# Follow-up feasibility study on sustainable batteries under FWC ENER/C3/2015-619-Lot 1

TASK 4 Report

Sustainable sourcing

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**ABBREVIATIONS**

| Abbreviations | Descriptions |
|---|---|
| APAC | Asia Pacific |
| ASM | Artisinal and Small Scale Mining |
| BEB | Battery Electric Busses |
| BEPV | Battery Electric Passenger Vehicles |
| BEV | Battery Electric Vehicle |
| BGS | British Geoligical Survey |
| BMS | Battery Management System |
| BOM | Bill of Materials |
| Cd | Cadmium |
| CRM | Critical Raw Materials |
| DRC | Democratic Republic of Congo |
| EC | European Commission |
| ED | Ecodesign Directive |
| ELR | Energy Labelling Regulation |
| EMEA | Europe, Middle-East and Africa |
| EPI | Environmental Performance Index |
| EU | European Union |
| EV | Electric Vehicle |
| FTE | Full Time Employee |
| Hg | Mercury |
| ILO | International Labour Organisation |
| IRMA | Initiative for Responsible Mining Assurance |
| LCE | lithium carbonate equivalent |
| LCO | Lithium-ion Cobalt Oxide |
| LFP | Lithium-Ion Phosphate |
| LIB | Lithium ion battery |
| Li-Cap | Lithium-ion Capacitor |
| LiPF | lithium hexafluorophosphate |
| LMNO | Lithium-Ion Manganese Nickel Oxide |
| LMO | Lithium-Ion Manganese Oxide |
| LTO | Lithium-Ion Titanate Oxide |
| MEErP | Methodology for Ecodesign of Energy related Products |
| NCA | Lithium Nickel Cobalt Aluminium |
| NiCd | Nickel-Cadmium |
| NiMh | Nickel-Metal hydride |
| NMC | Lithium-ion Nickel Manganese Cobalt Oxide |
| OECD DDG CAHRA | The OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High Risk Areas |
| OECD DDG for RBC | OECD Due Diligence Guidance for Responsible Business Conduct |
| OPC | Open Public Consultation |
| Pb | Lead |
| PHEB | Plug-in Hybrid Electric Busses |
| PHEPV | Plug-in Hybrid Electric Passenger Vehicles |
| SME | Small and Medium sized Companies |

| | |
|---|---|
| UBA | The German Environment Agency |
| UN | United Nations |
| USGS | US Geological Survey |
| WGI | Worldwide Governance Indicators |

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# 1. Aim of Work package 4

The aim of Task 4 is to identify and assess high risk raw materials used in batteries, by analysing their supply chains. Specifically risks to environment and people.

The general aim of this study is to support developing of a new internal market Regulation for batteries[1], which means; to set the performance and sustainability criteria that batteries will have to comply to be placed on the EU market. This may eventually be combined with the revision of the battery directive.

Task 4 investigates the possibility to set requirements related to the sustainable sourcing of some raw materials for the production of batteries.

Some precedents exist in the EU to regulate social, ethical and legal aspects of raw materials being imported in the internal market, such as the EU Timber Regulation and the Conflict Minerals Regulation.

The OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High Risk Areas describes how companies can identify and better manage risks throughout the entire mineral supply chain.

The purpose of this task is to analyse the feasibility of applying the regulatory principles laid out in the regulations and guidance documents mentioned above to the sustainable and responsible sourcing of the raw materials that are used in the production of batteries. Other relevant non-regulatory initiatives and approaches are considered as well.

This task provides an indication of which raw materials used in the manufacturing of rechargeable batteries with internal storage may conflict with widely accepted social and environmental standards in their extraction and supply. All main raw materials for batteries (cobalt, lithium, nickel, manganese, natural graphite and others) are looked at but with special focus on cobalt. The analysis is backed by figures on market volumes and geographic origin, where possible.

An analysis of all possible associated costs (e.g., administrative burden due to reporting or cost of monitoring by national authorities), as well as the possible benefits for society, will be included.

Key challenges:

- To assess the future needs of the raw materials, which may have issues to comply with social, ethical and legal aspects, because battery technologies are continuously in development and the market as well.
- To assess the costs and impacts of regulatory measures including the enforcement for a supply chain often starting in countries far away from EU, which effect therefore may be more uncertain compared to requirements being able to enforce and verify in EU.

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[1] http://europa.eu/rapid/press-release_IP-18-6114_en.htm, D. Linden and T. Reddy, “Handbook of batteries,” 1865, D. Linden, *Lithium-Ion Batteries*. 2002

# 2. Definition of sustainable sourcing

Sustainability as a term is used in many different contexts, and often with different meanings. For a long time, sustainability has been viewed as solutions that consider both people, planet and profit. In other words, it needs to protect the environment and people and their living conditions without being at an excessive cost that renders the solution uneconomic or impossible to sell in case of products.

However, with the adoption of the 17 sustainable development goals (shown in Figure 1) and 169 targets[2] this approach became more nuanced and specific. As written in the preambles of the decision the goals are "are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social and environmental."


*Figure 1: The 17 sustainable development goals*

Hence instead of seeing the three (where social, economic, and ecological development) as separate, economies and societies are seen as embedded parts of the biosphere, and "the economy serves society so that it evolves within the safe operating space of the planet"[3].

For the purpose of this study the meaning of sustainable sourcing therefore builds on the sustainable development goals. Based on this, the following specific focus areas have been identified as important to ensure sustainable sourcing of materials for batteries:

- Political stability and avoidance of corruption
- Regulatory compliance
- Human health and human rights including

[2] https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf
[3] https://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.htm

  - Fair remuneration and benefit sharing
  - Local land rights and land grabbing
- Working conditions including
  - Child labour
  - Labour rights and social risks
- local and global environmental protection including
  - Climate change
  - Any negative impacts on air, water or soil ecosystems
- avoidance of child labour

# 3. Identification of the relevant raw materials

The starting point for identifying relevant raw materials in battery supply chains is the raw materials listed in the BOM (Bill Of Materials) for batteries listed in the preparatory study. Data was collected for the markets and sustainability risks of each material. Based on this data the raw materials with the highest risks related to the focus areas listed in section 2, was short-listed.

## 3.1 Methodology

Nine raw materials have been identified in the preparatory study to be important in the production of Li-ion batteries for EVs:

- Cobalt
- Nickel
- Lithium
- Manganese
- Aluminium
- Iron
- Copper
- Phosphorus
- Graphite

The following sections provide a brief introduction to each raw material and present quantitative and qualitative data covering production, end-use, forecast and reserves, governance, environment, human health and working conditions. The methodology behind each theme and why they are relevant will be described below.

### 3.1.1 World production

The production data corresponds to the average global yearly production in the period 2013-2017. Data is primarily covering the initial sourcing country where the raw material has been mined. It should be noted that official data doesn't include sources from artisanal and small-scale mining (ASM). ASM is only relevant for some raw materials, for which it will be highlighted under each, where relevant. For raw materials where locations of refining and further processing are particularly relevant this have been included. Data are primarily acquired from British Geological Survey (BGS) and their World Mineral Production publication for 2013-2017[4]. Data for some minerals has been supplemented by data from World Mining Data[5]. The actual source of production data has been stated under each mineral.

### 3.1.2 End-use

In this section a general overview of the typical end-uses for the specific raw material is given. However, the overall purpose is to determine how large a share of the global production is consumed by the EV battery industry. Most statistics covering end-use do not distinguish

[4] https://www.bgs.ac.uk/mineralsUK/statistics/worldStatistics.html
[5] https://www.world-mining-data.info/

between the different battery types and whether they are used for EVs or other purposes. Table 1 gives an overview of the five dominant battery types, its prevailing applications and its overall market share. The three battery types used for EVs (LMO, LFP and NMC) constitute 70% of the market. For cobalt specifically, data has been adjusted according to the cobalt content for each battery. For the other four metals it has been assumed equal.

*Table 1: Types of lithium ion battery chemistries with a description of their properties and applications (source: JRC (2018) Cobalt demand-supply balances in the transition to electric mobility)*

| Name | Abb. | Cobalt content | Market share | Properties and applications |
|---|---|---|---|---|
| Lithium Cobalt Oxide | LCO | 60% | 21% | High capacity. Mobile phones, tablets, laptops, cameras |
| Lithium Manganese Oxide | LMO | no Co | 8% | Safest; lower capacity than LCO but specific power and long life. Power tools, e-bikes, EVs, medical devices. |
| Lithium Iron Phosphate | LFP | no Co | 36% | |
| Lithium Nickel Manganese Cobalt Oxide | NMC | 10-30% | 26% | |
| Lithium Nickel Cobalt Aluminium Oxide | NCA | 10-15% | 9% | High capacity; gaining importance in electric powertrain and grid storage; industrial applications, medical devices |

### 3.1.3 Forecast and reserves

This section is intended to give a brief overview of the trend in supply and demand for each raw material. It is based on desktop research and comes primarily from market reports and industry insights.

### 3.1.4 Governance

The Worldwide Governance Indicators (WGI) project constructs aggregate indicators of six broad dimensions of governance[6]:

1. Voice and Accountability
2. Political Stability and Absence of Violence/Terrorism
3. Government Effectiveness
4. Regulatory Quality
5. Rule of Law
6. Control of Corruption

The six aggregate indicators are based on over 30 underlying data sources reporting the perceptions of governance of a large number of survey respondents and expert assessments

[6] https://info.worldbank.org/governance/wgi/Home/Reports

worldwide. Details on the underlying data sources, the aggregation method, and the interpretation of the indicators, can be found in the WGI methodology paper[7].

A score for each indicator between -2.5 and +2.5 has been applied to every country in the World. The lower the number, the weaker (poorer) the level of governance in the specific country and conversely the higher the number, the stronger (better) the level of governance.

This assessment provides a weighted score for each mineral for each indicator based on each country's share of World production. Furthermore, it only covers the sourcing countries where the metal has been mined – it does not include countries where the metal has been refined or further processed.

Another index presented for each raw material is the Environmental Performance Index (EPI) which ranks 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality[8]. The German Environment Agency (UBA) has weighted the EPI score according to each country's share of global mine production and classified each raw material into three groups of environmental hazard potential – low (best), medium and high (worst)[9].

### 3.1.5 Environment, human health and working conditions

Each raw material has been rated using a qualitative approach determining the risk of problematic working conditions and impact to environment and human health. The scale has four levels: Low, Moderate, high and very high. The rating is based on a study on material sourcing produced by Drive Sustainability, the Responsible Minerals Initiative and The Dragonfly Initiative[10].

A study by the German Environment Agency has analysed a wide range of raw materials according to 8 environmental indicators from pollution risk to water stress and aggregated them into one results on a 5-level scale: low (best); low to medium; medium; medium to high; high (worst).

The final ratings can be seen in the summarizing table (Table 11) for each of these two indicators.

Information about GHG emissions related to the life cycle of each raw material has been included the environment sections. The life cycle covers the supply chain from extraction of the ore to refined material also referred to as cradle to gate. The data in GHG emissions are given in an interval based on different datasets such as Ecoinvent 3.1,Thinkstep GaBi and GREET 2016.

[7] Daniel Kaufmann, Aart Kraay and Massimo Mastruzzi (2010). "The Worldwide Governance Indicators : A Summary of Methodology, Data and Analytical Issues". World Bank Policy Research Working Paper No. 5430

[8] Wendling, Z. A., Emerson, J. W., Esty, D. C., Levy, M. A., de Sherbinin, A., et al. (2018). 2018 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. https://epi.yale.edu/

[9] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.

[10] https://drivesustainability.org/wp-content/uploads/2018/07/Material-Change_VF.pdf

### 3.1.6 Critical Raw Material rating

EUs Critical Raw Material List was first published in 2011 and is updated every three years most recently in 2017. It evaluates a number of materials on two parameters: Supply risk and economic importance. Each parameter is rated on a numerical scale based on quantitative and qualitative analyses. Materials that has supply risk ≥ 1 AND economic importance ≥ 2.8 are categorised as Critical Raw Materials and are subject to increased attention[11].

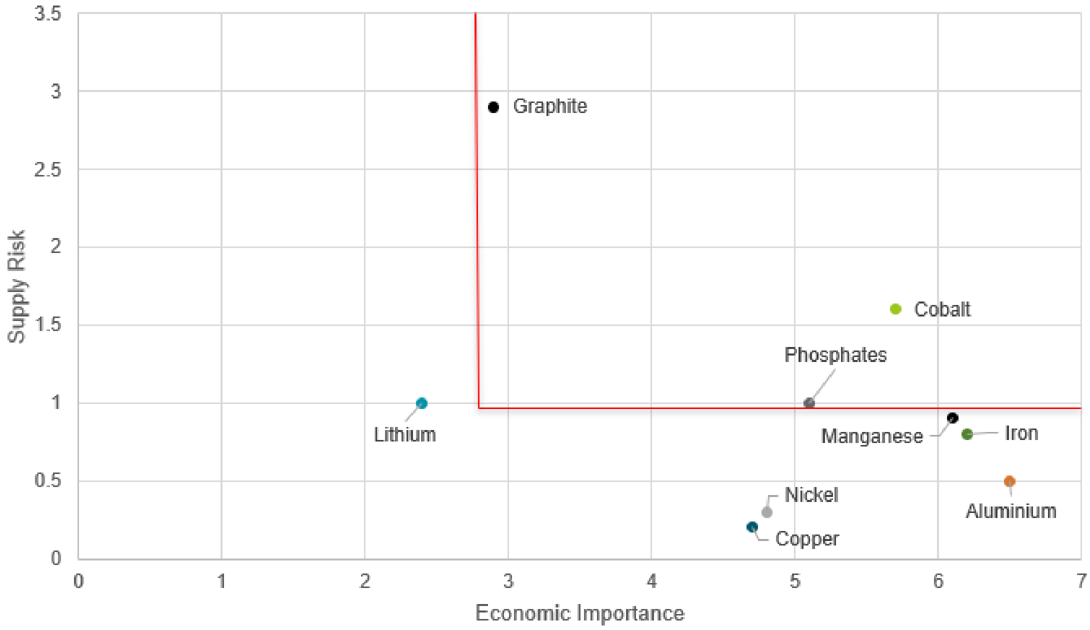


*Figure 2: EU Critical Raw Materials*

The list of critical raw materials is an important tool for the European Commission that always needs to be considered when considering any product regulation on resources. Some stakeholders have argued that this is not an important criteriar to include in the assessment because battery producers inside Europe do not buy raw materials, but rather component finished cells, and the material is not critical to cell manufacturers in for example China. However, as it is done in any Ecodesign regulation, any critical raw material that is part of a final product (where this might be produced) needs to be considered. The critical raw materials do not loose their economic importance for Europe because they are part of a product, especially of they can be recycled. Hence presence of critical raw materials in a product, will increase the benefits of a good recycling procedure within Europe. Furthermore, it is expected that a continuously larger share of batteries will be produced in Europe in the future, and therefore this criterion is important for the discussion.

[11] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

## 3.2 Cobalt

Besides lithium, cobalt is an essential component of the cathode for most types of lithium-ion batteries (LIB). Cobalt helps to stabilize the cell structure without compromising the capacity and is critical in increasing the rate performance – the rate at which the power is delivered – which is especially important for batteries used in electric vehicles.[12]

However, cobalt is suffering from a range of issues related to limited supply concentrated to only a few countries and social and environmental problems associated with the mining activities. Furthermore, it has been added to the EUs critical raw materials list with a high level of economic importance and a medium level of supply risk (see Figure 2)[13].

### 3.2.1 World cobalt production

Cobalt is mined in 22 different countries around the world, where the far majority at 55% is mined in the Democratic Republic of Congo (DRC) The second largest producer of Cobalt is New Caledonia (French territory in the Pacific) with only 8% of the world total. Finland is the only EU country with commercial cobalt mining production, but only constitutes less than 2% of the world total (see Figure 3).

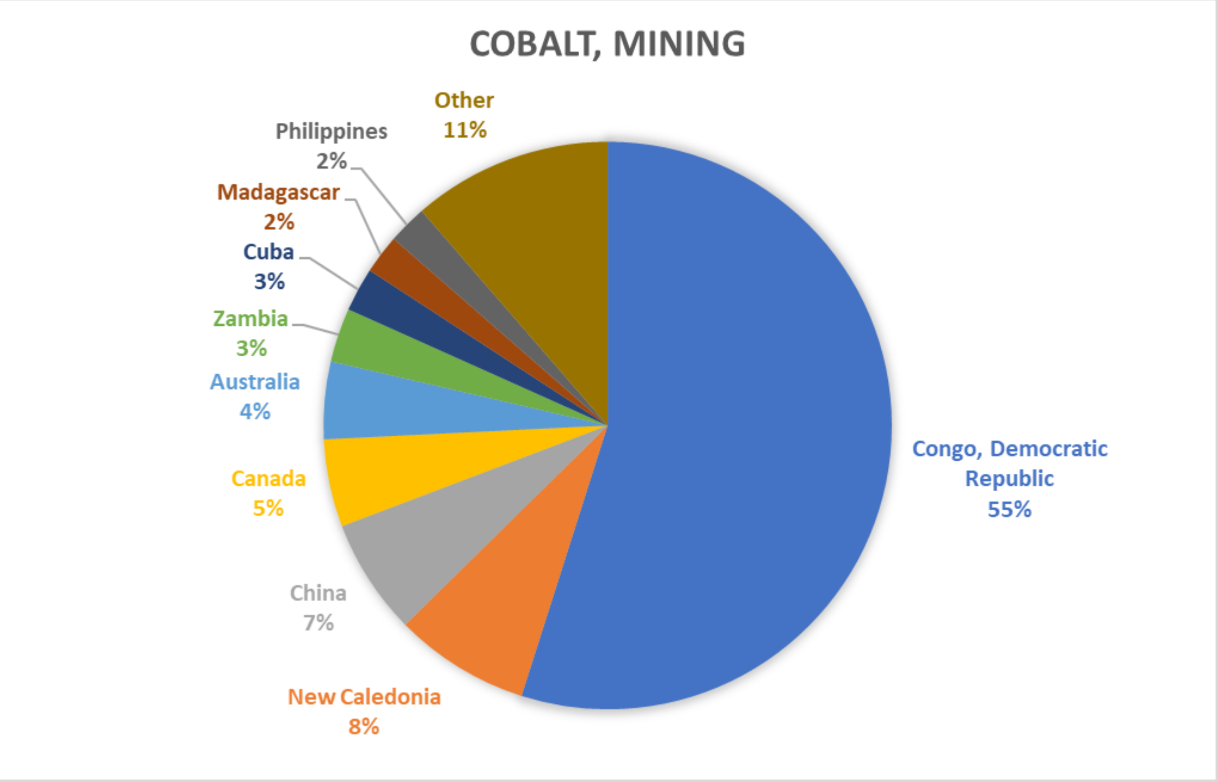


*Figure 3: Global cobalt mine production in percentage of global total based on average production in the period 2013-2017 (Source: BGS).*

[12] https://www.designnews.com/electronics-test/understanding-role-cobalt-batteries/63068579258429
[13] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

The global annual production of cobalt has on average been 141,000 metric tons in the period 2013-2017. The largest producer D.R.C. mined 82,000 metric tons of cobalt in 2017. It should be noted that ASM mining of cobalt is widespread in D.R.C. but are not included in the national statistics. According to a report by German UBA, 10-30% of cobalt is produced from ASM[14].

Cobalt is primarily mined as by- or co-product of nickel or copper mining. It is estimated that approximately 50% of global supplies of cobalt come from the nickel mining industry and 44% come from copper mining, whilst only 6% come from mining operations with cobalt as the principal commodity[15].

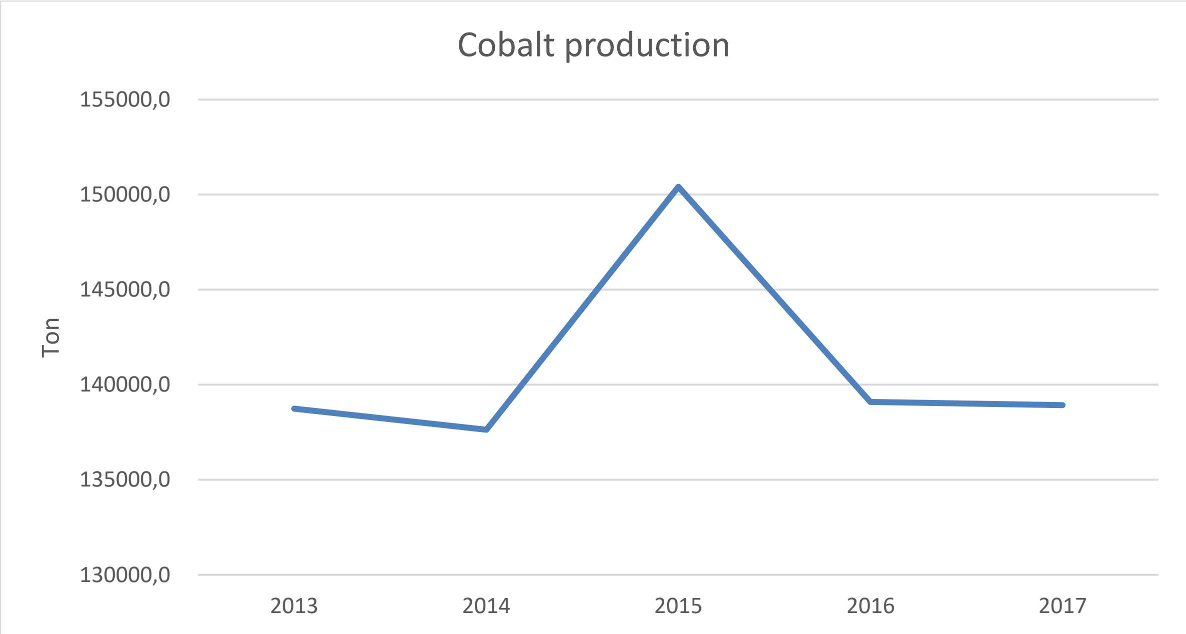


*Figure 4: Global production of Cobalt in metric tons in the period 2013 to 2017 (Source: BGS).*

### 3.2.2 End-use of Cobalt

The primary use of cobalt globally is for manufacturing of rechargeable batteries for consumer electronics and EVs at a share of 49% in 2015. The share going to EV batteries alone constitutes 9%[16]. Other uses of cobalt are in superalloys and composite materials for e.g. turbine engines and cutting tools that require high strength and resistance to high temperatures.

[14] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[15] https://publications.europa.eu/en/publication-detail/-/publication/7345e3e8-98fc-11e7-b92d-01aa75ed71a1/language-en
[16] JRC (2018) Cobalt demand-supply balances in the transition to electric mobility

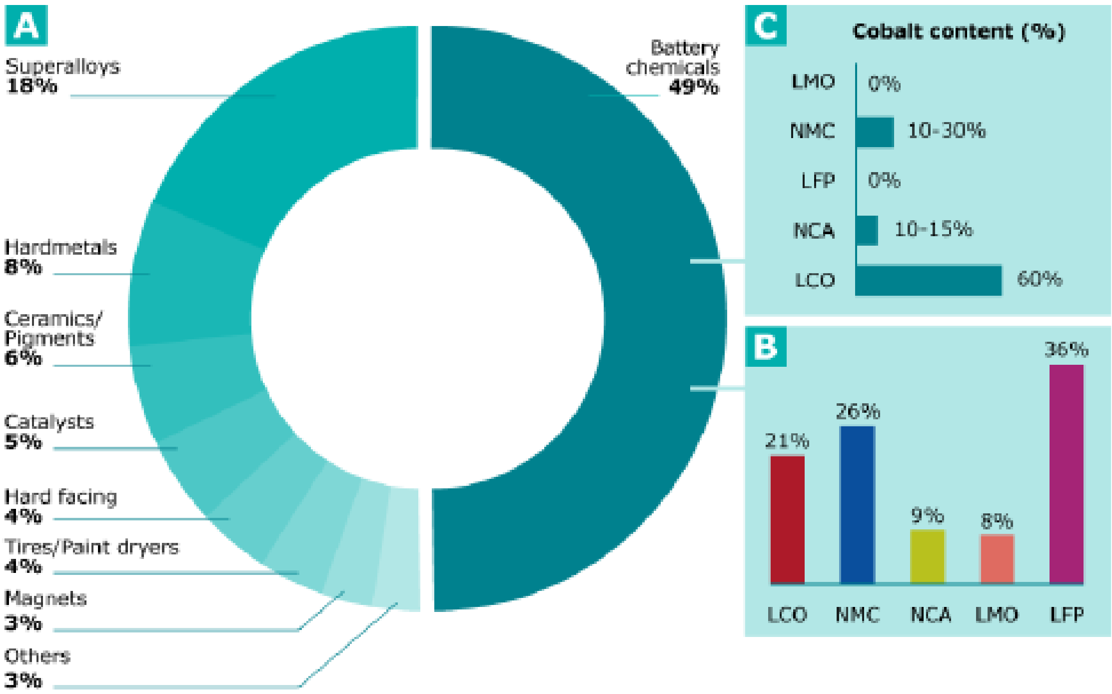


*Figure 5: End-use of global cobalt production (Source: JRC)*

### 3.2.3 Forecast and reserves

If there are no technological developments in reducing or limiting the cobalt content in EV batteries it is estimated that the global demand will increase from under 20,000 tons annually to between 300,000 and 400,000 tons in 2030[17]. 60,000 tons is estimated to be demanded by the EU in 2030[18]. Put in perspective, the annual production of cobalt is currently 134,000 tons. The global reserves have been estimated to about 12 million tons at current active mining operations. A further 5.9 million tons have been identified in exploration projects. Reserves are primarily found in D.R.C. and Australia. Since cobalt is primarily mined as a by-product of copper and nickel, its production has therefore been determined by the demand of these metals in the past and is likely to remain so for the foreseeable future. Recycling rates are also relatively low due to the complexity and low yields of recycling of raw materials from batteries[19].

### 3.2.4 Governance

The Democratic Republic of Congo, where most of the Worlds cobalt is sourced from, generally scores low on all 6 WGI indicators, thereby influencing the average weighted score on cobalt negatively (see Table 2). Cobalt producing countries scores lowest on Political Stability (-1.12) and highest on Government Effectiveness (-0.69). The average score for all 6 indicators is -0.82 and suggest poor to very poor governance.

[17] JRC (2018) Cobalt demand-supply balances in the transition to electric mobility
[18] Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1 Task 7
[19] https://batteryuniversity.com/learn/article/battery_recycling_as_a_business

*Table 2: Worldwide Governance Indicator scores for cobalt producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | -0.82 |
| Political Stability and Absence of Violence/Terrorism | -1.12 |
| Government Effectiveness | -0.69 |
| Regulatory Quality | -0.70 |
| Rule of Law | -0.88 |
| Control of Corruption | -0.72 |
| **Average score** | **-0.82** |

The weighted environmental performance index (EPI) classifies cobalt as having a high environmental hazard potential, thereby supporting the WGI score. Furthermore, ASM mining is of importance, which also influences the governance. The share of cobalt sourced from ASMs is estimated to be 10-30%[20].

### 3.2.5 Environment

Cobalt is an essential nutrient for most life, since it is part of the vitamin B-12 and is therefore common in the natural environment at varying levels. However, cobalt can become toxic to plant and animal life at elevated concentrations.

Mining, refining and processing of cobalt can lead to leakage of cobalt into the environment with the risk of reaching toxic levels. The risk of environmental contamination varies greatly depending on the type of mining and the level of measures implemented. All types of mining produce large quantities of solid and liquid waste (tailings) that need to be managed in order to avoid it being a source of contamination. Specifically, for cobalt ores, which are sulphidic (which is the majority), there is a high risk of creation of acid and potential drainage into water bodies[21]. Since small-scale artisanal mining is widespread in the DRC the risk of contamination is high for both health and environment, due absence of adequate chemical management, waste management and controlled mine closure and rehabilitation.

A more severe problem than leakage of cobalt is the leakage of several other materials found in the same deposits that are more toxic to the environment such as lead, cadmium, arsenic or radioactive metals like uranium[22]. While production in developed countries are clearly regulated regarding which chemicals can be released to waters and many chemicals are recovered and reused in the production processes, the mining operations in Africa often rely on “pollution prone technologies and the controls on the discharge of pollutants from African mines and smelters are lax or non-existent. The net result is that the air, water, soils and

[20] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[21] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[22] https://phys.org/news/2018-09-scientists-reveal-hidden-cobalt-dr.html

vegetation near the mining centres of Africa tend to be severely contaminated with toxic metals”[23].

Life cycle GHG emissions from ore to refined metal is estimated to between 1.45 and 10 kg CO2/kg cobalt[24].

### 3.2.6 Human health and working conditions

Small-scale artisanal mining is widespread in the DRC and it is estimated that about 10-30% of the cobalt exported from DRC is coming from artisanal mining. There are approximately 110,000 to 150,000 artisanal miners in the region also referred to as ‘creuseurs’. Their approach to mining is very primitive compared to the larger commercial mines. Most of the work is done by hand with primitive tools and with no or limited protection gear such as head gear, eye and face protection, respiratory protection, hearing protection, skin and foot protection.

Mining is done by children as young as seven years old who scavenge for rocks containing cobalt and is involved in washing and sorting the ore before it is being sold. It is estimated that approximately 40,000 children work in mines across southern DRC[25].

Mines are open-pit or primitively dug tunnels often located in or close to urban areas. The primitive mining operations result in release of dust containing cobalt and other metals that disperse and settle in the urban areas, thereby exposing not only the miners to toxic metals, but also their families and other residents. Research from artisanal mining regions have shown urine concentrations of cobalt and other metals 10 times higher than concentrations from a normal population.

All health effects from exposure to the toxic dust are not yet clear, but there are signs of DNA damage to the children living close to the mines and an increased risk of birth defects. Inhalation of dust containing cobalt over a long time period can result in fatal lung disease or other respiratory problems such as asthma and exposure to skin can evolve to dermatitis[26].

Also, a large share of the miners carries sacks that contain up to 50 kg of ore which result in strain and risk of long-term injury such as back problems or other physical disabilities. Lastly, miners are exposed to severe or fatal accidents due to lack of access to proper equipment, e.g. collapse of tunnels that are not supported properly. Nonetheless, there are no official statistics that provide an overview to the extent of human health effects and accidents.

## 3.3 Nickel

Nickel Cobalt Aluminium (NCA) and Nickel Manganese Cobalt (NMC) are the most widely used Li-ion batteries on the market and use 80% and 33% nickel in the cathode, respectively[27]. The advantage of nickel in battery chemistry is that it provides a higher energy density thereby increasing the storage capacity[28]. However, nickel is primarily used

[23] Dunn, J.B; Gaines, L.; Kelly, J.C.; James, C.; Gallagher, K.G. (2015). The significance of Li-ion batteries in electric vehicle life-cycle energy and emissions and recycling's role in its reduction. Energy and Environmental Science 8, 158–168.
[24] https://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf
[25] https://www.amnesty.org/download/Documents/AFR6231832016ENGLISH.PDF
[26] https://phys.org/news/2018-09-scientists-reveal-hidden-cobalt-dr.html
[27] https://www.nickelinstitute.org/media/2318/nickel_battery_infographic-finalen2.pdf
[28] https://www.nickelinstitute.org/about-nickel/nickel-in-batteries/

for stainless steel production where it provides strength, toughness and corrosion resistance at high temperatures[29].

### 3.3.1 World nickel production

Nickel is mined in 31 countries around the world, where 66% comes from five countries: Philippines, Indonesia, Russia, Australia and Canada. Nickel must undergo a comprehensive refining and smelting process before becoming pure nickel. The nickel ore is not necessarily refined in the country of origin and the largest producer of refined nickel is China with 31%[30] despite its mining share being only 4%.

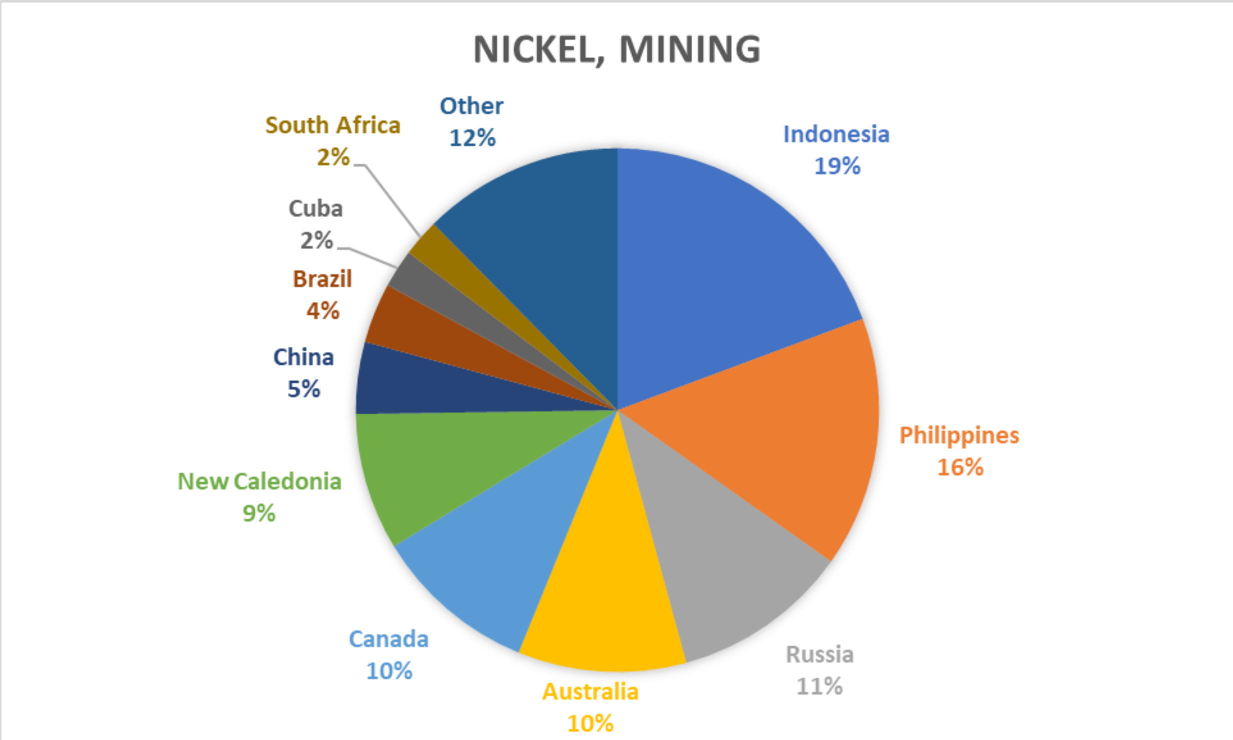


*Figure 6: World mining production of nickel (Source: BGS)*

The global annual production of nickel has on average been 2.3 million tons in the period 2013-2017. The global production has decreased 32% in the same period (see Figure 7).

[29] JRC (2018) Cobalt demand-supply balances in the transition to electric mobility
[30] EC (2017) Non Critical Raw Material Factsheet

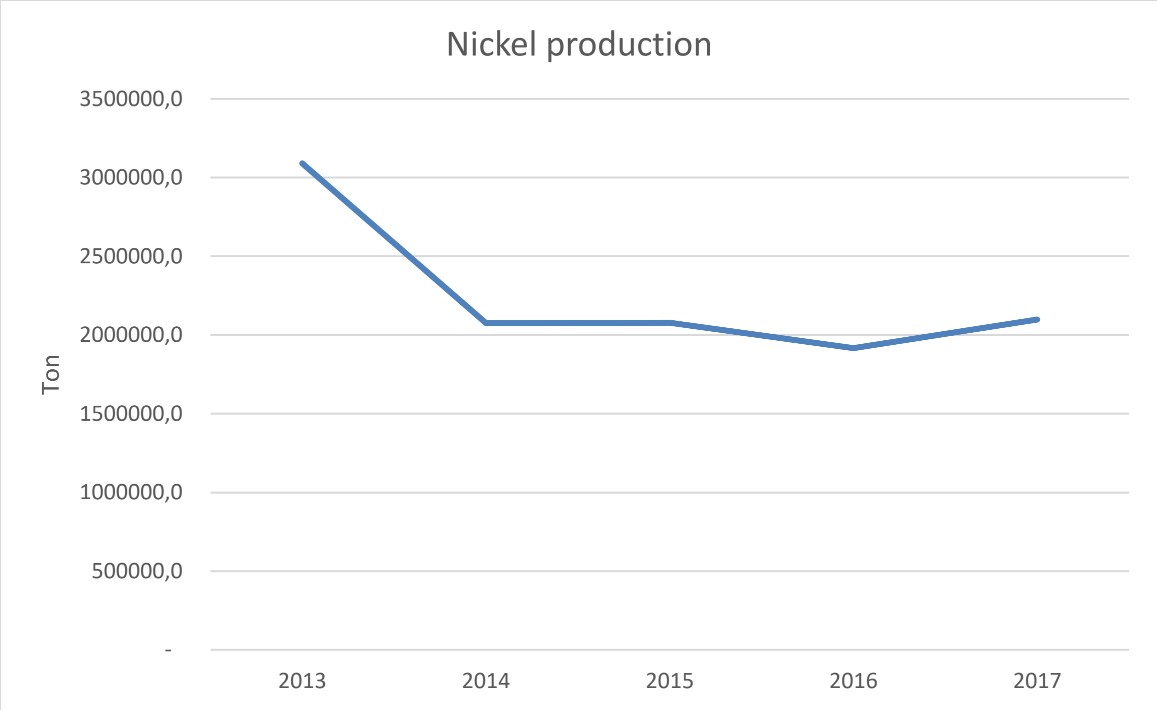


*Figure 7: Development in global nickel production*

### 3.3.2 End-use of nickel

70% of global nickel supply is used for stainless steel production where it provides strength, toughness and corrosion resistance at high temperatures. Other uses include other metal alloys and as thin layer plating on materials and equipment to increase corrosion and wear resistance[31].

Nickel consumption for batteries constitutes 6% of the global demand (see Figure 8). This primarily includes the li-ion batteries NMC and NCA. Other nickel-based batteries such as the Nickel - metal hydride battery (NiMH) constitutes a marginal market share. NMC has a market share of 26% of the li-ion battery market and is primarily used for EVs. NCA has a market share of 9% but is primarily used in industrial applications. However, the NCA contains 80% nickel whereas the NMC only contains 33%. A fair estimate of nickel demand going to EVs is therefore 3% or 66,000 tons.

[31] EC (2017) Non Critical Raw Material Factsheet

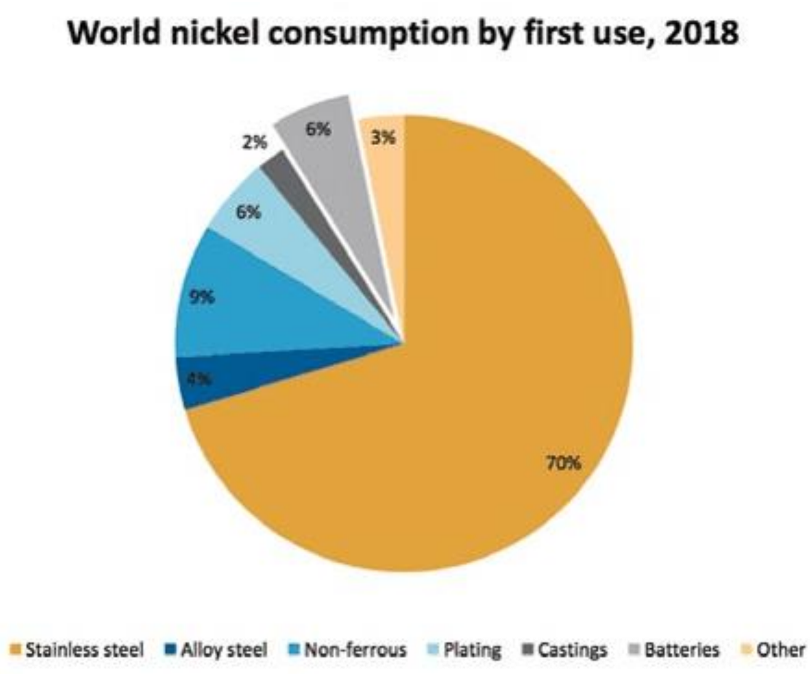


*Figure 8: End use of global nickel supply*[32]

### 3.3.3 Forecast and reserves

Global nickel reserves are estimated to 79 million ton with 27% located in Australia and Brazil, which is about 40 years of the current production rate. The demand for nickel from li-ion batteries is forecasted to increase by 16 times by 2030 to 1.8 million tons. This is 80% of the current annual production. 210,000 tons is estimated to be demanded by the EU in 2030[33]. EV battery suppliers are concerned of future nickel supply deficit mainly caused by lack of investments in new mines[34]. The timeline from exploration to a fully functioning mine can take at least a decade.

### 3.3.4 Governance

Five out of six governance indicators are positive with Government Effectiveness being the best at 0.36, as seen in Table 3. The only negative indicator is Political Stability at -0.19. This indicator is primarily influenced by the Philippines which has a score of -1.12 and is the second largest producer of nickel.

[32] https://www.theassay.com/base-metals-insight/nickels-chance-to-shine-again/
[33] Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1 Task 7
[34] https://www.bloomberg.com/news/articles/2019-08-05/there-s-one-metal-worrying-tesla-and-the-ev-battery-supply-chain

*Table 3: Worldwide Governance Indicator scores for nickel producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | 0.17 |
| Political Stability and Absence of Violence/Terrorism | -0.19 |
| Government Effectiveness | 0.36 |
| Regulatory Quality | 0.26 |
| Rule of Law | 0.07 |
| Control of Corruption | 0.10 |
| **Average score** | **0.13** |

An average WGI score of 0.13 is considered to be an intermediate level of governance, whereas the weighted environmental performance index (EPI) classifies nickel as having a low environmental hazard potential, implying a better level of governance.

### 3.3.5 Environment

Mining and refining of nickel have been associated with a range of environmental problems from leakage of mining waste into local waterways and emissions of sulphur dioxide to the air from nickel refining and smelting, which is the cause of acid rain and linked to heavy-metal contamination of water systems.

Environmental Impacts associated with nickel extraction and refining are heavily dependent on the type of extracted ore (sulfidic or lateritic), and on the type of process used (pyrometallurgy or hydrometallurgy). Lateritic ores are mainly extracted in areas which are considered hotspots of terrestrial and marine biodiversity (Indonesia, Philippines, New-Caledonia), and which are prone to erosion due to heavy rainfalls. Sulfidic ores may lead to acid mine drainage in the mining stage, and to large sulphur dioxide emissions in the smelting phase. Pyrometallurgical plants are associated with large energy needs and large $C0_2$ emissions. For hydrometallurgical plants, the tailings management is the main environmental issue. The highly controversial “deep-sea tailings placement” method is used by a small number of plants, or projected new plants.

The largest producer of nickel is the Philippines, which in 2017 closed or suspended 17 nickel mines because of environmental concerns. Also, Norilsk in Russia, one of the world’s largest sites for nickel mining and refining, have experienced leakage of mining waste to the local river and heavy emissions of sulphur dioxide[35]. Environmental concerns related to Nickel mining often arise because a considerable percentage of nickel is mined within or near to protected areas[36].

Life cycle GHG emissions from ore to refined metal is estimated to between 5.25 and 10 kg CO2/kg nickel[37].

[35] Drive Sustainability – Material Change
[36] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[37] https://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf

### 3.3.6 Human health and Working conditions

Sulphur dioxide air pollution, primarily related to sulphidic nickel ores, not only causes acid rain but also affects human health when breathed in. It can be fatal at very high concentrations and at lower concentrations cause breathing problems and eye irritation and lead to respiratory diseases such as asthma[38]. This affects both the local population living near mines and refining plants but also the workers if they don't wear proper protection gear[39]. This is especially a risk in countries with weak laws on worker rights.

## 3.4 Lithium

Lithium is a highly reactive mineral and therefore only becomes stable in compound with other elements. Lithium carbonate is the most widely used but also lithium hydroxide is becoming more common in battery production. Lithium is mined from two sources, either from hard rock which resembles mining of other metals, or extracted from brine, which is pumped from underground. Both sources of lithium can be transformed into the needed compound[40].

### 3.4.1 World lithium production

There are 9 countries in the world producing lithium. Australia, Zimbabwe, Portugal and Brazil are extracting from hard rocks, whereas Chile, Argentina, Bolivia and USA extract from brines. China is extracting from both sources. Chile and Australia produce the far majority of all lithium (76%), followed by Argentina (13%) and the remaining countries have a marginal share (see Figure 9). The specific compounds used in the battery chemistry are mainly produced in the same country where the lithium ore has been mined. However, China stands out with and increased share of lithium compounds production compared to its mining production, which means they import lithium ore for refining[41].

[38] https://www.epa.gov/so2-pollution/sulfur-dioxide-basics#effects
[39] http://stop-mad-mining.org/wp-content/uploads/2015/10/2017_philipppinenbuero_Nickel__ENG__web.pdf
[40] EC (2017) Non Critical Raw Material Factsheet
[41] EC (2017) Non Critical Raw Material Factsheet

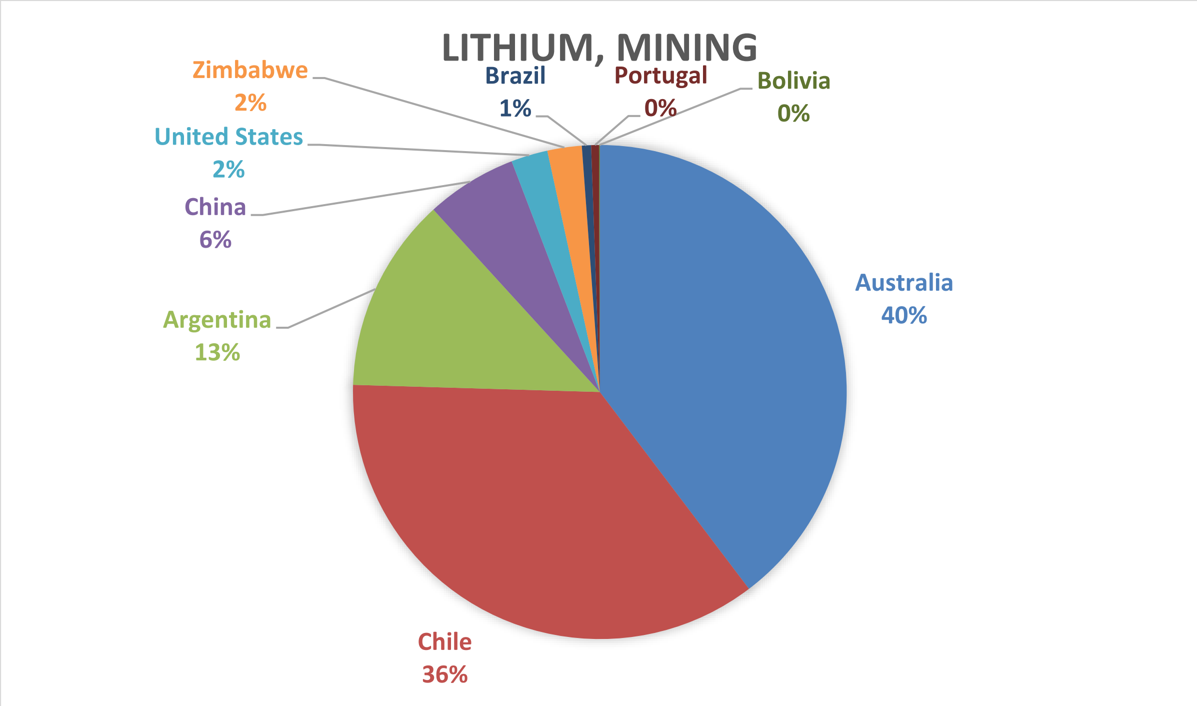


*Figure 9: World lithium mining (Li2O equivalents) (Source: World Mining Data).*

The average annual production of lithium was 76,000 ton in the period 2013-2017. However, is has seen a dramatic increase and almost doubled from 60,000 tons to 107,000 tons in the same period (see Figure 10).

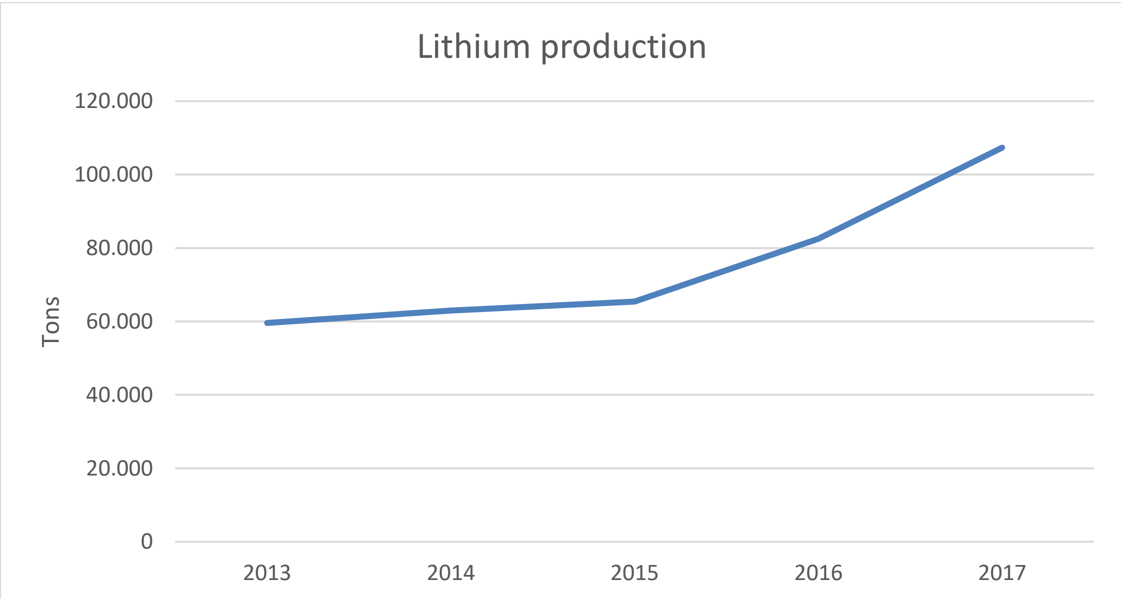


*Figure 10: Development of lithium production in the period 2013-2017.*

### 3.4.2 End-use

Globally, lithium is mainly used for rechargeable batteries (56%), where other primary uses are within the glass- and ceramics industry and for one of the most widely used types of lubricating greases. The most widely used batteries for EVs (LMO, LFP, NMC) constitute 70%

of the li-ion battery market. Consequently, a fair estimate of EV batteries' demand of the global lithium production is 39% equivalent to 42,000 tons in 2017.

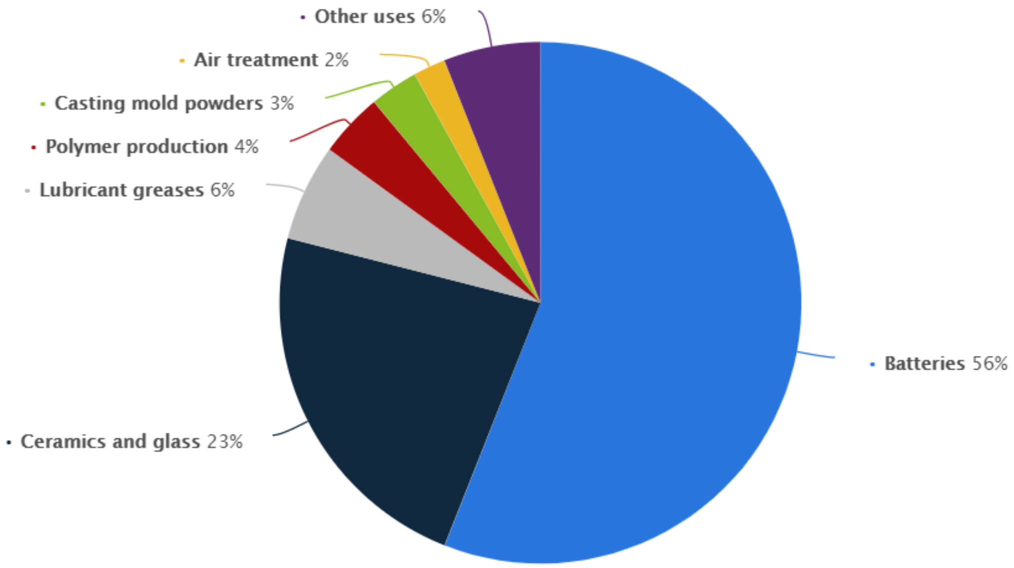


*Figure 11: World lithium end-use*[42]

### 3.4.3 Forecast and reserves

Global reserves of lithium are estimated to about 41 million tons with the most significant shares held by the already top producing countries – Chile (7.5 million tons), China (3.2 million tons), Argentina (2.0 million tons) and Australia (1.5 million tons). However, Chiles neighbouring country Bolivia are believed to hold the largest reserves of all at up to 9 million tons[43]. These reserves are practically untouched, and Bolivia only produced 120 tons of lithium in 2017. Bolivia is well aware of its major potential as a large lithium producer and has invested large sums into kickstarting mining developments[44]. 90,000 tons is expected to be demanded by the EU in 2030[45].

### 3.4.4 Governance

All six indicators are positive for lithium with an average of 0.97 suggesting a good level of governance for the lithium sourcing countries. Regulatory Quality has the highest score of 1.21 and Political Stability has the lowest score of 0.53 (see Table 4).

[42] https://www.statista.com/statistics/268787/lithium-usage-in-the-world-market/
[43] EC (2017) Non Critical Raw Material Factsheet
[44] https://www.mining.com/web/bolivia-revolutionaries-lithium-miners-go-die/
[45] Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1 Task 7

*Table 4: Worldwide Governance Indicator scores for lithium producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | 0.94 |
| Political Stability and Absence of Violence/Terrorism | 0.53 |
| Government Effectiveness | 1.07 |
| Regulatory Quality | 1.21 |
| Rule of Law | 1.05 |
| Control of Corruption | 1.06 |
| **Average score** | **0.97** |

The weighted environmental performance index (EPI) classifies lithium as having a low environmental hazard potential, thereby supporting the WGI score.

### 3.4.5 Environment

Regarding life cycle GHG emissions from ore to refined metal, brine extraction process is in general less intensive. On average it emits 2 kg $CO_2$ per kg lithium. However, there are examples from brine extraction where the brine is heated up in order to increase evaporation and thereby speeding up the process. This is very energy intensive and leads to higher GHG emissions[46]. In comparison, GHG emissions related to extraction from hard rock is as high as 27 kg $CO_2$ per kg lithium[47].

The main concern from brine extraction is the high water consumption in the already very dry region impacting both local farmers and the ecosystem[48]. The industry benchmark for water consumption in brine extraction operation is between 150-1000 m3/ton of lithium according to industry stakeholders. Both Argentina and Chile have experienced problems with the high water consumption from brine extraction of lithium[49].

There are also examples of leakage of toxic chemicals, used in the processing of lithium, into the local environment in Australia, United States and China[50].

### 3.4.6 Human health and Working conditions

Leakage of toxic chemicals from lithium mining can have adverse effects on human health, but the risk is considered low and only few examples have been identified. The toxicity of lithium itself is not very high but chronic exposure leading to lithium accumulation in the human body can lead to adverse health effects[51].

Brine extraction is a relatively less labour-intensive form of mining with little exposure to dust, fallen rocks and explosives. Lithium extraction from hard rock is dominantly occurring in Australia, where there is strong law on working conditions. The risk of poor working conditions is therefore considered low.

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[46] https://www.wired.co.uk/article/lithium-batteries-environment-impact
[47] https://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf
[48] Drive Sustainability – Material Change
[49] https://www.lexology.com/library/detail.aspx?g=7a3d0fa2-d817-4667-9315-92edbf36920d
And: https://eandt.theiet.org/content/articles/2019/08/lithium-firms-are-depleting-vital-water-supplies-in-chile-according-to-et-analysis/
[50] https://www.wired.co.uk/article/lithium-batteries-environment-impact
[51] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3918183/

## 3.5 Manganese

Manganese is a relative abundant element in the earth's crust and is typically found together with iron but is normally mined as a primary product. Manganese is a critical and irreplaceable metal used in steel production but is also an important part of many Li-ion battery types.

### 3.5.1 World manganese production

Manganese production is currently occurring in 34 countries in the World but is dominated by four countries: South Africa (27%), Australia (17%), China (16%) and Gabon (11%) with a combined share of 71% (see Figure 12).

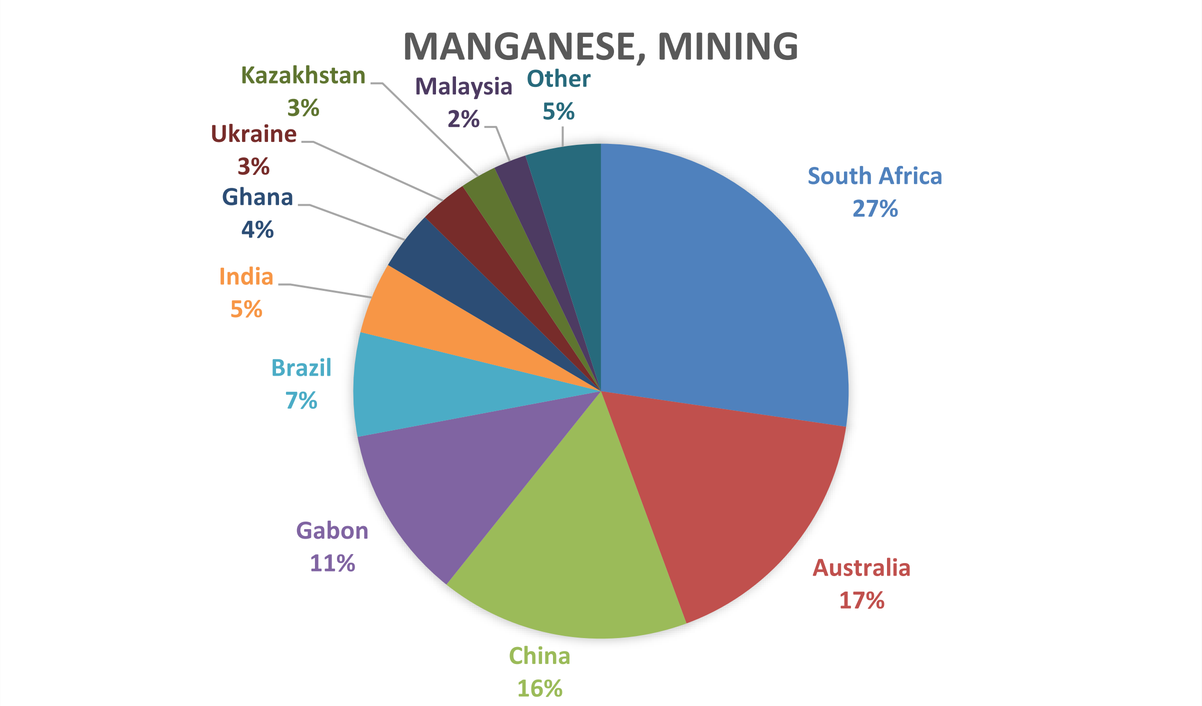


*Figure 12: World production of manganese (Source: World Mining Data).*

The average annual global production of manganese ore is 17.4 million tons in the period 2013-2017. The development in annual production has been fairly stable in the same period. It should be noted that ASM mining is occurring in a number of manganese producing countries, such as South Africa, China, Gabon, Brazil, India and Ghana. This production is not included in the national statistics[52] and it has not been possible to quantify the share of world manganese production from ASMs.

[52] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.

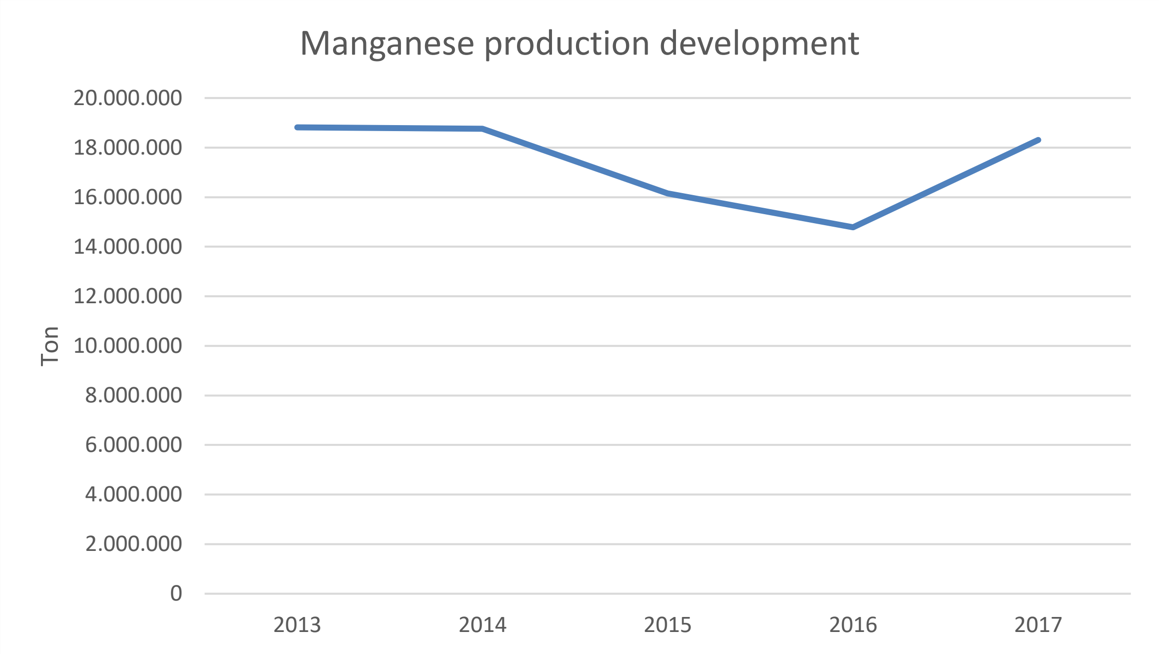


*Figure 13: Manganese production development in the period 2013-2017*

### 3.5.2 End-use

Manganese is a critical and irreplaceable metal in steel production because of its de-sulphurizing and deoxidizing properties that strengthens steel. Consequently, the dominant end-use of manganese is in steel production at 87% of total supply. Manganese is also used in other metal alloys and about 2% of the global production goes to batteries. Manganese share some of the same qualities as cobalt but is considerably cheaper, which is therefore replaced to some extent without compromising performance[53]. Manganese is an essential element in the Li-ion battery types LMO and NMC which are predominantly used for EVs. A fair assumption is therefore that the far majority of manganese used for battery production goes to EV batteries.

[53] http://www.manganesexenergycorp.com/single-post/2017/07/20/Manganese-Critical-Metal-for-Battery-and-Electric-Vehicle-Markets

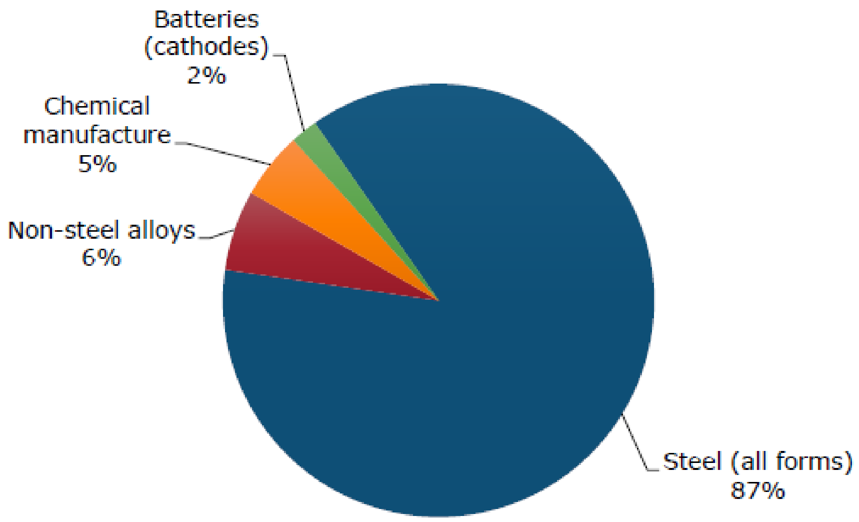


*Figure 14: End-use of manganese[54]*

### 3.5.3 Forecast and reserves

Manganese is a relatively abundant element in the Earth's crust and the global reserves are therefore large – estimated to 620 million tons. Almost 85% are located on South Africa and Ukraine. However, the manganese content in most minerals are quite small and therefore not economically viable to extract. Consequently, Ukraine's share of global production is a mere 3% despite their large resources[55]. Steel production is expected to increase by about 2% annually and will therefore continue to drive the manganese supply. However, manganese for battery production is expected to increase exponentially, since manufacturers are continuously researching in increasing the manganese content of batteries in order to limit the use of other more controversial metals[56]. 105,000 tons is expected to be demanded by the EU in 2030[57].

### 3.5.4 Governance

The average indicator score is slightly above zero at 0.11 suggesting an intermediate level of governance with the only negative indicator being Political Stability at -0.13. The highest scoring indicator is Government Effectiveness at 0.32 (see Table 5).

[54] EC (2017) Non Critical Raw Material Factsheet
[55] EC (2017) Non Critical Raw Material Factsheet
[56] https://www.mining.com/web/manganese-the-third-electric-vehicle-metal-no-one-is-talking-about-it-heres-how-to-take-advantage/
[57] Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1 Task 7

*Table 5: Worldwide Governance Indicator scores for manganese producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | 0.10 |
| Political Stability and Absence of Violence/Terrorism | -0.13 |
| Government Effectiveness | 0.32 |
| Regulatory Quality | 0.23 |
| Rule of Law | 0.10 |
| Control of Corruption | 0.06 |
| **Average score** | **0.11** |

The weighted environmental performance index (EPI) classifies manganese as having a high environmental hazard potential, implying a very poor level of governance, which to some degree is contradicting the WGI score.

### 3.5.5 Environment

Release of manganese to the environment will at lower levels not harm wildlife or animals. However, it will have a toxic effect at higher levels and has a tendency to accumulate in some plants and animals and potentially increase risks further up the food chain[58].

In general manganese mining possess the same risks as for other mining activities, including risk of releasing geogenic radioactive substances. The risk is more profound in countries with poor legislation and/or weak law enforcement and with ASM, which is likely the case for the countries where most of global manganese is sourced – such as South Africa, Gabon and China. Mining in or close to protected areas increases the environmental risks to ecosystems.

Life cycle GHG emissions from ore to refined metal is estimated to 6 kg CO2/kg manganese[59]. This estimate is based on a pyrometallurgical route. Manganese for EV batteries will most likely be in the form of electrolytic manganese dioxide, which follows a very different industrial route, probably with less GHG emissions, but no data has been found for this route[60].

### 3.5.6 Human health and Working conditions

Manganese is essential to development and metabolism in humans. However, overexposure to manganese from e.g. dust or water contamination typically occurring from mining activities has been observed to cause a Parkinson's disease-like neurological condition called manganism[61]. Some manganese ore deposits show high concentrations of radioactive nuclides, from which workers might get exposed if not handled properly[62].

[58] http://apps.sepa.org.uk/spripa/Pages/SubstanceInformation.aspx?pid=106
[59] https://link.springer.com/article/10.1007/s11367-015-0995-3
[60] Stakeholder comment
[61] https://www.sciencedirect.com/topics/engineering/manganese
[62] https://inis.iaea.org/collection/NCLCollectionStore/_Public/45/099/45099894.pdf

## 3.6 Aluminium

Aluminium is the most abundant metal in the Earth's crust (8.1%) and is the third most abundant element after oxygen and silicon.

Bauxite is the main ore of aluminium. Approximately 90% of bauxite mined in the world is converted to alumina (aluminium oxide). 80–90% of the world's alumina is smelted to aluminium. Almost all aluminium production is from bauxite[63].

### 3.6.1 World aluminium production

The first step of aluminium production is the mining of bauxite ore. It is currently occurring in 33 countries worldwide. The far majority (80%) of bauxite comes from five countries: Australia (29%), China (21%), Brazil (13%), Guinea (9%) and India (8%). The total production has on average been 288 million tons in the period 2013-2017.

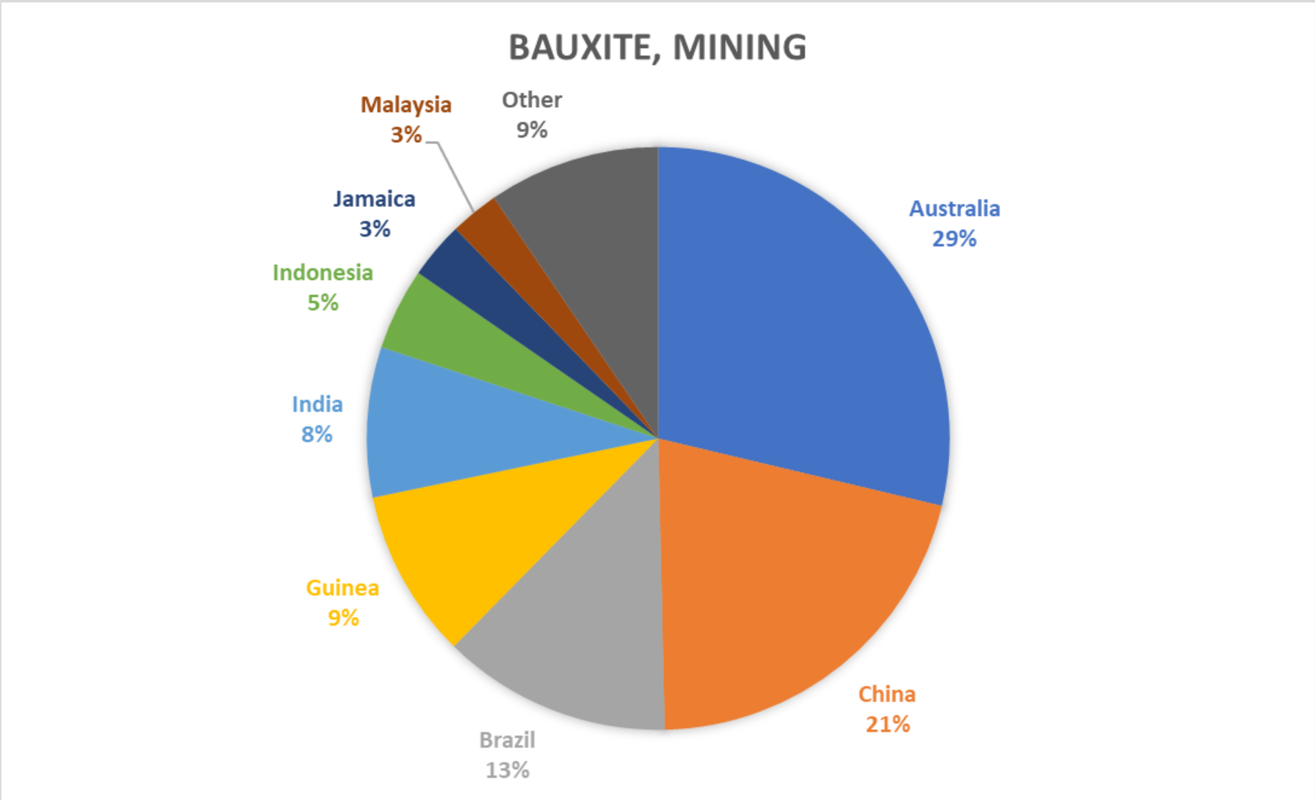


*Figure 15: World production of bauxite (Source: BGS).*

85% of all bauxite is further converted into aluminium oxide which can finally be processed into aluminium metal. The processing is not necessarily taking place in the mining country but is shipped to other countries. Australia which is mining the largest share of bauxite (29%) is only processing 3% of aluminium metal, as shown in Figure 16. China is by far the largest producer of aluminium at 53% of the world total. The remaining production is spread to 42 countries.

[63] EC (2017) Non Critical Raw Material Factsheet

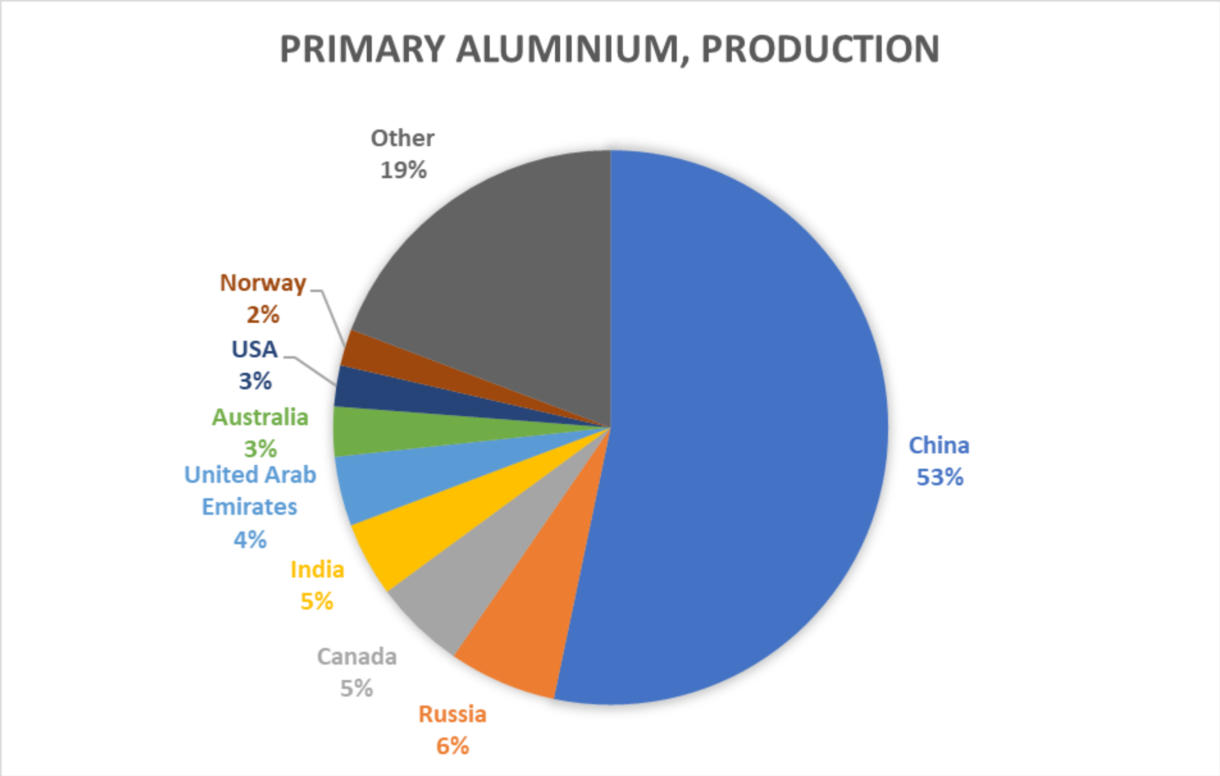


*Figure 16: World primary aluminium production (Source: BGS)*

Around 4-6 tons of bauxite is required to produce one ton of aluminium. The average annual global production was 57 million tons in the period 2013-2017. There has been a considerable increase in production in the same period at about 20% (see Figure 17).

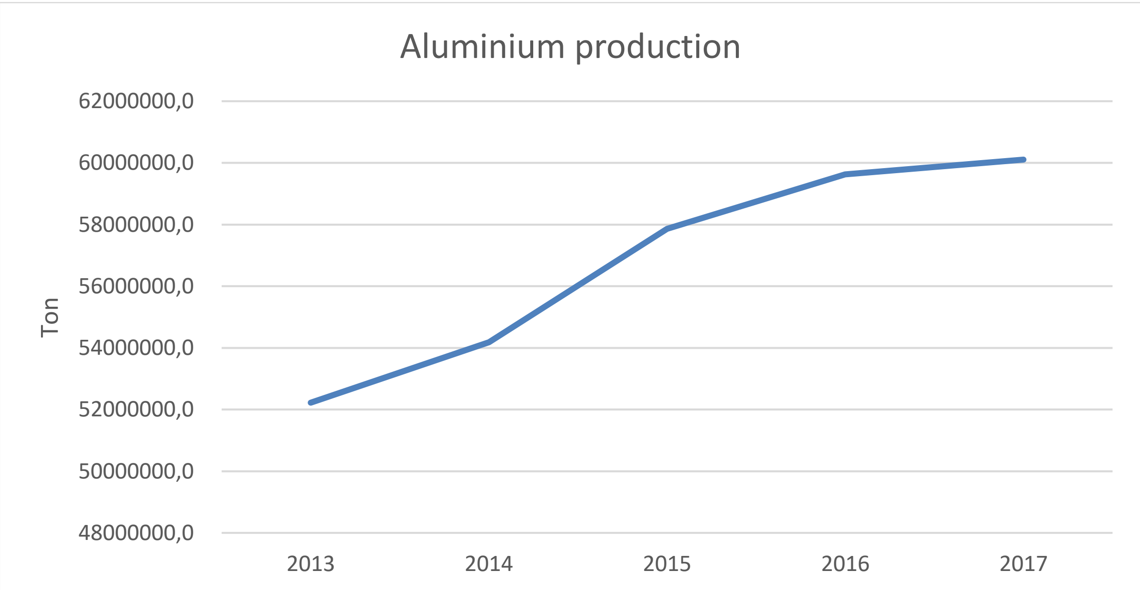


*Figure 17: Development in aluminium production in the period 2013-2017*

### 3.6.2 End-use

Due to its qualities as light, strong and flexible, aluminium is widely used in the transportation industry for cars, trains, aircrafts and bicycles instead of steel, which is significantly heavier but otherwise share the same qualities. For the same reasons it is also widely used in construction and equipment. Other uses include packaging, such as beverage cans and aluminium foils, and consumer durables such as cooking ware, phones and laptops.

The only Li-ion battery to include aluminium in its battery chemistry is the NCA type. It is similar to NMC and has a higher capacity. However, it is less safe and has higher cost and therefore not suitable for EVs[64]. Batteries have been developed where lithium is replaced by aluminium proving to have significantly higher capacities. However, these are still at an experimental level and not yet ready for upscaling[65].

The main use of aluminium in EV batteries is instead for peripheral use such as the casing of the battery system. Despite aluminium constituting a relatively large share of a battery systems weight it is considered as having an insignificant share of the overall global consumption.

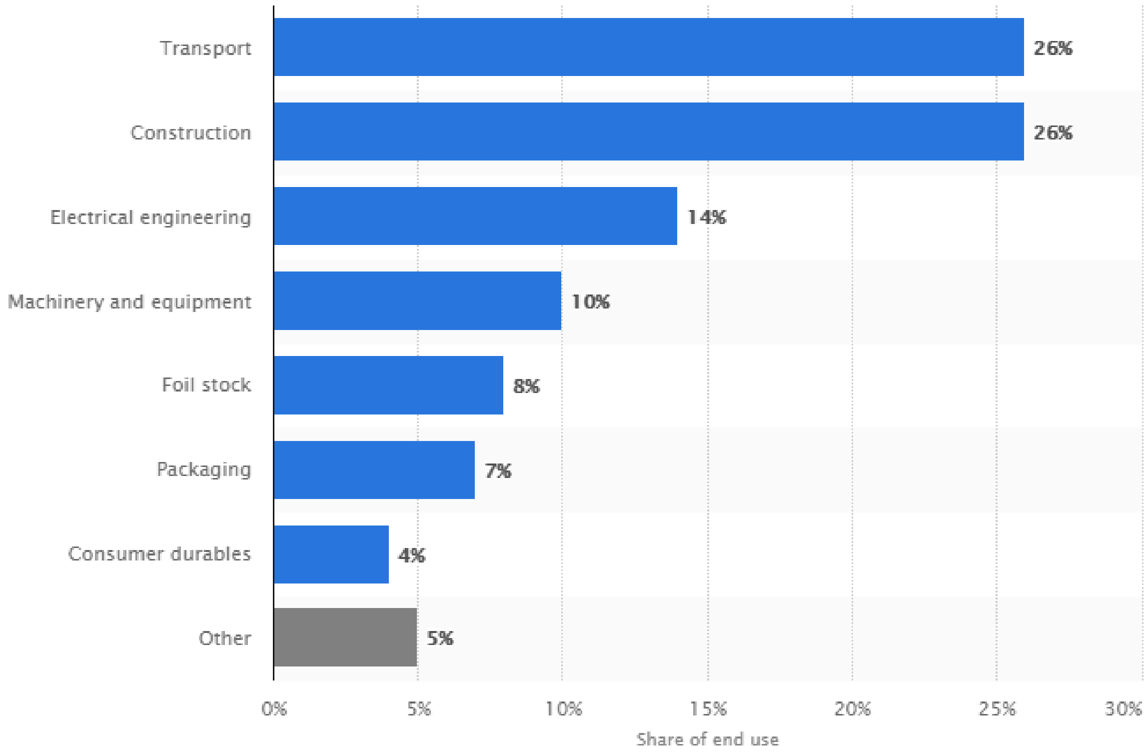


*Figure 18: End-use of aluminium[66]*

### 3.6.3 Forecast and reserves

The reserves of bauxite have been estimated to be about 28 billion tons globally with the largest reserves in Guinea, Australia and Brazil. Nonetheless, aluminium is termed an almost inexhaustible resource due to its abundance the Earth's crust also in other minerals besides bauxite. However, these resources are not yet economically viable to extract[67]. Furthermore, in many of the end-uses aluminium is not mixed with other metals, which makes the recycling

[64] https://batteryuniversity.com/index.php/learn/article/types_of_lithium_ion
[65] https://www.designnews.com/electronics-test/can-aluminum-take-us-beyond-lithium/44692193958697
[66] https://www.statista.com/statistics/280983/share-of-aluminum-consumption-by-sector/
[67] EC (2017) Non Critical Raw Material Factsheet

of aluminium easier and thus cheaper, especially compared to the energy intensive mining process.

A constant growth in the demand for aluminium is expected, particularly driven by the auto and aerospace industries. Ironically, it is the expected increase in EVs, requiring lightweight materials to decrease energy consumption, that is one of the primary drivers. An annual growth of 2.8% is expected towards 2028 creating a demand of about 80 million tons compared to the current 60 million tons[68].

### 3.6.4 Governance

The average score across all 6 indicators is just above zero at 0.05 suggestion an intermediate level of governance (see Table 5). One indicator standing out is Voice and Accountability with a low score of -0.70 which is mainly influenced by the large share of World production in China.

*Table 6: Worldwide Governance Indicator scores for aluminium producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | -0.70 |
| Political Stability and Absence of Violence/Terrorism | -0.07 |
| Government Effectiveness | 0.61 |
| Regulatory Quality | 0.20 |
| Rule of Law | 0.16 |
| Control of Corruption | 0.12 |
| **Average score** | **0.05** |

The weighted environmental performance index (EPI) classifies aluminium as having a medium environmental hazard potential, thereby supporting the WGI score.

### 3.6.5 Environment

Since it takes 4-6 tons of bauxite to produce one ton of aluminium there a very large amount of waste material which needs to be handled. The resulting bauxite residue is referred to as ‘red mud’ which are stored in open holding ponds. This creates a risk of sudden collapses that will release ‘red mud’ to its surroundings contaminating large areas and waterways. This happened in Hungary in 2010 exterminating all life in the nearby river and killing 10 people[69].

Another concern from aluminium production is the very high energy consumption compared to other metals. Consequently, the life cycle GHG emissions from ore to refined metal from one kg of aluminium is 12 kg CO2eq compared to steel of 1 kg CO2eq.

Furthermore, bauxite is mostly mined from open pit mines which have a significant impact on local wildlife and vegetation[70]. This is especially important since many bauxite deposits are located in tropical rainforest areas[71]. Land and soil degradation, biodiversity and proper rehabilitation practice are therefore major environmental concerns for aluminium production.

[68] https://www.mining.com/global-aluminium-market-remain-undersupplied-coming-years-report/
[69] http://www.greenspec.co.uk/building-design/aluminium-production-environmental-impact/
[70] https://recyclenation.com/2010/11/aluminum-extraction-recycling-environment/
[71] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.

### 3.6.6 Human health and Working conditions

Bauxite contains aluminium hydroxide, iron oxide and titanium oxide which all are damaging to human health to varying degrees. Local people and miners can be exposed to these substances through dust occurring from the mining operations and transportation of bauxite. Several regions in Malaysia have experienced problems with air pollution from nearby bauxite mines[72].

## 3.7 Iron

Iron is an abundant element in the Earth's crust and most widely used metal. Approximately 98% of mined iron ore in the world is used in iron and steel manufacturing. Pure iron is rarely used because it is soft and oxidises rapidly in air, instead it is combined with other elements into different types of steel to increase strength and durability. These elements are for example carbon, chromium, nickel, molybdenum, tungsten, copper, manganese, silicon, niobium and vanadium[73].

### 3.7.1 World iron production

Iron ore is currently mined in 54 countries around the world, but five countries supply 78%: Australia (31%), China (24%), Brazil (16%) and India (7%). Not all iron is processed locally but instead exported for steel production. China produces approximately half the World's steel[74].

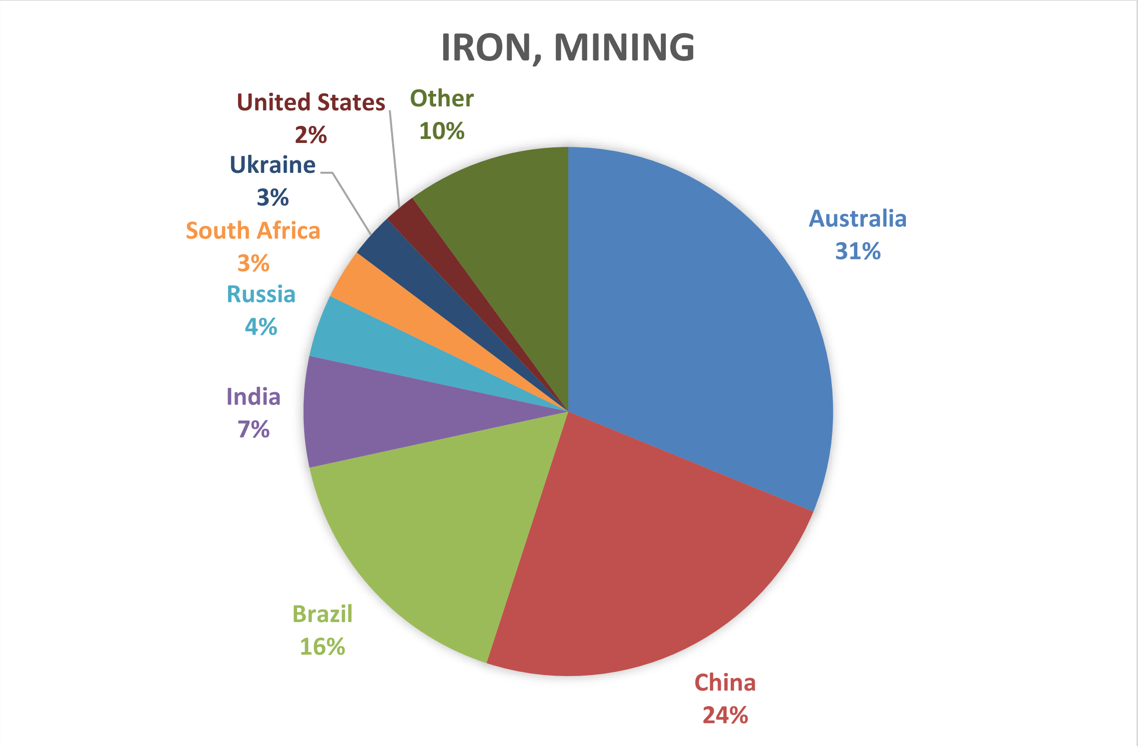


*Figure 19: Annual World mining of iron (Source: World Mining Data).*

[72] https://www.malaysiakini.com/letters/326807
[73] EC (2017) Non Critical Raw Material Factsheet
[74] EC (2017) Non Critical Raw Material Factsheet

The annual average production globally was 1.5 billion tons in the period 2013-2017. The production has seen a steady increase at about 8% in the same period (see Figure 20).

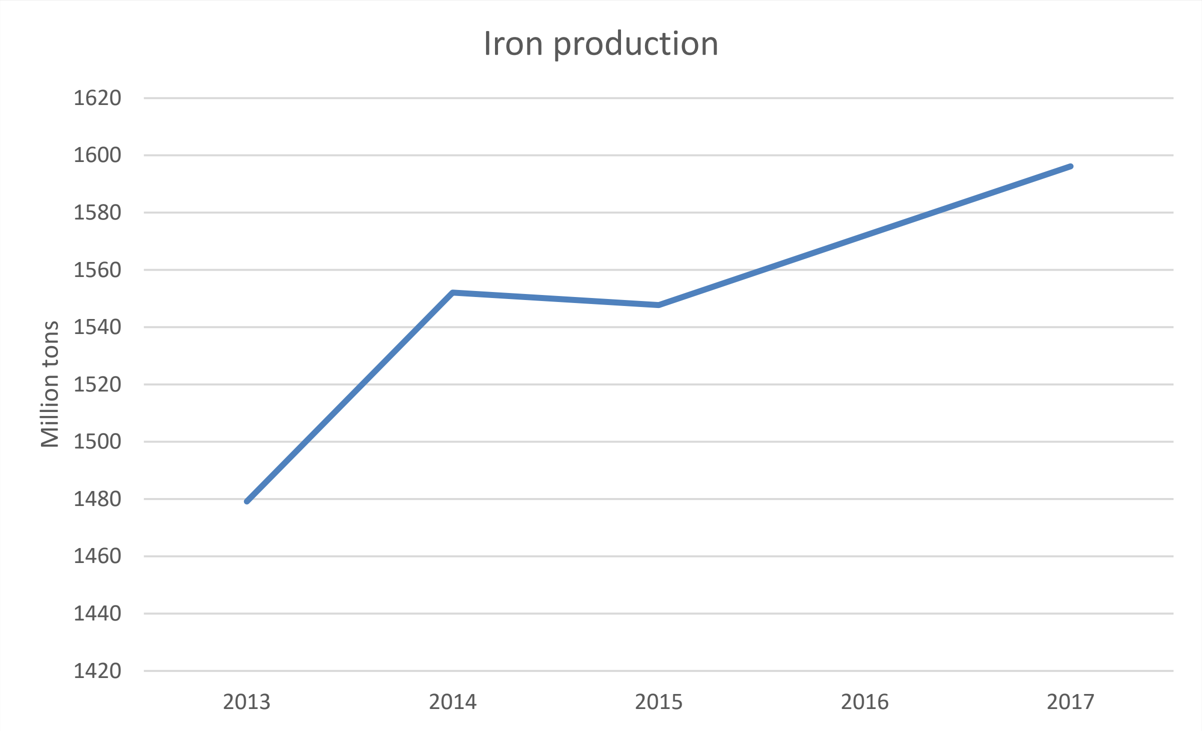


*Figure 20: Development in iron production in the period 2013-2017*

### 3.7.2 End-use (steel)

Iron is predominantly used for steel production, which has an array of different uses. The largest share (49%) is used in the construction sector, e.g. as structural material in buildings. Other uses include production of motor vehicles and in mechanical engineering for tools and machinery (see Figure 21).

Just like with aluminium, iron is not part of the battery chemistry but instead used at varying degrees for the housing and casing of the battery system. Despite iron/steel constituting a relatively large share of a battery systems weight it is considered as having an insignificant share of the overall global consumption.

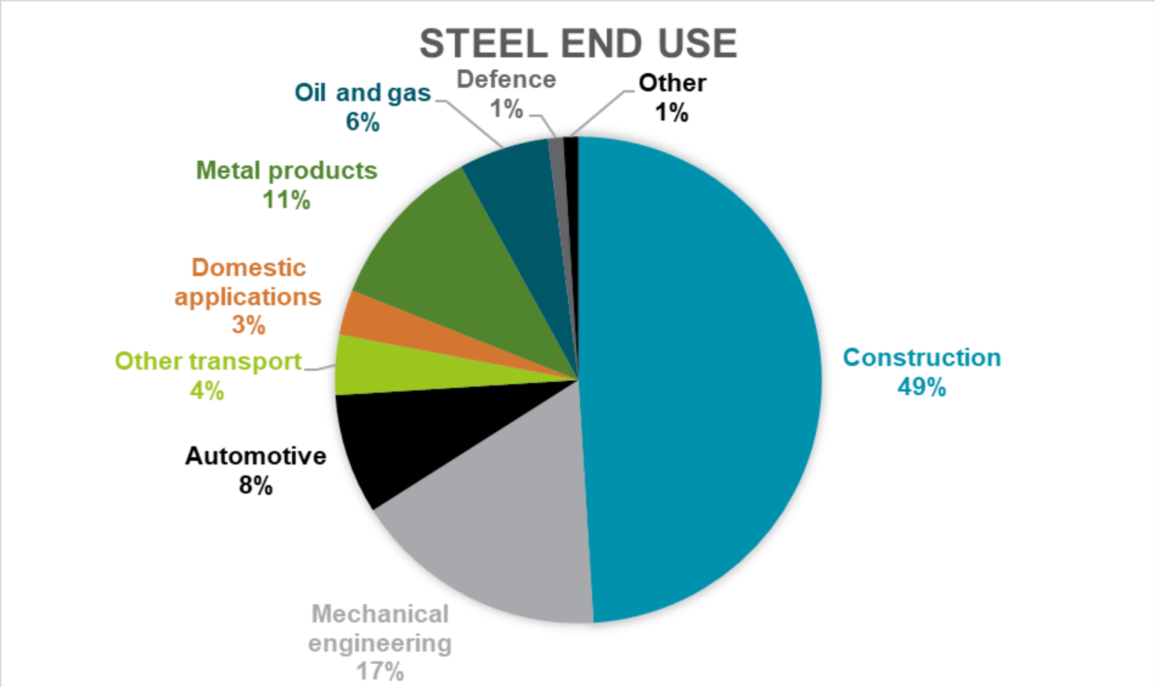


*Figure 21: End use of steel globally*[75]

### 3.7.3 Forecast and reserves

The global reserves of iron have been estimated to about 230 billion tons, primarily found in Australia, Russia, Brazil and China.

The global demand for steel is expected to increase at an annual rate of about 1.1% towards 2035 and reach 1.9 billion tons[76]. This trend is primarily driven by emerging economies requiring steel for buildings and infrastructure developments.

### 3.7.4 Governance

All six indicators are positive suggesting a good level of governance for the iron sourcing countries. Government Effectiveness has the highest score of 0.62 and Political Stability has the lowest at 0.05 (see Table 7).

*Table 7: Worldwide Governance Indicator scores for iron producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | 0.20 |
| Political Stability and Absence of Violence/Terrorism | 0.05 |
| Government Effectiveness | 0.62 |
| Regulatory Quality | 0.54 |
| Rule of Law | 0.44 |
| Control of Corruption | 0.41 |
| **Average score** | **0.38** |

[75] https://www.steelonthenet.com/consumption.html
[76] https://www.oecd.org/industry/ind/Item_4b_Accenture_Timothy_van_Audenaerde.pdf

The weighted environmental performance index (EPI) classifies iron as having a low environmental hazard potential, thereby supporting the WGI score.

### 3.7.5 Environment

Most environmental impacts from steel production are related to the production and use of coke. Coke is made of coal and used as a fuel and reactive reduction agent when melting iron ore. It is preferred over other fuels because it is cheap and produce high heat and little smoke. However, the production of coke is a major air pollution source where toxic gasses and dust is released. Large quantities of water are used in cooling the coke after use which then becomes contaminated. If not handled properly this possess a risk of leaking into the local environment[77].

Due to the very large volumes of iron ore processed globally there is an enormous amount of mining waste that needs to be stored in so-called tailing dams. There are several examples of tailing dam failures which can have grave consequences for the local environment and be fatal for nearby communities[78].Furthermore, an analysis by the German Environment Agency indicate that a considerable number of iron ore mines are located within protected areas[79]. Hence, while handling of mine tailings is an important issue for all mining, it needs additional focus for iron mining.

Life cycle GHG emissions from ore to refined metal related to steel production is fairly limited compared to other metals with an emission factor of between 1.7 -1.9 kg CO2 per kg steel[80]. Despite the low specific carbon footprint, the large amounts produced means that around 75% of all CO2 released from metals production is from steel.

### 3.7.6 Human health and Working conditions

Most health problems related to steel production are caused by air pollution from emissions of sulphur dioxide and dust. Especially in countries with weak environmental regulations such as China. In recent years the problems have reach a level that can no longer be ignored, and steel companies have started to implement various forms of environmental initiatives[81].

A large share of the World's iron and steel comes from China, where working conditions for miners are notoriously dangerous and many accidents and deaths have been reported through the years[82].

Failure of tailing dams which is mentioned above, can apart from being immediately fatal on the local communities also have long lasting indirect impacts from the contaminated tailings affecting local agriculture and fisheries and health of local communities.

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[77] http://www.greenspec.co.uk/building-design/steel-products-and-environmental-impact/
[78] Stakeholder comment
[79] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[80] https://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf
[81] http://www.seaisi.org/News/662/Dealing+with+Environmental+Pollution+in+the+Iron+and+Steel+Industry:+The+China+Case+Study
[82] https://www.mining-technology.com/features/featurechina-mine-death-rate-coal-safety/

## 3.8 Copper

Copper is the best electrical conductor (after silver) and is therefore widely used in all kinds of wiring and electrical equipment. It is also corrosion resistant and antibacterial and ideal for waterpipes and fittings[83]. It is mined all over the World primarily from open pit mines[84].

### 3.8.1 World copper production

Copper is found worldwide and is currently mined in 57 countries where four countries stands for 55% of the total production: Chile (29%), Peru (10%), China (9%) and USA (7%).

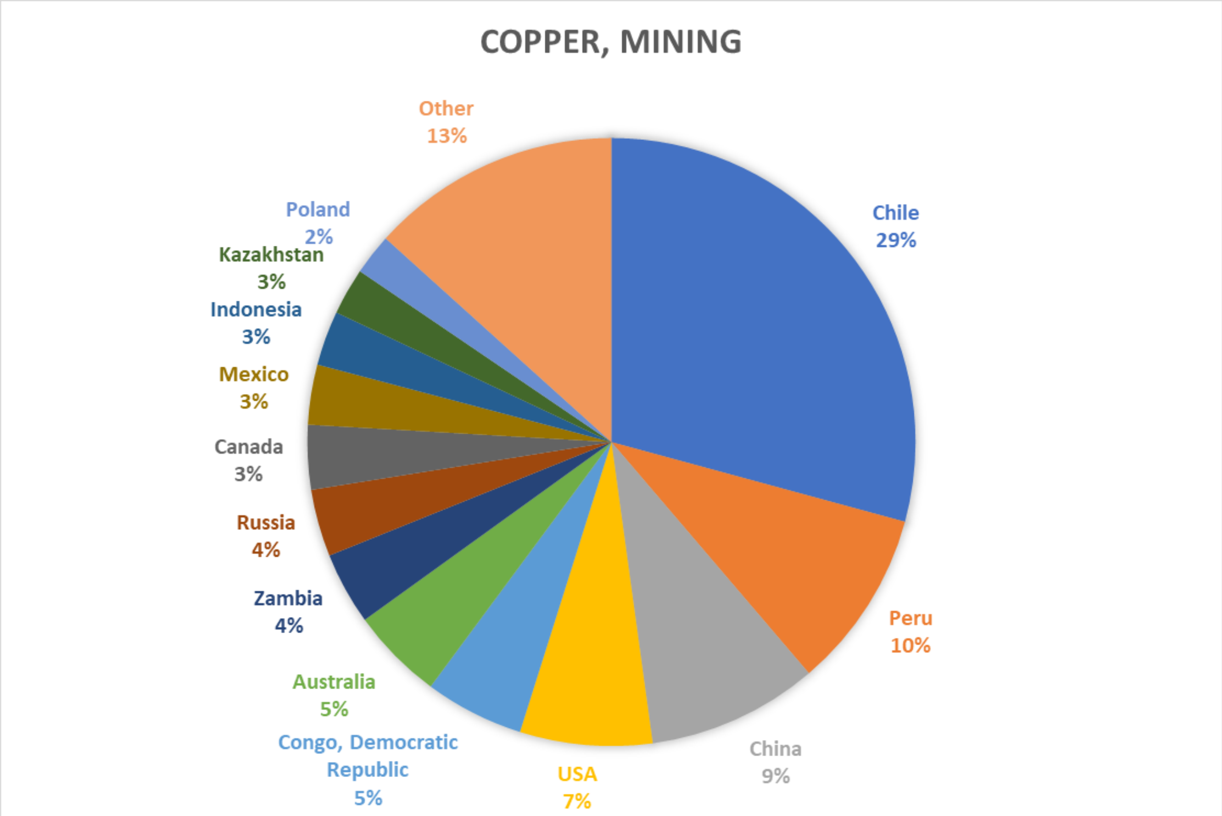


*Figure 22: Sources of world production of copper in the period 2013-2017 (Source: BGS).*

The annual average production of copper was globally 19 million tons in the period 2013-2017. It has seen a steady increase at about 9% in the same period, as shown in Figure 23 .

[83] EC (2017) Non Critical Raw Material Factsheet
[84] https://www.globalxetfs.com/copper-explained/

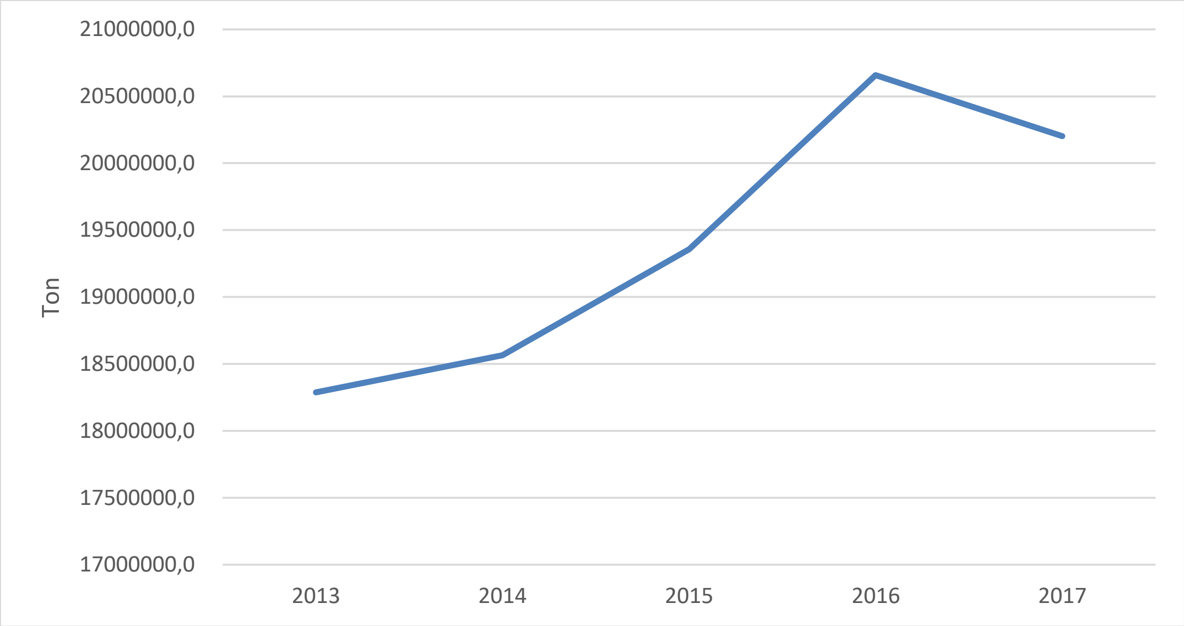


*Figure 23: Copper production in the period 2013-2017 (Source: BGS)*

### 3.8.2 End-use

Copper and its alloys (e.g. bronze and brass) have a wide range of applications due to their unique properties as a good conductor of electricity and heat, corrosion resistance, anti-bacterial, ductile and alloys easily.

Copper is used in all types of electronic equipment from computers, mobile phones and televisions to household wiring and large transmission systems and telecommunications. Due to its high thermal conductivity it is also widely used as heat exchangers in air conditioners and refrigerators. Its antibacterial properties and corrosion resistance make it useful in plumbing and other water systems[85].

For Li-ion batteries, copper is primarily used in combination with graphite to make up the anode of the battery. Copper is preferred over other metals due to its high electric conductivity, thermal conductivity to drain heat out of the battery cell and heat resistance. Furthermore copper is used in the wiring for batteries in EVs.

The global share of copper demanded by EV batteries and Li-ion batteries in general is estimated to be marginal given the relatively small volumes of material used per battery compared to other applications.

[85] https://www.globalxetfs.com/copper-explained/

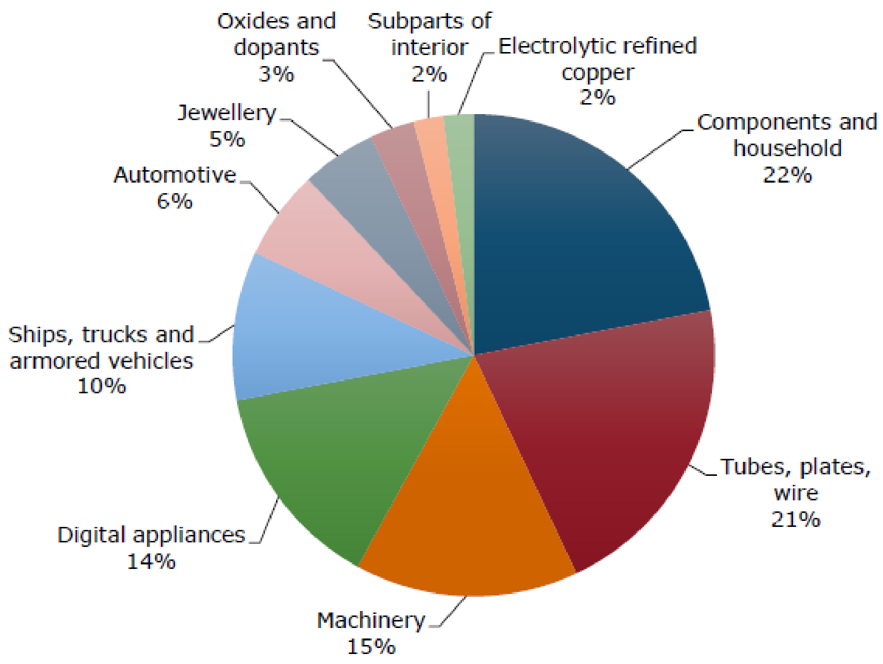


*Figure 24: End-use of copper*[86]

### 3.8.3 Forecast and reserves

The global known reserves of copper are estimated to about 720 million tons with about half located in Chile, Australia and Peru[87].

The global copper demand has seen an increase of about 2.5% annually in the last decade primarily driven by high growth in emerging economies, primarily China. Growth means demand for wiring and plumbing, transmission wires, consumer electronics and auto vehicles all using large volumes of copper. The growth in especially China is expected to decline which will consequently impact on copper demand and continue with a lower growth towards 2025 at about 1.9%. Copper plays an important part in renewable energy systems and EVs and hybrid vehicles, however it is not expected to impact the global copper demand significantly before the late 2020s[88]. Some analysts expect copper demand to increase by 43% by 2035 primarily driven by green technologies[89].

### 3.8.4 Governance

All indicator scores are positive with an overall average of 0.32 suggesting an intermediate to good level of governance. The lowest scoring indicator is Political Stability at 0.02 (see Table 8).

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[86] EC (2017) Non Critical Raw Material Factsheet
[87] EC (2017) Non Critical Raw Material Factsheet
[88] https://www.ft.com/content/2d2eef1e-5187-11e9-9c76-bf4a0ce37d49
[89] https://copperalliance.eu/about-us/europes-copper-industry/

*Table 8: Worldwide Governance Indicator scores for copper producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | 0.24 |
| Political Stability and Absence of Violence/Terrorism | 0.02 |
| Government Effectiveness | 0.48 |
| Regulatory Quality | 0.58 |
| Rule of Law | 0.31 |
| Control of Corruption | 0.26 |
| **Average score** | **0.32** |

The weighted environmental performance index (EPI) classifies copper as having a medium environmental hazard potential, thereby largely supporting the WGI score.

### 3.8.5 Environment

Copper is an essential metal for normal plant growth and development, but it is characterized as a heavy metal, however of the less-toxic kind. Excess copper levels are inhibiting plant growth and impair important cellular processes[90].

Copper is primarily found in sulphidic ores, thereby potentially leading to acid mine drainage in the mining stage. When sulphidic ores are exposed and react with air and water it forms sulphuric acid, which potentially precipitates to the surrounding environment causing acid rain.

Large open pit mines are common in copper extractions which are potentially destructive to the local ecosystem removing animal habitats and involving deforestation. Furthermore copper mines are often located in regions with high earthquake risks, making tailing handling more prone to leakage accidents.

An analysis from the German Environment Agency shows that a large number of copper mines are located in regions with high water stress. Since copper is commonly extracted from low ore grades, there is a high water demand for ore beneficiation putting additional stress on water resources[91].

Sulphuric acid is a primary by-product from the smelting process of copper concentrate which is normally collected and stored on-site and usually resold. Hence, not imposing any environmental concerns if handled properly[92].

Life cycle GHG emissions from ore to refined metal is estimated to between 1 and 5 kg CO2/kg copper[93]. In Europe, the copper industry has seen large efficiency gains in the period 1990-2015. The $CO_2$-intensity of copper has in that period dropped 40% from 2.67 to 1.62 kg CO2/kg copper. This is mainly cause by a shift to 'flash-melting'[94]. This is likely not the case for all

[90] http://www.scielo.br/pdf/bjpp/v17n1/a12v17n1.pdf
[91] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[92] https://www.eurometaux.eu/media/2005/full-report-8-56-17.pdf
[93] https://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf
[94] https://www.eurometaux.eu/media/2005/full-report-8-56-17.pdf

smelters in the world, as investment costs are high for advanced environmental technologies[95].

### 3.8.6 Human health and Working conditions

Copper is essential to human health and therefore needed in small quantities. However, excessive exposure to copper can be toxic to human health, e.g. inhaling of fumes, dusts or mists containing copper[96]. Industry stakeholders have underlined that there is no evidence showing that workplace dusts and fumes have an effect on worker health. Nonetheless, the main health concerns are related to release of sulphuric acid and other chemicals, used in the extraction and treatment of copper, into rivers and aquifers therefore contaminating local drinking water in case no state-of-the-art manufacturing technologies are applied. Grave examples have been reported from the largest copper mine in Africa in Zambia[97]. Hence, the broader copper industry decided to engage in a voluntary programme to demonstrate and improve the industry’s contribution to sustainable development over time by assessing the performance of copper mines and refiners against responsible production criteria and verifying performance through the Copper Mark Assurance Process[98].

## 3.9 Phosphorus

Phosphorus is highly reactive and is therefore never found as a free element on Earth, but only in its oxidized compound as phosphate. Phosphorus is an essential nutrient for all life and is often the limiting nutrient in agriculture. Therefore 96% of global phosphate production goes to fertilizers and animal feed. It is critical to current agriculture practices and there are indications that we are close to peak phosphorus production. It is therefore included on EU’s critical raw material list[99].

### 3.9.1 World phosphate production

Phosphate is currently mined in 39 countries in the World where the far majority (70%) comes from only three countries: China (49%), Morocco (11%) and USA (10%) as shown in Figure 25.

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[95] Stakeholder comment
[96] https://www.lenntech.com/periodic/elements/cu.htm
[97] https://old.danwatch.dk/undersogelseskapitel/impacts-of-copper-mining-on-people-and-nature/
[98] https://sustainablecopper.org/rmi-and-ica-partner-to-advance-responsible-copper-production-and-trade/
[99] EC (2017) Critical Raw Material Factsheet

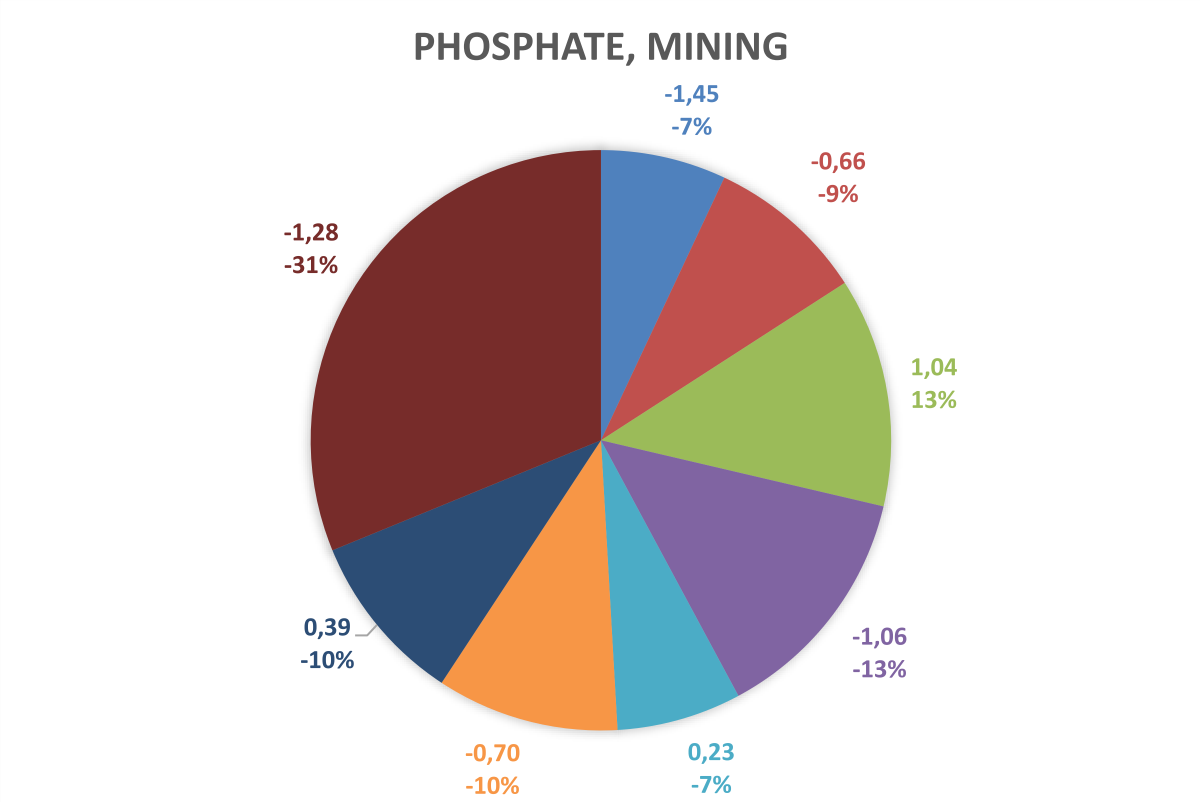


*Figure 25: Source of world phosphate (Source: World Mining Data).*

The average annual production of phosphate was globally 80 million tons in the period 2013-2017. The production has seen a steady growth of more than 13% in the same period as shown in Figure 26.

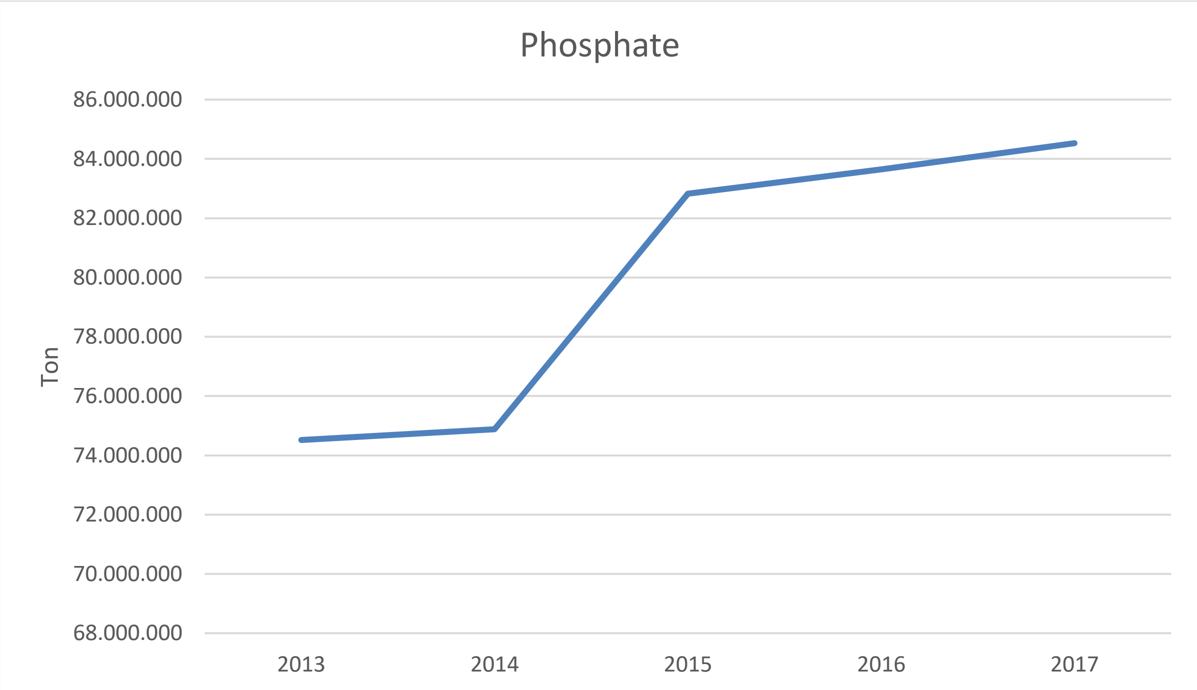


*Figure 26: Development of phosphate production in the period 2013-2017*

### 3.9.2 End-use

The main application of phosphate is as mineral fertilizer and as animal feed in the agricultural sector. Only 4% of the global phosphate production has other uses. Other uses mainly cover chemical industry applications where pure forms of phosphorus (white and red phosphorus) are used for lubricant additives, pharmaceuticals, detergents, matches and pyrotechnics among others (see Figure 27).

A purified form of phosphoric acid is used for the lithium iron phosphate (LFP) battery type where it acts as a replacement of cobalt in the cathode. LFP is most widely used for EVs and energy storage due to its higher safety and longer lifetime[100].

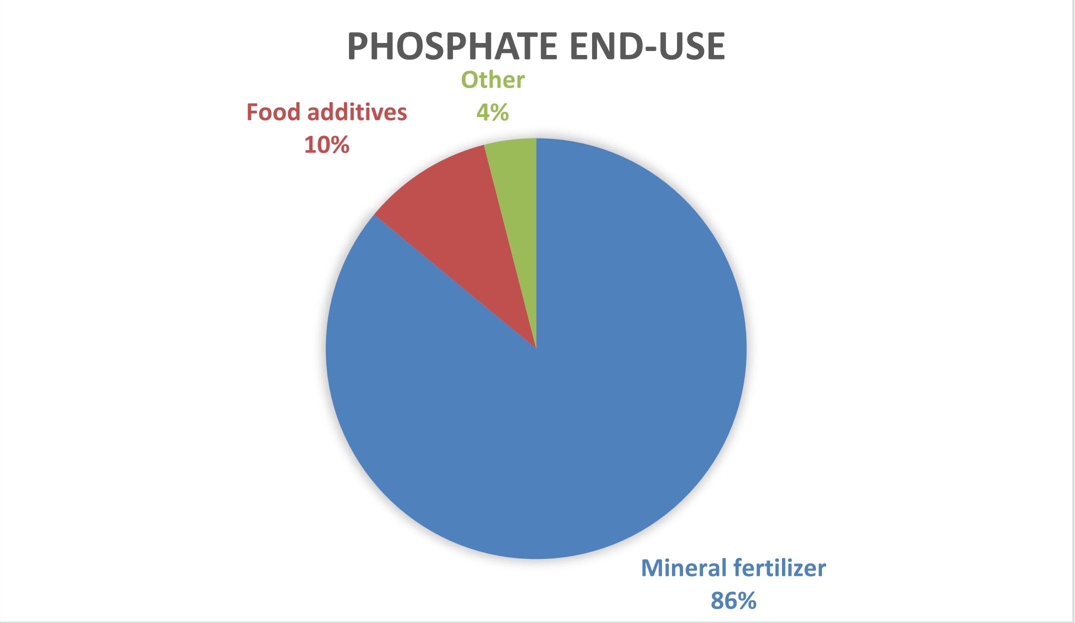


*Figure 27: Global end-use of phosphate*

### 3.9.3 Forecast and reserves

The global known reserves of phosphate rock are estimated to about 60 billion tons, but only between 4% and 20% of phosphate rock is actual phosphate mineral. By far the largest reserves (73%) are located in Morocco, other large deposits are found in China, Middle East and USA. Phosphate rock is relatively abundant in the Earth’s crust; however, many deposits are not yet economically viable to extract[101].

There is a growing concern that the World might hit a peak phosphorus in the next 30 to 60 years if current practices are continued and no new large reserved are discovered. Phosphate mining is and will continue to be driven by demand from the agricultural sector for fertilizer because there exists no substitute. Furthermore, phosphorus is not retrieved or recycled to any significant degree. When reserves are also isolated to a few countries then there is a large risk to future supplies of phosphate[102]. Consequently, phosphate has been included in the EU list of critical raw materials.

[100] http://www.prayon.com/en/news/2012/05/umicore-and-prayon-join-forces-to-develop-and-produce-phosphate-based-cathode-materials-for-lithium-ion-batteries
[101] EC (2017) Critical Raw Material Factsheet
[102] http://phosphorusfutures.net/the-phosphorus-challenge/peak-phosphorus-the-sequel-to-peak-oil/

### 3.9.4 Governance

Four out of six indicators score negatively with the worst being Voice and Accountability at -0.79. The average score is also negative at -0.14 suggesting a poor level of governance. It should be noted that phosphate mines in Morocco are located in Western Sahara, annexed by Morocco contrary to international law[103]. If this was taken into account, it might affect some of the indicators negatively.

*Table 9: Worldwide Governance Indicator scores for phosphate producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | -0.79 |
| Political Stability and Absence of Violence/Terrorism | -0.26 |
| Government Effectiveness | 0.35 |
| Regulatory Quality | 0.04 |
| Rule of Law | -0.05 |
| Control of Corruption | -0.13 |
| **Average score** | **-0.14** |

The weighted environmental performance index (EPI) classifies phosphate as having a medium environmental hazard potential, thereby presenting a slightly better level of governance than the WGI score.

### 3.9.5 Environment

As with mining for many other minerals open-pit or surface mining is also very typical with mining of phosphate rock. This results in severe land degradation such as rock desertification, loss of vegetation and habitats and ground erosion. Not only where the mine is located but also for the surrounding areas where surplus soil and waste is placed. Several studies have documented environmental impacts from phosphate mining such as local depletion of water resources and contamination of surface and ground water by discharge of mining wastewater.

In order to produce soluble phosphate products from the phosphate rock, large quantities of sulfuric acid are used. Acidic wastewater has in some locations drained into the local surface and ground water sources. Leakage of phosphate rich material into local surface waters has in some cases resulted in algal bloom and eutrophic conditions with increased fish mortality as a consequence[104].

Another concern is that phosphate rock is often associated with radioactive substances (e.g. uranium) which can be mobilized in the environment during mining and processing[105].

[103] Comment from stakeholder
[104] http://medcraveonline.com/IJH/IJH-02-00106.pdf
[105] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.

### 3.9.6 Human health and Working conditions

The major airborne emissions occur in the form of fine rock dust from drying and grinding operations of phosphate rock. At least 57 of the trace elements in phosphate rock have been reported to possess toxicity to varying degrees, and Be, As, Cd, Hg, Tl, and Ra are generally designated as extremely toxic. Fluoride is also associated with phosphate mining and can be released to air or water sources and is in higher concentrations toxic to human health[106].

It is especially the mining workers that are exposed to severe health effects from air pollution if they do not wear proper respiratory protection gear. There are examples of workers from Moroccan mines that only wear thin disposable face masks. As a result, many workers contract illnesses directly related to severe air pollution[107].

## 3.10 Graphite

Graphite is a naturally occurring form of crystalline carbon arranged in sheets formed under high temperature and pressure. Graphite is extremely soft, cleaves with very light pressure, and has a very low specific gravity. In contrast, it is extremely resistant to heat and nearly inert in contact with almost any other material. These unique properties give it a wide range of uses in metallurgy and manufacturing. It is possible to produce synthetic graphite by heating up carbon rich materials to a temperature of about 3,000 degrees; resulting in a very high purity[108]. Graphite is mainly used in steel production but is also an important material in Li-ion battery production. Due to limited resources in the EU and its economic importance it is listed as a critical raw material.

### 3.10.1 World graphite production

Graphite is currently mined in 19 countries worldwide and the far majority (89%) comes from only three countries: China (73%), India (9%) and Brazil (7%) (see Figure 28).

[106] http://medcraveonline.com/IJH/IJH-02-00106.pdf
[107] https://www.theguardian.com/global-development/2015/dec/16/toxic-shadow-phosphate-miners-morocco-fear-they-pay-high-price
[108] https://geology.com/minerals/graphite.shtml

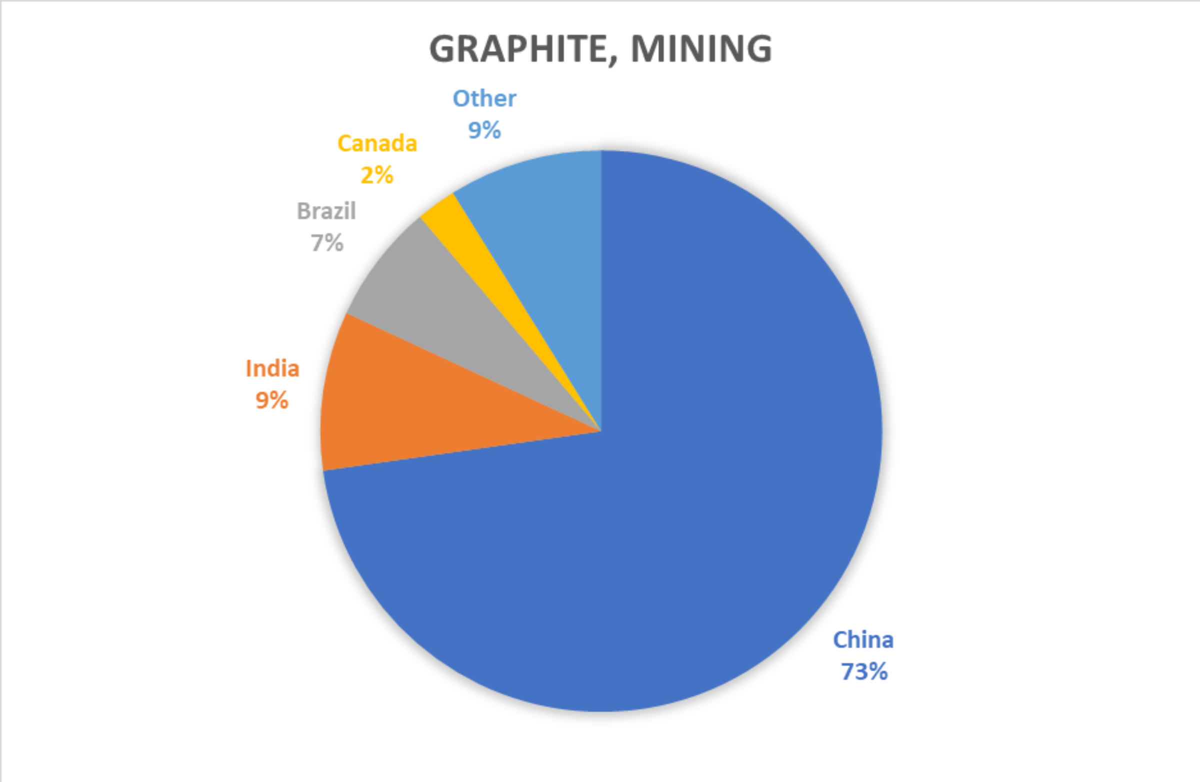


*Figure 28: Sources of World graphite production (Source: BGS).*

The annual average production of graphite was globally 1.2 million tons in the period 2013-2017. The production has been relatively stable in the same period; however, a sudden drop is seen in 2017 of about 6% (see Figure 29). Reportedly, this was due to capacity shutdowns in China as a consequence of environmental inspections[109]. It should be noted that ASM mining is occurring in a number of graphite producing countries, such as China, India and Brazil[110]. This production is not included in the national statistics

[109] https://investingnews.com/daily/resource-investing/battery-metals-investing/graphite-investing/graphite-outlook/

[110] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.

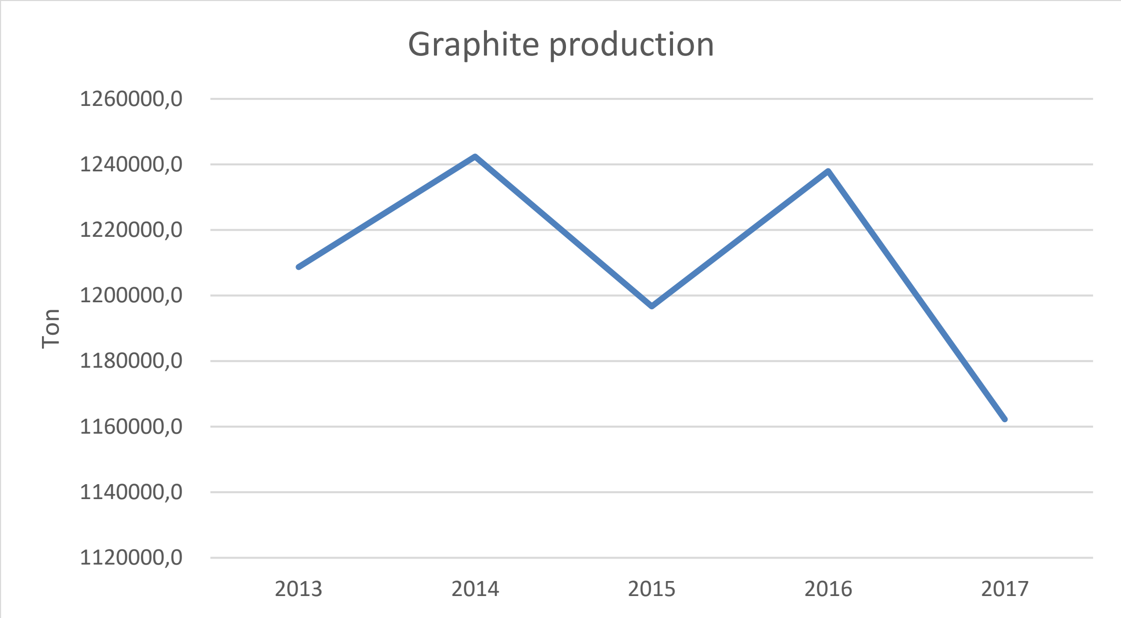


*Figure 29: Development in World graphite production in the period 2013-2017.*

### 3.10.2 End-use

More than half (66%) of globally produced graphite is used in refractory materials, which are used for very high temperature (>500 °C) applications such as in incinerators and ovens. Other applications include components in lubricants, lining of high friction products and pencils[111], as seen in Figure 30.

Graphite is an important component in Li-ion batteries used for the anode where it is typically coated onto copper foil. About 8% of the World's graphite production is used for batteries. Li-ion battery types used EVs constitute about 70% of the battery market and the share of graphite going to EV batteries is therefore estimated to about 6%.

[111] EC (2017) Critical Raw Material Factsheet

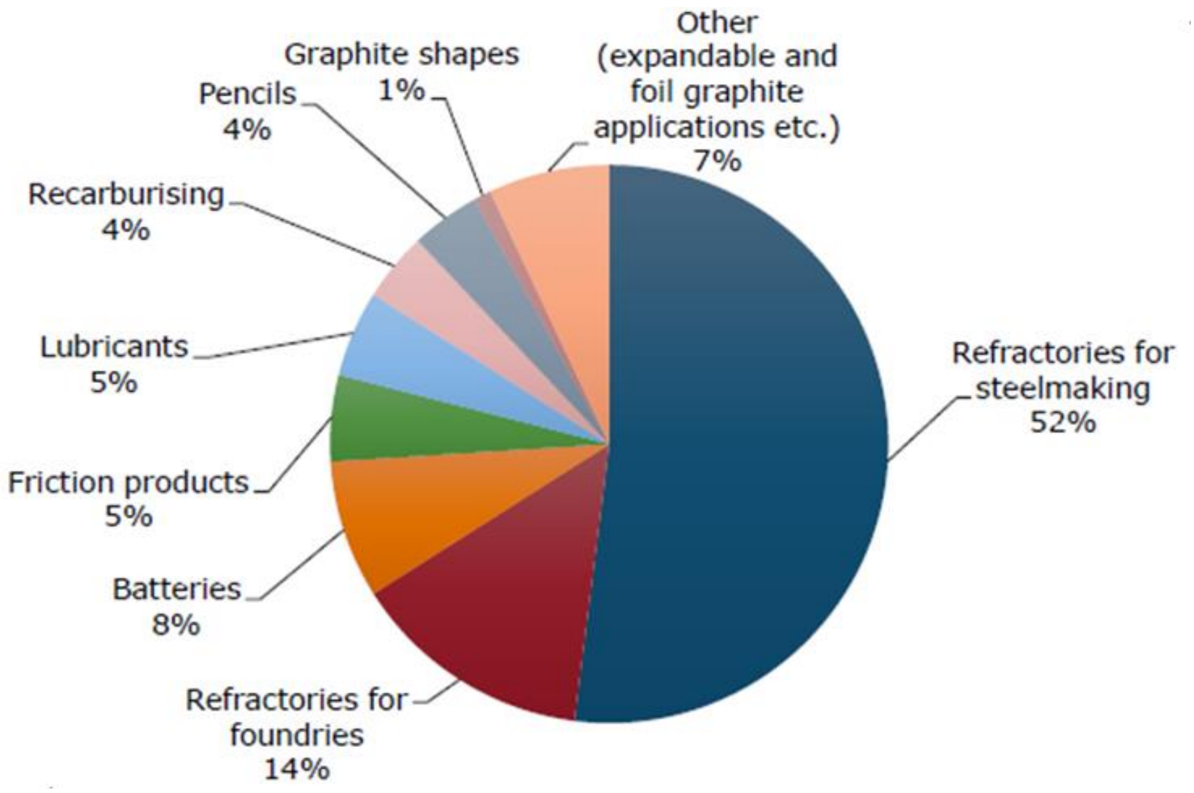


*Figure 30: End-use of global graphite demand (2014)[112]*

### 3.10.3 Forecast and reserves

The global reserves of natural graphite are estimated to be 230 million tons with the majority located in Turkey, Brazil and China. The supply of synthetic graphite is essentially unlimited since it is made from coal. Currently, China is the dominating power in graphite production, but projects are started outside China[113].

Despite synthetic graphite being perfectly applicable to Li-ion batteries it is more expensive than natural graphite and cannot acquire the same level of purity. Therefore, a future increase in demand for natural graphite will come from the Li-ion battery industry and is estimated to increase between 17 o 23% per year over the next decade[114]. 550,000 tons is expected to be demanded by the EU in 2030[115].

### 3.10.4 Governance

Five out of six governance indicators are negative with Voice and Accountability being the poorest at -0.97. The only positive indicator is Government Effectiveness at 0.39. Overall, indicator scores resemble that of China, since most of World graphite is source from here (see Table 10).

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[112] EC (2017) Critical Raw Material Factsheet
[113] https://roskill.com/market-report/natural-synthetic-graphite/
[114] https://roskill.com/market-report/natural-synthetic-graphite/
[115] Preparatory Study on Ecodesign and Energy Labelling of rechargeable electrochemical batteries with internal storage under FWC ENER/C3/2015-619-Lot 1 Task 7

*Table 10: Worldwide Governance Indicator scores for graphite producing countries. The results have been weighted by the share of World production.*

| Worldwide Governance Indicator | Weighted score |
|---|---|
| Voice and Accountability | -0.97 |
| Political Stability and Absence of Violence/Terrorism | -0.31 |
| Government Effectiveness | 0.39 |
| Regulatory Quality | -0.10 |
| Rule of Law | -0.13 |
| Control of Corruption | -0.21 |
| **Average score** | **-0.22** |

The weighted environmental performance index (EPI) classifies graphite as having a high environmental hazard potential, thereby largely supporting the WGI score. It should be noted that ASM plays a role in mining of natural graphite, and around 92% of natural graphite originates from countries known to have ASM mines such as China, india, Brazil and Mexico. However, even though 90% of graphite comes from small producers due to the geological conditions, most of the small mines are mechanised[116].

### 3.10.5 Environment

The majority of graphite is sourced from China, where there are numerous reports of environmental problems related to graphite production. A major concern is the dispersal of fine graphite dust from the mining activities that settle on the vegetation essentially killing it. In order to be utilized in Li-ion batteries the purity of the graphite needs to be very high. The purification process typically uses large quantities of strong acids. If not handled properly, the acid waste can leak into and contaminate local ground and surface waters[117].

Synthetic graphite can eliminate many of these issues, however they require a large amount of energy and the purity level is lower than what can be reached for natural graphite.

Life cycle GHG emissions from ore to refined material is estimated to between 1 and 4.4 kg CO2/kg graphite[118].

### 3.10.6 Human health and working conditions

Human health aspects of graphite mining are primarily related to the air pollution from graphite dust than can cause severe health effects such as heart attacks and respiratory diseases[119].

Due to the geological nature of graphite deposits the extraction of graphite is mostly done at a small scale in countries with a high degree of ASM[120]. Working conditions for mining workers

[116] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.
[117] https://www.washingtonpost.com/graphics/business/batteries/graphite-mining-pollution-in-china/
[118] https://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf
[119] https://www.washingtonpost.com/graphics/business/batteries/graphite-mining-pollution-in-china/
[120] Dehoust, G. et al. (manuscript submitted for publication) (2020). Environmental Criticality of Raw Materials - An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy (ÖkoRess II). Commissioned by German Environment Agency (UBA). Texte xx/2020. Dessau-Roßlau.

in China are generally described as poor with limited access to protective gear which is assumed to be the same with graphite mining.

Besides China a smaller producer of graphite is North Korea (1%), however some sources estimate its share of World production as high as 4%[121]. North Korea is associated with a number of human rights violations and mining specifically is connected to forced labour. Therefore, the UN has introduced a full ban on all minerals exported from North Korea. However, there have been reports on North Korea successfully circumventing some of these sanctions[122].

## 3.11 Shortlisting

The findings from the previous sections have been summarized in Table 11 below. Based on this data the raw materials with the highest social and environmental risks will be short-listed. However, the first criteria the selection will be based on is the current share of the global production utilised in the EV battery sector. The findings show that aluminium, iron, copper and phosphorus are all important elements of a battery; either as casing material (Al, Fe) or part of the battery chemistry (Cu, P, Mn). Nonetheless, their primary use is dominated by other sectors making their share of global production going to EV batteries negligible. It is therefore not considered meaningful to apply any regulatory or voluntary measures to these raw materials and they have then not been shortlisted.

- Al, Fe, CU, P and Mn are not shortlisted

On the other end of the scale, a large share of the global production of lithium is going into EV batteries (and batteries in general) and is only expected to increase further in the future. Even though lithium is neither on the list on of critical raw materials nor has any "high" ratings on risks related to environment or human health (see Table 11) it cannot be said to be without any risk at all, and increased demand in the future is likely to increase the risks. Lithium is therefore shortlisted based on in its extraction to a large degree being affected by the EV and ESS production.

- Lithium is shortlisted

The remaining three materials (Ni, Co and natural graphite) have medium to high shares of global production being used in batteries. The highest being cobalt and graphite with current EV battery share consumption of 9% and 6%, respectively, but both expected to increase to above 40% in the 2030 forecast. The share of global production of nickel utilised for EV batteries is currently small (3%) but expected to grow significantly in the coming decade.

Both cobalt and nickel mining and refining is related to a large range of social and environmental issues, especially cobalt which is already in the industry's focus. While the social and environmental impacts are rated low to moderate for graphite, mining of natural graphite has high shares of ASM, which mostly takes place in informal settings, which can lead to serious health and environmental impacts despite the otherwise low scores, for example no regular mine closure and no rehabilitation means destruction of ecosystems and soils.

- Nickel, cobalt and natural graphite are shortlisted.

[121] World Mining Data
[122] https://drivesustainability.org/wp-content/uploads/2018/07/Material-Change_VF.pdf

Hence, in total four key materials have been shortlisted for further in-depth supply chain assessment based on the screening: lithium, nickel, cobalt and natural graphite.

*Table 11: Summarizing table of section 3 on screening of materials*

| | Lithium | Nickel | Manganese | Cobalt | Aluminium | Iron | Copper | Phosphorus | Graphite |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | Li | Ni | Mn | Co | Al | Fe | Cu | P | C |
| **Compounds** | Li carbonate<br>Li hydroxide | | | | | Steel | | Phosphate | |
| **Global annual production (metric ton)** | 76,000 | 2,252,000 | 17,366,000 | 141,000 | 56,801,000 | 1,549,452,000 | 19,414,000 | 80,079,000 | 1,210,000 |
| **EU 2020 demand for EV batteries (metric ton)** | 5,000 | 5,000 | 5,000 | 5,000 | n/a | n/a | n/a | n/a | 25,000 |
| **EU 2030 demand for EV batteries (metric ton)** | 90,000 | 210,000 | 105,000 | 60,000 | n/a | n/a | n/a | n/a | 550,000 |
| **Price (EUR/ton)** | 9,900€<br>11,700€ | 15,400€ | 1,800€ | 32,500€ | 1,600€ | 460€ (steel) | 5,200€ | n/a | 2,700€ |
| **All batteries share% (2019)** | 56% | 6% | 2% | 49% | n/a | n/a | <0.1% | n/a | 8% |
| **EV battery share% (2019)** | 39% | 3% | 2% | 9% | n/a | n/a | <0.1% | n/a | 6% |
| **Battery types (Li-ion)** | All | NMC, NCA | LMO, NMC | LCO, NMC, NCA | All | All | All | LFP | All |
| **Governance - WGI 2.5(Best); -2.5(Worst)** | 0.97 | 0.13 | 0.11 | -0.82 | 0.05 | 0.38 | 0.32 | -0.14 | -0.22 |
| **Env. Governance Low (Best); High (Worst)** | Low | Low | High | High | Medium | Low | Medium | Medium | High |
| **Critical Raw Material (EU)** | Non-critical | Non-critical | Non-critical | Critical | Non-critical | Non-critical | Non-critical | Critical | Critical |
| **EU Economic importance** | 2.4 | 4.8 | 6.1 | 5.7 | 6.5 | 6.2 | 4.7 | 5.1 | 2.9 |
| **EU Supply Risk** | 1.0 | 0.3 | 0.9 | 1.6 | 0.5 | 0.8 | 0.2 | 1.0 | 2.9 |
| **CO2-emission (kgCO2/kg)** | 2 (brine)<br>27 (hard rock) | 5.25-10 | 6 | 1.45-10 | 12 | 1.7-1.9 (steel) | 1-5 | n/a | 1-4.4 |
| **Env. Hazard Potential** | Medium | High | Medium | High | Medium-high | Medium | High | High | Low |
| **Environment** | Low | Very high | High | Very high | High | High | Very high | Moderate | Low |
| **Working conditions** | Low | Low | Moderate | Very high | Low | Low | Low | Moderate | Low |
| **Human health** | Low | High | Moderate | Moderate | High | High | Very high | High | Moderate |
| **ASM relevance** | No | No | Yes | Yes | No | No | No | No | Yes |

# 4. Supply chain analysis

In this section the supply chains for the short-listed materials will be detailed further. The supply chain means all the processes of these metals from mining until they are part of a battery that is placed in the market. This is important, because the possible regulation is intended to apply to batteries placed on the EU market, and hence all risks along the supply chain of the selected materials will need to be accounted for in the due diligence procedure for the battery, not only risks related to mining.

For each of the shortlisted materials, the supply chains are detailed from the mining to the refining step, after which the material is usually in a form that can be traded as a commodity.

The process after refining involves mixing of different compounds and is therefore described below, before the material-specific sections. The refined materials need to be further processed into active materials specifically suited for batteries. This process is often done by specialised companies, before it is sold to cell manufacturers, and includes mixing of different compounds (e.g. nickel, cobalt and manganese are mixed for the cathode active material for NMC batteries) and can involve energy consuming processes such as burning in furnaces.

The cell manufacturers then further prepare the active materials by mixing them with binder, carbon and a solvent into a slurry, which is then coated onto copper foil (for anodes) or aluminium foil (for cathodes), see Figure 31. The coated foils are then compressed to control the electrode density (a process called calendaring), and then dried with heat to evaporate the solvent. Finally, the electrodes are cut into the correct shape and size for the specific cell[123]. After that comes that assembly of the battery cells[124], where the current carrying electronics are added, and when cells are then assembled into modules and then packs, the battery management system (BMS), heating and cooling etc. is added. This final assembly into packs are usually performed by the ESS or EV manufacturer (to make it fit the specific car/ESS system).

[123] https://www.batterypoweronline.com/articles/optimal-rheology-better-electrodes-understanding-the-links-between-battery-slurry-properties-and-electrode-performance/
[124] https://www.mpoweruk.com/battery_manufacturing.htm

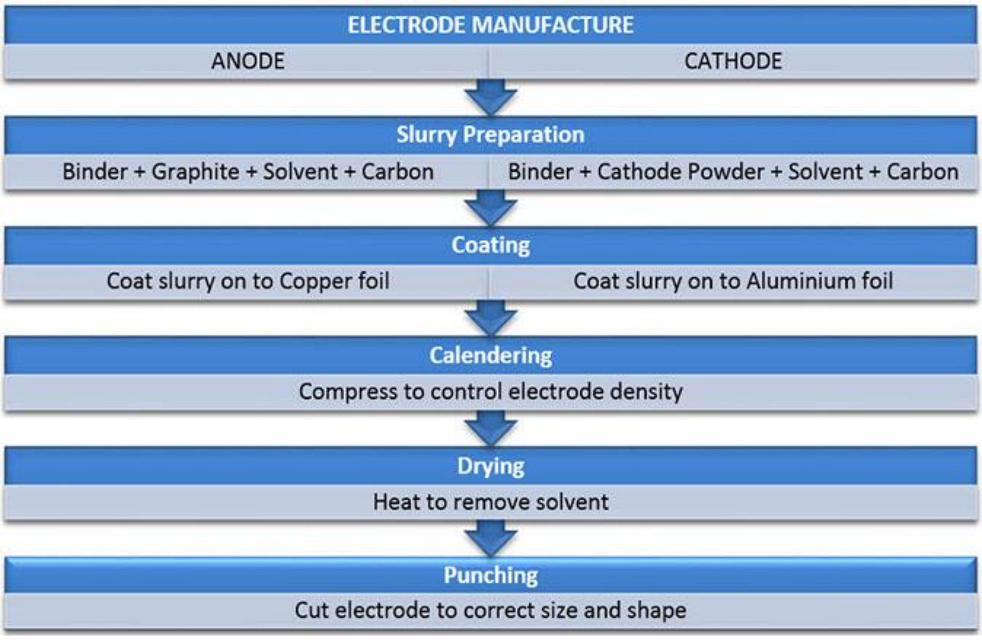


*Figure 31: General process of electrode manufacturing for batteries[125].*

Hence, the materials are traded several times throughout the supply chain, also after they have been integrated into battery parts (e.g. electrodes, cells). Regarding geographical location of these processes, China plays a major role on the global battery market.

Table 12 shows the production data for the components of lithium-ion batteries and the market shares (based on GWh) in different countries[126]. As seen from the table the major manufacturers of lithium-ion batteries (around 85% of the manufacturing capability) are China, Japan and Korea[127].

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[125] https://www.batterypoweronline.com/articles/optimal-rheology-better-electrodes-understanding-the-links-between-battery-slurry-properties-and-electrode-performance/

[126] Thielmann, Axel; Neef, Christoph (2019): Lithium-ion battery industry structure - Global value-creation chains and market structure. Internal Presentation, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany.

[127] Olivetti, Elsa A.; Ceder, Gerbrand; Gaustad, Gabrielle G.; Fu, Xinkai (2017): Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. Joule 1, pp. 229-243.
And: Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61.
And: Mercator Institute for China Studies (merics) (2018): China's battery industry is powering up for global competition. Link: https://www.merics.org/en/blog/chinas-battery-industry-powering-global-competition

*Table 12: Geographical distribution of market shares for lithium-ion battery component production*

| Material | Application | Market shares | |
|---|---|---|---|
| Cathode active materials | NMC, LCO and NCA for the greatest part | China (50%)<br>Japan (20%)<br>Korea (15%) | Belgium (10%)<br>Others (5%) |
| Anode active materials | Mainly, synthetic and natural graphite | China (65%)<br>Japan (29%) | Korea (3%)<br>Others (3%) |
| Electrolytes | Mostly based on $LiPF_6$ salt and carbonate solvents | China (72%)<br>Japan (23%) | Korea (3%)<br>Germany (2%) |
| Separators | Among others polyethylene or polypropylene based | Japan (58%)<br>China (33%) | Korea (7%)<br>US (2%) |
| Lithium-ion battery cells | Cell assembly | China (65%)<br>Japan (15%)<br>Korea 13% | US (3%)<br>EU (1%)<br>Others (6%) |

## 4.1 Cobalt

The flow of cobalt from the natural deposits to its use in batteries can be described by the process chain depicted in Figure 32. This process chain is a highly stylized representation of the different types of cobalt production techniques/processes that are employed at different production sites (depending among others on the type of cobalt ore processed) and differ significantly from each other regarding the chemical and energetic process requirements. All major types of ores can be used for production of class-I cobalt (i.e. cobalt metal) and cobalt chemicals, which are used for battery production[128].

Many of the chemicals involved in the production of cobalt (e.g., nickel tetracarbonyl[129]) are highly toxic and environmentally hazardous. In the following, the technical aspects of each of the steps of the process chain depicted in Figure 32 are described.

[128] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122
[129] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.

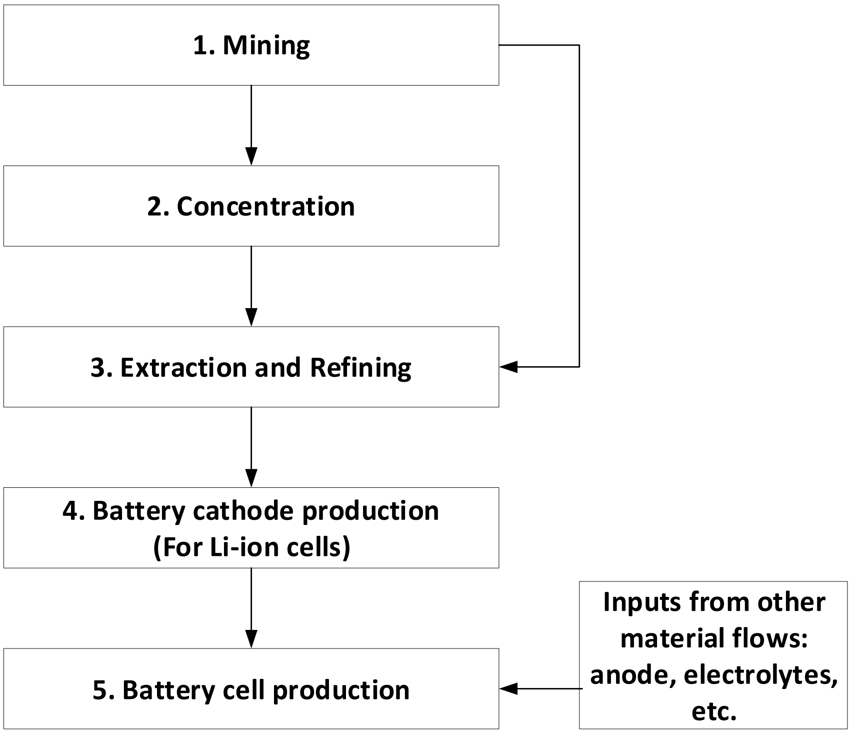


*Figure 32: Stylized representation of the Cobalt supply chain for Li-ion batteries.*

The main battery types containing cobalt are[130]:

- Lithium-ion batteries:
    - lithium cobalt oxide (LCO) batteries (used in the portable electronics market)
    - lithium nickel cobalt aluminium oxide (NCA) batteries (used in the automobile industry)
    - lithium nickel manganese cobalt oxide (NMC) batteries (used in the automobile industry and in cutting tools).
- Nickel metal hydride (NiMH) batteries (used in hybrid vehicles and power tools)
- Nickel cadmium (NiCd) batteries (industrial batteries and in power tools)

Cobalt has many different uses in various final products, other than batteries[131]:

a) bonding agent in cemented carbides (used as cutting tools),
b) uses of cobalt alloys (numerous applications; e.g., surgical implants, magnets, springs, and blades in aircraft engines)

[130] Olivetti, Elsa A.; Ceder, Gerbrand; Gaustad, Gabrielle G.; Fu, Xinkai (2017): Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. Joule 1, pp. 229-243.
And: Cobalt Institute (2019): Cobalt in Batteries. Link: https://www.cobaltinstitute.org/assets/files/Pages%20PDFs/Infographic-Cobalt-Batteries.pdf

[131] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.

c) uses of cobalt compounds/chemicals (in glasses, ceramics, refractories, driers, paints, varnishes, dressings[132], electronics, solid-state devices, and batteries; in electroplating, agriculture, nutrition and medicine; as catalyst).

For battery production specifically, the following compounds have been identified to be used: Cobalt powder and certain cobalt compounds/chemicals (cobalt sulphates, hydroxides and oxides) are used for battery production[133] cathode and anodes. For lithium-ion batteries cobalt is used in cathodes, whereas it can also be used in the anodes of other types of rechargeable batteries such as nickel-metal hydride rechargeable batteries[134].

It should be noted that metallic cobalt is thus not used directly in the cell, but that various steps take place as part of the cathode production step. One article state that different cobalt chemicals (sulphates, oxides, and cobalt powder) are all used on battery production[135], while one cell manufacturer stated in relation to the study that predominantly cobalt sulphates are used in battery cathode production for Li-ion batteries.

However, none of these compounds are used directly in batteries, but they are used to produce complex chemicals, such as:

- lithium cobalt oxide (LCO)
- lithium nickel cobalt aluminium oxide (NCA)
- lithium nickel manganese cobalt oxide (NMC)
- As well as other chemicals that are used in nickel metal hydride (NiMH) and nickel cadmium (NiCd) batteries.

### 4.1.1 Mining

Cobalt can be regarded as a by-product of the production processes of copper, nickel, silver and other metals[136], and therefore, the estimated losses of cobalt in mining are relatively high; for example the loss rate in China is estimated to 50%[137]. Losses here means that because the cobalt is seen as a by-product, it ends up in the mining waste, but it might potentially be available for future “re-mining” from heaps or ponds where mining waste is deposited.

The main types of cobalt ores are arsenide ores, sulfoarsenide ores, sulphide ores and oxide ores138. The ores of major importance for battery production are nickel sulphides, nickel

[132] This refers to the treatment of soils to correct cobalt deficiencies in soils
[133] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
And: Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.
And: Olivetti, Elsa A.; Ceder, Gerbrand; Gaustad, Gabrielle G.; Fu, Xinkai (2017): Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. Joule 1, pp. 229-243.
[134] Berndt, D. (2014). Batteries, 3. Secondary Batteries. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.o03_o12 . P41
[135] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122
[136] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.
[137] Harper, E.M.; Kavlak, G.; Graedel, T.E. (2012): Tracking the Metal of the Goblins: Cobalt’s Cycle of Use. Environmental Science & Technology 46, 1079−1086.
[138] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465

limonite, copper-cobalt sulphides and copper cobalt oxides[139]. The ores come from both artisanal and small-scale as well as industrial large-scale mines in for example DRC[140]. The global cobalt production share from ASM is between 10-30%, whereas in some countries, cobalt the target of ASM, especially in DRC. Here the numbers on the ASM production share vary between 35 and 90% of the national production. Besides DRC, other cobalt producing countries have prominent ASM production, for example China, Zambia, Philippines, Brazil and Madagascar. In total 84 % of cobalt is produced in countries with ASM[141]. Table 13 shows the cobalt world production by country from 2012-2016, including cobalt used for both class-I cobalt and for the chemicals that are used in battery production.

*Table 13: Cobalt World Mine Production, by Country or Locality[1, 2] (Source: USGS (2016)).in Metric tons,*

| Country or locality[3] | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Australia[4] | 5.870 | 6.410 | 5.978 | 6.000 e | 5.500 e |
| Botswana[5] | 195 | 248 | 196 | 316 | 281 |
| Brazil | 2.900 | 3.500 | 3.828 | 3.800 e | 300 e |
| Canada[6] | 3.698 r | 4.005 r | 3.907 r | 4.339 r | 4.245 p |
| China[e] | 2.200 r | 2.600 r | 2.800 r | 3.000 r | 3.100 |
| Congo, (Kinshasa)[e, 7] | 52.000 | 56.000 | 62.000 r | 66.000 r | 64.000 |
| Cuba[e, 8] | 4.700 r | 4.000 r | 3.700 | 4.300 | 5.100 |
| Finland[e] | 635 | 750 | 770 | 440 | 690 |
| Indonesia[e, 9] | 1.700 | 1.700 | 1.300 | 1.300 | 1.200 |
| Madagascar[e, 10] | 600 r | 2.400 r | 3.400 r | 4.000 r | 3.800 |
| Mexico[e] | -- | -- | -- | -- | 980 |
| Morocco[e, 11] | 2.000 | 2.000 | 2.150 | 2.250 r | 2.400 |
| New Caledonia[e, 12] | 2.670 | 3.190 | 4.040 | 3.690 r | 3.390 |
| Papua New Guinea[13] | 469 | 1.013 | 2.134 | 2.505 | 2.191 |
| Philippines[e, 14] | 2.700 | 2.800 | 4.600 | 4.300 | 4.100 |
| Russia[e, 15] | 6.300 | 6.300 | 6.300 | 6.200 | 5.500 |
| South Africa[e] | 2.500 | 3.000 | 3.000 | 2.900 r | 2.300 |
| United States[e, 15, 16] | -- | -- | 120 | 760 | 690 |
| Vietnam[15] | -- | 25 e | 223 | 277 | 134 |
| Zambia[17] | 5.435 | 5.919 | 4.600 e | 4.000 r, e | 3.000 e |
| Zimbabwe[18] | 195 | 319 | 358 | 355 r | 409 |
| Total | 96.800 r | 106.000 r | 115.000 r | 121.000 r | 113.000 |

[e]Estimated. [p]Preliminary. [r]Revised. -- Zero.

1 Includes data available through February 8, 2018. All data are reported unless otherwise noted. Totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.
2 Figures represent recoverable cobalt content of ores, concentrates, or intermediate products from cobalt, copper, nickel, platinum, or zinc operations.
3 In addition to the countries and (or) localities listed, Spain and Turkey are known to produce ores that contain cobalt, but information was inadequate to make reliable estimates of production. Poland produced copper ore containing 1,500 to 5,000

139 Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122
140 Resourcing Consulting Services Limited (RCS Global) (2016): The Battery Revolution: Balancing Progress with Supply Chain Risks. RCS Global Industry Briefing Paper. Link: https://www.rcsglobal.com/the-battery-revolution-balancing-progress-with-supply-chain-risks/
141 https://www.ifeu.de/en/project/oekoress-ii/ commissioned by German Environment Agency (UBA)

metric tons per year of cobalt, which was not recovered. Other copper-, nickel-, platinum-, or zinc-producing nations may also produce ores containing cobalt as a byproduct component, but recovery is small or nil.
4 Cobalt content of lateritic nickel ore and nickel concentrate reported by the government of Western Australia.
5 Reported cobalt content of pelletized nickel-copper matte.
6 Recoverable cobalt in ores and concentrates shipped.
7 Determined from estimated cobalt content of ores, concentrates, refined cobalt metal, and intermediate products such as crude cobalt alloys, crude cobalt hydroxide, and crude cobalt carbonate, produced from cobalt ores and concentrates, tailings, and slags sourced from Congo (Kinshasa).
8 Determined from estimated cobalt content of nickel-cobalt sulfide production and estimated cobalt content of ammoniacal liquor production.
9 Cobalt content of nickel matte plus estimated cobalt in lateritic ore processed in Australia.
10 Data are estimated cobalt content of ore production based on reported cobalt metal powder production and nickel recovery rates.
11 Cobalt content of concentrate estimated from reported gross weight.
12 Cobalt contained in the following materials: cobalt chloride produced in France from New Caledonian matte, cobalt carbonate and nickel hydroxide produced in New Caledonia, and lateritic nickel ore exported to Australia.
13 Cobalt content of nickel-cobalt hydroxide.
14 Cobalt contained in the following materials: nickel-cobalt sulfide produced in the Philippines and lateritic nickel ore exported to Australia.
15 Cobalt content of concentrates.
16 Negligible production prior to 2014.
17 Data for 2012−13 were reported by the Bank of Zambia.
18 Production reported by the Zimbabwe National Statistics Agency.

### 4.1.2 Concentration

The concentration is the separation of cobalt-bearing minerals from other minerals and gangue. In the mined ores cobalt content can be as low as around 2% of the volume. The concentration step is therefore usually done in the mining country to avoid transporting large amounts of ore. The concentration step is primarily taken in the case of sulphide ores. In the case of nickel limonite and copper-cobalt oxide ores, the typical concentration step is not taken. Rather, the ores are sent directly (after some screening and upgrading) to the extraction step[142]. Since artisanal mines primarily deals with copper-cobalt oxide ores[143], and they are not involved on the concentration of nickel-bearing ores, this step is often not taken for artisanal mined cobalt ore. In general, concentrates are produced in order to be traded internationally (see section 4.1.5).

The main method used for concentration of cobalt ores is froth flotation, while gravity separation can also be used. The methods used for concentration and, in particular, the chemicals used for froth flotation (lime, xanthate, hydrolyzed palm oil, gas oil, sodium cyanide etc.) differ across production sites and depend on the type of ore that is concentrated. Cobalt content of cobalt concentrates obtained by these concentration methods is up to 15% but in general much lower, down to a few percent[144].

### 4.1.3 Extraction and refining of cobalt

The extraction and refining of cobalt can be from cobalt concentrates or sometimes directly from cobalt ores that are not concentrated (see above). The main methods used for extraction and refining are hydrometallurgical methods, pyrometallurgical methods, electrometallurgical methods and vapometallurgical methods.

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[142] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.115.
[143] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.115.
[144] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.

In the hydrometallurgical methods the main steps are[145]:

i. Preparation of cobalt concentrates
ii. Leaching of cobalt concentrates (i.e., creation of a solution containing cobalt ions)
iii. Separation of cobalt ions from other metal ions contained in the solution
iv. Reduction of cobalt ions to metal.

The details of this process differ across cobalt production sites depending on the type of the ore/concentrate that is extracted/refined. In particular, there are differences in the type of the preparatory process (roasting[146]/smelting), leaching media (acidic/alkaline), required pressure and heat, etc.

The pyrometallurgical methods involve, e.g., mixing of cobalt concentrates with lime and coal, melting of the mixture and further processing of the resulting cobalt alloys for cobalt (and other metals).

Electrometallurgic method is the electrolysis of sulphate or chloride solutions for electro-winning and refining of cobalt, whereas vapometallurgical[147] method is the chemical vaporisation of the metal in the ore by using gases (carbon monoxide among others) and subsequent collection.

These different processes are all energy consuming, because heat and pressure is applied at the different steps of the processes. For example the Sherritt Gordon process (used at Fort Saskatschewan in Canada), which is a hydrometallurgical process that involves the following steps[148]:

- pressure leaching at 83°C and 7 bar
- pressure oxidation hydrolysis reaction at 65 bar
- sulfuric acid leaching at 140°C and 64 bar
- hydrogen treatment at 120°C and 46 bar

Falconbridge in Canada and Norway leach sulphide concentrates at 70°C and ambient pressure, while Laterite ores are typically acid leached at 250°C. Cobalt is more energy intensive that production of nickel and lithium, in terms of lifecycle energy[149].

Since cobalt for batteries can be produced in many different ways150 and from many different intermediate products (concentrates, matte, sulphides and hydroxides) using many different processes (froth flotation, smelting, roasting, leaching, pressure leaching, electrowinning...), it

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[145] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.
[146] Roasting means heating of the ore/concentrate (below melting point). For example, cobalt containing arsenide ores are roasted at 600-700°C.
[147] British Geological Survey (BGS) (2009): Mineral Profile. Cobalt. August 2009. Link: https://www.bgs.ac.uk/mineralsUK/statistics/mineralProfiles.html
[148] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465
[149] Dunn, J.B; Gaines, L.; Kelly, J.C.; James, C.; Gallagher, K.G. (2015). The significance of Li-ion batteries in electric vehicle life-cycle energy and emissions and recycling's role in its reduction. Energy and Environmental Science 8, 158–168.
[150] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.1115f.

has not been possible to separate cobalt-for-batteries production from cobalt-for-other-uses production at the extraction stage.

During the extraction/refining-process, different types of intermediate products arise, e.g., matte or cobalt hydroxide[151]. Some of these intermediates (in particular, cobalt hydroxide) are not only further transformed into refined cobalt (chemicals), but also put on the market for other uses than batteries and exported[152].

Table 14 and Table 15 gives an overview of the geographical location of the global cobalt refinery production, based on company and country/locality, respectively.

*Table 14: Refined Cobalt Production (Tonnes) of Cobalt Institute Member and Non-Member Companies[153]*

| MEMBER COMPANIES | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| Ambatovy, Madagascar | 0 | 0 | 2,083 | 2,915 | 3,464 | 3,273 | 3,053 | 2,852 |
| BHPB/QNPL, Australia(1) | 2,631 | 2,369 | 0 | 0 | 0 | 0 | 0 | 0 |
| CTT, Morocco | 1,788 | 1,314 | 1,353 | 1,391 | 1,722 | 1,568 | 1,428 | 1,619 |
| Eramet, France | 354 | 326 | 308 | 219 | 133 | 119 | 277 | 48 |
| Gecamines, DRC(2) | 650 | 870 | 700 | 500 | 400 | 400 | 400 | 400 |
| Glencore(3): Katanga, DRC | | | | 2,800 | 2,900 | 0 | 0 | 0 |
| Minara, Australia | | | | 2,900 | 3,300 | 3,200 | 3,000 | 3,200 |
| Mopani, Zambia | | | | 0 | 0 | 0 | 0 | 0 |
| Nikkelverk/Raglan/Sudbury(4) | 3,067 | 2,969 | 3,400 | 3,600 | 3,100 | 3,500 | 3,500 | 4,200 |
| NPMC, Canada (was ICCI) | 3,853 | 3,792 | 3,319 | 3,210 | 3,733 | 3,693 | 3,601 | 3,234 |
| Freeport Cobalt, Finland (was OMG) | 10,441 | 10,547 | 10,010 | 11,452 | 8,582 | 11,187 | 12,221 | 12,874 |
| Rubamin, India (Left CI 2012)(5) | 579 | 200 | 45 | 0 | 0 | 0 | 0 | 0 |
| Sumitomo, Japan | 2,007 | 2,542 | 2,747 | 3,654 | 4,259 | 4,305 | 4,159 | 3,669 |
| Umicore, Belgium (6) | 3,187 | 4,200 | 5,415 | 5,850 | 6,306 | 6,329 | 6,987 | 6,360 |
| Vale, Canada | 2,070 | 1,890 | 2,240 | 2,051 | 1,858 | 1,851 | 2,906 | 2,918 |
| Chambishi, Zambia (7) | 4,856 | 5,435 | 5,000 | 4,317 | 2,997 | 4,725 | 2,520 | 1,613 |
| **TOTAL** | **35,483** | **36,454** | **36,620** | **44,859** | **42,754** | **44,150** | **44,052** | **42,987** |

[151] Donaldson, John Dallas; Beyersmann, Detmar (2011): Cobalt and Cobalt Compounds. In: Fritz Ullmann (ed.): Ullmann's Encyclopedia of Industrial Chemistry, Bd. 9. 7th. Edition. Weinheim, Germany: Wiley-VCH, pp. 430-465.
And Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
And Farjana, Shahjadi Hisan; Huda, Nazmul; Mahmud, M.A. Parvez (2019): Life cycle assessment of cobalt extraction process. Journal of Sustainable Mining 18, pp.150-161
[152] Farjana, Shahjadi Hisan; Huda, Nazmul; Mahmud, M.A. Parvez (2019): Life cycle assessment of cobalt extraction process. Journal of Sustainable Mining 18, pp.150-161
and Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
[153] Source: https://www.cobaltinstitute.org/statistics.html

| Non-Member companies | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|
| China (8) | 34,969 | 29,784 | 36,062 | 39,292 | 48,719 | 45,046 | 69,600 | 78,360 |
| India (9) | 720 | 600 | 250 | 100 | 150 | 100 | 100 | 100 |
| Kasese, Uganda | 661 | 556 | 376 | 0 | 0 | 0 | 0 | 0 |
| Katanga, DRC (See Glencore)(10) | 2,433 | 2,129 | 2,300 | 0 | 0 | 0 | 0 | 0 |
| Minara, Australia (See Glencore)(10) | 2,091 | 2,400 | 2,700 | 0 | 0 | 0 | 0 | 0 |
| Mopani, Zambia (See Glencore)(10) | 1,100 | 230 | 0 | 0 | 0 | 0 | 0 | 0 |
| Norilsk, Russia(11) | 2,337 | 2,186 | 2,368 | 2,302 | 2,040 | 3,092 | 2,077 | 1,800 |
| QNPL, Australia(12) | 0 | 0 | 2,281 | 2,519 | 1,850 | 0 | 0 | 0 |
| South Africa | 840 | 1,100 | 1,294 | 1,332 | 1,300 | 1,101 | 1,062 | 1,089 |
| Votorantim, Brazil | 1,613 | 1,750 | 1,653 | 1,350 | 1,300 | 400 | 46 | 8 |
| TOTAL | 46,764 | 40,735 | 49,284 | 46,895 | 55,359 | 49,739 | 72,885 | 81,357 |
| DLA Deliveries | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL SUPPLY** | **46,764** | **40,735** | **49,284** | **46,895** | **55,359** | **49,739** | **72,885** | **81,357** |

1. 2009: BHPB 700mt Jan - Jul and Queensland Nickel Pty (QNPL) 1000mt Aug-Dec. (See also Note 12).
2. Estimated production after 2012.
3. Glencore joined CI 2014.
4. Previously reported as Xstrata, Norway.
5. Rubamin joined CI in 2009 and left in 2013.
6. Includes Umicore's global refined production.
7. Chambishi Metals plc Zambia (ERG).
8. Excludes Umicore's refined production in China.
9. Excludes Rubamin between 09 and 13 & est thereafter.
10. From 2014 this reports as Glencore in Table 1.
11. Norilsk ceased to be a CI member in 2009.
12. QNPL ceased to be a CI Member from 2014. Ceased trading 2016.

*Table 15: Cobalt World Refinery Production, by Country or Locality[1, 2] (Metric tons, cobalt content)[154]*

| Country or locality and form | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Australia, metal powder and oxide hydroxide[3] | 4.859 [4] | 4.981 | 5.419 | 5.150 | 3.350 [e] |
| Belgium, metal powder, oxide, hydroxide[3, 5] | 4.200 | 5.415 | 5.850 | 6.306 | 6.329 |
| Brazil, metal | 1.750 | 1.871 | 1.350 | 1.300 [3] | 400 [3] |
| Canada, metal, metal powder, oxide | 5.775 [r] | 5.602 | 5.491 | 6.126 [r] | 6.355 [p] |
| China, metal, metal powder, oxide, salts[e, 3, 6] | 29.800 | 36.100 | 39.300 | 48.700 | 45.000 |
| Congo, (Kinshasa), metal[7] | 3.021 | 2.777 | 2.859 | 3.141 | 82 |
| Finland, metal powder and salts[8] | 10.562 [*] | 10.798 | 12.551 | 9.615 | 12.393 |
| France, chloride[3] | 326 | 308 | 219 | 133 | 119 |
| India, metal and salts[3] | 800 | 295 | 100 | 150 | 100 |
| Japan, metal[3] | 2.542 | 2.747 | 3.654 | 4.259 | 4.305 |
| Madagascar, metal powder | 493 | 2.083 | 2.915 | 3.464 | 3.273 |
| Mexico, metal | -- | -- | -- | -- | 419 |
| Morocco, metal | 1.314 | 1.353 | 1.391 | 1.982 [r] | 2.081 |
| Norway, metal[9] | 2.969 | 3.348 | 3.600 | 3.100 | 3.500 |
| Russia, metal[3] | 2.186 | 2.368 | 2.302 | 2.040 | 3.092 |
| South Africa, metal powder and sulfate | 1.102 | 1.294 | 1.332 | 1.300 | 1.101 |
| Uganda, metal[3] | 556 | 376 | -- | -- | -- |
| Zambia, metal[3] | 5.669 [10] | 5.000 | 4.317 | 2.997 | 4.725 |
| Total | 77.900 [r] | 86.700 | 92.700 | 99.800 [r] | 96.600 |

[e]Estimated. [p]Preliminary. [r]Revised. -- Zero.

[154] U.S. Geological Survey (USGS) (2016): Minerals Yearbook, Cobalt, 2016 tables-only release. Link: https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information

1 Includes data available through February 8, 2018. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
2 Figures represent cobalt refined from ores, concentrates, or intermediate products and do not include productionfd of downstream products from refined cobalt.
3 Production reported by the Cobalt Development Institute, except as noted.
4 Production reported by the Cobalt Development Institute and Glencore plc.
5 Production from n.v. Umicore s.a.; includes production from China that is not otherwise included in this table.
6 Production from domestic and imported ores, concentrates, and intermediate materials; excludes production by n.v. Umicore s.a. that is included under Belgium.
7 Does not include production of cobalt in alloys, carbonate, hydroxide, and other materials that would require further refining.
8 Production reported by the Geological Survey of Finland.
9 Data were reported by Xstrata plc for 2012, the Geological Survey of Norway for 2013, and Glencore plc for 2014–16*
10 Includes production reported by Zambian Chamber of Mines.

### 4.1.4 Further processing and cell manufacturing

After the refining step, the cobalt has been transformed into forms that are traded as commodities for different uses. However, in order to be used in batteries the cobalt compounds need to be further processed into active materials specifically suited for batteries (see section 4 introduction). This can involve mixing of different compounds for the electrode to create the active cathode materials needed for batteries.

### 4.1.5 Geographic routes of cobalt for batteries

A 2016 article investigated the primary production routes of cobalt (and nickel) used for Li-ion batteries155. Figure 33 and Figure 34 show the trade flows of cobalt metal and cobalt chemicals, respectively, as well as the relevant intermediate products. Both cobalt (metal) powder and cobalt chemicals (sulphates, hydroxides and oxides) are used in battery production, but unfortunately, the available trade data is not specific enough to include only the cobalt used in batteries. Thus, the cobalt flows depicted in Figure 33 and Figure 34 do not only depict the cobalt products that are relevant for battery production (powder, sulphates, hydroxides and oxides) but also other products:

- Figure 33 depicts the flow of "cobalt class I". This category does not only include cobalt (metal) powder but also other forms of cobalt metal (e.g. briquettes and cathodes).
- Figure 34 depicts the flow of "cobalt chemicals". This category does not only include sulphates, hydroxides and oxides, but also possibly carbonates and other cobalt chemicals, which are not used in batteries.

It is, however, the most comprehensive source of trade flow data that the study team was able to find, and it does give a proxy for the global trade flows of cobalt specifically for batteries.

[155] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.

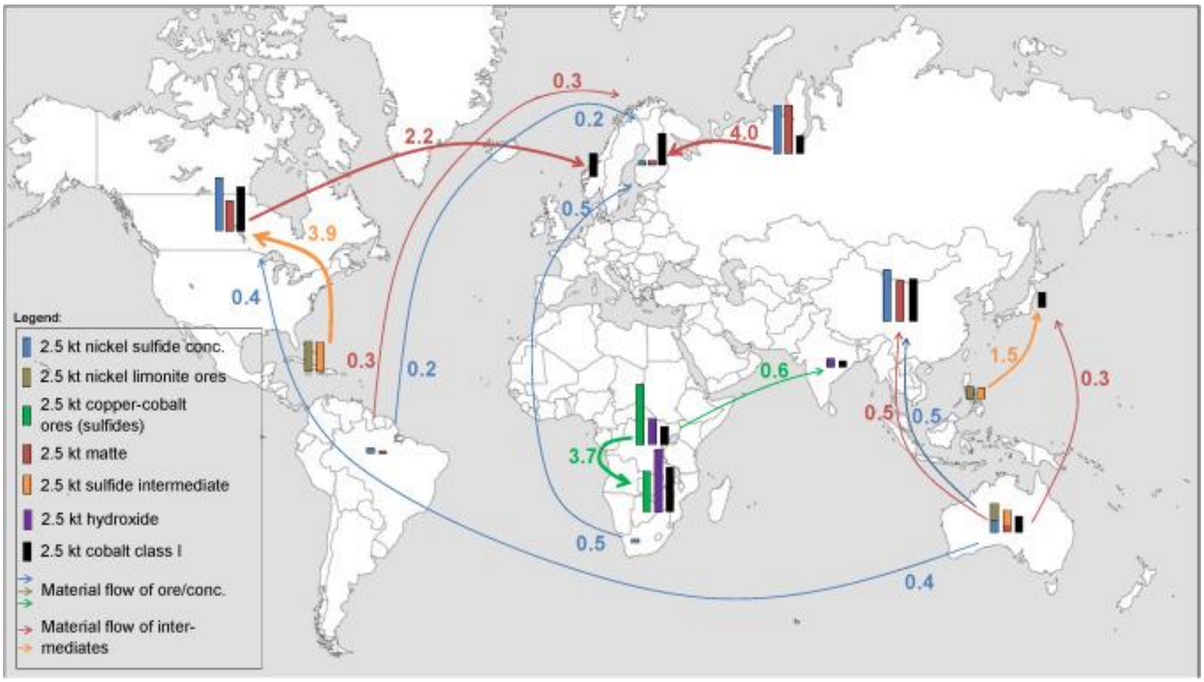


*Figure 33: Primary production and global trade flows of "cobalt metal"/"cobalt class I" (year 2011; kt cobalt content). Red: flow of matte. Matte is an intermediate product that is obtained after roasting/smelting. Orange: flows of sulphide intermediates. They are obtained by leaching of (nickel limonite) ores. Blue: flow of nickel sulphide concentrate, which is obtained after concentration of (nickel sulphide) ores. Brown: nickel limonite ores. Green: copper-cobalt sulphide ores.*

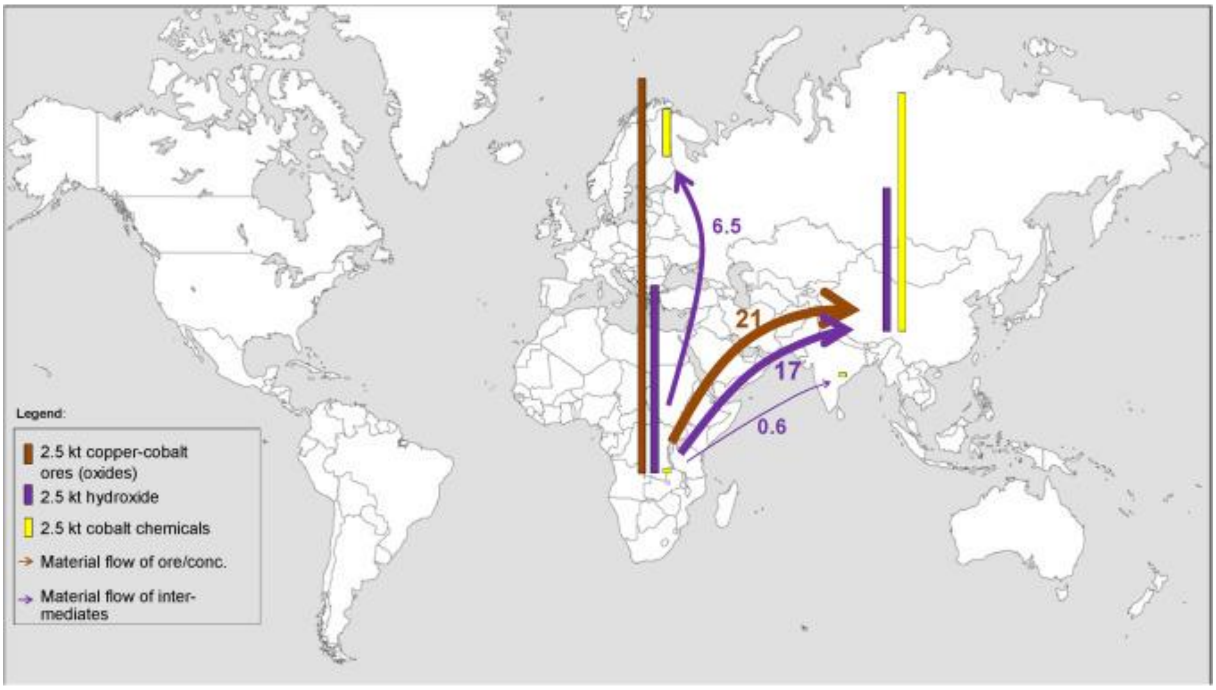


*Figure 34: Primary production and global trade flows of "cobalt chemicals" (year 2011; kt cobalt content). Brown: flow of copper-cobalt oxide ores. Purple: flow of hydroxide intermediates. They are obtained after leaching of copper-cobalt oxide ores.*

The article[156] identified three major primary production routes for cobalt metal/cobalt class I, and one for cobalt chemicals. The cobalt metal/ class I routes include:

- the nickel sulphide route (sulphide concentrate is transformed into matte and then into cobalt metal)
- nickel limonite route (limonite ores are transformed into sulphide/hydroxide intermediates and then into cobalt metal)
- copper-cobalt sulphide route (copper-cobalt sulphide ores are transformed into hydroxide intermediates and then into cobalt metal).

These are the routes depicted in Figure 33. All these ores, concentrates and intermediates are used in the production of cobalt metal/powder.

The "cobalt chemicals" route identified by Schmidt et al. (2016) is the copper-cobalt oxide route, along which copper-cobalt oxide ores are transformed into hydroxide intermediates and then into cobalt chemicals. This route is depicted in Figure 34. These ores and intermediates are used in the production of cobalt chemicals.

The figures show that DRC and China are major players in the worldwide supply chains of cobalt, and Finland also plays a role for both. It is also possible to see that the majority of cobalt chemical production (Transformation from ore to chemicals) happens in China, and to a smaller extent Finland. For the cobalt metal trade flows also Canada, Australia, Russia, Cuba and Brazil play a role in production of intermediates and cobalt metal.

According to this model, the cobalt metal and cobalt chemicals are produced through different routes, and there might thus be some mixing of the flows. However, it is also possible to produce cobalt chemicals from cobalt class I, but there is only little information available on the exact production processes of cobalt chemicals in the context of battery production specifically. This is true for all/most studies that try to identify the flows of metals from extraction to its uses in batteries.

### 4.1.6 Cobalt price fluctuations

Cobalt prices have fluctuated considerably in the past decades due to a variety of factors including geopolitical unrest, recessions, stockpiling and de-stocking and joint price setting from major producers.

The most recent development is shown in Figure 35, which shows that prices have been increasing dramatically for a two-year period from 2016 to 2018. This can be explained by higher demand from EV manufacturers and future expectations of exponential growth has resulted in investors stockpiling cobalt. However, the pace of the EV industry was lower than expected and resulted in a price crash in July 2018 dropping from almost 100,000 UDS per ton to 25,000 USD per ton one year later. Nonetheless, prices are expected to rise again when the EV market picks up momentum[157].

[156] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
[157] https://oilprice.com/Energy/Energy-General/Whats-Behind-The-Cobalt-Price-Crash.html

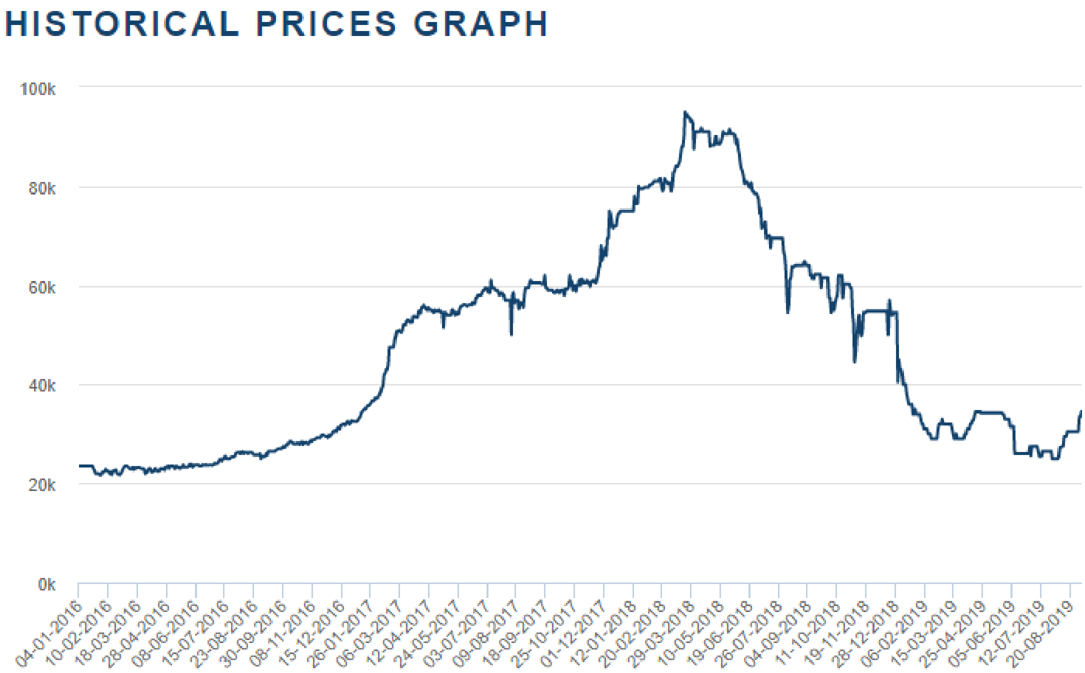


*Figure 35: Price development of Cobalt from January 2016 until now*[158]

## 4.2 Nickel

The flow of nickel from its natural deposits to its uses in batteries can be described by the process chain depicted in Figure 36. This is a stylized representation of the different types of nickel production techniques/processes that are employed at different production sites (depending among others on the deposit type) and differ significantly from each other regarding the chemical and energetic process requirements.

Figure 36 depicts the aspects of the nickel production process that are important for battery production (and, therefore, neglects the production of e.g., ferronickel and nickel pig iron). In the following sections the technical aspects of each of the links of the process chain are explained further.

[158] https://www.lme.com/Metals/Minor-metals/Cobalt#tabIndex=0

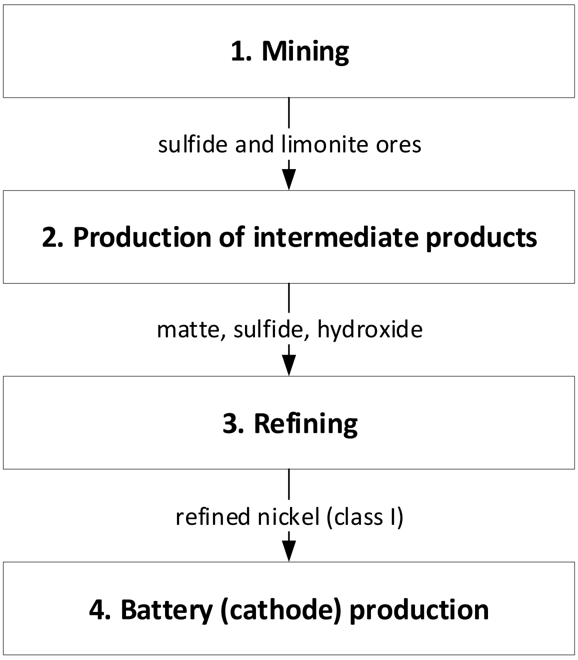


*Figure 36: Stylized representation of the nickel supply chain for Li-ion batteries.*

### 4.2.1 Mining

Nickel used in batteries is primarily won from sulphide and laterite ores, and among the laterites, limonite is primarily used for battery production [159]. The world nickel mine production is more spread out than for cobalt, as seen in Table 16, with Indonesia as the largest producer, followed by the Phillipines, Russia and New Caledonia.

*Table 16: Nickel - World Mine Production and Reserves (metric tons of nickel content) in 2017 and 2018*

| | Mine production | | Reserves[8] |
|---|---|---|---|
| | 2017 | 2018[e] | |
| United States | 22,100 | 19,000 | 110,000 |
| Australia | 179,000 | 170,000 | [9]19,000,000 |
| Brazil | 78,600 | 80,000 | 11,000,000 |
| Canada | 214,000 | 160,000 | 2,700,000 |
| China | 103,000 | 110,000 | 2,800,000 |
| Colombia | 45,500 | 43,000 | 440,000 |
| Cuba | 52,800 | 53,000 | 5,500,000 |
| Finland | 34,600 | 46,000 | NA |
| Guatemala | 53,700 | 49,000 | 1,800,000 |
| Indonesia | 345,000 | 560,000 | 21,000,000 |
| Madagascar | 41,700 | 39,000 | 1,600,000 |
| New Caledonia[10] | 215,000 | 210,000 | — |
| Philippines | 366,000 | 340,000 | 4,800,000 |
| Russia | 214,000 | 210,000 | 7,600,000 |
| South Africa | 48,400 | 44,000 | 3,700,000 |
| Other countries | 146,000 | 180,000 | 6,500,000 |
| World total (rounded) | 2,160,000 | 2,300,000 | 89,000,000 |

[e]Estimated. NA Not available. W Withheld to avoid disclosing company proprietary data. — Zero.

[159] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
And: Kerfoot, D.G.E. (2012). Nickel. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.a17_157
And: Elshkaki, A.; Reck, B.K.; Graedel, T.E. (2017). Anthropogenic nickel supply, demand, and associated energy and water use. Resources, Conservation & Recycling 125, 300–307.

[9]For Australia, Joint Ore Reserves Committee-compliant reserves were about 6.0 million tons.
[10]Overseas territory of France. Although nickel-cobalt mining and processing continued, the leading producing company reported zero reserves owing to recent nickel prices.

More detailed an historical data on worldwide nickel production is given in Table 17.

*Table 17:* Nickel - World Mine Production by Country or Locality[1,2] and Ore Type (metric tons, contained nickel)[160]

| Country or locality[3] | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Albania, laterite ore[e] | 1,000 | | 2,100 | | 4,900 | | 6,500 | r | 3,960 | |
| Australia, undifferentiated or other | 282,067 | r | 290,986 | r | 266,181 | r | 225,227 | r | 204,356 | |
| Botswana, sulfide ore, content of matte produced | 17,942 | r | 22,848 | | 14,958 | | 16,789 | | 16,878 | |
| Brazil, undifferentiated or other | 109,000 | r | 108,000 | r | 102,000 | r | 89,302 | r | 77,000 | e |
| Burma, laterite ore | 5,000 | e | 6,100 | r | 21,000 | | 26,400 | | 22,800 | |
| Canada, sulfide ore, concentrate | 211,701 | | 227,743 | | 228,867 | | 234,519 | r | 235,707 | |
| China, undifferentiated or other | 93,300 | r | 93,200 | r | 101,100 | r | 101,400 | r | 98,000 | e |
| Colombia, laterite ore:[4] | | | | | | | | | | |
| Mined | 77,900 | r | 74,400 | r | NA | | NA | | NA | |
| Dry | NA | | NA | | 47,400 | r | 43,900 | r | 41,600 | |
| Cuba, laterite ore | 68,007 | r | 55,620 | r | 51,587 | r | 56,400 | | 51,600 | |
| Dominican Republic, laterite ore | 25,590 | | 15,825 | | -- | | 4,000 | r | 19,900 | |
| Finland, undifferentiated or other | 19,590 | | 19,440 | | 18,730 | | 9,383 | r | 20,654 | |
| Greece, laterite ore | 21,980 | | 19,100 | | 21,405 | | 19,610 | | 19,431 | |
| Guatemala, laterite ore | 2,400 | | 10,200 | r, e | 46,800 | | 56,400 | r | 45,900 | |
| Indonesia, laterite ore | 648,400 | | 834,200 | | 177,100 | | 129,600 | r | 198,900 | |
| Kazakhstan, laterite ore | 450 | e | -- | | -- | | -- | | -- | |
| Kosovo, laterite ore | 4,436 | | 7,606 | | 6,724 | | 7,418 | | 4,300 | |
| Macedonia, laterite ore | 1,680 | | -- | r | -- | r | -- | | -- | |
| Madagascar, laterite ore, nickel-cobalt sulfide[e] | 8,300 | | 29,000 | r | 43,000 | r | 55,000 | r | 49,000 | |
| Morocco, undifferentiated or other | 288 | | 160 | r | -- | r | -- | r | -- | |
| New Caledonia, laterite ore | 131,693 | | 164,406 | | 175,174 | r | 193,199 | r | 204,207 | |
| Norway, undifferentiated or other | 352 | r | 335 | r | 400 | r | 285 | r | 220 | |
| Papua New Guinea, laterite ore, nickel-cobalt hydroxide[5] | 5,283 | | 11,369 | | 20,987 | | 25,582 | | 22,269 | |
| Philippines, laterite ore | 322,424 | r | 315,633 | r | 443,909 | r | 470,042 | r | 347,423 | |
| Russia: | | | | | | | | | | |
| Laterite ore | 26,620 | | 10,400 | r, e | 11,200 | e | 7,400 | r | 7,000 | e |
| Sulfide ore, concentrate | 270,030 | | 270,700 | | 271,950 | | 269,310 | | 245,520 | |
| South Africa, sulfide ore, concentrate | 45,945 | | 51,208 | | 54,956 | | 56,689 | | 48,994 | |
| Spain, sulfide ore, concentrate | 2,398 | | 7,574 | | 8,631 | | 7,213 | | -- | |

[160] *US Geological Survey (USGS), Minerals Yearbook 2016, tables-only-release:* https://www.usgs.gov/centers/nmic/nickel-statistics-and-information

| Country or locality[3] | 2012 | | 2013 | | 2014 | | 2015 | | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Turkey, laterite ore | 4,400 | r | 1,200 | | 3,223 | r | 9,600 | | 10,200 |
| United States, sulfide ore, concentrate | -- | | -- | | 4,300 | | 27,200 | | 24,100 |
| Venezuela, laterite ore[e] | 8,100 | | -- | | 5,000 | r | 4,800 | r | -- |
| Vietnam, sulfide ore, concentrate | -- | | 1,166 | | 6,854 | | 8,607 | | 4,272 |
| Zimbabwe, sulfide ore, concentrate | 7,899 | | 12,962 | | 16,633 | | 16,109 | r | 17,743 |
| Total | 2,420,000 | r | 2,660,000 | r | 2,170,000 | r | 2,180,000 | r | 2,040,000 |
| Of which:[6] | | | | | | | | | |
| Laterite ore | 1,360,000 | r | 1,560,000 | r | 1,080,000 | r | 1,120,000 | r | 1,050,000 |
| Sulfide ore | 556,000 | | 594,000 | | 607,000 | | 636,000 | r | 593,000 |
| Undifferentiated or other | 505,000 | r | 512,000 | r | 488,000 | r | 426,000 | r | 400,000 |

[e]Estimated. [r]Revised. NA Not available. -- Zero.

[1]Includes data available through March 1, 2018. All data are reported unless otherwise noted. Totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Insofar as possible, this table represents recoverable mine production of nickel. Where actual mine output is not available, data related to a more highly processed form have been used to provide an indication of the magnitude of mine output, and this was noted.

[3]North Korea may have had an active nickel mine, but information was inadequate to make reliable estimates of output.

[4] Prior to 2013, mine production was as reported by the International Study Group. From 2014 onward, mine production data were estimated using data from South32 Company.

[5]Often called mixed hydroxide product or MHP by industry.

[6]An effort has been made to characterize each country's mine production by ore type (laterite, sulfide, undifferentiated and other), but the data may include a small amount of production from other ore types.

### 4.2.2 Concentration and conversion

The intermediate processing of nickel ores depends on the type of ore. Here only the types of ores relevant for battery production (sulphide ore and limonite) are included, and the focus is on processes that are applied in the production of class-I nickel, which is what is relevant for batteries.

For nickel sulphite ore, the processing includes firstly a concentration step, where the ore is crushed, ground, and concentrated by froth flotation (as described in section 4.1.2 for cobalt). This produces nickel concentrate, which is then roasted, smelted and converted. Nickel-copper converting is a type of metallurgical smelting that includes treatment of molten metal sulphides to produce crude metal and slag / matte.

In case of limonite ores the processing instead involves pressure leaching of the prepared ore with sulfuric acid, followed by neutralization and precipitation. The output from this process is sulphites and hydroxides[161].

[161] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
And: Kerfoot, D.G.E. (2012). Nickel. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.a17_157

### 4.2.3 Refining

In the process of refining, the intermediates (matte, sulphides and hydroxides) are transformed into refined nickel. In the case of class I nickel production, refining involves the following three main alternatives[162]:

- (re-)leaching, solvent extraction and hydrogen reduction or electro-winning
- direct electrorefining of matte, or
- the application of the carbonyl process (in the case of matte).

The final product of these refining processes is nickel class I, or simply nickel metal, meaning the nickel content is more than 99%. The nickel metal is used for battery production but also has other uses (e.g., in the alloy steel and nickel compounds/chemicals production).

Besides class-I nickel, there are other nickel products, such as oxide sinter, ferronickel, nickel pig iron and nickel compounds/ chemicals, which are used in for example the production of stainless steel and alloys, electroplating, and as catalysts. Nickel compounds/chemicals that are not produced from class-I nickel can also be used in production of batteries, however, this production route is not common. Table 18 gives an overview of where the different nickel products are produced in the world.

*Table 18:* Nickel - World Plant Production by Country or Locality and Product[1,2] (metric tons, contained nickel)[163]

| Country or locality | 2014 | | 2015 | | 2016 | |
|---|---|---|---|---|---|---|
| Australia: | | | | | | |
| Metal | 129.862 | r | 132.074 | r | 117.920 | |
| Unspecified | 7.901 | | 20.904 | r | 2.600 | |
| Total | 137.763 | r | 152.978 | r | 120.520 | |
| Austria, ferronickel, including ferronickel molybdenum | 1.000 | | 1.000 | r | 1.000 | |
| Brazil: | | | | | | |
| Ferronickel | 37.237 | | 54.700 | r,e | 68.600 | |
| Metal | 21.000 | | 21.900 | r,e | -- | |
| Total | 58.237 | | 76.600 | r | 68.600 | |
| Burma, ferronickel[e, 3] | 16.000 | r | 16.000 | r | 8.800 | |
| Canada, unspecified | 149.486 | | 149.717 | r | 158.381 | |
| China:[4] | | | | | | |
| Chemicals, including unspecified | 20.000 | r | 18.891 | r | 28.400 | |
| Ferronickel, high-nickel pig iron | 471.500 | r | 385.035 | r | 375.645 | |
| Metal | 247.000 | | 236.700 | r | 216.200 | |
| Total | 738.500 | r | 640.626 | r | 620.245 | |
| Colombia, ferronickel | 41.221 | | 36.671 | | 37.091 | |
| Cuba, oxide sinter, including oxides[5] | 13.251 | r | 13.300 | r,e | 13.300 | e |
| Dominican Republic, ferronickel | -- | | -- | | 9.913 | |
| Finland:[e] | | | | | | |
| Chemicals, including powder, salts, solutions, and other | 5.960 | r | 7.130 | r | 8.050 | |
| Metal, electrolytic, including cathode and briquets | 36.600 | r | 36.400 | r | 45.600 | |

[162] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.
And: Kerfoot, D.G.E. (2012). Nickel. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.a17_157
[163] US Geological Survey (USGS), Minerals Yearbook 2016, tables-only-release (https://www.usgs.gov/centers/nmic/nickel-statistics-and-information).

| Country or locality | 2014 | | 2015 | | 2016 |
|---|---|---|---|---|---|
| Total | 42.600 | | 43.500 | r | 53.700 |
| France:[e] | | | | | |
| Chemicals | 1.260 | r | 980 | r | 696 |
| Metal | 7.140 | r | 5.550 | r | 3.940 |
| Total | 8.400 | r | 6.530 | r | 4.640 |
| Greece, ferronickel | 18.481 | | 17.114 | | 17.070 |
| Guatemala, ferronickel | 5.040 | r | 10.826 | | 8.688 |
| Indonesia, ferronickel | 16.851 | | 17.211 | | 20.293 |
| Japan: | | | | | |
| Chemicals | 5.673 | | 10.045 | r | 11.152 |
| Ferronickel[e] | 70.100 | r | 71.200 | r | 70.300 |
| Metal | 56.129 | | 64.068 | r | 63.442 |
| Oxide sinter[e] | 45.900 | | 47.500 | r | 46.900 |
| Total[e] | 178.000 | r | 193.000 | r | 192.000 |
| Korea, Republic of: | | | | | |
| Ferronickel | 22.799 | | 39.005 | r | 45.600 |
| Metal | (6) | | (6) | | (6) |
| Total | 22.799 | | 39.005 | r | 45.600 |
| Kosovo, ferronickel | 7.700 | r | 11.300 | r | 1.200 |
| Macedonia, ferronickel | 18.054 | | 17.699 | | 10.603 |
| Madagascar, metal | 37.053 | | 47.271 | | 42.105 |
| Morocco, chemicals, nickel hydroxide[7] | -- | r | -- | r | -- |
| New Caledonia: | | | | | |
| Ferronickel | 54.863 | | 56.486 | | 67.518 |
| Oxide sinter | 7.366 | | 21.044 | | 28.465 |
| Total | 62.229 | | 77.530 | | 95.983 |
| Norway, metal | 90.500 | | 91.220 | r | 92.700 |
| Russia: | | | | | |
| Chemicals[e] | 2.700 | | 2.900 | | 2.400 |
| Ferronickel, high nickel | -- | | -- | | -- |
| Ferronickel, other | -- | | -- | | -- |
| Metal | 234.700 | r | 231.200 | r | 192.000 |
| Total | 237.000 | r | 234.000 | r | 194.000 |
| South Africa: | | | | | |
| Chemicals[e, 8] | 3.500 | | 5.200 | r | 4.800 |
| Metal | 34.100 | | 41.910 | r | 42.100 |
| Total | 37.600 | | 47.100 | r | 46.900 |
| Taiwan, metal | (6) | | (6) | | (6) |
| Ukraine, ferronickel[9] | 18.615 | | 17.952 | r | 18.100 |
| United Kingdom, metal[10] | 39.100 | | 38.804 | r | 45.194 |
| Venezuela, ferronickel | 5.000 | r | 4.000 | | -- |
| Zimbabwe, metal, toll refined from imported nickel feed[11] | 2.915 | | 617 | | -- |
| Grand total | 2.000.000 | | 2.000.000 | r | 1.930.000 |
| Of which: | | | | | |
| Chemicals | 39.100 | r | 45.100 | r | 55.500 |
| Ferronickel | 804.000 | r | 756.000 | r | 760.000 |
| Metal | 936.000 | r | 948.000 | r | 861.000 |
| Oxide Sinter | 66.500 | r | 81.800 | r | 88.700 |
| Unspecified | 157.000 | r | 171.000 | r | 161.000 |

[e]Estimated. [r]Revised. -- Zero.

[1]Includes data available through November 23, 2017. All data are reported unless otherwise noted. Grand totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

| Country or locality | 2014 | 2015 | 2016 |
|---|---|---|---|

[2]North Korea was thought to have produced metallic nickel and (or) ferronickel, but information was inadequate to make reliable estimates of output levels. Several countries produced nickel-containing matte and other intermediate nickel products, but output of nickel in such materials has been excluded from this table to avoid double counting. Countries that produced matte for export are listed in table 11.
[3]Imports to other countries of ferronickel from Burma, assumed 26% nickel content.
[4]Figures for ferronickel and chemicals were derived from data published by Beijing Antaike Information Development Co. Ltd. Figures for electrolytic and other class I nickel are based on data provided by the China Nonferrous Metals Industry Association and the International Nickel Study Group. China also produced nickeliferous pig iron from lateritic ores imported from Indonesia, New Caledonia, and the Philippines.
[5]An estimated 1% of reported production is unrecovered cobalt. Cuba also produces nickel sulfide and ammoniacal liquor precipitate, but because they are used as feed material elsewhere, they are not included in this table to avoid double counting.
[6]Utility® Nickel production figures for the Republic of Korea and Taiwan were not included because the production was derived wholly from imported metallurgical-grade oxides and to include them would result in double counting.
[7]Most of the nickel hydroxide was a byproduct of the concentrating, smelting, and refining of domestically mined copper ores. Some production, however, may have been derived from imported nickeliferous raw materials that were blended with the domestic copper concentrates.
[8]Primarily in the form of crystalline nickel sulfate. Estimates include nickel sulfate plus exported metal in concentrate.
[9]May include nickel in remelt alloys derived from scrap.
[10]Includes nickel content of chemicals.
[11]Data represent production from matte imported from Botswana and nickel sulfate imported from South Africa.

### 4.2.4 Further processing and cell manufacturing

The main battery types containing nickel are shown in Table 19. Nickel is an essential component of the cathode of these battery types, and Most Li-ion batteries now rely on nickel. Two of the most commonly-used types of batteries, Nickel Cobalt Aluminium (NCA) and Nickel Manganese Cobalt (NMC) use 80% and 33% nickel respectively. Newer formulations of NMC are also approaching 80% nickel[164].

[164] https://www.nickelinstitute.org/about-nickel/nickel-in-batteries/

*Table 19: Nickel content in different types of batteries where nickel is used[165].*

<table>
<tr><th>BATTERY TYPE</th><th></th><th>CATHODE</th><th>ANODE</th><th>ELECTROLYTE</th></tr>
<tr><td>Alkaline</td><td>Single use</td><td>Manganese dioxide ($MnO_2$)</td><td>Zinc</td><td>Aqueous alkaline</td></tr>
<tr><td>Lead acid (secondary)</td><td>Rechargeable</td><td>Lead dioxide ($PbO_2$)</td><td>Lead</td><td>Sulphuric acid</td></tr>
<tr><td>Nickel Cadmium (NiCd) (secondary)</td><td>Rechargeable</td><td rowspan="2">Nickel oxyhydroxide (NiOOH)</td><td>Cadmium</td><td rowspan="2">Potassium hydroxide</td></tr>
<tr><td>Nickel Metal Hydride (NiMH) (secondary)</td><td>Rechargeable</td><td>Hydrogen-absorbing alloy</td></tr>
<tr><td>Lithium Ion (LCO) (secondary)</td><td>Rechargeable</td><td>Lithium cobalt oxide ($LiCoO_2$)</td><td rowspan="3">Carbon-based, typically graphite</td><td></td></tr>
<tr><td>Lithium Ion (NMC) (secondary)</td><td>Rechargeable</td><td>Lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$)</td><td rowspan="2">Lithium salt in an organic solvent</td></tr>
<tr><td>Lithium Ion (NCA) (secondary)</td><td>Rechargeable</td><td>Lithium nickel cobalt aluminium ($LiNiCoAlO_2$)</td></tr>
</table>

The most important of the battery types containing nickel for the EV industry are the NCA and NMC batteries (used in EVs) as well as the NiMH (used in hybrid vehicles). NiMH batteries are also used in power tools, and NiCd batteries are used in both power tools and industrial batteries[166].

### 4.2.5 Geographic routes of nickel for batteries

The primary production levels and trade flows for nickel are shown in Figure 37. As for cobalt (section 4.1.5) the figure shows the stages of nickel from mining to battery production and the trade of the intermediates. These have been separated into the following stages:

- nickel sulfide/limonite ores
- nickel intermediate products:
  - nickel sulfide concentrates
  - matte
  - sulfide/hydroxide
- nickel end-products (class-I nickel).

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[165] https://www.nickelinstitute.org/about-nickel/nickel-in-batteries/

[166] Dunn, J.B; Gaines, L.; Kelly, J.C.; James, C.; Gallagher, K.G. (2015). The significance of Li-ion batteries in electric vehicle life-cycle energy and emissions and recycling's role in its reduction. Energy and Environmental Science 8, 158–168,
And: Olivetti, Elsa A.; Ceder, Gerbrand; Gaustad, Gabrielle G.; Fu, Xinkai (2017): Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. Joule 1, pp. 229-243.

As seen from Figure 37, Russia, Canada, Australia and China play important roles for the nickel supply chain for batteries.

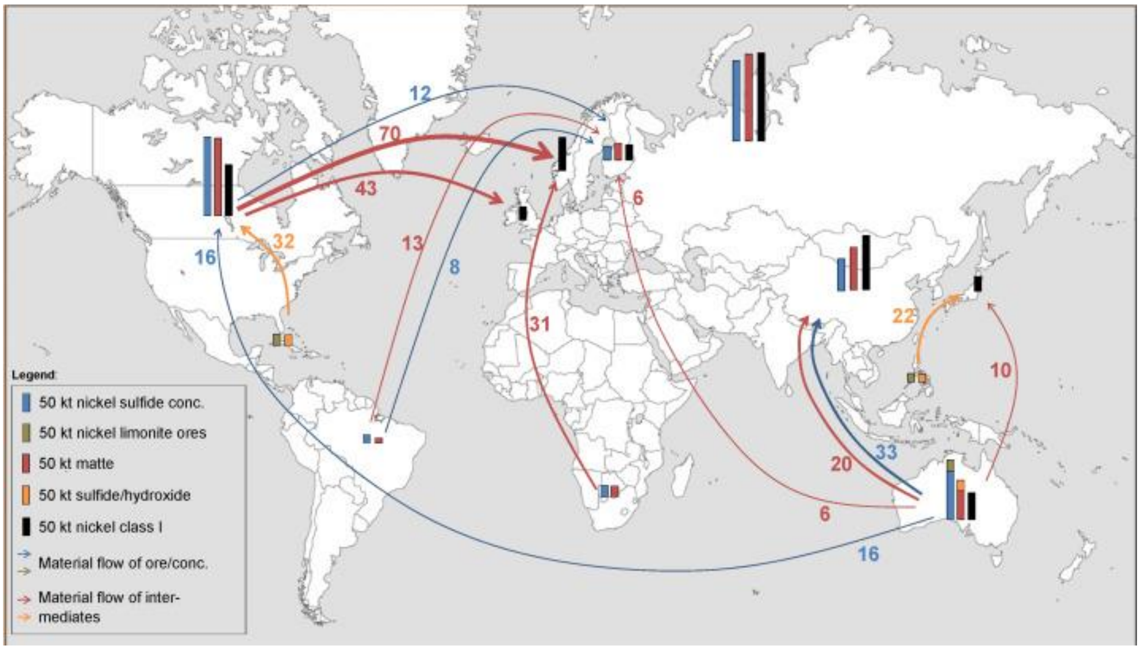


*Figure 37: Primary production and global trade flows of different nickel products/commodities (year 2011; kt nickel content). Blue: flow of nickel sulphide concentrate. Red: flow of matte. Orange: flow of sulphide/hydroxide.* [167]

## 4.3 Lithium

The flow of lithium from its natural deposits to its uses in batteries can be described by the process chain depicted in Figure 38. This is a stylized representation of the different types of lithium production techniques/processes that are employed at different production sites (depending among others on the deposit type) and differ significantly from each other regarding the chemical and energetic process requirements.

In the following sections the technical aspects of each of the links of the process chain for lithium will be described, focusing on the aspects of the lithium production process that are important for (lithium ion) battery production and, therefore, neglecting the production of e.g., lithium metal and lithium alloys.

[167] Schmidt, Tobias; Buchert, Matthias; Schebek, Liselotte (2016): Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling 112, pp.107-122.

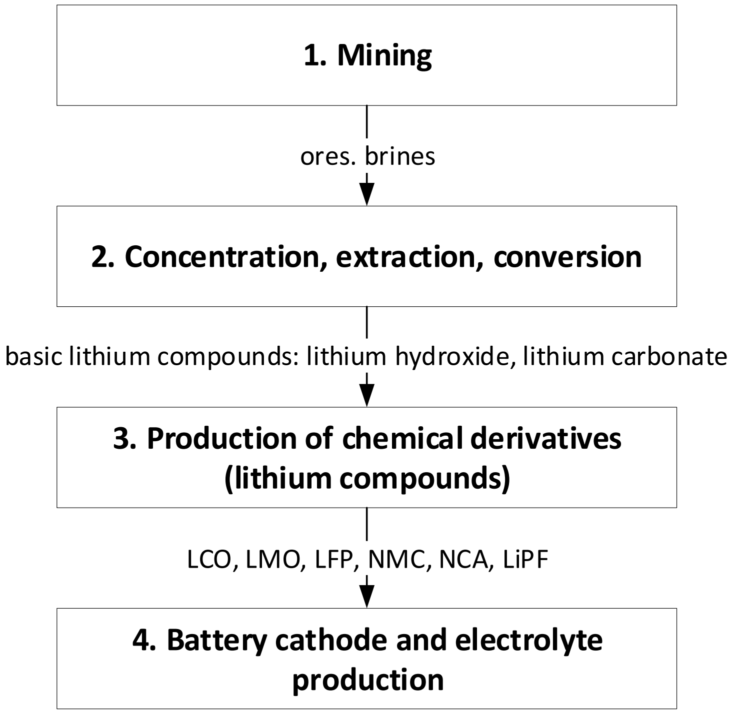


*Figure 38: Stylized representation of the lithium supply chain for Li-ion batteries.*

### 4.3.1 Mining

Lithium is contained in the hard rock mineral pegmatite, in clay (in particular, hectorite), brines (fluids containing dissolved solids) and seawater. Currently, the major sources of lithium are spodumene, which is a mineral contained in pegmatite and brines. To a much lesser extent, petalite, amblygonite and eucryptite (minerals contained in pegmatite) are used as a source for lithium[168]. In the past, lepidolite (a mineral contained in pegmatite) was among the most important sources of lithium. Pegmatite (ore) is extracted from the deposits by quarrying, open-pit mining and underground mining. Brines are extracted (i.e. pumped) from boreholes drilled into the brine aquifer. Table 20 gives an overview of where in the world lithium is extracted and the potential reserves.

Potential sources of lithium, which are currently explored, are geothermal and oilfield brines as well as clay. Also seawater has been investigated but since it has a relatively low content of lithium it is not an economically relevant source of lithium (currently).

*Table 20: Lithium - World Mine Production and Reserves (metric tons of lithium content)*[169]

[168] Wietelman, U.; Steinbild, M. (2013). Lithium and Lithium Compounds. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.a15_393.pub2
[169] U.S. Geological Survey (USGS), Mineral Commodity Summaries, February 2019, p.99.

| | Mine production | | Reserves[6] |
|---|---|---|---|
| | 2017 | 2018[e] | |
| United States | W | W | 35,000 |
| Argentina | 5,700 | 6,200 | 2,000,000 |
| Australia | 40,000 | 51,000 | [7]2,700,000 |
| Brazil | 200 | 600 | 54,000 |
| Chile | 14,200 | 16,000 | 8,000,000 |
| China | 6,800 | 8,000 | 1,000,000 |
| Portugal | 800 | 800 | 60,000 |
| Namibia | — | 500 | NA |
| Zimbabwe | 800 | 1,600 | 70,000 |
| World total (rounded) | [8]69,000 | [8]85,000 | 14,000,000 |

[e]Estimated. W Withheld to avoid disclosing company proprietary data. NA Not available. — Zero.
[7]For Australia, Joint Ore Reserves Committee-compliant reserves were about 1.4 million tons.
[8]Excludes U.S. production.

### 4.3.2 Concentration and conversion

The further processing of lithium depends on whether it is mined from ores (hard rock minerals) or extracted from brines

The processing of lithium from hard rock mineral ores, involves the following steps[170]:

1. Concentrate production
    - Preparatory steps: crushing, milling sieving of the ore and desliming by a hydro-cyclone (electrodynamic and optical sorting processes are also possible).
    - Flotation by using anionic fatty acids in alkaline medium and sulfonated oils in acidic medium and several follow-up treatments (washing/cleaning, magnetic separation, filtration, drying).
    - In this process, the lithium-bearing mineral is separated from other substances/minerals (e.g., spodumene is separated from quartz, feldspar, mica, iron).

The result of these processes is a mineral concentrate, for example spodumene concentrate, which contains around 7% lithium oxide.

2. Conversion ("digestion of lithium")
    - In this production step, lithium ores/concentrates are transformed into lithium carbonate and lithium hydroxide (and lithium chloride).
    - Three major types of conversion in the case of lithium: (i) acid-roast conversion, (ii) lime-roast conversion and (iii) ion-exchange processes.
        i. The acid-roast conversion (in particular, the sulfuric acid digestion process) generates lithium carbonate from lithium mineral concentrates or (crushed) lithium ores. This is a multi-stage procedure, which involves the use of sulfuric acid (in roasting of the prepared ores/concentrates), leaching with hot water, neutralization with lime and soda, and precipitation of lithium carbonate (by

[170] Wietelman, U.; Steinbild, M. (2013). Lithium and Lithium Compounds. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.a15_393.pub2

concentrated sodium carbonate solution). It is applicable to all lithium ores (e.g., spodumene and petalite) and has a relatively low energy requirement and relatively high lithium yield in comparison to the alternatives ((ii) and (iii))

ii. In lime-roast conversion, spodumene (or lepidolite) are mixed with lime and heated to 900°C-1000°C. Several further process steps follow including crushing, milling, and leaching with hot water. The output from this process is lithium hydroxide.

iii. In the Ion-exchange processes, the lithium ore is heated with a sodium or potassium salt followed by several further steps, such as leaching. The output from this process is either lithium carbonate or in some cases lithium chloride.

The processing of brine also contains both a concentration and a further step:

1. Concentration of the brine:
   - The brine is concentrated by solar evaporation in large pond systems.
   - During the evaporation, different chemicals (salts) crystalize and are separated from the brine.
   - Depending on the brine type/production site, a preparation of the brine may be necessary before it is sent to the ponds (e.g. treatment with slaked lime).
   - The concentration processes last up to 18 months
   - The result of the processes is concentrated, lithium-rich brine (brine concentrate).

2. Production ("extraction") of lithium carbonate from brine concentrate:
   - In a multistep procedure, the brine concentrate is treated with different chemicals (alcohol-kerosene, sodium hydroxide, soda ash, lime), filtered, centrifuged, washed, dried and milled. The output after this step is lithium carbonate.

In summary, the lithium-bearing ores and brines are transformed into the following basic lithium compounds or, "basic chemicals" for short:

a) (lithium) mineral concentrate (e.g. spodumene concentrate). These mineral concentrates can be used for production of lithium carbonate (point b), lithium hydroxide (point c) and lithium chloride (point d), but also for production of other/end products,
b) lithium carbonate. This is used for production of lithium hydroxide (point c) and lithium chloride (point d).
c) lithium hydroxide and
d) lithium chloride.

Table 21 shows the world production of these basic chemicals from 2012 to 2016.

*Table 21:* Lithium Minerals and Brine: World Production, by Country or Locality[1] (metric tons, gross weight)[171]

| Country or locality[2] | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Argentina, subsurface brine: | | | | | |
| Lithium carbonate | 10,535 | 9,248 | 11,698 | 14,137 | 25,500 |
| Lithium chloride | 4,297 | 5,156 | 7,370 | 5,848 | 6,000 |
| Australia, spodumene | 456,921 | 415,000 | 463,000 | 490,000 | 560,000 |
| Brazil, concentrates | 7,084 | 7,982 | 8,519 | 8,500 | 8,500 |
| Chile, subsurface brine: | | | | | |
| Lithium carbonate | 62,002 | 52,358 | 55,074 | 50,418 | 67,300 |
| Lithium chloride | 4,145 | 4,091 | 2,985 | 2,069 | 1,600 |
| Lithium hydroxide | 5,447 | 4,197 | 4,194 | 3,888 | 6,000 |
| China, lithium carbonate equivalent[e, 3] | 10,000 | 11,200 | 10,100 | 10,700 | 12,200 |
| Portugal, lepidolite | 20,698 | 19,940 | 17,459 | 17,120 | 25,800 |
| United States, lithium carbonate | W | 4,600 [4] | W | W | W |
| Zimbabwe, amblygonite, eucryptite, lepidolite, and petalite | 53,000 | 50,000 [e] | 50,000 [e] | 50,000 [e] | 50,000 |

[e]Estimated. W Withehld to avoid disclosing proprietary data.
[1]Includes data available through May 2, 2017. All data are reported unless otherwise noted. U.S. data and estimated data are rounded to no more than three significant digits.
[2]In addition to the countries listed, other nations may have produced small quantities of lithium minerals, but available information was inadequate to make reliable estimates of output.
[3]Produced from subsurface brine and concentrates.
[4]Source: Rockwood Holdings, Inc., 2014, 2013 annual report: Rockwood Holdings, Inc., p. 16.

### 4.3.3 Further processing

The basic lithium compounds (lithium mineral concentrate and lithium carbonate, hydroxide and chloride) are used in the production of chemical (lithium) derivatives, lithium metal and final goods[172]:

- lithium mineral concentrates are used in the production of ceramics and glasses,
- lithium carbonate is used in the production of lithium hydroxide/chloride, in rechargeable batteries and in glazing
- lithium hydroxide is used in lubricating greases
- lithium chloride is used in the production of lithium metal, which is used in primary (i.e., non-rechargeable) batteries among others

Among all basic lithium compounds, lithium carbonate is the most important. It accounts for more than 90% of consumption.

Different types of lithium derivatives are produced from lithium carbonate for use in rechargeable li-ion batteries. These include[173]:

a) lithium manganese oxide (LMO),
b) lithium nickel manganese cobalt oxide (NMC),
c) lithium cobalt oxide (LCO),

[171] U.S. Geological Survey (USGS) 2016 Minerals Yearbook - LITHIUM [ADVANCE RELEASE]
[172] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61
And: British Geological Survey (BGS) (2016). Lithium. https://www.bgs.ac.uk/downloads/start.cfm?id=310
[173] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61
And: British Geological Survey (BGS) (2016). Lithium. https://www.bgs.ac.uk/downloads/start.cfm?id=310
And: Wietelman, U.; Steinbild, M. (2013). Lithium and Lithium Compounds. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. doi: 10.1002/14356007.a15_393.pub2

d) lithium iron phosphate (LFP) and
e) lithium hexafluorophosphate (LiPF)

Lithium hydroxide, which is also produced from lithium carbonate, is used in the production of NMC and LFP (lithium ferrophosphate) batteries.

Lithium can be used both as cathode material and as electrolyte in lithium-ion batteries. For electrolytes, the compound used is LiPF, while for cathodes it is LMO, NMC, LCO, LFP and NCA (Lithium nickel cobalt aluminium oxide).

### 4.3.4 Geographic routes of lithium for batteries

Since lithium carbonate is the base compound that all of the lithium battery compounds can be derived from, the trade flows in this section are expressed as tones lithium carbonate equivalent (t LCE). Figure 39 gives a detailed overview of lithium production and trade, including lithium ion batteries production and trade[174].

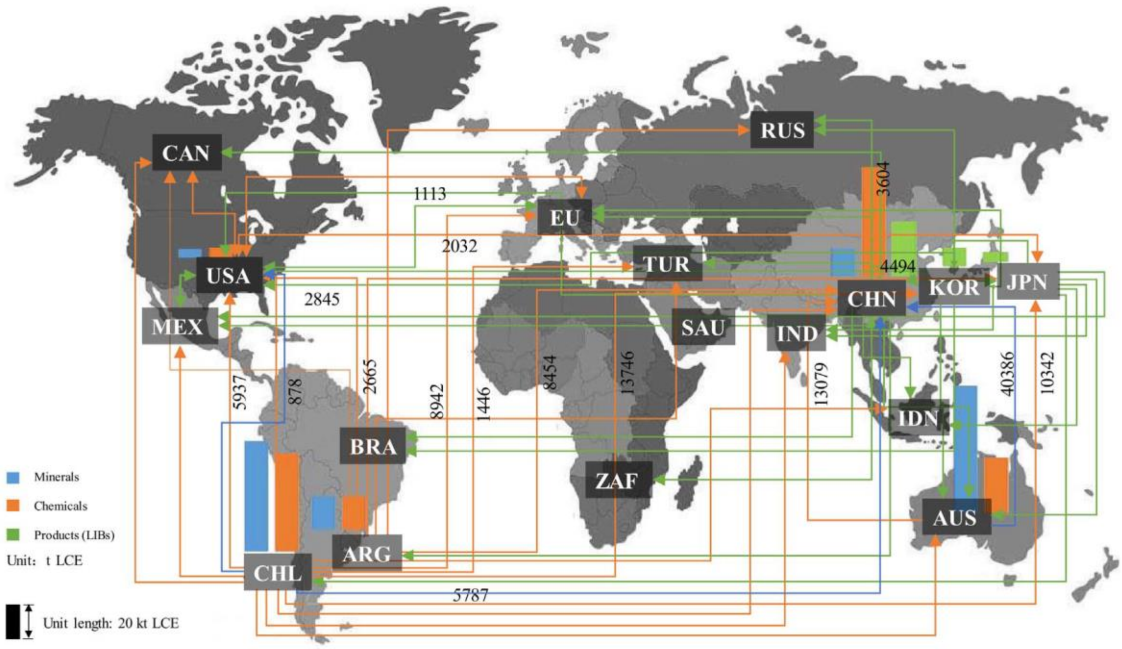


*Figure 39: Global production and trade of lithium "minerals", "chemicals" and "products" (only LIB) in 2014 (t LCE)[175]. Blue: flow of lithium minerals. Orange: flow of lithium chemicals. Green: flow of final products (lithium-ion cells/batteries).*

The trade flows shown in Figure 39 are divided into three categories: minerals chemicals and products. The minerals category includes lithium ores and brines. Chemicals include both basic lithium chemicals (lithium mineral concentrate, lithium carbonate, lithium hydroxide, lithium chloride) and chemical derivatives (lithium hydroxide and lithium chloride as well as

[174] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61
[175] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61

derivatives used in batteries (LMO. LCO, LFP, NMC and LiPF). The products included in the figure is only lithium-ion batteries (LIB).

Figure 40 and Figure 41 detail the flows further, by subdividing the categories and including LIB derivates/products. This category includes the products that use LIBs, including:

1. consumer electronics
    - mobile phones
    - portable computers
2. electric vehicles (EV)
    - battery electric busses (BEB)
    - battery electric passenger vehicles (BEPV)
    - plug-in hybrid electric busses (PHEB)
    - plug-in hybrid electric passenger vehicles (PHEPV)
    - electric bicycles
3. energy storage systems

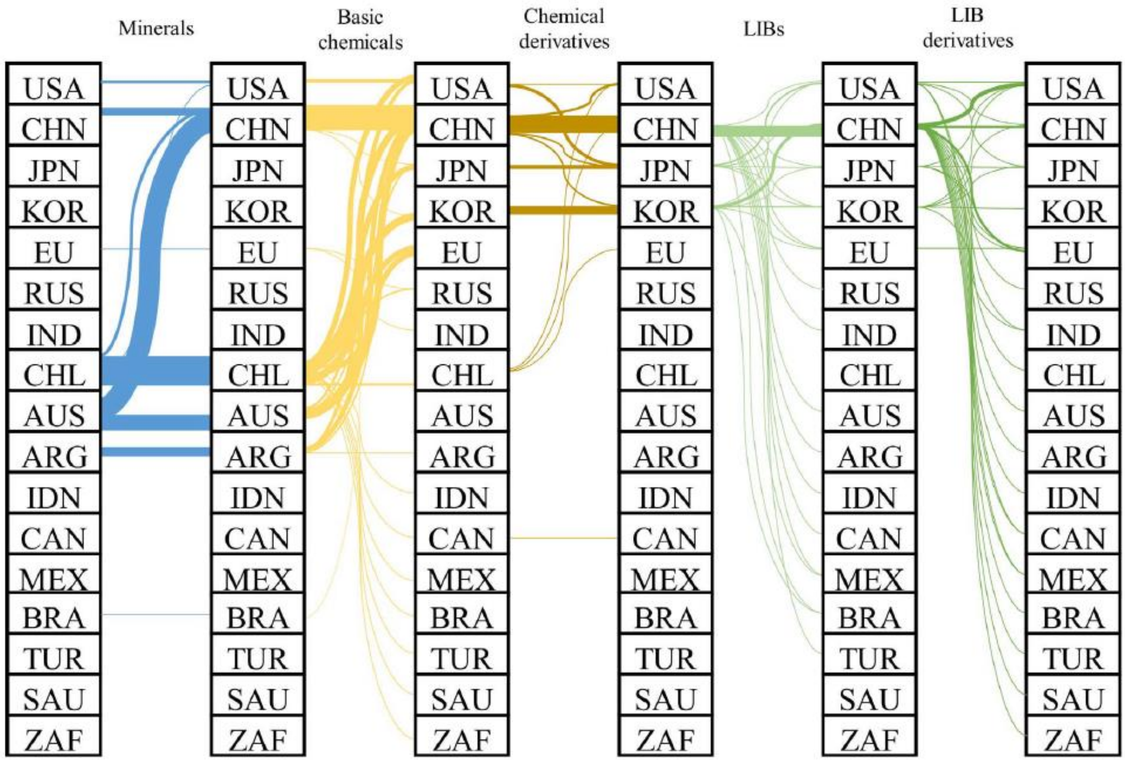


Figure 40: *Global production and trade of (lithium) minerals, basic (lithium) chemicals, chemical (lithium) derivatives, lithium ion batteries (LIBs) and LIB derivatives in 2014 (t LCE)*[176]*.*

[176] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61

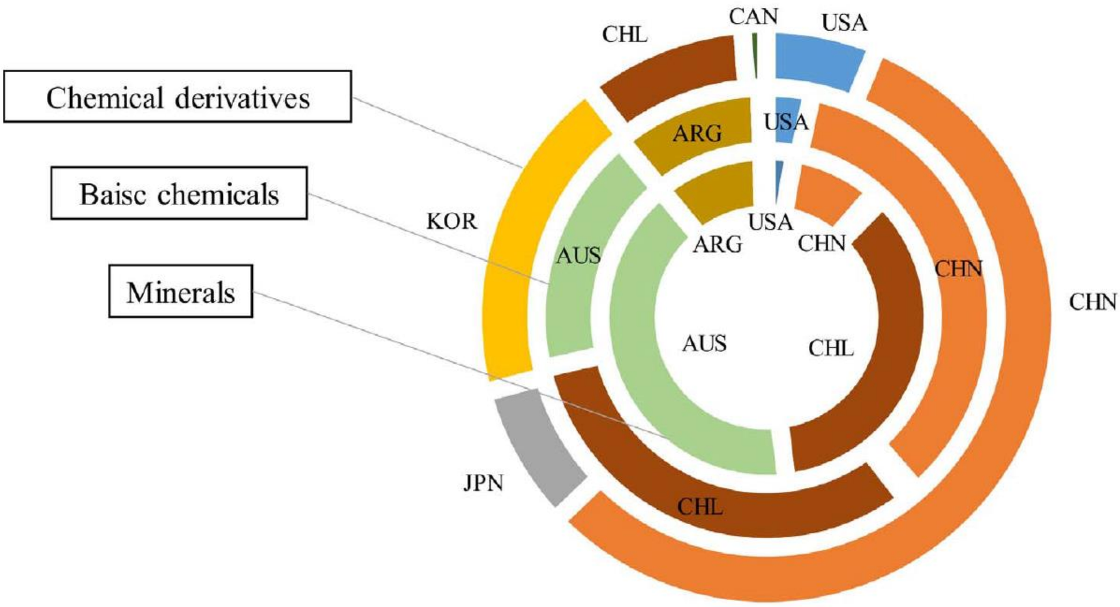


*Figure 41: Global production of lithium "minerals" and "chemicals" (in particular, "basic chemicals" and "chemical derivatives") in 2014 (t LCE) - country shares[177].*

The production and trade of lithium minerals (i.e. ores and brines containing lithium) happens primarily in Chile and Australia where the minerals are extracted. Moreover, Argentina, China and USA contribute significantly to world lithium mineral production (measured by t LCE). Australia exports the major part of its lithium minerals output to China for processing, while Chile exports only a small parts of its lithium mineral output (also to China). The other production countries of lithium minerals do not export to any significant extent. Hence, China is the only major importer of these minerals.

The next step, the production of basic lithium chemicals (lithium mineral concentrate, lithium carbonate, lithium hydroxide and lithium chloride) is dominated by China and Chile, while also Australia, Argentina and USA have significant shares in world basic lithium chemicals production. Chile, Australia and Argentina are the major exporters of these chemicals, while China do not export significant shares of their production, but on the other hand imports further amounts. EU, Korea, Japan and USA are also major importers of the basic lithium chemicals.

The further refined chemicals, the chemical lithium derivatives (LCO, LMO, NMC, LFP, LiPF, lithium hydroxide and lithium chloride) is primarily produced in China, based on their imports of both minerals and basic chemicals. Moreover, Korea, Japan, Chile and USA (and Canada) have significant shares in world chemical lithium derivative production. The chemical derivatives are for a large part kept in the countries where they are produced, but some are exported, mainly from USA, China and Chile. The major importers of these flows are oJapan, USA, Korea, China and EU.

For the production of batteries themselves, China is the major producer, followed by Korea and Japan. These countries produce nearly all LIBs and are therefore also the major

[177] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61

exporters. The finished LIBs are traded to most of the world, but with the most significant trade flow being from Korea to China, followed by the flow from Japan to USA.

For the final products wherein the LIBs are included (i.e. consumer electronics, electric vehicles and energy storage systems), the major trade flow is from China to USA and EU.

Figure 42 gives a breakdown on the different sub-types of minerals, basic chemicals, derivatives and products produced worldwide, rather than on geographical location. In this diagram it is seen that brine is a slightly larger source of lithium than ores. Also, as mentioned previously, lithium carbonate is the most important basic lithium chemical followed by lithium hydroxide and lithium mineral concentrate; lithium chloride has a rather small share in world output of basic chemicals. Regarding end uses in products, LIBs and Ceramics are the most important uses, but with an equally large share of "other" uses.

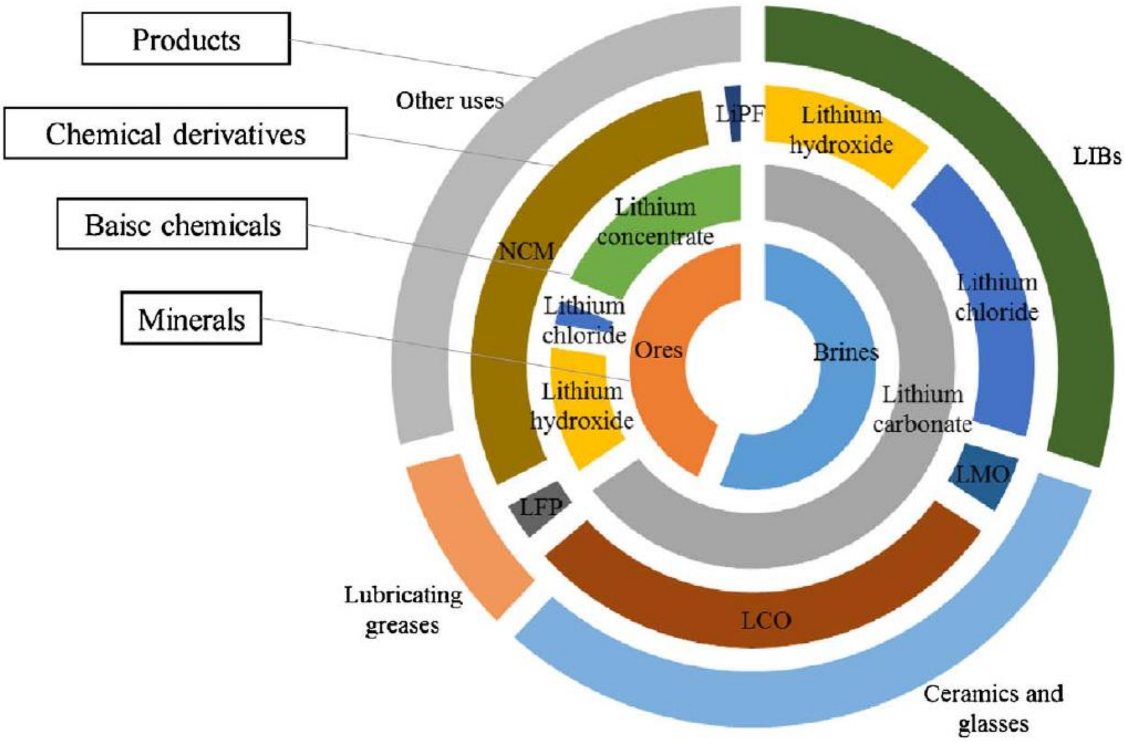


*Figure 42: Inner-circle: Global production of lithium minerals (ores and brines), 2nd circle: basic chemicals (lithium mineral concentrate, carbonate, hydroxide and chloride), 3rd circle: chemical derivatives (LCO, LMO, NMC, LFP, LiPF, lithium hydroxide and lithium chloride), outer-circle: products (LIB, ceramics and glasses, lubricating greases and other uses) in 2014 (t LCE) - sub-category shares[178].*

## 4.4 Natural Graphite

The flow of graphite from its natural deposits to its uses in batteries can be described by the process chain depicted in Figure 43. This is a stylized representation of the crystalline flake graphite production techniques/processes that are usually employed. Figure 43 depicts the aspects of the graphite production process that are important for battery production (and,

[178] Sun, Xin; Hao, Han; Zhao, Fuquan; Liu, Zongwei (2017): Tracing global lithium flow: A trade-linked material flow analysis. Resources, Conservation & Recycling 124, pp. 50-61

therefore, neglects the production from lump and amorphous graphite). In the following sections the technical aspects of each of the links of the process chain are explained further.

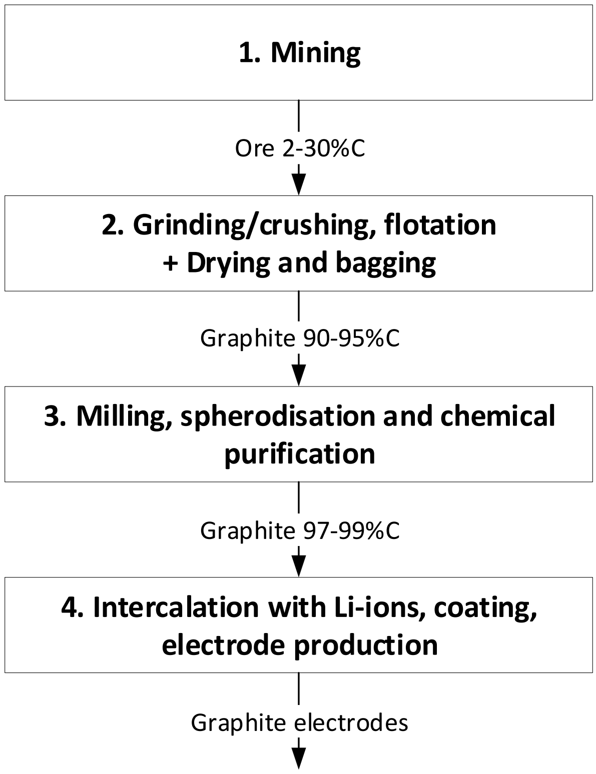


*Figure 43: Stylized representation of the natural graphite supply chain for Li-ion batteries[179].*

The battery sector uses both synthetic and natural graphite flake in a ratio of about 60:40[180], however, this section will concentrate only on natural graphite as a raw material for batteries, While both lump and flake graphite can be used as raw materials for anodes, the lump graphite is very limited in amount and comparatively expensive[181].

### 4.4.1 Mining

Natural graphite can be classified into three principle types: crystalline flake graphite, crystalline vein or lump graphite, and amorphous graphite. Only the flake graphite is used in batteries[182]. Crystalline flake graphite is usually mined in open pit mines with bulldozers, and ripper. Since it is usually near the surface and highly weathered drilling and blasting is rarely necessary[183]. Graphite is embedded in different rocks, often shales and limestones (calcareous sedimentary or metamorphic rocks)[184]. The concentration of flake graphite

[179] https://www.indmin.com/Article/3238613/Spherical-graphite-how-is-it-made.html
[180] https://www.metalbulletin.com/Article/3896232/BATTERY-MATERIALS-EUROPE-Anode-grade-graphite-poses-reputational-risk-to-buyers-RHO-Motion-says.html
[181] Jara, A. D., Betemariam, A., Woldetinsae, G., Kim, J. Y. (2018). Purification, application and current market trend of natural graphite: A review. In: International Journal of Mining Science and Technology 29 (2019) 671–689
[182] Jara, A. D., Betemariam, A., Woldetinsae, G., Kim, J. Y. (2018). Purification, application and current market trend of natural graphite: A review. In: International Journal of Mining Science and Technology 29 (2019) 671–689.
[183] Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc. By U.S. Geological Survey, Harold A. Taylor Jr.
[184] Weis PL, Friedman I, Gleason JP. The origin of epigenetic graphite: evidence from isotopes. Geochim Cosmochim Acta 1981;45(12):2325–32.

(measured as % Carbon, C) is typically between 2-30% and thus varies significantly between regions. For example in Brazil the ore grade is between 10-23%, in Norway it is 26%, I Mexico it is 4% and in Madagascar it is 5-9%[185]. Table 22 shows the world mining production of graphite from 2013 to 2017, for all graphite forms. Most of these countries produce flake graphite, with exemption of Sri Lanka producing lump graphite, and Mexico and North Korea producing both flake and amorph graphite.

*Table 22: Natural graphite - World Mine Production and Reserves (metric tons of graphite content)* [186]

| | Mine production | | Reserves[2] |
|---|---|---|---|
| | 2017 | 2018[e] | |
| United States | — | — | (3) |
| Brazil | 90,000 | 95,000 | 72,000,000 |
| Canada | 40,000 | 40,000 | (3) |
| China | 625,000 | 630,000 | 73,000,000 |
| India | 35,000 | 35,000 | 8,000,000 |
| Korea, North | 5,500 | 6,000 | 2,000,000 |
| Madagascar | 9,000 | 9,000 | 1,600,000 |
| Mexico | 9,000 | 9,000 | 3,100,000 |
| Mozambique | 300 | 20,000 | 17,000,000 |
| Namibia | 2,220 | 2,200 | (3) |
| Norway | 15,500 | 16,000 | 600,000 |
| Pakistan | 14,000 | 14,000 | (3) |
| Russia | 17,000 | 17,000 | (3) |
| Sri Lanka | 3,500 | 4,000 | (3) |
| Tanzania | — | — | 17,000,000 |
| Turkey | 2,300 | 2,000 | 90,000,000 |
| Ukraine | 20,000 | 20,000 | (3) |
| Vietnam | 5,000 | 5,000 | 7,600,000 |
| Zimbabwe | 1,580 | 2,000 | (3) |
| Other | 1,900 | 4,000 | (3) |
| World total (rounded) | 897,000 | 930,000 | 300,000,000 |

e Estimated. — Zero.
1 Defined as imports – exports.
3 Included with "World total."

### 4.4.2 Concentration

Since natural graphite is embedded in the host rock, this needs to be crushed in order to release the graphite flakes. Several steps are taken in order to upgrade the carbon content and remove impurities from the graphite flakes. The most common method for concentration is multiple grinding/crushing and flotation cycles, most commonly using froth flotation. After three to six cycles, a carbon content of 85-96% is typically achieved, depending on the specific methods, ore grade and number of cycles[187].

The crushing and grinding is carefully monitored in order to prevent breaking of the flakes, since larger flakes are more valuable (from 4000-6000 USD/ton for Super-Jumbo flakes to

[185] Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc. By U.S. Geological Survey, Harold A. Taylor Jr
[186] U.S. Geological Survey, Mineral Commodity Summaries, February 2019. Link: https://www.usgs.gov/centers/nmic/mineral-commodity-summaries.
[187] Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc. By U.S. Geological Survey, Harold A. Taylor Jr

500-800 USD/ton for small flakes[188]). After passing the crude ore through a primary crusher, ball mills are usually used for the regrinding between flotation cycles in order to liberate more gangue minerals[189]. After flotation, the graphite is dried and bagged for transportation.

### 4.4.3 Refining

To achieve the graphite necessary for batteries the purified flake graphite needs to be modified into spherical graphite morphology. This is done through physical milling to manipulate the graphite layers to bend in on themselves and form spheres as seen in Figure 44. This step often increases the graphite prices greatly since the spherical graphite production has yield of around 30%[190]-50%[191].

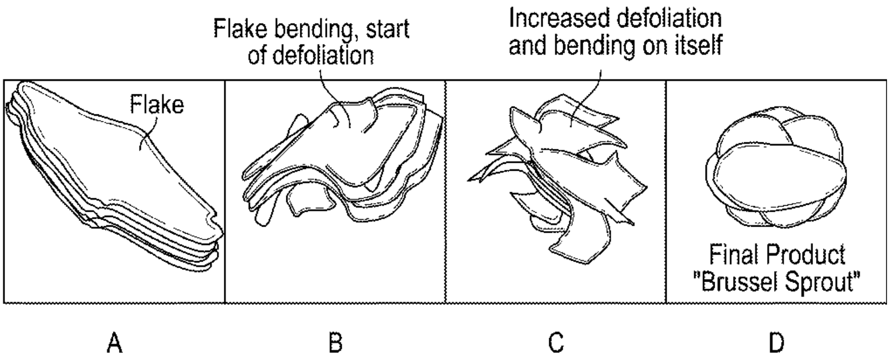


*Figure 44: illustration of flake re-shaping transformation process. A: pure graphite flake, B: After substantial impacts with the processing equipment, the flake starts to bend and partially disintegrate at the edges, C: After further processing more substantial defoliation and dislocation of the flake occurs and more substantial bending of these defoliated layers, D: final product, the approximately spherical, rounded particle[192].*

After spheroidization, the graphite needs to be further purified in order to be suitable for battery electrodes. This is usually done by roasting and acid leaching of the graphite. If the graphite concentrates have carbonate gangue, hydrochloric acid is used for the leaching, resulting in chloride acid waste. If the graphite concentrate has silica or silicate gangue, which is more common, it is leached with hydrofluoric acid. The fluoride acid waste is reactive and poisonous is usually treated to make it less hazardous (e.g. by neutralisation with lime), before being disposed of. The largest acid leaching plants are found in China and Brazil, while very little of this refining step takes place in Europe[193]. The heating and chemical treatment processes of

[188] Jara, A. D., Betemariam, A., Woldetinsae, G., Kim, J. Y. (2018). Purification, application and current market trend of natural graphite: A review. In: International Journal of Mining Science and Technology 29 (2019) 671–689
[189] Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc. By U.S. Geological Survey, Harold A. Taylor Jr
[190] Jara, A. D., Betemariam, A., Woldetinsae, G., Kim, J. Y. (2018). Purification, application and current market trend of natural graphite: A review. In: International Journal of Mining Science and Technology 29 (2019) 671–689
[191] https://ecs.confex.com/ecs/imlb2016/webprogram/Paper76389.html
[192] United States Patent Application Publication, Pub . No . : US 2017 / 0333913 A1, Nov . 23 , 2017, method and system for precision spheroidisation of graphite https://patents.google.com/patent/US20170333913A1/en
[193] Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley & Sons, Inc. By U.S. Geological Survey, Harold A. Taylor Jr

graphite can increase the concentration to more than 99.9% C, which is necessary for batteries[194].

### 4.4.4 Further processing and cell manufacturing

In batteries, specifically lithium-ion batteries graphite is used in the anode, which are made of highly purified graphite (>99%) into which lithium ions are intercalated. The spherical graphite is coated with various materials, e.g. AlF3 coating[195], other forms of carbon[196], or AlPO4[197] to improve the anode properties of graphite.

In most batteries a blend of natural and synthetic graphite is used in the anodes to with market shares around 65-70% for natural and 30-35% for synthetic graphite[198]. The purified natural flake graphite has slightly better electrical and thermal conductivity[199] than synthetic material, as seen in Table 23.

*Table 23: Properties of Graphite Anode Active Battery Materials for natural and synthetic graphite, based on information from producer's portfolio[200]*

| Product Series | Characteristics | Discharge Capacity | First Efficiency | Design Capacity/Full Cell | $D_{50}$ | BET | Tap Density | Compressed Density |
|---|---|---|---|---|---|---|---|---|
| | | mAh/g | % | mAh/g | um | $m^2/g$ | $g/cm^3$ | $g/cm^3$ |
| High performance anode material | Compound natural graphite, high capacity, high first efficiency, good machinability | 365.2 | 95.1 | 345-355 | 18-21 | 1.68 | ≥1.15 | 1.60-1.65 |
| | High performance artificial graphite, high capacity, high rate capability, good cycle/ safety performance | 338.52 | 94.5 | 325-335 | 23-27 | 0.92 | ≥1.08 | 1.55-1.60 |
| | | 340.3 | 94.5 | 325-335 | 13-17 | 2 | ≥0.95 | 1.45-1.55 |

### 4.4.5 Geographic routes of graphite for batteries

Even though mining of graphite happens in various places on the globe, China mines around 68% of the World's natural graphite, and regarding spherical graphite (specifically for use in batteries), China is the only commercial scale producer. They produced more than 100 kt in 2018, all which was almost exclusively used for anodes for lithium-ion batteries[201]. This is also true for production of anode material, where China is both the largest producer and consumer and produces most lithium-ion battery cells as well. Also, China's market share of synthetic graphite is around 50%[202].

[194] Jara, A. D., Betemariam, A., Woldetinsae, G., Kim, J. Y. (2018). Purification, application and current market trend of natural graphite: A review. In: International Journal of Mining Science and Technology 29 (2019) 671–689

[195] https://www.researchgate.net/publication/234094664_Enhanced_performance_of_graphite_anode_materials_by_AlF3_coating_for_lithium-ion_batteries

[196] https://www.researchgate.net/publication/245108279_Carbon-coated_graphite_for_anode_of_lithium_ion_rechargeable_batteries_Carbon_coating_conditions_and_precursors

[197] https://onlinelibrary.wiley.com/doi/abs/10.1002/ente.201801078

[198] https://batteryuniversity.com/learn/article/bu_309_graphite

[199] https://batteryuniversity.com/learn/article/bu_309_graphite

[200] http://www.indmin.com/events/download.ashx/document/speaker/6562/a0ID000000X0jaHMAR/Presentation

[201] https://www.kitco.com/commentaries/2019-04-29/Graphite-The-race-for-non-Chinese-spherical-graphite-heats-up.html

[202] https://www.slideshare.net/MorganAdvancedMaterials/2016-international-lithium-graphite-conference

However, with the increasing demand for graphite for batteries, a number of companies are aiming at developing a commercial-scale spherical graphite production outside China[203]. This is an attractive business due to the higher return on investments and prospects of a growing market. However, the barriers for market entry to spherical graphite production are high, especially due to China's low cost of labour and energy and its less stringent environmental restrictions, which is especially relevant when using hydrofluoric and other strong acids. Producers outside China therefore also look to develop different purification methods[204].

## 4.5 Risks related to the supply chains

The risks related to the first steps of the supply chains for each of the shortlisted materials, specifically in the originating countries and mining sector, are described in the sections 3.2, 3.2., 3.3., and 3.4. for cobalt, nickel, lithium, and natural graphite. For the risks in the further processing of the materials, it is much more difficult to find detailed information. However, the trade flows show the majority of the materials are processed and traded in the following countries: DRC, Indonesia, Philippines, Russia, Australia, Canada, Chile, Argentina, China, Cuba, Brazil, Japan and Korea.

When looking as far as the production and assembly of li-ion battery cells, the far majority of production takes place in China, with around 55% of the global manufacturing capacity in 2018. Japan, Korea and America have around 10% of the world production capacity each, and the rest is shared between other APAC and EMEA regions[205].

Many of the risks related to low governance, human rights and occupational health and safety are also present in several of these countries and the production processes undertaken in the later steps of the supply chain. The WI scores are shown for these production countries in Table 24. Environmental impacts are also an issue for several of these processes, both in terms of energy consumption and the use of various chemicals that can be hazard to natural ecosystems if not handled correctly.

*Table 24: WGI government indicators on cell producing countries*

| Parameter | China | Japan | Korea | USA |
|---|---|---|---|---|
| **Market share, 2018** | **55%** | **10%** | **10%** | **10%** |
| Voice and Accountability | -1.45 | 1.02 | 0.80 | 1.04 |
| Political Stability and Absence of Violence/Terrorism | -0.26 | 1.06 | 0.54 | 0.48 |
| Government Effectiveness | 0.48 | 1.68 | 1.18 | 1.58 |
| Regulatory Quality | -0.14 | 1.33 | 1.09 | 1.58 |
| Rule of Law | -0.20 | 1.53 | 1.24 | 1.45 |
| Control of Corruption | -0.27 | 1.42 | 0.60 | 1.32 |
| **Average** | **-0.31** | **1.34** | **0.91** | **1.24** |

[203] https://roskill.com/news/graphite-the-race-for-non-chinese-spherical-graphite-heats-up/
[204] https://roskill.com/news/graphite-the-race-for-non-chinese-spherical-graphite-heats-up/
[205] https://www.sustainable-bus.com/news/lithium-ion-battery-market-asian-players-to-support-european-growth/

# 5. Regulatory measures and impacts

In this section the different regulatory measures are identified, and their impacts estimated. The policy measures aim at increasing the share of responsibly sourced materials for batteries, specifically aiming at the four shortlisted materials: cobalt, nickel, natural graphite and lithium. The identified measures can be applied either as voluntary schemes or mandatory requirements. The identified options are described in the first part of this section, and their impacts will be elaborated further the second part.

In order to identify the best possible policy measures, a screening was made on other examples of due diligence and supply chain traceability regulations in different areas, as well as voluntary schemes evolving in the battery and mineral industries specifically. Due to the large number of standards, initiatives and frameworks for different areas affecting the sourcing of materials for batteries (including mining, environment, human rights and due diligence of supply chains), it has not been possible within the scope of this study to create a full list describing each. However, several studies already exist that describe and compare these frameworks within different areas of interest[206].

## 5.1 Possible regulatory measures

The possible policy measures identified and described in this section are:

- Due diligence throughout supply chain of shortlisted materials and batteries, related to human rights, environment and occupational health and safety
- Requirement on applying certain standards in the companies involved in the supply chains
- Minimum requirements for practices related to human rights, environment and occupational health and safety, focusing on shortlisted materials and batteries.
- A combination of the above

### 5.1.1 Due diligence requirements

Risk-based due diligence procedures have become an accepted way of moving towards more responsible sourcing, especially within the metal and mining industries. Due diligence in short terms involves identifying the supply chain, assess the risks, take mitigating actions, and disclose a report of the steps.

[206] Karoline Kickler, Jan Kosmol, Gudrun Franken, Christine Schol, Renzo Mori Junior, Lukas Rüttinger, Kathryn Sturman (2018): Mapping sustainability standards systems for mining and mineral supply chains, Commodity TopNews 59. Link: https://www.bgr.bund.de/DE/Gemeinsames/Produkte/Downloads/Commodity_Top_News/Rohstoffwirtschaft/59_sustainability_standards.html
And: Umwelt Bundesamt (2019): Verantwortung für Mensch und Umwelt: Unternehmen und ihre Sorgfaltspflichten: Hintergrundpapier aus dem Forschungsvorhaben des Umweltbundesamtes. Link: https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/hintergrundpapier_unternehmerische_sorgfaltspflichten.pdf
And: ISSD (2018): State of Sustainability Initiatives Review: Standards and the Extractive Economy, International Institute for Sustainable Development ISBN: 978-1-894784-79-5 https://www.iisd.org/sites/default/files/publications/igf-ssi-review-extractive-economy.pdf
And: Transport & environment (2019): Cobalt from Congo: how to source it better: Comparative analysis of existing supply chain certification schemes and artisanal practices https://www.transportenvironment.org/sites/te/files/publications/Cobalt%20from%20Congo_how%20to%20source%20it%20better_Final.pdf
And: Federal Environment Agency, UBA (2019): International Governance for Environmentally Sound Supply of Raw Materials - Policy options and recommendations (InGoRo) FKZ 3716 32 103 0. https://www.ecologic.eu/14297

Due diligence of the supply chain is seen as an important tool to achieve responsible sourcing for batteries and is therefore suggested as the basis for any regulatory requirement or voluntary scheme in this context. It is imperative, however, that the due diligence approach chosen for this purpose lives up to the following four criteria:

1. Covers the following parameters in the risk assessment: human rights, environment, occupational health and safety
2. Covers the entire supply chain from mining of a material until a battery is placed on the market in the EU
3. Has a robust verification system to ensure risks in the supply chain are indeed identified and responded to
4. Ensure that the results of the due diligence are reported upon annually and made publicly available

In this context risk should not be understood as risks to the company in terms of financial risk, market risk, operational risk, reputational risk, etc. Instead, risk is understood here as the likelihood of adverse impacts on people, the environment and society that enterprises cause, contribute to, or to which they are directly linked. In other words, it is an outward-facing approach to risk.

#### 5.1.1.1 Which due diligence framework should be used?

The OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas[207] (OECD DDG CAHRA) has been discussed as a possible framework for the implementation of due diligence in the supply chain for batteries. This is also the guidance on which the EU Conflict Minerals Regulation is based[208] and many of the due diligence frameworks developed by industry, that was screened for this study, are based on this guidance as well.

One of the disadvantages of using the OECD DDG CAHRA alone as basis for a requirement, is that this framework does not explicitly include environmental issues and occupational health and safety as part of their “red flags”, as is also highlighted by the fact that many of the voluntary schemes developed by the industry includes these as additional parameters.

One possibility that has therefore been discussed is to follow the requirements in the Conflict Minerals Regulation, where industry certification frameworks can be approved as compliant with the regulation, and in order to proof regulatory compliance, a company need a certification from one of these frameworks. This approach has been discarded, however, because the industry certification frameworks often consist of a simple report, where companies evaluate themselves and do not include any certification, third-party audits or verification[209], and selecting only one or few of these specific frameworks might favour some parts of the industry unintentionally. Hence, it was agreed among several stakeholders that compliance with such industry certification schemes cannot replace due diligence at EU level.

[207] https://www.oecd.org/corporate/mne/mining.htm
[208] https://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/regulation-explained/
[209] https://www.transportenvironment.org/sites/te/files/publications/Cobalt%20from%20Congo_how%20to%20source%20it%20better_Final.pdf

Another solution to ensure inclusion of all relevant risk areas in the due diligence (human rights, environment, occupational health and safety) is to instead use the OECD Due Diligence Guidelines for Responsible Business conduct[210] (RBC). These guidelines explicitly address adverse impacts related to workers, human rights, the environment, bribery, consumers and corporate governance that may be associated with their operations, supply chains and other business relationships. The guidelines on RBC build on a framework very similar to that of the guidelines for responsible supply chains of minerals, and consists of the following six steps for companies to implement:

- Embed responsible business conduct into policies and management systems
- Identify and assess actual and potential adverse impacts associated with the enterprise's operations, products or services
- Cease, prevent and mitigate adverse impacts
- Track implementation and results
- Communicate how impacts are addressed
- Provide for or cooperate in remediation when appropriate

In order to ensure that all relevant criteria are covered in the due diligence and that it can be applied to all parts of the supply chain (the two first criteria listed in section 5.1.1), it is thus recommended to use the OECD Due Diligence Guidance for Responsible Business Conduct as basis for any regulatory requirements or voluntary schemes implemented for batteries.

#### 5.1.1.2 Who should perform due diligence?

The intention of the policy measure is that it should apply to all batteries for EVs and ESS placed on the market in the EU. Hence, the actor placing the battery on the market need to make sure the due diligence is performed for the battery components and materials (cobalt, nickel, lithium) that comprise the battery. However, in order for the final actor in the supply chain to be able to perform due diligence, all the companies involved in the supply chain needs to perform due diligence to provide the necessary information.

While the EU cannot set requirement for companies operating solely outside the EU, they can set requirements for any material, component or product imported into the EU. Hence, for the due diligence requirement/voluntary scheme to be effective, it should apply to all the following materials / products imported to the EU:

- Any ore or refined product used for production of cobalt, nickel, lithium or their derivatives necessary for battery production
- Any battery cell, electrode or electrolyte
- Any battery modules, packs and systems

Any company trading these materials to the EU would need to ensure their due diligence reports living up to the regulatory requirements/voluntary schemes. Especially where metals are purchased from different sources, due diligence of all materials need to be ensured before mixing or processing the materials together.

The advantages of this approach as well as the impacts would therefore also be much in line with those of the Conflict Minerals Regulation, except that the regulation for batteries would

[210] http://www.oecd.org/investment/due-diligence-guidance-for-responsible-business-conduct.htm

set material specific due diligence obligations on the downstream sector producing finished battery cells. This would be an advantage in the case of batteries as most of the short-listed high-risk metals is imported to Europe in batteries and not as metal or minerals. In addition, the metals and their minerals short-listed in section 3.11 could be included in the Conflict Minerals Regulation to cover this part of the supply chain. This should not stand alone, however, as the majority of these metals enters the EU as part of batteries.

#### 5.1.1.3 How should the option be implemented?

The due diligence can be implemented either as voluntary scheme or mandatory requirement. Whichever approach is chosen by the Commission, in order to claim to adhere to the scheme or comply with the regulation, the following factors should be included:

- Disclosing information on the results of the due diligence process
- Verification of the results by 3rd party audits

The results of the due diligence process each year, should be disclosed as part in the companies' annual report for shareholders. This is to ensure that the information is easily available for any interested party, and that it would have direct consequences for companies if risks are not treated adequately, in terms of reputational drawbacks. The report should there for include a specific focus on risk mitigation measures.

The information disclosed regarding the due diligence results, should be audited by an independent third party through audits of the company procedures (e.g. audits of the mines, the refineries, the battery cell production sites etc.). Independent third-party audits are crucial to ensure compliance. Audits should tackle specific requirements on how to respond to risks and be performed at least annually. This will eliminate the drawback of due diligence, which is that it is up to each independent importer of batteries to assess whether identified risks should be responded to, and how exactly to respond.

In case of mandatory requirements, a notification system for conformity assessment bodies could be set up, in accordance with decision 768/2008/EC, who would then be qualified to perform the audits. If a voluntary scheme is chosen, there should likewise be strong authorisation procedures for third party actors to undertake audits, probably using a similar notification system. Since no system currently exist for these types of third-party audits its competences and requirements would need to be developed from the bottom, no matter if a voluntary or mandatory approach is chosen. However, experience might be drawn from auditing schemes like the EU Ecolabel[211] or existing voluntary mining due diligence audit systems.

For recycled materials, specific considerations should be made, to ensure that they should be traced back to the first use, but that due diligence should start from the recycling facility until part of new battery.

### 5.1.2 Standards as support to requirements

In order to strengthen the due diligence approach described above, standards on environment and occupational health and safety could be included for supporting voluntary or mandatory measures in a regulation for batteries.

[211] https://ec.europa.eu/environment/ecolabel/

#### 5.1.2.1 Which are the relevant standards?

Relevant standards to support due diligence could for example be:

- ISO 140001 on environmental management
- ISO 45001 (replacing OHSAS 18001) on occupational health and safety
- ISO 22095 on Chain of custody - General terminology and models (under development)
- ILO Convention No.87: Freedom of Association and Protection of the Right to Organize, 1948;
- ILO Convention No.98: Right to Organize and Collective Bargaining, 1949;
- ILO Convention No.29: Forced Labour, 1930;
- ILO Convention No.105: Abolition of Forced Labour, 1957;
- ILO Convention No.138: Minimum Age Convention, 1973;
- ILO Convention No.182: Worst Forms of Child Labour, 1999;
- ILO Convention No.111: Discrimination (Employment and Occupation), 1958;
- ILO Convention No.100: Equal Remuneration, 1951

In order to set clear expectations for these aspects in a possible regulation, and to live up to all of the aspects of “sustainable sourcing”, elevating these standards or equivalent to be a regulatory requirement could be considered as a solution, however taking into account the complexity of compliance for smaller companies (SMEs[212]).

ISO 14001 sets specific requirements for the company to identify and understand the environmental impacts of their activities, products and services. ISO 14001 requires the company to comply with all relevant environmental laws, establish an environmental policy and goals for reducing environmental impacts. The standards explicitly refer to upstream and downstream supply chain in doing this assessment[213]. Furthermore, a risk assessment related to negative environmental impacts is required, as well as a plan for how to prevent these risks.

ISO 45001 is based on OHSAS 18001, but with some changes[214]. The goal with ISO 45001 is to ensure a safe and healthy working environment. Besides complying with all legal requirements on work environment and safety, ISO 45001 also requires the company to build a structure for improving employee safety, reduce risks at the workplace and create better and more safe working conditions worldwide. As with ISO 14001, ISO 45001 also requires a risk assessment procedure assessing how employees’ working environment and safety is potentially negatively affected by the company’s activities, products and services, as well as a plan to solve any issues. ISO 45001 requires employee participation.

Both of these ISO standards are thus a systematised way to work with the environmental and occupational health and safety aspects in an organisation, to identify risks and prevent them.

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[212] https://ec.europa.eu/growth/smes/business-friendly-environment/sme-definition_en
[213] https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/background_paper_duediligence.pdf
[214] https://www.dnvgl.com/assurance/Management-Systems/new-iso/transition/key-changes-in-iso-45001-vs-ohsas-18001.html

For both standards an ISO auditor inspects the company premises and management systems and issues a certification as proof of compliance.

The ISO 22095[215] is under development (recently been on public hearing), and is intended to provide:

- a consistent generic approach to the design, implementation and management of Chains of Custody;
- harmonized terminology;
- the requirements for different Chain of Custody models;
- general guidance on the application of the defined Chain of Custody models, including initial guidance on the circumstances under which each Chain of Custody model might be appropriate;

Chain of custody systems enable information associated with a product and/or production characteristic to be shared among various organizations active in the supply chain. Hence a chain of custody system could be used to ensure transparency in the battery supply chain.

Any chain of custody system should benefit the interests of all relevant actors in the value chain so that it does not benefit special interest. This means that end manufacturers, recycling industries, interest groups and small and medium-sized enterprises must be encouraged to participate in the standardization process. Any Chain of Custody system developed must promote recycled metals.

The ILO conventions mentioned above are the eight essential core ILO conventions that cover the “fundamental principles and rights at work, which are universal and applicable to all human beings in all States, regardless of the level of economic development.”[216] The conventions express in detail and in a formal legal structure the scope and content of the fundamental principles, which are:

- freedom of association and the effective recognition of the right to collective bargaining;
- the elimination of all forms of forced or compulsory labour;
- the effective abolition of child labour; and
- the elimination of discrimination in respect of employment and occupation.

#### 5.1.2.2 Who should adhere to the standards?

As for the due diligence option, all actors in the supply chain should adhere to the standards, however, the complexity of the standards and the nature of some of the first steps of the mineral supply chains, might make it near impossible. This could for example be the case for artisanal mines regarding the ISO standards. It is therefore suggested that the ISO standards described above should not be mandatory. However for middle and down-stream actors in the supply chains, the standards could be useful tool to manage environmental and occupational health and safety aspects of the companies, and it should be possible to provide information about adherence to standards in the due diligence report.

For the ILO conventions, these are in principles intended to be respected by States, however, companies could adhere to the principles therein as well. In order to ensure that the materials

[215] https://dgn.isolutions.iso.org/obp/ui#iso:std:iso:22095:dis:ed-1:v1:en
[216] http://www.claiminghumanrights.org/_ilo.html

that end up in the batteries placed on the market in the EU, all companies along the supply chains should adhere to the principles in order to avoid forced labour, child labour, discrimination etc.

#### 5.1.2.3 How should the option be implemented?

As for the due diligence option, the standards can be implemented either as mandatory requirement or on a voluntary basis. For ISO standards, which have a build-in certification scheme, obtaining and maintain a certification within an ISO standard would be the legal requirement if these standards were elevated to legislation. Caution should be kept, however, as to who is required to adhere to which standards.

For ILO conventions, there is no certification scheme. The conventions are aimed at states, and not directly at companies. However, the conventions in question are regarded as human rights by all other parts of the United Nations system and are incorporated into other international law. It would therefore be reasonable to ensure that all companies in the battery supply chains adhere to these conventions, and to verify this as part of the due diligence procedure as part of the human rights and occupational health and safety aspects. Hence, it is suggested that compliance with all ILO conventions is mandatory.

### 5.1.3 Specific sustainability requirements

Specific requirements for the materials (cobalt, nickel and lithium) and the production processes throughout the supply chain could also be considered. This could for example be avoidance of certain worst practices, or adherence to certain best practices.

#### 5.1.3.1 What could be the requirements?

An example of avoidance of worst practices was suggested by one stakeholder during the study, which regarded the mining stage. The requirement suggested was:

- Metals cannot be sourced from mines practicing deep-sea tailing placement (marine disposal of mine tailings)

No other specific requirements were suggested, but one stakeholder suggested looking to the IRMA framework (Initiative for Responsible Mining Assurance[217]), because they have an elaborate a complete definition of “clean production” in the mining sector. This could for example help to establish a differentiation between “clean” and “dirty” cobalt, lithium and nickel. These definitions also apply the mining stage.

For the middle and downstream steps in the supply chain, no suggestions have been raised by stakeholders.

#### 5.1.3.2 Who should comply to the requirements?

Specific sustainability requirements could be implemented for all steps of the supply chains, in order to set a higher standard for sustainability of raw materials that can be obtained through due diligence alone. However, the specific options considered are thus far related solely to the mining of metals and therefore only the mining step would be affected by such requirements. Middle and downstream actors of the supply chain would however need to

[217] https://responsiblemining.net/

ensure that the metals/compounds/semi-manufacture they source does not contain metals not adhering to the specific requirements.

#### 5.1.3.3 How should requirements be implemented?

The requirements should be part of the due diligence procedure as one of the parameters that should be checked at the mining stage (and other stages in case of elaboration with more requirements for these steps). They could be either voluntary or mandatory. In regard to the two specific requirements suggested above, it is recommended that avoidance of deep-sea tailing placement is made a mandatory requirement. For the IRMA certification however, it is recommended to make this a voluntary certification such as is the case for other industry frameworks.

It should also be ensured that any specific requirements do not have the unintended consequence of eliminating the livelihood of people. This is a consideration that has been made for conflict minerals in general, since many of the adverse impacts in the supply chains is often related to poverty issues.

### 5.1.4 Combination of the options

These presented policy options are not mutually exclusive but should be understood as complementary multi-level governance system. The due diligence procedure should be used as backbone and underpinned by standards and specific requirements, which in turn are made part of the checklist for due diligence audits.

In such a combination option, the following requirements would be made:

- General Supply Chain Due Diligence according to OECD Guidance for Responsible Business Conduct should be mandatory for up- and downstream users for the entire supply chain of the materials cobalt, nickel and lithium. For batteries not containing any of these metals, the due diligence should apply from the step in the supply chain where electrodes and electrolytes are produced.
- Adhering to ILO conventions should be mandatory for all actors of the supply chain
- Avoidance of deep-sea tailing placement should be mandatory for all mines mining or co-mining cobalt, Nickel and Lithium.
- Adherence to ISO standards should be voluntary
- Adherence to IRMA or other industry frameworks standards should be voluntary

The evaluation of a regulation implementing these factors, should specifically consider whether the scope should be expanded to include further specific metals the cobalt, nickel and lithium, and whether further specific requirements should be added.

## 5.2 Impacts of options

The impact of introducing the policy options described above will be a mitigation of risks to environment and people in the supply chain of batteries. Since at least one of the four shortlisted materials are expected to be used in every EV and ESS battery placed on the market in the EU, it is assumed that all battery cells will have been subject to the requirements in their supply chain. Hence, even though only some materials are covered all the way from the mining stage, as soon as they enter the battery supply chain (often at conversion stage), the battery cells or cell component they are incorporated into, are subject to due diligence.

### 5.2.1 Effectiveness of the option

The effectiveness of the regulation is quantified by the share of each selected metal (cobalt, nickel, lithium and natural graphite) contained in the batteries put on the market in the EU, that has been sourced responsibly. Responsible sourcing in this context is defined as adhering to the requirements defined in the policy options. Table 25 shows the expected share of metals sourced according to the responsible sourcing criteria in case of a voluntary or a mandatory reporting requirement by 2025, compared to no requirements (no action). The numbers are a forecast of the current market trends, where more and more companies already perform due diligence for cobalt, and is based on the assumption that around 30% of battery purchasers will also choose batteries with sustainably sourced nickel, lithium and graphite, if the information is available to them. In case of a mandatory requirement, it is assumed that all batteries put on the market will have had a due diligence process for the selected materials.

*Table 25: Effect of voluntary and mandatory reporting on sustainable sourcing compared to BAU*

| Metal | Option | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Cobalt | No action | 50% | 60% | 70% | 80% | 90% | 95% | 95% |
| | Voluntary | 50% | 70% | 80% | 85% | 90% | 95% | 95% |
| | Mandatory | 50% | 100% | 100% | 100% | 100% | 100% | 100% |
| Nickel | No action | 0% | 0% | 5% | 5% | 10% | 10% | 15% |
| | Voluntary | 0% | 5% | 10% | 15% | 20% | 25% | 30% |
| | Mandatory | 0% | 100% | 100% | 100% | 100% | 100% | 100% |
| Lithium | No action | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | Voluntary | 0% | 5% | 10% | 15% | 20% | 25% | 30% |
| | Mandatory | 0% | 100% | 100% | 100% | 100% | 100% | 100% |
| Graphite | No action | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | Voluntary | 0% | 5% | 10% | 15% | 20% | 25% | 30% |
| | Mandatory | 0% | 100% | 100% | 100% | 100% | 100% | 100% |

### 5.2.2 Economic impacts

Economic impacts of implementing due diligence happens to each link in the supply chain needing to perform due diligence and is thus expected to be transferred to end-users through increasing product prices. In case of a voluntary scheme this applies only to the manufacturers and supply chains adhering to the voluntary due diligence requirements, while for mandatory requirements it will apply to all.

For supply chain actors, the costs are estimated based on stakeholder inputs, which were, however, quite limited. The indications given was that around one Full Time Employee (FTE) would be needed for managing due diligence procedures for each 50-100 million € turnover. This number is averaged and very uncertain, however, and also depends on the number of sub-suppliers that are overseen and the quality of their due diligence. Sub-suppliers could be mines, refineries, cell producers etc., as the entire supply chain needs to be covered. Furthermore there might be some costs related to improving the practices used in the supply chain, i.e. minimising the risks identified in the due diligence. However, this will depend on the individual company and supply chain, and cannot be quantified in general.

A more tangible cost is the cost of third party independent audits, which was estimated to be around 20 consultant hours, once a year at each supply chain step. At a cost of around 150 EUR/hour, this amounts to 3000 EUR per year for each third party audit necessary. These costs are thus quite insignificant for the single supplier.

One of the major economic impacts is expected to be on the raw material prices, if some are in higher demand because they live up to the regulatory requirements. However, with time the price increase initiated by the voluntary scheme or regulatory requirements, is likely to level out and become closer to the average market price of non-compliant material. Approximate data was only available for cobalt, and one supplier estimated a 1USD increase per kg cobalt. Based on a high-grade cobalt price of around 30 USD/kg[218], this would correspond to an increase in material prices of around 3.5%, which is quite significant. This is the material price itself and thus comes in addition to the direct costs of managing the due diligence procedure.

The increase in material prices are likely to be conveyed to the end-user through increased battery prices. However, there are many other costs of a battery than the raw materials, and the price increase is therefore not assumed to be significant for the end-user in comparison with the cost of the EV.

The economic benefit is difficult to quantify but the expected impact of voluntary scheme or mandatory requirement is a reduction of the risks in supply chain, which can be worth a premium due to the improved market reputation for manufacturers. If due diligence is not performed, or performed poorly, manufacturers have a risk of a public scandal, which could be a large risk to future sales. Furthermore, there will be an economic benefit in the countries where environmental and health risks have been mitigated. This benefit has not been quantified due to lack of data.

### 5.2.3 Social and environmental impact

The main social and environmental benefit of this policy option will be the improvement of political and social stability for local operators and communities in conflict regions and the strengthening of environmental aspects, reducing contamination and health issues. However, in order to not further risk impoverishment and unemployment of local operators and communities through reduced economic activity in the regions concerned, it is important to ensure improvement of the small and artisanal mines, e.g. through formalisation processes[219], rather than avoid them completely in the supply chains.

Due to the uncertainty of the economic impacts described above, it is not possible to estimate the number of jobs created in the EU, but due to additional activities within the battery manufacturing companies, market surveillance etc., there is no doubt additional jobs are created. The share of these jobs inside and outside EU also depends on the specific supply chains and how much of them lies outside the EU.

[218] https://www.metalbulletin.com/Article/3314661/Cobalt-prices-hit-two-year-highs.html
[219] https://www.africaportal.org/documents/18664/IMPACT_ASM-Best-Practices_May-2018-EN-web.pdf

### 5.2.4 Administrative impact for European Commission and Member State authorities

Depending on how the requirements are implemented, the costs for the European Commission will vary. If the Commission needs to develop an implementing guidance, detailing how manufacturers should implement the requirement or voluntary scheme, previous experience from the conflict mineral regulation show that an estimated 200,000 EUR will be needed for one external study to make this guidance. As well as one Commission staff FTE is assumed to be needed for this work[220].

Furthermore, if the Commission chooses to publish a list of sustainable suppliers to show who adhere to the voluntary scheme, the costs for keeping this up to date, is estimated at 120,000 EUR annually[221].

In case of a mandatory requirement, there will be no need to keep a list of manufacturers adhering to a voluntary scheme, but instead the scheme would require up to 1.5 FTEs in designated control bodies per Member State to handle market surveillance and coordination of compliance control.

### 5.2.5 Stakeholders' views of the option

When asked about the most relevant social and environmental impacts in battery production, almost 60% of respondents of the Open Public Consultation (OPC) (carried out in relation to the Impact Assessment) were in favour of setting reporting obligations on the responsible sourcing of raw materials.

When asked about the type of policy and regulatory interventions most appropriate for the promotion of battery manufacturing in Europe, requirements on the ethical sourcing of raw materials was favoured by 47% of the OPC respondents.

When consulting stakeholders involved in the preparatory study, the general replies were positive towards due diligence, but most favoured mandatory requirements rather than voluntary, even though transparency of the supply chain was raised as a concern.

**Mandatory requirements**

Arguments for implementing mandatory rather than voluntary requirements included ensuring a level playing field for all battery manufacturers selling their products in the EU. This was especially a concern for some industry members, with regard to the minimum requirement on “worst” practices used for mining and transforming materials. It will often require substantial investments to improve production above the worst practices and avoid techniques and processes that are especially harmful to people and the environment. For the producers it is important the EU ensures legislation will not hamper the competitiveness of businesses making these investments and not using these practices. Therefore, they argue that some of these worst practices should be banned through a specific hard requirement, as is suggested for the deep-sea tailings placement (only worst-practice identified).

[220] commission staff working document - Part 1 (Impact Assessment) Accompanying the document
Proposal for a Regulation of the European Parliament and of the Council setting up a Union system for supply chain due diligence self-certification of responsible importers of tin, tantalum and tungsten, their ores, and gold originating in conflict-affected and high-risk areas. COM(2014) 111 final, Brussels, 5.3.2014, SWD(2014) 53 final

[221] commission staff working document - Part 1 (Impact Assessment) Accompanying the document
Proposal for a Regulation of the European Parliament and of the Council setting up a Union system for supply chain due diligence self-certification of responsible importers of tin, tantalum and tungsten, their ores, and gold originating in conflict-affected and high-risk areas. COM(2014) 111 final, Brussels, 5.3.2014, SWD(2014) 53 final

**Type of requirements**

This recommendation of a specific ban of certain practices also related to the statement from several stakeholders that due diligence alone is not enough, but that they recommend the EU to opt for the combination option, as recommended in this report. Such statement was made by Member States as well as NGOs and industry stakeholders. While including information on potential compliance to ISO standards (e.g. ISO 14001) would ensure that an environmental management system is in place to improve the environmental performance, it would not ensure that some practices are not used, or that certain worker rights are not violated. Therefore stakeholders from both industry and Member States recommended to make a combination option and argued that as long as there is no global UN convention on responsible mining, national or supranational due diligence regulations in combination with voluntary standards seem to be the best governance model for global responsible supply chains.

A specific concern was raised by several stakeholders that the OECD DDG for Responsible Supply Chains of Minerals from CAHRA were mainly focused on human rights and governance issues and would not help to tackle relevant environmental issues such as CO2 emissions, tailings management, erosion prevention, dust and chemical contamination and other environmental problems. The OECD DDG on Responsible Business Conduct was therefore raised as a better alternative by especially Member States. Furthermore, stakeholders supported that a regulation should encourage the industry to source from supply chains that have fully implemented the 8 ILO conventions and truly implement them within their facilities.

**Scope of the regulation**

The broad scope of including both human rights, worker rights and environment was agreed by all stakeholders with whom the study team has been in contact during the study. Another issue agreed upon by all was that the regulation should cover the entire value chain, from raw materials extraction and materials refining, to cell and battery/battery pack manufacturing. Again this was related to ensuring a level playing field, and stakeholders argued that without requirements on the entire supply chain there is a risk that European subcontractors for battery production will be disadvantaged.

Also, it was mentioned by stakeholders that to ensure batteries placed on the market in Europe are sustainably sourced, the materials need to be traced all the way from mining to finished battery system, and that level of transparency in the supply chain requires each actor along the chain to take action for due diligence. It was suggested that for each step of the supply chain, operational performance should be evaluated towards due diligence criteria and mandatory minimum sustainability requirements. Third party audits at each level of the supply chain was mentioned as an important tool, as well as sharing the conclusions of the audit along the supply chain.

**Transparency**

In terms of transparency different options were mentioned by stakeholders, for example the idea of a battery passport was raised, which should then be a digital record that tracks information about the battery along its entire life cycle, starting with raw material extraction to the stage of end-of-life where batteries are de-registered. In each step of the battery's life, essential information should be registered on the passport, in accordance with proposals from the Global Battery Alliance.

Other stakeholders mentioned block chain technology solutions, which are under development, to ensure supply chain traceability.

## 5.3 Conclusion and recommendation

Based on the findings of the report, it is clear that a regulation is necessary to ensure the sustainability of sourcing of battery materials over the entire supply chain and to avoid a trade-off between EV low-carbon transport and environmentally and socially harmful extraction and production processes for batteries. Such a regulation is recommended, based on this study, to consider the following:

- A mandatory due diligence requirement for the entire supply chain as a backbone of the regulation, from mining of the selected raw materials until the battery is placed on the European market
    - Preferably the due diligence should be required to be made according to the OECD DDG for RBC guidelines to ensure that environment and occupational health aspects are included in the due diligence process
    - If instead the OECD DGG on CAHRA is chosen as framework for the regulation, it should be explicitly mentioned that these aspects are mandatory to include in line with human rights issues highlighted in this guidance
- A mandatory, annual report on due diligence activities including results, risks identified, and mitigation actions taken. Should be published as part of the company's annual report to shareholders.
- Independent third-party auditing should be mandatory for all due diligence procedures
- Make it voluntary to comply with ISO or other environmental standards, and to report on it in the annual due diligence report
- Mandatory minimum requirements to environmental performance in the form of a blacklist of specific worst-practice mining and production methods
- Evaluate the regulation to make sure sustainability requirements increase over time by regularly assessing:
    - The effectiveness of a due diligence-based approach
    - Further worst-practices to be blacklisted