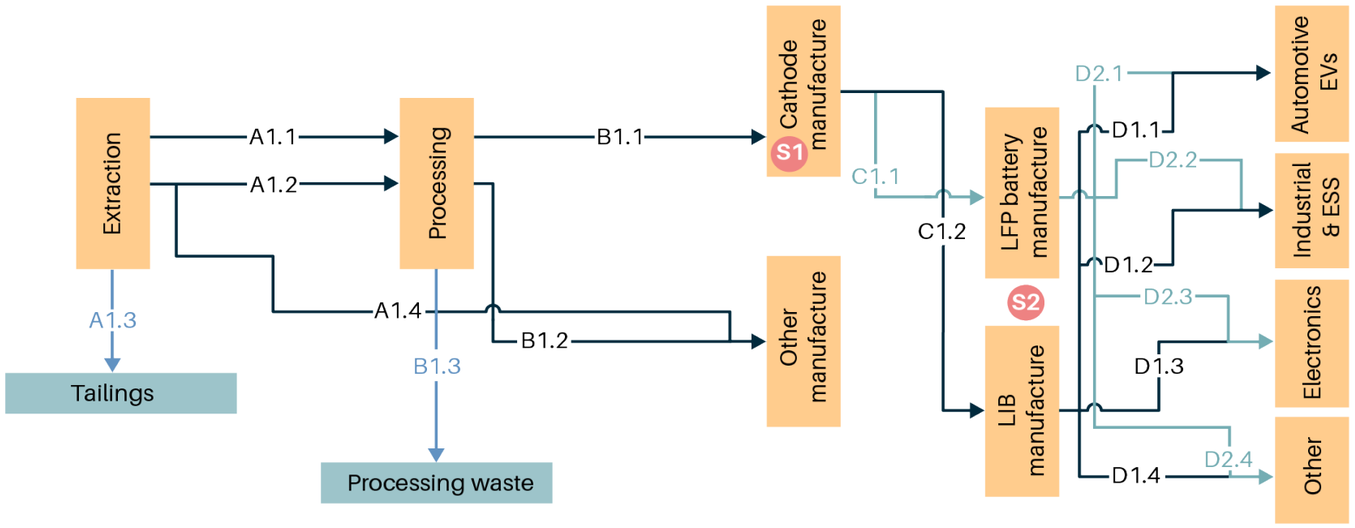
**Lithium system**




A1.1 Lithium brine production
A1.2 Lithium mineral production
A1.3 Mine waste production
A1.4 Lithium (other grades) feeding into other manufacture
B1.1 Production of lithium compounds battery grade
B1.2 Production of other grades of lithium
B1.3 Processing waste
C1.1 LFP cathodes
C1.2 LIB cathodes (all chemistries)
D1.1 LIB batteries in electric vehicles
D1.2 LIB batteries in enery storage & industrial uses
D1.3 LIB batteries in electronic devices
D1.4 LIB batteries in other applications
D2.1 LIB LFP batteries in electronic vehicles
D2.2 LIB LFP batteries in ESS & industrial uses
D2.3 LIB LFP batteries in electronics
D2.4 LIB LFP batteries in other applications

Material flows
LFP material flows
Waste flows
System boundaries

Stocks
S1 S2

| | Value | Unit | Year | Geographical cover | Data source | Type of data | Comments |
|---|---|---|---|---|---|---|---|
| **EXTRACTION** | | | | | | | |
| A0.0.1 Average pumping rate of brine extraction in Salar de Ata | 1.5 | m3/sec | 2018 | Atacama, Chile | [OS] 14 | [OS] -Original source | Based on figures reported for 2018 in Figure 4 of this paper. |
| A0.0.2 Gross daily lithium brine extraction - Chile | 129,600 | m3 | 2018 | Atacama, Chile | [E] 13 | [E] - Estimate | Based on A 0.0.1. Multiplied by 60(sec)*60(min)*24hr to produce a daily figure |
| A0.0.3 Gross annual lithium brine extraction - Chile | 47,304,000 | m3 | 2018 | Atacama, Chile | [E] 13 | [E] - Estimate | Based on A 0.0.2. Multiplied by 365 days to produce an annual figure |
| A0.0.3 Gross annual lithium brine extraction-Chile | 57,143,232 | tonnes | 2018 | Atacama, Chile | [E] 13 | [E] - Estimate | Based on A0.0.3. Calculated by multiplying A 0.0.3 by the average brine density 1208 kg/m3 and changing to tonnes. |
| A0.0.4 Gross annual lithium brine extraction - Chile | 47,429 | t Li | 2018 | World but based on Atacama brine extraction figures | [E] 5, 13 | [E] - Estimate | Calculated by multiplying A 0.0.3 by the average Li concentration in brine 0.083% wt. The average brine concentration calculated based on the Munk et al 2016 paper is estimated at around 0.5 g/l. However, this includes the majority of known salars, many not producing as yet. The producing sites tend to have concentrations higher than this ranging between 0.5g/l to 1.5 g/l. We therefore assumed that a realistic brine concentration would be somewhere in the middle of these too figures and converted this to wt %. - 0.083% |
| A0.0.5 Ratio of gross lithium brine extraction to lithium carbonate production | 2.50 | Ratio | 2019 | Chile | [E] based 13, 2 | [E] - Estimate | Brine extraction (well) to lithium carbonate extraction ratio calculated using the SQM data as a basis divided by the Chile Li production figure (18,948 tLi) recorded by source 2. |
| A1.0 Gross lithim brine production (mine) | 72,769 | t Li | 2018 | World | [E] based on 2, 13 | [E] - Estimate | Calculated by using the generic ratio estimated in A0.0.5 This equals to 2.5 t Li brine required to produce 1t Li of Li2CO3 . |
| A1.1 Lithim brine production (mine - concentrated) | 36,385 | t Li | 2018 | World | [E] based on 2 | [E] - Estimate | This represents the Li rich brine concentrated at the end of the evaporation process and an assumed average recovery efficiency of 50% |
| A1.2 Lithium hard rock mineral production (spodumene) | 66,049 | t Li | 2018 | World | [OS] 2 | [OS] -Original source | This represents the spodumene production only. We assume that it all goes into the battery market. |
| A1.3(i) Tailings lithium mineral production (mine) | 26,420 | t Li | 2018 | World | [E] based on 2, 4, 6, 7, 8 | [E] - Estimate | Assuming average recovery of 60%; source 6, 7, 8 |
| A1.3(ii) Waste brine production (mine) | 36,385 | t Li | 2018 | World | [E] based on own notes from field t | [E] - Estimate | Assuming average efficiency of 50%, although depending on the operation this figure can vary from 30% to 70%. This is by no means all waste, because throughout the evaporation process different minerals are extracted and processed for industrial production e.g. KCl, KNO3 etc. In this case we simplify our approach and assume that this material flow is waste as no more lithium is revovered. Also in many operations there is reinjection of brine taking place, which means that between 10 to 20% of the extracted brine is reinjected into the salar. However, this is not a universal practice . |
| A1.3 Mine waste production | 62,804 | t Li | 2018 | World | [E] A1.3(1) plus A1.3(ii) | [E] - Estimate | A1.3(i) and A1.3(ii) |
| A1.4 Lithium hard rock (non-spodumene) feeding into other manufacture | 1,984 | t Li | 2018 | World | [OS] 2 | [OS] -Original source | From BGS World Mineral Statistics |
| **PROCESSING** | | | | | | | |
| B1.0.1 Production of lithium carbonate (from brine) | 29,072 | t Li | 2018 | | [OS] 2 | [OS] -Original source | From BGS World Mineral Statistics; We assume that the total lithium brine production is convenrted into lithium carbonate. Currently lithium brines are converted into lithium carbonate prior to being changed into different compounds. |
| B1.0.2 Production of lithium carbonate (from hard rock) | 56,142 | t Li | 2018 | World | [E] based on 2, 4 | [E] - Estimate | Assumes an average recovery rate of Li2CO3 from spodumene to be 85%; We assume that the total spodumene production is going towards lithium carbonate production. |
| B1.0 Production of lithium carbonate TOTAL | 85,214 | t Li | 2018 | World | [E] based on 2, 5 | [E] - Estimate | Sum of B1.0.1 and B1.0.2 |
| B1.1 Production of lithium compounds for the battery market - gross | 39,198.26 | t Li | 2018 | World | [E] based on 2, 3 | [E] - Estimate | Based on battery market share for Li carbonate to be a flat rate of 46% (based on USGS data). This is a gross figure |
| B1.1.1 Production of lithium compounds for the battery market - net | 20,710.67 | t Li | 2018 | World | [E] based on B1.1 and S1 | [E] - Estimate | Estimating by subtracting the gross lithim compounds production figure (B1.1) from the estimated stock figure. |
| B1.2 Production of other lithium compounds | 46,015.35 | t Li | 2018 | World | [E] based on B1.0 and B1.1 | [E] - Estimate | Deduction of lithium carbonate battery grade from the total lithium carbonate |
| B1.3.1 Processing waste from lithium carbonate brine production route | 7,313 | t Li | 2018 | World | [E] based on A1.0 | [E] - Estimate | The residual figures equal the concentrated brine entering the lithium carbonate production (A1.0) minus the lithium carbonate produced from brine (B1.0.1). |
| B1.3.2 Processing waste from lithium carbonate hard rock production | 9,907 | t Li | 2018 | World | [E] based on B1.0.2 and A1.2 | [E] - Estimate | The residual figures equals the spodumene concentrate entering the lithium carbonate production process (A1.2) minus the lithium carbonate produced from hard rock (B1.0.2). |
| B1.5 Processing waste | 17,220 | t Li | 2018 | World | [E] B1.5.1 plus B1.5.2 | [E] - Estimate | This is the sum of B1.3.1 and B1.3.2 |
| **CATHODE MANUFACTURE** | | | | | | | |
| C1.0.1 Global LIB cathode production | 350,000 | t cathode | 2018 | World | [OS] 12 | [OS] -Original source | Estimated based on a CAGR of 14% reported by source 12 for 2016 |
| C1.0.2 Global LFP cathode production | 133,000 | t cathode | 2018 | World | [E] based on C1.0.1, 12, 10 | [E] - Estimate | Figure calculated based on the 2018 reported tonnage by 12 and the cathode materials shares (LFP 38%) reported by 10 for 2018 |
| C1.1 Global LIB cathode production | 20,711 | t Li | 2018 | World | [E] based on C1.0.1, 12, 10 | [E] - Estimate | Estimated based on source 12 and stoichiometric calculation of different cathode chemistries and their market shares given by source 10 |
| C1.2 LFP cathode manufacture | 5849 | t Li | 2018 | World | [E] based on C1.0.2 | [E] - Estimate | Estimated based on stoichiometry of LFP (LiFePO4) and the global 2018 LFP production figure. The mass percentage of lithium equals to 4.437% based on stoichiometry. |
| C1.1.1 Other LIB cathode manufacture (excl. LFP) | 14862 | t Li | 2018 | World | [E] based on C1.0.1, C1.1 | [E] - Estimate | Estimated by subtracting the global LFP cathode production (C1.1) from the global LIB cathode production (C1.0.1) |
| S1: Stock of lithium cathode compounds | 18488 | t Li | 2018 | World | [E] based on mass balance | [E] - Estimate | We estimate this by mass balance. We assume that the difference between input flow to output flow corresponds to stocks of lithium compounds for cathode materials. It is very likely that some of this material corresponds to manufacturing waste, but no data to estimate this material flow has been found. |
| **LFP BATTERY MANUFACTURE** | | | | | | | |
| D1.0.0 All LIB sold | 14940 | t Li | 2017 | World | [E] based on 12, 11 | [E] - Estimate | Estimated based on GWh of LIB sales reported for 2017 (125 GWh). Assumed an average Li content of 0.12 kg/Kwh |
| D1.0 All LIBs sold | 18674 | t Li | 2018 | World | [E] based on D1.0.0 and 12 | [E] - Estimate | Estimated based on the D 1.0.0 figure and an average CAGR of 25%, as reported by 22. Assumed an average Li content of 0.12 kg/KWh |
| D1.1 LIBs used in automotive battery manufacture | 12334 | t Li | 2018 | World | [E] based on 1, 11 | [E] - Estimate | Estimated based on the 2018 battery demand figures provided by source 1 and source 11 data on battery metal content |
| D1.2 LIBs used in Industrial, ESS | 934 | t Li | 2018 | World | [E] based on D1.0, 12 | [E] - Estimate | Estimated using the 2018 LIB all sales market calculation and the market shares for LIB sales provided by source 12 |
| D1.3 LIBs used in electronic devices | 4855 | t Li | 2018 | World | [E] based on D1.0, 12 | [E] - Estimate | Estimated using the 2018 LIB all sales market calculation and the market shares for LIB sales provided by source 12 |
| D1.4 LIBs used in other applications | 2241 | t Li | 2018 | World | [E] based on D1.0, 12 | [E] - Estimate | Estimated using the 2018 LIB all sales market calculation and the market shares for LIB sales provided by source 12 |
| D2.0 LIB with LFP cathodes all markets | 7,096 | t Li | 2018 | World | [E] based on D1.0 | [E] - Estimate | |
| D2.1 LIB LFP in Automotive | 4628 | t Li | 2018 | World | [E] based on 9 and D2.0 | [E] - Estimate | Estimated by multiplying the market share (65%) of the individual sector estimated for 2020 by D2.0 |
| D2.2 LIB LFP in Industrial & ESS | 1543 | t Li | 2018 | World | [E] based on 9 and D2.0 | [E] - Estimate | Estimated by multiplying the market share (22%) of the individual sector estimated for 2020 by D2.0 |
| D2.3 LIB LFP in Electronics | 617 | t Li | 2018 | World | [E] based on 9 and D2.0 | [E] - Estimate | Estimated by multiplying the market share (9%) of the individual sector estimated for 2020 by D2.0 |
| D2.4 Other | 309 | t Li | 2018 | World | [E] based on 9 and D2.0 | [E] - Estimate | Estimated by multiplying the market share (4%) of the individual sector estimated for 2020 by D2.0 |

| Data source No | Title | URL |
|---|---|---|
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| 2 | BGS World mineral production | https://www2.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html |
| 3 | USGS  Mineral Statistics  - Lithium. Mineral Commodity Summaries | https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/lithium/mcs-2018-lithi.pdf |
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