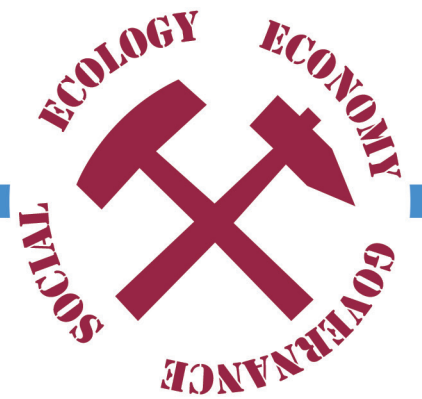


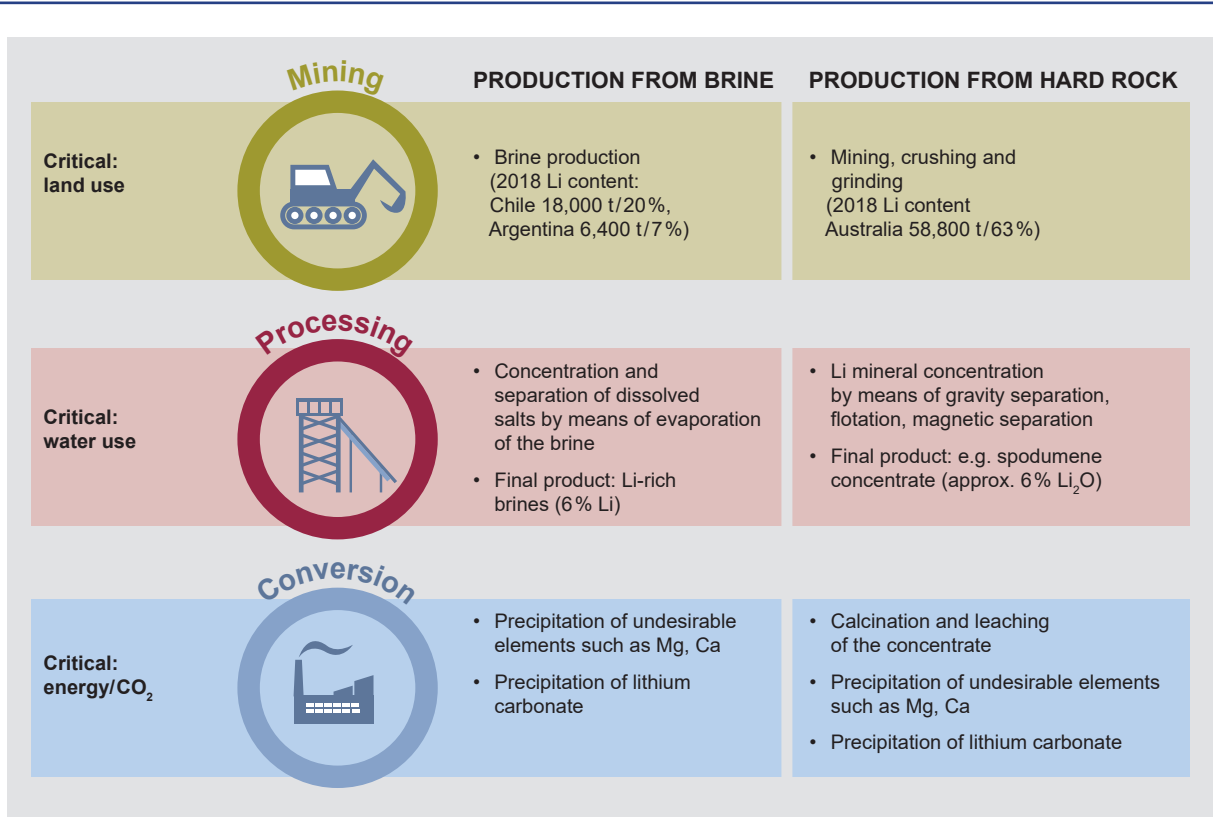
# Lithium

## Sustainability Information



3	6,941
<b>Li</b>	
Lithium	

## AT A GLANCE



**Fig. 1:** Mining, processing and conversion (to lithium carbonate), shown for lithium produced from brines and hard rock, as well as critical points from a sustainability perspective.

- As the central element of lithium-ion batteries (LIBs), lithium is indispensable for electromobility and mobile devices, and demand is expected to rise.
- The greatest added value lies in the further processing of the lithium carbonate and other raw materials in the batteries.
- Treatment and processing steps in production and processing into lithium carbonate differ for extraction from salars (primarily Chile and Argentina) and from hard rock (primarily Australia).
- The majority (88 % of global production [1]) is currently produced in countries that enjoy comparatively good mining sector regulation.
- In the case of production from salars, water consumption in particular is a point for discussion, because around 200–1,000 m<sup>3</sup> of brine must be pumped to produce 1 t of lithium carbonate.
- At the moment, recycling can only make a comparatively small contribution to meeting demand, and probably also in the mid-term future.

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## 1 LITHIUM'S RELEVANCE

Until the 1990s lithium was traditionally used in the glass and ceramics industry, and in the production of lubricants. The mineral concentrates used generally comprise the minerals spodumene or petalite.

In the glass and ceramics industry, lithium is used to lower the melting point. In addition, the viscosity is reduced, which increases the processability of the glass melts. Moreover, as an admixture, lithium increases the hardness and strength of glasses exposed to high temperature fluctuations and which must be protected from early breakage, e.g. on hobs.

Lithium is also used as an alloying metal, although the percentages are relatively small. In the alloy, it has an especially positive effect on weight and strength. Currently, the main application of lithium is in lithium-ion batteries (LIBs), with a rapidly increasing trend. It is therefore currently indispensable for achieving the goals of the energy revolution. The DERA study [2] indicates that the lithium demand for battery production and other applications will be approximately 80,000 t/a in 2025, assuming an average increase in demand (Fig. 2). The most important growth driver in the use of LIBs is electromobility, which has already shown a significant increase between 2015 and 2019 (Fig. 3). Today, it can already be seen that the 2017 forecasts for 2025 will be exceeded.

Due to its specific properties, lithium represents an indispensable component of current battery technologies. It is used in the electrolyte, as well as in the anode and the cathode, of rechargeable batteries. However, its dispersed distribution within the battery

makes recycling more difficult. Of all metals, lithium has the highest electrochemical potential (-3.05 V) and the highest weight-specific capacity (3860 Ah/kg). At approx. 250 Wh/kg, the energy density of LIBs is highest, the life cycle the longest, the temperature range the widest and the self-discharge rate of 1 – 2 % per year the lowest [5] compared to other battery types.

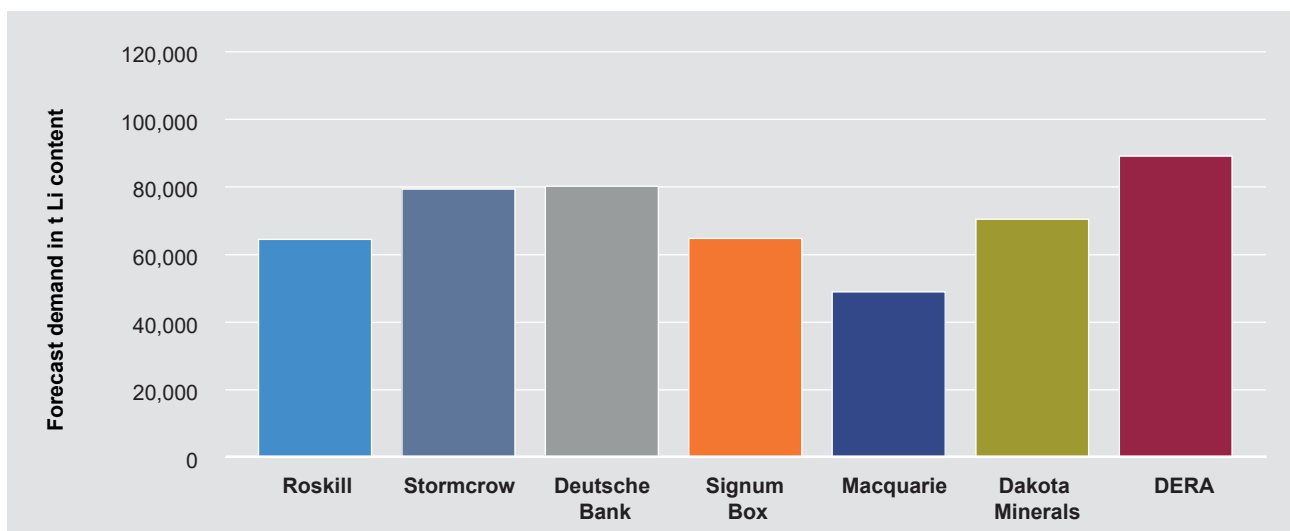
## 2 FROM DEPOSIT TO COMMODITY

Two production processes are differentiated in the production of lithium(carbonate) (Fig. 1):

- 1.) Mining of hard rock and production of concentrates
- 2.) Production from lithium-containing brines (salars)

Lithium carbonate is usually obtained from the lithium-containing brines (salars) or concentrates (pegmatites) (sometimes also directly lithium hydroxide) and is then further processed.

Until a few years ago, Chile dominated the lithium market with an average of 42 % of world production (2000 – 2016). During this period, production increased from 6,500 t to 14,500 t of lithium (Li content). In the same period, Australia increased production from almost 2,000 t to 16,000 t. Due to extraordinarily strong investments in the Australian sector, triggered by increasing demand and rising prices, production grew to almost 60,000 t lithium in 2017 and 2018. As a result, the Chilean share of world production fell to 20 %, while that of Australia rose to 63 % (Fig. 4).



**Fig. 2:** Global lithium demand forecast for 2025. The forecasts of the various companies and organisations were made in 2017 [2].

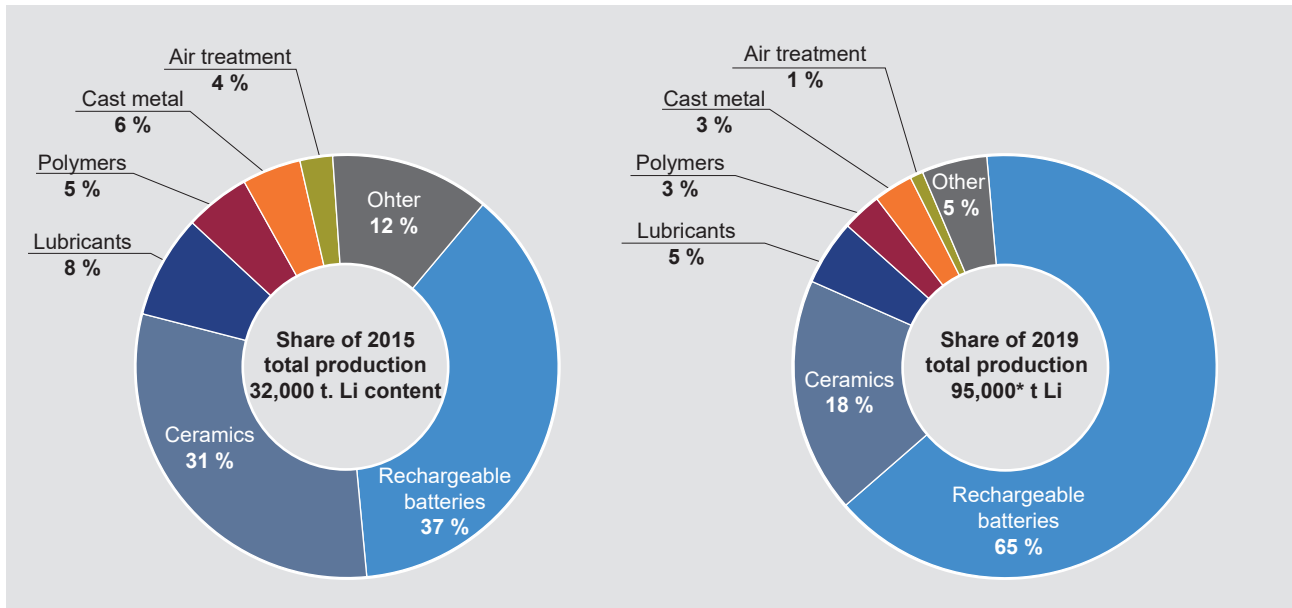


Fig. 3: Percentage of rechargeable batteries in total use of lithium in 2015 and 2019 [3,4].

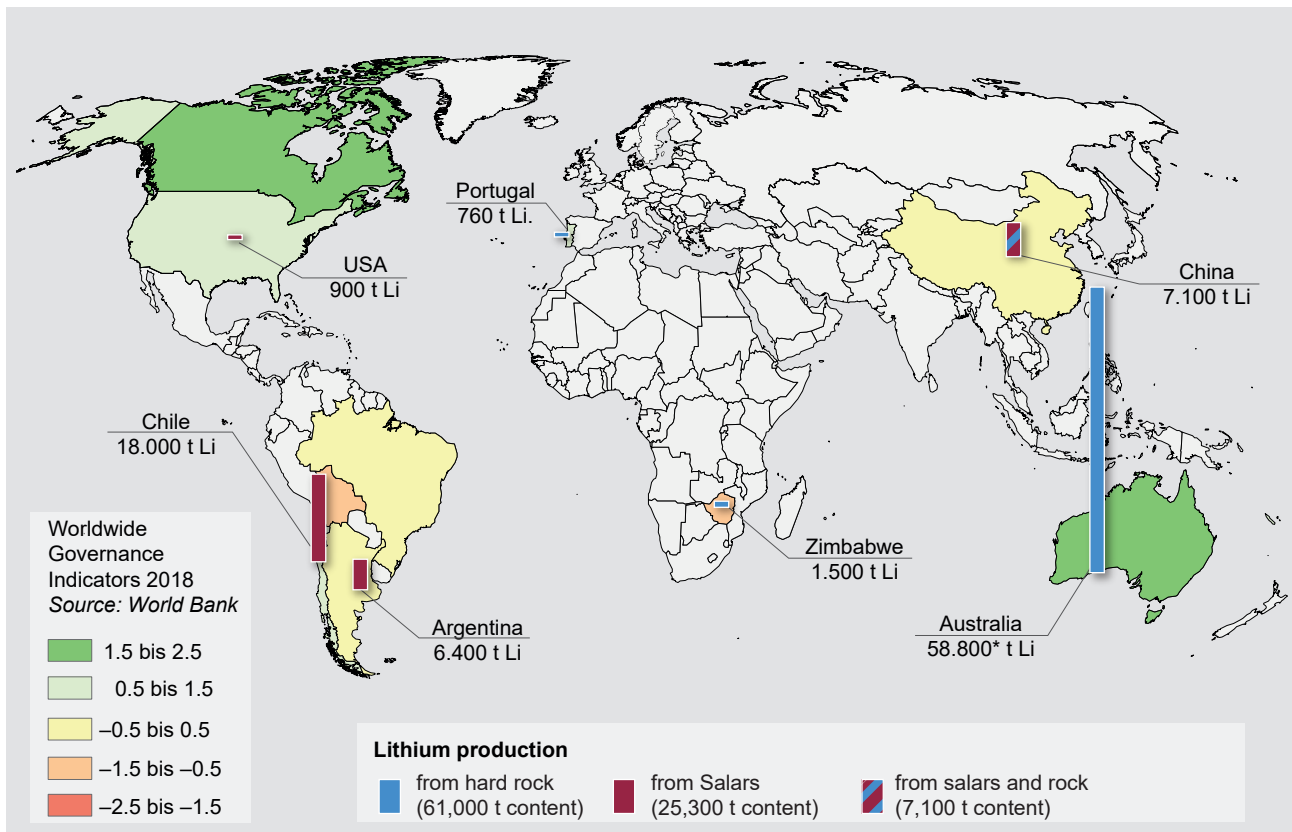
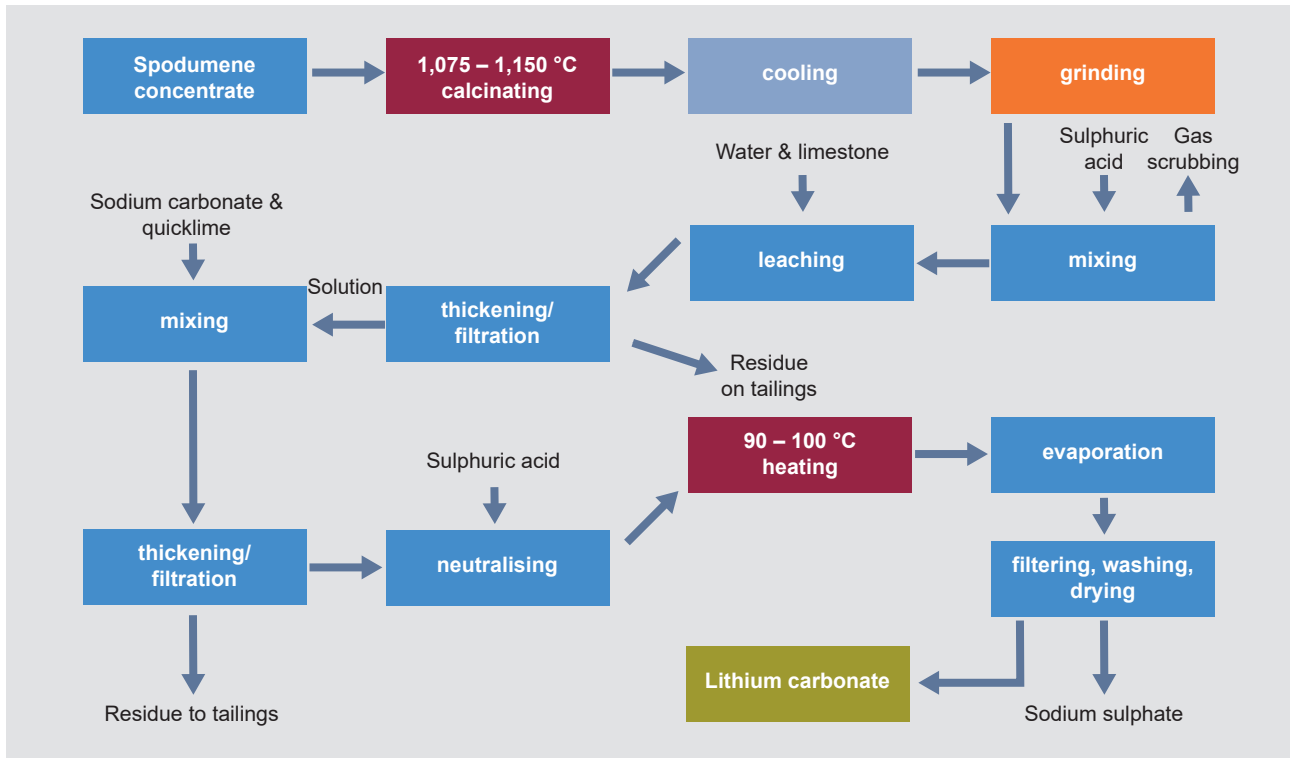


Fig. 4: Main producing countries for lithium from hard rock and salars in 2018, and governance [6] in the producing countries.

The largest lithium reserves can be found in salars in the so-called lithium triangle between southern Bolivia, northern Chile and north-west Argentina.

Australia currently has the world's largest production capacity. Here pegmatites, i.e. hard rocks, are mined,

generally using open-cast mining methods. Lithium pegmatites occur worldwide, however grades and tonnage in Australia are greater than in most other regions of the world. Other important deposits exist in Zimbabwe, the Democratic Republic of the Congo,



**Fig. 5:** Schematic of the processing of a spodumene concentrate to lithium carbonate using the acid-roast process [7].

Portugal, China and Brazil, among others. Important by-products of lithium mining are tantalum and tin.

Pegmatites are formed from the residual melts of granitic intrusions. They are extremely coarse-grained rocks which, in addition to quartz and feldspars, can contain a number of elements that do not fit into the crystal lattice of most minerals. Among these elements is lithium, which is incorporated into various minerals in certain pegmatites. The most economically important minerals are spodumene, petalite and lepidolite.

The pegmatite ore is extracted in the traditional way of blasting and loading and is then transported from the pit to the processing facility. Here, the rock is crushed and ground. In order to obtain a saleable product with appropriate lithium content and low levels of impurities, enrichment processes that concentrate the lithium must be employed. Frequently used concentration processes include density sorting, flotation and magnetic separation. The mineral concentrate obtained is divided into different qualities depending on purity, with the „battery grade“ category indicating the highest purity. The „technical grade“ category may contain a certain degree of deleterious elements. The „battery grade“ quality is primarily used for further processing into LIBs, while the „technical grade“ quality is mainly utilised in the glass and ceramics industry.

In order to produce lithium carbonate from the concentrate, the lithium must be leached out of the minerals. This is primarily achieved using the acid roast process (Fig. 5). The concentrate (in this case spodumene) is roasted at around 1,100 °C to convert the minerals into a form that is soluble in sulphuric acid. By adding calcium carbonate first and then soda, undesirable elements such as iron, manganese, aluminium and calcium are removed and at the end lithium carbonate (99.3 % purity; technical grade) is precipitated. Ion exchangers are employed to further increase the purity (to 99.5 % and higher; chemical- and battery grade) [7].

In order to allow the lithium to be utilised in battery production and to manufacture battery cells, the lithium carbonate is converted into lithium hydroxide in yet another process.

When producing lithium carbonate from salars, a brine with a salt content of around 300 g/l is pumped first [7]. This salt content is more than eight times greater than that of seawater (35 g/l). Predominant elements dissolved in the brines are chloride, as well as sodium, potassium, magnesium, calcium, lithium and other [8, 9]. The lithium content of the brine varies between 10 mg per kg and 2,000 mg per kg [10]. The economical recoverability (minimum cut-off grade) for most salars is at least 600 – 700 mg Li per kg. The Chinese deposits, however, have significantly lower





**Fig. 6:** Evaporation basin for concentrating and purifying Albemarle's lithium-containing brine in the Salar de Atacama, Chile, photo: BGR..

grades at 100 – 400 mg per kg, similar to the Clayton Valley deposit in the USA, where the grade is around 200 mg per kg [2, 7]. Mining deposits with significantly lower lithium content than 600 mg per kg may be economically viable if additional by-products can be obtained from the brine or if there are very few deleterious elements. However, both infrastructure and climate play an important role in the economic extraction of lithium from salars. The lithium in the salar brines originates in subsurface rocks and has been concentrated in closed, internal drainage basins. It is then extracted by pumping the lithium-containing brine (lithium content up to 0.2 %, salt content up to over 30 %). The brine is then passed through evaporation ponds connected in series. The ponds are constructed in such a way that ideally only one saleable salt crystallises per pond (Fig. 6). The crystallization sequence is normally as follows:

Gypsum (calcium sulphate) → Rock salt (sodium chloride) → Potash (potassium chloride) → Carnallite (potassium-magnesium chloride) → Bischofite (magnesium chloride) → Li-rich brines (6 % Li).

The brine is enriched with lithium as a result of the evaporation of water at the end of this precipitation step and is then further processed into lithium carbonate in a chemical plant. In such a plant, boron is removed in a first step by means of solvent extraction. At the end, the remaining magnesium and sulphate are precipitated with quick lime (CaO) and soda (Na<sub>2</sub>CO<sub>3</sub>). Lithium

is then extracted as carbonate from the now pure, concentrated liquid. The purity can be increased to „battery grade“ through further washing steps and by employing the ion exchange process [7].

Data availability, especially for the recovery (proportion of the lithium that is extracted from the brine) is poor, because numerous companies do not publish their figures. However, SQM, which produces in the Chilean Salar de Atacama, provides information in their annual report 2018 [12], which is used here as an example. Assuming a lithium content of 2,000 ppm in the brine (corresponds to 0.2 % or 2 kg/m<sup>3</sup>), an average recovery of 35 % would require around 1,400 m<sup>3</sup> of brine to produce one ton of lithium (or approx. 270 m<sup>3</sup> brine for one ton of lithium carbonate).

Not only the lithium content, but also the ratio of lithium to magnesium or lithium to sulphate, for example, as well as the climatic conditions, are critical for profitability. Because evaporation is necessary to concentrate lithium and precipitate the other elements, a very arid climate is required.

The effectiveness of the extremely slow evaporation process, which can take two years from brine pumping until reaching the final lithium concentration, is influenced by solar radiation, wind and precipitation and their seasonal fluctuations. Barely any technical options are available for improving evaporation. Even

in the extremely dry region of the South American salars described here, there remain relatively large differences. Evaporation in the Salar de Atacama in Chile, where the two largest salar lithium production facilities are located, is around 3,200 mm per year. East of the main ridge of the Andes, on the Argentine side, evaporation is „a mere“ 2,300 mm per year (Salar de Hombre Muerto) and in Clayton Valley in the USA it is 1,800 mm per year [7]. Additionally, the effectiveness of lithium production from salars is determined by the composition of the brine. Primarily, the initial concentration of lithium in the brine is a decisive factor. However, the elements present in addition to lithium are also relevant. Sodium, potassium and occasionally sulphates can be precipitated relatively easily from the brine. This is much more difficult for magnesium because the chemical properties of magnesium and lithium are remarkably similar. Lime is normally used to remove magnesium. The more magnesium there is, the more lime must be used, causing extra costs. In addition, some of the lithium is lost during precipitation. The process therefore becomes uneconomical above a certain magnesium/lithium ratio. The recovery of lithium from the original brine is around 50 – 70 % in the majority of salars [7, 11]. However, the data situation is uncertain, because almost no figures are published by the few operators. The Chilean company SQM, which produces lithium carbonate in the Salar de Atacama, states in its 2018 annual report that its total recovery up to lithium carbonate is only 28 – 40 % [12].

Depending on the initial composition of the brine, potassium and magnesium fertilizers can also be produced in addition to lithium. At SQM in Chile, for example, they made a major contribution to the overall economic result. The revenue that was achieved with potassium chloride was about 1/3 of the revenue with lithium products [12].

In addition to the current technology of concentrating brines by evaporation, there are efforts to use other methods to concentrate lithium from salars. They are intended to reduce brine consumption and increase economic efficiency. The use of saline water from oil wells or geothermal energy is also being investigated. This applies to the Vulcan Energy Resources geothermal project in the Upper Rhine Graben, for example [13], where the aim is to extract lithium in addition to geothermal energy. The water pumped for geothermal use contains lithium, which is to be separated out for production. However, at less than 200 mg/l [13], the concentrations are low. Here, the aim is therefore to use a process in which an organic solvent selectively extracts the lithium from the brine [7, 14, 15, 16], or ion exchangers [16] which selectively concentrate lithium.

Another option currently being researched consists of the use of nano-membranes to concentrate lithium under high pressure [17].

Due to the increasing demand for lithium, there is a high probability that more lithium will be extracted from both salars and pegmatites in the future. It can be assumed that production from pegmatites will increase to a greater extent than from salars, because the directly available potential is greater. Additionally, salars have risks associated with the production process such as increased precipitation, contamination of the brine or insufficient extraction.

### 3 RECYCLING

Currently, recycling is not an important factor in lithium production. On one side, the volume of lithium-containing material available for recycling is still relatively small and on the other, recycling is relatively expensive when compared to mining [18]. In addition, lithium is not mounted as a pure metal in the LIBs, but is used together with other components that cannot be easily separated from each other, for example in the anode.

Furthermore, electric car batteries are not yet available for recycling due to the length of their lifespan and possible subsequent use as stationary storage systems. However, concepts and pilot plants are available to reuse the largest possible proportion of the batteries. This not only applies to electric cars, but also to batteries from mobile devices such as smartphones and laptops. If the application is within the glass or ceramics industry or in lubricants, they are regarded as consumables. Here, one can only attempt to collect glass as pure as possible and remelt it in order to utilise the properties of lithium again. Lubricants cannot be recycled because the element is distributed in exceedingly small quantities.

However, legal requirements such as the European Battery Directive 2006/66/EC, the WEEE Directive 2012/19/EU (Waste of Electric and Electronic Equipment), the RoHS Directive 2011/65/EU (Restriction of Hazardous Substances), among others, will lead to the expansion of recycling in the mid-term [19]. The demands on purity for lithium when used for LIBs, however, are extremely high, which makes it difficult to reuse the material for this purpose after recycling. Manual dismantling and/or mechanical shredding is initially envisaged in LIB recycling. The sorted components can then be recycled for the respective target material. With regard to the material

that cannot be separated directly, including the lithium-containing electrodes, hydrometallurgical processes (leaching) or pyrometallurgical processes (smelting), or a combination of the two process paths in succession, can be employed. The Umicore company operates a recycling plant in Hoboken (Belgium) that is designed for 7,000 t of LIBs. This corresponds to around 250 million smartphone batteries (approx. 30 g each) or 35,000 electric car batteries (approx. 200 kg each). However, because the metal value (approx. 10 – 12 kg cobalt, nickel and manganese with a combined value of approx. € 590 per car battery) in these batteries clearly exceeds the value of the lithium (approx. 4 kg per car battery with a theoretical value of € 180 maximum), the focus here is on the more valuable metals. Additionally, the value of lithium has only been determined theoretically, because, as described above, only very pure lithium is suitable for battery cell production. This is not the case by simple recycling. The material would need to be further upgraded in complex processes, which would increase the costs of recycling. Because it is difficult to estimate how much lithium will be used in the future, it is also difficult to forecast the future recycling volume. According to a 2011 source [20], 10 – 25 % of the lithium demand could be covered by the secondary sector in 2030, depending on recycling success.

## 4 SUSTAINABILITY ASPECTS OF LITHIUM MINING AND PRODUCTION

With regard to the sustainability aspects of lithium mining, a distinction must also be made between hard rock mining and lithium extraction from salar brines, because the respective processes are associated with vastly different effects.

### 4.1 Environmental aspects

#### *Land-use and mining residues*

Due to the relatively low ore value, **hard rock** production is done by means of open-cast mining in all major mines. First, the overburden and the barren country rock must be removed. Subsequently it is deposited on waste rock heaps. The waste-to-ore ratio for lithium pegmatites is typically in the range of 3:1 to 10:1. This results in around 3 to 10 tons of waste per ton of ore. In individual cases the ratio can be lower.

In humid agricultural or forested regions, such as in south-west Australia, the impact on land-use should be kept as low as possible.

Land-use is less of a problem in arid, sparsely populated areas, such as the northwest of Australia. This is also reflected in the area required for the production of 1 t of lithium carbonate. Data from feasibility studies and licensing application documents, published by the government of Western Australia, reveal that an area of only 4 m<sup>2</sup> is required for the production of 1 t of lithium carbonate in the Greenbushes mine, which is located in a temperate climate zone, while the Pilgangoora and Mount Marion mines require 12 – 13 m<sup>2</sup>/t lithium carbonate. On one hand, this is due to the very high Li content in Greenbushes, but undoubtedly also to the fact that the approved areas in the semi-arid regions in the north of Western Australia were applied for and approved much more generously, because the impact on nature and conflicts of use with other parties are much lower. For comparison, the production of 1 t of copper requires 3 – 4 m<sup>2</sup> of land and the production of aluminium requires around 1 m<sup>2</sup>/t [21].

Land-use on the **salars**, predominantly evaporation ponds, is relatively large, but no data are available for consumption per ton of lithium carbonate. However, the salars are not used by other stakeholders, because they are extremely arid salt plains. Discussions around the salars, dealing with areas outside of the evaporation basins, are ongoing. They revolve around the effects of brine extraction on freshwater wells just outside the salars, as well as around fears that brine pumping will dry out lagoons at the peripheral area of the salt flats and thus destroy the livelihood of the flora and fauna there. Indirectly, this may also have a negative impact on tourism.

#### *Water demand*

In **hard rock** mining, water is required in particular for milling the ore, as well as for the subsequent concentrating stages (density sorting, magnetic separation, flotation). Mineral concentrates (Li and other valuable materials) are the products of sorting, and are dewatered before marketing. Processing residues are deposited in tailings ponds. Once the solids have settled, some of the water can be reused, but some will remain in the tailings as pore and interstitial water, which makes up about 40 % of the volume of the tailings. This water consumption is less unproblematic in relatively humid areas, such as at the Greenbushes mine in south-west Australia. According to the operator, only rainwater is used here for processing. In arid regions, such as the Pilbara region in northern Australia, supplying the operation with water is more of a challenge. However, water use conflicts are also rare here, because this region is only very sparsely populated and is not used agriculturally. Fossil groundwater is mostly used and in one case the water from a flooded, former open-



cast mine, in which the tailings are also deposited, is pumped.

If conflicts concerning the use of water should arise in hard rock mining, the use of thickeners and filter presses to dewater the tailings may allow water loss to be minimised, but this is currently not planned for most projects. The residual moisture after deploying filter presses is between 15 % and 25 %. However, this still means that, given an ore throughput of 5 Mt per year, around 500,000 m<sup>3</sup> of unrecoverable water are required. According to the feasibility study of the Pilgangoora mine, operated by Pilbara Minerals [23], the planned water content in the tailings is around 35 % without the use of filter presses, which corresponds to around 875,000 m<sup>3</sup> of water given a throughput of 5 Mt of ore. This would be 375,000 m<sup>3</sup> more per year than when using filter presses.

In contrast to metal mining (copper, lead, zinc, gold concentrates), lithium ore, which is extracted from pegmatites, usually does not display sulphide mineralisation, meaning that groundwater or surface water acidification is unlikely.

When extracting brines from **salars**, a relatively large volume of water is consumed through the process of evaporation and fractionated crystallization of various salts until the final, desired concentration of lithium is achieved. However, this is saltwater, which cannot be used as industrial or potable water. The amount of water that must be evaporated depends on the initial concentration of lithium in the brine and the lithium recovery (proportion that is transferred to a final product) from the brine. In order to increase the lithium concentration (maximum 0.2 %) to the 6 % required for further processing, the lithium must be concentrated by at least a factor of 30. This means that approx. 97 % of the water evaporates and cannot be reinjected into the subsurface. This leads to a lower saltwater table, especially in the vicinity of the pumping wells; if this happens over an extended period of time and in a large number of wells, this draw down is also perceptible regionally. It is not clear how great the draw down due to lithium production is. If saltwater extraction is excessive, freshwater may flow in and mix with the saltwater. As a consequence, the freshwater levels would also be lowered and the mixed salt-freshwater is not anymore useable for agriculture.

The producing companies primarily require freshwater for the production of lithium hydroxide, which is obtained from lithium carbonate. SQM states that a total of 26 m<sup>3</sup> of fresh water are required for 1 ton of lithium hydroxide, whereby only 1 m<sup>3</sup> is actually pumped as groundwater,

with the remainder coming from Antofagasta's wastewater treatment system. The actual freshwater requirement is therefore low.

Water rights over 4 m<sup>3</sup>/s of freshwater exist in the entire catchment area of the Salar de Atacama. SQM's share is 0.18 m<sup>3</sup>/s. Copper mining in the Salar de Atacama catchment area extracts 2.8 m<sup>3</sup>/s, i.e. 15 times as much. In addition, SQM not only produces lithium, but also potash and bischofite, which also require freshwater during production. This means not all of the extracted water is used for lithium production.

As a result of the numerous discussions around water withdrawal, concepts dealing with how lithium could be produced without evaporating large amounts of water have been drawn up. Direct production by means of solvent extraction or ion exchange [7], and the subsequent re-injection into the salar, would lead to a quasi-closed loop. This means that there would no longer be any large-scale brine draw down. However, the same authors point out that injecting such large volumes of water is not without its own problems. Reinjecting low lithium content water into the actual deposit, thus reducing the profitability of the project or rendering the deposit uneconomical, must be avoided. In addition, organic compounds that could not be completely removed can be introduced into the subsurface as a result of solvent extraction. Such scenarios remain in the future, however, because the corresponding technologies cannot currently be deployed on a large-scale.

## 4.2 Social and socio-economic relevance

As basins, the salars represent the deepest depressions in their catchment. Freshwater aquifers, which are used for the potable water supply and for cultivating the fields of the local population, are located at elevated areas outside the salt flats. By pumping brine, the water level is lowered locally and, in some cases, regionally; mixing of salt and fresh water (see 4.1) can thereby render water unusable for both humans and the traditional agriculture of the neighbouring communities. There have been reports of falling groundwater tables and wells running dry as a result [24]. This leads to restrictions in the traditional way of life of the indigenous population. However, measuring the influence of lithium mining on groundwater levels is a complex matter. On one side, the lithium producers SQM and Albemarle abstract only a small percentage of the fresh groundwater and, on the other, it is extremely difficult to scientifically measure the influence of the lowered saltwater table on the adjacent freshwater. In addition to water withdrawal for

mining, a drawdown of the freshwater table can also be the result of a reduction in precipitation [25], freshwater withdrawal by the copper industry, and increased water consumption due to tourism. So at the end it is difficult to say who is in charge for impacts on lagoons drying out or being so negatively impacted that the fauna, some of which is endemic, is harmed. A negatively impacted environment would in turn have an impact on tourism, because the flamingos are one of the main attractions of the Salar de Atacama and the Salar de Uyuni. It is extremely difficult to objectively portray a link between the lack of precipitation, water withdrawal by a variety of industries and saltwater pumping for lithium production.

Parts of the copper industry, which is also located in the region, are planning to dispense with freshwater withdrawal from the catchment area of the salars and use desalinated seawater in the future. This could reduce the water stress on the region and thus help to resolve the conflicts.

Conflicts involving the true extraction of brine volume and the effects of this extraction on local freshwater supplies are not a specifically Chilean phenomenon. These discussions also take place in Argentina and Bolivia, where similar deposits exist. Here, too, the benefits of lithium production at the expense of water withdrawal are discussed. Even if the withdrawn water is predominantly saline water, the question of interaction with the adjacent freshwater remains. It is therefore of central importance to investigate the precise interrelationships if sustainable lithium production with simultaneous sustainable freshwater management is to be ensured. The influence of the changing climate on precipitation and, as a result, on the groundwater level and groundwater recharge, remains problematic.

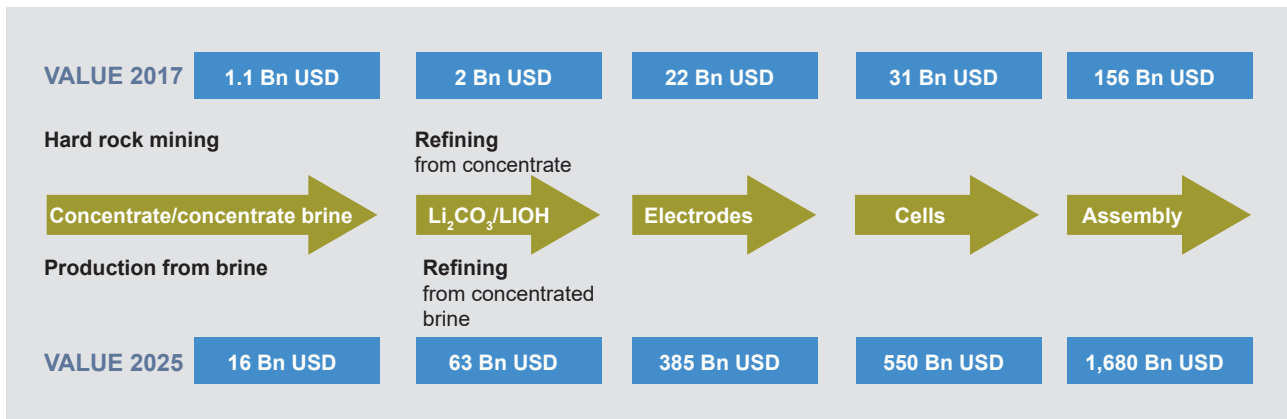
From mining to battery production, lithium production is associated with an extremely long value chain (Fig. 7), although the given value for battery assembly does not, of course, reflect the value of the lithium only, but instead that of the entire product with all the raw materials it contains. In relation to mining and processing, the end product in brine mining is always a salt, generally lithium carbonate (lithium hydroxide and lithium chloride are also possible end products). In hard rock mining, concentrates are usually produced, or the ore is occasionally shipped directly (direct shipping ore). In the latter case, an extension of the value chain from concentrate to lithium carbonate would be possible on site or nearby. To achieve this, however, relatively high investments are necessary, which only exist in planning to date, but have not yet been implemented. The value of the lithium content from a spodumene concentrate to lithium carbonate increases by a factor of 5 – 6 [1]. The

primary causes are the costs for energy and chemicals, as well as the stringent purity requirements for „battery grade“ lithium carbonate. Further processing into electrodes, cells and final assembly are predominantly undertaken in China, South Korea and Taiwan [4]. However, a number of initiatives aimed at transferring battery production for use in electromobility closer to the domestic market are underway in Europe. The endeavours of Chile and Bolivia to also start manufacturing batteries is understandable, because of the added value associated with it. However, much more money is being invested in new production facilities and research in Europe and North America than in South America. It is therefore questionable whether the desired expansion in added value will actually take place in South America. In Australia there were, or are, also ideas to at least produce the lithium carbonate within the country. A corresponding project for the Greenbushes mine concentrates will not be pursued for the time being due to fallen prices. But even without further processing, several hundred people each are employed in the respective mines in the production of mineral concentrates, and in brine extraction and the subsequent production of lithium carbonate. Chile's SQM lithium producer has almost 5,000 employees, meaning that the mining companies are not only important as taxpayers, but the employees also pay taxes and contribute to economic development with their purchasing power.

An extension of the value chain beyond the production of lithium carbonate remains questionable, because numerous countries compete for the required capacities in the market for lithium ion batteries. Bolivia remains an exciting example with the large resources in the Salar de Uyuni, because the state stipulates that further processing must take place within the country. Lithium production, however, has not yet begun.

### **Greenhouse gases**

According to some authors, the effects of lithium carbonate production on the CO<sub>2</sub> footprint are insignificant overall, if more pegmatites with lower grades go into production in the future [26]. The overall CO<sub>2</sub> footprint would continue to be a relatively low amount per kWh of battery power produced, at around 4 kg CO<sub>2</sub> equivalent (CO<sub>2</sub>e)/kWh. For lithium carbonate production from salars, ROMARE & DAHLLÖF [27] assume 1 – 2 kg CO<sub>2</sub>e/kWh. The total CO<sub>2</sub> footprint is given here at around 37 – 71 kg CO<sub>2</sub>e per kWh of battery power. This means that the contribution of battery production's lithium carbon footprint would be well below 10 %. However, conversion of the spodumene concentrates to „battery grade“ lithium carbonate is not taken into account in this analysis. As a result of the



**Fig. 7: Battery value chain for lithium.** Sales in billion USD per year were taken from the study by [22]. The value of the spodumene concentrate to lithium carbonate increases approximately by a factor of 5–6. It is not possible to directly determine this value in the case of the transition from Li-rich brine to lithium carbonate, because the brine is not traded as a product but is processed directly on site.

process shown in (Fig. 5), this spodumene conversion into lithium carbonate is much more energy-intensive than the production of „battery grade“ lithium carbonate from salars, in which the brine merely requires cleaning and the carbonate then precipitated.

The total contribution naturally also depends on the type of energy used to produce the battery. Here, ROMARE & DAHLÖF [27] give values of 7 kg CO<sub>2</sub>e/kWh for Sweden, due to the different energy mixes (extensive use of hydropower). This compares to 159 kg CO<sub>2</sub>e/kWh for China and 226 kg CO<sub>2</sub>e/kWh for the case of the production in India (predominantly coal). Other authors give a standard value of 107 kg CO<sub>2</sub>e/kWh [28]. The principal factor is not the raw material used, but the location of battery cell production, respectively the energy mix that is used.

### 4.3 Governance

By far the largest proportion of total lithium production is located in countries with very good (Australia) or good (Chile) governance (average of the World Bank's World Governance indicators [6]). The mean weighted governance according to production has a very good value of 1.16 (on a scale from -2.5 to +2.5). The only country with critical governance among the currently producing countries is Zimbabwe (-1.19). Should Bolivia significantly expand production, the country would also be concerned critical with a governance index below -0.5 (-0.55). However, even in countries with good governance, such as Chile, there are numerous critical voices, especially regarding the withdrawal of water by lithium producers. Here, there is an occasional lack of trust between the local population, the mining companies and the monitoring authorities. In response,

SQM publishes the abstraction volumes from their wells on a daily basis, but it appears to be a long journey to regain the trust of the local population.

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\* The production figures for Australia are from BGS/USGS. These are presumably based on export figures, which have been converted with a conversion factor of 6 % Li<sub>2</sub>O content (standard concentrate) for all ores and concentrates exported from Australia. Because the individual producers' Li<sub>2</sub>O concentrations fluctuate between 1.2 – 7 % depending on the product, and only the total export volumes of the country are known, the stated annual production (in t of product) is probably considerably higher than the actual annual production (in t of Li content).

## IMPRESSUM

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