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Editorial

The Need for Lithium Recovery from Liquid Resources

Lithium (Li) is an essential component in modern industry due to its one-of-a-kind chemical qualities and the diversity of the uses to which it can be put (Swain, 2017). As the most considered application, it has been used extensively in the creation of rechargeable lithium-ion batteries, which power a wide variety of electronic gadgets, ranging from smartphones and laptops to electric vehicles and renewable energy storage systems (DuChanois et al., 2023). This is the primary reason for its significance, and it is also the one of the main reasons why Li is so important. Moreover, Li is required to develop products in other industries, such as ceramics and glasses, greases and high-temperature lubricants, and air conditioning (Zavahir et al., 2021). The relevance of Li has significantly increased as the worldwide demand for these products continues to rise, particularly in light of the movement towards global decarbonization and environmentally friendly energy solutions. Figure 1 shows the trend in the global demand for Li and the prediction until 2030. It is also anticipated that the demand for Li in commercial applications would skyrocket, reaching 4.5 Mtons annually by the year 2100 (Ambrose & Kendall, 2020).

The Li supply, however, is confronted with obstacles, including a dearth of raw materials, environmental concerns, and the complexity of Li processing and extraction. This disparity between supply and demand has caused a surge in Li prices. For example, the current trend in Li demand resulted in a remarkable increase in price of almost 300% (Khalil et al., 2022). As a result, it is obvious that both the demand for Li and its price will continue to skyrocket, and more focus needs to be placed on new resources and efficient recovery and extraction techniques.

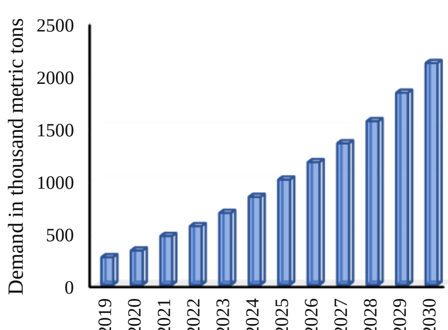

Fig. 1. Trend in global demand for Li in commercial products (Source: https://www.statista.com).

Li is traditionally extracted from solid sources, i.e., pegmatites and ores in mines. Some of the main producers of Li from solid sources include Australia, China, Canada, Brazil, Africa, and Russia. However, all these solid sources contain only small amount of available Li in the world (Figure 2). Therefore, if supplies continue to dwindle and ore grades continue to fall in the future, it is not certain that there will always be an endless supply of this essential metal (DuChanois et al., 2023; Zavahir et al., 2021). Moreover, the traditional mining of Li, particularly from hard rock, may have major negative effects on the surrounding environment, including the deterioration of land, the contamination of water, and the pollution of air. For example, a report carried out in 2017 came to the conclusion that mining corporations spilled approximately 2 billion pounds of hazardous waste into the rivers, posing a significant risk to both human health and the wellbeing of aquatic life (Khalil et al., 2022). It also takes a significant quantity of water that can be challenging in arid regions where water is scarce. Moreover, the conventional method of mining can also be expensive and energy intensive (Meng et al., 2021).

Given the challenges associated with Li extraction from traditional solid sources, it is becoming more vital to identify alternate sources of Li that are not only sustainable but also economically feasible. The extraction of Li from liquid resources, such as salt lake brine, geothermal brine, industrial wastewaters (like gas- and oil-field brine, reverse osmosis (RO) brine), and seawater, is where the process comes into play at this point. Figure 2 compares the availability of Li from solid and liquid resources and shows a significantly higher amount of Li from liquid sources compared to solid sources.

When comparing the amount of Li that can be obtained from different liquid sources, it is necessary to investigate the concentrations, total reserves, accessibility, and practicability of extraction in each of these settings, while among them the Li concentration plays an important role. It is worth noting that the high cost for water removal step in concentrating of diluted streams can lead to higher production cost, which is not feasible for Li production (DuChanois et al., 2023). Thus, the higher the Li concentration in the liquid source, the more affordable the Li production cost from liquid sources. Figure 3 shows the values for the Li concentration in different liquid sources.

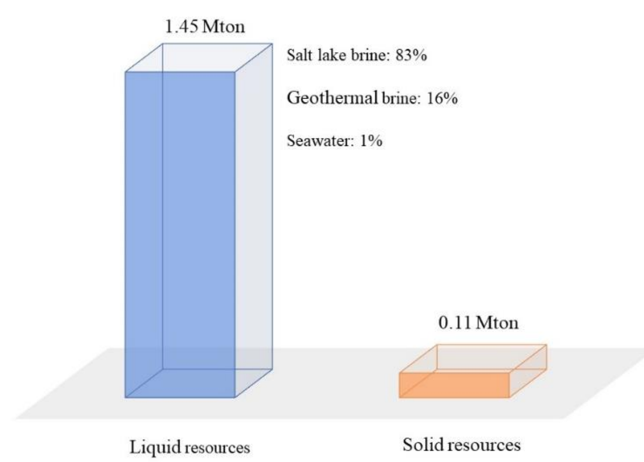

Fig. 2. Availability of Li in solid and liquid resources (inspired from (Zavahir et al., 2021) and (Flexer et al., 2018)).

Seawater is the most prevalent liquid source of Li. It is estimated to contain large amount of Li, up to 230 billion tons. However, the concentration of Li in

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seawater is very low, i.e., typically around 0.1-0.2 mg/L, requiring the processing of enormous volumes of water to extract significant quantities of Li (Swain, 2017). The combination of the low concentration and the high concentration of other ions such as sodium (Na), magnesium (Mg), and potassium (K), which can interfere with Li extraction, makes it a significant technical challenge (Vera et al., 2023). However, the brine generated during seawater desalination, also known as RO brine, possesses higher Li concentration, i.e., up to 4 mg/L. Thus, it has been considered as a more promising source for Li extraction in comparison with the seawater (Figueira et al., 2023). However, this concentration is still low for a feasible Li extraction in industrial scale, as large amount of water should be processed to reach a Li-rich solution (DuChanois et al., 2023).

Geothermal brine extracted during the production of geothermal energy may contain 160-400 mg/L of Li, making it a potentially valuable Li resource (Sutijan et al., 2023). This form of brine is typically found in regions with a high heat flux and is characterized by a high concentration of total dissolved solids, including a variety of metal ions, salts, and other minerals (Stringfellow & Dobson, 2021). Despite the relative abundance of Li in geothermal brines, the total Li reserve in these resources has not yet been precisely determined due to the limited development of geothermal energy initiatives around the globe. Produced water, a kind of geo-brine solution, is formed during the extraction of oil and gas, and it is another source of Li. This by-product is often considered to be a waste product and is frequently re-injected into wells as a disposal method or an enhanced oil recovery technique (Seip et al., 2021). The geology of an oilfield can have a significant impact on the range of Li concentrations found in its brines, which typically fall somewhere between 1 and 40 mg/L. As is the case with geothermal brines, the overall Li reserves in oilfield brines are not clearly characterized. However, taking into account the enormous volume of brine generated in oil and gas activities, the prospective reserves might be rather substantial (Kumar et al., 2019).

Due to their distinct advantages, saline lake brines, also known as continental brines, have become an essential resource for Li extraction. Typically, they are found in high-altitude salt plains, primarily in the "Lithium Triangle" of Argentina, Chile, and Bolivia (Heredia et al., 2020). Li concentrations ranging from a few hundred to a few thousand milligrams per liter (up to 1600 mg/L) are one of the most significant advantages of extracting Li from these brines. Compared to other natural liquid sources with a lower Li content, this high concentration makes the extraction process economically feasible (Zhang et al., 2019). Additionally, the extraction procedure is simpler and less energy-intensive than conventional mining operations. The simplicity of the traditional extraction procedure, i.e., evaporation and precipitation, and the abundance of brine resources result in reduced operational costs and consistent production capabilities, making saline lake brines more economically viable source of Li. As a consequence of these advantages, saline lake brines have become one of the most desirable sources for Li extraction in the current circumstance of rising Li demand (Liu et al., 2019; Song et al., 2017).

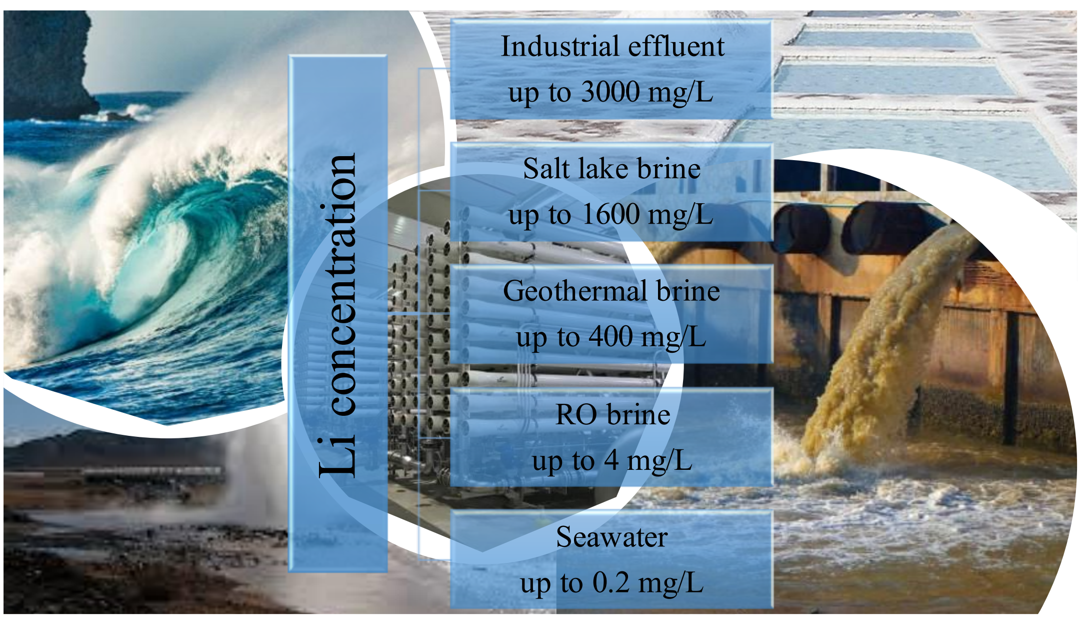

Fig. 3. Li concentration in different liquid sources.

The extraction of Li from industrial effluent is another promising option, which offers a number of advantages that reflect the dual goals of resource recovery and environmental sustainability. Some industrial effluent streams contain high Li concentrations. One example is the effluent generated after Cobalt (Co) recycling from used Li-ion batteries. After recovering Co, Copper (Cu), nickel (Ni), and graphite from one tone of Li-ion battery black cathodic material, approximately 8 m^3 of waste effluent containing up to 3 g/L Li is produced (Devda et al., 2021; Qasem et al., 2021). The high Li concentration in industrial effluent along with the conversion of wastewater product into a valuable resource are the principal benefits of this strategy, which could reduce environmental contamination and demand for existing Li mines. By delving into this underutilized resource, businesses not only gain an additional revenue stream, but also increase operational efficiency by utilizing what was once considered a waste stream (Diaz-Elsayed et al., 2019). In addition, this method adheres to the guiding principles of the circular economy, which emphasize resource optimization and waste reduction. Recovering Li from effluent can reduce the amount of waste that would otherwise need to be treated and disposed of, thereby mitigating environmental damage (Kong & Liu, 2020; Wang et al., 2022). Moreover, relatively high concentration of Li in industrial wastewater compared to other sources can enhance the efficiency and economic viability of Li extraction from wastewater (Rahighi et al., 2022; Zheng et al., 2018). The extraction of Li from industrial effluent stands out as a strategy that could contribute to a more sustainable Li supply chain, given the growing emphasis on sustainable and responsible procurement of critical or strategic metals. However, there are still challenges in using traditional techniques to recover critical metals from waste, such as their relatively high cost and energy and time-consuming nature, which require further research (Zhou et al., 2021).

The significance of Li extraction from various liquid sources mainly saline-lake brine and industrial effluent cannot be underestimated and exaggerated in our increasingly energy-conscious world. These sources offer unique economic, sustainability, and resource optimization benefits. With their high Li concentration and less energy-intensive extraction procedure, saline-lake brine and industrial effluent are presently the most efficient and environmentally friendly liquid sources of Li for a sustainable supply. They have the potential to serve as unconventional sources of Li, thereby adhering to the circular economy principles and contributing to environmental protection. The key to realizing the maximum potential of these liquid sources is continued technological innovation that improves extraction efficiency, reduces costs, and reduces environmental impacts. As we continue to transition to a more sustainable and renewable future, these liquid resources will unquestionably play a crucial role in securing a reliable and sustainable Li supply, a crucial component of renewable energy storage and electric mobility.

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