August 2022

GRAPHITE

A strategic raw material, indispensable to implementing the EU, regional and national policies, achieving the climate targets and overcoming the current energy-related crisis

Contents

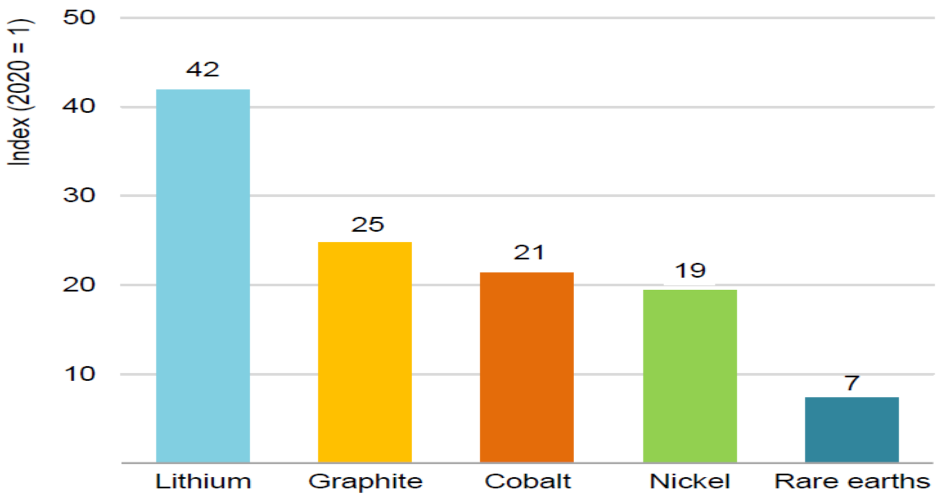
European Carbon and Graphite Association asbl
Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net

ECGA
European Carbon and Graphite Association

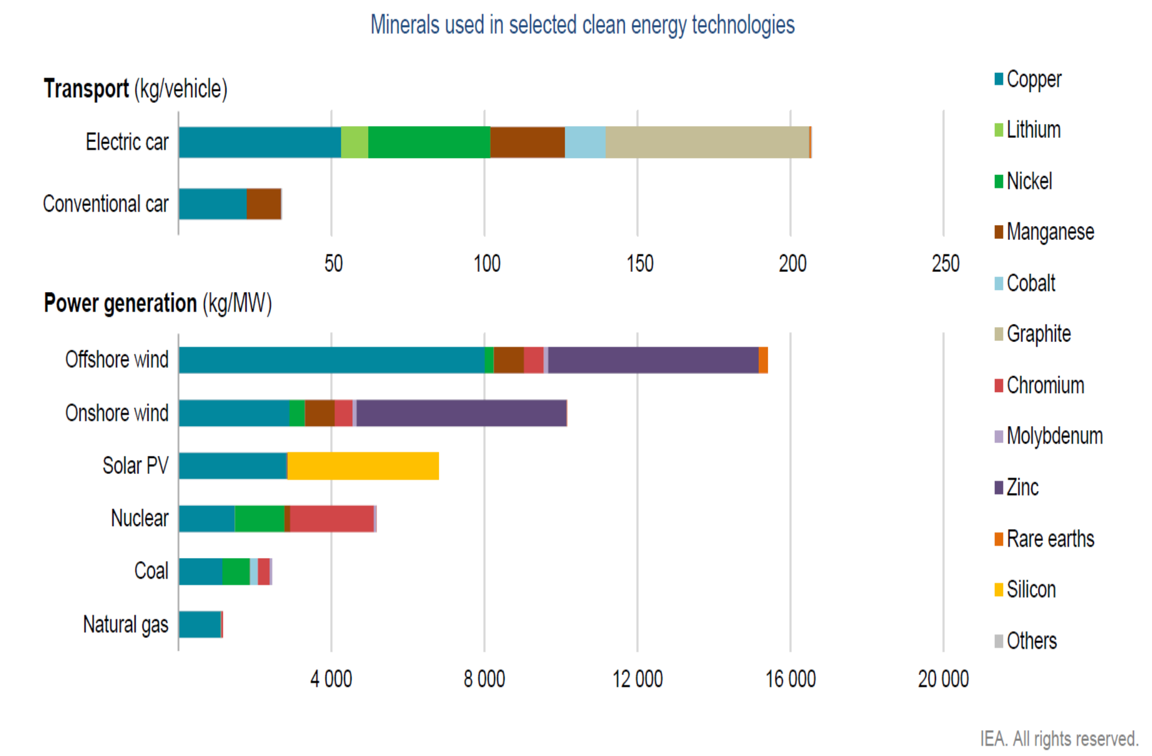
A. Introduction

According to the Note on Critical Raw Materials (CRMs), published by the Council Presidency on August 4th, "securing the EU's access to critical raw materials is essential for the industrial transition of strategic economic sectors such as e-mobility, aerospace, renewable energies, digital industries, health, agriculture, security and defence". Just to reach the goals of the Paris Agreement, the world needs 42 times more lithium, 25 times more graphite and 7 times more rare earths in 2040 compared to 2020 (IEA 2021 report).

Growth of selected minerals in the SDS, 2040 relative to 2020



According to IEA's The Role of Critical Minerals in Clean Energy Transitions, Flagship Report, an energy system powered by clean energy technologies differs profoundly from one fuelled by traditional hydrocarbon resources. Building solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) requires more minerals than their fossil fuel-based counterparts. For example, lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. The same holds true for larger energy storage modules. The shift to a clean energy system will generate an exponential increase in the demand for these minerals. In climate-driven scenarios, mineral demand for use in EVs and battery storage is a major force, growing at least thirty times by 2040. Lithium sees the fastest growth, with demand growing by over 40 times in the SDS by 2040, followed by graphite, cobalt and nickel (around 20-25 times).



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies

Source: The Role of Critical Minerals in Clean Energy Transitions, Flagship Report (IEA, 2021)

B. Both natural and synthetic graphite are strategic raw materials

Graphite, both natural and synthetic, represents an integral part of the EU's strategy for decarbonisation, performing as a reliable and safe material able to provide sufficient energy density for many applications, including batteries in electric vehicles. For synthetic graphite production, which is highly electricity intensive, improvements can be made predominantly by 'greening' the national electricity grids. The industry continuously works on implementing best and new technologies to foster progress.

Both graphite types are equally important, critical materials strategic to Europe's economy and vital to the implementation of the Joint European action for more affordable, secure energy, the increased resilience of EU economy as well as of EU Green Deals objectives. Synthetic graphite has in certain cases been used as a substitute for natural graphite and hence has reduced the EU's dependency on this critical raw material; however, that is not always possible, not because of economics but for technical performance reasons.

For example, 50% in weight of a Li-ion battery is graphite. Depending on the type of battery roughly 25% is synthetic, 25% is natural graphite, and this is not just a substitution for cost reasons but also for supply security and functionality. Also, without graphite moulds and tools there will be no silicon crystal production for solar panels in Europe, without synthetic graphite electrodes there will be no steel recycling in Europe and without needle and metallurgical coke or without High Temperature Coal Tar Pitch, (HT CTP) (the two raw materials required to produce synthetic graphite), there will be no synthetic production in Europe anymore.

Applications of natural and synthetic graphite (JRC Report on Critical Raw Materials: 2020, Eurostat, ECGA)

Graphite		Applications	NACE sectors related to applications	Value added of application (current prices, million Euro) (Euro 28)					
Natural	Synthetic			2014	2015	2016	2017	2018	2019
x	x	Refractories for steel making Recarburising	C24: Manufacture of basic metals • 2410 Manufacture of basic iron and steel and of ferro-alloys	66.406,0	69.511,8	68.695,0	71.942,4	75.687,6	68.292,1
x	x	Refractories for foundries	C23: Manufacture of other non-metallic mineral products • C23.2.0 - Manufacture of refractory products	66.923,6	69.083,9	71.767,0	73.093,9	75.958,0	78.910,8
x	x	Batteries	C27: Manufacture of electrical equipment • 2720 Manufacture Of Batteries And Accumulators	94.814,9	96.804,9	98.931,8	101.470,4	103.713,9	102.768,2
x	x	Friction products Pencils	C23: Manufacture of other non-metallic mineral products • 2399 Manufacture of other non-metallic mineral products	66.923,6	69.083,9	71.767,0	73.093,9	75.958,0	78.910,8
x	x	Lubricants	C20: Manufacture of chemicals and chemical products • 2013 Manufacture of other inorganic basic chemicals	131.063,9	NA	NA	NA	NA	NA
x		Pencils	C23: Manufacture of other non-metallic mineral products	66.923,6	69.083,9	71.767,0	73.093,9	75.958,0	78.910,8
x	x	Graphite shapes	C28: Manufacture of electrical equipment • 2849 Manufacture of other machine tools	94.814,9	96.804,9	98.931,8	101.470,4	103.713,9	102.768,2

ECGA
European Carbon and Graphite Association

B.1 Graphite demand

Graphite, both natural and synthetic, represents an integral part of the EU's strategy for decarbonisation, performing as a reliable and safe material able to provide sufficient energy density for many applications, including batteries in electric vehicles. For synthetic graphite production, which is highly electricity intensive, improvements can be made predominantly by 'greening' the national electricity grids.

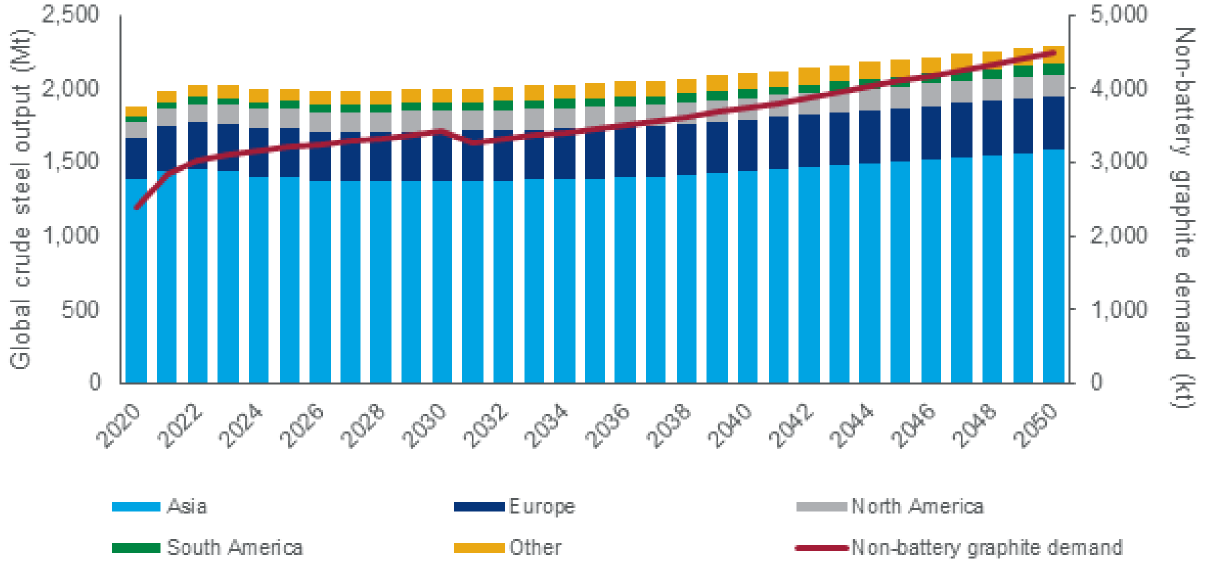
According to Wood Mackenzie, Graphite Market 2021 Outlook to 2050, published in December 2021, the global demand for graphite has tripled in size between 2015 and 2020 and is forecast to reach 1.9 million tonnes by 2028. To 2050, the graphite industry will secure its place as a cornerstone raw material for energy transition. Graphite is the choice for around 90% of all lithium-ion battery anodes materials and is used with all the cathode chemistries in major commercial production. Robust growth in the battery sector will underpin graphite demand for both natural and synthetic graphite and require new projects to come online. We forecast battery sector demand for raw material graphite to rise by more than 1,400% between 2020 and 2050. By the end of the forecast period, total graphite demand could be three times the 2021 supply level.

Batteries are the second-largest application for graphite in 2021 after synthetic graphite electrodes for electric arc furnace (EAF) steelmaking; they account for 17% of the total market. Batteries will increase market share, surpassing electrodes in volume terms around 2026 and, by 2050, are forecast to grow to account for 58% of the total graphite market. The battery sector will be underpinned by the rapid adoption of lithium-ion batteries in automotive and energy storage applications.

Kt	2020	2021	2022	2023	2024	2025	2030	2040	2050	*CAGR*	
										2020-30	*2030-50*
Graphite consumption, by type											
Natural graphite	978	1,154	1,266	1,319	1,376	1,453	1,983	3,119	3,759	7.30%	3.20%
Flake	775	931	1,028	1,087	1,149	1,230	1,779	2,905	3,549	8.70%	3.50%
Amorphous	203	223	237	231	227	223	205	214	210	0.10%	0.10%
Synthetic graphite	1,808	2,278	2,521	2,693	2,856	3,043	4,107	5,812	6,838	8.50%	2.60%
Graphite consumption, by application											
Batteries	397	587	755	920	1,086	1,282	2,669	5,195	6,109	21.0%	4.2%
Electrodes	886	1,169	1,249	1,297	1,338	1,388	1,510	1,521	1,831	5.5%	1.0%
Refractories	464	526	520	501	481	469	436	421	418	-0.6%	-0.2%
Recarburising	333	377	404	411	423	428	447	503	635	3.0%	1.8%
Foundries	158	171	177	179	180	184	197	228	266	2.2%	1.5%
Graphite shapes	125	132	137	141	144	148	167	209	259	3.0%	2.2%
Lubricants	158	173	181	186	191	196	208	236	231	2.8%	0.5%
Friction products	72	92	150	154	160	164	176	202	193	9.3%	0.5%
Other	193	205	215	222	229	237	282	417	654	3.8%	4.3%

Source: Wood Mackenzie

European Carbon and Graphite Association asbl
Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net

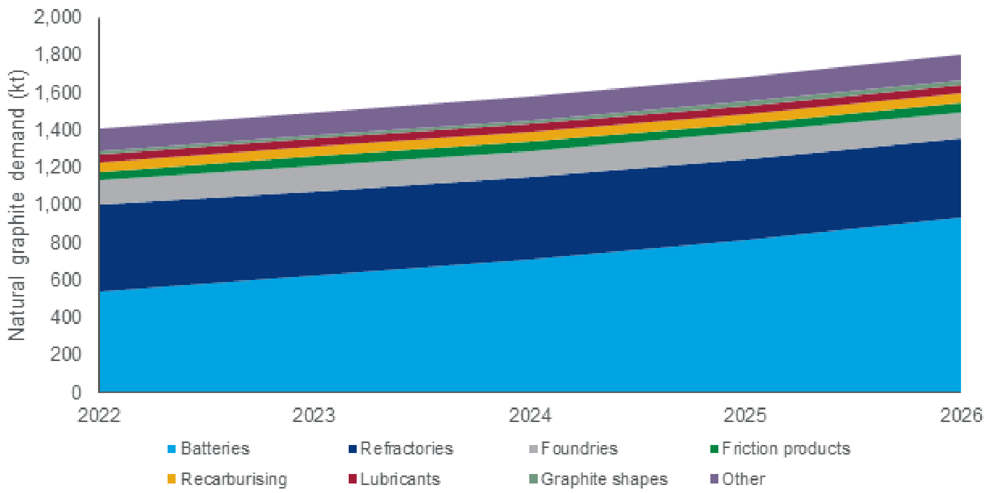


Source: Wood Mackenzie

B.1. 1. Natural graphite

Natural graphite demand is forecast to rise by 11.3% to 1.41 Mt in 2022 based mainly on 28.4% growth in batteries. Natural demand is forecast to grow by 6.4% per year between 2022 and 2026, with the battery market maturing and growing by 14.7% per year over the whole forecast period. Natural graphite's other main uses of refractories, foundries and other traditional, mainly steel-based, industries are growing slowly or in decline.

Natural graphite demand by application

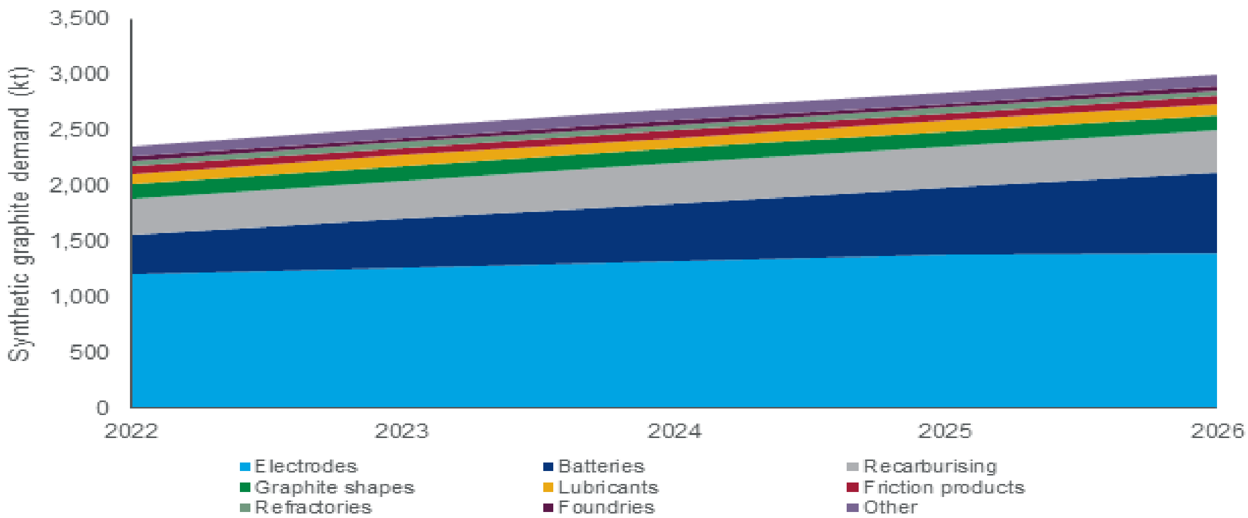


Source: Wood Mackenzie

B.1.2. Synthetic graphite

Synthetic graphite demand is forecast to rise by 9.7% to 2.36 Mt in 2022, also based mainly on growth in batteries where demand is expected to increase by 30.2%. Between 2022 and 2026, graphite demand is forecast to grow at 6.2% per year, with a maturing battery market seeing growth of 20.0% per year. Electrodes will also see relatively strong mid-term growth of 3.9% per year to 2026 based on a continuous shift to EAF steel in China, India and other countries looking to increase their rate of scrap steel use.

Synthetic graphite demand by application



Source: Wood Mackenzie

B.2 Graphite: Supply

While demand continues to increase, China dominates production of both streams of graphite supply: natural and synthetic. China accounts for around 64% of all graphite supply in 2021 and will continue to dominate supply to 2050.

Key mine supply forecast data

Kt	2020	2021	2022	2023	2024	2025	2030	2040	2050	CAGR 2020-30	CAGR 2030-50
Graphite supply, by region											
Asia	2,317	2,775	3,070	3,315	3,532	3,758	4,983	7,191	8,591	*8.00%*	*2.80%*
Europe	201	263	277	301	311	319	389	499	535	*6.80%*	*1.60%*
North America	132	203	214	217	222	230	296	364	350	*8.40%*	*0.80%*
South America	87	110	129	134	143	148	181	224	243	*7.60%*	*1.50%*
Other	49	150	210	228	246	273	434	828	1,159	*24.40%*	*5.00%*
Total	**2,785**	**3,501**	**3,900**	**4,196**	**4,453**	**4,728**	**6,282**	**9,106**	**10,879**	*8.50%*	*2.80%*
Graphite supply, by type											
Natural graphite[1]	978	1,224	1,379	1,503	1,598	1,685	2,174	3,292	4,040	*8.30%*	*3.10%*
Flake	776	954	1,124	1,261	1,367	1,462	1,947	3,043	3,767	*9.60%*	*3.40%*
Amorphous	202	269	255	242	231	223	228	250	274	*1.20%*	*0.90%*
Synthetic graphite	1,808	2,278	2,522	2,693	2,855	3,043	4,108	5,813	6,839	*8.60%*	*2.60%*

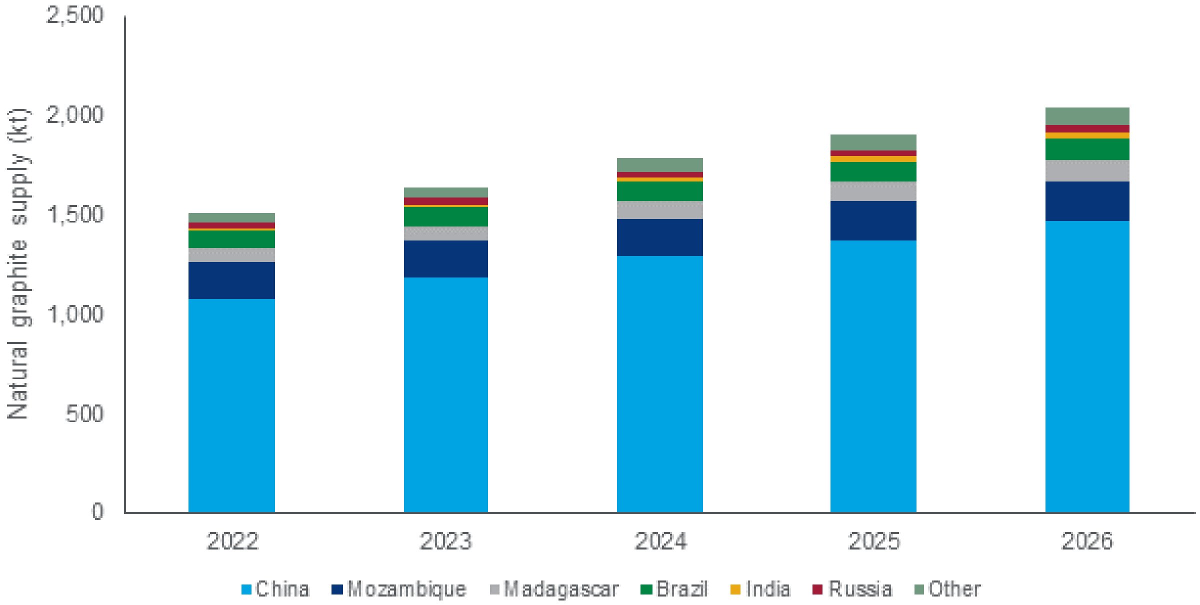
Source: Wood Mackenzie

Note: 1-raw material concentrate

B.2.1. Natural graphite

Global production of natural (flake and amorphous) graphite is now expected to be 1.51 Mt in 2022, a 17.8% increase on 2021. Production is forecast to rise by 7.9% per year to 2026, reaching 2.04 Mt.

Natural graphite supply by region



Source: Wood Mackenzie

China

China accounted for around 67% of global natural graphite exports in 2021 and is also a significant importer from Africa. Strong demand from the battery sector will require increased supply from both domestic sources and imports. Flake and spherical graphite have been in overcapacity in recent years and, although some overcapacity has been reduced by the ongoing environmental closures, there will still be room for increased production at existing operations in the short term. Considering the strategic importance of natural graphite for lithium batteries, several mechanisms have been implemented by the Government of China to encourage the production of this product.

Europe

Europe is a minor producer of natural graphite but one which could play a larger role in future, potentially offering a more environmentally sound and sustainable supply chain.

Russia is currently Europe’s largest producer. The Reports published by Wood Mackenzie state that Uralgraphite in Russia will produce around 17 kt of flake graphite in 2021 and increase its output following a recent capacity upgrade to 25 ktpa. A doubling of this capacity is expected to meet rising domestic demand from the steel industry, automotive and other markets. Russia’s Krasnoyarsk Graphite also produces an estimated 8 ktpa of amorphous graphite for domestic uses and we expect this to continue to 2050. Dalgrafit is developing the Topolikhinsky flake graphite project on the Soyuznoye deposit close to the Russian border with China.

In Ukraine, Zavalivskiy Graphite produces around 18 ktpa and could increase its production marginally to 2050. While further development of the Zavalye graphite field is underway (including plans for 40 ktpa of new capacity by BGV Group Management), these are early stage and have not been included in the forecast.

Skaland Graphite in Norway is assumed to produce at its maximum 12 ktpa capacity from the Trælen pit. Production switched to the site in 2007 after the previous deposit was depleted and mine life is reported to be 30 years. We have, therefore, modelled production to decline towards the end of the forecast period. Its production is currently being shipped to China for processing.

AMG Mining, an international graphite miner and processor based in Germany, imports graphite from its worldwide operations for downstream processing. It operates the Kropfmühl mine and plant with an estimated capacity of 20 ktpa, but concentrate production is assumed to be much lower at around 250 tpa with little appetite to increase outside of specialist markets over the forecast period.

Sweden is not currently a natural graphite producer but provides the most likely opportunity for future growth in Europe. Small amounts were produced from the restarted Woxna flake mine in 2015 but this project was put on hold because of low global pricing. Leading Edge Materials currently owns the mine, which is on care and maintenance and ready to restart if prices improve at 10 ktpa of concentrate. Meanwhile, Talga Resources completed a prefeasibility study on its 19-ktpa Vittangi flake graphite project in May 2019 and announced a scoping study to expand the project with new resources as of December 2020 and is currently running a pilot plant in Germany. Overall, for Sweden, some capacity has been assumed to come online in the latter half of the forecast, reaching 35 ktpa by 2050.

Greenland has a major deposit which currently being developed and could contribute in the future.

Older deposits are available in the Czech Republic as well as in Ireland, which need further assessments with new technologies.

Less than 2 ktpa of amorphous graphite are also produced by Grafitbergbau Kaisersberg in Austria.

Other parts of the world

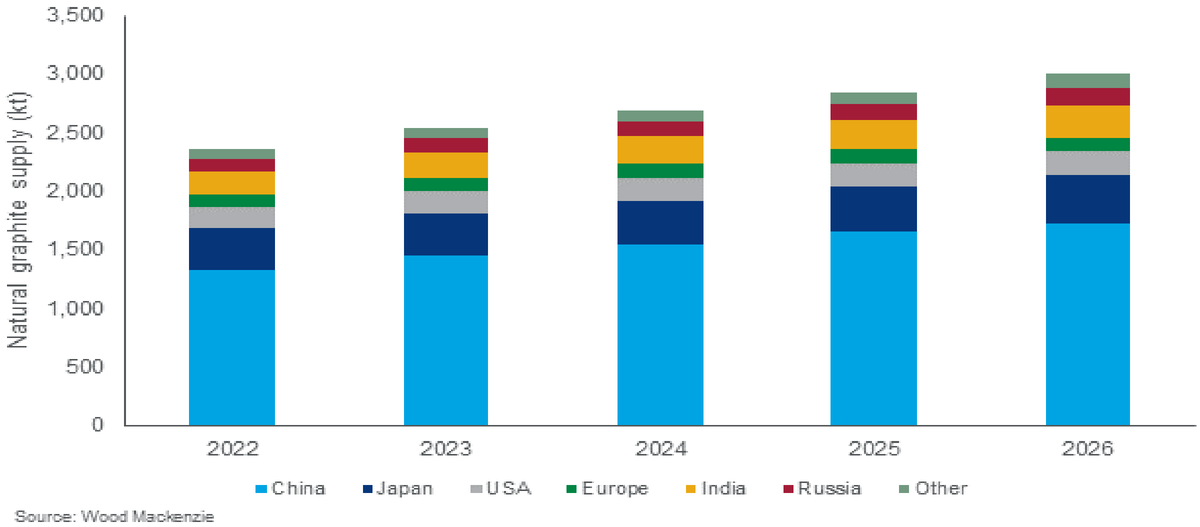
Other parts of the world such as Madagascar, Mozambique, Tanzania, USA and Canada have continued to explore and develop new mines. Some of their material is being imported into Europe and is gradually reducing Europe’s high dependency on Chinese material in the past few years.

B.2.2. Synthetic graphite

Global synthetic graphite supply will reach 2.36 Mt in 2022 with China accounting for around 56% and Japan 15%. Global supply will grow by 6.2% per year to 2026, with the strongest growth in India (9.3% per year) and China (6.9% per year) to meet rising demand from batteries. Growth in mature industries such as Japan, the US and Europe are forecast to grow more moderately at 1-3% per year.

Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net

Synthetic graphite supply by region



China

Chinese production of synthetic graphite has grown in line with rising demand from both batteries and EAF steelmaking electrodes. Chinese capacity for synthetic graphite electrodes has increased significantly in recent years, by around 0.6 Mtpa since 2017, because of growing demand from the domestic EAF steelmaking sector and encouraged by a period of sustained high electrode prices. However, capacity expanded so rapidly that the industry is now in overcapacity.

In 2021, Chinese synthetic supply was estimated at 1,326 kt with a rise by 8.1% a year between 2020 and 2030 to reach 2,431 kt, before slowing to 1.6% a year between 2030 and 2050 to reach 3,319 kt. The total Chinese capacity is estimated at 1.19 Mtpa of synthetic graphite products, however, actual Chinese capacity is thought to be far higher, with Chinese capacity for electrodes alone estimated to be in the order of 1.5 Mtpa. The major electrode producers are highly competitive and likely to increase capacity in the coming years to maintain market position.

Europe

In the longer term, the growth rate will decline by 0.5% a year between 2030 and 2050 with production reaching 107 kt by 2050. Most producers are mature and numerous plants have closed in recent years.

Imerys Graphite & Carbon is headquartered at Bodio in Switzerland, where it produces synthetic graphite. In late September 2020, it announced plans to expand capacity for synthetic graphite at its Bodio plant to meet rising demand from the lithium-ion battery sector in Asia, Europe and North America. The company says the "investment is the first of a series of capacity expansion projects the Group envisages to support and accompany the expected strong growth of the electric vehicle market worldwide". Imerys has been increasing its presence in the lithium-ion battery supply chain in recent years.

In October 2019, Chinese synthetic graphite electrode producer CIMM Group announced plans to build a new electrode plant in Sisak, Croatia.

Showa Denko Carbon of Japan operates synthetic graphite electrode plants in Steeg in Austria and La Coruña in Spain.

Several major players are headquartered in Germany. International synthetic graphite producer SGL Group is based in Wiesbaden. In Germany, SGL Group produces graphite products through its Graphite Materials & Systems business unit from at least two German plants, located in Meitingen and Bonn. Further feedstock production is located in Poland and further manufacturing in Italy and Spain. Its plant in Limburg produces equipment for the chemical industry. In 2019, production capacity for fuel cell components was increased at Meitingen. AMG Mining, an international graphite processor, is also based in Germany and processes imported synthetic and natural graphite. Tokai Erftcarbon, a subsidiary of Tokai Carbon of Japan, produces large-format synthetic graphite electrodes for EAFs at a 40-ktpa plant in Grevenbroich. Graphite India operates an 18-ktpa plant in Nürnberg as part of its Graphite Cova subsidiary. The plant produces mainly graphite electrodes as well as electrode coatings and other specialty graphite and carbon products.

The US company GrafTech International has electrode production plants in Pamplona in Spain and Calais in France for which it reported nearly 100% capacity utilisation in 2017 and 2018 because of increased global electrode demand. Elsewhere in France, SGL Group operates two plants producing specialist synthetic graphite products. Mersen Group is an international company, headquartered in France, that manufactures products based on both synthetic and natural graphite.

C. Graphite, vital to the development of strategic economic sectors such as e-mobility, aerospace, renewable energies, digital industries, security and defence.

C.1 Graphite electrodes, crucial for a green, low-emission steel industry

Graphite electrodes are large cylindrical structures which due to their high level of electrical conductivity and capability of withstanding the extremely high temperatures of up to 1600 degree Celsius are a vital input in Electric Arc Furnaces (EAF), ladle refinement of steel and the production of ferroalloys. In this process, graphite electrodes account for about 2-3% of the total steel production costs[1].

The largest market for synthetic graphite, accounting for about 32% of the worldwide total graphite market and worth about 3.7 billion EUR is the electrode market used mostly by the steel industry. The electrodes for electric arc furnaces make up the biggest revenue share and create considerable interdependencies between the two sectors. Recycling steel is carried out in Electric Arc furnaces (EAF)[2] which are using graphite electrodes to obtain the temperatures necessary to melt the steel scrap and to ensure the steel qualities of the recycled steel. Graphite electrodes are an integral part of the latest steel recycling technology and given the increased use of steel in infrastructure around the world, graphite electrodes will continue to be required to save resources for the future. Compared to Basic Oxygen Furnace (BOF)[3] steelmaking producing about

[1] https://www.metals-hub.com/blog/why-graphite-electrodes-are-crucial-for-the-steel-industry/

[2] An electric arc furnace (EAF) is a furnace that heats material by means of an electric arc.

[3] Basic oxygen steelmaking (BOS, BOP, BOF, or OSM) is a method of primary steelmaking in which carbon-rich molten pig iron is made into steel. Blowing oxygen through molten pig iron lowers the carbon content of the alloy and changes it into low-carbon steel. The process is known as *basic* because fluxes of burnt lime or dolomite, which are chemical *bases*, are added to promote the removal of impurities and protect the lining of the converter.

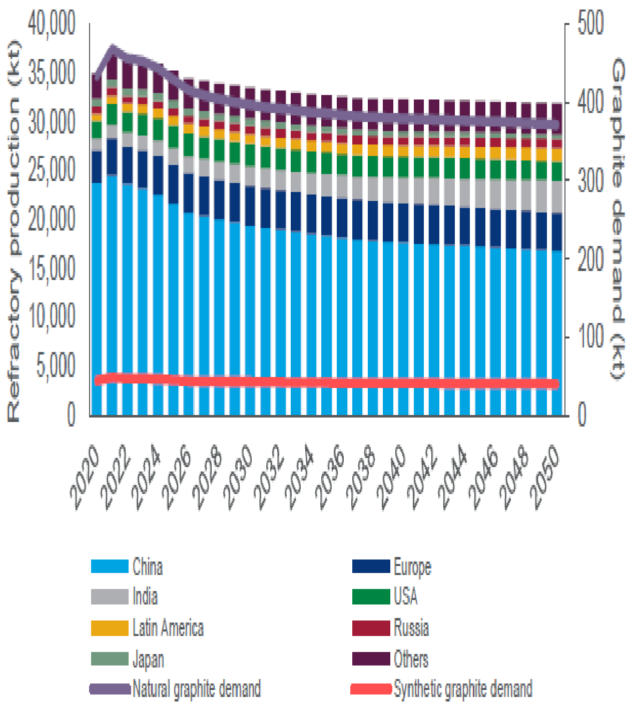
European Carbon and Graphite Association

3,5 t CO2 per t of steel, steel scrap recycling with graphite electrodes used in EAFs produce only 0, 5 t CO2 per t of steel.

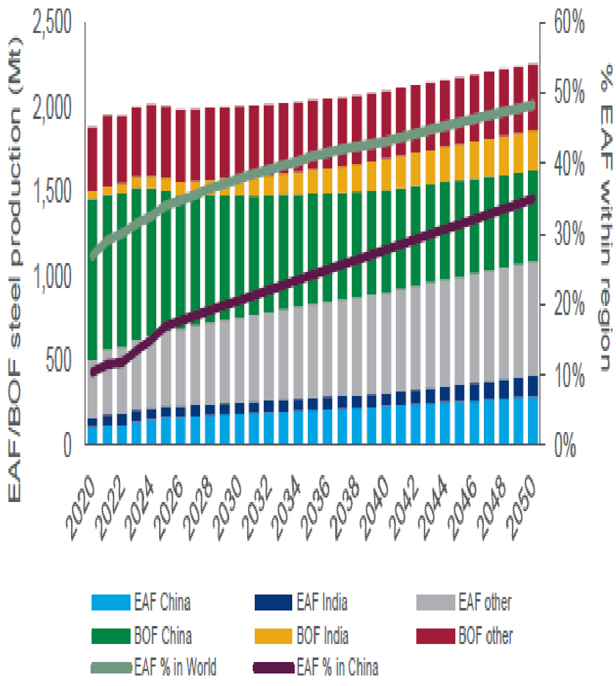
According to Wood Mackenzie, Global graphite strategic planning outlook to 2050, traditional steel-based applications -including EAF steel electrodes, refractory bricks, recarburising of molten steel and foundry casts/mould washes follow trends in crude steel and will see flat long-term graphite demand growth of 1-2% per year to 2050. Wood Mackenzie forecasts global crude steel production to grow by a CAGR of 0.3% to 2032 and by 0.6% between 2032 and 2050, while Chinese production will decline by 1.5% and 0.4%. Slightly stronger rates of graphite-refractory production will be offset to some extent by a falling specific consumption of refractories per tonne of steel in China and India.

Electrode demand follows trends in EAF steel output which will see some rise with the increasing availability of end-of-life steel scrap in China and other countries with maturing steel industries. Global EAF growth is expected to have a CAGR of 3.0% to 2032, based on strong growth in China of 4.9%.

Refractory production and graphite consumption by type

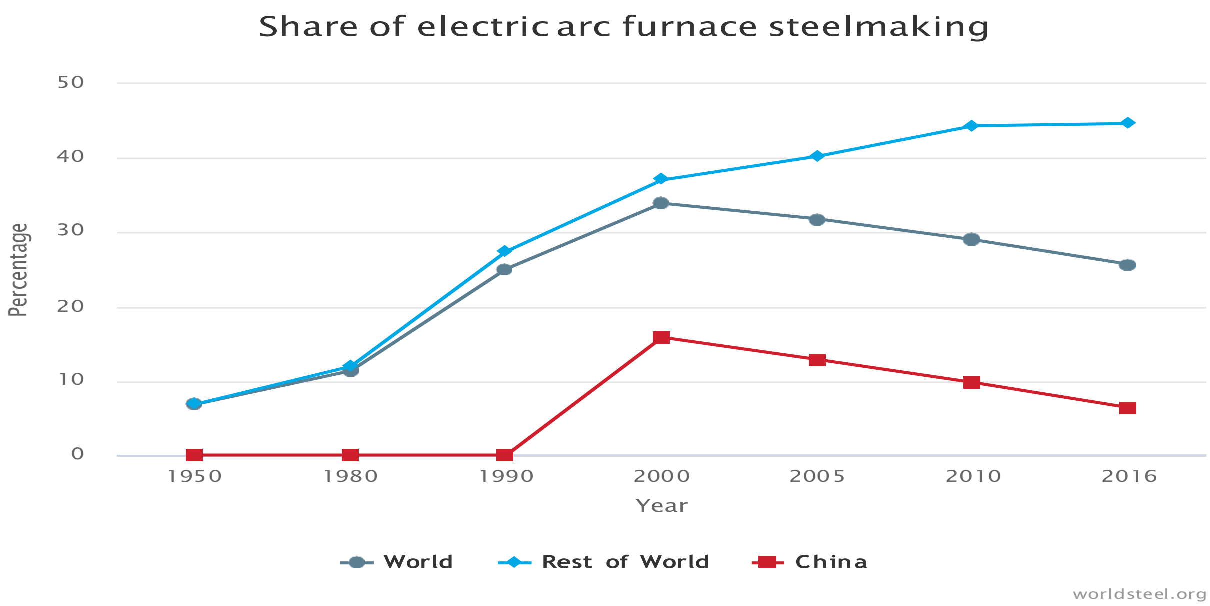


Forecast trends in global crude and EAF steel production



Source: Wood Mackenzie, Global graphite strategic planning outlook to 2050, June, 2022

European Carbon and Graphite Association asbl
Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net



In Europe, 27.5 million mt of new EAF capacity are to be built in by 2035, at a cost of transformation estimated at $100 billion excluding infrastructure costs.

EEC 2021 – NO CHANGE TO ALL CHANGE - GREEN FUTURE

Based on current "intentions" 27 Mt of EAF and 20 Mt of DRI capacity will be built by the incumbent European steel industry

Stated Incumbent European Steel Company Decarbonisation Intentions

	2020 BOF Capacity	BOF Capacity Closed by 2035	EAF Capacity Built by 2035	DRI capacity Built by 2035
ArcelorMittal	40.5	14.5 (36%)	12.0	6.0
ThyssenKrupp*	14.5	--	--	3.5
Tata Steel	12.5	5.0 (40%)	2.0	--
Salzgitter	7.0	2.5 (36%)	2.5	2.0
SSAB	6.5	4.0 (62%)	4.0	2.0
voestalpine	6.0	3.0 (50%)	3.0	1.5
Liberty/SHS	4.5	2.4 (70%)	4.0	4.5
Others (IUD, USSK)	5.0	No Specific Details		
Total	**96.5**	**31.4 (33%)**	**27.5**	**19.5**

*TKS's plan is to replaces BF hot metal with DRI "electric hot metal" to feed existing BOFs

Source: VDEh, Companies and First River

© PinzaMeld Limited, 2021

Source: Mike Walsh – Consultant. Presentation at the EEC 2021: "European Electric Steelmaking – No Change to All change"

European Carbon and Graphite Association

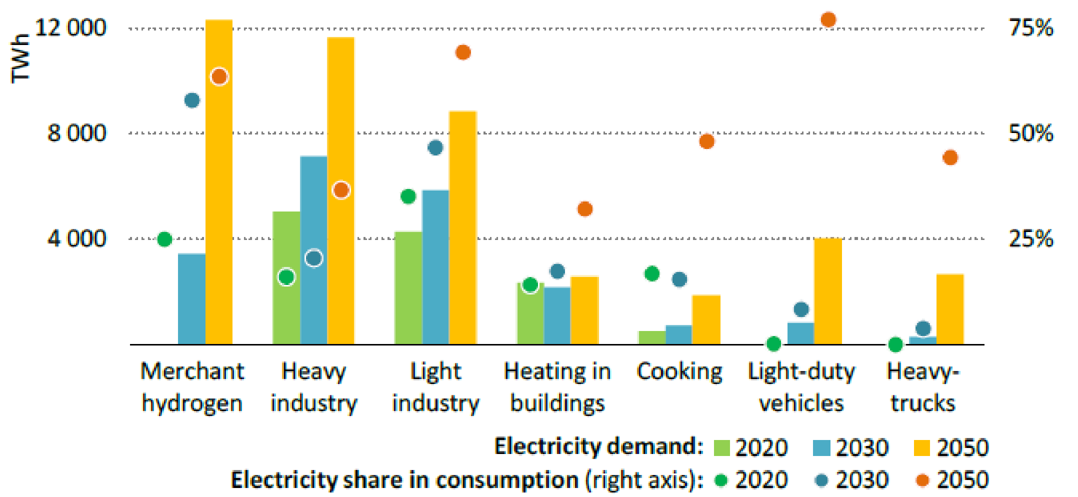
On the other hand, Celsa Group suspended steelmaking operations at all its Spanish plants in March due to costlier energy, while other EAF stoppages have become widespread in Spain.

In Italy, skyrocketing energy costs and difficulty in procuring raw materials because of the war in the Ukraine have seen Pittini Group idle three facilities with other large EAF based rebar and specialty steel producers also suspending production[4].

C.2 Graphite, essential in ensuring clean energy

According to the International Energy Agency (2021), Net Zero by 2050, IEA, Paris, the key pillars of decarbonisation of the global energy system are energy efficiency, behavioural changes, electrification, renewables, hydrogen and hydrogen-based fuels, bioenergy and carbon capture. The direct use of low-emissions electricity in place of fossil fuels is one of the most important drivers of emissions reductions, accounting for around 20% of the total reduction achieved by 2050. Global electricity demand more than doubles between 2020 and 2050, with the largest absolute rise in electricity use in end-use sectors taking place in industry, which registers an increase of more than 11 000 TWh between 2020 and 2050.

Figure 2.16 ▷ Global electricity demand and share of electricity in energy consumption in selected applications in the NZE



The same IEA's Net Zero Emissions by 2050 Scenario states that at a global level, renewable energy technologies are the key to reducing emissions from electricity supply. Hydropower has been a leading low-emission source for many decades, but it is mainly the expansion of wind and solar that triples renewables generation by 2030 and increases it more than eightfold by 2050. The share of renewables in total electricity generation globally increases from 29% in 2020 to over 60% in 2030 and to nearly 90% in 2050. Dispatchable

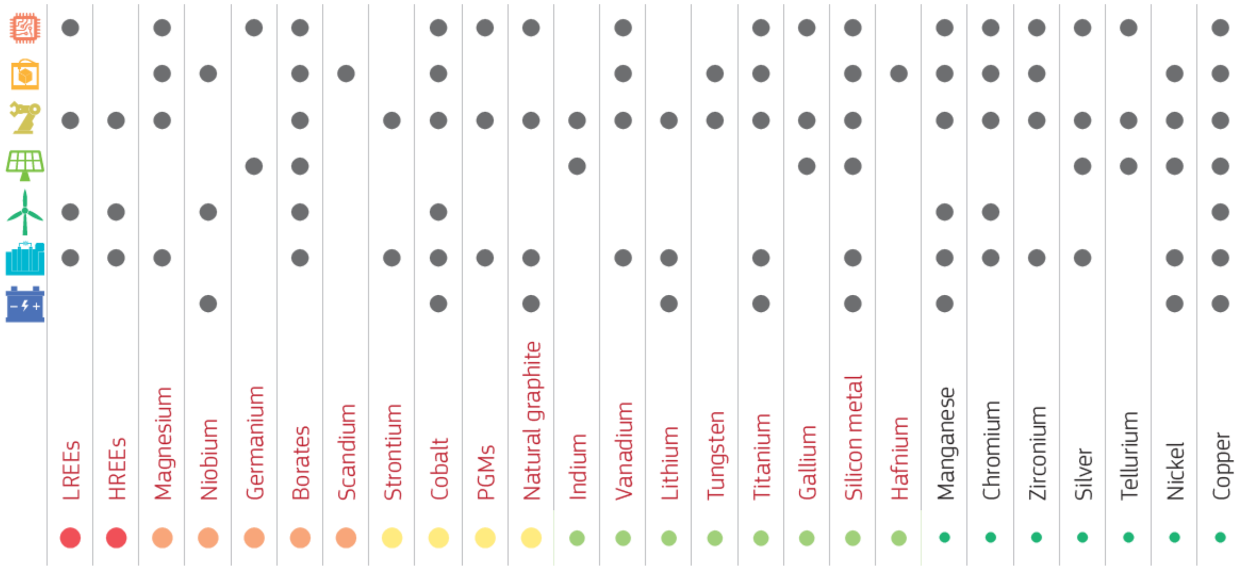
[4] Source: Kallanish – March 9th, 2022

Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net

renewables are critical to maintain electricity security, together with other low-carbon generation, energy storage and robust electricity networks.

According to the latest IEA Report[5], *Securing Clean Energy Technology Supply Chains,* published in July 2022, secure, resilient, and sustainable clean energy supply chains are central to the global energy transition. The huge increase in the deployment of solar photovoltaics, EVs and low-carbon hydrogen in that scenario calls for rapid growth in the manufacturing of these technologies, as well as the production of essential material and mineral inputs, amongst which graphite.

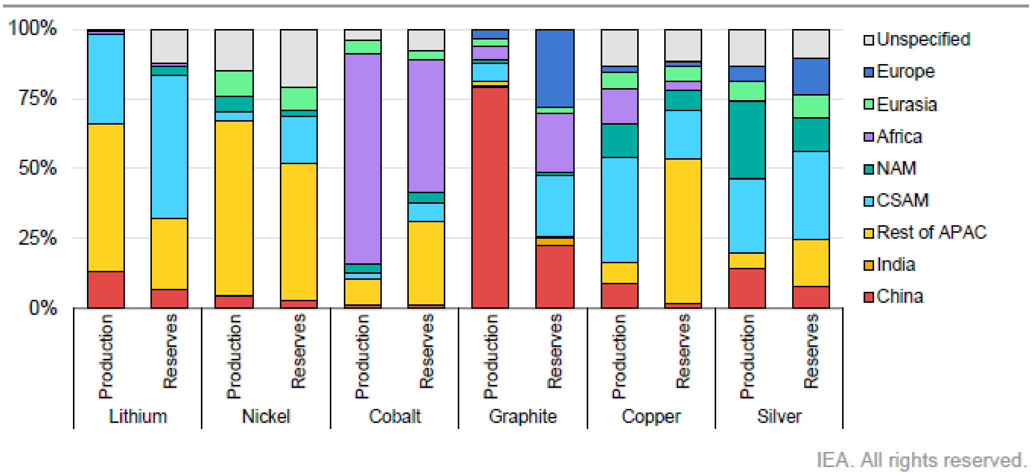
Figure 48. List of critical and non-critical raw materials used for renewables ranked by their 2020 supply risk



Source: Critical Raw materials for Strategic Technologies, a Foresight Study (European Commission, 2021)

[5] IEA Report, *Securing Clean Energy Technology Supply Chains,* published in July 2022

Figure 9 Production and proven reserves of selected critical minerals for battery and PV cell materials, 2021



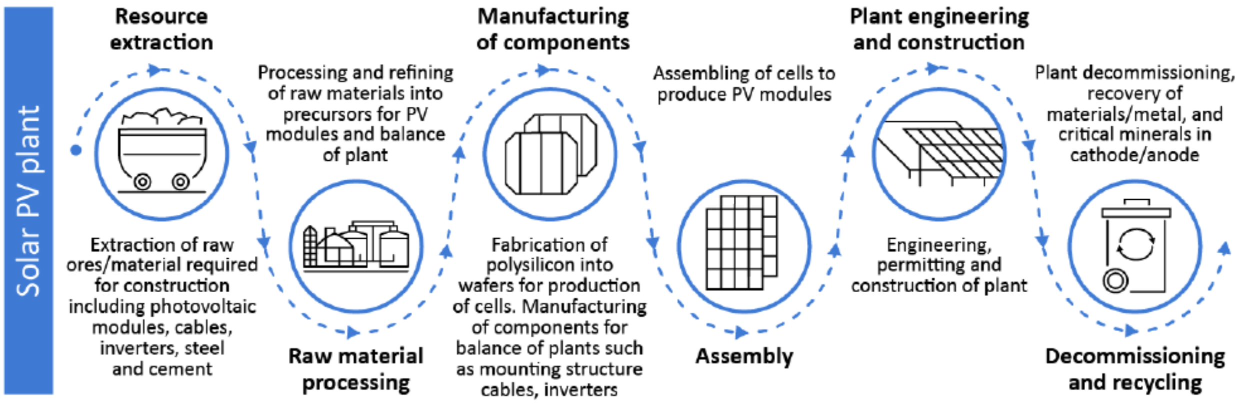
Notes: NAM: North America; Rest of APAC: Asia-Pacific excluding China and India; CSAM: Central and South America. Reserves refer to economically extractable resource as defined and determined by the US Geological Survey.

Source: IEA analysis based on US Geological Survey (2022).

C.2.1 Energy generation: importance of graphite for the renewables industry

The generation of electricity using solar PV technology is a central pillar of the clean energy transition. Annual average capacity additions in the Net Zero Emissions by 2050 Scenario quadruple over 2020-2030, with solar accounting for roughly one-third of total generation by mid-century – up from just 3% today. The annual installation of PV panels reaches 630 GW in 2030 (up from 151 GW in 2021), with associated demand for critical minerals increasing to 4 000 kilo tonnes (kt) by 2030 (up from 1 000 kt in 2021). Solar PV panel production already accounted for 10% of global demand for silver and over 40% of global tellurium use in 2021. The aggregate demand for critical materials for solar PV is estimated to expand by 150% to 400% between 2021 and 2030 in the Net Zero Emissions by 2050 Scenario[6].

[6] IEA Report, *Securing Clean Energy Technology Supply Chains,* published in July 2022



Source: International Energy Agency (2022), Securing Clean Energy Technology Supply Chains

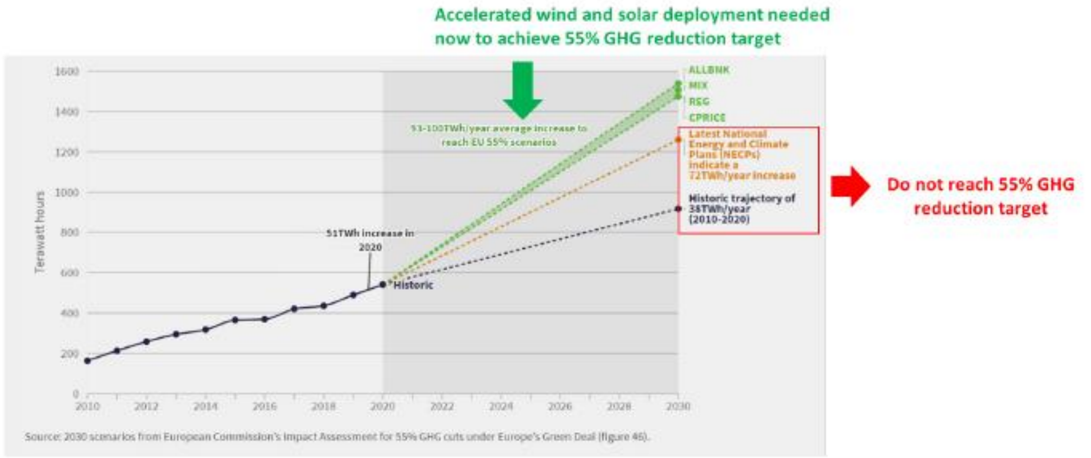


Figure 3: *Wind and Solar Growth required to reach EU's 55% Emissions Target by 2030, (adapted from EMBER, Agora Energiewende, The European Power Sector in 2019)*

Source: European Association for Storage of Energy

High-purity graphite, carbon fibre reinforced materials, and felts are used for the production process of multi- and monocrystalline silicon for solar panels. Graphite is used in renewable energy technologies, such as solar panels, because it is resistant to extreme heat, perfect for the crucibles and moulds used to cast the silicon in solar panels and works as a heat shield and thermal insulator. Without high-purity graphite, there would be no manufacturing equipment for multi and monocrystalline silicon and, hence, no solar panels.

Today, most solar panels are being produced in China, resulting in Europe's dependency on the country in this market segment. If solar panels are to be produced to a much larger degree in Europe, as some policymakers have already announced, then not only the silicon but also the isostatic graphite should be produced in much larger quantities in Europe.

New applications such as EVs having solar panel roofs will, for example, require more solar panels, and hence, more graphite tooling. However, the largest market of lithium-ion batteries will then be the battery market for home solutions – for example, solar panel roofs powered by battery packs that require even more graphite. If battery-powered homes are the future, the projected increase in demand for graphite will continue to grow even more.

To have sufficient graphite available for usage in renewable energy technologies, permitting for European mines needs to be streamlined and accelerated, and financial support for the energy-intensive synthetic graphite production needs to be made available.

C.2.2 Energy Storage: importance of graphite for batteries and electric vehicles (EVs)

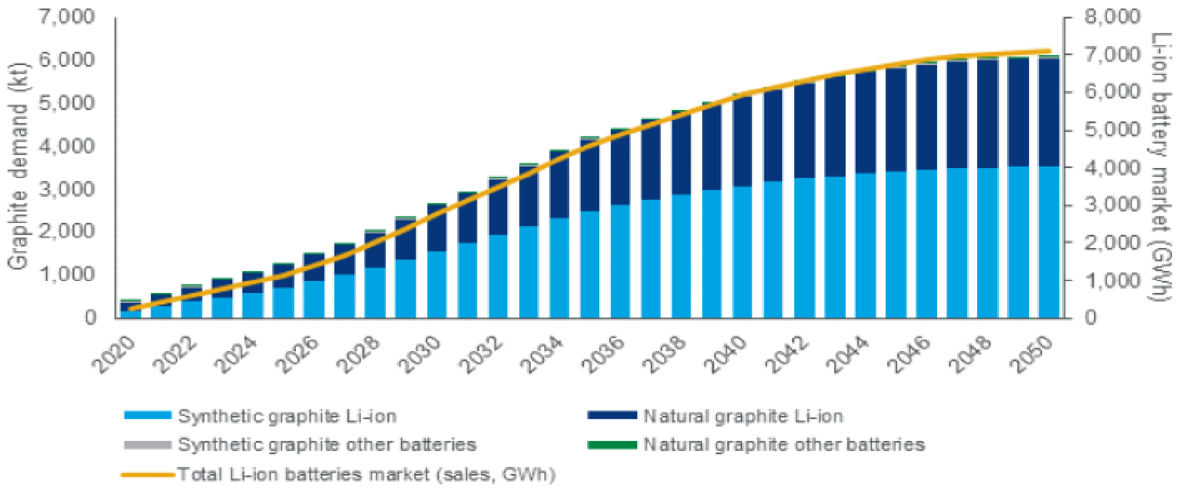
Since one of the key features of renewables is that they are not necessarily continuously available, energy storage becomes an important feature. Sales of electric vehicles is expected to grow at a 20 to 30 % compound annual rate through 2030, and likely beyond. Each car is equipped with a lithium-ion battery and while the design of those batteries is much the same as the one in our smartphone or in the power tools, electric vehicle batteries are, by necessity, much bigger. A single car battery can weigh several hundred kilograms and is made up of materials like manganese, graphite, nickel, cobalt and lithium.

Batteries typically accounts for 30% to 40% of the value of an electric vehicles (EV), and the race to net zero will focus attention on the security of supply of the critical minerals and metals needed to manufacture them. Battery and minerals supply chains will have to expand ten-fold to meet government EV ambitions. Demand for EV batteries will increase from around 340 GWh today, to over 3500 GWh by 2030 in the Announced Pledges Scenario (APS).

Graphite is used as the primary material the batteries' anode. 50% in weight of a Li-ion battery is graphite. Both natural and synthetic graphite are used in lithium-ion batteries alongside other carbon and non-carbon materials, with the choice coming down to final battery application, cost and regional availability of material.

According to Wood MacKenzie, by 2030, batteries could account for 44% of all graphite consumption at 2,669 kt, up from 17% in 2021 at 587 kt. Batteries are expected to overtake electrodes to become the largest application for graphite around 2026.

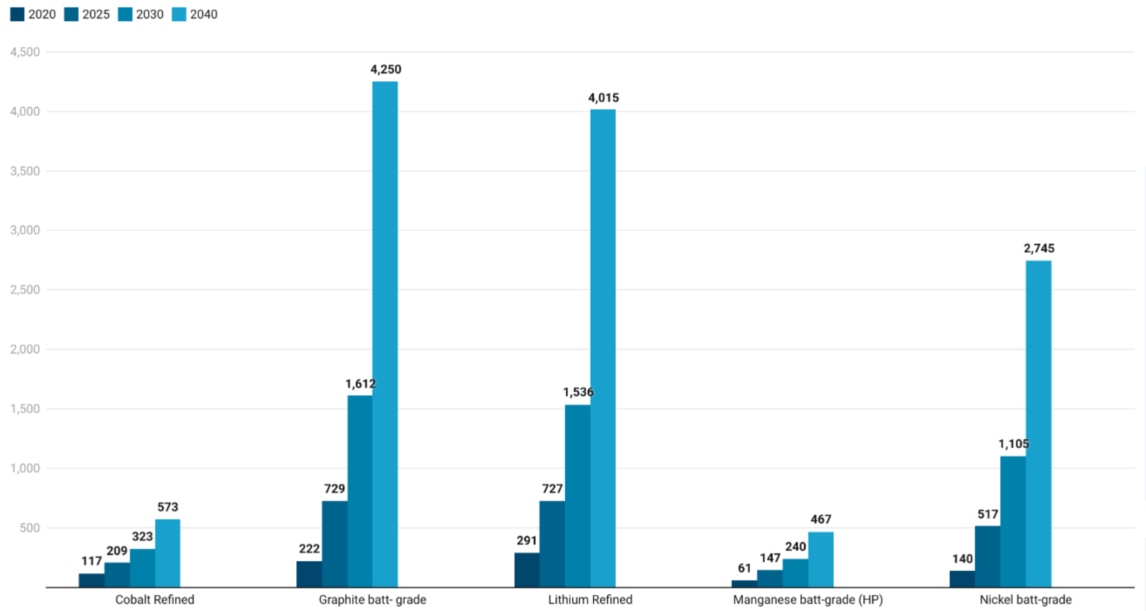
Battery market growth and associated graphite demand



Source: Wood Mackenzie

Demand for battery raw materials is expected to increase dramatically over 2040, following the exponential growth of electric vehicles (EV) and, to a minor degree, energy storage system (ESS) applications. The largest increase2 in the medium (2030) and long term (2040) is anticipated for graphite, lithium and nickel (e.g. lithium demand for batteries is foreseen to grow fivefold in 2030 and have a 14-fold rise in 2040 compared to the 2020 level).[7]

Forecast of battery demand globally from processed raw materials [kt]



Source: JRC analysis.

[7] European Commission, EU Science HUB, Raw Materials Information System

The supply[1] of each processed raw material and components for batteries is currently controlled by an oligopoly industry, which is highly concentrated in China. Although China is expected to continue holding a dominant position, geographic diversification will increase on the supply. Deficits in the short term are expected for graphite as the global market balance will remain very tight between now and 2024. Demand will continue to surpass supply unless new investments timely provide the supply required by the rapid growth of demand.

The EU is expected to expand its production base for battery raw materials and components over 2022-2030 and improve its current position and global share. However, dependencies and bottlenecks in the supply chain will remain creating vulnerabilities. The refining of natural graphite for anodes will rely on both domestic production and imports.

C.3 High-purity graphite components, crucial to processes in the semiconductor industry

Recent global semiconductors shortages forced factory closures in a wide range of sectors from cars to healthcare devices. In the car sector, for example, production in some Member States decreased by one third in 2021. This made more evident the extreme global dependency of the semiconductor value chain on a very limited number of actors in a complex geopolitical context. But it also illustrated the importance of semiconductors for the entire European industry and society.

Currently, Europe has an overall global semiconductors production market share of less than 10% and is heavily dependent on third-country suppliers. In case of severe disruption of the global supply chain, Europe's chips' reserves in some industrial sectors (e.g., automotive or healthcare devices) could run out in a few weeks, bringing many European industries to a standstill. As the digital transformation accelerates and penetrates every part of society, industrial needs for chips are set to increase, opening new market opportunities.

In its updated Industrial Strategy published in 2021, the EU stated its intention to double its share of global semiconductor manufacturing to 20% of worldwide manufacturing by 2030.

Europe witnessed the largest annual growth in semiconductor sales in May 2021, according to the European Semiconductor Industry Association (ESIA), sales increased by 31.2% compared with May 2020, totalling $3.8bn. However, Europe accounts for only 8.7% of global semiconductor sales. This constitutes a significant gap in the EU reaching its target of 20% of the global market by 2030[8].

High-purity graphite components are crucial to processes in the semiconductor industry. All processes used to grow semiconductor crystals operate at high temperatures in aggressive environments – whether Czochralski (CZ) for silicon, Heat Exchange-Method (HEM) for sapphire or Physical Vapor Transport (PVT) for SiC bulk growth. Therefore, the hot zones of industrial crystal growth furnaces are generally equipped with heat- and corrosion-resistant graphite components. Graphite’s unique ability to conduct electricity while dissipating or transferring heat away from critical components makes it a great material for electronics applications including semiconductors.

[8] https://blog.ohiocarbonblank.com/high-thermal-electrical-conductivity-properties-graphite-make-widely-used-electronics-applications/

Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net

Nanotechnology and Semiconductors

As devices and electronics are becoming smaller and smaller, carbon nanotubes are becoming the norm, and they are proving to be the future of nanotechnology and the semiconductor industry. Graphene is what scientists and engineers call a single layer of graphite at the atomic level, and these thin layers of graphene are being rolled-up and used in nanotubes. This is likely due to the impressive electrical conductivity and the material's exceptional strength and stiffness. Today's carbon nanotubes are constructed with a length-to-diameter ratio of up to 132,000,000:1, which is significantly larger than any other material. Besides being used in nanotechnology, which is still rather new in the world of semiconductors, it should be noted that most graphite manufacturers have been making specific grades of graphite for the semiconductor industry for decades.

Ion Implantation

Graphite is also being used with more frequency in the electronics industry. Ion implantation is an engineering process where ions of a particular material are accelerated in an electrical field and are impacted into another material, as a form of impregnation. It is one of the fundamental processes used in the production of microchips for our modern computers, and graphite atoms are typically one of the types of atoms that are infused into these silicon-based microchips.

Besides graphite's unique role in the production of microchips, graphite-based innovations are now being used to replace traditional capacitors and transistors as well.

C.4 Graphite, the ideal material for defence purposes

Carbon-based composites, including carbon reinforced composites and carbon-matrix composites, in defence technologies have raised a lot of attention due to its significant physical capabilities, superior thermal and mechanical stability, and its eco-friendly nature. Carbon-based composite are the greatest viable option for the development of advanced defence technologies[9].

Graphite is the ideal material for defence purposes thanks to several its unique properties:

- It has the ability to withstand very high temperatures, with a high melting point;
- It is stable at these high temperatures;
- It is lightweight and easy to machine;
- It is corrosion-resistant.

Without graphite, aeroplanes could not be built in these modern times from the aluminium skin and components, titanium frame and structural components, engine seals, bearings, turbine blades. Vacuum furnaces for heat treatment, vacuum casting, electron beam welding, coating, annealing, surface hardening, purity and consistency of parts, all require equipment with graphite parts and components.

9 Recent applications of carbon-based composites in defence industry: A review
Author links open overlay panel M.M.Harussani[a] S.M.Sapuan[ab], GoharNadeem[cd] TahrimRafin[a] W.Kirubaanand[a], https://doi.org/10.1016/j.dt.2022.03.006

As it’s an industry where there is little room for error. Itis essential that the materials used are able to withstand extreme environments. Luckily, graphite meets such requirements:

- It can withstand temperatures of over 3000°C.
- It is very stable, allowing it to retain its strength, even at these high temperatures.
- Graphite is a chemically inert material, so it won’t undergo any type of reaction when it comes into contact with other chemicals.
- Graphite components can be long-lasting and can be reused many times.

High-temperature applications such as the heat treatment of metals under vacuum or hot gas duct components require the use of Graphite and Carbon. Machined to the appropriate shape and size, Graphite and Carbon can withstand the demanding high temperatures where other products would fail.

Current applications of carbon-based composites in defence fields[10].

Carbon	Defence fields	Key points
Carbon	Aerospace	In rockets, it was employed in the combustion chamber.
Graphite	Aerospace	Raw material for the Hubble Space Telescope's antenna boom.
CNT yarn	Aviation and aerospace	The ability to build net form multifunctional components using additive manufacturing on a quadcopter frame.
Continuous CF	Aviation and aerospace	The printed composite with 27% fibre content has a flexural strength of 335 MPa and a modulus of 30 GPa.
CF	Aviation and aerospace	The compressive strength of the 3D printed composites was 17.17 MPa, with a fibre content of 11.5%.
Short CNTs	Airframes for commercial aircraft	The laminated FFRC plates have greatly increased vibration amplitude attenuation and natural frequency attenuation.
Recycled CF	Aircraft	It makes reused CF more active on the surface.
CF	Aeronautic structural	The CFs were found to be able to tolerate a power density of around 1 kW/cm^2 and a surface temperature of 3250 °C.
Woven CF cloth	Aviation and aerospace	Since laser-induced plasma absorbed a considerable portion of the input laser energy, the ablation effects on the layer were decreased.
CF	Aviation and aerospace	Due to the sheer high temperature at the laser spot's centre, an elevation in laser energy contributed to surface coating ablation.

10
Recent applications of carbon-based composites in defence industry: A review
Author links open overlay panel M.M.Harussani[a] S.M.Sapuan[ab], GoharNadeem[cd] TahrimRafin[a] W.Kirubaanand[a], https://doi.org/10.1016/j.dt.2022.03.006

Carbon	Defence fields	Key points
CF	Aeronautic and defence	Both the 4 and 8 ply laminas have a tensile strength of roughly 292 MPa.
Graphite	Aeronautic materials	Carbon fibre laminates exposed to laser irradiation experience thermomechanical weakening.
CNT	Aerospace	CNT/PI composites' strength and modulus were dramatically increased, reaching 3.9 GPa and 182 GPa, respectively.
Continuous carbon	Military automotive	The tensile strength of the reinforced nylon polymer increased equivalent to 6.3 times that of the control one.
CF	Military automotive	By raising the fibre volume percentage, the Young's modulus were enhanced.
SWCNT	Military automotive and defence	PVOH grafting improved the stability of the SWCNT loading fractions (45 wt%), leading in higher strength (1100 MPa) and stiffness (38.5 GPa); simultaneously, its strain-to-failures rose significantly (23.3%), leading to elevated toughness (125 J/g).
CNT	Military automotive and defence	In modified composites, there is increased peeling (74.38%) and tensile (164.76%) strength.
CF	Military automotive, aviation and aerospace	With increased stiffness, it has the best interlaminar shear performance.
Continuous carbon fibre	Military automotive, aviation and aerospace	The mechanical properties of these novel printed thermosetting composites were better.
Nano-phased carbon	Military maritime	In comparison to a pristine one, flexural strength and modulus were enhanced by 25% and 13%, respectively.
Short carbon fibre	Military automotive	Increased fibre length can improve the thermal stability and damping qualities of SCF/PP composites.
Carbon	Navy ships	As collapse pressures approaching 600 levels (6000 m intensity) were obtained for deep ocean applications.
Activated carbon fibre	EMI	In the frequency range of 1–1.5 GHz, the shielding efficacy is 39 dB. The emergence of surface pores increased the surface area.

D. References

Batteries Europe (2020), Strategic Research Agenda for batteries 2020.

Council of the European Union, Trio Presidency (2022), Critical raw materials

European Commission (2020), Study on the EU's List of Critical Raw Materials - Critical Raw Materials Factsheets

European Association for Storage of Energy (EASE) (2022), Energy Storage Targets 2030 and 2050, https://ease-storage.eu/publication/energy-storage-targets-2030-and-2050/

European Commission (2021), EU Reference Scenario 2020: Energy, transport and GHG emissions - Trends to 2050.

European Commission (2021), Raw Materials Scoreboard

European Commission, EU Science HUB, Raw Materials Information System, https://rmis.jrc.ec.europa.eu/?page=analysis-of-supply-chain-challenges-49b749

International Energy Agency (2021), The Role of Critical Raw Materials in Clean Energy Transitions

International Energy Agency (2020), Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems

International Energy Agency (2021), Net Zero by 2050 Scenario

International Energy Agency (2022), Securing Clean Energy Technology Supply Chains

Joint Research Centre (2013), Critical Metals in the Path Towards the Decarbonisation of the EU Energy Sector.

Joint Research Centre (2020), Raw materials demand for wind and solar PV technologies in the transition

towards a decarbonised energy system.

Joint Research Centre (2011), Critical Metals in Strategic Energy Technologies.

Kiemel, S., Smolinka, T., Lehner, F., Full, J., Sauer, A., Miehe, R. (2021), Critical materials for water

electrolysers at the example of the energy transition in Germany.

McKinsey & Company (2022), The raw-materials challenge: How the metals and mining sector will be at

the core of enabling the energy transition.

MetalHub (2021) Why graphite electrodes are crucial for the steel industry, https://www.metals-hub.com/blog/why-graphite-electrodes-are-crucial-for-the-steel-industry/

Mike Walsh (2021) European Electric Steelmaking – No Change to All change

Rieger et al. (2021), Residue Valorization in the Iron and Steel Industries: Sustainable Solutions for a Cleaner and More Competitive Future Europe.

ScienceDirect, Harussani, Sapuan, Nadeem, TahrimRafin, Kirubaanand (2022), Recent applications of carbon-based composites in defence industry: A review

SolarPower Europe (2021), Global Market Outlook for Solar Power 2021-2025.

SolarPower Europe (2021), Solar Sustainability: Best Practices Benchmark.

SolarPower Europe & LUT University (2020), 100% Renewable Europe: How to Make Europe's Energy System Climate-Neutral Before 2050.

Swann, W., Hanus, F., Vasart, O., Knight, A. (2021), Steel: friend or foe in the face

The OCB Blog Insights (2018) Graphite Use In Electronics Applications

Wood Mackenzie (2021) Graphite Market 2021 Outlook to 2050

Wood Mackenzie, (2022) Global graphite short-term outlook April 2022

Wood Mackenzie, (2022) Global graphite short-term outlook July 2022

European Carbon and Graphite Association asbl
Avenue de Tervueren 168, box 11 • B-1150 Brussels, Belgium • Tel +32 477 225 303 • E-mail: graphit@ecga.net