Global Energy Perspectives

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Global Energy Solutions e.V.

Part 1: Basic elements for avoiding greenhouse gases and generating climate-neutral energy (technical toolbox)

Chapter 2-13

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2.13 Critical raw materials

2.13.1 Introduction

The transition towards the production of renewable energy and the avoidance of fossil fuels means that other materials are needed, for example, to produce equipment for energy production or use. For example, an electric vehicle requires about six times more minerals than a conventional vehicle with an internal combustion engine and a rural wind turbine requires about nine times more minerals than a gas-fired turbine (see Figure 235).

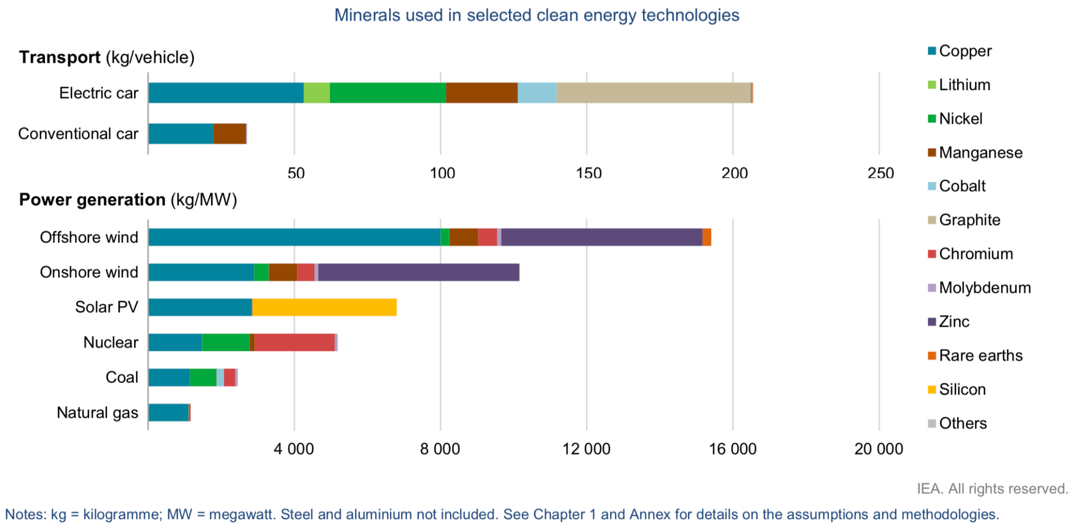
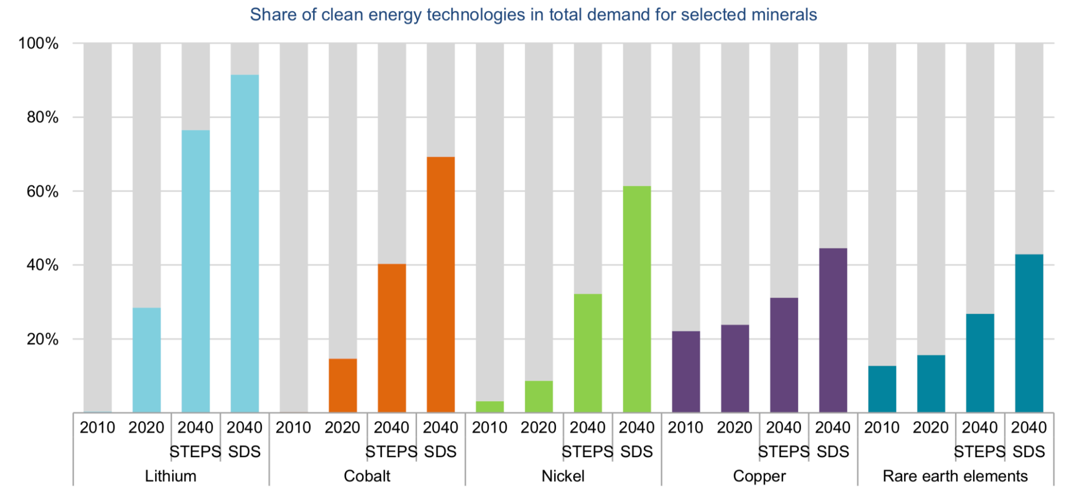


Figure 235: Specific consumption of various minerals in kg/vehicle or kg/MW for different energy producers.

Source: IEA, 2021

This global transition has changed the world's commodity markets. With the increasing transition of energy production (actually "conversion of energy"), this sector became the leading consumer of mineral raw materials such as lithium, cobalt, nickel, copper and the rare earths. These minerals are described in detail in the following chapters.

Even in the period before the war in Ukraine and also before the Corona pandemic, we observe rising commodity prices on the world's stock exchanges. The Corona pandemic has extremely aggravated the situation by the fact that numerous mines were closed during this period and subsequently with ramped-up production the demand cannot be met. The problems in logistics caused by the closure of ports and the blockade of the Suez Canal exacerbate the problem today.



Notes: Demand from other sectors was assessed using historical consumption, relevant activity drivers and the derived material intensity. Neodymium demand is used as indicative for rare earth elements. STEPS = Stated Policies Scenario, an indication of where the energy system is heading based on a sector-by-sector analysis of today's policies and policy announcements; SDS = Sustainable Development Scenario, indicating what would be required in a trajectory consistent with meeting the Paris Agreement goals.

Figure 236: Proportion of minerals needed for renewable clean energy technology.

Source: IEA, (2021).

Press releases such as "nickel price at record level", "prices for aluminium higher than they have been for years", "magnesium is becoming scarce" cause raw material prices to skyrocket.

Figure 237: Price development for rhodium between 2020 and 2021.

Source: Neitzel, (2021).

The **rhodium price** increased by 375 % within 1 year, currently: 500,000 USD/kg,
(for more details see Table 57.)

The iridium price rises by 300 % within 3 months, but is now at 4500 USD/oz.

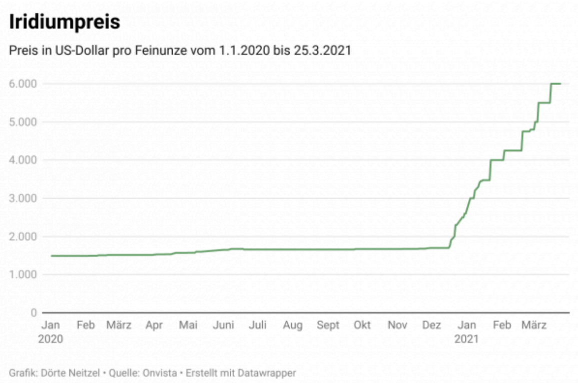


Figure 238: Price development for iridium between 2020 and 2021.

Source: Neitzel, (2021).

But also platinum (+22 %), ruthenium[44] (+57 %), palladium (+30 %), copper (+44 %), tin (+60 %), nickel (+12 %), aluminium (+25 %) will see rapid price increases in the period from 2020 to spring 2021.

This is reason to examine the importance of the so-called critical raw materials and the possible impact of price increases in this document, especially since knowledge of the use of some of the products belonging to this group of elements, minerals or raw materials cannot be assumed to be widespread.

Figure 239 shows the quantities of individual substances/elements needed to manufacture all smartphones sold in 2016. This illustrates that not only the functional complexity of mobile phones but also the amount of materials involved in its production has increased significantly.

Now, it would certainly be acceptable for citizens to forego the premature purchase of a new mobile phone because of the unavailability of raw materials. However, unavailability that delays the expansion of renewable energies or even prevents the energy transition is not. Therefore, this document also describes the strategies of individual countries to secure the supply of materials to be imported.

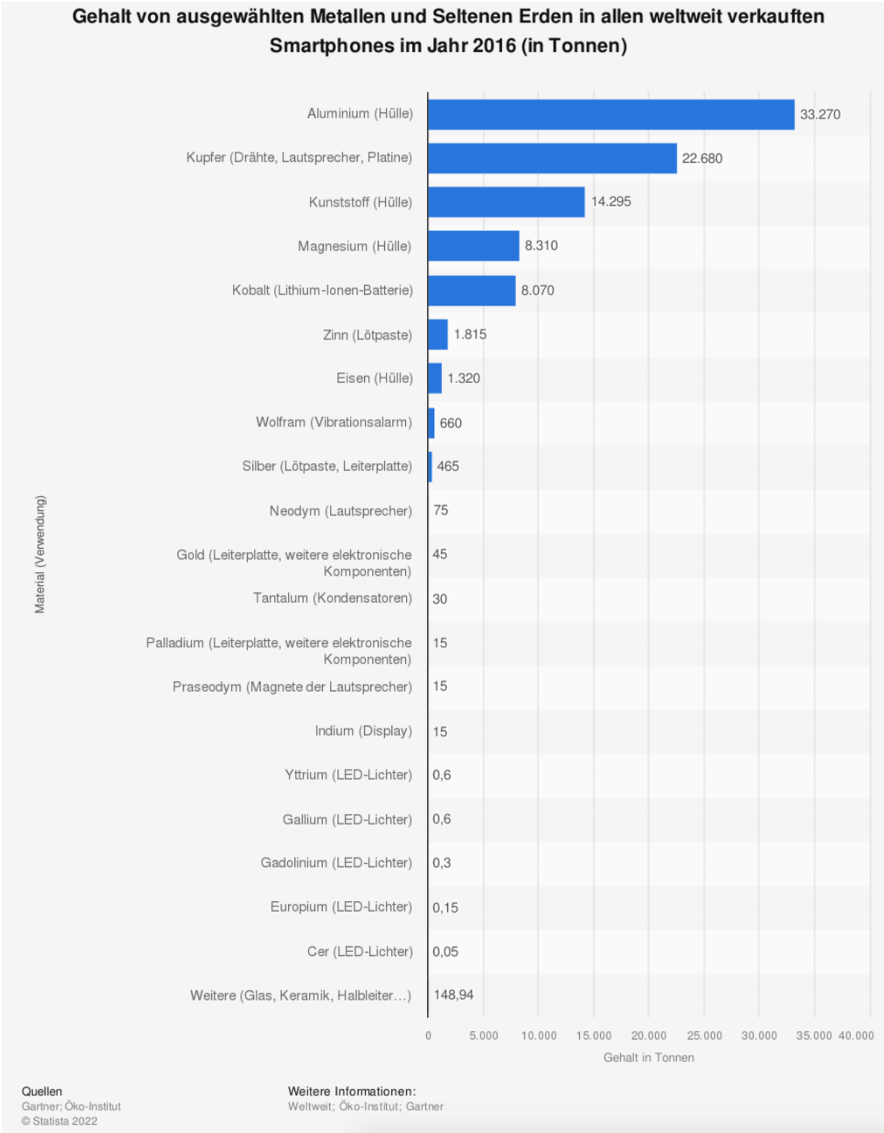


Figure 239: Content of selected substances in all smartphones sold worldwide in 2016.

Source: Statista (2016)

2.13.1.1 Definition of critical raw materials

The European Commission has issued lists of "critical raw materials" (CRM) since 2011, which started with 14 materials in 2011 and has now grown to 30 in 2020 (cf. Appendix Table 61, page 448). "Critical" *raw materials are those for which the risk of a supply shortage in the next ten years is particularly high and which are considered particularly important for the value chain. The risk of supply shortages is related to the concentration of production in a few countries and the low political and economic stability of some suppliers. This risk is compounded for some minerals by the fact that the raw material is difficult to substitute and its recovery rate* *is low. In many cases, a stable supply situation is an important element of climate policy objectives and technological innovation*".[680]

The definition of what constitutes critical raw materials or minerals is often also seen in terms of strategic importance for national defence. The overview of commodity strategies in Chapter 2.13.6. makes it clear that these can vary greatly internationally.

The EU uses a methodology here in which variables such as "supply risk" or "import reliability" are determined numerically from existing evaluation indices.[681] With RMIS, the EU has created a database accessible to everyone with information on critical materials and secondary raw materials, which provides further information on the raw materials.[682]

2.13.1.2 Relevance to the overall context

In the transition from a fossil energy economy to one that strives to produce or convert energy in a sustainable, environmentally friendly and cost-effective way that preserves prosperity, the availability of raw materials that have already been used for many years, but also and especially those whose use has only recently become common and necessary in new technologies, plays an extremely important role.

Since raw materials and minerals as mineral resources are not equally distributed in all countries, and their extraction and processing partly also require a high level of technical and procedural know-how, their usability for resource-poor countries is also dependent on the export strategies of the producing countries and the sometimes exploding prices on the world markets.

Whether and how quickly the global transformation to a CO_2-free economy will take place also depends on the availability of the substances referred to as critical raw materials or critical minerals or, more generally, still critical materials, which are described below. Most countries have recognised the critical situation for them and reacted by formulating raw material strategies, which are described in chapter 2.13.6. Here, not only primary raw materials play a role, but also the handling of secondary raw materials that result from the processing of waste and recycling. Just as civil societies will adjust to restrictions in the availability of resources such as electricity and water as a result of the climate crisis and global political crises, for example, the increasing scarcity and price of raw materials also requires a rethink towards the production of durable and repairable economic goods with high recyclability.

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680 Cf. European Commission, 2011, p. 2.
681 Cf. European Commission, (2017).
682 RMIS: Raw Material Information System, see RMIS (n.d.).

In particular, the shortage and accompanying increase in commodity prices is important for developing countries, as they will find it difficult to realise their purchasing intentions on the world market against developed countries. In addition, industrialised countries such as China are on their way to gain access to attractive raw material deposits in less developed or poorer countries. As a result, these countries are becoming dependent on these industrialised nations through long-term contracts and are jeopardising the prospect of being able to develop their economies independently.[683]

2.13.1.3 Core statements

- A large and ever-growing number of minerals and chemical elements can be classified as critical raw materials.
- In the case of lithium, cobalt and the rare earths, the world's three largest producers, led by China, control three quarters of the global market (IEA 2021).
- The increasing demand for raw materials needed for the turnaround in mobility and energy production and supply faces problems in the supply of raw materials caused on the one hand by the Corona pandemic and on the other hand also by the necessary lead time for exploration and the development of production and logistics capacities.
- The procurement costs of raw materials are exploding due to the mismatch between supply and demand on the one hand and due to the increased production costs of raw materials with deposits in low concentrations, as in the case of rare earths, for example.
- The industrialised nations' dependence on critical raw materials can be used for their political blackmail in conflicts.
- Even if global problems can only be solved through cooperation between the producers and users of critical raw materials, the ability to control critical raw materials will be used in some countries to strengthen their own position as a production and trading power to the detriment of others.
- If it is not possible to reduce dependence on critical raw materials, e.g. by developing substitutes or improving recycling and expanding it to include urban mining, then the energy and transport transition will be seriously jeopardised.

[683] Cf. Saam, 2008.

2.13.2 Selected critical raw materials

2.13.2.1 Overview of critical raw materials

An initial overview of critical raw materials can be obtained by looking at the periodic table to see the availability of the elements and the compounds in which they occur. Figure 240 shows in the periodic table of elements in red those elements for which Mike Pitts estimates that there will be a shortage in the next 100 years. [684]

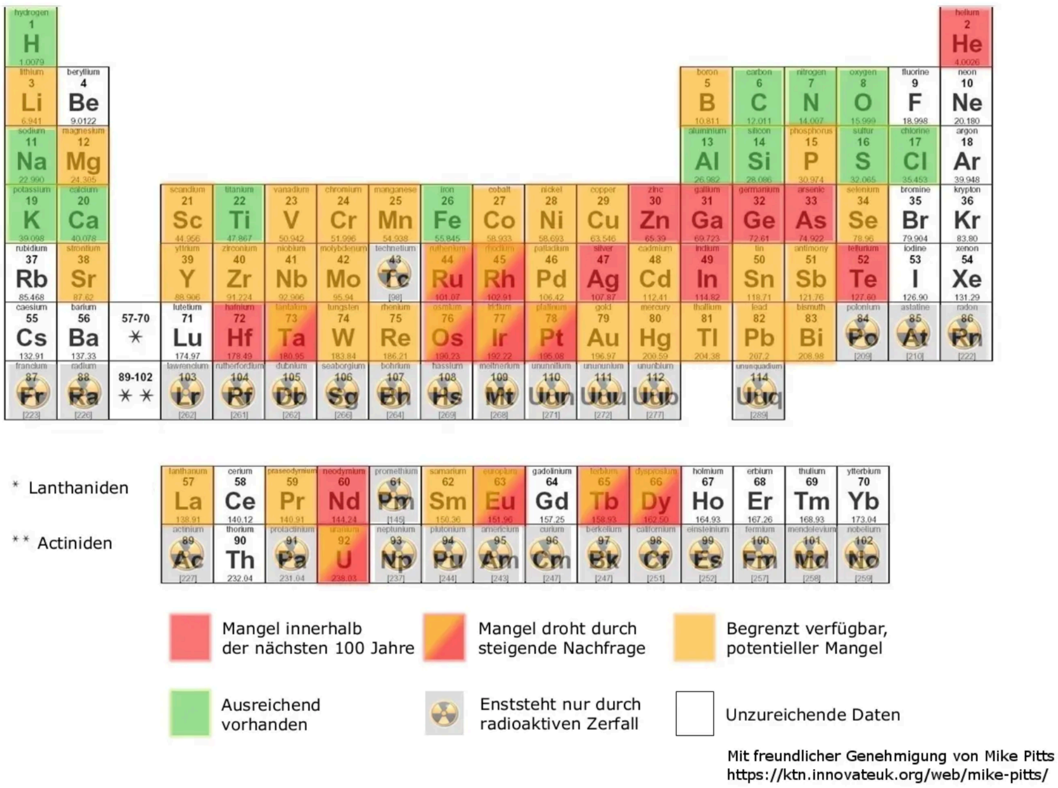


Figure 240: Periodic table of endangered elements. Source: Pitts, 2011.

The general impression when looking at the coloured boxes is that most of the elements will be in short supply either in the short or medium term.

Examples:

Even **helium** (He^2), one of the most abundant elements on our planet (0.004 ppm in Earth's atmosphere), will be in short supply, as helium is increasingly used to cool magnets or high-performance computers, and to generate superconductivity. The main source of helium is not, as is often assumed, the liquefaction of air, but, since helium is produced in radioactive alpha-decay, from substances that are dissolved from the rock during the extraction of oil or natural gas and release helium during decay.

[684] Cf. Pitts, 2011.

Zinc (Zn^{30}) is also one of the "threatened elements", as its use for galvanising steel and use in batteries has increased worldwide. Zinc is a relatively abundant element in the earth's crust (76 ppm). [5]

Zinc is essential for all living things as it is a component of important enzymes.

Gallium (Ga^{31}), which is used in light-emitting diodes or solar cells but is also needed for doping silicon-based semiconductor components, is rare in nature and only found in small quantities (14 ppm in the earth's crust[5]). The EU estimates that as early as 2030, four times as much gallium will be needed as is produced today. The U.S. Geological Survey estimates the factor to be as high as 6. Another problem is that China controls 75 % of world production.[685]

Germanium (Ge^{32}), like gallium, also occurs in only small concentrations, often in combination with zinc ores. Its share in the earth's crust is 5.6 ppm.[686] Germanium is also needed for doping silicon and for manufacturing optical components. According to EU calculations, the increasing demand in the field of fibre optics alone will lead to a demand twice as high as the production of germanium in 2030.[687]

Arsenic (As^{33}) is just as common as germanium and is often a companion in lead, cobalt or copper deposits. Both elements occur together in gallium arsenide. Arsenic is used for doping semiconductors.

The European Commission has issued a list of critical raw materials in 2020 (see Table 61 in the appendix p. 448), which lists not only the elements colour-coded in the periodic table, but also other compounds such as borates (used in high-performance glass, fertilisers, magnets), fluorspar (calcium fluoride e.g. as a flux in aluminium production, production of lenses) or natural graphite and coking coal. The use of critical materials is also Table 57 on page 419 on page 428.

As part of the Commission's action plan on the identified dependencies on raw materials necessary for industrial production, the European Raw Material Alliance (ERMA) was launched with the aim of securing the supply chain for the materials identified as critical, including diversification of suppliers, such as in 2021 through an EU partner contract with Ukraine for the sourcing of materials for the production of batteries/battery packs.[688]

[685] Cf. Fischer, 2011.
686 Cf. Wikipedia
[687] Cf. Fischer, 2011.
[688] Cf. ERMA, n.d.; IRENA, (2022).

2.13.2.2 Rare earths

General information

The name "rare earths of metals" or "rare earths" comes from the time of their discovery (e.g. Yttrium in 1794 at the Ytterby mine near Stockholm). The name indicates that the elements were found in their oxidic compound (formerly called "earths").

"The rare earth elements (REE) are a family of 16 elements (see Figure 240, the elements scandium and yttrium have been counted!) that, as a group, share distinctive chemical similarities, while as individual elements they possess distinctive and diverse electronic properties. These atomistic, electronic properties are extremely useful and motivate the application of rare earths in many technologies and devices. From their discovery to the present day, the separation of RE elements has been a major challenge for chemists, evolving from laborious crystallisation to sophisticated solvent extraction techniques. The increasing involvement and dependence of REE in technology has raised concerns about their sustainability and motivated recent studies on improved separation processes to achieve a circular economy for RE".[689]

The subdivision into light (LREE: scandium^{21}, lanthanum^{57} to europium^{63}) and heavy (HREE: yttrium^{39} , gadolinium to lutetium^{71}) rare earth elements is sometimes disputed. In geochemistry, scandium and yttrium are often not considered rare earths.

In contrast to semiconductors and metals, rare earths do not have a band structure due to the structure of their atomic shells in the solid state. Due to their chemical similarity, their separation by process engineering is difficult, so that mixed metals are often used in technical applications.

Rare earths have unique electronic, optical, luminescent and magnetic properties that make them crucial for a wide range of products and applications. For example, rare earths are used as catalysts, in manufacturing, medicine, ceramics and glasses. They are fundamental to the generation of clean energy and, more generally, to the transition from the fossil fuel age to the low-carbon age (see Figure 241).

" Although there are enough known rare earth resources to meet all the needs of the energy transition, the main challenge is to expand mining and processing across the value chain in line with demand growth." [690]

[689] Translation from Cheisson & Schelter, (2019).
[690] Translation from IRENA, 2022, p. 6.

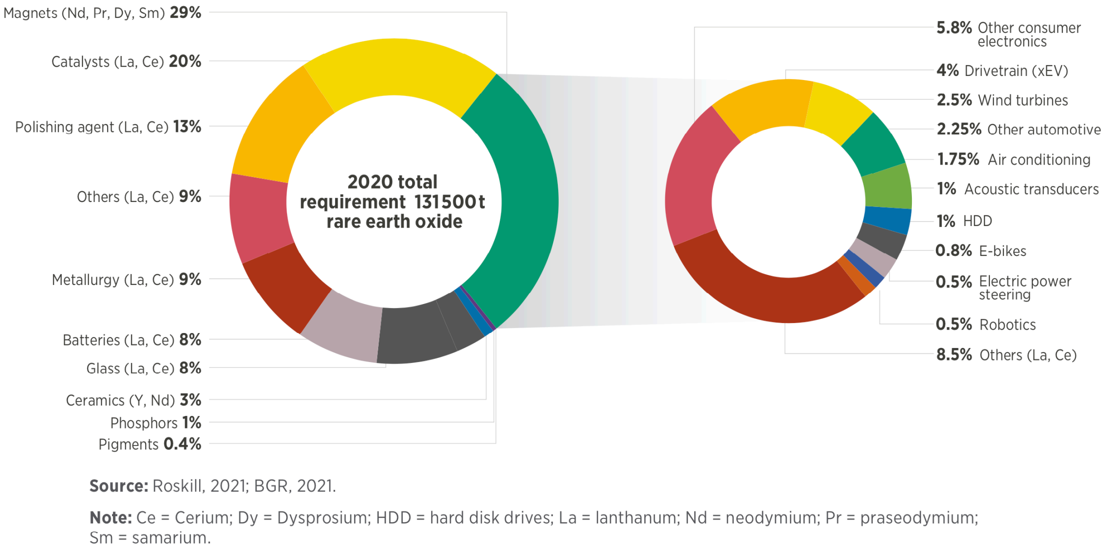


Figure 241: REE demand by end-use sectors and breakdown of demand for magnets by mass Status 2020.

Source: IRENA, 2022, P. 12.

Use for energy production

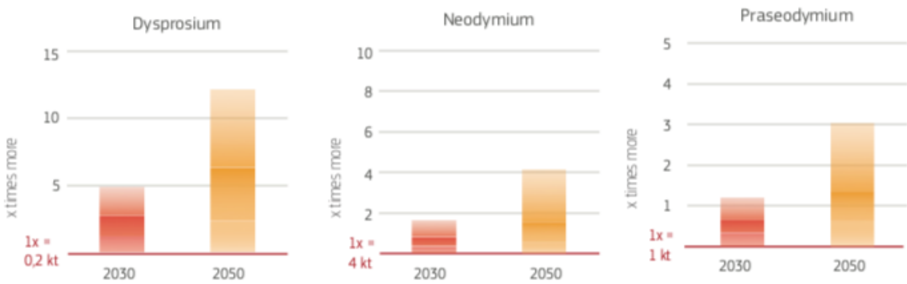


Figure 242: Additional material requirements for the construction of electric motors for selected REE.

Source: European Commission, (2020).

Figure 242 illustrates for selected rare earth elements (Dy, Nd and Pd) the projected and extremely large increase in demand for these elements by 2050.

The U.S. Department of Energy has differentiated between short- and medium-term element availability.[691]

[691] Cf. DoE, 2011.

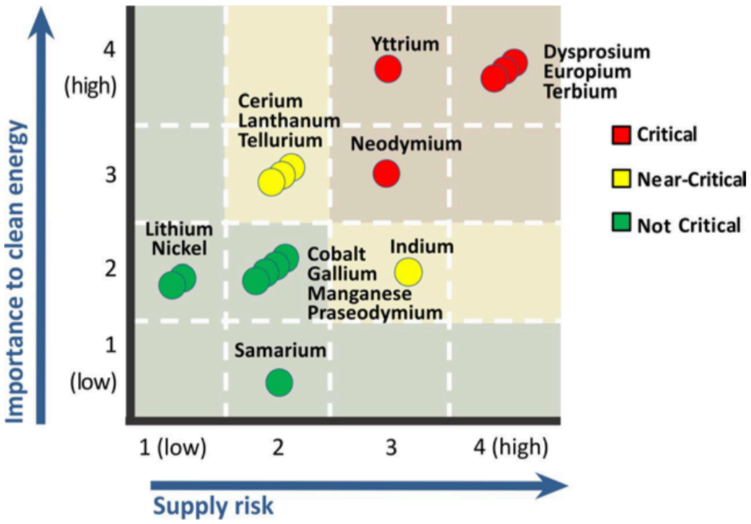


Figure 243: Short-term bottlenecks (2011 to 2015) in the supply of raw materials.

Source: DoE, 2011.

Expected bottlenecks

In the short term, in this case until 2015 (see Figure 243), supply shortages for wind power generation and energy-efficient lighting were seen mainly for dysprosium, europium, terbium, neodymium and yttrium, which are needed for the magnets in wind turbines or, in the case of europium and terbium, for the production of CFLs and LFLs.

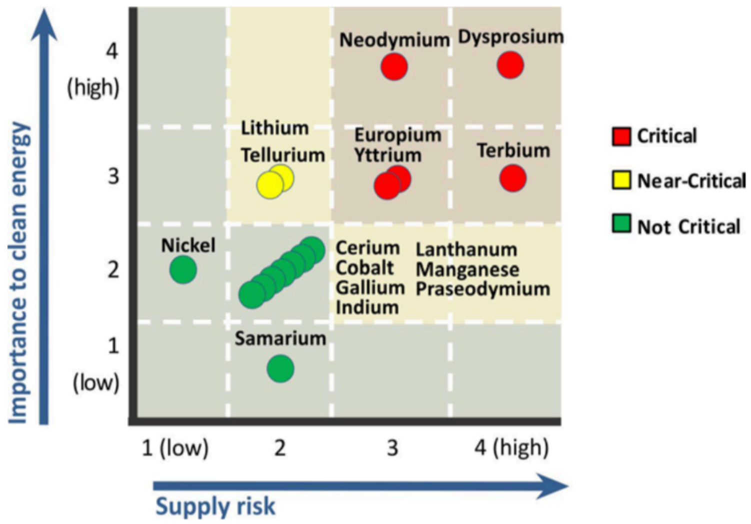


Figure 244: Medium-term (years 2015-2025) bottlenecks in the supply of raw materials.

Source: DoE, 2011.

Figure 244 shows that in the medium term, i.e. until the mid-2020s, other raw materials such as lithium, tellurium will show a shortage in supply, which will also affect the production of smartphones, computers and flat screens (see also Figure 239).

Achieving independence from the dominance of Chinese rare earth suppliers seems impossible, at least in the short term. Currently, there are only seven major plants worldwide that process rare earths, six of which are in China and one in Malaysia. New projects have been set up in various countries such as Australia, Canada, South Africa and the USA. However, these projects are controversial due to environmental concerns and the long time frames for their development. For example, the Greenlandic parliament recently banned the development of one of the largest undeveloped rare earth deposits in the world.

Recycling rates

The US Geological Survey estimates that there are 137 Mt of developed rare earth reserves. Undeveloped resources are reported at 308 Mt, which would last another 1100 years if current rates of reserve consumption are extrapolated. "In addition to natural resources, certain residues such as red mud (from aluminium production), fly ash from coal combustion and gypsum (from coal-fired power generation) contain significant amounts of rare earths that can be recovered".[692]

Despite their rare occurrence, the recycling rate of rare earths has so far been less than 1 %.[693] The problem of urban mining of SEE in e.g. discarded mobile phones, screens, energy-saving light bulbs and cars is that the SEE in these products are finely distributed. However, low-cost chemical processes such as "SepSelSA" have been developed, e.g. at the TU Freiberg, with the help of which SEE can be extracted from the scrap. Even the highly pure separation of SEE (>99.999 %) is possible with the help of ion exchange chromatography. An environmentally sound recycling strategy without high heat and aggressive acids for the phosphor Yox ($Y_2O_{3:}Eu$) from the waste of energy-saving lamps was developed in Belgium.[694]

Some bacteria need light LEE (La, Ce, Pr, Nd) to grow, which makes them suitable for extracting these elements from e.g. e-waste. Once the bacteria have incorporated the LEE, the elements can be extracted by biomining processes. In 2016, researchers at Harvard University presented a process in which bacteria separate heavy SEE (Tm^{69}, Yb^{70}, Lu^{71}) from other SEE by binding all SEE on their surface at a p_H =6 and releasing all but the three mentioned, which have the smallest ionic radius, in an acidic medium with p_H=2.5.

A process was developed at Lawrence Livermore National Lab in 2021 that holds out the prospect of recovering REE using natural proteins.[695]

692 Translation from IRENA, 2022, p. 7.
693 Cf. Daumann, (2018).
694 Cf. Daumann, (2018).
695 Cf. Dong et al., (2021).

Table 55: Production and reserves of rare earths.

	Promotion 2021 in REO kt[696]	Reserves in REO kt[697]	
China	168	44.000	Export quotas or export ban of HREE in 2010 38 % of world reserves[698]
USA	43	1.800	1.3 % of world reserves
Myanmar	26		
Australia	22	3.400	3.5 % of world reserves
Madagascar	3.2 ( )[8]		
India	3 (2020)	6.900	6 % of world reserves
Russia	2,7 (2020)	18.000	10 % of the world's reserves
Brazil	0,5	21.000	18 % of the world's reserves
Vietnam	0,4	22.000	19 % of world reserves
Greenland	n.a.	1.500	1.3 % of world reserves
Worldwide	240[8]	120.000	

2.13.2.3 Nickel (Ni^{28})

General information

Although nickel is not on the EU's list of critical substances, nor is it on the US industry's list (see Annex 2.13), nickel is now considered a critical raw material, as the total share of imports from Russia is about 40% (as of 2019, see Figure 245) and the criticality had not yet been taken into account in the lists due to the Russian invasion of Ukraine.

[696] Values from Statista, 2023b.
[697] Reserves from Statista (2022) with indication of oxide quantities REO Rare Earth Oxide
[698] Cf. IRENA, (2022).

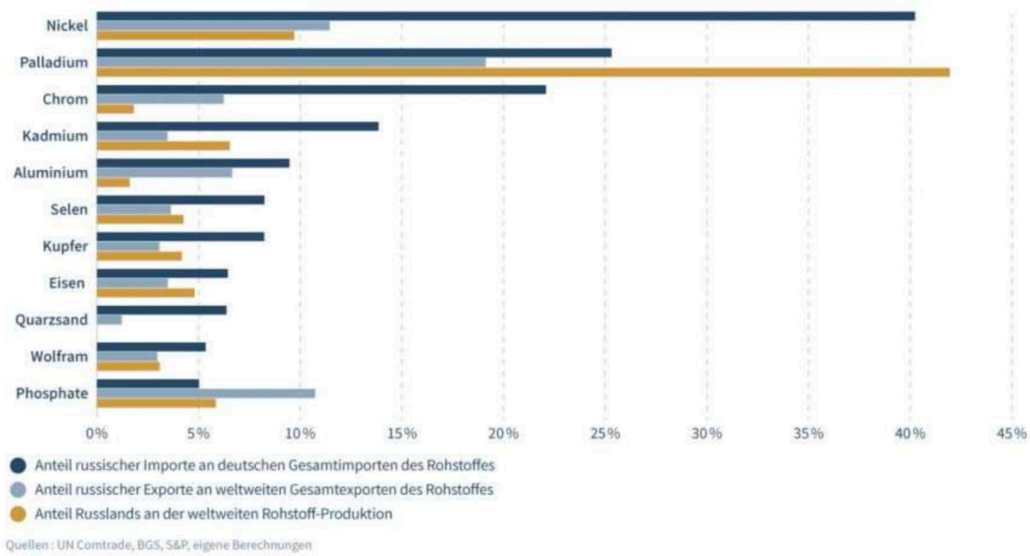


Figure 245: Share of Russian imports in total German imports.

Source: Neitzel, 2022b.

Fortunately, Russia is not the only producer of nickel, nor is it the largest (see Table 56), so there is a very good chance of avoiding supply bottlenecks. Statista also lists Canada (export of nickel worth USD 3.6 billion) and the USA (USD 2.2 billion) ahead of Russia (USD 2 billion) for 2021. However, large shares of the nickel ores mined are processed in China (see Figure 246, page 400), so that, as with rare earths, there is also a dependence on a geopolitically uncertain country.

Land	Förderung (in t)
Indonesien	771.000
Philippinen	334.000
Russland	283.000
Neukaledonien (Frankreich)	200.000
Australien	169.000
Kanada	167.000
Volksrepublik China	120.000
Brasilien	77.100
Vereinigte Staaten	16.700
Andere Länder	373.000
Gesamt	**2.510.000**

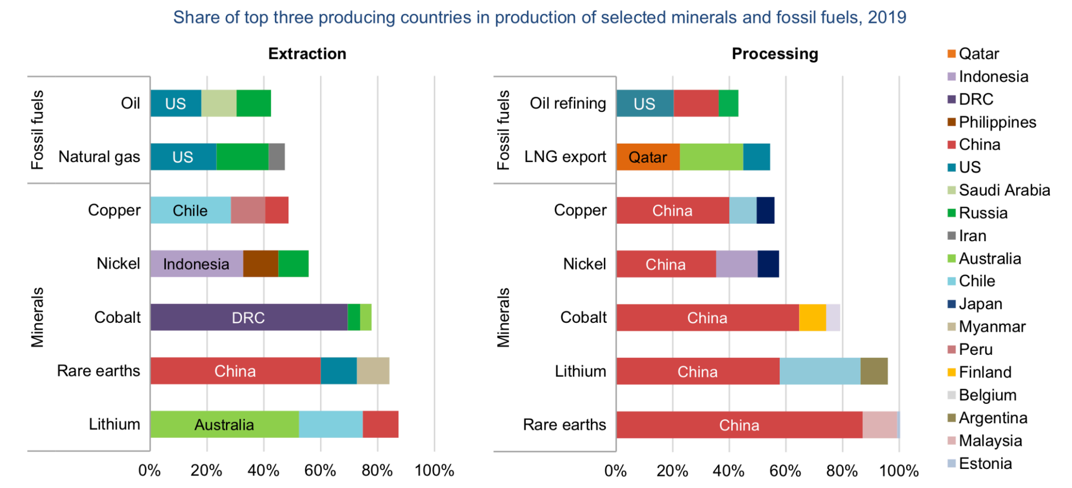
Table 56: The largest nickel producers worldwide, as of 2020.

Source: Wikipedia https://de.wikipedia.org/wiki/Nickel.

The majority of nickel is extracted from nickel- and copper-bearing iron ores by roasting and a subsequent, rather complex separation process from copper. Small amounts of nickel are also found in New Caledonia (part of France).

In addition to rare earths, lithium and cobalt, nickel also plays a decisive role in the production of electric vehicles. The IEA expects demand to continue to rise by 60-70% in the coming decades, as it has already done in recent years (see Figure 248 on page 401).[699]

[699] Cf. IEA, 2021, p. 5.



Notes: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations.
Sources: IEA (2020a); USGS (2021), World Bureau of Metal Statistics (2020); Adamas Intelligence (2020).

Figure 246: Production of some minerals necessary for energy transformation.

Source: IEA, 2021

Use for energy production

The most commonly used battery types (NCA: Nickel Cobalt Aluminium and NMC: Nickel Manganese Cobalt) use 80% and 33% nickel, respectively.

Nickel is also used in Li-Ion batteries to enable higher energy densities and higher storage capacities, i.e. higher ranges for electrically powered vehicles at lower costs.[700]

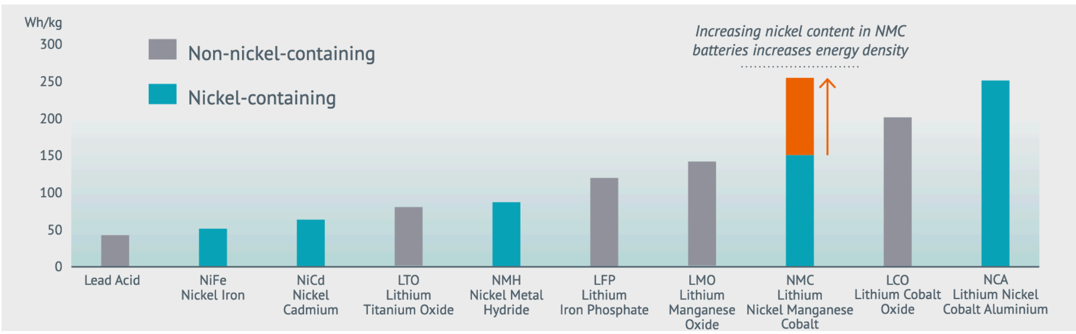


Figure 247: Overview of different types of batteries with and without nickel.

Source: Nickel Institute

Alkaline electrolyser design requires "nickel in quantities greater than one tonne per MW or 1,000 tonnes for a 1 GW electrolyser plant, which is an advised size of electrolyser today. Nickel demand for alkaline electrolysers is expected to decrease, but nickel is not expected to be completely eliminated from future designs. However, if today's state of the art consumption of about 800 kg/MW were representative of future demand, and even if alkaline electrolysers dominate the market, nickel demand for electrolysers would remain much lower than that for

[700] Cf. Nickel Institute, n.d.

batteries in SDS. However, if in such a case nickel prices were to rise sharply due to challenges in the battery supply chain, the cost of electrolyzers would change. In addition to nickel, an alkaline electrolyser with a capacity of 1 MW today could require about 100 kg of zirconium, half a tonne of aluminium and more than 10 tonnes of steel, as well as smaller quantities of cobalt and copper catalysts."[701] (see Figure 272, page 437).

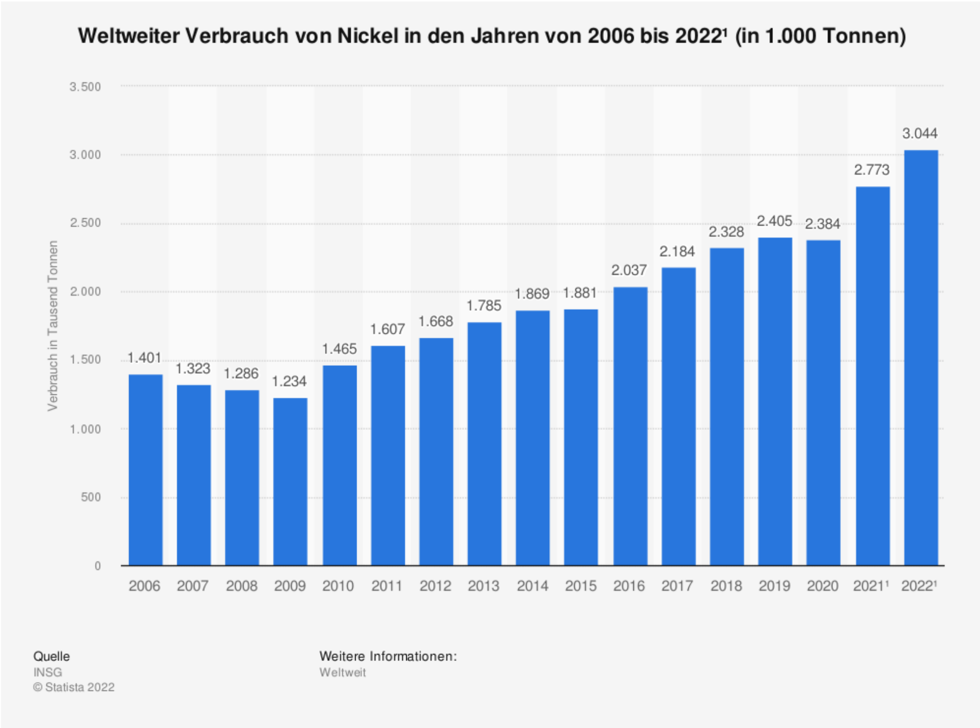


Figure 248: Global consumption of nickel from 2006 to 2022.

Source: Statista, 2022i.

The estimated mineable deposits of nickel are about 70 - 170 Mt.

Expected bottlenecks

With the demand for nickel for the production of accumulators/batteries and electrolysers increasing very strongly with electrification, a shortage of this transition metal may arise on the world market. The IEA says: "There is no shortage of resources worldwide and there are significant opportunities for those who can extract minerals in a sustainable and responsible way. Since no country alone will be able to solve these problems, increased international cooperation is essential",[702] but we cannot see any signs of this at present.

[701] Translation from IEA, 2021, p. 112.
[702] Translation from the foreword to IEA, (2021).

Recycling rates

The recycling of nickel is considered one of the most efficient reuse processes.[703] The Nickel Institute estimates that 68 % of the nickel contained in products is recycled (as of 2010). Another 15 % is reused through the steel cycle and only 17 % ends up in landfill. Nickel can be recovered from stainless steels through recycling and there are now reports of processes that can reuse nickel from nickel-cadmium batteries.[704]

The use of nickel-containing Li-Ion batteries is expected to increase very strongly in the next 20 years, so that the recycling of batteries will become increasingly important.

Currently, Umicore in Belgium recycles these batteries (approx. 7000 t/a) on an industrial scale through a hydrorefining process that separates nickel, cobalt, copper and lithium.[705] Glencore, the Swiss commodity trader, is also one of the largest recyclers and reprocessors of nickel-containing materials.

Crude oil contains a natural proportion of nickel, so nickel occurs in the ash of burnt heavy oil at a concentration of about 10 %.

The future prospects for urban mining are also very good for nickel, since in many countries waste contains more valuable metals than locally occurring ores.

2.13.2.4 Copper (Cu^{29})

General information

Copper is an excellent conductor of heat and electricity and is therefore generally essential for transformation in the energy industry and electrification. The electrical conductivity of copper is only slightly worse than that of silver and significantly better than that of gold. Since impurities in copper greatly reduce conductivity, copper is usually produced with the highest purity level of 99.9 %. Although copper can also be found in its pure form, the majority of copper production is obtained by smelting copper ores.

The highest production volumes of copper will be achieved by Chile (5,600 kt in 2021) and Peru (2,200 kt in 2021), followed by China (1,800 kt) and DRC Congo (1,800 kt).

CO_2 emissions from copper smelting have been significantly reduced in recent years, at least in Germany. Figure 249 from Aurubis AG data.

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703 Cf. Nickel recycling, (2022).
704 See Espinosa & Tenório, 2006.
705 Cf. Umicore, n.d.

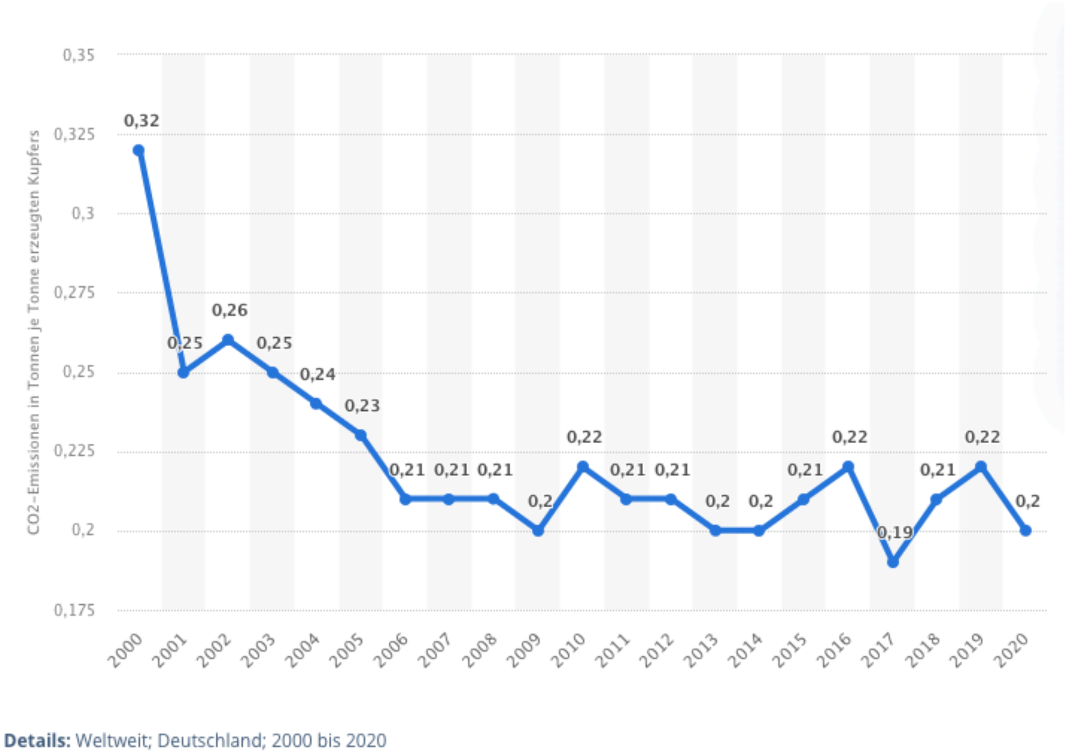

Figure 249: CO_2 emissions in tonnes per tonne of copper produced from 2000 to 2020 .

Source: Statista, 2022d.

Use for energy production

Copper is also referred to as the "metal of electrification", as all areas from energy production, to the transport of energy and the transformation of electricity into locomotion, mechanical work or heat are inconceivable without copper. Because of its excellent conductivity of electricity, the majority of copper production is used for cables and electrical (57 %)[706] such as in the windings of generators and electric motors. From Figure 235 shows the share of copper in power generation: 8,000 kg/MW for offshore and about 3,000 kg/MW for onshore wind and PV.

Copper cables are characterised by high flexibility and breaking strength. For railway overhead lines, magnesium is added to increase the tensile strength and the resulting deterioration in conductivity is accepted.

Expected bottlenecks

According to an S&P Global report, energy production by solar power plants requires twice and offshore wind power five times more copper per megawatt of installed capacity than

[706] Cf. Statista, 2022g.

classical generation with natural gas or coal.[707] The demand for copper today is 25 Mt/a and will increase to 50 Mt/a by 2035 and further increase to 53 Mt/a by 2050.[708] According to the "Rocky Road Scenario" (see Figure 250), which assumes an improvement in utilisation and recycling efficiency, this means that in 2035 there will be a shortfall of about 10 Mt/a to reach the Net-Zero target.

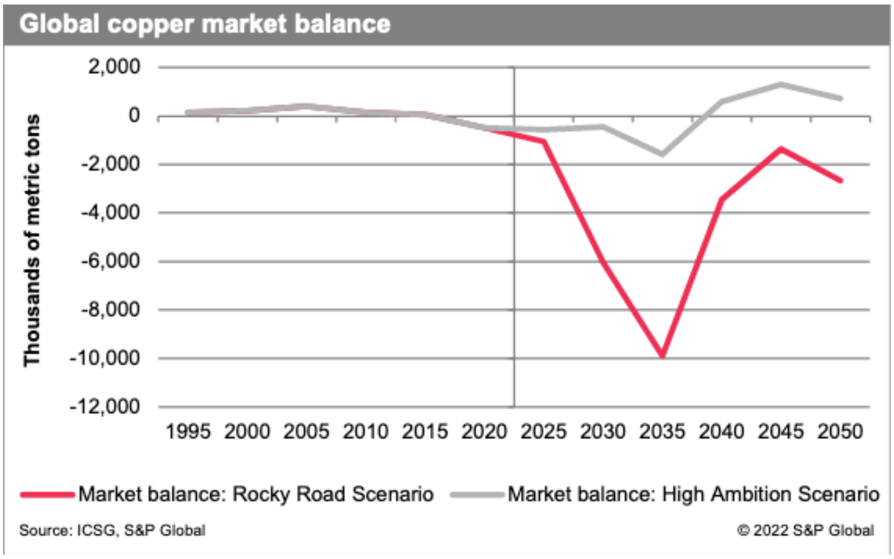

Figure 250: Global balance of the copper market according to the "Rocky Road Scenario".

Source: S&P Global, (2022).

Figure 251 shows the increase in global copper demand forecast by S&P until 2050.

Per capita consumption rises to a maximum of about 5.5 t/1000 people in 2036 and remains at a high level until 2050. The "Dr. Copper" price had its all-time high of 10,000 USD/t at the beginning of 2022. The drop in the price to around 7,000 USD/t is seen as an indicator of the cooling of the global economy and the beginning of the decline in inflation.[709]

[707] Cf. S&P_Global, (2022).
[708] Cf. S&P_Global, (2022).
[709] Cf. Finanzen.net, (2022).

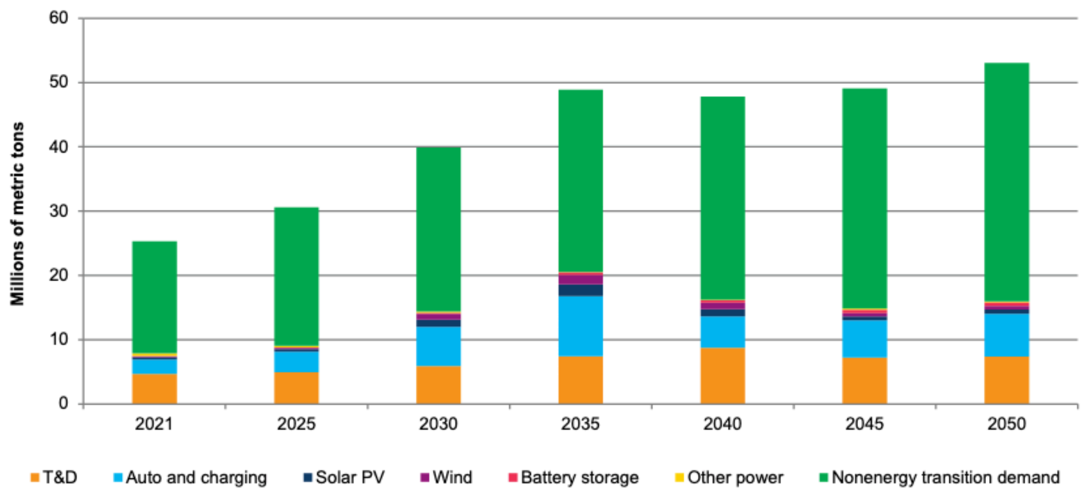

Figure 251: World demand for refined copper.

Source: S&P Global, (2022).

"*In the 21st century, copper shortages could become a key destabilising threat to international security. The projected annual shortages will put unprecedented strain on supply chains. The challenges posed are reminiscent of the struggle for oil in the 20th century, but could increase due to even greater geographic concentration of copper resources and the downstream industry that refines copper into products*."[710]

Recycling rates

In Germany, about 50 % of copper is recycled;[711] this figure is only about 33 % worldwide. With an average life span of copper products of approx. 33 years and the production capacities, the share of recycled copper is approx. 80 %.[712]

2.13.2.5 Manganese (Mn^{25})

General information

Manganese is a brittle transition metal that resembles iron in some properties. Manganese is one of the unknown micronutrients and is needed, for example, for the formation of enzymes in the body. In steel production, ferromanganese is used as an alloying component and removes oxygen and sulphur from the steel, thereby improving the through-hardening of the steel. In alkaline manganese batteries, manganese is used as a cathode. But manganese is

[710] Cf. S&P_Global, 2022, p. 9.
[711] Cf. German Copper Institute, (2019).
[712] Cf. Wikipedia, n.d. b

also used in Li-Ion batteries (see Figure 256, S. 409). The share of manganese in electricity generation can be taken from Figure 235 on p.386.

The countries with the highest production volumes of manganese are shown in Figure 252 shown.

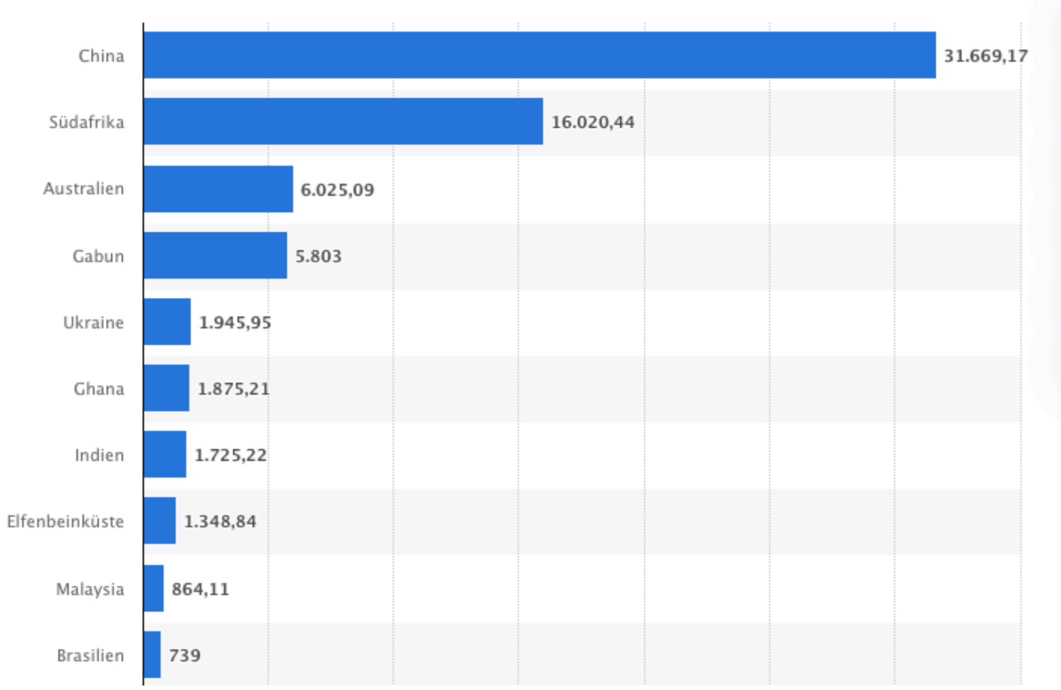

Figure 252: Manganese production in 1,000 t (kt) by country in 2020.

Source: Statista, 2022e.

Again, China is the largest producer of manganese.

About 60 % of the seabed is covered with manganese nodules.[713] The deposit is estimated at 10 Gt (billion tonnes). Depending on the location, the manganese content varies up to a maximum of 34 % (Peru Basin). The highest iron content of 16 % is found in nodules from the Penrhyn Basin (Indian Ocean), which also contain about 0.4 % cobalt. But copper and nickel as well as traces of platinum and tellurium can also be found in the potato-sized tubers.[714] The density of the nodules on the seabed also varies from 25 kg/m^2 (Cook Islands) to 5 kg/m^2 in the Penrhyn Basin.

Since the tubers lie at the bottom of the deep sea at a depth of about 5,000 m, their extraction or collection poses considerable technical and financial problems. Although successful attempts were first made to recover the nodules from great depths in the 1970s, driven by a search for alternative energy and mineral sources sparked by the oil crises, the efforts were not continued, as the effects on the marine ecosystem cannot yet be estimated but will certainly

[713] Cf. manganese nodules, n.d.
[714] Cf. Zeitler, 2011.

be considerable due to the destruction of the seabed caused by mining. In March 1978, about 800 t of manganese nodules were pumped to the surface. As it was estimated that about 5,000 t/day would be necessary to cover the costs of extraction, the activities were stopped.[715]

Use for energy production

From Figure 253 shows the special importance of manganese for the construction of NMC and LMO batteries. Especially for the LMO batteries needed for electromobility, approx. 100 kg/BEV are used.

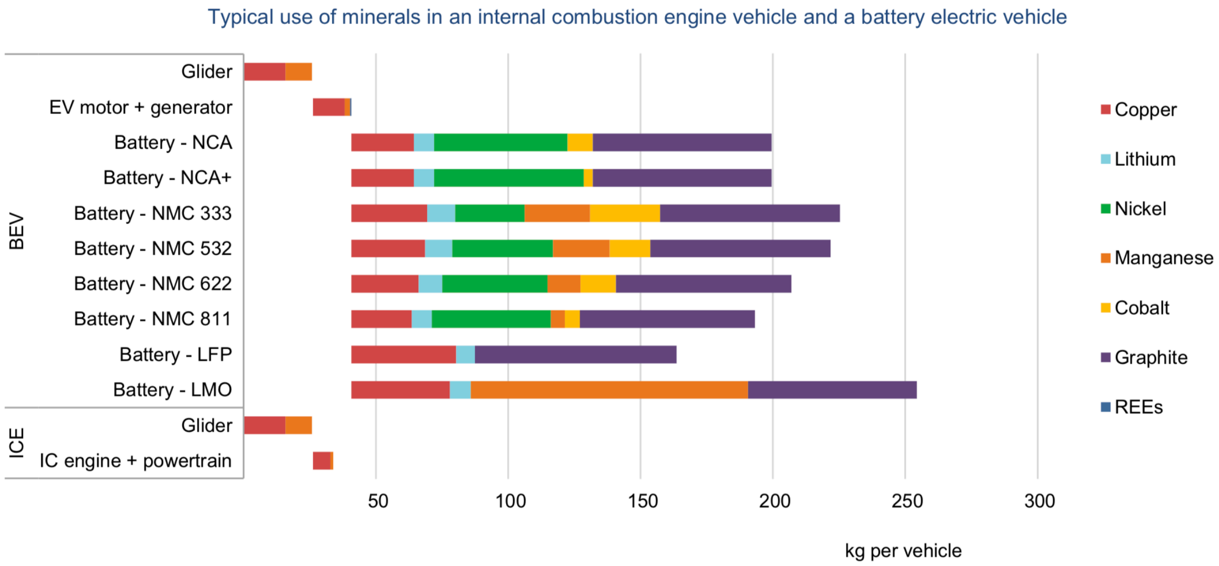

Figure 253: Use of different minerals for the construction of batteries for electric vehicles.

Source: IEA, 2021, all batteries with 75 kWh and graphite electrodes.

Expected bottlenecks

In chapter 2.13.3.4, it is described in Table 58, S. 425 refers to the enormously increasing demand for manganese in the area of high-performance storage. The demand in 2018 of about 11,140 t of manganese will increase to a projected 461,300 t - i.e. more than forty times as much - in 2040.[716]

[715] Cf. Zeitler, 2011.
[716] Cf. Statista, 2022h.

Recycling rates

When looking at the Figure 268, S.430 it is noticeable that manganese does not yet appear in the recycling rates. However, it is to be expected that with the expansion of battery recycling, the recycling rates of manganese will also increase.

2.13.2.6 Lithium (Li[3])

General information

Lithium is an alkali metal that is either mined (using high energy and chemical processes) or extracted from a brine with impurities of magnesium and sulphates (e.g. Atacama using solar energy).

Talison Lithium, the largest producer in Australia, mines lithium using conventional mining methods. The lithium production of various countries is shown in Figure 254 can be seen. Australia is the world's largest producer of lithium, but the largest deposits are found in Chile (see Figure 255).

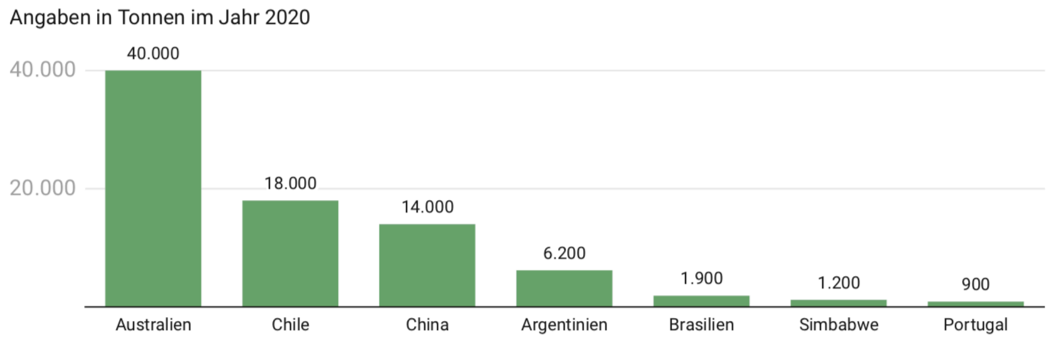

Figure 254: Lithium production by country.

Source: Neitzel, (2021).

The shift in traffic towards electric cars has boosted the demand for materials enormously, including lithium, particularly because of the batteries.

Mining areas are being found and opened up again and again. Even in the Upper Rhine Graben, lithium can be filtered out of the thermal water in small quantities.

Since 2020, lithium has also become a critical raw material in the EU, as some calculations predict a demand for lithium in 2030 / 2050 that is 18 / 60 times higher than in 2020 for the production of e-cars and energy storage. In Figure 256 however, "only" double the consumption of lithium carbonate equivalents is forecast for 2025 compared to consumption in 2015.

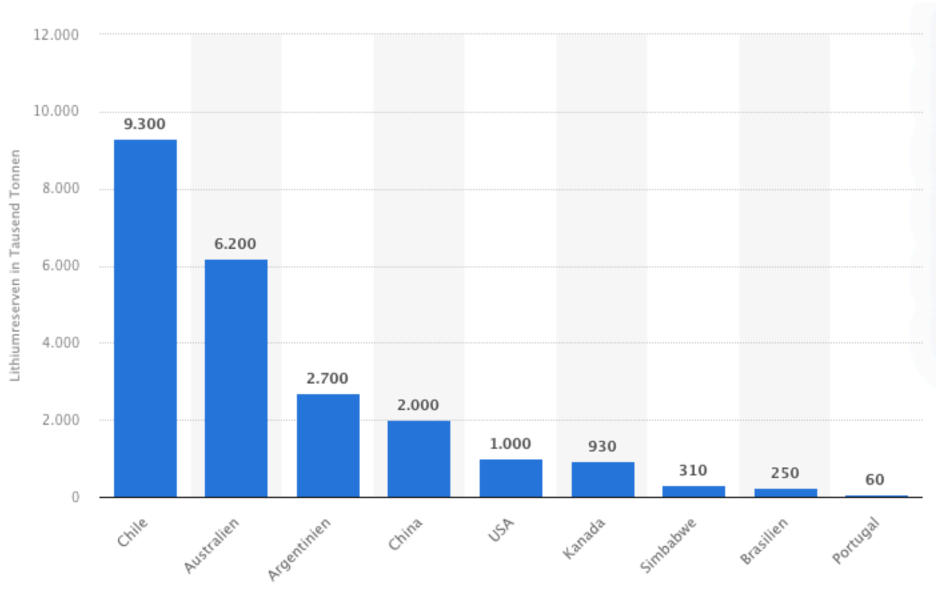

Figure 255: Countries with the largest lithium deposits in 2022 in kt.

Source: Statista (2022j).

Use for energy production

Lithium is used in Li-Ion accumulators with a consumption of about 120-180 g Li/kWh. Figure 256 shows that a strong increase in consumption is expected for all minerals that are important for the production of accumulators, but especially for lithium.

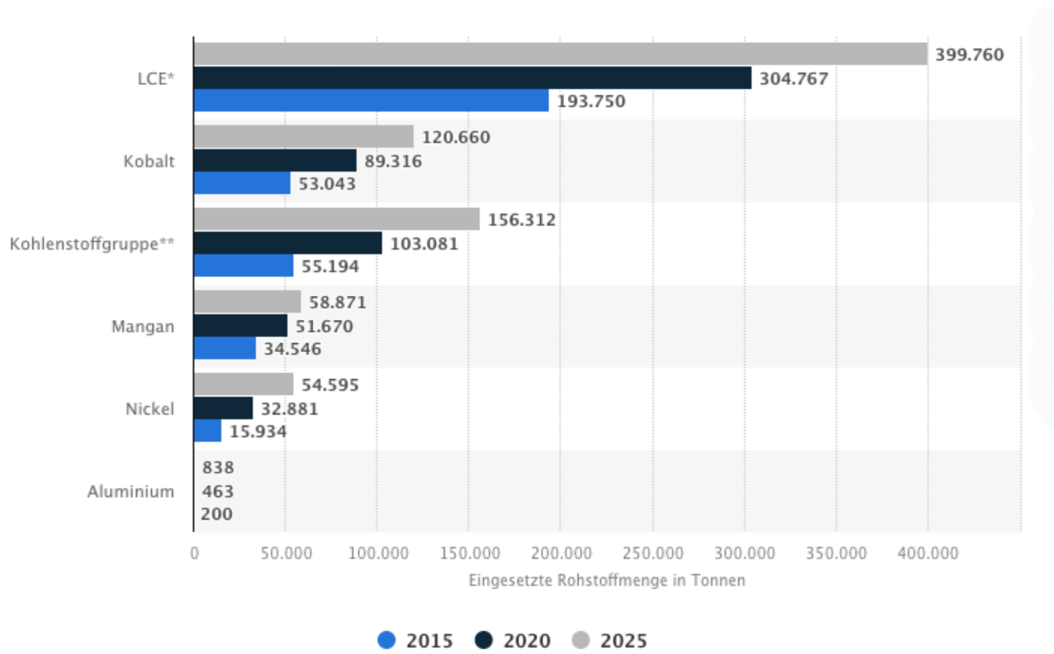

Figure 256: Raw material quantities in Li-ion batteries by raw material in 2015 and forecasts for 2020 and 2025.

Source: Statista, 2022f.

Expected bottlenecks

Large quantities of water are needed to extract lithium. In Chile, the country with one of the largest extraction volumes, there has been a water war since the complete privatisation of the water supply, as more water is consumed, especially by the agricultural industry, than comes naturally.[717] The question is when the extraction of lithium and copper, the largest consumers of water in Chile, will have to cut back their production.

Recycling rates

Currently, there is no recycling of lithium (see Figure 269, S.430). As the number of registrations for electric vehicles increases, so does the need to recycle the raw materials used in them, especially lithium, nickel and cobalt from the battery. For example, BWM, together with its Chinese partner Brilliance, is currently setting up recycling for the batteries installed in the brand's vehicles with the aim of recovering around 90 kg of Ni, Li and Co from 100 kWh batteries, which corresponds to an unspecified "high percentage".[718] As the market for electric vehicles in China is growing faster than in Europe, and carmakers are also legally obliged to ensure the retrieval of batteries, it is expected that by 2025 about 780,000 t of discarded batteries will accrue at recycling companies.

2.13.2.7 Cobalt (Cobalt, Co[27])

General information

Cobalt ores have been known for a long time and were used to colour ceramics and glass because of their blue colour. In the Middle Ages, the ores were considered to be bewitched by goblins and worthless because of the bad smells during processing. Like other elements, this is how cobalt got its derisive name.

Cobalt is mainly extracted from copper and nickel ores. Since cobalt occurs at only about 40 ppm in the earth's crust, it is always a by-product of copper and nickel extraction. Nevertheless, extraction and production have skyrocketed in the 21st century (see Figure 257).

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[717] Cf. Boddenberg, (2020).
[718] Neitzel, 2022a.

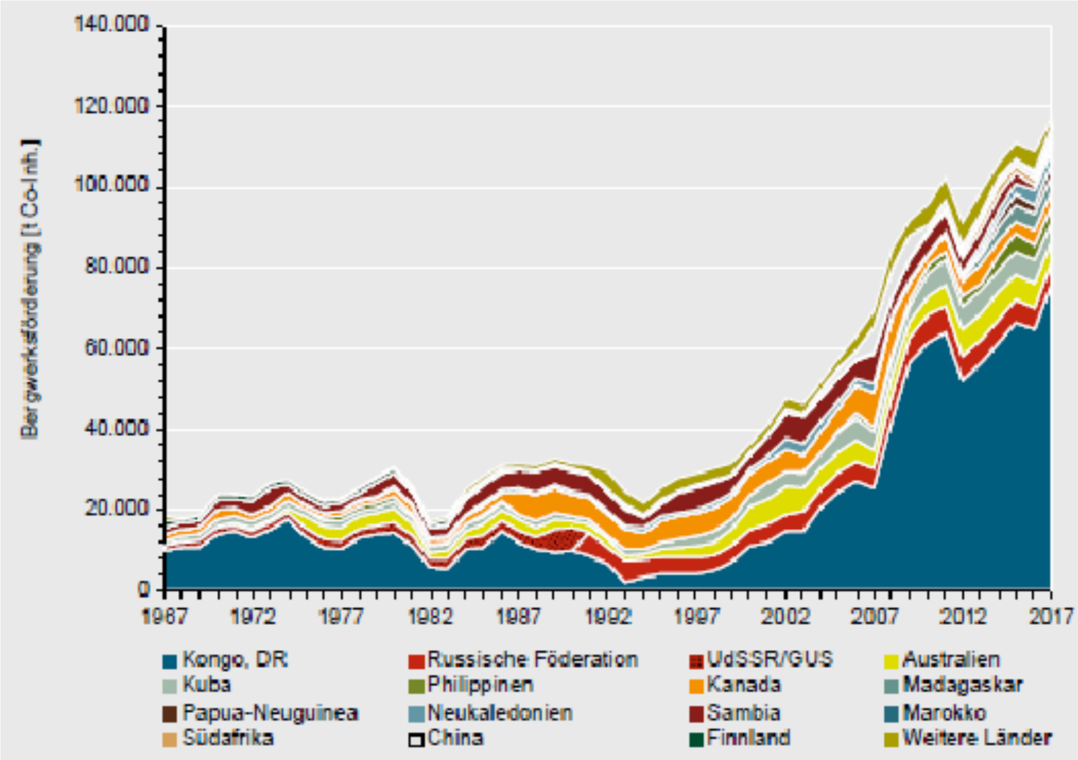


Figure 257: Development of cobalt mining and production over time.

Source: BGR, 2018; CRU, (2018).

Cobalt is a ferromagnetic transition metal and is placed between iron and nickel in the periodic table because of its atomic weight. It conducts heat and electric current well.

Use for energy production

Cobalt is extremely important for the production of accumulators (batteries), especially those with small dimensions (e.g. for mobile phones), and the largest exporter of cobalt is the Democratic Republic of Congo (DRC) (see Figure 258).

Other materials with a low proportion of cobalt are now used for the anodes of lithium batteries (NMC nickel, manganese, cobalt with e.g. only 2.8 % Co in the Tesla batteries), so that not so much cobalt is needed for the batteries of e.g. vehicles.

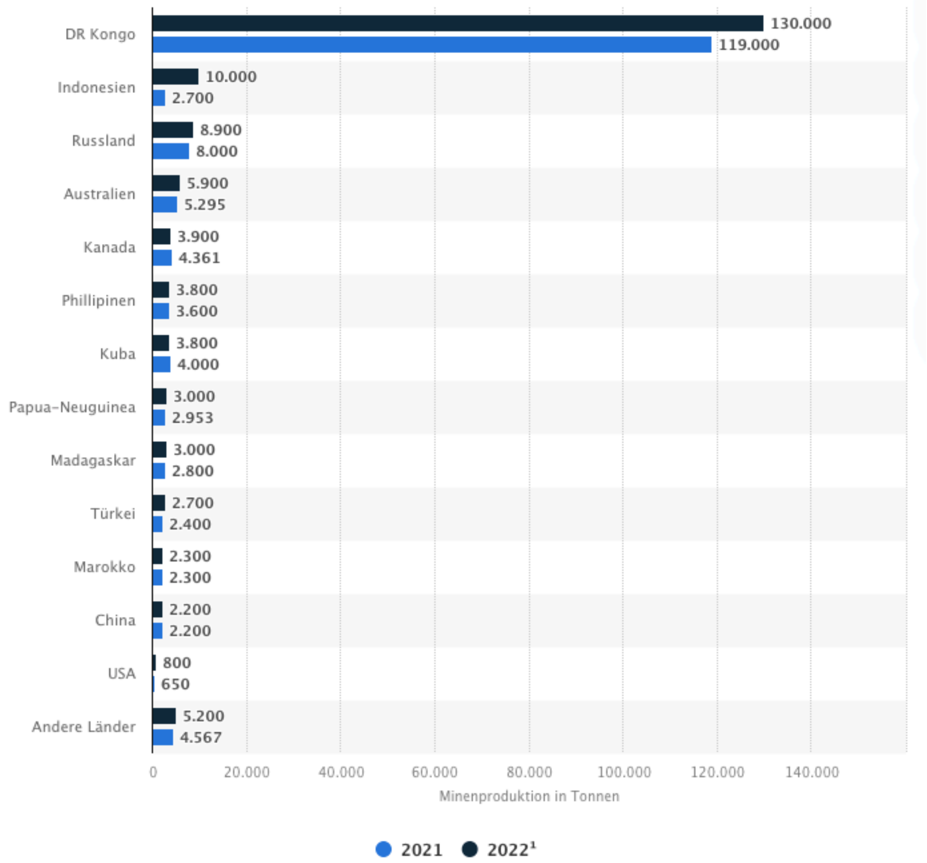


Figure 258: Global availability of cobalt in selected countries 2021 and 2022) in 1,000 t.

Source: Statista (2022k).

The joy at the fact that an important raw material for the development of the Western world is not coming from China for once quickly evaporates when one looks at the countries to which Congo exports (see Figure 259). Congo's high export rates to neighbouring Zambia indicate that Zambia's Copperbelt smelts Congo's ores along with its own production. Congo is a resource-rich country, mining mainly cobalt but also a whole range of Au, Ag, Cu, Mn, Pb, Zn, Nb, Ta and uranium, but also fuels such as oil and coal.

As recently as 1995, Europe and the USA bought about 80 % of the products exported by DRC. This share had fallen to less than 20 % by 2012, with an increase in exports to Southeast Asia of 77 %.[719] The fact that China took better care of African countries than the former colonial masters, especially shortly after their independence (Congo was released from the cruel rule of Belgium into independence in 1960) and supported Congo, e.g. through lending, is now bearing fruit, as its own industrial growth could be secured through contracts with borrowers on the supply of raw materials.[720]

[719] Cf. Südwind, 2014.
[720] Cf. Saam, 2008.

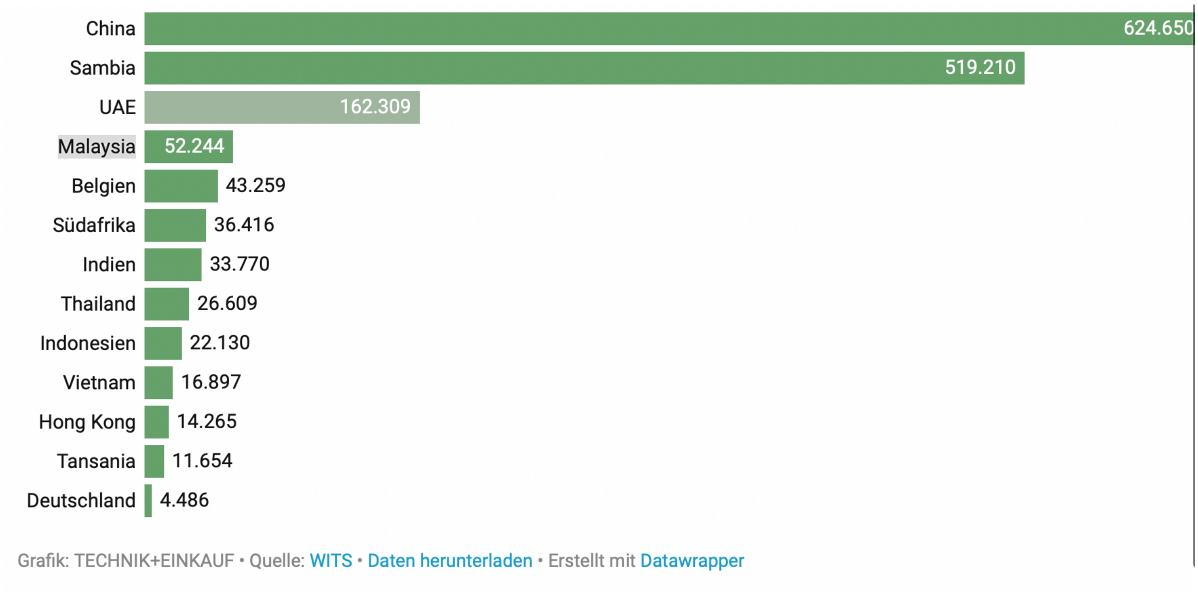


Figure 259: Countries and quantities to which DR Congo exports how much raw material, in 1000 USD. Source: Neitzel, (2021).

Expected bottlenecks

Although the safe reserves of cobalt amount to 25 Mt and another 120 Mt are suspected under the sea,[721] the Wirtschaftswoche considers the availability of cobalt to be dramatic because the deposits are located in the politically "extremely unstable south-east Congo", the exploration consumes billions and is also risky. Congo's annual production is 124 Mt of cobalt and the annual demand for 30 million BEVs with 90 kWh batteries (the auto industry's plan for annual production in the near future) is 400 Mt. I.e. the demand is more than twice the current supply. If it is not possible to replace cobalt with other materials in the battery, the energy transition will be seriously endangered.

At least Tesla/Panasonic managed to reduce the cobalt content in the cathode from 33 % to 15 %. Nevertheless, the gap between supply and demand continues to widen, which drove up the price of cobalt.

Recycling rates

The figure below shows that the recycling of ferrous metals, which includes cobalt, is not so bad compared to the rare earths in the lanthanide group and the light elements lithium and beryllium.

[721] Cf. Wirtschaftswoche, n.d.

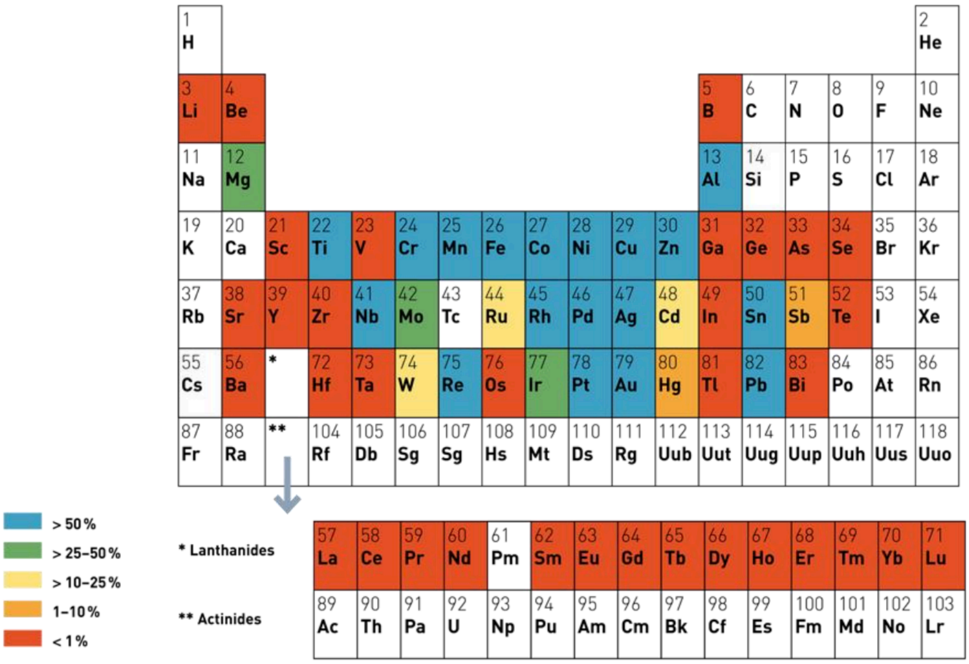


Figure 260: Global end-of-life recycling rates of 60 metals.

Source: Buchert, (2018).

The recycling of cobalt has been carried out for years with spent catalytic converters, hard metal and superalloy scrap. As already mentioned in chapter 2.2.4, some companies such as Umicore in Belgium and Accurec in Krefeld (Germany) have already started recycling batteries on a large scale.

2.13.2.8 Iridium (Ir^{77})

General information

Iridium^{77} belongs to the platinum group metals (PGM), which in addition to platinum^{78} also include palladium^{46}, rhodium^{45}, ruthenium^{44} and osmium^{76}, which are located in groups 8, 9 and 10 and periods 5 and 6 in the periodic table and are characterised by high densities (iridium and osmium are the densest elements) and similar chemical and physical properties. The elements are a by-product of the extraction of nickel and copper.

Since iridium is considered the most corrosion-resistant element, the original kilogram and the original metre are made of this precious metal. At the same time, iridium is also one of the rarest non-radioactive elements on Earth, with a mass fraction of 1 ppb in the Earth's crust. Since iridium occurs quite frequently in the universe, it is assumed that the Earth's iron core contains significantly more iridium than the crust.

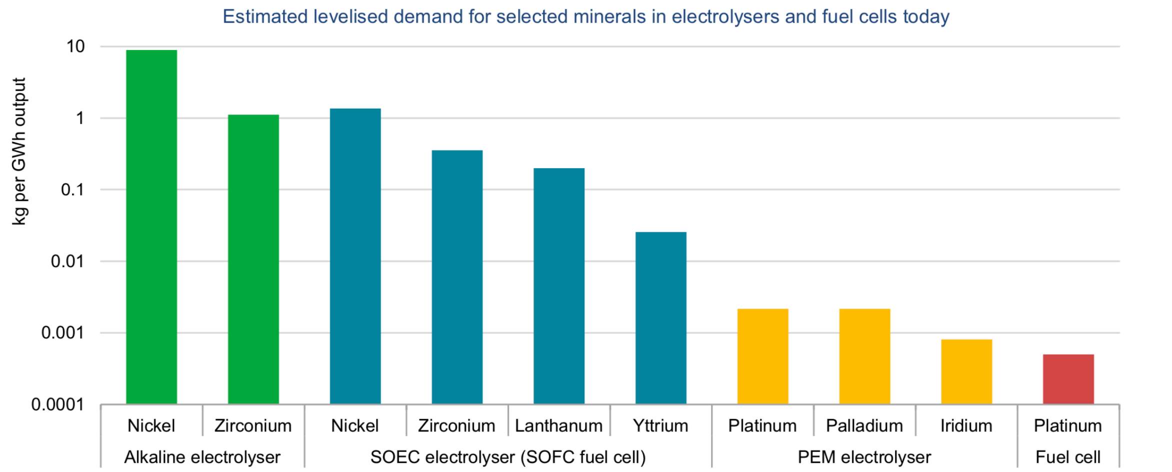
The deposits of iridium are located in South Africa, the Urals, North and South America, Tasmania, Borneo and Japan.

In 2020, approximately 9 t were mined worldwide, with 7 t extracted from the platinum mines in South Africa alone. The rarity of iridium is also expressed in its high market price of 6,100 USD/oz (in comparison, gold in June 2022: 1,747 USD/oz).

Use for energy production

Because of its hardness, iridium is used in the manufacture of spark plugs for aircraft engines, in addition to applications in the jewellery industry and medical and dental technology. Iridium becomes superconducting at temperatures below 0.11 K, but is not irreplaceable in this context, as there are elements that already become superconducting at higher temperatures.

Iridium oxide is used in PEM electrolysis (see Figure 261) is used to increase the cell reversal tolerance.



Notes: PEM = proton exchange membrane; SOEC = solid oxide electrolysis cells; SOFC = solid oxide fuel cell. Normalisation by output accounts for varying efficiencies of different electrolysis technologies. Full load hours of electrolysers assumed to be 5 000 hours per year.
Sources: Bareiß et al.(2019); Fuel Cells and Hydrogen Joint Undertaking (2018); James et al. (2018); Kiemel et al. (2021); Koj et al. (2017); Lundberg (2019); NEDO (2008); Smolinka et al. (2018); US Department of Energy (2014; 2015).

Figure 261: Use of elements in the design of electrolysers of different types and fuel cells .

Source: IEA, 2020b.

Applications are:

- Catalyst for the decomposition of hydrazine (N H_{24}) as a fuel for controlling satellites
- Catalyst for fuel cells

- Multifunctional iridium-based catalyst [722]

Expected bottlenecks

The static range of iridium is 431 years.[723] Nevertheless, iridium could prove to be a bottleneck in the development of electrolyser capacities if, on the one hand, the iridium catalyst loading in PEM electrolysis cells is not drastically reduced and, on the other hand, the development of a recycling infrastructure for iridium catalysts with technical end-of-life recycling rates of at least 90 % is not established.[724]

Recycling rates

50 % of the iridium processed in industry is recycled (Mis22). A variety of processes are described in the literature, e.g. for the recycling of CCMs (catalyst coated membranes) used in PEM electrolysers .[725] According to experts, a recycling infrastructure for membranes should be easy to set up.[726]

2.13.2.9. Platinum (Pt[78])

General information

Platinum is a precious metal from the nickel group that always occurs in a solid state. South Africa produces by far the most platinum. The production amounts to almost ¾ of the world's production as Figure 262 shows.

[722] Cf. Frontis Energy, (2021).
[723] Cf. Mischler, (2020).
[724] Cf. Minke et al., (2021).
[725] Cf. Carmo et al., 2019; Müller et al., 2018; Neitzel, 2022b.
[726] Communication with Heraeus employees.

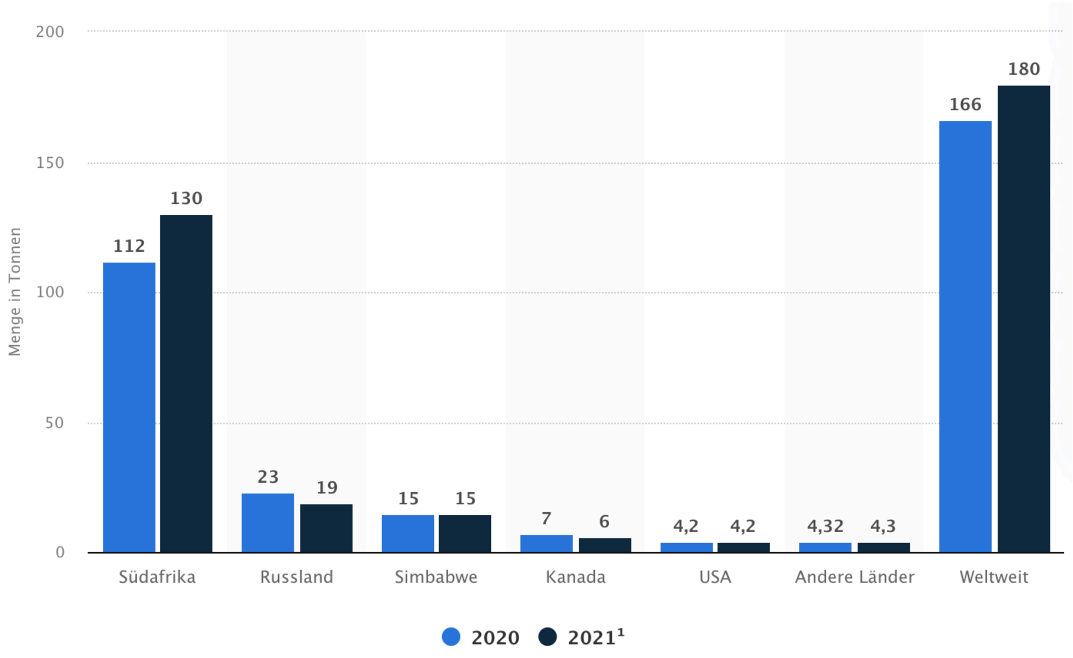


Figure 262: The mine production of platinum from five countries in 2020 and 2021.

Source: Statista, 2023a.

Platinum (from platina, the little silver) is currently about fifty times more expensive (32,690 EUR/kg) than silver but only about a little more than half the price of gold (56,170 EUR/kg).

In addition to its use in the jewellery industry, platinum is used in technology to make thermocouples or resistance thermometers (Pt100). Also of great importance is the versatile use as a catalyst, e.g. as an exhaust gas catalyst in the exhaust systems, in the combustion of hydrogen with oxygen (Döbereiner lighter), in the contact process for the production of sulphuric acid or in the ammonia oxidation to nitric acid (Ostwald process).

The disadvantage of platinum catalysts is that they are relatively quickly "poisoned" by impurities and thus become unusable. Regeneration can make them usable again.

Use for energy production

As already mentioned, platinum can be used as a catalyst both in electrolysis and in the reverse process of hydrogen combustion, e.g. in the fuel cell. In order to prevent possible shortages or to reduce costs by using cheaper materials, work is being done on replacing platinum in the fuel cell.[727]

[727] Cf. Solarserver, (2021).

The quantities used in an electrolyser and in the fuel cell per GW of electrical power can be taken from the Figure 261 on page 415 can be seen.

Expected bottlenecks

An oversupply of platinum can currently be observed on the market, as the automotive industry and also the jewellery industry, which together account for 70% of demand, are weakening. Demand as a catalyst material in oil refineries and in the chemical industry is likely to continue. However, Heraeus does not see any current bottleneck overall.[728]

Recycling rates

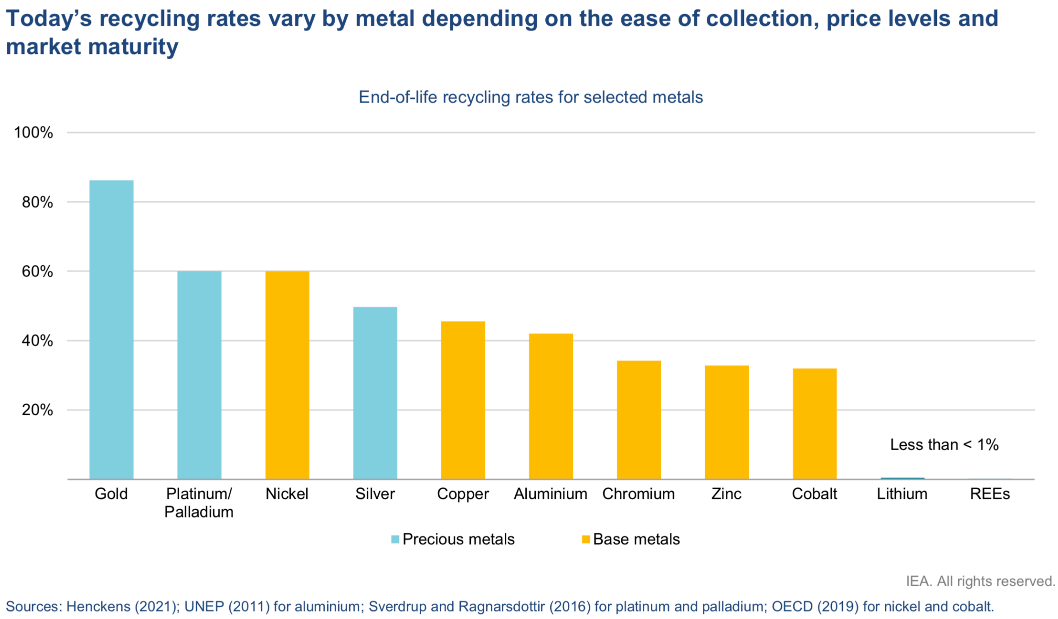


Figure 263: Current (2021) recycling rates.

See also Figure 260 on p. 414.

In Germany, Heraeus is an important company for the recycling of precious metals such as gold, silver, platinum, palladium, rhodium, ruthenium, iridium, osmium and rhenium.

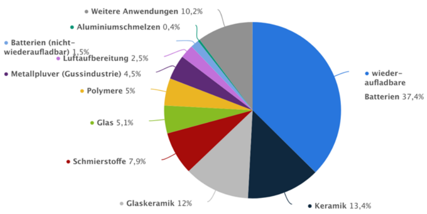
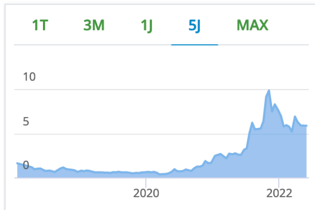
[728] Cf. Heraeus, (2020).

2.13.3 Fields of application

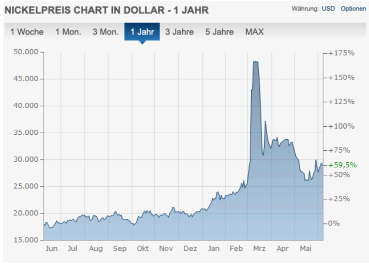
Overview of raw materials and their fields of application

The table below briefly describes the fields of application for some of the raw materials classified as critical and adds the market prices researched in May 2022 for information.

Table 57: Use of selected critical elements including rare earths, table sorted by atomic number .

<table>
<tr><th>Element</th><th>Description</th><th>Market price REO from China[729]</th></tr>
<tr><td>Lithium (Li^{3})</td><td>Lithium-ion batteries, glass and ceramic products[730]

</td><td>6 EUR, falling prices after peak

</td></tr>
<tr><td>Scandium (Sc^{21})</td><td>Lighting, fuel cells, X-ray technology, lasers, alloying element for aluminium, market price dropped from 4600 USD/kg in 2018</td><td>836 USD/kg</td></tr>
<tr><td>Manganese (Mn^{25})</td><td>As an alloying component with Al and Cu, Mn increases strength, corrosion resistance and ductility. In the alloy with Fe, it increases hardenability. In constantan, it reduces the dependence of conductivity on temperature.
Occurrence in the earth's crust: 0.085 %.</td><td></td></tr>
<tr><td>Cobalt (CO^{27})</td><td>Cobalt is a very hard ferromagnetic transition metal that was used to colour (cobalt blue) glass and ceramics before its use in electrics and electronics. Use of ^{60} Co in cancer therapy.
In rechargeable batteries, Co enables high energy densities and fast charging.
Proportion in the earth's crust: 0.04 %.</td><td>220 - 320 EUR/kg depending on quantity[731]</td></tr>
<tr><td>Nickel (Ni)[28]</td><td>Alloy content in stainless steels, alnico magnets, electrode material in rechargeable</td><td>399 EUR/kg[733] 28,856 USD/t[734]</td></tr>
</table>

[729] Values from Statista, 2022c; values from IRENA, (2022).
[730] Cf. Statista, 2022a.
[731] Cf. MyMetalls, n.d.
[733] Cf. MyMetalls, n.d.
[734] Cf. Börse Online, n.d.

Element	Description	Market price REO from China[729]
	batteries, strings for electric guitars, plating for sanitary fittings. Worldwide consumption rising strongly see Figure 248. Share in the earth's crust: 0.015 %.[732]	
Copper (Cu)[29]	Cu is an excellent conductor of heat and electricity and is therefore essential for the transformation in the energy industry.	
Zinc (Zn^{30})	47 % of production in 2018 was used for galvanising as rust protection for iron and steel. Remainder in alloys with Cu (brass), Al, Mg. Occurrence in the earth's crust: 76 ppm	 approx. 3500 EUR/t (june 22)
Gallium[31]	Ga is similarly rare in the earth's crust as lithium and lead and only occurs as a compound with Al, Zn or Ge ores. As gallium arsenide, Ga is used in HF technology for the production of transistors, also for the production of light-emitting diodes. It is used in semiconductors for doping silicon (p-doping).	822 EUR/kg
Germanium[32]	Until the 1970s, the leading element in electronics for the production of diodes and transistors until it was displaced by silicon. Today it is used for the production of lenses for night vision devices and thermal imaging cameras. Ge is also a catalyst in the production of polyester fibres and granulates for e.g. PET bottles. Its use in food supplements to fight	2261 EUR/kg

[732] For comparison: the proportion of Fe in the earth's crust is 4.7 %, that of O_2 49.4 %.

Element	Description	Market price REO from China[729]
	cancer and fatigue syndrome is controversial.	
Yttrium (Y^{39})	Fluorescent lamp, LCD and plasma screens, LEDs, fuel cell, YAG laser, increases the activity of cerium oxide in catalytic converters to reduce NO_x levels, increases the efficiency of the electrolyte in fuel cells à lowering the temperature of the BSZ	11.9 USD/kg
Rhodium (Rh^{45})	Similarity to precious metals: low reactivity, high catalytic effect (à NO_x catalytic converters in cars)	500,000 USD/kg[735] Stockbroker-speak: "Multibagger"
Indium (In^{49})	Because of its low melting point, it is used in sprinkler systems, thermostats and for fuses. As an alloy with tin, it is used as a transparent conductor for flat and touch screens. Frequency in the earth's crust similar to silver.	160,771 USD/kg[736] for comparison Silver: 656 EUR/kg
Lanthanum (La^{57})	In alloys Use in accumulators, use as catalyst in fluid catalytic cracking (FCC)	2 USD/kg
Cerium (Ce^{58})	Car catalytic converters, soot particle filters, semiconductor technology, LED	1.48 - 1.5 USD/kg
Praseodymium (Pr^{59})	Permanent magnets, electric motors, glass and enamel colouring, praseodymium and neodymium occur together in ores and also have similar properties and are therefore also difficult to separate.	140 USD/kg
Neodymium (Nd^{60})	Permanent magnets are produced in alloys with iron and boron, which are used, for example, in the generators of wind turbines. Neodymium accounts for about 20 % of the occurrences.	104.6 - 143 USD/kg[13]
Promethium (Pm^{61})	All isotopes are radioactive, occur only as fission products of uranium and a europium isotope. Technical use only as b-emitters, e.g. also in luminous paints.	n.a.

[735] Cf. Onvista, n.d.
[736] Cf. Onvista, n.d.

Element	Description	Market price REO from China[729]
Samarium (Sm^{62})	Doping of CaFI single crystals for masers and lasers, neutron absorber ("neutron poison" in nuclear reactors) $SmCo_5$ strong permanent magnets for e.g. quartz clocks, stepper motors (hard disk drives), SM oxide is catalyst for hydrogenation and dehydrogenation of ethanol Medicine: palliative therapy of bone and skeletal metastases	2.45 - 4.5 USD/kg
Europium (Eu^{63})	Generation of the red component of the RGB colour space in stirred and plasma screens, semiconductor technology, LED	32 USD/kg
Gadolinium (Gd^{64})	Semiconductor technology, LED, contrast agent in magnetic resonance imaging	76.2 USD/kg 2940 EUR/kg
Terbium (Tb^{65})	Additive for permanent magnets to improve thermal stability, additive for fluorescent lamps CFL	1720 USD/kg
Dysprosium (Dy^{66})	Permanent magnets, possibly samarium and cobalt as substitutes to improve the thermal stability of the magnets Dy accounts for 8.7 % of the weight of magnets for electric drives and 6.4 % for generators[737]	417.8 - 452 USD/kg
Holmium (Ho^{67})	Strong ferromagnetic properties, has together with Dy the highest magnetic moment of all naturally occurring elements.	n.a.
Erbium (Er^{68})	Erbium-doped optical fibres are used for optical amplifiers because there is no need to convert them into an electrical signal. Gold with low doping of Er are used as sensors for magnetic calorimeters. Along with Y use in the YAG laser, isotope ^{169}Er is used in nuclear medicine, $ErCl_3$ is pink and is used as a colourant in pottery and glassblowing.	38.7 USD/kg
Thulium (Tm^{69})	Apart from promethium, Tm is the rarest lanthanoid, yet more common than iodine or silver.	n.a.

[737] Cf. DOE, 2011.

Element	Description	Market price REO from China[729]
	Activation of luminescent substances on the screen surface. Use by doping $CaSO_3$ as personal dosimeter for low doses, use by doping LaOBr as scintillator in X-ray technology.	
Ytterbium (Yb^{70})	Only minor technical applications, e.g. as doping in the YAG laser or in fibre lasers, in the atomic clock with four times the accuracy of Cs.	61 EUR/kg[738]
Iridium[77]		Mischler, 2020

Figure 275 on page 453 shows the influence of raw materials with supply risk on nine technology sectors. The high supply risk of rare earths in particular has an impact on the area of motors in windmills and drive motors, which can directly lead to impediments in the renewable energy and e-mobility sectors.

However, raw materials with a moderate supply risk, such as cobalt, metals from the PGM group and graphite, also have a massive impact on the production of batteries, fuel cells and, as already mentioned in chapter 2.2, on the urgently needed development of electrolyser production in order to produce green hydrogen with the help of renewably generated electricity, especially surplus electricity and water. The production of renewable electricity is not only endangered on the wind power line but also on the photovoltaic line, since materials for the construction of PV modules are subject to a supply risk, even if it is still low.

Magnet production

Wherever electricity is generated by rotary motion or rotary motion is generated with its help, strong magnets are needed that do not lose their magnetic moment even when the unit heats up during use. Electric vehicle (EV) manufacturers have recognised the heavy dependence on rare earths and are trying to reduce this in motor development through modified design. So far only at the expense of the range of EVs, so the search for substitute materials for the lanthanides continues.

Until now, the most important patents for the production of magnets (bonded magnets and sintered magnets) were held by Japanese developers. In the past decade, more than 500 new

[738] Cf. HMW-Hanauer, n.d.

patents for sintered magnets have been filed, which can be seen as an indicator of the importance of this market.[739]

Fuel cell production

Since fuel cells (FCC), unlike heat engines, are able to convert energy from fuels into electricity without the diversions of generating heat, they are potentially more efficient than heat engines. Since their invention in 1838 by C.F. Schönbein, research and experiments have been carried out to improve them, so that as early as 1875 Jules Verne expressed the hope in his book "The Mysterious Island" that fuel cells would secure the earth's energy supply for the foreseeable future.

Obviously, further development has taken a little longer. For off-grid electrical systems, methanol fuel cells are very often used today for electrical supply, numerous small vehicles such as lift trucks are equipped with fuel cells and they are also intended for power supply in networks, e.g. to catalytically burn hydrogen produced by electrolysers and to bridge power bottlenecks with the generated electricity, e.g. in the dark lulls of a network with renewables.

In order for electrochemical reactions to take place in fuel cells, both electrodes are coated with catalysts, mainly platinum, ruthenium or palladium or mixtures of these elements. Nickel, nickel oxides, tungsten cabide and sulphide are also used.

In the SOFC (Solid Oxide Fuel Cell), the electrolyte consists of zirconium oxide $Zr(Y)O_2$ stabilised with yttrium.

Construction of high performance storage

If, in the context of the energy transition, there is an overproduction of electricity caused by high installed capacities of wind and solar plants, which at the same time cannot find any consumers in the grid (see chapter 2 of the overall report "Generation and storage of green electricity"), the short- and medium-term storage of electricity is necessary. One possibility for this is the construction of lithium ion storage systems. Table 58 shows that there will be an enormous demand for the elements nickel, manganese, lithium and cobalt, and especially for graphite.

[739] Cf. IRENA, 2022, p. 7.

Table 58: Global demand for raw materials in tonnes for the production of lithium-ion batteries in 2018 and the forecast for 2040.

Source: Statista, 2022h.

Merkmal	2018	2040[1]
Nickel	32.320	1.742.000
Graphit (natürlich und synthetisch)	21.900	886.400
Mangan	11.140	461.300
Lithium	7.460	328.100
Kobalt	12.750	270.400

Looking at the list of lithium-ion battery manufacturers, it is noticeable that in 2017 only manufacturers from the Far East and namely LG and Samsung from South Korea, BYD, CATL and Lishen from China and Panasonic from Japan can be found on this hit list.

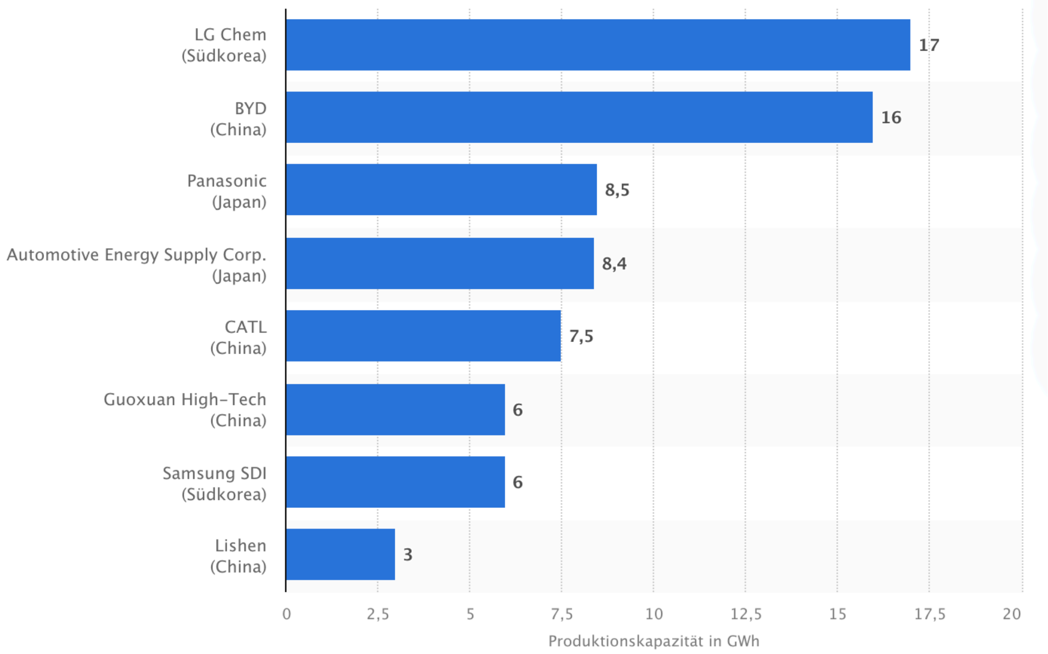


Figure 264: Installed production capacity for lithium-ion batteries by selected manufacturers worldwide in 2017.

Source: Statista, 2022m.

2.13.4 Occurrence, ranges, mining risks

Sufficient information on the occurrence of the critical raw materials has already been provided in the individual chapters dealing with the substances in detail.

2.13.4.1 Basic information on ranges

In the **static paradigm** for calculating ranges, it is assumed that resources on earth are fixed and their size can usually be well estimated. However, the constant extraction and use of resources sooner or later leads to their scarcity, which inevitably leads to an increase in their unit costs. The static period until they become more expensive can be extended by measures such as recovery from waste, finding substitutes, restrictions on their use. Uncertainty in determining the static range exists in the static paradigm only due to the ignorance of future price and demand developments. In the static paradigm, it cannot be clarified why over time the estimated resource sizes remain the same or even increase, although they should actually decrease. Static ranges therefore say something about the characteristics of mining exploration cycles rather than the physical availability of raw materials.

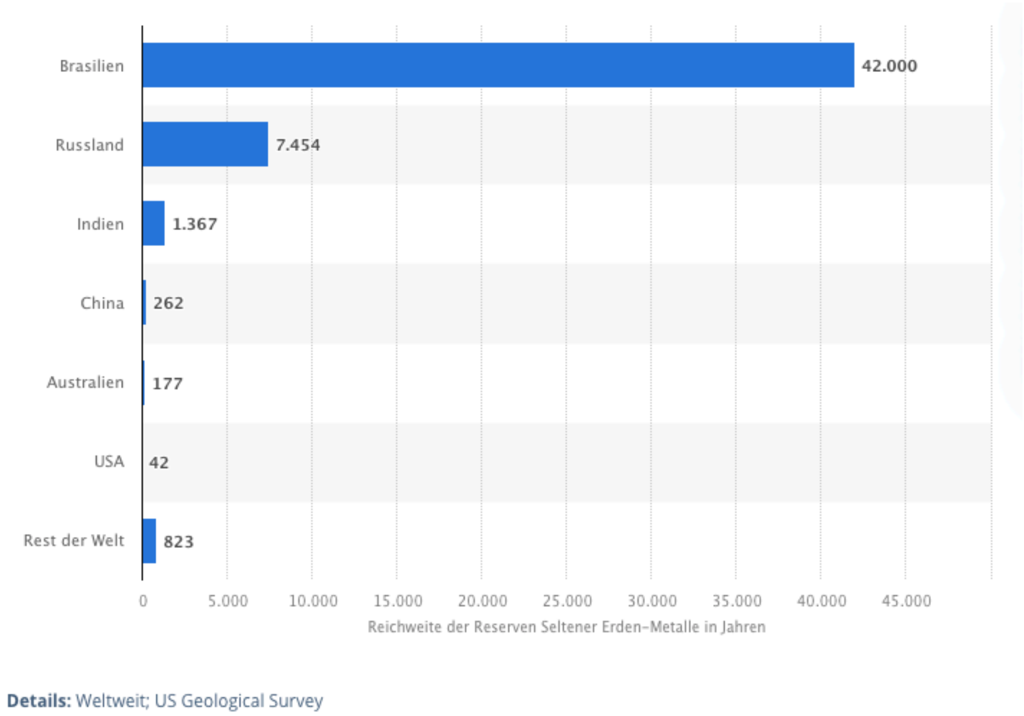


Figure 265: Static range of rare earth metals for some countries in 2021.

Source: Statista, 2021a.

Figure 265 shows the static range as the number of years that results as the so-called R/P ratio from the known reserves and production under the boundary conditions of constant production and unchanged static reserves.

The relatively low range of China's rare earths compared to Brazil does not indicate the size of the reserves, as the Figure 266 illustrates, but rather to the small amount of mining in Brazil.

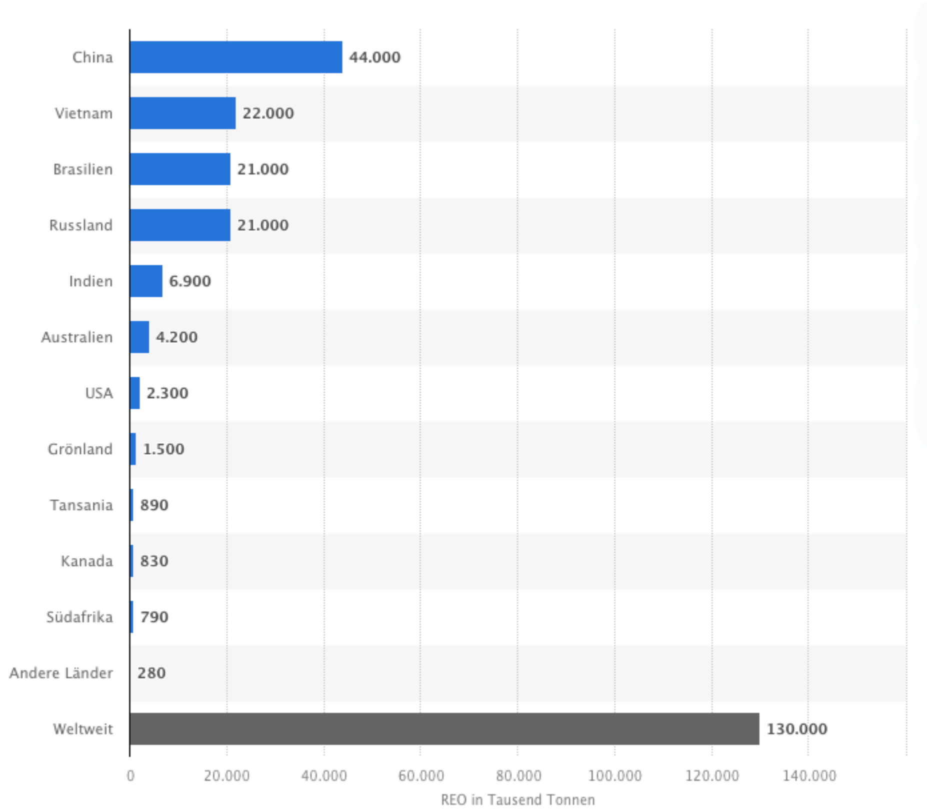


Figure 266: Rare earth reserves in selected countries in 2022.

Source: Statista, 2022l.

The **dynamic paradigm** attempts to move away from static boundary conditions. Since time immemorial, the availability of mineral deposits has been estimated on the basis of local deposits with extrapolation to the terrestrial totality. The estimates are partly very speculative and their accuracies vary from element to element. If only the deposits of aluminium and gold in the Earth's crust are taken into account, it could be estimated that, if the mining rates of the 20th century are maintained, aluminium will still be available for 57 billion years and gold for five million years.[740] This would obviously mean that the supply of minerals from the Earth's crust would no longer be an issue.

In fact, new deposits are constantly being found or known ones are suddenly degradable due to technology developed in the meantime or changed market prices and can be attributed to the resources. A dynamic analysis of the availability or range of resources must therefore take into account significantly more parameters, such as regulations in business and environmentally relevant processes, development of recycling processes, than would be necessary for a static analysis.

[740] Cf. HCSS & TNO, p. 13.

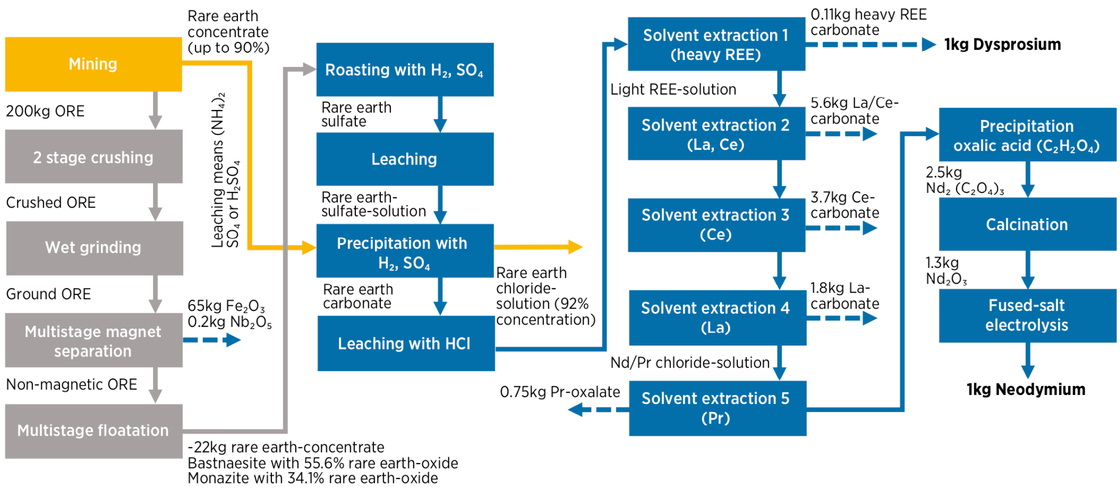
Even though rare earths are sometimes no rarer in the earth's crust than other elements such as lead, copper or arsenic, the deposits are usually small and were often too small to be economically exploitable before the boom in their use. However, since rare earths usually occur in combination with other ores and minerals and especially with other REE (rare earth elements), their extraction is sometimes a by-product of the chemical processing and exploitation of a deposit.

Rare earths are mainly extracted by fused-salt electrolysis of the oxides converted into chlorides or fluorides. The resulting salts can be obtained by various processes such as precipitation, crystallisation, ion exchange with elution, liquid-liquid extraction in countercurrent. The latter process is the most effective, although the conversion of the rare earths into an organic phase with subsequent extraction and precipitation of the oxalates, hydroxides and carbonates formed with subsequent annealing to oxides is very costly (cf. Figure 267).

In the report of the Federal Environment Agency, the extraction processes for LREE are consistently given the attribute "high aUGP" (high aggregate environmental hazard potential) and those of the HREE group are given the attribute "h-m aUGP" i.e. high to medium potential.[741]

Achieving sustainability of rare earths requires careful economic assessment and determination of environmental and societal impacts. To achieve this goal, new chemical and engineering technologies are needed, starting with the recycling and reuse of the many products in which rare earths are currently used. Ultimately, products and applications should be designed so that rare earths can be reused immediately and economically."[742]

[741] Cf. Dehoust et al., (2020).
[742] Translation from Atwood, 2012; Mischler, (2020).



Source: BGR, 2021.

Note: Ce = Cerium; Fe_2O_3 = ferric oxide; HCl = hydrochloric acid; H_2SO_4 = sulphuric acid; kg = kilogramme; La = lanthanum; Nd = neodymium; Nb_2O_5 = niobium pentoxide; NdCl3 = neodymium(III) chloride; Nd_2O_3 = neodymium oxide; $Nd_2(C_2O_4)_3$ = neodymium oxalate; $(NH_4)_2SO_4$ = ammonium sulphate; Pr = praseodymium.

Figure 267: Process diagram for the production of neodymium.

Source: IRENA, (2022).

2.13.5 Recycling methods and rates

2.13.5.1 General remarks on the recycling of critical raw materials

The current state of recycling of critical raw material in the EU is shown in Figure 268 is shown. According to the EU, the rates for iron, zinc and platinum are now greater than 50% and the secondary raw materials of these metals cover more than a quarter of EU consumption.

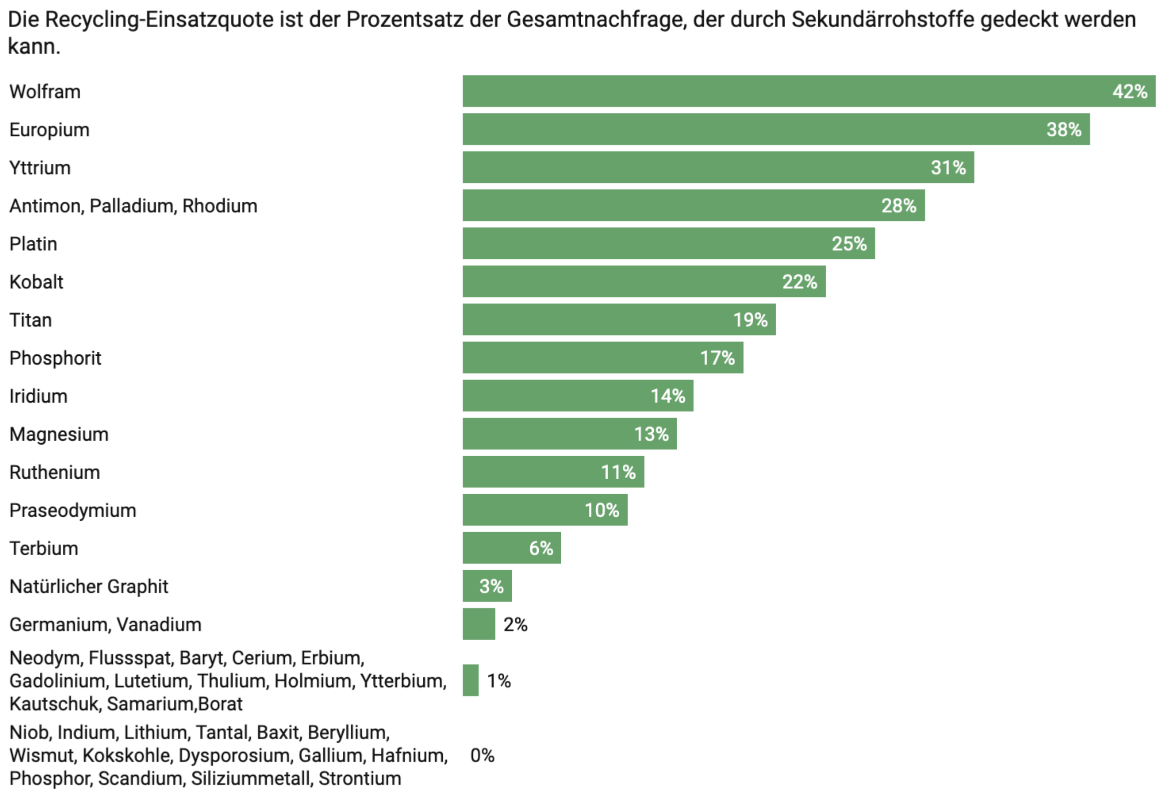


Figure 268: Recycling input rate in the EU.

Source: Neitzel, (2021).

Looking at the masses of accumulators and batteries recycled within the EU in Figure 269only the Spanish values actually show a clear increase. Unfortunately, no recycling rates are available in Eurostat for this.

Progress in the expansion of the recycling sector is less frequently reported.[743]

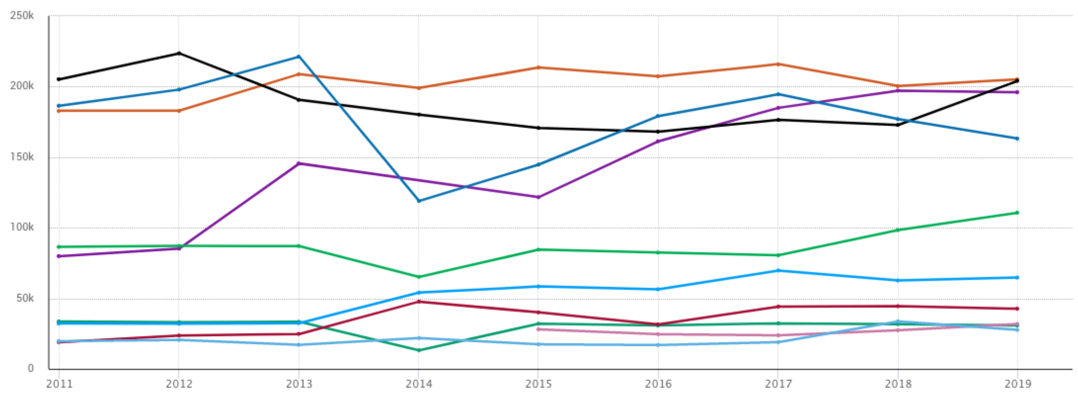


Figure 269: Recycling of batteries and accumulators from 2011 to 2019 for some EU countries in tonnes/a.

Source: eurostat (2023).

[743] Cf. Baumann (2022a), Baumann (2022b), Lewicka (2021)

It should not be forgotten that in many countries there are informal waste pickers (e.g. "pepenadores", "catadores", "waste pickers") on the road who sort and recycle waste in order to secure their livelihood. Their number is estimated at 15 - 50 million people who cannot carry out complex hydro-refining, but who can pre-sort the valuable waste with a sure eye and send it for professional reprocessing.

In projects, the German GIZ supports the development of national and local waste management plans,[744] the involvement of informal waste collectors and the development of know-how for waste and circular economy.

2.13.5.2 Urban Mining

In recent years, the term "urban mining" has become established for the effort to recover valuable raw materials from the "anthropogenic stockpiles" of about 50 Gt in Germany at a per capita growth rate of 10 t/a in accordance with the dictum "waste is raw material".[745]

With a recycling rate of 30 % for copper and over 50 % for iron and steel, dependence on imports can be significantly reduced. Without recycling, the rising demand for gold, tin or antimony, for example, would exceed the deposits currently considered mineable in a few decades.

Figure 270 shows the increase in global resource extraction per capita, which has more than doubled compared to 1990.

[744] Cf. GIZ https://www.giz.de/de/html/suchergebnisse.html?query=abfallwirtschaft&send_button_search=Suchen
[745] Federal Environment Agency, (2017).

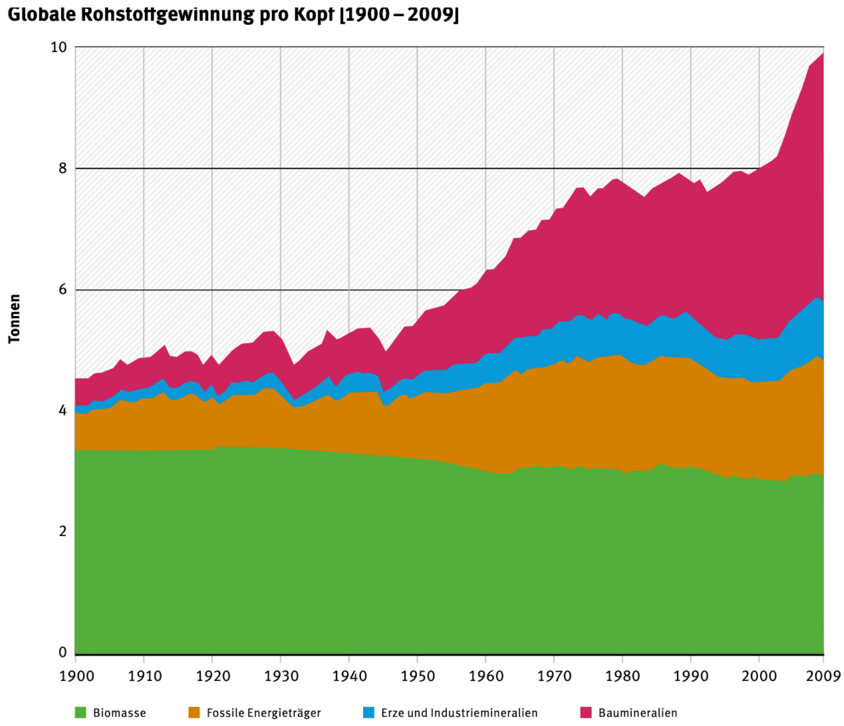


Figure 270: Global raw material extraction per capita between 1900 and 2009.

Source: Federal Environment Agency, (2017).

While the production of biomass per capita has slightly decreased over time, the extraction of ores and tree minerals has massively increased. It should also be taken into account that by far the largest share of these extracted raw materials is used by industrialised nations ($^1/_3$ of raw materials for 15 % of the population). [746]

The use of secondary raw materials not only reduces production costs (in 2007, EUR 8.6 billion worth of copper and steel was produced through recycling, with a saving of EUR 1.5 billion compared to production from primary raw materials), but the reduction in the demand for primary raw materials can also facilitate access to primary raw materials for emerging countries, for example, so that recycling and urban mining make a contribution to global distributive justice. Recycling also saves energy, as can be clearly seen in the example of copper and steel: compared to the primary input, 406 PJ were saved, which corresponds to the annual energy consumption of two large lignite-fired power plants.

The energy savings are also evident in the area of plastics, for example: Compared to primary plastics made from crude oil, for example, the use of high-quality recycled plastics saves more than 50 % greenhouse gas emissions. [747]

The conditions for urban mining are very good, as:

[746] Cf. Federal Environment Agency, 2017, p. 13.
[747] Cf. Prudence, (2021).

- the prospecting effort is significantly lower compared to the classic mining of geological deposits,
- the anthropogenic repositories are usually located much closer to economic centres and in a well-developed environment, so that costs for transport to further processing are lower.
- the valuable material content of anthropogenic deposits is significantly higher than in natural ore deposits. For example, the gold content of an average mobile phone is equivalent to that of 16 kg of gold ore.

Figure 271 shows the use of a household waste landfill as a storage site for iron, copper, aluminium and as an energy source. The quantities indicated were determined during the dismantling of a landfill in Switzerland.

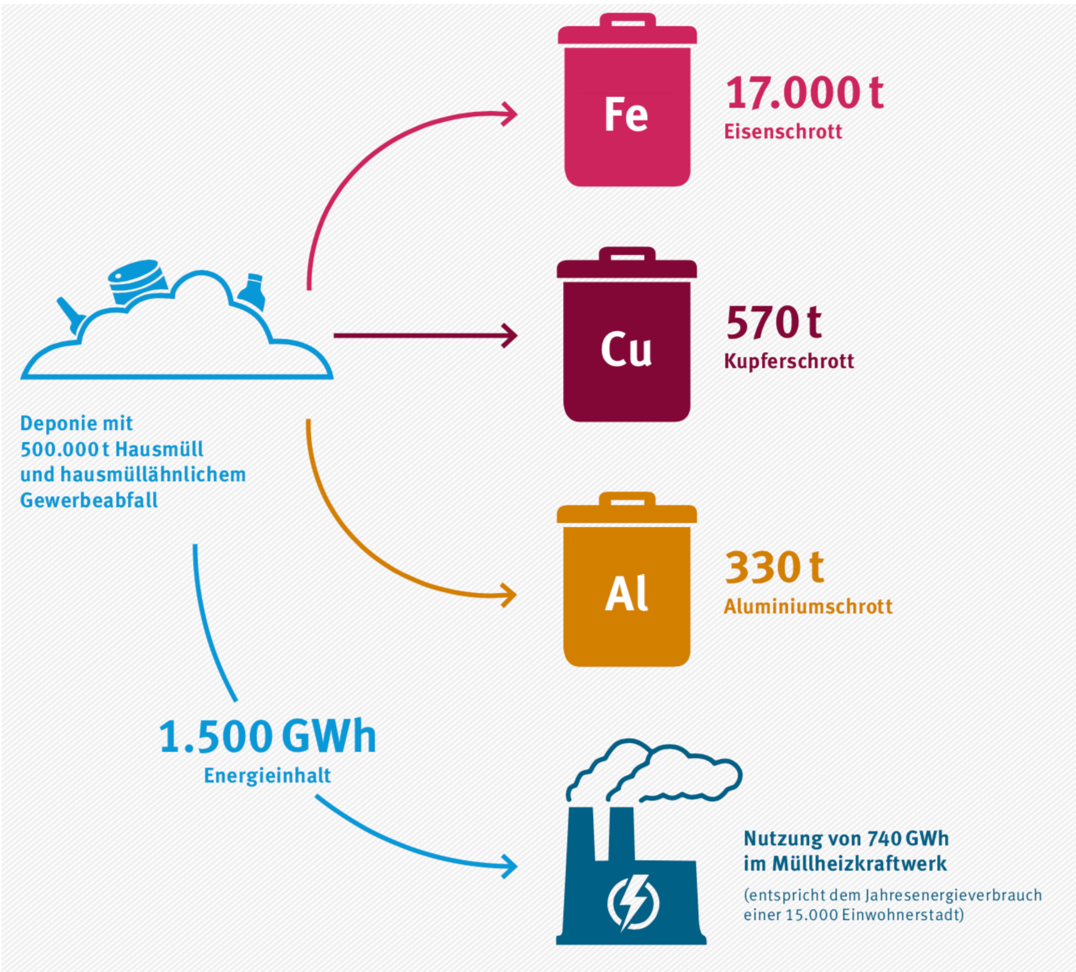


Figure 271: Raw material potential in terms of iron, copper and aluminium yields a landfill with 500 kt of household waste.

Since there were hardly any organised landfills in Germany before 1972, many interesting materials can be found in old landfills. For the landfills from 1975 to 2005, it is assumed that material with a calorific value of EUR 60 billion is stored there and 26 Mt of ferrous scrap, 1.2 Mt of copper scrap and 0.5 Mt of aluminium can be lifted. It is also estimated that 0.65 Mt of phosphorus with a value of EUR 14 billion are stored there.

The dismantling of the collected quality is usually very time-consuming and technologies to automate this are currently being developed. "The content of critical/valuable raw materials in individual products is often not known. This makes recycling expensive and companies prefer to obtain raw materials from primary sources. Therefore, there is often no economic incentive to develop and operate appropriate recycling. In addition, corresponding raw materials are often exported and are thus no longer available to the local recycling industry."[748]

2.13.5.3 Worldwide search for substitutes for REE

The US Department of Energy (DOE) has historically focused significant R&D efforts on various battery chemicals and PV materials. Starting in 2010, the DOE increased its investment in substitutes for magnets, motors and generators, not least because China began reducing REO export quotas in 2005, slashing the reduction by 12% in 2009 and by as much as 40% in 2011.[749] China is also building up strategic stocks of REO.

In the EU, too, the search for substitutes for REEs and other chemical elements that are in danger of becoming scarce has become the subject of R&D policies.

2.13.6 International raw material strategies to secure critical raw materials

In the following, the main features of the commodity strategies of selected countries and alliances of states are summarised in order to give an international overview of the fact that strategic considerations in this regard were already made in part in the previous century and that the basic strategies are similar internationally. Detailed information is compiled below for Germany, the EU, the UK, Japan, China and the USA. The Western and Asian industrial nations are taken into account in the selection. We can only guess at the strategies of China and Russia, which aim to make the rest of the world dependent on their raw materials. We will also provide information on this in this chapter.

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[748] Private communication with A. Buckow/Heraeus.
[749] Cf. DOE, 2011, p. 67.

2.13.6.1 The German Raw Materials Strategy

Germany renewed its raw materials strategy, first drawn up in 2010, in January 2020. Until then, the guiding principle was that companies themselves were primarily responsible for putting their raw material supply on a secure footing. The federal government's main task was to provide political support for measures taken by companies to supply raw materials - both domestic raw materials and imported raw materials. This free-market approach based on free and fair world trade will continue to form the regulatory framework of German raw materials policy.[750] However, too little consideration has been given in the German strategy to the fact that not all countries that supply us with raw materials always want to comply with the customs of world trade to a sufficient degree, that it may well be that suppliers exploit their key position to blackmail the recipient of the supply.

Since not all states have pursued and are pursuing the free trade approach, it must be the task of policy-makers to create a "level playing field" in the supply of raw materials, i.e. to establish a level playing field and rules of competition and "in doing so, also to reconsider the role of the state where appropriate",[751] whatever exactly is meant by this.

"The aim is to initiate measures to support companies in a secure, responsible supply of raw materials that is committed to sustainability, to strengthen the competitiveness of German industry, to keep the use of primary raw materials as low as possible through efficient handling of raw materials and thus to increase the social benefits for citizens."[50]

The German government sees its raw materials strategy in the context of the National Industrial Strategy, the goals of the Paris Climate Agreement, the Climate Protection Plan 2050 and the Climate Protection Programme 2030 as well as the global goals of the 2030 Agenda for Sustainable Development (SDGs).

As a new challenge in the procurement of raw materials, the Federal Government has grasped that as a result of technological developments such as energy storage, the demand for raw materials, in this case lithium, cobalt, nickel, is changing extremely. Due to the small shares of Germany and Europe in raw material extraction and processing, the dependence on raw materials endangers the competitiveness of this zone.[752]

In organisational terms, the Federal Institute for Geosciences and Natural Resources (BGR) in the BMWK (Federal Ministry for Economic Affairs and Climate) with the DERA (German

[750] Cf. BMWi, (2019).
[751] BMWi, 2019, p. 3.
[752] Cf. Federal Government, (2020).

Mineral Resources Agency) department in the Berlin field office is responsible for the measures of the Raw Materials Strategy.[753]

In the new edition of the Raw Materials Strategy, the Federal Government has adopted 17 concrete measures,[754] ranging from the promotion of recycling and the use of secondary raw materials, support for the federal states in the transformation of mining regions to the continuation of the Untied Financial Credits (UFK) ,[755] with which projects of German companies for the exploration and extraction of raw materials are secured against political and economic default risks. Furthermore, measures to secure domestic raw materials and those in developing and emerging countries, as well as the securing and disclosure of geological data, monitoring of raw materials are promoted. The goals of the strategy are to promote the circular economy, recovery and reuse through concrete R&D projects.

A study on the effectiveness of the measures is available.[756]

Within the framework of a round table with representatives of business, science and administration, the use of secondary raw materials obtained from waste and recycling is to be promoted. Raw material and resource efficiency can be promoted through a BMWi technology transfer programme for lightweight construction.

Of course, the implementation of the German measures is carried out in cooperation with the EU Commission on the sustainable supply of raw materials.

Specifically in Baden-Württemberg, the goals of the state strategy were:

- Decoupling economic growth from resource consumption (see Figure 272, orange and blue curve) while maintaining and expanding the manufacturing sector
- Doubling of raw material productivity by 2020 (see Figure 272, orange curve)[757]
- The secure supply of raw materials to the economy through more efficient extraction of primary raw materials and increasing the share of secondary raw materials.

[753] Cf. DERA, (2022).
[754] Cf. Federal Government, (2020).
[755] Cf. BMWK, n.d.
[756] Cf. DERA, (2022).
[757] "Raw material productivity expresses how much economic output (represented as GDP) is "produced" by the use of one unit of raw materials. The extraction and use of a raw material is always accompanied by land, material and energy consumption, material displacement and pollutant emissions. Within the framework of the national sustainability strategy, the German government's goal is to roughly double raw material productivity by 2020 compared to 1994. Behind this is the goal of achieving economic growth with such a low environmental impact that the natural balance is not overburdened" (LAU Sachsen-Anhalt, 2015).

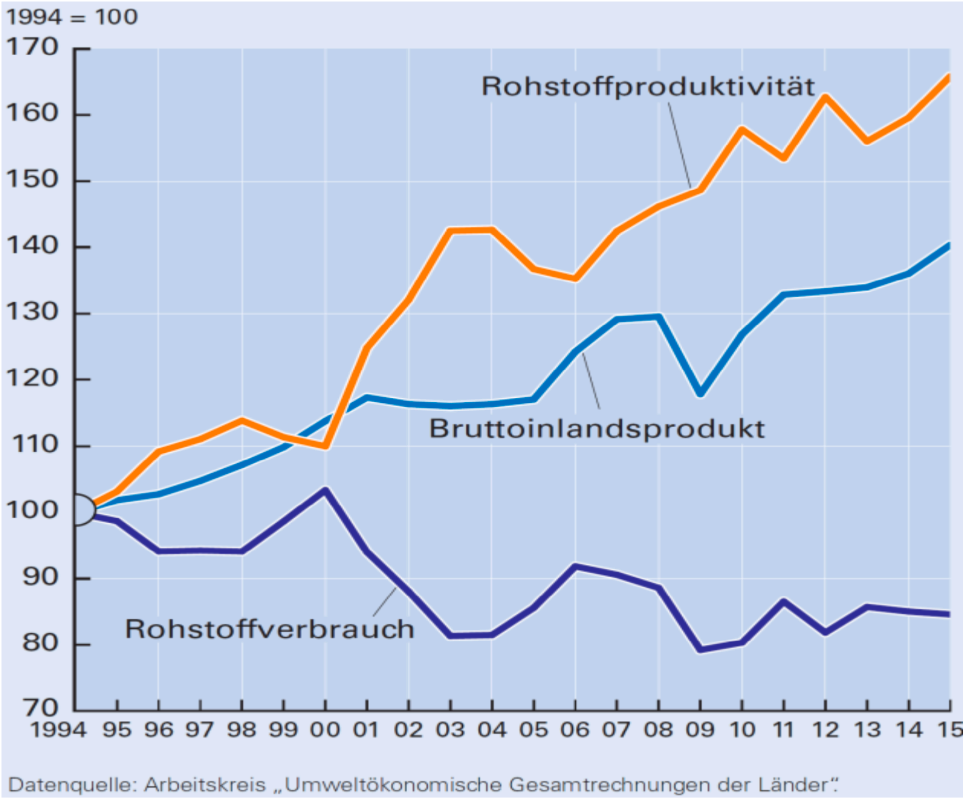

Figure 272: Raw material consumption, gross domestic product (GDP) and raw material productivity in Baden-Württemberg.

Source: Steinmüller, (2020).

In Figure 273 the weighted country risks (GLR, see list of abbreviations) for metals and industrial minerals are plotted against the country concentrations (HHI, see list of abbreviations) for Germany. The area highlighted in red contains raw materials for which there are only a few suppliers and which are imported from countries for which the World Bank has determined a higher risk and worse governance indices. An example is cobalt, for which there are only a few suppliers and which are extracted in countries such as Congo (DRC) with unstable political conditions and poor governance.

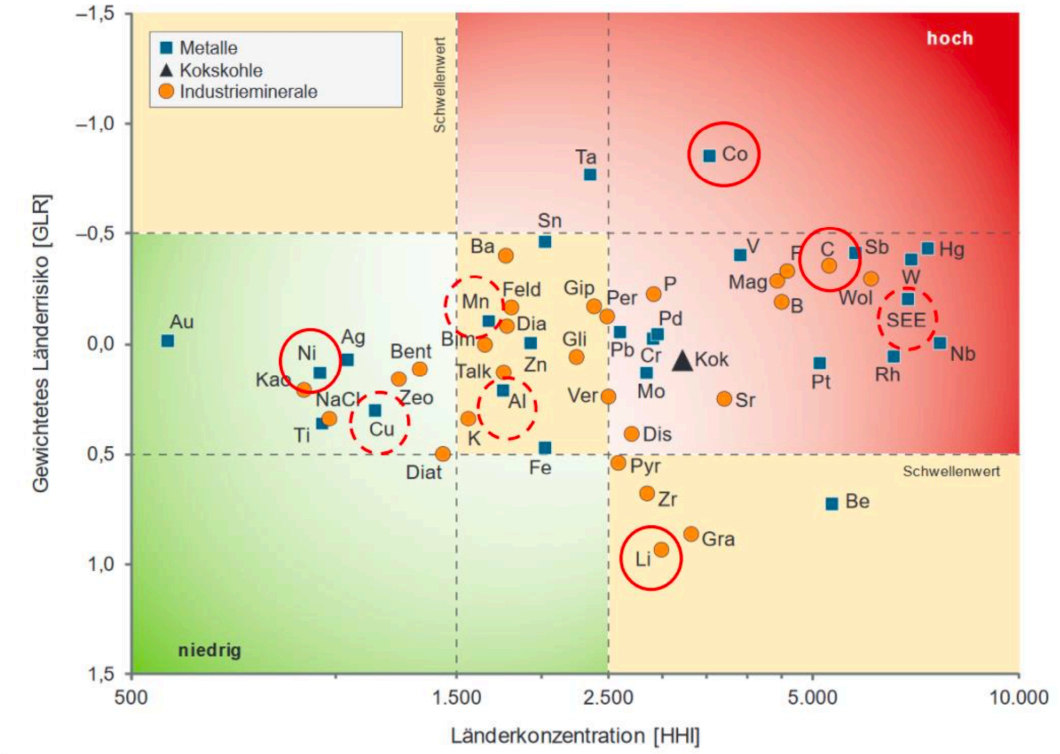

Figure 273: The critical raw materials for Germany (battery raw materials are circled in red).

Source: Steinmüller, (2020).

2.13.6.2 The European Raw Materials Strategy

In 2020, the European Commission recognised that no country can afford to trade dependence on fossil fuels for dependence on critical materials. Their definition of what critical raw materials are has already been described at the beginning of chapter 2.13.1. Their assessment of what the critical raw materials are differs from the German assessment in Figure 273.

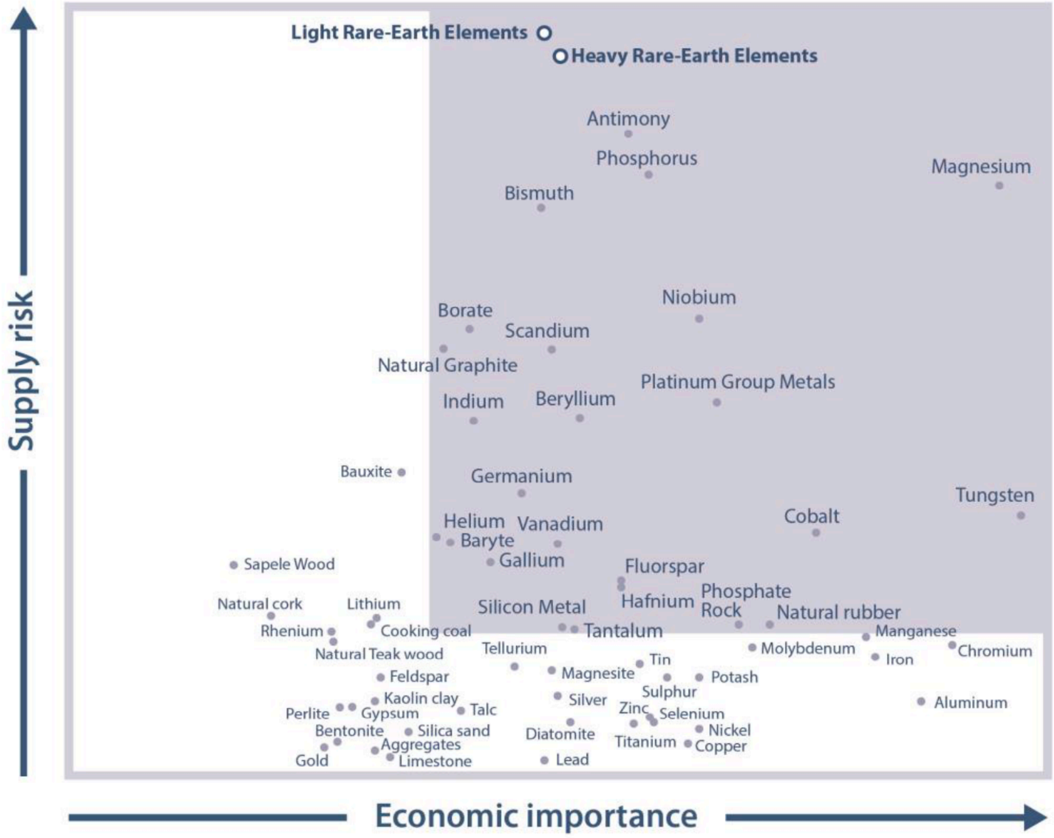

Figure 274: Critical raw materials (light blue rectangle) for the EU in 2017.

Source: Steinmüller, (2020).

In its strategy, the EU relies on three pillars:[758]

- Commodity diplomacy through strategic partnerships and talks to secure access to raw materials.
- Promoting sustainable supply in the EU:
    - Establish a national minerals policy to ensure economically viable resource extraction.
    - Establish a spatial planning policy for raw materials with the creation of a geological database, a transparent method for the exploration of mineral raw materials, estimation of long-term consumption, exploration and securing of mineral raw material deposits.
    - Establish a comprehensible procedure for authorising the exploration and extraction of mineral resources.

[758] Cf. European Commission, 2011.

- Increasing resource efficiency and promoting recycling. In particular, the "recovery of useful substances from municipal waste" (urban mining), represents one of the most important sources of metallic and mineral raw materials for European industry. The use of secondary raw materials contributes to resource efficiency, the reduction of greenhouse gas emissions and environmental protection. However, the potential of many of these resources is not fully exploited. For example, there are considerable differences between Member States, even though the levels of municipal waste recycling in the EU have doubled over the last decade. Given the need to curb CO_2 emissions, protect human health and reduce import dependency, there is a need to look more closely at what is hindering waste recycling." [759]

The Commission plans to do this:

- Revision of the strategy for waste prevention and recycling.
- Promote research and pilot measures on resource efficiency, create economic incentives for the establishment of recycling and deposit systems.

Revision of the 2012 Action Plan for Sustainable Consumption and Production.

2.13.6.3 The US commodity strategy

The United States is the second largest consumer of metallic raw materials for its industrial production after China. Although the US has ample mineral resources, it is completely dependent on imports for many raw materials and the government had already considered and implemented the quality and quantity of minerals to be stockpiled in 1939 as part of a programme to ensure national defence preparedness. The programme was driven by the hope that this 'National Defence Stockpile' would deter aggressors from attempting to cut off the US from supplies to cripple the defence industry. The high cost of stockpiling has been the subject of debate about its purpose and scope several times in history. For example, the supply problems during the Korean War gave rise to the 'Defence Production Act', which provided for the subsidisation of domestic mines and smelters for the production of aluminium, copper, tungsten. However, after the end of the Cold War, the DOD decided to liquidate the National Defense Stockpile. The sale, which includes the divestment of rare earth minerals, continues to this day.[760]

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[759] European Commission, 2011.
[760] Cf. HCSS & TNO, 2010, p. 22.

The USA was always concerned that unrest in, for example, South Africa could jeopardise their country's supply of platinum in this example. In fact, political conflicts in Zaire (now DR Congo) of 1978 and 1979 expressed themselves in a high decline in cobalt production, which led to shortages in the USA. As a great power, the USA also tended to intervene militarily in political conflicts or trouble spots in order to secure the supply of critical and/or strategic raw materials.

In US policy, the terms 'critical minerals' and 'strategic minerals' are not clearly distinguishable. Their definition identifies, as it were, military and civil uses for which disruption of supply by US and selected non-US companies would be unacceptable and for which there is no economically viable substitute.[761]

In the USA, the DOD and DOE reports in the 1970s and 1980s included Al, Cr, Co, Mn, Ni and the PGM (platinum group metal) elements as particularly critical metals. The NRC developed a method to determine the criticality of non-fuel minerals. Table 59 illustrates the change in assessment in determining criticality.

The importance of REE for the production of e.g. magnets was known in 2010, but the criticality was not yet classified as high at that time. The availability of beryllium for the production of sensors, rockets, satellites, aircraft and nuclear weapons was considered more important at the time.

In 2010, a vote was underway in the US Congress to classify REEs as substances that are strategic or critical to national security. The incident in which a Chinese ship collided with a Japanese one and China reduced the export of REEs to Japan was decisive for the "Rare Earths and Critical Revitalization Act" of 2010, in which, among other things, the establishment of an information centre was resolved, in which reports on REEs were to be prepared for Congress. Other acts also initiated, for example, investigations into which military systems depend on REE and support for US production of magnets.

To improve the US' ability to monitor and respond to developments in the strategic materials market, the SMSP (Strategic Material Security Program) was established. The US government aimed to restart REE production in the Mountain Pass Min (Southern California) in 2012, where the gneiss rock contains about 8 % - 12 % rare earths (Ce, La, Nd and Eu).

In 2017, the US government requested the Department of Commerce to develop a national strategy to ensure secure and reliable supplies of critical metals ("A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals"), which expanded on the measures of the

[761] Cf. HCSS & TNO, 2010, p. 23.

"Critical Materials Strategy" of 2010/2011. The list of critical minerals from 2018 can be found in the appendix on p.452 asA-2 List of US Critical Minerals

Table 62: List of critical minerals of US industries.

Source: Steinmüller, (2020).

Table 59: Strategic and critical minerals in DOD reports recommended for inclusion in the National Defense Stockpile in various years.

Source: HCSS & TNO, 2010, P. 25.

1970s-80s Strategic Minerals (W.C.J. van Rensburg)	2008 Critical Minerals (National Research Council)	2010 DOD Recommended Materials for National Defense Stockpile (Report to Congress)
Aluminium	Platinum Group Metals	Beryllium Metal
Chromium	Rare Earth Elements	Chromium Metal
Cobalt	Indium	Cobalt
Manganese	Manganese	Columbium (Niobium)
Nickel	Niobium	Ferro Chromium
Platinum Group Metals		Ferro Manganese
Titanium		Germanium
		Iridium
		Platinum
		Tantalum
		Tin
		Tungsten
		Zinc

2.13.6.4 The UK Commodity Strategy

As the UK's position as a major exporter of minerals began to falter - the UK had been a leading exporter of iron, tin, copper and lead until the mid-19th century - and shortages of some raw materials were felt during the First and Second World Wars, the government decided to reduce the export of critical raw materials, improve the recycling of metals and support domestic industry. The British Geological Survey (BGS) recognised during the Cold War that the availability of metals and minerals was critical and therefore supplier relationships were diversified and stockpiles were built and maintained. The UK, like the US, maintained stockpiles of materials it considered strategic: tungsten (for ballistic missiles) and chromium, manganese and vanadium.

In 1975, the government established the Minerals Reconnaissance Program (MRP) to promote the exploration and processing of minerals in the UK. The MRP was also tasked with providing the government with information on the global supply situation of minerals.

Table 60: List of materials classified as critical in the UK.

Source: HCSS & TNO, 2010, P. 43.

Industrial Minerals	Construction Minerals	Material Risk Materials
Kaolin	Aggregates	Zirconium
Ball clay	Brick clay	Indium
Limestone	Cement making materials	Lithium
Silica sand	Gypsum	Potash
Potash	Sand	Molybdenum
Salt	Gravel	Borate
Fluorspar barites	Slate	Iron
Sulphur		Feldspar
Bentonite		
Magnesia		

At the end of the Cold War, the MRP was no longer considered up to date, as globalisation meant that it was safe to assume that the supply of everything could be secured even in the event of local unrest or war. Today we know that this assessment was incorrect.

Even though the UK produced a large proportion of building materials domestically, it was not self-sufficient. The UK therefore had a vested interest in keeping its mining sector functioning. The industry, represented by the Confederation of British Industry (CBI), is facing increased obstacles in the search for and exploitation of new deposits due to environmental and mineral legislation, which was heavily influenced by EU legislation before Brexit.

The UK does not have a comprehensive strategy for dealing with raw materials/minerals. The government and administration have their own programmes that revolve around the expansion of domestic resources and industries and otherwise document a belief that the need for raw materials can be met by the global market.

2.13.6.5 The Japanese commodity strategy

Japan's commodity strategy is based on four main pillars:

- Diversify sourcing by developing alternative sources of raw materials in resource-rich regions or on Japan's seabed and maintain good relations with its neighbours
- Reuse of indigenous minerals through the "urban mining" approach
- Development of alternative materials through strong research and development efforts
- Stockpiling of strategically important materials

The Ministry of Economy, Trade and Industry (METI) established the Metal Mining Agency of Japan (MMAJ) in 1963 to secure the supply of non-ferrous metals and minerals. The oil crisis in the 1970s highlighted Japan's vulnerability as an importer of fuels and non-fuels. Japan is itself a resource-poor country with an expansive industry that is entirely dependent on foreign suppliers. Although Japan was a leading exporter of indium until 2010, there is no domestic production capacity today.

Another government organisation, the Japan Oil, Gas and Metal National Corporation (JOG-MEC), also keeps stocks of materials classified as critical: Ni, Cr, W, Co, Mo[42], Mn[25] , V[23]. Here, JOGMEC describes critical materials simply as those "essential to modern life and industry".[762]

2.13.6.6 The Chinese raw materials strategy

There are no citable documents on China's commodity strategy. We can only observe its consequences and comment on them here. "The People's Republic has secured access to most metals and mineral raw materials through decades of strategic groundwork. If German cars are to roll off the production line as planned, they need preliminary products made in China."[763] China has built up a very strong position in the raw materials market. The list of the German Raw Materials Agency shows that the People's Republic is the largest mining country for 22 of 53 raw materials and ranks among the top three for many other raw materials. This is a considerable share, it is almost half of the world's mine production. In addition, China is the largest producer of 25 out of 27 refined products - that is, products that result from the processing and refining of the basic materials extracted in the mine. "The People's Republic has secured access to most metals and mineral raw materials through decades of strategic groundwork".[764]

The situation was similar for silicon, which is eminently important for chips that are built into everything from washing machines and kitchen appliances to cars and mobile phones. Here, too, China ranks well ahead of the USA (14.8%) and Brazil (6.5%) with a production share of almost 62%. In autumn 2021, the price quadrupled within only two months because the provincial government of Yunnan only allowed ten percent of the previously usual quantities to be produced. The reason: energy-saving targets.

And Beijing is strategically building on this advantage. At the beginning of the year, the government merged three of six previously independent rare earth companies into one conglomerate, the state-owned China Rare Earth Group Ltd. From the beginning, it was the global

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[762] Translation from HCSS & TNO, 2010.
[763] Jakobs, (2022). The texts for chapter 2.6. are excerpts from this article.
[764] Jakobs, (2022).

champion with a 62 % share of the world market. Such a monopolist has the best chance of exploiting its own pricing power. A new rare earth giant is developing here.

After all, it is not only about rare earths, but also about magnesium, for example, which is important for the chemical industry, for aluminium and ceramics. 86 % of US imports of this substance come from the Middle Kingdom. And so it goes on: via gallium (82 %), bismuth (81 %), tungsten (81 %) and arsenic (69 %) to manganese (26 %).

How big the raw materials hoarded in the country are is one of the secrets of the empire. Beijing does not respond to requests to store critical raw materials abroad. Mining and raw materials - that is a matter for the boss in China, is the message.

In 2020, the COVID-19 pandemic led to a global economic downturn and a decline in demand. Together with the trade war between China and the United States and US trade restrictions against Huawei and other Chinese companies, this forced the Chinese government to focus domestically. The result was domestic-international parallel circulation as a strategy to rebalance the Chinese economy, prioritising domestic consumption ("internal circulation") while leaving the economy open to international trade and investment. The first academic study on parallel circulation defined it as "the economic rebalancing driven by domestic consumption to achieve sustainable economic development".

The intellectual precursor of parallel circulation was the "great international circulation", a strategy of economic growth through export-oriented production formulated in the era of Chinese leader Deng Xiaoping.

Analysts said the strategy would involve supporting domestic companies and reducing China's dependence on imports, including for energy, microchips and other technologies. Economists said that an important part of the project should be to ensure China's food and energy security and that the new policy should be seen as a response to deteriorating relations between China and the United States, China must prepare for the worst case scenario.[765]

The Economist summarised the strategy as "keeping China open to the world (the 'great international circuit') while strengthening its own market (the 'great domestic circuit')". More precisely, according to The Economist, dual circulation is about opening up the Chinese economy to foreign companies in order to make them dependent on China, which in turn would give the Chinese government more geopolitical influence.

[765] Cf. Wikipedia, n.d. a

2.13.6.7 The Russian raw materials strategy

"The geo-economic power strategies of allies Russia and China are permanently changing the commodity markets and the global economy. Autocrats like Russia's warlord Putin and China's state and party leader Xi Jinping are distancing themselves from the democratic West and shredding the noble principles of free trade. British economist David Ricardo's theories apply to open markets - but not to economic blocs that want to fight mercantile wars."[766]

2.13.7 Summary

- Germany, the EU, China and the USA promote the development and production of critical, metallic raw materials domestically.
- China and Japan maintain stockpiling systems for critical, industry-relevant raw materials. The USA has a stockpiling system only for the military sector.
- China and Japan are driving the development of and participation in extractive projects abroad with national companies and massive financial support (loans, guarantees).
- Germany supports its industry in foreign activities in the raw materials sector with instruments of foreign trade promotion such as loans and guarantees. Government measures of the first raw materials strategy, such as exploration funding and strategic raw materials partnerships with various countries, have failed or have not achieved the desired results.
- All countries strongly support the recycling and reuse of metallic raw materials and are working towards a circular economy.
- Germany, the EU, China and Japan aim at a strong integration of environmental and social aspects in national and international raw material extraction and at strengthening sustainability in supply and value chains.
- Germany, the EU and the USA in particular are working to ensure that trade in commodities remains open worldwide and that transparency in trade is improved.
- Germany, the EU, Japan and the USA are conducting research projects concerning the exploration, mining, preparation and further processing of critical raw materials.
- Germany, the EU and the USA favour the free market and trade and do not (currently) promote any central state control elements.
  Germany and the EU are promoting sustainability in commodity extraction and supply

[766] Jakobs, (2022).

chain management in the commodity sector worldwide with their commodity strategies. China has been working hard for several years to improve the sustainability of its extractive industries abroad and their supply chains.

- China and Japan are massively supporting their mostly vertically integrated industries with government measures in foreign activities in the raw materials sector.

Appendix to 2.13

A-1 List of EU critical raw materials in 2020[767]

Table 61: List of EU critical raw materials in 2020 .

Rohstoffe	Phase	Weltweit größte Erzeuger	Wichtigste Lieferländer[33] der EU	Importabhängigkeit[34]	EoL-RIR[35]	Ausgewählte Verwendungen
Antimon	Förderung	China (74 %) Tadschikistan (8 %) Russland (4 %)	Türkei (62 %) Bolivien (20 %) Guatemala (7 %)	100 %	28 %	• Flammschutzmittel • Verteidigungsanwendungen • Bleibatterien
Baryt	Förderung	China (38 %) Indien (12 %) Marokko (10 %)	China (38 %) Marokko (28 %) Andere EU-Länder (15 %) Deutschland (10 %) Norwegen (1 %)	70 %	1 %	• Medizinische Anwendungen • Strahlenschutz • Chemische Anwendungen
Bauxit	Förderung	Australien (28 %) China (20 %) Brasilien (13 %)	Guinea (64 %) Griechenland (12 %) Brasilien (10 %) Frankreich (1 %)	87 %	0 %	• Aluminiumproduktion
Beryllium	Förderung	Vereinigte Staaten (88 %) China (8 %) Madagaskar (2 %)	k. A.	k. A.36	0 %	• Elektronische und Kommunikationsgeräte • Komponenten für die Auto-, Luft- und Raumfahrt- sowie die Verteidigungsindustrie
Wismut	Verarbeitung	China (85 %) DVR Laos (7 %) Mexiko (4 %)	China (93 %)	100 %	0 %	• Pharmazeutische und Futtermittelindustrie • Medizinische Anwendungen • Legierungen mit niedrigem Schmelzpunkt
Borat	Förderung	Türkei (42 %) Vereinigte Staaten (24 %) Chile (11 %)	Türkei (98%)	100 %	1 %	• Hochleistungsglas • Düngemittel • Permanentmagnete
Kobalt	Förderung	Kongo, DR (59 %) China (7 %) Kanada (5 %)	Kongo, DR (68%) Finnland (14 %) Französisch-Guyana (5 %)	86 %	22 %	• Batterien • Superlegierungen • Katalysatoren • Magnete

[33] Auf der Grundlage von inländischer Produktion und Einfuhren (ohne Ausfuhr)
[34] IA = (Einfuhr – Ausfuhr) / (Inlandsproduktion + Einfuhr – Ausfuhr)
[35] Die End-of-Life-Recycling-Einsatzquote (EoL-RIR) ist der Prozentsatz der Gesamtnachfrage, der durch Sekundärrohstoffe gedeckt werden kann.
[36] Die Importabhängigkeit der EU kann für Beryllium nicht berechnet werden, weil in der EU weder die Produktion noch der Handel mit Berylliumerzen und -konzentraten stattfinden.

[767] Cf. European Commission, 2020, pp. 20-24.

Rohstoffe	Phase	Weltweit größte Erzeuger	Wichtigste Lieferländer[33] der EU	Importabhängigkeit[34]	EoL-RIR[35]	Ausgewählte Verwendungen
Kokskohle	Förderung	China (55 %) Australien (16 %) Russland (7 %)	Australien (24 %) Polen (23 %) Vereinigte Staaten (21 %) Tschechien (8 %) Deutschland (8 %)	62 %	0 %	• Koks für die Stahlerzeugung • Kohlenstofffasern • Batterieelektroden
Flussspat	Förderung	China (65 %) Mexiko (15 %) Mongolei (5 %)	Mexiko (25 %) Spanien (14 %) Südafrika (12 %) Bulgarien (10 %) Deutschland (6 %)	66 %	1 %	• Stahl- und Eisenerzeugung • Kälte- und Klimaanlagen • Aluminiumproduktion und andere Metallurgie
Gallium	Verarbeitung	China (80 %) Deutschland (8 %) Ukraine (5 %)	Deutschland (35 %) VK (28 %) China (27 %) Ungarn (2 %)	31 %	0 %	• Halbleiter • Photovoltaische Zellen
Germanium	Verarbeitung	China (80 %) Finnland (10 %) Russland (5 %)	Finnland (51 %) China (17 %) VK (11 %)	31 %	2 %	• Optische Fasern und Infrarotoptik • Satelliten-Solarzellen • Polymerisationskatalysatoren
Hafnium	Verarbeitung	Frankreich (49 %) Vereinigte Staaten (44 %) Russland (3 %)	Frankreich (84 %) Vereinigte Staaten (5 %) VK (4 %)	0 %[37]	0 %	• Superlegierungen • Steuerstäbe • Feuerfeste Keramik
Indium	Verarbeitung	China (48 %) Korea, Rep. (21 %) Japan (8 %)	Frankreich (28 %) Belgien (23 %) VK (12 %) Deutschland (10 %) Italien (5 %)	0 %	0 %	• Flachbildschirme • Fotovoltaikzellen und Photonik • Lötmetalle
Lithium	Verarbeitung	Chile (44 %) China (39 %) Argentinien (13 %)	Chile (78 %) Vereinigte Staaten (8 %) Russland (4 %)	100 %	0 %	• Batterien • Glas und Keramik • Stahl- und Aluminiummetallurgie
Magnesium	Verarbeitung	China (89 %) Vereinigte Staaten (4 %)	China (93 %)	100 %	13 %	• Leichte Legierungen für die Auto-, Elektronik-, Verpackungs-oder Bauindustrie • Entschwefelungsmittel in der Stahlerzeugung

[37] Die EU ist Nettoexporteur von Hafnium und Indium

Rohstoffe	Phase	Weltweit größte Erzeuger	Wichtigste Lieferländer[33] der EU	Importabhängigkeit[34]	EoL-RIR[35]	Ausgewählte Verwendungen
Natürlicher Grafit	Förderung	China (69 %) Indien (12 %) Brasilien (8 %)	China (47 %) Brasilien (12 %) Norwegen (8 %) Rumänien (2 %)	98 %	3 %	• Batterien • Feuerfestmaterialien für die Stahlerzeugung
Naturkautschuk	Förderung	Thailand (33 %) Indonesien (24 %) Vietnam (7 %)	Indonesien (31 %) Thailand (18 %) Malaysia (16 %)	100 %	1 %	• Bereifung • Gummiteile für Maschinen und Haushaltswaren
Niob	Verarbeitung	Brasilien (92 %) Kanada (8 %)	Brasilien (85 %) Kanada (13 %)	100 %	0 %	• Hochfester Stahl und Superlegierungen für Transport und Infrastruktur • High-Tech-Anwendungen (Kondensatoren, supraleitende Magnete usw.)
Phosphorit	Förderung	China (48 %) Marokko (11 %) Vereinigte Staaten (10 %)	Marokko (24 %) Russland (20 %) Finnland (16 %)	84 %	17 %	• Mineraldünger • Phosphorverbindungen
Phosphor	Verarbeitung	China (74 %) Kasachstan (9 %) Vietnam (9 %)	Kasachstan (71 %) Vietnam (18 %) China (9 %)	100 %	0 %	• Chemische Anwendungen • Verteidigungsanwendungen
Scandium	Verarbeitung	China (66 %) Russland (26 %) Ukraine (7 %)	VK (98 %) Russland (1 %)	100 %	0 %	• Festoxid-Brennstoffzellen • Leichte Legierungen
Siliciummetall	Verarbeitung	China (66 %) Vereinigte Staaten (8 %) Norwegen (6 %) Frankreich (4 %)	Norwegen (30 %) Frankreich (20 %) China (11 %) Deutschland (6 %) Spanien (6 %)	63 %	0 %	• Halbleiter • Fotovoltaik • Elektronische Bauteile • Silikone
Strontium	Förderung	Spanien (31 %) Iran, Islamische Rep. (30 %) China (19 %)	Spanien (100 %)	0 %	0 %	• Keramikmagnete • Aluminiumlegierungen • Medizinische Anwendungen • Pyrotechnik

Rohstoffe	Phase	Weltweit größte Erzeuger	Wichtigste Lieferländer[33] der EU	Importabhängigkeit[34]	EoL-RIR[35]	Ausgewählte Verwendungen
Tantal	Förderung	Kongo, DR (33 %) Ruanda (28 %) Brasilien (9 %)	Kongo, DR (36 %) Ruanda (30 %) Brasilien (13 %)	99 %	0 %	• Kondensatoren für elektronische Geräte • Superlegierungen
Titan[38]	Verarbeitung	China (45 %) Russland (22 %) Japan (22 %)	k. A.	100 %	19 %	• Leichte hochfeste Legierungen, z. B. für Luft- und Raumfahrt und Verteidigung • Medizinische Anwendungen
Wolfram[39]	Verarbeitung	China (69 %) Vietnam (7 %) Vereinigte Staaten (6 %) Österreich (1 %) Deutschland (1 %)	k. A.	k. A.	42 %	• Legierungen z. B. für Luft- und Raumfahrt, Verteidigung, Elektrotechnik • Fräs-, Schneid- und Bergbauwerkzeuge
Vanadium[40]	Verarbeitung	China (55 %) Südafrika (22 %) Russland (19 %)	k. A.	k. A.	2 %	• Hochfeste Niedriglegierungen, z. B. für Luft- und Raumfahrt, Kernreaktoren • Chemische Katalysatoren
Metalle der Platingruppe[41]	Verarbeitung	Südafrika (84 %) - Iridium, Platin, Rhodium, Ruthenium Russland (40 %) - Palladium	k. A.	100 %	21 %	• Chemische Katalysatoren und Katalysatoren für die Autoindustrie • Brennstoffzellen • Elektronische Anwendungen
Schwere seltene Erden[42]	Verarbeitung	China (86 %) Australien (6 %) Vereinigte Staaten (2 %)	China (98 %) Andere Nicht-EU-Länder (1 %) VK (1 %)	100 %	8 %	• Permanentmagnete für Elektromotoren und Stromgeneratoren • Leuchtphosphore • Katalysatoren

[38] Für Titan-Metallschwamm gibt es keine Handelscodes für die EU
[39] Die Verteilung der Wolframschmelzen und -raffinerien wurde stellvertretend für die Produktionskonzentration verwendet. Handelsdaten sind aus Gründen des Geschäftsgeheimnisses nicht vollständig verfügbar.
[40] Die Importabhängigkeit der EU kann für Vanadium nicht berechnet werden, weil in der EU weder die Produktion noch der Handel mit Vanadiumerzen und -konzentraten stattfinden.
[41] Die Handelsdaten umfassen Metall aus allen Quellen, sowohl aus primären als auch aus sekundären Quellen. Die Quelle und die relativen Beiträge von Primär- und Sekundärmaterialien konnten nicht ermittelt werden.
[42] Die weltweite Produktion bezieht sich auf Konzentrate von Seltenerdoxiden sowohl für leichte als auch für schwere seltene Erden.

Rohstoffe	Phase	Weltweit größte Erzeuger	Wichtigste Lieferländer[33] der EU	Importabhängigkeit[34]	EoL-RIR[35]	Ausgewählte Verwendungen
Leichte seltene Erden	Verarbeitung	China (86 %) Australien (6 %) Vereinigte Staaten (2 %)	China (99 %) VK (1 %)	100 %	3 %	• Batterien • Glas und Keramik

A-2 List of US Critical Minerals

Table 62: List of critical minerals of US industries.

Source: Steinmüller, (2020).

Mineral commodity	Sectors: Aerospace (non-defense)	Defense	Energy	Telecommunications & electronics	Transportation (non-aerospace)	Other	Top Producer	Top Supplier	Notable example application
Aluminum	■	■	■	■	■	■	China	Canada	Aircraft, power transmission lines, lightweight alloys
Antimony		■	■	■	■	■	China	China	Lead-acid batteries
Arsenic		■	■	■		■	China	China	Microwave communications (gallium arsenide)
Barite			■	■		■	China	China	Oil and gas drilling fluid
Beryllium	■	■	■	■		■	United States	Kazakhstan	Satellite communications, beryllium metal for aerospace
Bismuth		■	■	■		■	China	China	Pharmaceuticals, lead-free solders
Cesium and rubidium	■	■	■	■		■	Canada	Canada	Medical applications, global positioning satellites, night-vision devices
Chromium	■	■	■	■	■	■	South Africa	South Africa	Jet engines (superalloys), stainless steels
Cobalt	■	■	■	■	■	■	Congo (Kinshasa)	Norway	Jet engines (superalloys), rechargeable batteries
Fluorspar			■	■		■	China	Mexico	Aluminum and steel production, uranium processing
Gallium	■	■	■	■		■	China	China	Radar, light-emitting diodes (LEDs), cellular phones
Germanium	■	■	■	■		■	China	China	Infrared devices, fiber optics
Graphite (natural)	■	■	■	■	■	■	China	China	Rechargeable batteries, body armor
Helium				■		■	United States	Qatar	Cryogenic [magnetic resonance imaging (MRI)]
Indium	■	■	■	■		■	China	Canada	Flat-panel displays (indium-tin-oxide), specialty alloys
Lithium	■	■	■	■	■	■	Australia	Chile	Rechargeable batteries, aluminum-lithium alloys for aerospace
Magnesium	■	■	■	■	■	■	China	China	Incendiary countermeasures for aerospace
Manganese	■	■	■	■	■	■	China	South Africa	Aluminum and steel production, lightweight alloys
Niobium	■	■	■	■		■	Brazil	Brazil	High-strength steel for defense and infrastructure
Platinum group metals	■		■	■	■	■	South Africa	South Africa	Catalysts, superalloys for jet engines
Potash			■	■		■	Canada	Canada	Agricultural fertilizer
Rare earth elements	■	■	■	■	■	■	China	China	Aerospace guidance, lasers, fiber optics
Rhenium	■		■	■		■	Chile	Chile	Jet engines (superalloys), catalysts
Scandium	■	■	■	■		■	China	China	Lightweight alloys, fuel cells
Strontium	■	■	■	■	■	■	Spain	Mexico	Aluminum alloys, permanent magnets, flares
Tantalum	■	■	■	■		■	Rwanda	China	Capacitors in cellular phones, jet engines (superalloys)
Tellurium		■	■	■		■	China	Canada	Infrared devices (night-vision), solar cells
Tin		■		■		■	China	Peru	Solder, flat-panel displays (indium-tin-oxide)
Titanium	■	■	■	■		■	China	South Africa	Jet engines (superalloys) and airframes (titanium alloys), armor
Tungsten	■	■	■	■		■	China	China	Cutting and drilling tools, catalysts, jet engines (superalloys)
Uranium	■	■	■			■	Kazakhstan	Canada	Nuclear applications, medical applications
Vanadium	■	■	■	■		■	China	South Africa	Jet engines (superalloys) and airframes (titanium alloys), high-strength steel
Zirconium and hafnium	■	■	■	■		■	Australia	China	Thermal barrier coating in jet engines, nuclear applications

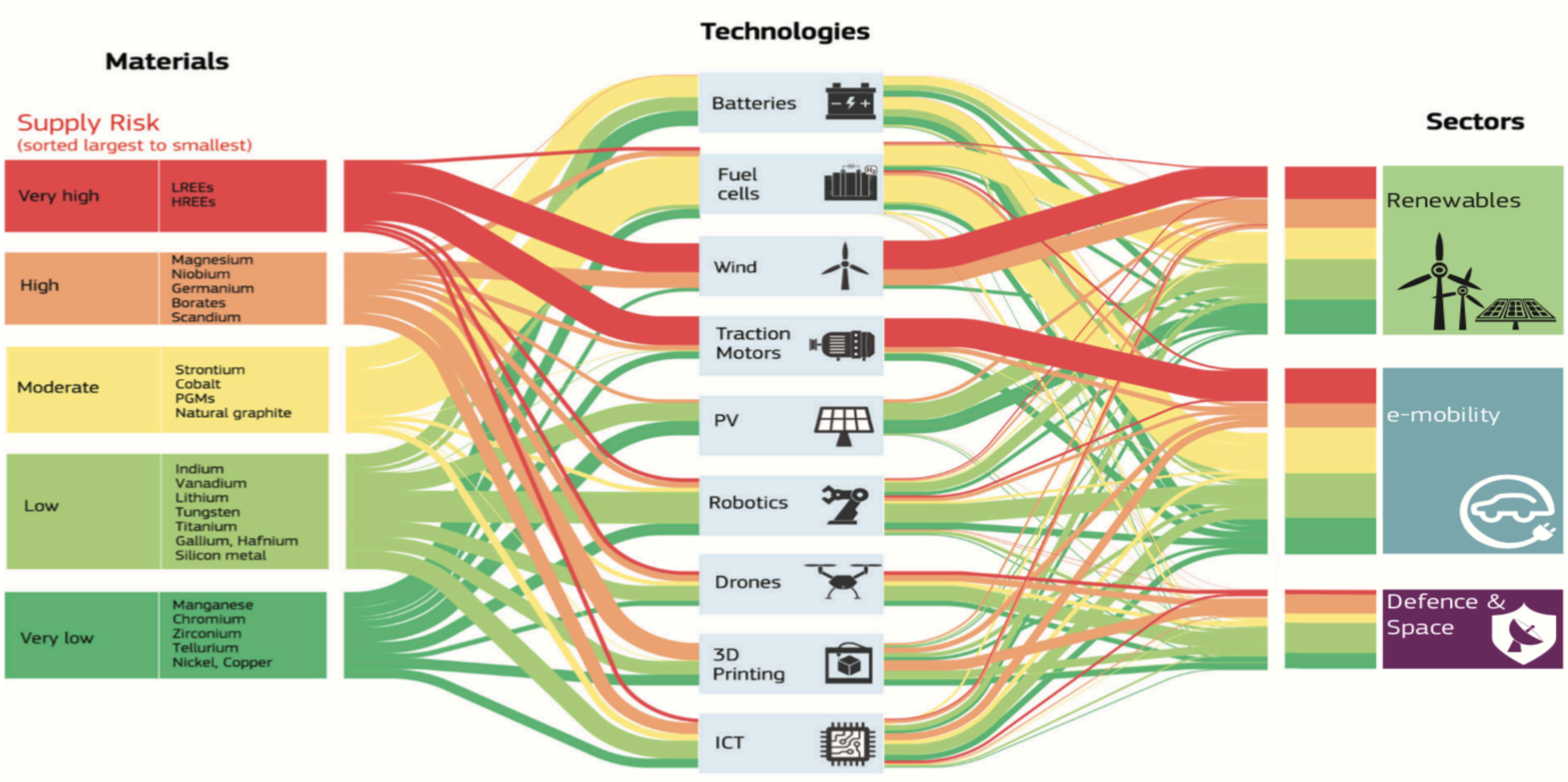

Figure 275: Semi-quantitative representation of the flow of raw materials and their supply risk to the nine selected technology sectors in renewable energy, e-mobility, defence and space .

Source: European Commission, (2020).

Figure 276: Distribution of rare earth production.

Source: Statista from onePioneer from 13.05.22