used in newer mobile phones.
2. *Lithium-manganese-oxide,* $LiMn_2O_4$, ***(LMO)*** battery, has a cathode made of lithium manganese oxide and an anode made of graphite. It has an operating voltage of 3.7 V, specific energy of 100-150 Wh/kg, and energy density of 350 Wh/l. The number of charge/discharge cycles is 300-700, and it is used in electric bicycles, garden machinery, medical equipment, and in screwdrivers and drills.
3. *Lithium-iron-phosphate,* $LiFePO_4$ ***(LFP)*** battery
   Where high specific energy is not required, but high safety, long cycle life, and large battery capacity are needed, lithium iron phosphate batteries are used. They are also used in the automotive industry (electric vehicles), for industrial machines in automation, robotics, for various types of vehicles, airport vehicles, and more. They have an operating voltage of 3.2 V, specific energy of 170 Wh/kg, and energy density of 350 Wh/l. Their number of charge/discharge cycles exceeds 4,000, which has led to the widespread use of these batteries in many electric vehicles.

4. *Nickel-manganese-cobalt, LiNixMnyCozO*$_2$ *(**NMC**)* battery
   This battery uses a mixed oxide of nickel, manganese, and cobalt. It has a high specific energy (220 – 240 Wh/kg). Such batteries are most commonly used in the electric vehicle industry because they can deliver a large amount of energy stored in a small mass and volume. They have an operating voltage of 3.6 V, specific energy of 150-220 Wh/kg, and energy density of 500 Wh/l. Their number of charge/discharge cycles ranges from 1,000 to 2,000.
5. *Nickel-cobalt-aluminium, LiNiCoAlO*$_2$*, (**NCA**)* battery
   In the automotive industry, these batteries are most commonly used for the production of electric vehicles. They have an operating voltage of 3.6 V, specific energy of 250 Wh/kg, and energy density of 550 Wh/l. Their number of charge/discharge cycles exceeds 1,000.
6. *Lithium titanate,* $Li_4Ti_5O_{12}$ *(**LTO**)* battery
   The characteristic of this type of battery is its exceptionally high number of cycles (charge/discharge), ranging from 15,000 to 20,000. These batteries have a lower energy density. Their operating voltage is 2.4 V, specific energy is 70 Wh/kg, and energy density is 177 Wh/l. They have a number of charge/discharge cycles greater than 15,000 – 20,000. They are used in the automotive industry.

Lithium-ion batteries with solid electrolyte

The latest type of lithium-ion batteries is the one with a solid electrolyte. These batteries represent huge progress compared to lithium -ion batteries with liquid electrolytes. They have larger capacity, longer charge/discharge cycle, and quicker charging times. They are completely safe as they cannot combust. Solid-state lithium-ion batteries do not generate flammable gases, which makes them the safest lithium-ion batteries. Solid-state electrolytes are non-toxic and have no impact on the environment, do not evaporate, are thermally stable, have good mechanic properties, good ionic conductivity, allow the diffusion of lithium ions and will have a significantly shorter charging time. It is stated that solid-state electrolytes with sulphides (lithium, sulphur, chlorine, etc.), oxides (lithium, titanium, zirconium, aluminium, tantalum, lanthanum), and phosphates (lithium, phosphorus, aluminium, titanium, germanium) have been successfully applied so far. The Japanese car manufacturer, Toyota, has announced the production of such batteries by 2028. With these new batteries, cars will be able to travel up to 1,200 kilometres, and the charging time will be reduced to ten minutes.

Lithium production and demand

Due to the increasing use of lithium-ion batteries, not only for the production of electric cars but also for the production of many electrical and electronic devices, the demand for lithium is constantly rising. A significant increase in demand for lithium is also predicted in the next ten to twenty years. This increase in demand has been influenced by the decisions of many governments to ban the use of internal combustion engine cars within the next decade.

For example, the ban on the production of internal combustion engine cars will apply in Norway until 2025, in the EU and the UK until 2035. In the US, half of the cars sold by 2030 are expected to have „zero emissions." It is predicted that in China, by 2025, half of the cars will be powered by „new energy," while in India, by 2030, about 30% of the cars sold will be electric. In Japan, a ban on the sale of internal combustion engine cars is planned for 2030.

Given these already made decisions, many governments are already taking measures to ensure sufficient quantities of lithium to meet the growing demand. The European automotive industry currently imports 100% of the raw materials for production (lithium, cobalt), mostly from China, so the EU has adopted regulations aiming to reduce this dependency as soon as possible. This list includes thirty-four „critical raw materials." In addition to lithium, there are rare metals that are essential for the production of lithium-ion batteries, as well as for the production of semiconductors and special alloys. These raw materials are necessary for the EU to progress, not only in the production of electric cars but also in the production of semiconductors, computer technology, and artificial intelligence.

The largest lithium reserves (about 60% of the world's reserves) are located in South America, in Argentina, Bolivia, and Chile (in the so-called *ABC triangle* – **A**rgentina, **B**olivia, **C**hile). The top ten countries with the largest lithium reserves are Bolivia (21 million tons), Argentina (19 million), Chile (9.8 million), Australia (7.3 million), China (5.1 million), DR Congo (3 million), Canada (2.9 million), Germany (2.7 million), Mexico (1.7 million), Czech Republic (1.3 million), and Serbia (1.2 million). The largest lithium producers, according to 2021 data, are Australia (around 55,000 tons of lithium annually), Chile (26,000 tons), China (14,000 tons), and Argentina (6,200 tons).

According to the *EV Battery Market* forecast for 2033 (EV Battery Market), the global battery market will be worth around 508.8 billion dollars, with lithium-ion batteries holding the largest share of this value. This forecast is also based on the production of new types of batteries with improved characteristics and extended lifespan. The forecast also applies to Europe, where there has been an improvement in lithium-ion battery technology, which now has higher energy density, shorter charging times, longer operational life, and improved safety during use.

Here is the forecast for the increase in lithium demand over the next twenty years.

In China, which is the world's largest producer of lithium-ion batteries (with around 75% of global production), there are also the largest number of large (gigafactories) battery plants. In Europe, around 11% is produced, in the US around 7%, and in all other countries, around 7% of the total global battery production. It is predicted that by 2033, the share of European manufacturers will increase to 22%, at the expense of Chinese manufacturers whose share is expected to fall to 55%, the US to 18%, while all other countries will produce only 5% of total global production. This forecast is supported by data on the construction of new gigafactories for lithium-ion batteries: in Germany (14), Norway (4), Sweden (3), Hungary (5), France (5), Spain (8), Italy (4), and one each in Poland, Russia, the Czech Republic, and Serbia (France24). As a result, the EU has signed memoranda of understanding with Argentina and Serbia (in 2023) to ensure sufficient lithium supplies for the factories whose construction is planned.

To accelerate this process, the EU plans to allocate three billion euros in incentives for lithium production, while the US plans an investment of around sixty billion dollars for the same purposes. This is particularly emphasized in countries that host major car and truck manufacturers (*AB Volvo, Mercedes Benz Group AG* and *Scania AB*).

Jadar Project

As already stated, jadarite was unearthed in 2004, in the Valley of the Jadar River, 10 or so kilometres southwest of the Cer Mountain in Serbia (Stanley et

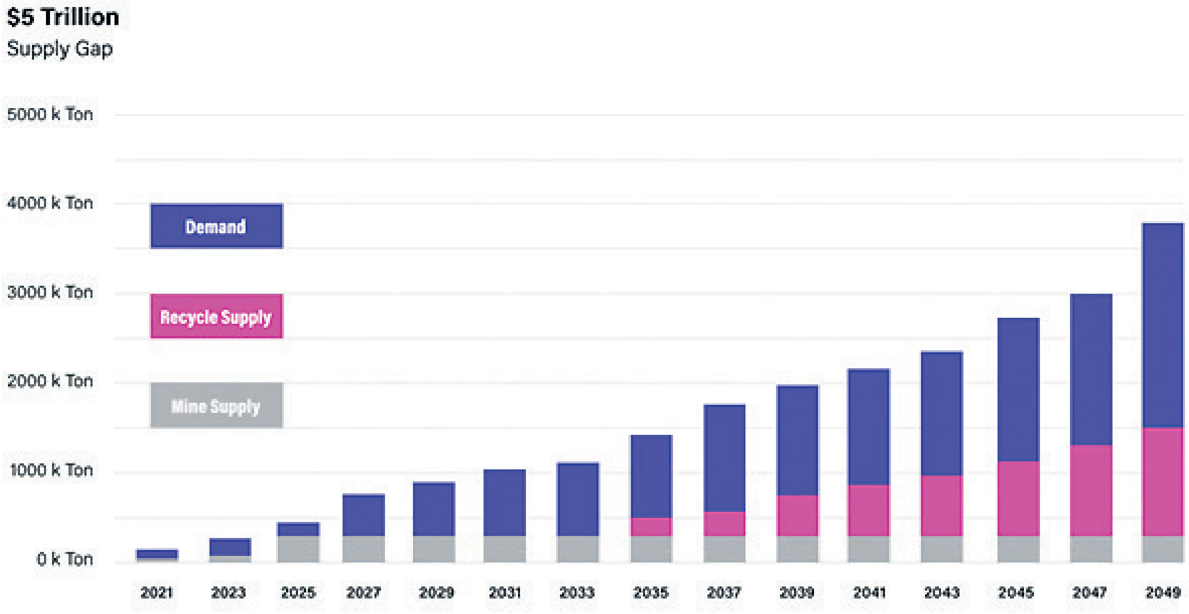

Figure 5. Predicted lithium demand by 2049 (blue bars), lithium obtained from recycling (purple bars), and lithium production from mines (grey bars).
Source: Wall Street Star

al, 2007), a mineral that contains lithium and boron. Its chemical composition is sodium lithium boron silicate hydroxide ($LiNaSiB_{3O_7}(OH)$ or $Na_2OLi_2O(SiO_2)_2(B_2O_3)_3H_2O$), with an average lithium content of 1.8%, or 3.04% (as Li_2O, after enrichment), and a boron content of 13.1%.

In this paper, we will not address the mining aspect of this project, but only the technological process for the production of lithium carbonate and boric acid [Study 1], as well as the waste materials [Study 2] that are created during this process. Of course, this technological process is presented without delving into the details.

The technological process, after crushing and enriching the ore, includes dissolution with sulphuric acid, neutralization, selective crystallization, and the production of the final products: lithium carbonate, boric acid, and sodium sulphate as a by-product. In addition, this process also includes the treatment of wastewaters generated during production, as well as the processing of solid waste before it is sent to the landfill.

The project envisages the processing of approximately 1.9 million tons of jadarite ore annually, with the production of 58,000 tons of lithium carbonate, 286,000 tons of boric acid, and 259,000 tons of sodium sulphate as by-products, each per year. The jadarite ore concentrate is dissolved in sulphuric acid in closed vessels at a pH of 3, at 90°C, with the pH being maintained around 3 by adjusting the sulphuric acid and water dosage. This process results in a leachate rich in boron, lithium, and sulphates. By lowering the temperature, a saturated solution is obtained, from which boric acid crystallizes (two-stage crystallization). The precipitated boric acid is filtered, dried, and ground to a specified granulation. By adding slaked lime, magnesium and heavy metals are precipitated, and gypsum is formed. After the separation of boric acid and heavy metals, sodium bicarbonate is added to convert lithium sulphate into lithium bicarbonate, and by increasing the temperature, lithium bicarbonate is further converted into lithium carbonate. Through two-stage crystallization, lithium carbonate is obtained, which is then dried and ground to a specified granulation. In the remaining liquid, sulphuric acid is added to adjust the pH to 6-8, causing the formed carbonates to be converted into sulphates, while sodium sulphate crystallizes, is dried, and ground.

During the execution of the process, the exhaust gases are controlled: RM2.5 (particles the size of 2.5 mm, NO_2, CO, HCl, SO_4).

The treatment of wastewater from the production process involves five stages: ultrafiltration (removal of micron-sized particles), nanofiltration (removal of submicron particles, reverse osmosis 1, reverse osmosis 2 (removal of heavy metal ions), and ion exchange (removal of remaining ions). Demineralised water is obtained in that way, and in order for it to be discharged into the Jadar River, it is necessary to carry out mild mineralization (adding a certain amount of minerals to the level of concentrations present in the Jadar River).

Solid waste, obtained during the production process, is dried until it reaches a moisture content of 25%, and then it is being transferred to a solid waste landfill [Study 1]. The standard method for examining the dangers of solid waste is the so-called leaching test, and is prescribed by EU and US standards [Study 2]. This method is performed by pouring a certain amount of solid waste with a water solution (or an acid solution), stirring the sample continuously for a certain time, and then analysing the solution to determine the concentrations of washed heavy metals. Standards prescribe threshold concentrations of washed elements up to which the waste is considered harmless (Townsend et al., EPA). Among inorganic substances, arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver are analysed. Tests of solid waste from the lithium and boron production process showed that the "washed" (leached) concentrations (antimony, arsenic, copper, mercury, cadmium, molybdenum, nickel, lead, chromium, zinc) from the solid waste were far below the limit (100-1,000 times below) acceptable by the mentioned standard. This means that the mentioned solid waste, generated during the production of lithium and boron, will not leach heavy metals and pollute the environment.

The technological procedure for obtaining lithium carbonate and boric acid from jadarite indicates that the usual and well-known technological processes are used: dissolution with acid, neutralization with a base, precipitation and crystallization, filtering, drying, grinding. There are no flammable or explosive substances, no high pressures, no high temperatures, and the cycle is completely closed. The entire technological process involves no unknown or new, untested processes.

Controversy over lithium in Serbia

Since 2004, when the mineral jadarite was discovered in the Jadar River valley (Stanley et al., 2007), until 2020, lithium was considered the safest and most useful element in the periodic table. The Jadar project was declared a strategic project for Serbia in 2008 and again in 2011. The 2011 Strategy of Mineral Resources Management of the Republic of Serbia until 2030 states, among other things: „The Jadar basin, with its quantity and content of lithium and boron in the ore, is one of the most significant potentials on a global scale." (Government of Serbia)

Since 2020, a negative campaign against the Jadar project has begun, spreading nonsense, inaccuracies, and lies. It all started with an interview given by D. Đorđević to a portal (Balkan Green Energy News) on December 9, 2000, which later became a political platform for certain parties and movements. Nothing said in that interview was true, and it was the first time the story about sulphuric acid at 250°C and hydrofluoric acid was introduced, even though the latter is not even used in this technological process. It is untrue that sulphuric acid at will be used 250°C, that the vapours of aggressive acids will evaporate into the atmosphere, that they will destroy the green cover, or that „waste mining water" will be discharged into the Jadar River, as no such waste exists. It is untrue that underground waters that could be used as drinking water will be endangered, and it is not true that the Drina River, then the Sava, and the cities along these rivers will be threatened. It is untrue that ores in our region contain extremely toxic elements, that flotation waste water will be discharged into the Jadar River (since there is no flotation in the process), or that Serbia will receive 4% of the mining royalties along with all the environmental catastrophes that will follow. It is untrue that all agriculture in the area surrounding the mine, along the Jadar River, and beyond, will be destroyed, and it is untrue that the environment will be polluted or that the population will suffer from the most severe, incurable diseases. It is untrue that toxic mining water came out of exploration wells. It is not true that waste water and thousands of tons of sulphuric acid will be discharged daily, or that due to the mine in western Serbia, cities like Loznica, Valjevo, Šabac, and Belgrade will run out of water. All lies, nonsense, and fabrications.

To make matters worse, all these lies were spread by people with academic degrees and titles. This explains why so many people believed these lies. Then, the negative campaign spread on social media, where everyone, literally everyone, could express their „opinion" about the Jadar project and lithium. People competed to present shocking information about the Jadar project and lithium, while some media outlets, alongside social networks, eagerly spread these lies. Here, anyone can say whatever they want about lithium, and this was led by some academics, actresses, doctors, gynaecologists, singers, athletes, directors, and filmmakers—basically, self-proclaimed experts on lithium. „Negative information, news, and rumours spread very quickly," much faster than positive ones. „Fake or negative news, rumours, and information spread rapidly and cause chaos and instability in the social order." „People become addicted to mobile phones," and as a result, they become disconnected from social reality (Sociology Group). Furthermore, social media leaves consequences, not just on mental, but also on physical health, and negatively impacts creativity. Constant use of social media makes people lazy and less active.

Given that over 15,000 negative articles about the Jadar project have been published in the last two years in our country, it is clear that it is impossible to disprove all the nonsense and lies told about this project in a single text. The author of this paper has repeatedly presented accurate and truthful data about the project. In the text „Lithium in Serbia: Then and Now" (Simonović, 2023), some of the nonsense and lies spoken by people with academic degrees and titles are mentioned. A worrying fact is that there are over 300,000 people in Serbia who claim to know everything about lithium („lithium experts"), but none of what they know is true. „At least 2,000 hectares of fertile land will be destroyed (it is actually 390 hectares), 22 villages will be displaced (52 households), 500 cubic meters of water will be used for one ton of lithium (it is actually 8-9 cubic meters), 10% of the world's lithium reserves are located here (it is actually 1.5%), sulphuric acid at 250°C (it is actually 90°C)."

The story about sulphuric acid at 250°C kept resurfacing, even though the author of that statement later contradicted herself. However, once the genie is out of the bottle, the professor from the Belgrade Faculty of Economics will be suffocated by sulphur gases and acid rain will fall on her head. Anyone can verify, if they look for the correct data about sulphuric acid, which is one of the most widely used raw materials in the chemical industry, how things really stand. The industrial development of a country is measured by its sulphuric acid consumption. Over 380 million tons of sulphuric acid are consumed worldwide annually, and in Serbia, over 600,000 tons per year. How false the story is about sulphur gases poisoning the residents of Jadar, Loznica, Šabac, Belgrade, and even the entire country, can be seen from the fact that sulphuric acid at 140°C evaporates five times less than water at 0°C (Marti et al., 1997). And it is known that water at 0°C practically does not evaporate, so there will be no sulphur gases and, consequently, no suffocating of Serbia's population. In the middle of Hamburg, a city with over two million inhabitants, there is a sulphuric acid plant, *Aurubis*, which produces two million tons of sulphuric acid annually. No one in Germany has thought of relocating this sulphuric acid plant that would suffocate the residents of Hamburg.

In another article (Simonović, 2024a), the author of this text pointed out the nonsense put forward by certain academics and demonstrated that they have no knowledge of the topic they are discussing and presenting falsehoods about. None of these loudest academics have ever dealt with lithium or environmental protection, but that has not stopped them from constantly speaking about lithium and environmental protection. In doing so, they have violated the Code of Conduct in scientific research, which „mandates that objectivity in interpretation and conclusions must be based on facts and data that can be proven and verified," and „impartiality and independence from interested parties, ideological or political groups" (Prosveta). None of the claims made by these anti-lithium advocates have been refuted with new data. The same article also mentions a political gathering on the Jadar project held at the Serbian Academy of Sciences and Arts (SANU) in 2021, which some academics claim was a scientific event. The tone of science at this political gathering was provided by various non-governmental organizations and citizen groups, as well as a letter sent to the then president of SANU by minor local NGOs and political parties.

Some academics, although it is not their area of interest or expertise, have put in tremendous effort to show that the Jadar project is catastrophic and the worst possible thing that could happen to Serbia, without providing any real evidence for their claims. It's all in the style of: "I know it is very dangerous, but I don't know what exactly is dangerous or why. But still, it's dangerous, more dangerous than you can imagine." They demonstrate such bias and present things that any reasonable person would be ashamed of. A good example of this are two articles by academic S. Vukosavić, a professor at the Faculty of Electrical Engineering (whose scientific fields he has listed include electromechanical energy conversion, digital control, and industrial robotics), published in Nin (Vukosavić, 2024a, Vukosavić, 2024b). He does not mention a single word about what is specifically dangerous about the lithium project. He claims "... the realization of the Jadar project would lead to massive devastation of the area, permanent changes to the landscape, land degradation, deforestation, contamination of surface and groundwater, displacement of the population, cessation of agricultural activities, and the establishment of a permanent health risk scenario for the population on a large scale." However, as true scientists do, academic Vukosavić does not provide any evidence for these claims of an impending catastrophe in Serbia, but he confidently declares that it will be "on a large scale." The unfounded nature of these catastrophic claims can be best seen by looking at the real data concerning the Jadar project. The term "massive devastation of the area" refers to about 300 hectares, which the Jadar project would occupy, representing only 1.02% of the total area of the Jadar region. If areas with settlements are excluded, this percentage is less than 0.5%. This data disproves Vukosavić's second claim about "permanent changes to the landscape." If he had taken the time to find accurate data on the land in this area, academic Vukosavić would have found that "the planned area is (partially) classified as a degraded environment with negative impacts on humans, plants, and animals" (Institute for Urban Planning, 2019). In 2014, a pond containing waste water and flotation sludge from antimony ore overflowed in this area, resulting in the release of "1.2 million tons of mining waste" and "over 110,000 cubic meters of tailings sludge" from the Stolice mine in Kostajnica, which entered the Kostajnik stream, a seasonal tributary of the Jadar River (Environmental Protection Agency, 2018). This incident contaminated 120.8 km^2, which makes up 41.1% of the total Jadar area (293.91 km^2). If areas with settlements are excluded, the percentage of permanently contaminated land is significantly higher, probably 60-70%. Considering the previously mentioned data on the type and degree of land and water contamination, all of academic Vukosavić's claims about some future agricultural production that would feed Serbia and part of Europe (as some street environmentalists have claimed) fall apart. Academic Vukosavić speaks of *"the establishment of a permanent health risk scenario for the population on a large scale."* However, he failed (again deliberately) to specify what those "permanent health risks for the population on a large scale" are. This is what happens when an academic gathers data for their claims from street protests and social media, while disregarding available real, reliable data.

The analysis by the Academy of Engineering Sciences of Serbia (AINS) is similar to the political gathering held at the SANU, with the only difference being that they added a few elements to make it seem different, even though it is fundamentally the same. They are even against investing significant funds in infrastructure (in line with the "everything must stop in Serbia" rhetoric), as if someone would take those roads, any potential railway, or other infrastructure out of Serbia, leaving it behind in the region. Here too, there is a strong push for the idea that "everything must stop in Serbia," even investments in infrastructure.

And the engineering academics are concerned "because the development of agriculture will be hindered." The author of this analysis seems to have forgotten what he wrote in the same statement, as he later writes the following: "It is indicative that, at a distance of 20 km down the Jadar River, arsenic concentrations were measured to be 8.9 times higher, and boron concentrations 17.1 times higher. In an area with increased concentrations of toxic substances in the soil, water, or air, profitable production of healthy food cannot be organized." So, it will not just be "hindered"; in fact, even before mining and lithium extraction begin, food production— of healthy or any kind of food — has already been rendered impossible. This AINS analysis contains the same nonsense and falsehoods as the conclusions from the aforementioned political meeting at the SANU, so it is obvious that the same hand wrote both of these conclusions. There is no sense in commenting on the nonsense about thousands of tons of boron, arsenic, nickel, cadmium, and lead. How could have the engineering academics overlooked the fact that someone planning to produce boron would release thousands of tons of boron, not to mention other expensive metals, into the tailings? Another catastrophic claim follows, stating that these thousands of tons of heavy metals and arsenic will "travel via the Sava River and through Šabac and Belgrade, creating a constant risk to the water supply security of much of Serbia." If this is coming from engineering academics, it is too much. Serbia is in trouble with such engineers and academics. How this AINS statement came about can be seen in Dr. S. Maksimović's reaction to the text by Academic S. Vukosavić (Maksimović, 2022). "Based on superficial statements, the text shows that the winds of new knowledge have led the academic into an unfamiliar territory of mineral raw materials exploitation and environmental protection. This explains why, as an expert in electrical control, he struggles in a vacuum without professional and scientific guidance. In an attempt to appear convincing, he references daily newspapers instead of authoritative mining and geological sources. He refers to the authority of a scientific gathering at the Serbian Academy of Sciences and Arts (SANU) dedicated to the issue of lithium exploitation, where, as far as I know, the opinion of the competent mining profession was not heard. In the effort to generalize the positions of the Presidency of the Academy of Engineering Sciences of Serbia as the stance of engineers in Serbia, it is not noted that the Department of Mining, Geological, and System Sciences distanced itself from the positions of the Presidency." These words confirm the claim that the same hand wrote both statements, from SANU and the Academy of Engineering Sciences.

Listing the nonsense and lies spoken about the Jadar Project could take a long time. In conclusion, we present a few of the most nonsensical statements about this project, which anyone with at least a little sense would be ashamed of. The writer and director Vida Ognjenović stated (Ognjenović, 2024): 'The mine will start operating. A foreign corporation will triple the return on invested funds and will sell lithium as its own product. A dozen survivors with some deviations will be kept in a strictly guarded facility on Stara Planina. And the few who can speak, with all the deviations caused by the toxins, will continue their debate about lithium..." According to the 2022 census, Serbia had 6,664,449 inhabitants. And imagine that someone, even if they were a director or a writer, could claim that 6,664,439 people in Serbia would perish from lithium, and only a dozen would survive "with some deviations." All that remains is to ask whether anyone with even a little bit of common sense could make such a ridiculous statement? The director is a Nobel Prize-worthy inventor because, until now, no one has known of anyone who invented a weapon for such massive destruction.

Equally nonsensical is the statement made by director Goran Marković: "Only if we are not covered with drill holes, which, with the help of chemicals, extract the Earth's guts and turn the fertile and forested landscapes of Serbia into a desert, do we have a future. If people give in now to the unscrupulous interests of capital and the local corrupt government – we are finished" (Marković, 2024). The director knows everything, even that they will extract the Earth's guts using chemicals and turn Serbia (fertile and forested) into a desert. This example shows that ignorance does not prevent people from spouting nonsense, which any reasonably minded person would be ashamed of. These examples illustrate how ignorance is well-distributed among writers, directors, filmmakers, and actors... The only comment for such nonsense is the Latin saying: *"Beati pauperes spiritu."*

One of the main questions in this whole fuss about lithium in Serbia remains: Why has much of Serbian "intelligence" not come together and worked to find the best solution for Serbia, both in terms of environmental protection and the economy, so that everything would be to the benefit of Serbia? How come a smaller, but fervent part of the Academy, that is, Serbian science itself, has been so engaged, and continues to be engaged, in trying to stop the lithium project in Serbia? Imagine if all that Serbian "intelligence" and all that "knowledge" about mining and extracting lithium had been harnessed and dedicated to solving all those "problems" they cite. Serbia would have the safest mining and lithium extraction in the world. But that did not happen, nor will it, because it does not align with the slogan around which all of them have gathered: "Let everything stop in Serbia."

What needs to be done

The author of this text proposed in his writings (Simonović, 2023) that "the Government should appoint a working group composed of people from universities and institutes with different profiles (mining-geological, hydrological, agricultural, as well as chemists, physical chemists, technologists, mechanical engineers, biologists, etc.) who, based on all available documents or additional ones that could be prepared, and based on scientific literature and global experiences in this field, would propose a decision to the government regarding this project."

Recent regulations and decisions made by the EU should also be taken into account, primarily the adherence to the standards for responsible mining (*IRMA* standard), which prescribe the conditions for responsible mining (environmental protection, social responsibility, etc.) (Initiative for Responsible Mining Assurance, 2023). Compliance with this standard should be a condition for the implementation of the Jadar Project (Simonović, 2024b). Furthermore, the EU Resolution on Sustainable Products (REGULATION (EU), 2024) and EU regulations on the digital product passport (Commission Europa, 2024) should also be considered. Along with all of this, there must be mandatory compliance with all domestic and EU regulations on environmental protection.

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