Global Lithium Mining and Processing
Environmental and Social Impacts



Carrie Snyder, More Than Sustainability
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History of Lithium

- Lithium is named after the Greek word “lithos” meaning “stone”, represented by the symbol Li and has the atomic number 3[1]
- **Lithium’s beneficial neurological effects have been exploited since the height of the Roman Empire**. Starting in the 1800s, lithium was seen as a miracle neuroprotective agent and was added to tonics and sodas through the 1920’s, until cases of toxicity appeared and the mineral was banned being used in this way[2]
- The exact mechanisms by which lithium acts neurologically are not fully understood[2], however **lithium continues to be used as an effective treatment for bipolar disorder today**

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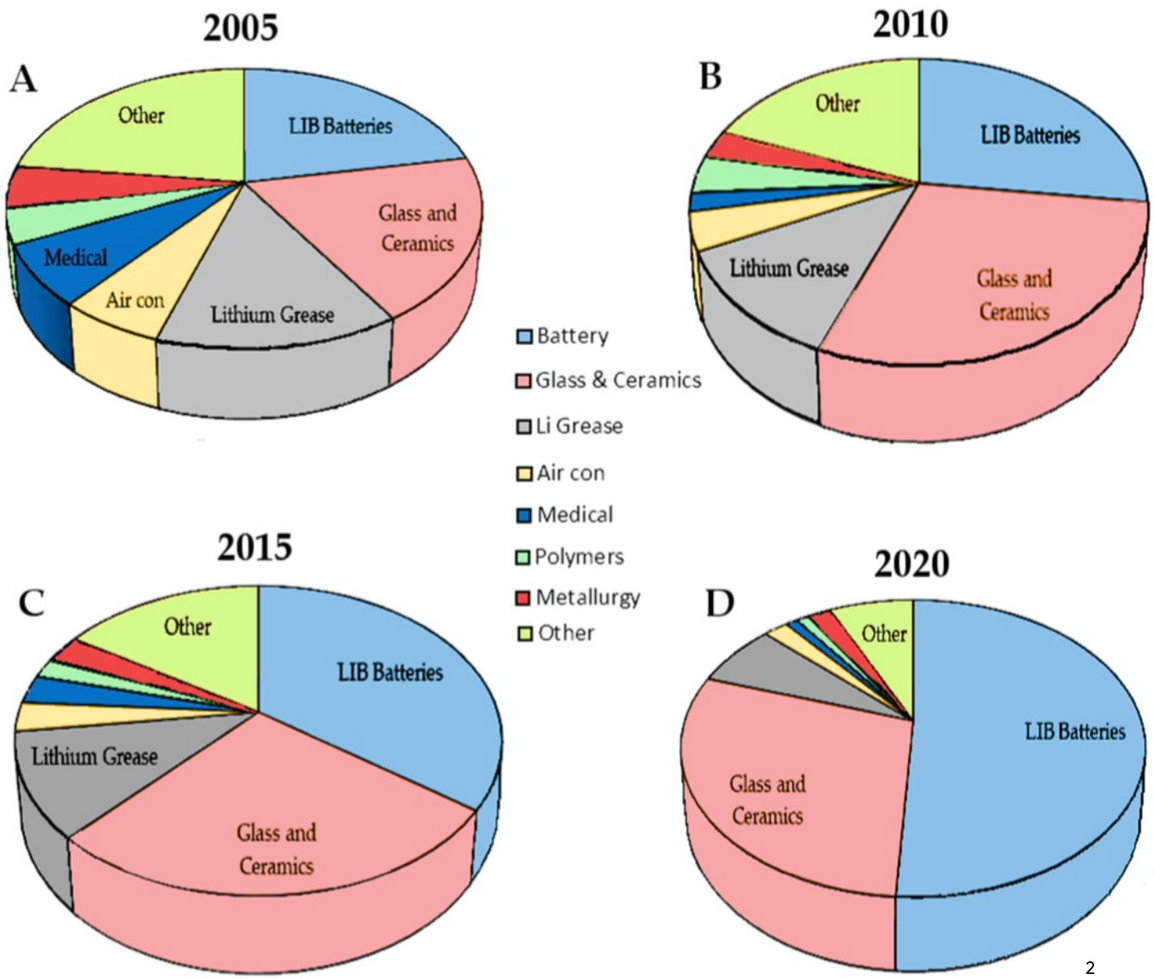
History of Lithium (cont.)

- The chemical history of lithium began with the characterisation of the aluminosilicate minerals petalite and spodumene[2]
- These minerals were discovered at the start of the 18th century, and **lithium was finally isolated as an individual element in 1821**[2]
- Lithium production was very limited until 1950s, since its useful applications were poorly understood until after World War II[1]
- **In 1997, lithium production changed dramatically by the emergence of brine operations in Salar de Atacama in Chile** capable of producing cheap lithium carbonate[1]

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Uses: Batteries, Batteries, and More Batteries

- **Over 70 percent of lithium produced today is used in batteries** – notably in consumer electronic devices[3]
- **Lithium in batteries can be used for the anode, cathode, and electrolyte**. Each combination affects voltage, energy density, and charging / dis-charging cycles[4]
- The most promising alternatives to LIBs are zinc–iron batteries and solid-state batteries, but the mining of zinc presents its own sustainability issues[5]



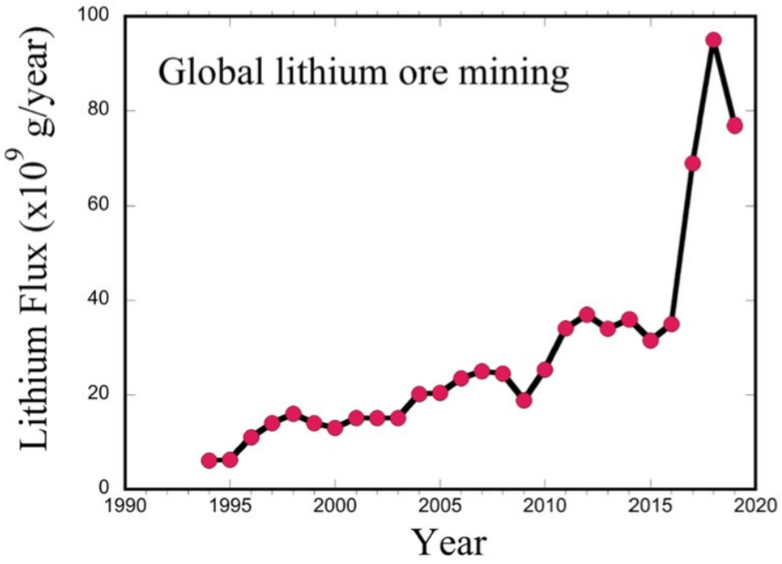
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Elemental Properties

- **Lithium is preferred as the material for batteries owing to three properties: (1) it is the lightest metal, (2) it has the highest electrochemical potential of all metals, and (3) it has the highest energy density among all metals**[6]
- In addition, due to lithium's small ionic radius, it has a low coefficient of thermal expansion[2]
- Because of the high reactivity of lithium the whole system must be kept strictly free of water[7]
- Li follows in the periodic table after the two most abundant elements in the universe H and He, but it is far less abundant in the universe than expected. The leading theory is that lithium is transmuted to other elements early within stars[2], possibly because its two stable isotopes have among the lowest binding energies per nucleon[1]

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Deposits and Reserves



- **Lithium is not a particularly rare metal**[2], and is slightly more abundant in the Earth's crust than Cu, Cr, Ni, and Zn and less abundant than Al, Mg, Mn, and Ti[2]
- It is widely distributed globally[2]
- It is difficult to estimate the world's lithium reserves, because of the abundance of contradictory estimates which are typically made by both investors and venture capitalists rather than researchers in the field[2]
- In addition, the demand for lithium is difficult to project due to the uncertainty over the growth and continuing popularity in lithium based electric vehicles[8]

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Deposits and Reserves (cont.)

- Today approximately 59% of the world's lithium resources are found in brines and 25% in minerals, the remainder is found in clays, geothermal waters, and oil field brines[2]
- **57% of the world's lithium resources are contained in just three locations**, the Salar de Atacama, Chile; the Salar de Uyuni, Bolivia, and the Kings Mountain belt, USA ("salar" is Spanish for "salt lake")[2]

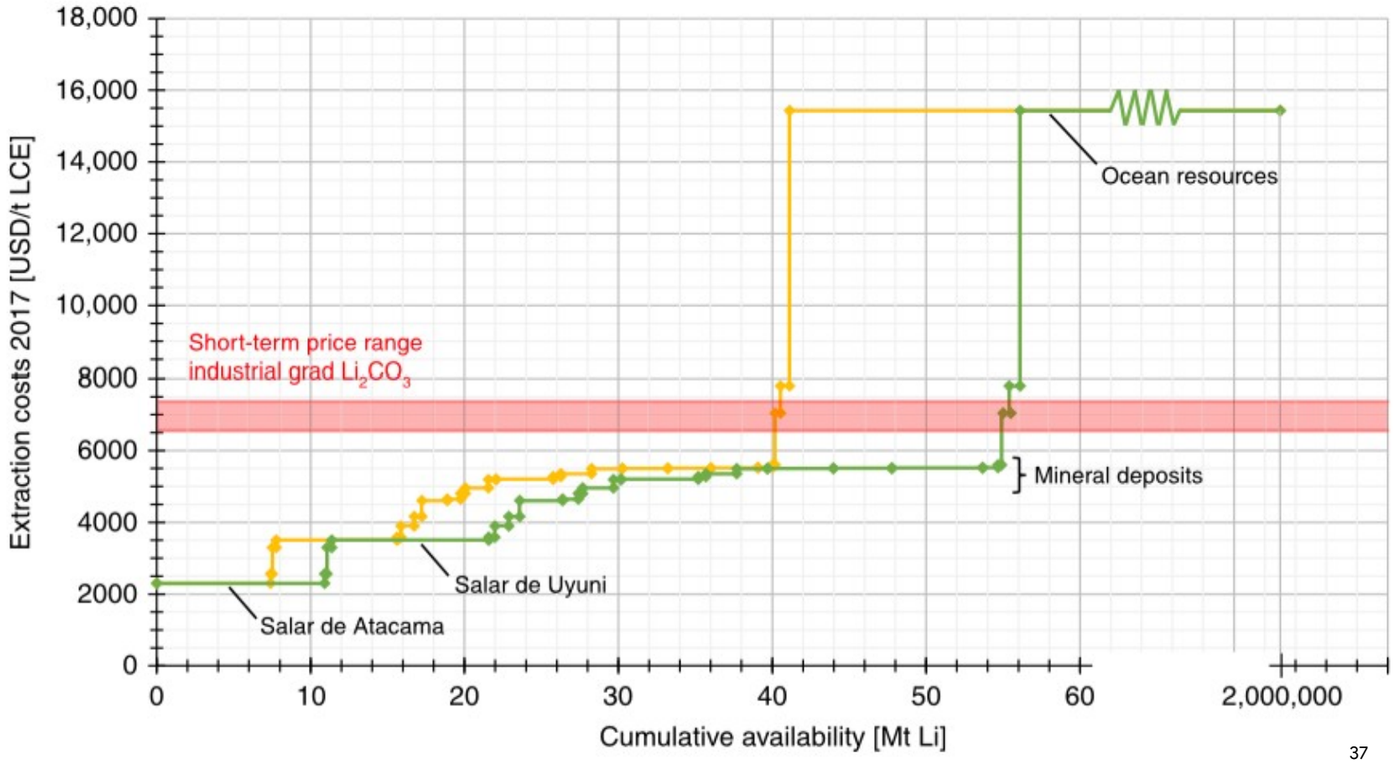


Salar de Altacama, Chile
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Other Sources of Lithium

- **The ocean contains approximately 5000 times more lithium than is found on land**[9]
- However, the **extraction of lithium from seawater is extremely challenging** because of its low concentration and the high concentration of competing ions (i.e., sodium, magnesium, calcium, and potassium ions, among others)[9]



- In addition to hard-rock and brines, Tesla was hoping to extract lithium from clays using salt. However, this source is often infeasible due to the low grade and high extraction cost[10]

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Ores

- Lithium is found in more than 145 different minerals, but it is extracted only from spodumene, lepidolite, petalite, amblygonite, and eucriptite[4]
- Among those, **spodumene is the most abundant lithium ore**[4]
- Theoretically, the chemical composition of spodumene is 8.07% Li_2O, 27.44% Al_2O_3, and 64.49% SiO_2, but **the actual content of Li_2O in spodumene is 2.9–7.6% by weight** because of other elements that can replace the Al and Li in this mineral formation[11]

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Mining and Production Locations

- **Australia spodumene mining (in 2018) represented the largest producer of lithium**[12]
- **Along with brine production in Chile, these two countries produce 80% of lithium**[13]
- China does not have a dominant position in lithium mining, but it has acquired over the last decade a dominant position in lithium processing; e.g. virtually all of the raw material mined in Australia is processed in China[5]
- **Four multinational companies**—Albemarle, SQM, FMC Corporation and Tianqi Lithium —**accounted for more than 83% of world lithium output in 2016**[14]

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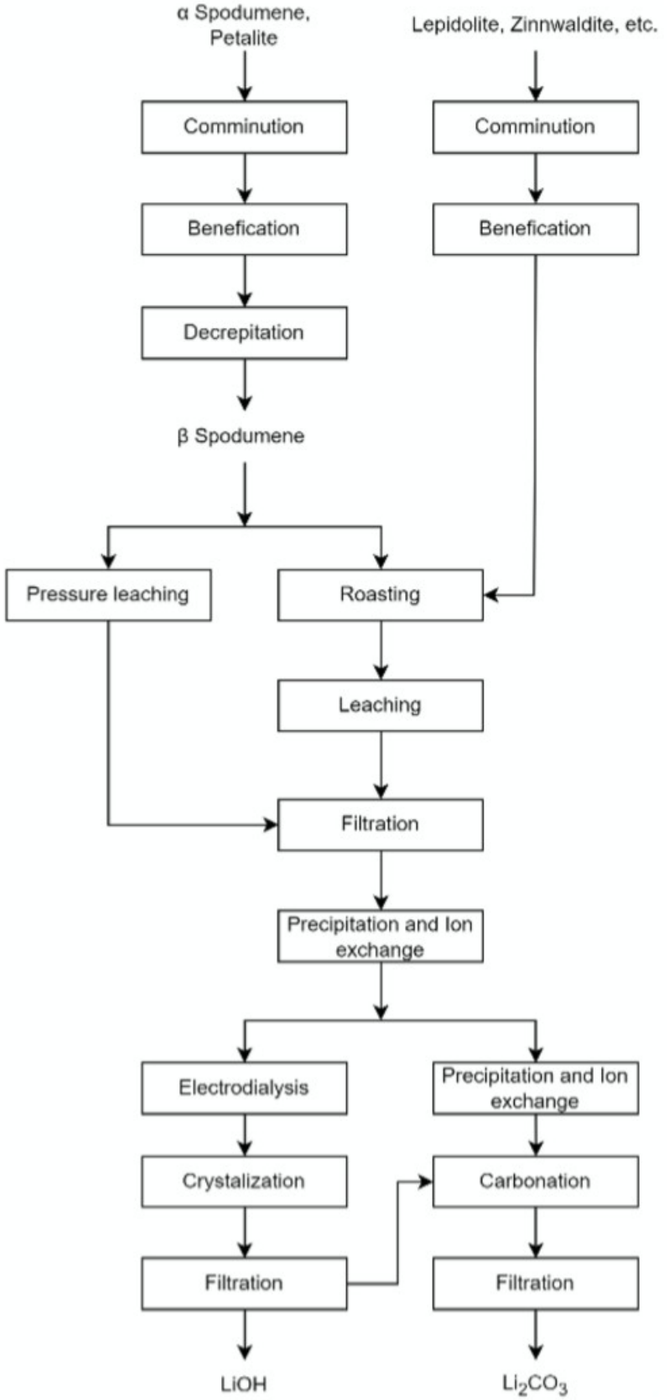
Mining Process: Brines

- Typically, the brines are concentrated via evaporation ponds before the lithium is precipitated in the form of lithium chloride or lithium carbonate[8]
- Broadly, the process involves evaporation, precipitation, adsorption, and/or ion exchange. Usually, the brine is pumped into a series of open, man-made (PVC-lined[15]) ponds, where **solar evaporation is used to concentrate the lithium into a smaller volume of brine, taking 18 to 24 months**[2]
- Since the brine is open to the environment, the process may be slowed down by rain or flooding (and flooding of the South American salars is common)[2]
- Lithium and magnesium have similar chemistries and are difficult to separate in brine deposits. The higher the Mg/Li ratio, the more expensive it is to process[2]
- Additionally, both sodium and lithium ions have similar chemical properties, so it is difficult to extract lithium from high-sodium brine[16]

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Mining Process: Hard Rock Ores

- **The processing route for spodumene ore follows conventional mining and processing, similar to many other hard rock operations**[17]
- In contrast to brine processing, **the spodumene treatment chain is short, requiring roughly five days**, and can be constantly productive throughout the year[1]



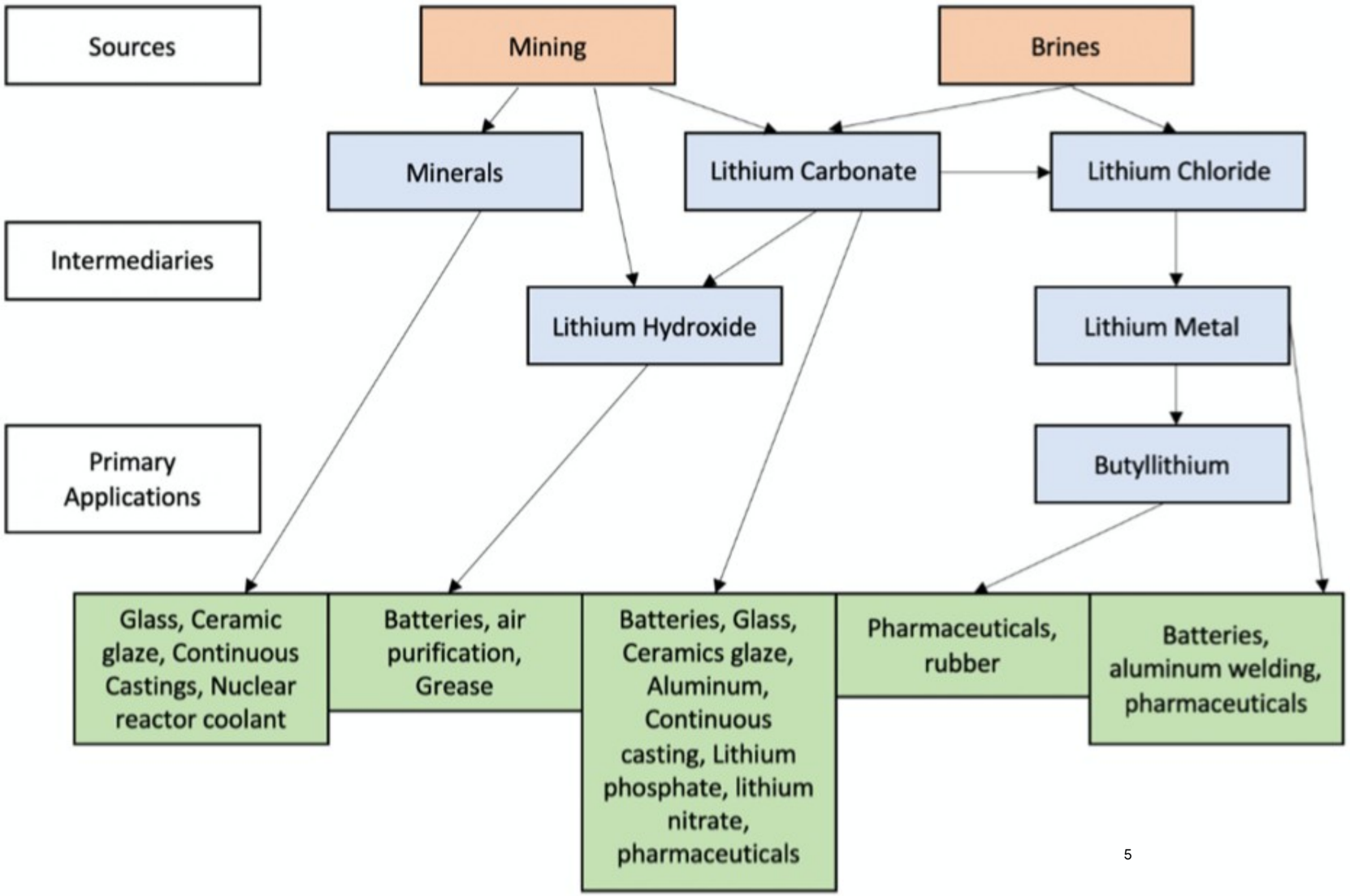
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New Mining Technology: Direct Lithium Extraction

- **A new lithium mining technology called "direct lithium extraction" (DLE) could change the mining process in the future.** One approach to DLE is the production of lithium hydroxide from brine using the geothermal energy of the brine itself as the process energy. It could have virtually zero carbon intensity[5]
- Techno-economic analysis suggests the DLE may be economically feasible but the production costs, estimated around $4000 per metric ton of lithium carbonate equivalent, need to be validated in real-world demonstrations and large-scale commercialization[5]
- Moreover, developers must handle large volumes of water and wastes on the surface[5], and it is possible many DLE technologies might require larger freshwater volumes than current evaporative practices, compromising their applicability in arid locations[19]

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Processing



- **Battery-grade lithium carbonate and lithium hydroxide require purities of >99.8% and >99.9% respectively, which places enormous demands on selectivity and purification during processing**[20]

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Environmental Impacts

- In terms of overall environmental impact (including energy demand and GWP), **the production of lithium carbonate from brines or ore does not differ substantially**[21]

	Environmental health impacts
Lithium	Australia: large volumes of waste rock, high water use Argentina & Chile: Water pollution and depletion; leaching, spills or air emissions of chemicals

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- Of additional concern is that most LIBs end up in landfills, where improper containment can lead to Li leaching into the surrounding soil and water streams. **~40% of the Li in a battery can be leached**[22]

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Biodiversity

- The **Center for Biological Diversity (CBD), a national conservation advocacy group, sued the Bureau of Land Management for failure to account for how the Ioneer mine in Nevada might harm a rare desert flower called Tiehm's buckwheat**[5]
- Ioneer and the CBD disagree on whether the plant could be safely transported to other locations[5]
- **Separately, CBD sued BLM regarding Thacker Pass in Nevada, arguing that BLM did not adequately consider the potential harm to the sage grouse, a rare bird in the Western US**[5]
- CBD claims the bird's survival is threatened by the proposed project which will consume large amounts of scarce groundwater resources and could have possible mismanagement of mining wastes[5]

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Water Use

- Li production from brine entails drilling a hole in the salt flat, and pumping of the mineral-rich solution to the surface, which depletes water tables[23]
- **Extracting a ton of lithium from requires 1,900 tons of water to extract**, which is consumed by evaporation[23]
- **In Chile's Salar de Atacama (SdA), 65% of the region's water is consumed by mining activities**. Farmers in the region must then import water from other regions[23]
- **Scientists argue that current water allocations in SdA are based on an inadequate hydrological representation of the system and as a result, are substantially greater than what can be replenished on modern time scales**. For example, they have documented that most of the current inflow to the basin was recharged before the modern climate regime[24]

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Water Use Impacts

- **Flamingos could be a strong indicator of environmental damage, owing to the landscape scale at which they use wetlands**[19]
- **In the Salar de Atacama, a reduction of 10% and 12% has been reported in the populations of James and Andean flamingos**, respectively, which is linked to the reduction of surface water, particularly in winter[19]
- Humans could then be impacted, as cyanobacteria that are normally kept at bay by native flamingos increase[15]

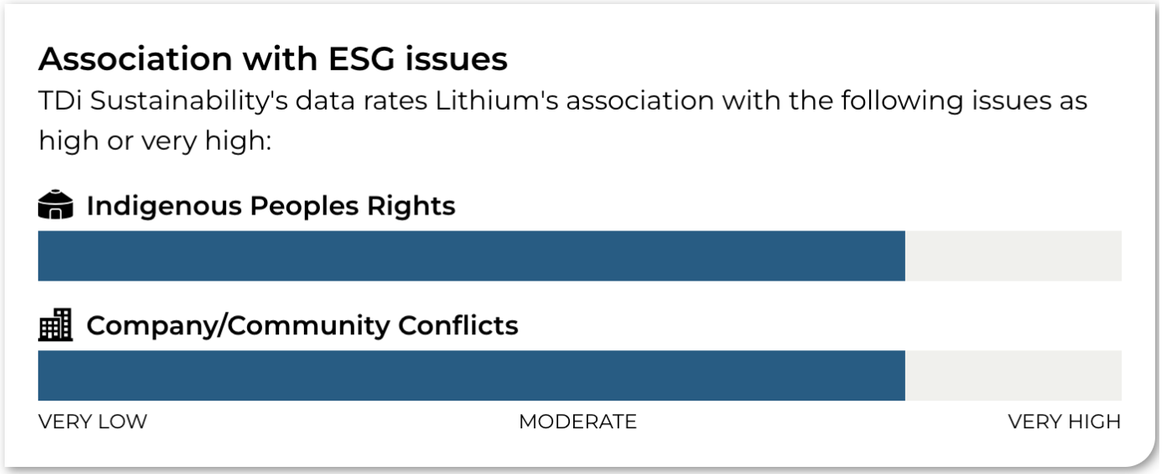
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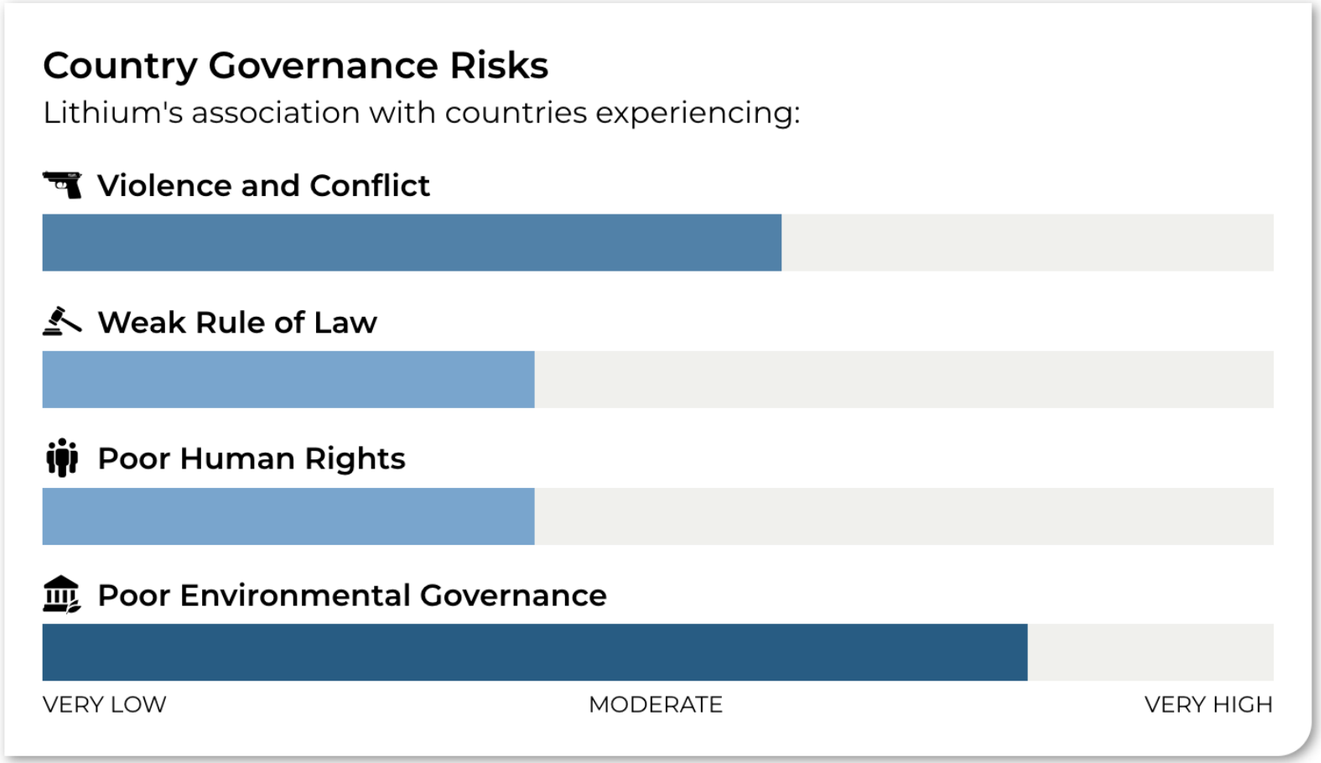
Waste

- **To produce one ton of lithium, it is necessary to mine 250 tons of spodumene or 750 tons of mineral rich brine**[25]
- By contrast, secondary production would require only 28 tons of used LiBs (around 256 used electric-vehicle LiBs)[23]
- In overall, only 6% of the total amount of lithium compounds extracted is actually lithium, the remaining 94% of the resources are other substances that will end up as waste[4]
- **In addition, during lithium production, a high amount of lithium slag is generated as industrial waste and stacked open, causing environmental pollution and occupying land resources**[26]

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Social Sustainability





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Protests against Lithium Mining

- **Chile**: A 2021 Human Rights Impact Assessment identified serious impacts to human rights of the indigenous Lickanantay people and SQM's prolonged operations in the Atacama Salt Flat. Such harms include, among others, **impositions on traditional lands, loss of water sources for household use, loss of traditional breeding and farming activities, and a lack of appropriate remedies**[35]
- **China**: Several years of active mining triggered concerns and protests from local villagers who alleged that the mine spawned toxic chemical pollution that led to fish kills and the death of yaks that drank water from the nearby Liqi River. The company denied that the environmental damages were related to the mine's operations. **The government responded to the protests with security crackdowns**[5]

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Protests against Lithium Mining (cont.)

- **Portugal:** A project proposal in a northern municipality was canceled after intense local controversy and concerns about the quality of the environmental impact assessment commissioned by the developer. The group fears that the project would damage the region's farm and tourism sectors and see risks to water flows in nearby mountain streams and runoff of pollutants. More generally, **the group argues that "Green mining doesn't exist. Politicians need to stop trying to get rid of pollution in cities by polluting our villages instead"**[5]
- **USA**: The Big Sandy lithium project is a proposed open-pit lithium mine on the homelands of the Hualapai Nation in Arizona, USA. Exploratory drilling encroached within 700 feet of Ha'Kamwe: a medicinal hot spring on Hualapai sovereign, sacred land. They report **the flow of water from their well, "is now only a trickle compared to what it used to be"**. They were not consulted prior to exploratory drilling that occurred in 2018-19[36]

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Lithium Recycling Today

- **Less than 1% of lithium is currently recycled**[2]
- **The majority of mined lithium is still in use**, for example, as LIBs[2]
- Lithium-ion batteries last for 15–20 years, 3 times longer than the 5–7 years for lead- acid batteries[27]
- **The remaining ~20%** used in products such as lubricants, greases, rubber, and pharmaceuticals[2] **is considered dissipative** and assumed to end up as waste[4]
- **Current recycling of lithium battery systems is mainly targeted towards the recovery of cobalt, copper and nickel**[28] due to the prices of those materials
- The high reactivity of Li towards oxygen and nitrogen has been the major reason why Li anode production residues are not recycled[33]
- The lithium content of spent LIBs is approximately 10 times that of primary lithium ore and 30 times that of lithium chloride salts found in brine pools[29]

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Comparison of different LiB recycling methods



	Technology readiness	Complexity	Quality of recovered material	Quantity of recovered material	Waste generation	Energy usage	Capital cost	Production cost
Pyrometallurgy	●●●●●	●●●●●	●	○○○	●●	●	●	●●●●●
Hydrometallurgy	●●●●	○○○	○○○	●●●●	○○○	○○○	○○○	○○○
Direct recycling	●●	●	●●	●●●●●	●●●●	○○○	○○○	●

	Presorting of batteries required	Cathode morphology preserved	Material suitable for direct re-use	Cobalt recovered	Nickel recovered	Copper recovered	Manganese recovered	Aluminium recovered	Lithium recovered
Pyrometallurgy	●●●●●	No	No	●●●●●	●●●●●	●●●●●	○○	No	●
Hydrometallurgy	●●●●	No	No	●●●●●	●●●●●	●●●●	○○○	●●●●●	○○○
Direct recycling	●	●●●●●	●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●

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Direct Battery Recycling

- **Direct recycling reuses reconditioned anode and cathode material removed from electrodes for remanufacturing**[25]
- In parallel to reusing the battery cathodes, it is necessary to restore the amount of lithium to its initial level to counter lithium loss due to material degradation[25]
- The direct recycling process eliminates expensive and lengthy purification processes[25]
- However, the direct recycling process has some challenges and obstacles:
  - batteries with a low state of health are less advantageous to recycle
  - most efficiency comes when based on specific cathode formulation
  - contamination with other metals in the cathode makes the direct recycling method highly sensitive and affects the electrochemical performance[25]
- **One of the major challenges with direct recycling methods is the need for manual disassembly, which creates safety risks for the workers**[34]

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Should Batteries Always be Recycled? Cell Chemistries Matter

- The lithium content of spent LIBs is approximately 10 times that of primary lithium ore and 30 times that of lithium chloride salts found in brine pools[29]
- **Most recycling routes for lithium-ion batteries appear to reduce the net GWP compared to production – especially for nickel- based chemistries**[30]
- Studies on hydrometallurgical recycling of nickel-based batteries show a reduction of net impacts by 25-41%[30]
- However, pyrometallurgical and hydrometallurgical **recycling of LFP and LMO LIBs has benefits which don't outweigh recycling process impacts**[30]
- Part of this reason is that LFP has a more environmentally friendly production process in the first place[10]
- Especially for the final hydrometallurgical treatment, **the process would need to be adapted to the cell chemistry, to obtain maximum environmental benefit**[31]

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Process Company	Forms of Output Materials				
	Co	Li	Fe	Al, Cu Foils	Loses
Umicore Valéas™	$CoCl_2$	x	Recovered in alloy	Recovered in alloy	Al, polymer
Sumitomo-Sony	CoO	x	Recovered in alloy	Recovered in alloy	Al, polymer
Retriev Technologies	MeO + cake	Li_2CO_3	Recovered in shaking table	Not specified	Not specified
Recupyl Valibat	LCO/$Co(OH)_2$/Co	Li_2CO_3/ Li_3 PO_4	Recovered with magnetic separator	Al, Cu recovered with density separation	Not specified
Akkuser	Co + graphite	x	Recovered with magnetic separator	Al, Cu recovered from fin powder	Al fraction
Accurec	Co alloy	Li_2CO_3	Recovered via air filtration	Al, Cu recovered via air separator, Al via leaching	Polymer
Battery Resources	$NMC(OH)_2$	Li_2CO_3	Recovered with magnetic separator	Cu recovered via dense media separation and precipitation	Not specified
LithoRec	MeO	Li_2CO_3/ LiOH	Recovered via air filtration	Al, Cu recovered via sieves and zig-zag sifter	Not specified
OnTo	Cathode powder (refurbished)	Li_2CO_3/ cathode	Recovered, not specified	Recovered, not specified	Not specified

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Summary

- Lithium's recent rapid growth in use in Lithium Ion Batteries (LIB) makes the future supply and demand of the element difficult to predict
- The most economic lithium resources are concentrated in Chile (as well as Argentina and Bolivia) and Australia
- Lithium comes from both hard-rock and brine sources, both of which have similar negative environmental impact
- In particular, there is a concern with high water use in arid regions where the brines are located, and the subsequent impacts it could have on biodiversity and humans
- Protests around opening lithium mines have occurred around the world; questions of "green sacrifice zones" have arisen where local populations (often indigenous) are being asked to sacrifice their land and lives to support the transition to green technologies such as electric vehicles elsewhere
- LIB recycling can be ~25-40% more beneficial than virgin production but it depends on the battery cell chemistry
- Today, not all LIB recycling operations are recovering lithium (but instead cobalt, nickel, and others), due to both prices and the chemistry challenges with lithium itself (which is highly reactive)

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Thank you

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