

*MARKET  
OVERVIEW  
BATTERY  
MATERIALS*

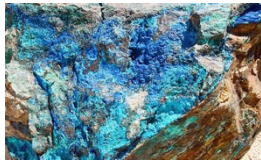
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## Introduction to Battery Materials

Batteries were first made in 1800 by the scientist Volta, who discovered a way to store energy through chemical manipulation. Over the years, many batteries were made, more portable and more efficient. Today, the most common battery is the Lithium-ion battery. They are the ones that give rise to electronic vehicles, consumer electronics and stationary storage. (3) Battery materials are essentially a mix of 4 main commodities: Cobalt(Co), Lithium(Li), Natural Graphite and Manganese(Mn). (5)



Cobalt



Lithium



Graphite



Manganese

### Cobalt

Cobalt was first employed in the production of pigments in Egypt in the XVI century BC. Later, it was used in China as a coloring agent for blue dye. It then became a cheaper substitution of “blue out-mer”. Today, half of the world’s Cobalt is used for Batteries Cathodes due to its chemical properties and is traded worldwide. It is used in most devices and in electric vehicles like Tesla. The rest is used for super alloy products due to its high temp melting point. It is usually found in rock form and mostly in combination with nickel and/or copper. (4)

### Lithium

Lithium was first found in the 1800 in Sweden by a Brazilian chemist. It cannot be found under natural form and is obtained by electrolyze. It is used for special alloy such as alloy with aluminum or magnesium, that reduces the density of the metal and increases stiffness. It makes it a good commodity for the aerospace industry. It can also be used for ceramic and glass, medicine and others. Today, significant percent is now used for the production of Lithium-ion batteries. (4)

### Graphite

First discovered in North England in the 16th century. It was initially used for color pigments (black) for marking sheep, then for writing. Its erasability made it more suitable than charcoal. These factors made it already a tradable commodity where England and Canada were the main suppliers. Today, it is mainly used in steelmaking and metallurgy, but also semiconductors, diodes, lightweight high-strength composites. There is a growing demand in fuel cell anodes for batteries. (4)

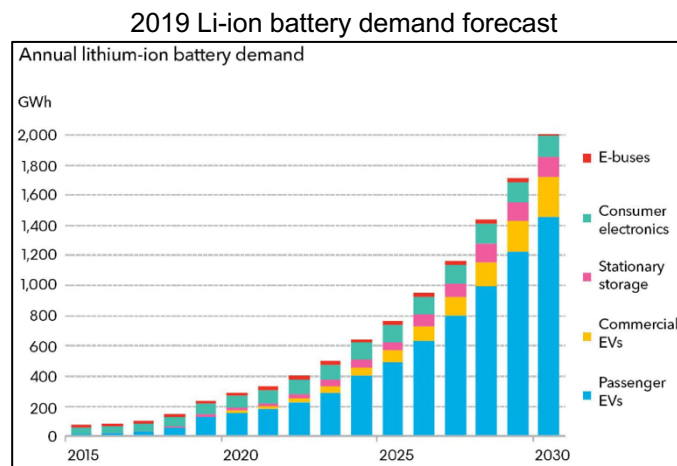
Graphite is mainly composed of carbon where the higher the carbon percent content, the purer the form which makes it less costly to refine. It is found under three forms: vein, flakes and amorphous where vein is the purest (90-99% carbon content). Amorphous is the most common form. It has two properties, metallic and non-metallic, which makes it unique: the metallic properties include thermal and electrical conductivity and the non-metallic properties consist of inertness, high thermal resistance, and lubricity. (4)

### Manganese

It was discovered for its usefulness in the 19th century. It increased iron toughness without changing the malleability. Still today, manganese is 90 percent used for steel production (alloy iron for steel) and the remaining 10 percent is used for the Batteries Cathodes and some chemicals. For that reason, our market overview will not focus on manganese. It is not found in nature on its own form. It is mainly found in several minerals where it has to be electrolyzed. (4)

### History: How has the trade evolved?

Nowadays, due to continuous technological advancement and an increasing demand for batteries in laptops, smartphones but especially vehicles, the trade flow has shifted towards the main battery producers that are all in China. The country has control over 80 percent of the world's raw material refining, 77 percent of the world's cell capacity and 60 percent of the world's component manufacturing. (3)



Evolution of the trade of the four commodities depend largely on the level of its demand as shown in the graph above because more than half of the production is used for lithium ion batteries. (3)

### Key drivers: What Influences the Market of the commodity?

Factors influencing the supply can be the geopolitical stability and demand dynamics of battery materials. (2) "Rise in demand for electric vehicles and usage of electronic devices especially smart devices"(1) are the foremost drivers of battery materials. As the importance for oil recedes and need for replacement of fossil fuel increases, the demand for rechargeable batteries grows rapidly. Increasing recognition for the need to lower greenhouse gas emissions and growing importance of electric mobility influence the market of raw materials used to manufacture rechargeable batteries. There is a boom in electric cars in recent years. (1,2) As the world is going more and more digital, demand and production of electronic devices are skyrocketing, and it influences the market of the battery materials.

### Market structure

The market structure for the four elements are highly controlled by few players. Basically, the supply chain is as follows:



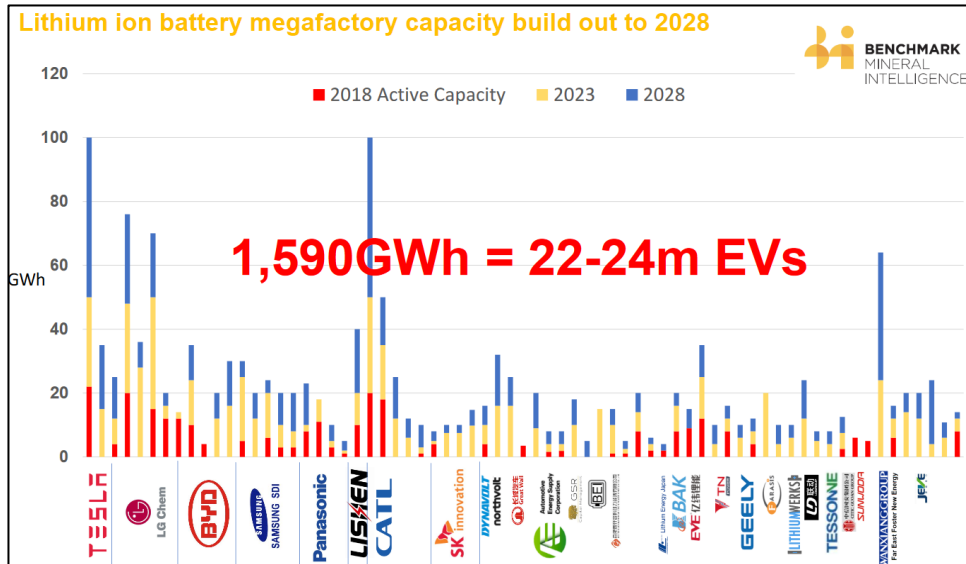
#1. Mining - #2. Refining - #3. Cathode/anode production - #4. Battery cell production - #5. Assembly - #6. OEM (original equipment manufacturer, an organization that makes devices from component parts bought from other organizations.)

For the first step, mining will be done by the big mining companies such as Glencore who mined the most Cobalt in 2017. The market is highly concentrated between the few top companies. Moreover, most of the resources are concentrated in few countries. For instance, Lithium is mostly found in the « lithium triangle » in Latin America: Chile, Argentina and Bolivia. Democratic Republic of Congo exports

more than half of the world trade of cobalt and produces almost all of it. (3,7) Thus, value added is generated outside the countries with the natural reserve that produce/mine the battery materials. (2)

For the second step, as mentioned above, refining companies are mainly concentrated in China where over 80 percent of the raw materials refining are found. Seven Chinese companies are found in the top ten biggest refineries worldwide. (3,7)

For the last four parts, most battery manufacturers are also assembling and producing the battery cells and using them for their own goods. Companies such as Samsung, Tesla, LG can be found here. (3,7)



## Supply and demand

### Supply

Highly concentrated production. So, it is an oligopoly-monopolistic market depending on the commodity. "Reserves of the raw materials for car batteries are highly concentrated in a few countries. Nearly 50 percent of world cobalt reserves are in the Democratic Republic of the Congo, 58 percent of lithium reserves are in Chile, 80 percent of natural graphite reserves are in China, Brazil and Turkey, while 75 percent of manganese reserves are in Australia, Brazil, South Africa and Ukraine".(2)

### Demand

In all stages of the supply chain, it is very concentrated with only a few players. At the level of demand from refineries, it's concentrated on the big Chinese refineries. Manufacturers of electric vehicle producers such as Tesla, Volvo, Volkswagen and BYD (china's largest electric carmaker) all forecast big growth by 2025-2030. Volkswagen for example invested 24 billion USD. The end of supply chain indicates the demand from the end-consumer who consume goods such as smartphones, laptops, smart devices. (6)

## Market structure per commodities

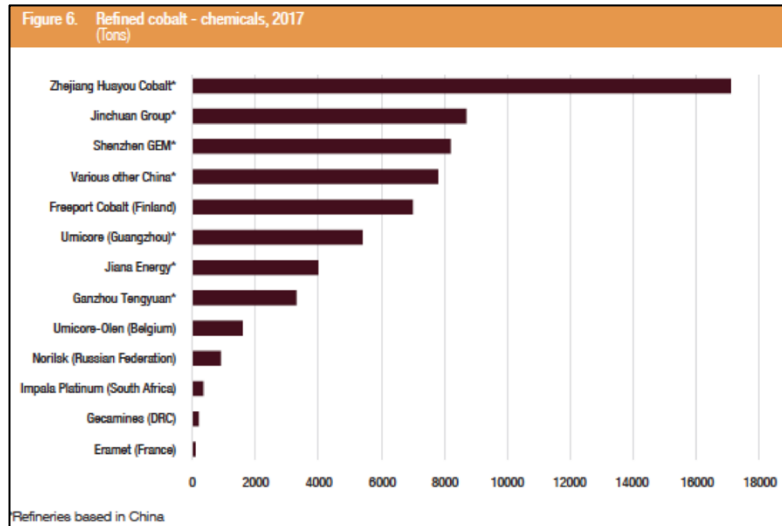
### Cobalt

#### Mining

The top five cobalt mining companies in 2017 in terms of volume were Glencore (27'400 tons), China Molybdenum (16'419 tons), Fleurette Group (7'595 tons), Vale (5'811 tons) and Gecamines (4'167 tons). The latter is a state controlled cobalt mining company in the Democratic Republic of Congo.(2)

## Refineries

The top cobalt chemical refineries are concentrated in China which holds 50 to 60 percent of the global refinery capacity. The largest refineries outside of China are Freeport Cobalt's Kokkola refinery in Finland (annual production of 11 kt in 2017), Glencore's Nikkelverk refinery in Norway (annual production of 5 kt in 2017) and Sumitomo's refinery in Japan (annual production of 4 kt in 2017). (2)



## **Lithium**

### Mining

The top five lithium mining companies in terms of global market share are Albemarle (18%); Jiangxi Ganfeng Lithium (17%); Sociedad Química y Minera S.A. (14%); Tianqi Lithium Industries Inc. (12%) and FMC/Livent (5%). Over 50 percent of lithium resources are concentrated in the lithium triangle which is composed of Chile, Bolivia and Argentina. The largest lithium reserves are in Chile, which holds approximately 58 per cent of the world total. They control most of the mine output. (2)

### Refineries

The top producers of refined lithium are in Chile, where the world's largest lithium sources are located. The U.S. Argentina and China are also major producers of refined lithium. Four companies dominate the market for refined lithium: Sociedad Química y Minera de Chile, Australia's Talison, Chemetall in Germany and FMC in the United States. (2)

## **Graphite**

### Mining

Leading countries of graphite, in order, are: China (780k MT), India (150k MT), Brazil, Canada and Mozambique.(9) We can find most of Chinese mining companies in Northern east regions of China. (10,11)

### Refineries

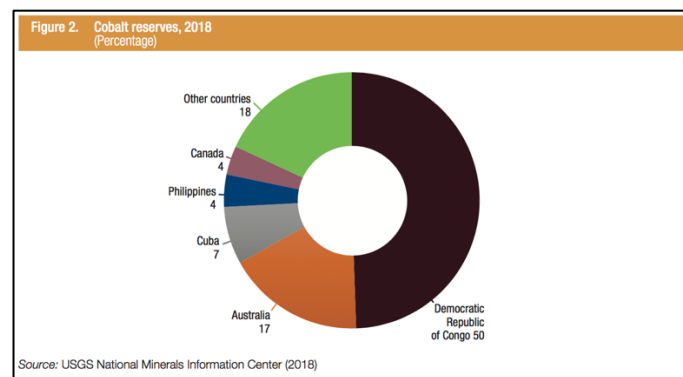
More than 90 percent of world graphite is found in China. Many graphite refining companies are around the world. The leading producers of refined graphite are China, Mexico and Canada. (2)

## Reserves, production and trade flows

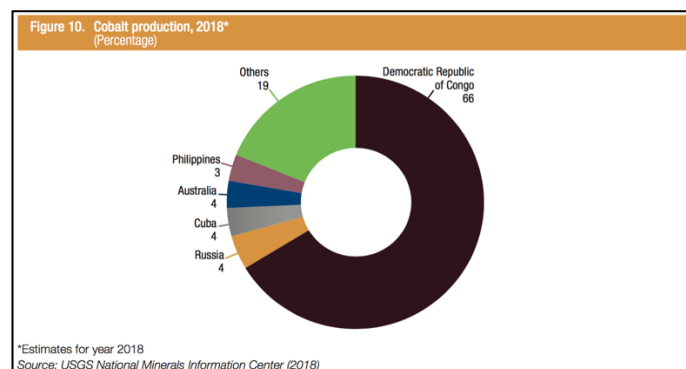
### Cobalt

Cobalt is present in the earth's crust as well as on the seafloor. However, only the cobalt present in the earth crust is economically viable to extract with current technology. The world terrestrial cobalt resources are estimated to be about 25 million tons. (4)

Less than 10 percent of cobalt supply occurs as a primary product. Currently, the only primary cobalt operations are from the Mukondo mine in the Democratic Republic of Congo and the Brou Azzar mine in Morocco. The majority is found as a by-product of copper (55 percent) and nickel (35 percent) mines.<sup>i</sup> The figure below shows the top five countries that have cobalt reserves by percentage for the year 2018. The Democratic Republic of Congo has half of the world cobalt reserves where cobalt can be extracted from copper deposits. Australia holds 17 percent of the world reserve and Cuba holds 7 percent. Both have cobalt in nickel-bearing deposits. (4)



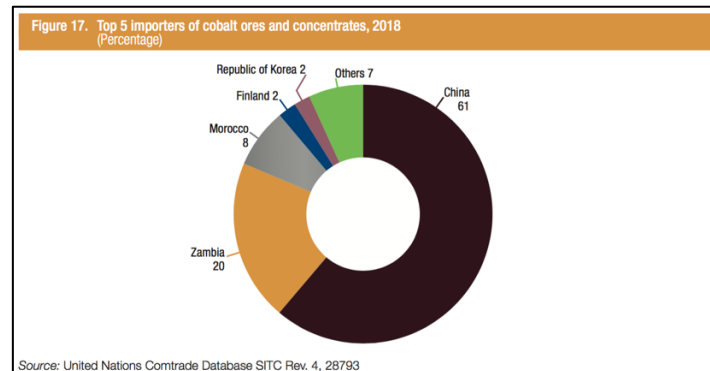
The figure below shows the top five countries producing cobalt by percentage for the year 2018. The biggest producer of cobalt is its main holder, the Democratic Republic of Congo which accounts for 66 percent of global production. Yet, eight of the largest mines in the Democratic Republic of Congo are Chinese owned, accounting for almost half of the global cobalt supplies. Russia, Cuba, Australia and the Philippines are the next largest producers accounting together however for only 16 percent of global production. (4)



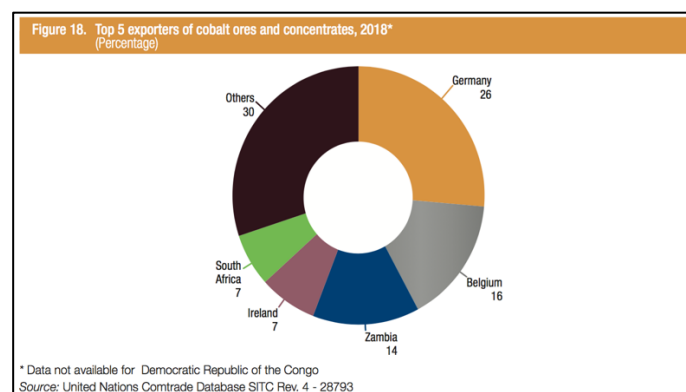
The major product categories of cobalt traded are ores and concentrates, oxides and hydroxides, as well as chlorides. In 2018, Cobalt was the world's 392nd most traded product, with a total trade of 7.87 billion USD. Between 2017 and 2018 the exports of Cobalt grew by 51.6 percent, from 5.19 billion USD to 7.87 billion USD. (13)

First, we will discuss the trade of cobalt ores and concentrates. The figure below shows the top five cobalt ores and concentrates importers' countries by percentage for the year 2018. More than half of cobalt ores and concentrates are imported by China. The next biggest importer is Zambia who imports 20 percent of the world trade in 2018. In terms of value China imported 601.6 million USD, Zambia 198.4 million USD, Morocco 73.4 million USD, Finland 23 million USD and the Republic of Korea 19.9 million USD in 2018. Most of the ores and concentrates imported to China originated from the Democratic

Republic of Congo. The imported ores and concentrates are refined to produce metals at the Chambishi Metals plant and then exported to other markets. (4)

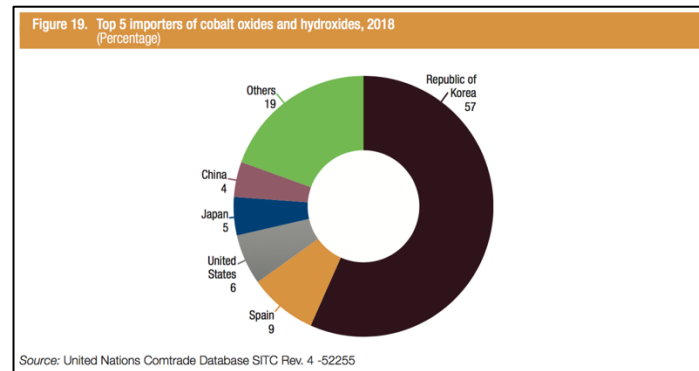


In the same way, we will look at the cobalt ores and concentrate on the exporter's countries. Please beware that no data was available from the Democratic Republic of Congo. Mirroring the importing data from China suggests that the Democratic Republic of Congo is a major exporter but doesn't figure in the reported data below. The figure below shows the top five cobalt ores and concentrates exporter's countries by percentage for the year 2018. Germany was the biggest exporter according to that data representing 26 percent followed by Belgium for 16 percent of the world trade. Zambia who is the second biggest importer of cobalt ores and concentrate is also the third exporting country representing 14 percent of the world trade. In terms of value, Germany exported 2.6 million USD, Belgium 1.5 million USD, Zambia 1.3 million USD, Ireland 0.7 million USD and South Africa 0.6 million USD in 2018. (4)

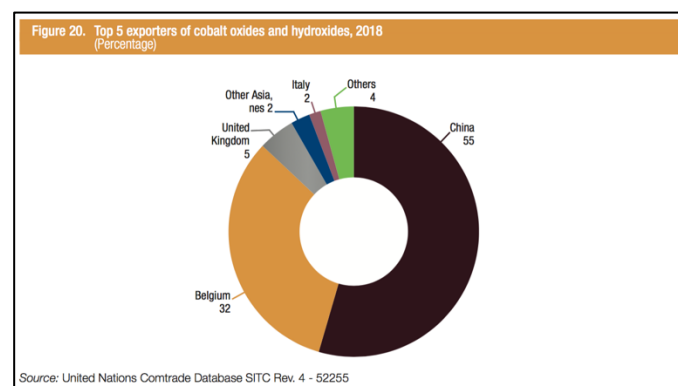


Secondly, we will discuss cobalt oxide and hydroxides trade. The figure below shows the top five cobalt oxides and hydroxides importers' countries by percentage for the year 2018. The Republic of Korea is the biggest importer of cobalt oxides and hydroxides representing 57 percent of the world trade even though they are the fifth larger importer of cobalt ores and concentrate by world trade percentage. China on the other hand who's the biggest importer of cobalt ores and concentrate is the fifth importer of cobalt oxides and hydroxides. In terms of value, the Republic of Korea imported 837.2 million USD, Spain 125.4 million USD, the United States 92.5 million USD, Japan 70 million USD, and China 64.5 million USD in 2018. (4)





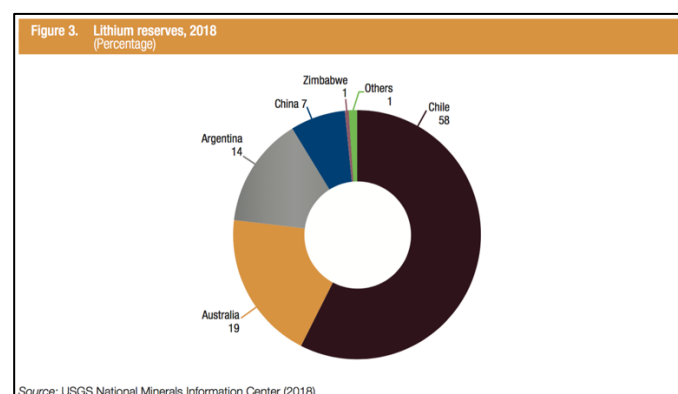
In the same way, we will look at the cobalt oxides and hydroxides in the exporter's countries. The figure below shows the top five cobalt oxides and hydroxides exporter's countries by percentage for the year 2018. In terms of value, China exported 548.7 million USD, Belgium 314.3 million USD, the United Kingdom 32.4 million USD and Italy 10.9 million USD. (4)



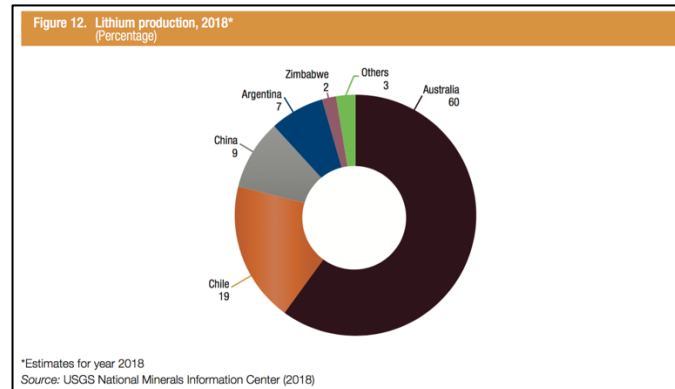
## Lithium

Lithium does not occur as a metal in nature but is found in hard rock forms in crystals that are hosted in Pegmatites which form when mineral rich magma is cooled in fissures in the continental plates. Additionally, lithium is highly reactive with water the consequence of which means that lithium is always found bound with one or more other elements. Although lithium is found in many rocks and several natural brines, commercial exploitation is only possible in a few deposits with high concentration that make exploitation feasible. The total world resources are estimated to be about 62 million tons. (4)

The figure below shows the top five countries that have lithium reserves by percentage for the year 2018. Over 50 percent of lithium resources are concentrated in the lithium triangle which is composed of Chile, Bolivia and Argentina. The largest lithium reserves are in Chile, which holds 58 percent of the world total. Australia is the second biggest reserve of lithium and holds 19 percent of the world resources. (4)

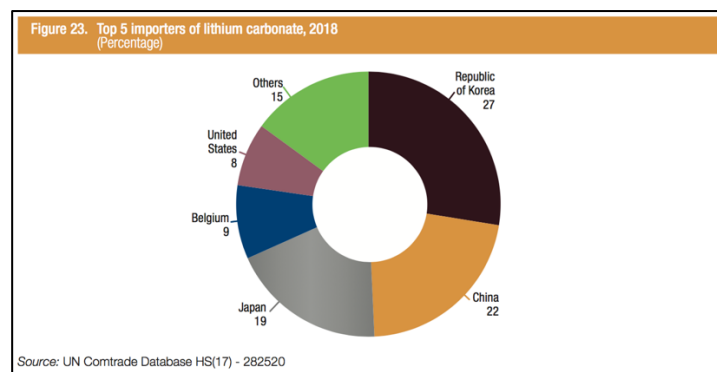


The figure below shows the top five countries that produce lithium by percentage for the year 2018. There are currently only eight countries producing lithium of which three - Chile, Australia, and China - account for 85 percent of global production. Australia is the largest producer of lithium from rocks, while Chile, Bolivia and Argentina supply lithium originating from brines. China is an exception as it produces from both brines and hard rock. In 2015, 56 percent of global output was from brines and the remaining 44 percent from hard rock sources. (4)

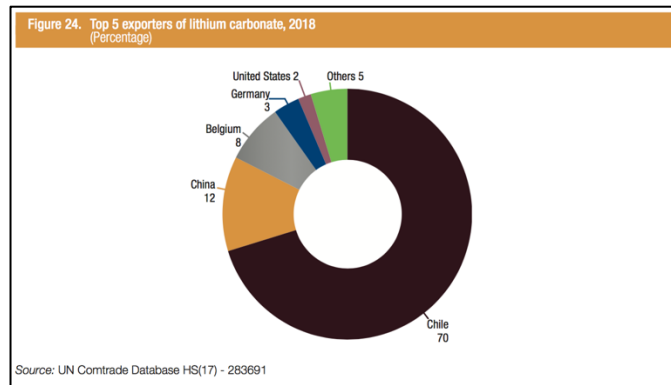


Lithium products traded globally are mainly in the form of oxides and hydroxides, lithium carbonates and lithium metal. The principal material used in rechargeable batteries is lithium carbonate, but development in battery technology is increasing demand for lithium hydroxide. We will look at both.

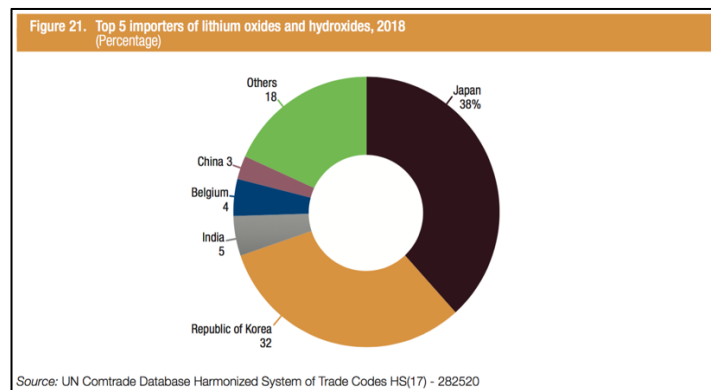
First, we will discuss the trade in lithium carbonate. In 2018, Lithium carbonates were the world's 1467th most traded product, with a total trade of 1.74 billion USD. Between 2017 and 2018 the exports of Lithium carbonates grew by 53.3%, from 1.14 billion USD to 1.74 billion USD. (14) The figure below shows the top five lithium carbonate importer's countries by percentage for the year 2018. The Republic of Korea, China and Japan account for almost 70 percent of total global imports of lithium carbonates. In terms of value, the Republic of Korea imported 458 million USD, China 363 million USD, Japan 317 million USD, Belgium 150 million USD and the United States 128 million USD.(4)



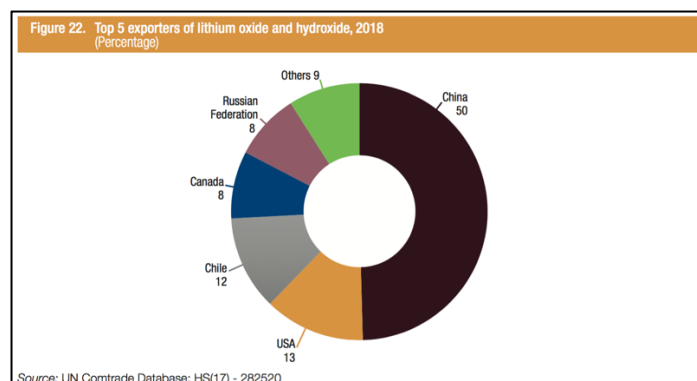
In the same way, we will look at the lithium carbonate exporter's countries. The figure below shows the top five lithium carbonate exporter's countries by percentage for the year 2018. Approximately 70 percent of lithium carbonates exports originated from Chile which holds the biggest lithium reserves. China is the second biggest importer as well as exporter of lithium carbonate. Belgium is holding 9 percent of the world import and 8 percent of the world export. In terms of value, Chile exported 948 million USD, China 165 million USD, Belgium 104 million USD, Germany 46 million USD and the United States 23 million USD. (4)



Secondly, we will discuss trade in lithium hydroxide. The figure below shows the top five lithium hydroxide importer's countries by percentage for the year 2018. We find that Japan and the Republic of Korea are also the biggest importer of lithium oxide and hydroxide. Together they account for approximately 70 percent of the value of total global supplies. China however only imports 3 percent of lithium hydroxide compared to 22 percent of the world lithium carbonate. In terms of value, Japan imported 280 million USD, the Republic of Korea 229 million USD, India 35 million USD, Belgium 32 million USD and the United States 19 million USD. (4)



In the same way, we will look at the lithium hydroxide exporter's countries. The figure below shows the top five lithium hydroxide exporter's countries by percentage for the year 2018. Even though China isn't the main importer of lithium oxide and hydroxide, they are the main exporter. In terms of value China exported 398 million USD, the United States 102 million USD, Chile 95 million USD, Canada 68 million USD and the Russian Federation 67 million USD. (4)

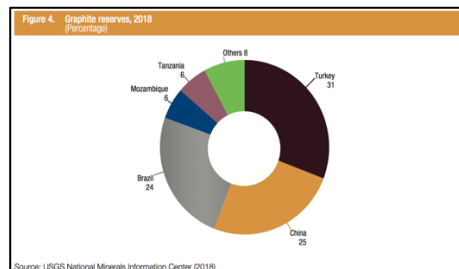


**Natural graphite**

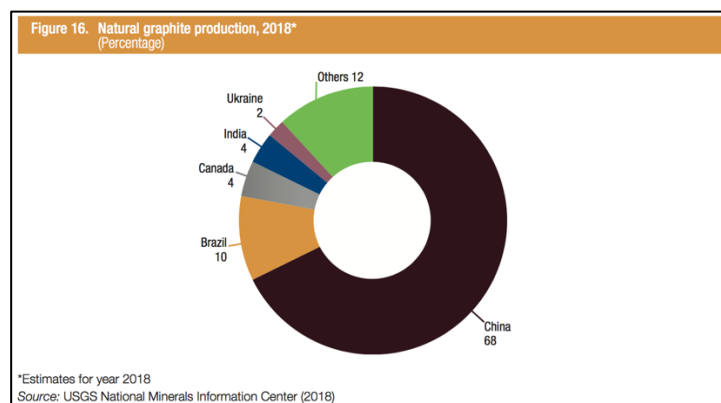
Natural graphite is formed when carbon is subjected to heat and pressure in the earth's crust and in the upper mantle. It comes in three different forms: amorphous, flake and vein. The amorphous type is the most abundant form of naturally occurring graphite making up about 60 percent of the market. On the other hand, the vein or lump type of graphite is the rarest and most valuable form of graphite for its

higher grade that lowers the milling and refining cost. Sri Lanka is the only country that produces commercially viable vein graphite. Global graphite reserves are estimated at 300 million tons. (4)

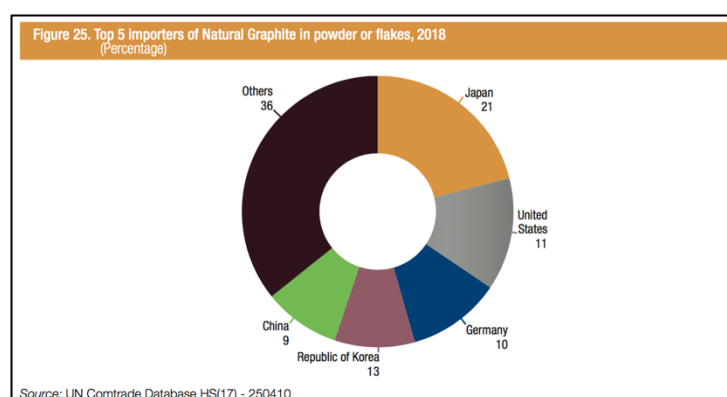
The figure below shows the natural graphite reserves by country by percentage for the year 2018. The largest reserves of natural graphite are in Turkey for 31 percent, China for 21 percent and Brazil for 24 percent. (4)



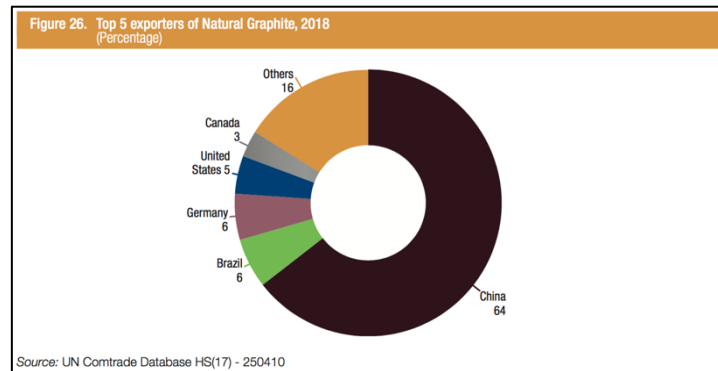
The figure below shows the natural graphite production by country by percentage for the year 2018. China is the largest producer of natural graphite by producing 70 percent of the world total graphite production of which approximately 44 percent is amorphous graphite and 56 percent is flake. (4)



The figure below shows the top five natural graphite importer's countries by percentage for the year 2018. The largest importer is Japan, accounting for about one fifth of the global imports. In terms of value, Japan imported 128 million USD, the Republic of Korea 81 million USD, the United States 68 million USD, Germany 58 million USD and China 55 million USD. (4)



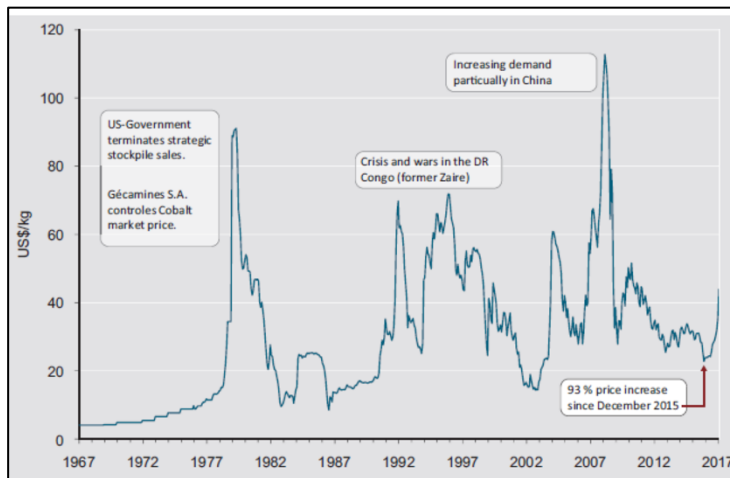
In the same way, we will look at natural graphite exporter's countries. The figure below shows the top five natural graphite exporter's countries by percentage for the year 2018. China dominates exports of natural graphite accounting for almost 65 percent of total graphite exports. In terms of value China exported 14.9 million USD, Brazil 31.2 million USD, Germany 29.5 million USD, the United States 21.1 million USD and Canada 17 million USD. (4)



To conclude, China has one fourth of the world reserves of natural graphite, they produce 68 percent of it and export 64 percent of the world trade.

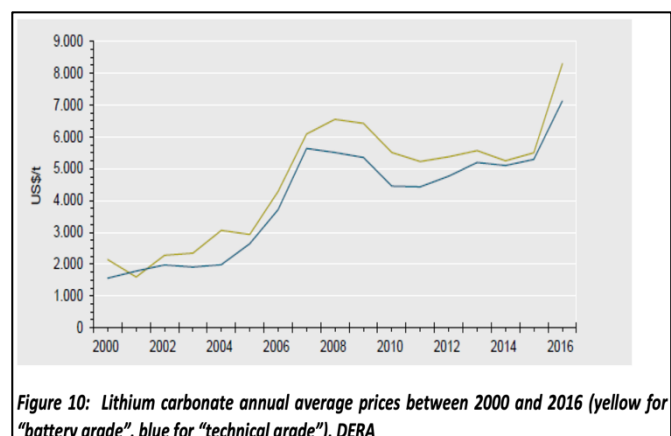
### Description of the price

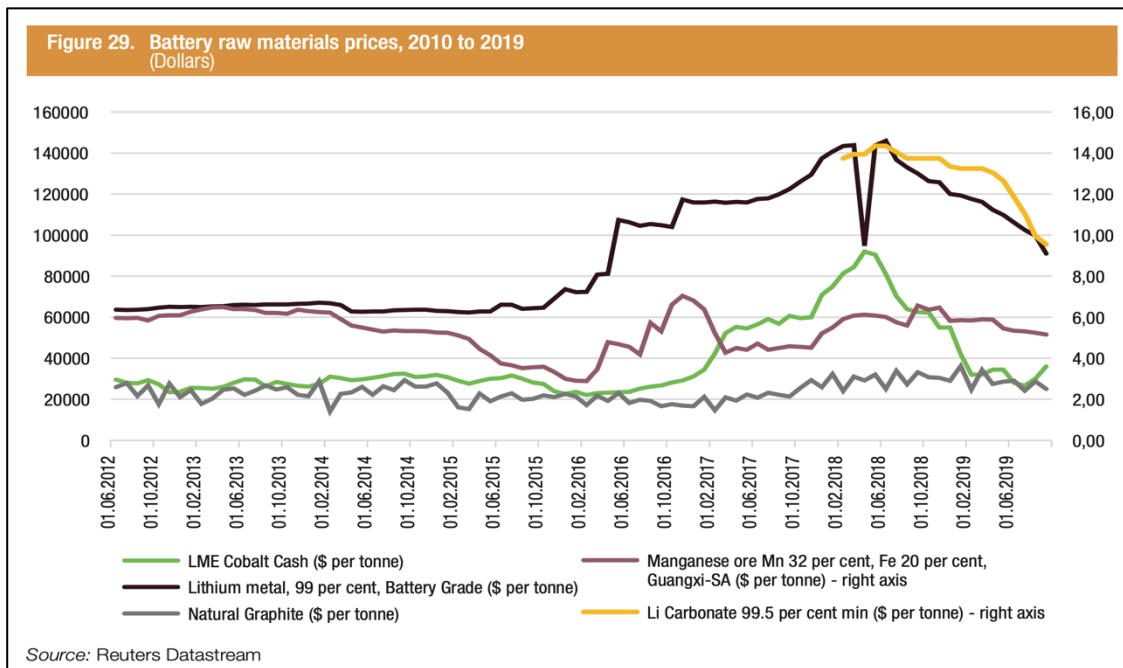
The price of battery raw materials, especially the two main commodities; lithium and cobalt like every other commodity, is essentially determined by the supply and demand. As we already mentioned that more than 95 percent of the world's lithium comes as an essential item as brines or hard rock ores, with a worldwide creation impression including Latin America, Australia, and China. Then again, under 10% of cobalt occurs as a primarily item, with remainder mostly mined as a by-product of either copper or nickel. The decisions to explore and produce copper and nickel strongly affect the supply of cobalt in the market. Moreover, 65 percent of global production of cobalt is concentrated in the Democratic Republic of Congo (DRC). The price spikes have seen a swathe of expansion announcements for lithium over the next several years, suggesting ample capacity to meet the growth in demand to 669 kt LCE by 2025. (12)



Cobalt production has been consistently growing in the last 50 years and in any event, accelerating since the 2000's. The price has additionally been increasing. However, it has been firmly impacted by supply (crisis in DR Congo) and demand (from Asia) interruptions. The price of the cobalt peaked in 2008 nearly reaching €80 (\$120) per kg. After a sharp decline in 2009-2016, the prices again quadrupled in the next two years, reaching again around €80 (\$90) per kg in 2018. (15)

The price of lithium (see Figure 10.) have dropped in 2001 yet expanded since 2005 to recoup their 2000's estimation of about 4.500 dollar per ton (USGS, 2016a). Costs have significantly increased somewhere in the range of 2005 and 2008 and balanced out for quite a long while. As indicated by the DERA crude materials prices, lithium carbonate prices have again expanded since 2015 from a cost of 6.222 US\$/t in normal over the period 2011-2015 to 7.091 US\$/t in normal over the period December 2015 - November 2016, that's almost a price increment of 14%. (15)





Looking at the graph, we can see the price of the battery raw materials has been increasing due to rising demand due in part to rising sales of EVs. Cobalt prices for example rose from US\$22,650 per ton in December 2015 to a peak of US\$92,000 per ton in May 2018. This is mainly due to the rapidly expanding market of electric vehicles and rechargeable batteries as well as stifled supply. Other elements contributing to this sharp rise in price were speculative buying and lower producer stocks. The sharp increase in the demand was largely driven from Chinese consumption and EVs but also aerospace industry for whom the cobalt is an essential irreplaceable element as well as within power generation with gas turbines using cobalt. Furthermore, the drop in prices between May 2018 and July 2019 was due to slow growth rates in the EV sector and abundant supply in the market. Moreover, China's activities slowed down in 2018, contributing to the buildup stocks and leading to lower prices.(4)

As the demand for Lithium rose, the prices of lithium metal also increased sharply from US\$62,498 per ton in February 2015 to reach US\$145,973 per ton in June 2018. However, the prices after that have declined in September 2019 due to oversupply and slowdown in EV growth. The lithium metal in rechargeable batteries represents a limitation used as it contributes to safety risks. Lithium carbonate that is widely produced and consumed lithium compounds was pressured by slow demand due to global trade tensions, slowing growth and the scaling back of Chinese electric vehicle (EV) subsidies and oversupply in the market. Leading Chinese players with destocking was the reason for price fall down in September 2019. (4) One important aspect about lithium prices are they're not only different across different product types but also within each individual product type like lithium carbonate, chloride and hydroxide. These products are traded using long-term contracts, and prices differ based on both the lithium content and impurities and the price-negotiating strategies of the operating company. These distinctions in prices between different items and within individual item types make it hard to analyze different operations on a like-for-like premise on the cost curve. (16)

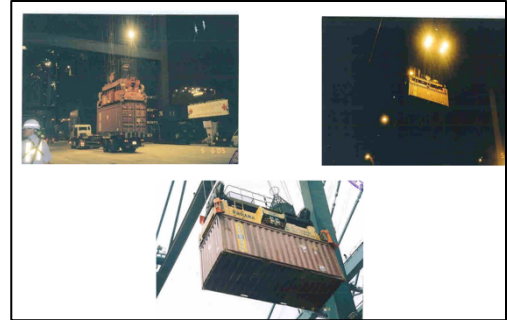
Talking about natural graphite prices also faced a downward and volatile path in 2017, then followed an upward and volatile path in 2018 to reach a peak of US\$36,201 per ton in January 2019. Natural graphite's primary consumer remains the steel industry, while batteries only account for only about 13 per cent of total natural graphite demand. The upward trend in natural graphite prices was largely driven by steel production. LIBs are only beginning to have an impact on demand and consumption. Prices for natural graphite are negotiated bilaterally between buyers and sellers because of the wide range of graphite qualities and purity. (4)

On the other hand, lithium and cobalt prices could be influenced by other various kinds of elements, like politics (Trade war between China and the US, tension and child labor problem in DR Congo, other social, environmental factors, macroeconomics, speculation, technological advancements such as alternative energies).

Does a platform of prices exist? Yes. Metals. Argus Metals provides current metal prices for over 1,000 of the most commonly traded primary and secondary materials across the globe. Surely, battery raw materials are covered in the list and countless websites await to be found on search engines.

### **Cost curves**

As far as it concerns cost curves, as already mentioned since commodities are so complex and the prices vary from one product to other, these distinctions in prices between different products and within individual item types make it hard to analyze different operations on a like-for-like basis on the cost curve. And therefore, it was hard to find information related to it.



### **Shipment**

Depending on the commodity, they're shipped differently according to the rules and regulations which can vary from one country to another. But mostly, they're shipped in containers like shown in the picture above.(15)

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