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Equity Research
Global | Asia Pacific | Australia

Climate Transition Super Materials

Graphite – Electrifying Net Zero

ESG Report

Thematic Research | Environmental, Social and Governance (ESG) Research

ESG Research

We return to the Climate Transition Super Materials series after our initiation report on Boron, in which we assess transition materials critical for all the technologies needed for reaching Net Zero. In this report we review Graphite, a material which combines strong heat resistance, electrical conductivity and chemical inertness, giving it unique exposure to electrification.

- **Graphite – a critical enabler of electrification**: Close to half of graphite demand is from steel-making, with graphite for electrodes and refractories representing 32% and 17% of demand, respectively. But, graphite's unique suitability to forms of electrification sees end demand from decarbonisation technologies rise to 85% of total demand by 2050 due to exposure to Li-ion batteries, electric arc furnaces (EAF), vanadium redox flow batteries (VRFBs), and potentially, in hydrogen fuel cells, and nuclear power. The importance of graphite is underlined by its recent classification as a critical mineral by the US and EU, and with 73% of natural graphite extraction in China, there are moves to diversify supply.
- **Graphite is a high impact transition material with a growing supply deficit:** We estimate potential demand for graphite could be 5.3x greater than current levels by 2050. While changes in technology may have big implications for overall demand (EVs grow to 74% of total demand), our assessment of alternative materials and technologies leads us to conclude that graphite will remain the dominant anode material for the foreseeable future. A combination of mining lead times, lengthy material qualification processes, China energy policy impacts to synthetic production, and the unfunded status of several new mines, may cause a sustained supply deficit and put significant upward pressure on pricing, in our view. We forecast a 10% deficit in CY2022 in the battery anode market, but this widens substantially to 32% by 2025. For comparison, CS forecasts lithium to have a 17% supply deficit for CY22 but return to a more manageable 1% surplus by 2025.
- **Natural graphite grows in importance**: Currently 58% of battery anode material is made from synthetic graphite and 39% from natural graphite. In 2030, it is projected that 41% will be synthetic and 49% natural. Spherical graphite made from natural graphite has a higher power capacity and is less expensive than synthetic. Moreover, production of synthetic has an emissions-intensity >3x greater than natural graphite, and this is playing a larger role in auto OEMs supply considerations, especially as carbon pricing mechanisms extend. We also note that developments in purification and spheronisation technologies may be lowering costs and could see natural graphite disrupt other end-market applications. Natural graphite pricing is already responding, with the average flake price increasing by 19% through 2021 but spiking 38% since November 2021.
- **Value chain and stock ideas**: Currently, 61% of synthetic graphite production and 83% of anode production occurs in China. However, the value chain is evolving rapidly, marked by increased vertical integration. Throughout the report we identify 50 stocks across the value chain comprised of coke producers, natural graphite producers, battery anode suppliers, and EAF graphite electrode manufacturers. From these we have applied financial screens to identify our top 35 exposures to the graphite thematic (See Figure 7).

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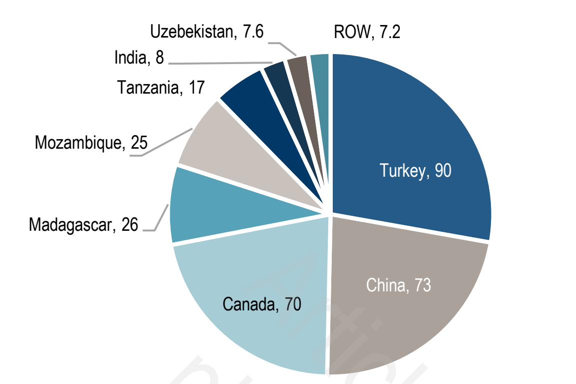
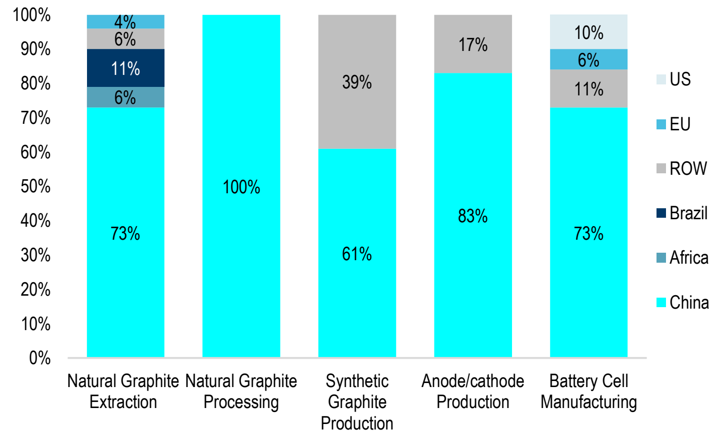
Key charts

Figure 1: Natural graphite reserves by country (Mt)



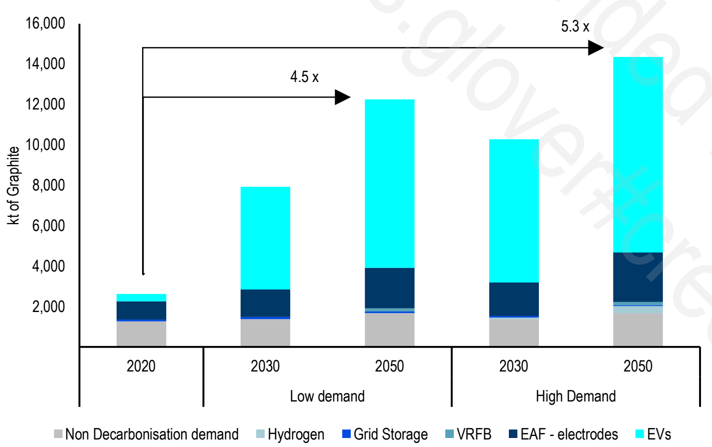
Source: Credit Suisse - Super Materials Demand Model

Figure 2: China dominates the graphite anode value chain



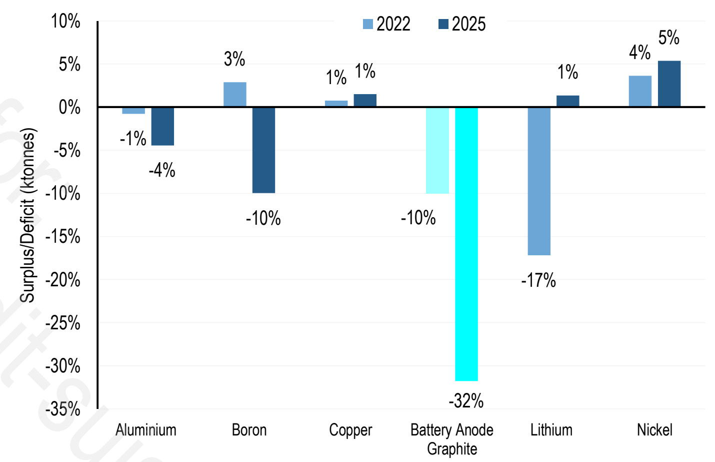
Source: USGS 2021

Figure 3: Annual graphite demand to be 4.5-5.3x demand today under CS Super Materials demand model



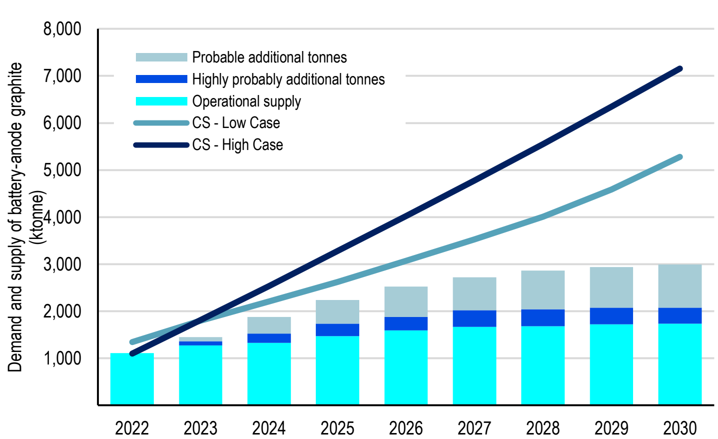
Source: Credit Suisse - Super Materials Demand Model

Figure 4: 2022E vs 2025E forecasted surplus/deficit shows a sustained deficit for graphite used in Li-ion batteries



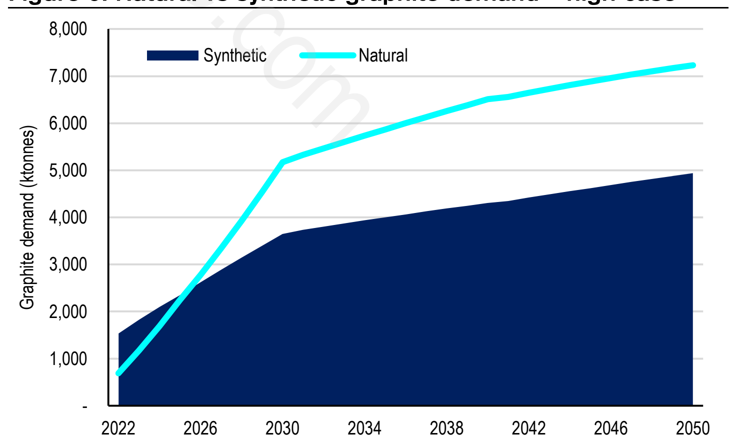
Source: Credit Suisse - Super Materials Demand Model; CS commodities

Figure 5: Demand outstrips supply in both a high and low case



Source: Credit Suisse - Super Materials Demand Model; CS commodities

Figure 6: Natural vs synthetic graphite demand – high case



Source: Credit Suisse - Super Materials Demand Model

Figure 7: Companies with exposure to the graphite value chain

Theme	RIC	Company	Rating	Market Cap (US$ Bn)	PE (x)		EV/EBITDA		Sales growth		EBITDA growth		Key HOLT metrics			ESG (Refinitiv)	
					2022	2023	2022	2023	2022	2-yr growth	2022	2-yr growth	Quality	Momentum	Valuation	ESG Score	ESG Momentum
Synthetic graphite coke	PSX	Phillips 66	O	41.6	11.1	10.8	6.7	6.5	15%	3%	14%	7%	29	73	63	84	20%
	8053.T	Sumitomo Corp	NC	21.5	6.7	7.4	13.6	13.6	5%	1%	1%	-1%	21	91	86	61	5%
	5401.T	Nippon Steel	NC	16.0	5.5	6.0	4.9	4.9	8%	1%	-1%	0%	10	69	89	59	8%
	IOC.NS	Indian Oil Corpn	NR	15.1	5.7	5.6	5.7	5.6	17%	9%	-4%	0%	49	53	70	71	13%
	5020.T	ENEOS Holdings	NC	11.9	5.9	6.4	4.7	4.6	9%	5%	-12%	-6%	17	43	93	67	9%
	600516.SS	FangDa Carbon	NR	5.1	18.4	11.4	16.0	9.6	32%	35%	61%	74%	48	76	54	29	10%
	600688.SS	Sinopec Shanghai Petrochemical	U	4.8	14.3	14.3	7.8	7.7	8%	5%	-12%	-6%	31	22	55	62	60%
	EAF	Graftech International Ltd.	O	2.5	5.3	5.5	5.3	4.8	13%	7%	4%	1%	97	14	77	46	12%
	1907.HK	China Risun	NR	2.4	4.5	3.4	na	na	26%	23%	na	na	na	na	na	na	na
	300080.SZ	YCNE	NR	1.5	na	na	na	na	na	na	na	na	na	na	na	na	na
	601011.SS	BNMC	NR	1.4	na	na	na	na	na	na	na	na	na	na	na	na	na
	GRPH.NS	Graphite India	NR	1.3	10.0	8.3	na	na	37%	25%	173%	84%	27	25	81	na	na
	HEGL.NS	HEG	NR	0.7	5.5	4.9	na	na	25%	21%	42%	27%	27	16	84	na	na
Natural graphite	SYR.AX	Syrah Resources	N	0.9	na	29.9	42.6	11.1	377%	158%	na	na	24	91	75	50	26%
	RNU.AX	Renascor Res	NR	0.4	na	na	na	na	na	na	na	na	na	na	na	na	na
	TLG.AX	Talga Group	NR	0.4	na	9.3	na	na	13811%	5293%	na	na	na	na	na	na	na
	NOU.V	Nouveau Monde	NR	0.4	na	na	na	na	na	na	na	na	na	na	na	na	na
	MNS.AX	Magnis Energy	NR	0.4	na	na	na	na	na	na	na	na	na	na	na	13	8%
	NEXT.TO	NextSource	NR	0.3	na	na	na	77.3	na	na	na	na	na	na	na	na	na
	EGR.AX	Ecograf	NR	0.2	na	na	na	na	na	na	na	na	na	na	na	na	na
	BKT.AX	Black Rock Mining	NR	0.2	na	na	na	na	na	na	na	na	na	na	na	na	na
Anode material supplier	603659.SS	Shanghai Putailai New Energy Tech.	NR	15.6	37.1	26.3	28.0	20.0	57%	49%	59%	50%	67	93	25	1	na
	600884.SS	Ningbo Shanshan	N	9.5	16.4	12.8	11.7	9.5	16%	20%	17%	20%	19	43	66	na	na
	4188.T	Mitsubishi Chem	NC	9.4	7.5	7.5	6.0	5.7	8%	5%	2%	2%	12	57	47	61	0%
	5411.T	JFE Holdings	NC	7.9	5.1	5.7	5.5	5.7	7%	1%	-2%	-3%	10	52	90	70	4%
	003670.KS	Posco Chemical	NR	7.6	61.3	44.4	32.6	24.1	23%	32%	24%	32%	32	29	9	51	1%
	000009.SZ	China Baoan Grp	NR	4.6	18.9	12.3	na	na	40%	38%	na	na	23	48	34	na	na
	300035.SZ	HNZK Electric.	NR	3.6	28.1	18.9	na	na	81%	62%	95%	73%	na	na	na	na	na
	4004.T	Showa Denko	NC	3.5	9.8	6.6	5.8	5.5	-3%	2%	2%	8%	37	19	82	64	9%
	NVX.AX	Novonix	NR	2.3	na	na	na	75.9	314%	262%	na	na	27	35	36	5	na
	300077.SZ	Nations Tech	NR	1.8	na	na	na	na	na	na	na	na	31	66	8	na	na
	300890.SZ	XFH Technology	NR	0.8	26.9	17.7	na	na	26%	28%	61%	52%	na	na	na	na	na
EAF graphite electrode	600516.SS	FangDa Carbon	NR	5.1	18.4	11.4	16.0	9.6	32%	35%	61%	74%	48	76	54	29	10%
	4004.T	Showa Denko	NC	3.5	9.8	6.6	5.8	5.5	-3%	2%	2%	8%	37	19	82	64	9%
	EAF	Graftech International Ltd.	O	2.5	5.3	5.5	5.3	4.8	13%	7%	4%	1%	97	14	77	46	12%
	5301.T	Tokai Carbon	NC	2.0	9.8	8.0	na	na	16%	12%	38%	25%	30	12	71	57	24%
	300080.SZ	YCNE	NR	1.5	na	na	na	na	na	na	na	na	na	na	na	na	na
	GRPH.NS	Graphite India	NR	1.3	10.0	8.3	na	na	37%	25%	173%	84%	27	25	81	na	na
	SGCG.DE	SGL	NC	0.8	17.6	12.1	9.1	7.1	4%	5%	1%	13%	7	35	11	69	7%
	HEGL.NS	HEG	NR	0.7	5.5	4.9	na	na	25%	21%	42%	27%	27	16	84	na	na
	5302.T	Nippon Carbon	NC	0.4	11.2	8.4	na	na	12%	11%	45%	32%	24	21	51	na	na

Source: Credit Suisse HOLT®, Credit Suisse Research, Refinitiv Eikon
(as at 1 April 2022)

Executive Summary

We return to the Climate Transition Super Materials series after our initiation report on the opportunity in Boron. In this series, we expand on the role of critical minerals in the *energy transition* by outlining a framework for assessing all materials critical for enabling all technologies needed for reaching Net Zero. In this report, we apply the CS Super Materials assessment framework to Graphite, a crystalline form of carbon which combines strong heat resistance with electrical conductivity and chemical inertness, giving it unique exposure to electrification.

- **Use today and decarbonisation tomorrow:** Close to half of all graphite demand is from the steel-making industry, with graphite for electrodes and refractories representing 32% and 17% of demand, respectively. Outside of this graphite is critical for lubricants, coatings, metallurgy, various auto engine components and the trusty pencil. Demand for graphite from the lithium-ion battery market holds a lot more growth opportunity and has already reached 13% of global demand, but is forecast to grow aggressively. We also find that graphite is essential for other decarb technologies, such as electric arc furnaces (EAF), vanadium redox flow batteries (VRFBs), hydrogen fuel cells, and nuclear power.

- **Graphite - a high impact transition material:** Using the CS Super Materials demand model, we estimate potential demand for graphite could be 5.3x greater than current levels by 2050 with over 85% of demand coming from decarbonisation technologies. Graphite therefore has major applications under a Net Zero world and is classified as a **high impact material.** While graphite has high levels of future demand relative to 2020 levels, changes in technology may have big implications for overall demand. Under our technology concentration index, graphite is essential for technologies that contribute 21% of emission reduction under Net Zero, however demand is concentrated in EVs at 74% of total demand, giving it a higher relative level of technology concentration risk.

- **Supply deficit set to grow**: We forecast a 10% deficit in CY2022 for the battery anode graphite market, but this widens substantially to 32% by 2025. For comparison, CS forecasts lithium to have a 17% supply deficit for CY22 but return to a more manageable 1% surplus by 2025. While there is no shortage of natural graphite reserves, a combination of mining lead times, lengthy material qualification processes, China energy policy impacts to synthetic production, and the unfunded status of several new graphite mines, may cause a sustained supply deficit and put significant upward pressure on pricing. The average flake price increased by 19% through 2021 but has spiked 38% since November 2021.

- **Natural graphite grows in importance**: Currently 58% of battery anode material is made from synthetic graphite and 39% from natural graphite. In 2030, it is projected that 41% of anode material will be synthetic and 49% natural. Natural spherical graphite has a higher power capacity and is less expensive than synthetic. Moreover, production of synthetic has an emissions-intensity >3x greater than natural graphite and new developments lowering spheronisation costs may see natural graphite disrupt other end-market applications. Finally, our assessment of the potential for greater silicon doping in anodes and All Solid State Batteries leads us to conclude that graphite will remain the dominant anode material for decades to come.

- **An evolving value chain**: Currently, 73% of natural graphite extraction and 61% of synthetic graphite production occurs in China on lower energy cost / environmental standards. Further downstream, 83% of anode production occurs in China. We note the value chain is rapidly evolving, marked by increased vertical integration to capture value and lower costs. Notably, while there is a high barrier to entry in anode manufacturing, there is rising competition in the spheronisation stage, which may lower cost and benefit natural graphite suppliers or those vertically integrated. Throughout the report we identify 50 stocks across the value chain comprised of synthetic graphite coke producers, natural graphite producers, battery anode material suppliers, and EAF graphite electrode manufacturers. From these we have applied market cap and other financial screens to identify our top 35 exposures to the graphite thematic.

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Climate Transition Super Materials

Society is in the midst of a major climate transition to lower carbon technologies and clean energy. The efforts of an ever-expanding number of countries, industries and companies to reduce emissions to Net Zero requires the deployment of a wide range of new climate technologies. The growth in the technologies critical for this climate transition will, in turn, be dependent on a wide range of critical minerals and specialty materials.

Low-carbon technologies and enabling infrastructure are significantly more mineral intensive vs fossil fuel technologies. A typical EV requires 6x the mineral inputs of a conventional car, and an onshore wind plant requires 9x more mineral resources than a gas-fired power plant (IEA). Since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% (as renewables have risen).

This creates risks and opportunities. While there has been a great deal of focus on modelling the demand for core energy transition materials such as copper, aluminum, and lithium, there is a broader range of materials with demand exposure to all of the technologies needed for Net Zero. In this report series, we outline a framework for assessing all investment opportunities under the concept of Climate Transition Super Materials. In this new report we review Graphite following our earlier initiation report on Boron.

For a complete description of the assessment methodology please see the Appendix.

CS Super Materials Framework

- **Demand opportunity from decarbonisation**: Building on modelling work undertaken by the World Bank to assess demand growth for critical minerals, we have developed a Climate Super Materials Demand Model that captures a broader range of low carbon technologies. This is made up of two equally weighted components: (1) **The Production-Demand Index** captures the scale to which production must increase to meet demand from energy technologies and includes by relative and absolute demand; and (2) **The Technology Concentration Index** captures how cross-cutting or concentrated in the decarbonisation technologies the minerals are in the model. Finally, we also review the extent to which efficiency improvements could impact demand.

- **Supply-demand dynamic**: Here, more traditional supply metrics are incorporated such as reserves and production and committed mine production vs primary demand. However, we also consider this in the context of the average lead times from discovery to production, to see how much actual production could lag growing demand. Finally, we also assess the geographic concentration of production. For example, in the cases of lithium, cobalt and rare earth elements, the world's top three producers control well over three-quarters of global output (IEA).

- **Circular economy**: Recycling relieves the pressure on primary supply. For bulk metals, recycling practices are well established, but this is not yet the case for many climate transition materials such as lithium and rare earth elements. Emerging waste streams from clean energy technologies (e.g. batteries and wind turbines) can change this. The amount of EV batteries reaching the end of their first life is expected to surge after 2030, at a time when mineral demand is set to still be growing rapidly (World Bank). We therefore also assess Super Materials on both current End of Life Recycling Rates and the percentage of New Product made using Secondary Materials recovered.

- **Impact intensity of production:** Finally, we consider a broad range of environmental factors to consider the relative attractiveness of different materials based on the impact of production and refining methods. This includes the global warming potential of the production, such as through assessment of Cradle to Gate Emissions and Emissions Intensity per Tonnes of Production. Energy intensity of production through assessment of Energy Share in Mining Cash Cost and Electricity Cost in Total Refining. Finally we review water consumption and pollution, biodiversity and waste risks.

Graphite 101

Graphite is one of the three crystalline forms of carbon, where the others are diamond and fullerenes. These are allotropes of carbon as they all contain the same element, in this case carbon, but present in different forms because the carbon atoms are bonded together in different arrangements or lattices. This creates different physical and chemical properties. Graphite has favourable properties that make it an effective material in a range of applications. It has high electrical and thermal conductivity, yet is extremely heat resistant. It has a high energy density, but is nearly inert so that it doesn't react with other materials.

Types of graphite

There are three types of natural graphite and synthetic graphite:

- **Amorphous Graphite**: Although its name is a misnomer as it is not "amorphous" as the material is still crystalline, it has the lowest carbon content of the natural graphites. Amorphous graphite is made from the metamorphosis of anthracite coal seams. The graphite content varies from 70% to 85% according to the geological environment and must undergo the most extensive processing because of its low graphite content. Amorphous graphite makes up approximately half of the global natural graphite supply.
- **Crystalline Vein Graphite:** Also known as Sri Lankan graphite, Ceylon graphite, and Plumbago, the alternative names stem from the region where this graphite is mined. It's only sourced and processed in Sri Lanka although this form of natural graphite is also found in the UK and the US. Crystalline vein graphite is the highest quality natural graphite. Its graphitic content between 94-99%. The exact formative process is still uncertain but it is suspected it is deposited by a fluid phase transformed into graphite through time, temperature, and pressure.
- **Flake Graphite:** Formed when deposits of carbon come under pressure and temperature, the flake graphite is most often found in metamorphic rock and deposits are distributed fairly uniformly throughout the rock. It can vary in flake size and purity/carbon content. Sizes range from jumbo flake to a fine flake and content range between 5-40% although most economic deposits of flake graphite contain up to 90%.
- **Synthetic graphite** is fabricated by heat treatment of petroleum coke, coal-tar pitch or oil. Although this graphite is not as crystalline as natural graphite, it is likely to have higher purity, but its purity is dependent on the purity of the starting petroleum coke. Synthetic graphites are not a single material but are rather members of a broad family of essentially pure carbon. They can be tailored to vary widely in their strength, density, conductivity, pore structure, and crystalline development. These attributes contribute to their widespread applicability. Synthetic graphite typically comes in two forms: electrodes and graphite blocks for different use cases.

Figure 8: Amorphous Graphite

Source: BariteWorld

Figure 9: Flake Graphite

Source: Graphite Sop

Figure 10: Crystalline Vein Graphite

Source: BariteWorld

Figure 11: Synthetic Graphite

Source: BariteWorld

Uses of Graphite

Traditional uses of graphite reflect its unique material properties such as an unusually high melting point, suitability for thermal and electrical conduction and lubrication. Another advantage of graphite has been the varying purities and properties across the four main categories – amorphous, flake, crystalline and synthetic – thus enabling more precise applications within industry and at differing cost points.

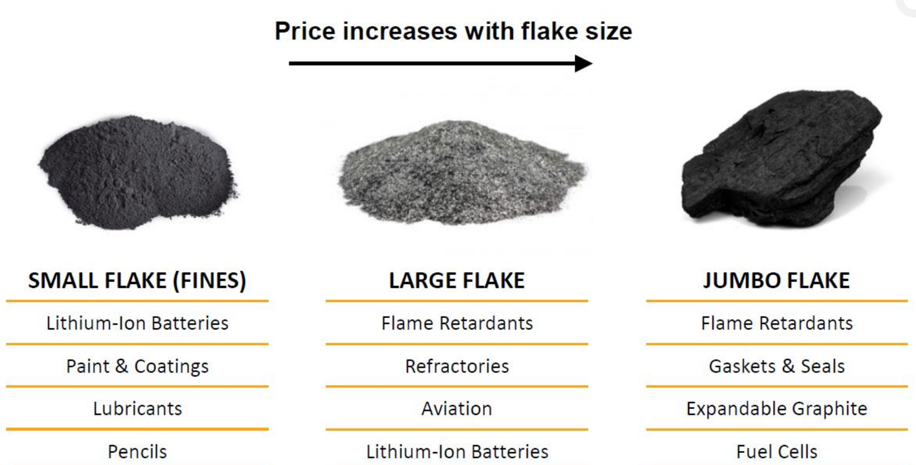
Close to half of all graphite demand is from the steel-making industry, with graphite for electrodes and refractories representing 32% and 17% of demand, respectively. In 2018, global steel production provided good support for the natural graphite market, with growth of more than 5% vs 2017 (World Steel Association). Looking ahead, demand from the steel industry is expected to remain flat given the maturity of this market. Demand for graphite from the lithium-ion battery market holds a lot more growth opportunity and has already reached 13% of global demand, and is forecast to grow aggressively as EV demand reaches a tipping point. Outside of this graphite is critical for lubricants, coatings, metallurgy and various auto engine components and the trusty pencil.

Figure 12: Uses of graphite by type

	Amorphous Graphite	Flake Graphite	Crystalline Vein Graphite	Synthetic Graphite
Foundries, Refractories, Crucibles	✓	✓		✓
Graphite electrodes in arc furnaces				✓
Lubricants and coatings	✓	✓	✓	✓
Powder Metallurgy		✓	✓	✓
Brake lining, clutch materials, gaskets, motor brushes	✓	✓	✓	✓
Pencils	✓	✓		
Lithium-ion batteries		✓	✓	✓
Vanadium redox flow batteries			✓	✓
Nuclear reactors		✓	✓	✓
Hydrogen Fuel cells		✓		✓

Source: Credit Suisse

Figure 13: Uses of natural flake graphite



Source: Black Rock Mining

Non-decarbonisation uses

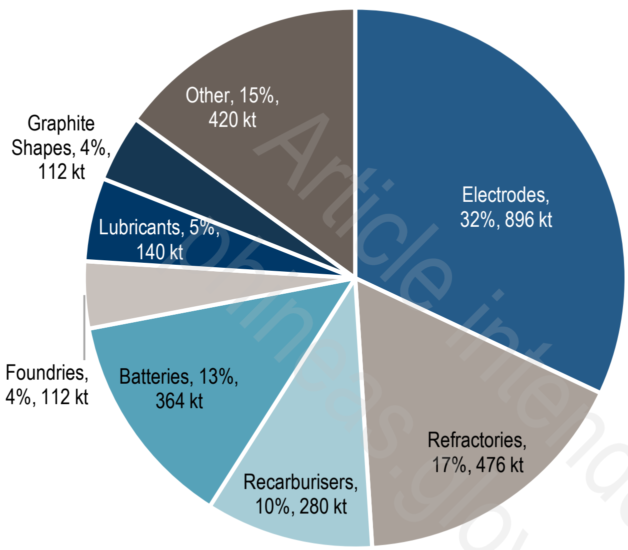
- **Refractories, Crucibles and Foundries:** Graphite is a refractory, a material with an unusually high melting point. Crucibles are furnace pots made from refractories used to heat and/or melt metals. Graphite is usually combined with other refractories including alumina and silicon carbide, with graphite being added for use in highly reducing environments including reducing iron to steel in steelmaking in both blast furnaces and electric arc furnaces. Flake and amorphous natural graphite or synthetic graphite are used.
- **Lubricants and coatings:** Typically amorphous graphite is used in lubrication. Graphite is a major additive to many coating systems where it provides functionality as a refractory, lubricant, thermal conductor, electrical conductor, UV shield, electromagnetic pulse shield, corrosion shield and pigment. The flexibility of flake graphite makes it an effective coating additive. Crystalline vein graphite and synthetic graphite are used to deliver superior performance with slightly higher thermal and electrical conductivity. Amorphous graphite is used when less reflectance is required as it is darker in colour.
- **Powder metallurgy:** Graphite is used in powder metallurgy as an alloying element to increase the strength of sintered parts. Graphite with different grain sizes are required to be employed for metal graphite alloys.
- **Brake lining, clutch materials, gaskets, motor brushes:** Graphite is a central material in the friction industry, especially in the production of brake and clutch linings for road, rail and industrial systems. This is due to its lubricating properties contributing to braking easily and noise reduction as well as its thermal conductivity. All types of natural and synthetic graphite are used depending on the breaking system, but vein crystalline is used in the automotive industry for high performance clutches and breaks.
- **Pencils:** Pencil lead is normally made from the lowest-quality amorphous graphite, and this particular use is primarily found in China.

Climate transition exposures

- **Lithium-ion batteries:** Graphite is used as the battery anode material in a lithium-ion battery. While silicon is being added to the anode to aid power density, there are no substitutes for use of graphite as the core anode material. Natural flake graphite and synthetic graphite are used but need to be transformed into spherical graphite, battery-grade graphite. The size and the purity of the flake graphite is taken into account in determining suitability but also due to cost considerations in the spheronisation process.
- **Electric arc furnaces (EAFs):** In addition to its application as a refractory used in the crucible in steelmaking, graphite electrodes are used in EAFs. As large electrical currents are passed through the low conductivity electrodes, the power crosses 'electric arcs' between the tips of the electrodes and across the liquid steel. There are no substitutes for graphite electrodes as graphite is the only material that can withstand the high temperatures and efficiently transmit the electrical power required to create the arc. Electrodes come in different grades depending on the energy requirements and are currently made from synthetic graphite using petroleum-based needle coke.
- **Nuclear:** Graphite can be used as nuclear moderators and as reflectors, but this is dependent on the type of nuclear reactor. Graphite bricks are used as a moderator to sustain the nuclear reaction by encasing the uranium. Nuclear-grade graphite is mainly manufactured from synthetic graphite from coke, but flake graphite and vein crystalline are used in some cases.
- **Vanadium-redox flow batteries (VRFBs):** Graphite is the most common electrode type used in VRFBs. The graphite electrode is a graphite felt created from graphitizing raw felt. Graphite can also be used in the bipolar plates, but metallic plates are also an alternative.

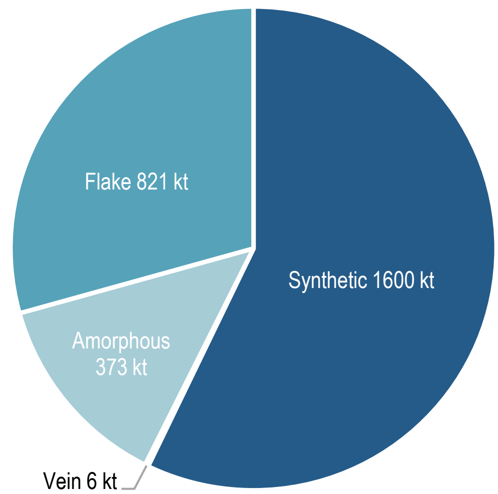
- **Hydrogen fuel cells:** Graphite bipolar plates can be used in hydrogen fuel cells. The graphite used in bipolar plates must be processed specifically for fuel cells and batteries, not all forms of graphite can provide the traits that bipolar plates need. Natural flake graphite is typically used for this purpose but needs to be mechanically or chemically processed or "upgraded" to reach the necessary purity levels.

Figure 14: World graphite demand by end use sector 2020



Source: BMO

Figure 15: Graphite production by type in 2020



Source: Argus Media, BMO, Credit Suisse estimates

Spherical graphite – turning graphite into anodes

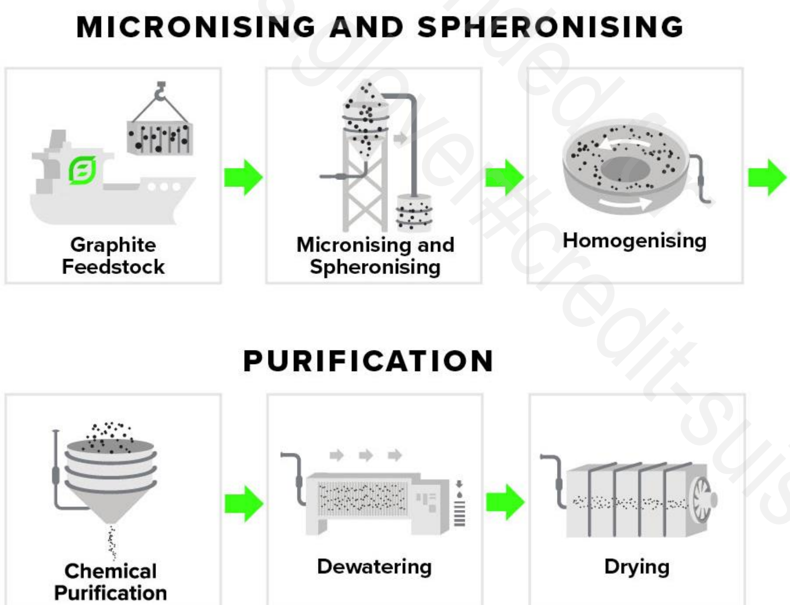
Anode material requires significant value-added processing across various technical steps in order to meet sufficient specification and performance requirements for autos and battery OEMs. Spherical graphite is manufactured from flake graphite concentrates to create high purity, high concentrated graphite to be used in battery anode materials. The spheronisation process decreases the surface area to allow more graphite into a smaller volume. This creates a smaller, denser, more efficient anode product for the battery, which allows for faster discharge rates. The process involves micronizing, rounding and purification.

- **Micronizing** involves reducing the flakes in size to approximately 10 to 15 microns from 100-300 microns. A human hair is about 70 microns in diameter. This is done in a train of pulverisers where flakes move through a cascading series of mills as they are crushed. This allows the lithium ions to transfer in and out of the anode, with lower micron levels harder to achieve but resulting in better battery/vehicle performance.
- **Spheronisation or "rounding":** Once the target size is achieved, the micronized graphite is then "rounded" which essentially involves rolling the flakes up like a snowball in similar mills. This increases surface area density and thus energy density potential but also results in significant yield losses (~30-70%) as flake edges are prone to breaking. This is where graphite quality pays; if the graphite flakes are too brittle then they break. Process yields have a direct impact on the amount of graphite concentrate feedstock required and consequently on costs as well (average industry anode process yields are ~50%).
- **Purification:** The rounded materials are then purified to increase carbon content to 99.95% using acid and thermal purification. This is a crucial step as impurities affect the overall chemistry of the battery and therefore performance. The main differences include power source, environmental standards, and purity.

- *Hydrofluoric acid* purification is the main method used in China where environmental and labour safety regulations are less stringent than other countries in the graphite value chain. This method is cheaper but creates issues with wastewater contamination.
- *Thermal purification* involves putting the material through high-temperature furnaces (1,500-3,000◦C), and hence requires low cost power sources to be cost competitive.

- **Coating:** Spheres are coated with a thin layer of pitch or asphalt and baked at over 1,200OC, the final step to reach battery-grade anode material. This covers the uSPG with a hard carbon shell that protects the sphere from exfoliation and degradation during expansion and contraction with charging and discharging. This enhances energy density as a smoother surface enables more lithium ions to attach to the anode during battery charging. Finally, it increases the safety and longevity of the battery by inhibiting side reactions with the electrolyte causing battery degradation.
- **Natural vs Synthetic process:** Synthetic graphite has a more isotropic structure, therefore the degree of milling/spheroidisation required is less. This is why purer and higher quality natural graphite has a cost advantage. Synthetic size distribution ranges are similar to what you see for natural graphite materials, but usually has a lower tap density. Milling yields are generally therefore higher; 70-90% depending on requirements (distribution, morphology and bulk density).

Figure 16: Manufacturing process for creating spherical graphite



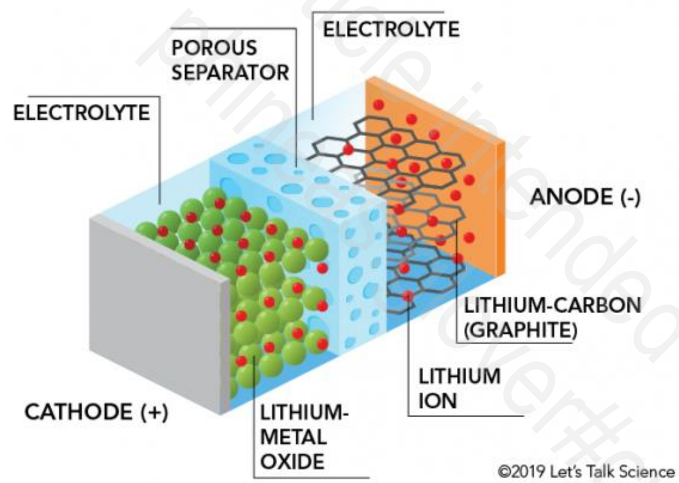
Source: EcoGraf

Climate Transition Technology Exposures

Lithium-ion batteries

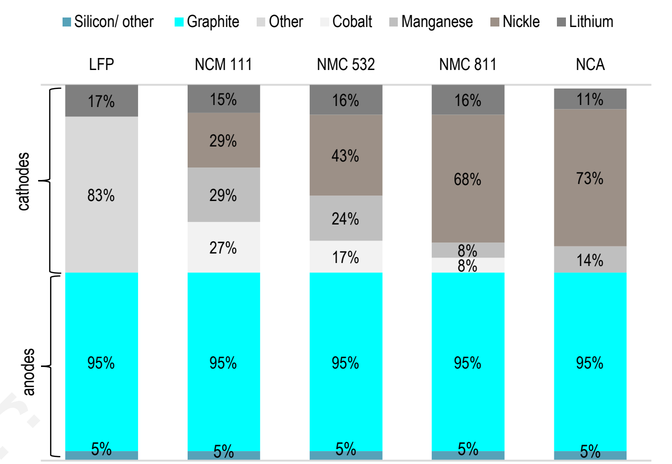
- **Li-ion technology:** A battery is made up of an anode, cathode, separator and electrolyte. A lithium-ion (Li-ion) battery is an advanced battery technology used in fuel cell electric vehicles and electricity storage, which uses lithium ions as a key component of its electrochemistry. During a discharge cycle, lithium atoms in the anode are ionized and separated from their electrons. The electrolyte carries positively charged lithium ions from the anode to the cathode, where they recombine with their electrons and electrically neutralize. Li-ion batteries can use a variety of different cathodes, but can currently only use graphite anodes for battery applications.

Figure 17: Parts of a Li-ion battery



Source: Let's Talk Science

Figure 18: Graphite is the dominant anode material



Source: Pallinghurst-Traxys, Black Rock Mining, Credit Suisse estimates

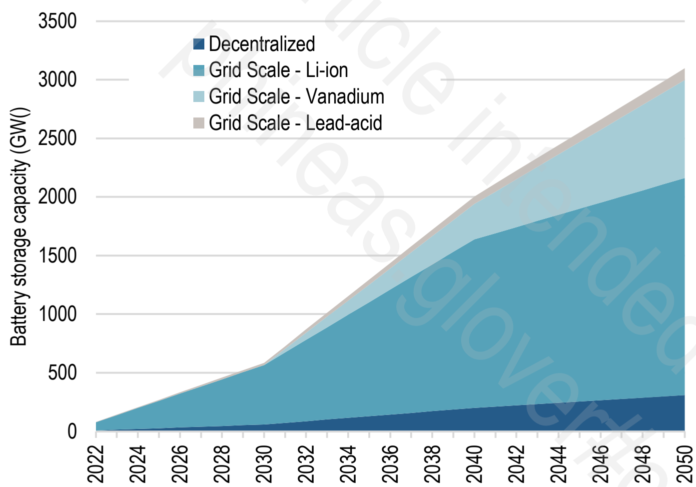
- **Graphite is the only anode material that can be used**. There are currently no commercial substitutes for this specific battery chemistry despite extensive research efforts on alternative anode materials. Graphite is currently the dominant choice for the anode in most lithium-ion batteries, although certain manufacturers also use lithium titanate instead of graphite. Efforts to replace some or most atoms of carbon in the graphite anode with silicon atoms are underway (e.g. Tesla, Porsche) and are expected to drastically improve the energy density of the cells. However, silicon anodes swell during charging, causing its surface to crack and performance to drop. For this reason, general industry consensus is that silicon will reach a 'battery stability' cap at approximately 10-15% of the anode.

- **Natural vs synthetic:** Both natural and synthetic graphite are used for Li-ion anode material, but natural flake graphite remains the preferred material with the highest carbon grades (94-97%) considered the best suited for use in batteries. It is this flake graphite that is then upgraded to 99.9% purity to make "spherical" graphite used in Li-ion batteries. Purified natural flake graphite has a more crystalline structure and offers better electrical and thermal conductivity than synthetic material, while synthetic material has a longer lifespan. Size is also an important factor when it comes to natural graphite for batteries. Typically, only small and medium flake sizes or fines (with a mesh size of -100) are used in the production of spherical graphite for battery production. Flake sizes that are larger than -100 mesh are not used.

- **How much graphite is used in a battery for electricity storage?** The amount of graphite anode in a lithium ion battery is around 1.2 kg per kWh. Under the IEA NZE, it estimates that there is over 3 TWh of storage by 2050.

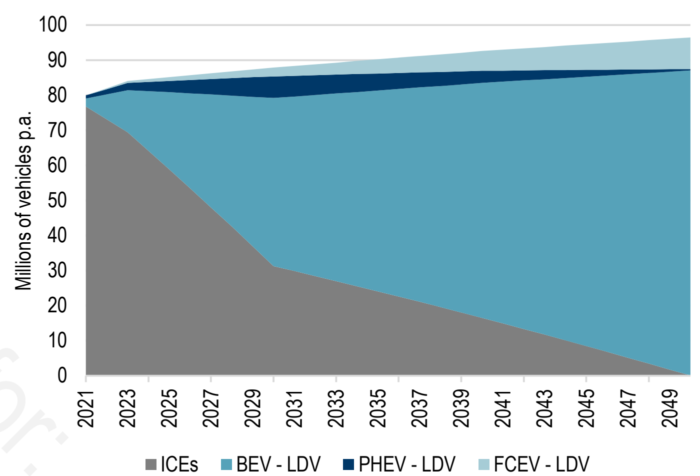
- **How much graphite is needed in an EV?** Graphite represents just under 50% of battery minerals in a Li-ion battery. There is up to 10kg of graphite in the average Hybrid Electric Vehicle and is between 60-80kg in an EV depending on the kWh. Li-ion batteries have a graphite intensity of 1.2kg/kWh (Benchmark Minerals), and assuming 64kWh per EV, there is approximately 76.8kg per EV (IEA). There is far more in a Tesla Model S. In our modelling we consider two demand scenarios. Our **high graphite demand scenario** uses the EV sales penetration rates under the IEA NZE where by 2025 global EV sales will make up 25%+ and beyond 50% in 2030, and reach 90% in 2040. We also test a **low graphite demand scenario** which takes a BAU approach to EV sales penetration to 2030, using our CS xEV model. Under this scenario, EV uptake is initially slower, reaching 19% in 2025 and 40% by 2030.

Figure 19: Demand for batteries under NZE



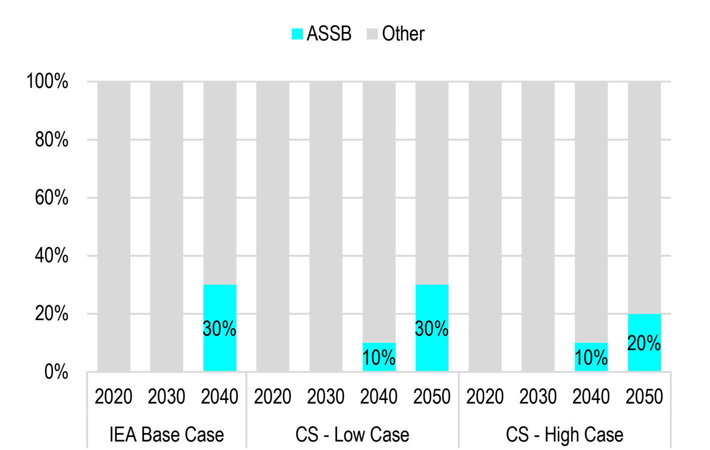
Source: IEA NZE, Credit Suisse estimates

Figure 20: Annual demand for EVs for new light vehicles sales under NZE



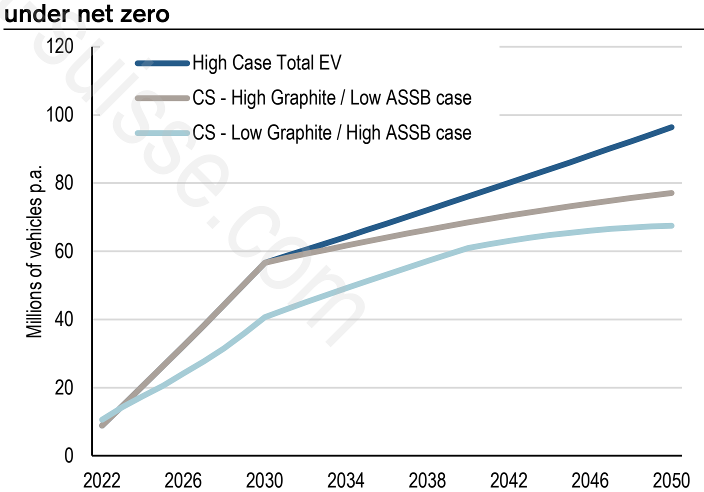
Source: IEA, Credit Suisse estimates

Figure 21: IEA Battery cathode chemistry penetration



Source: IEA, Credit Suisse estimates NB: Other refers to graphite-based-anodes

Figure 22: Annual demand for EVs for new light vehicles sales under net zero



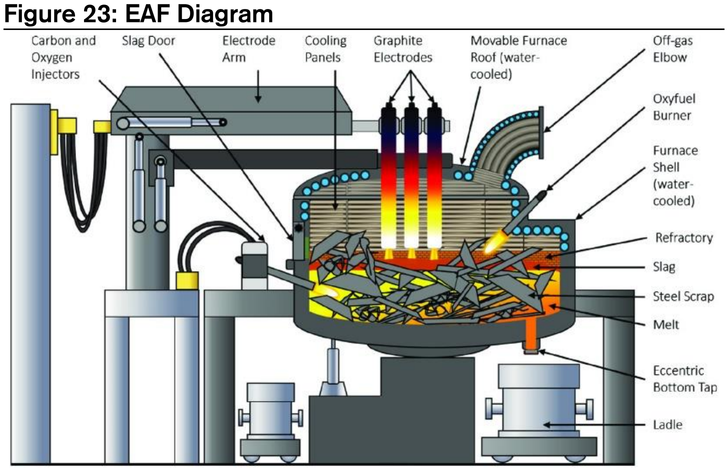
Source: IEA, Credit Suisse estimates

NB: the dark blue line is the number of EVs with graphite anodes under a net zero trajectory, the grey line shows the impact of low proliferation of ASSBs on graphite-anode EVs and the light blue line shows the impact of high proliferation of ASSBs

Electric Arc Furnaces

- **Graphite electrodes are used in electric arc furnaces (EAFs) and there is no alternative** material in this steel production process. As large electrical currents are passed through the low conductivity electrodes, the power crosses electric arcs between the tips of the electrodes and across the liquid steel. Ordinarily an EAF has three electrodes.
- **Graphite electrodes are consumed so are continually replaced:** Due to the heat and power required within EAFs, the electrode is consumed by the turbulent gases in the immediate vicinity. Consequently the electrodes are continually fed into the furnace, maintaining the optimal distance between the electrode and the liquid steel for arc continuity. Graphite is the only material that can withstand the high temperatures and efficiently transmit the electrical power required to create the arc mentioned above.
- **Synthetic graphite is currently used to make the electrodes:** Needle/petroleum coke is the main raw material used in the electrodes that producers say can take up to six months to make with processes including baking and rebaking to convert the coke into graphite. New purification and spheronisation technologies are being developed to provide cost-effective means to use greater amounts of natural graphite in electrodes.
- **1.7– 6 kg of graphite electrodes to produce one tonne of steel.** We've found a range of estimates for the amount of graphite in the electrodes which are consumed to create a metric tonne of steel. This is largely due to there being multiple different types of industrial EAF facilities. On average we believe there is approximately 3kg of graphite electrode used per tonne of steel produced.
- **Under NZE, EAF displaces met coal in steel making:** The NZE sees a radical technological transformation in the production of primary iron and steel driven by scrap-based electric arc furnaces, including hydrogen-based direct reduced iron facilities (DRI-EAF). In 2050, hydrogen-based DRI-EAF will contribute 13%, iron ore electrolysis-EAF 6%, and scrap-based EAF 53% of total steel production. EAF's total share of streel production rises from 24% currently to 38% in 2030 and 72% in 2050. As a result, the share of coal in total energy use in steel making drops from 75% in 2020 to 22% by 2050 and global steel demand in 2050 is 12% higher than today's current levels.
- **Graphite refractories are also used in steelmaking, with EAF have a slightly higher demand.** All steelmaking requires refractories, some that use graphite and some that do not. EAF consumes more refractory material than blast furnaces. Total consumption globally is about ~0.2kg/mt steel for BOF process and ~0.25-3/mt for EAF process.

Figure 23: EAF Diagram

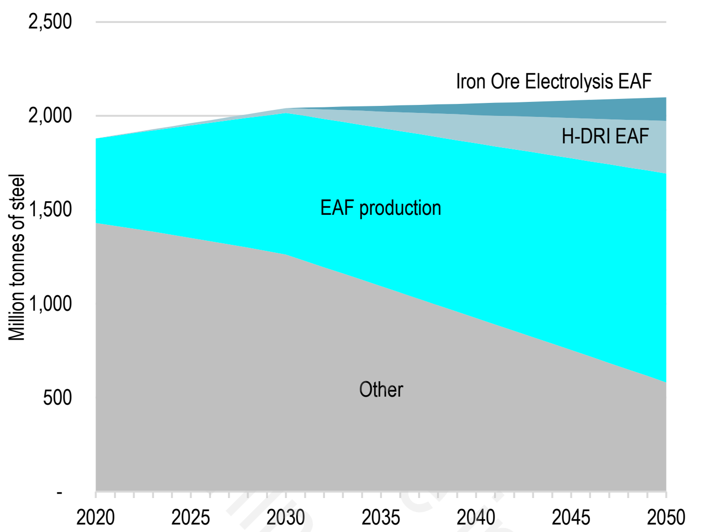


Source: Mainz 2016

Figure 24: Graphite electrodes

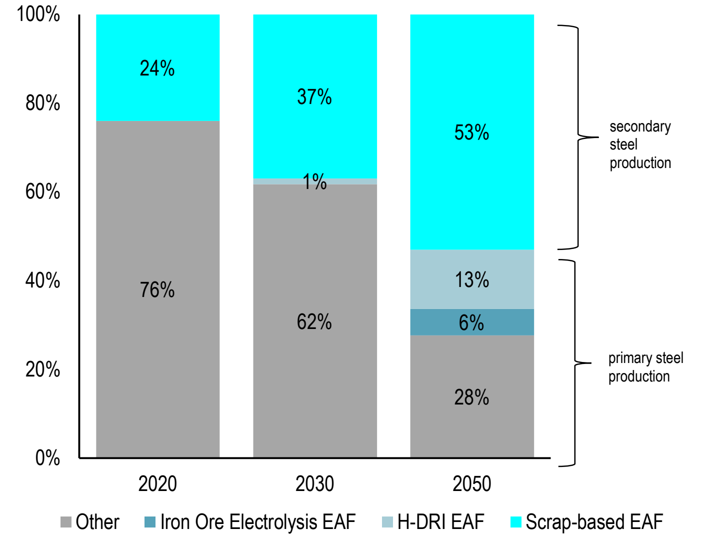
Source: Yeson

Figure 25: EAF steel production under NZE



Source: IEA NZE, Credit Suisse estimates

Figure 26: EAF production reaches 72% of total by 2050



Source: IEA NZE, Credit Suisse estimates

Vanadium redox flow battery

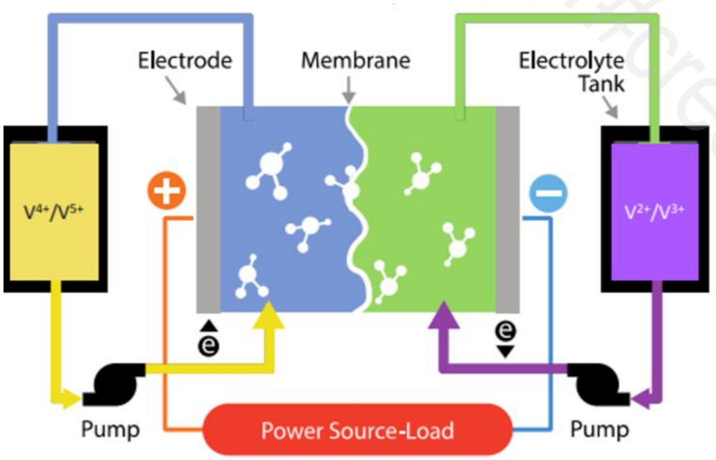
- **VRFB technology:** A vanadium redox flow battery (VRFB) is unlike conventional batteries where electrolytes are stored in the power cell of the battery. Instead the liquid electrolytes are stored in separate storage tanks and are pumped through a positive and negative electrode separated by a membrane. It is built on the chemistry of a reversible oxidation (redox) reaction to charge or discharge the battery. Redox flow batteries employ a completely novel technology, wherein their specific energy depends on the volume of the electrolyte and specific power depends on the surface area of the electrodes.

- **Graphite is the most common electrode in VRFBs…** The electrodes in a VFRB surround the power cell and proton exchange membrane, and the material used as the electrode plays a key role in determining the performance. Graphite felt created from graphitizing raw felt is the most common material due to its high conductivity, permeability, electrochemical stability and low production costs.

- **… and it can also be used in the bi-polar plates**: Graphite can also be used to as the bipolar plates, although metallic plates are also an alternative. See the next section on hydrogen fuel cells for more information on graphite bi-polar plates.

- **Nascent technology with scalable opportunity**: Although the technology was developed by NASA in the 1970s, VRFB is an emerging technology in stationary energy storage. Only 1 GW of capacity exists today globally. Despite this, the technology has the unique ability to scale or adjust the power and capacity independently compare to other battery technologies. They are heavy and large, and thus unsuitable for vehicles, but they can be built with extremely large capacities (up to 200 MW, compared with 100 MW for Li-ion) and have a long life span.

Figure 27: Design of a VRFB



Source: Bushveld Minerals

Figure 28: Graphite felt electrode

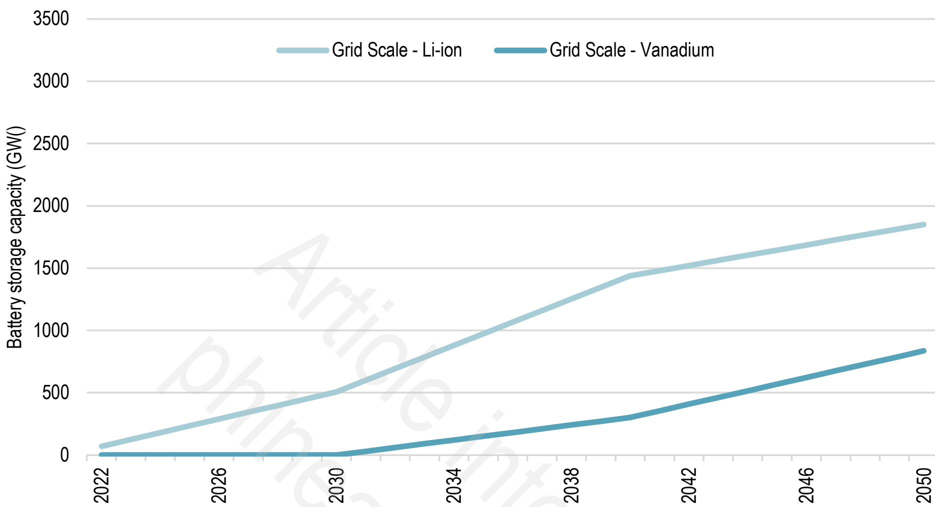
Source: SGL Carbon

- **Growth in VRFB:** As seen in Figure 29 , the capacity of VRFBs under the IEA NZE is expected to increase from 1 GW in 2021 to 23 GW in 2030 and to 124 GW in 2050, or 4% of total battery capacity. This is similar to the modelling completed by the World Bank which estimates VRFBs will account for 3-4% of battery capacity by 2050.

- **IEA expects VRFBs to be commercial by 2030.** Under a high demand scenario, the IEA models market share increases from 2030 onwards and captures almost a third of the energy storage market by 2050, with maximum applications in large wind and solar farms. To the extent that there is early commercialisation of VRFBs this would result in lower market shares for NMC chemistries. For example, demand for nickel, cobalt and manganese would be c. 20% lower in 2040 compared to the base case.

- **How much graphite is needed in VRFBs**: From consulting with industry, we find graphite electrodes in VFRBs use 3 tonnes of graphite per MW.

Figure 29: IEA NZE grid scale VRFB capacity to 2050 compared Li-ion batteries

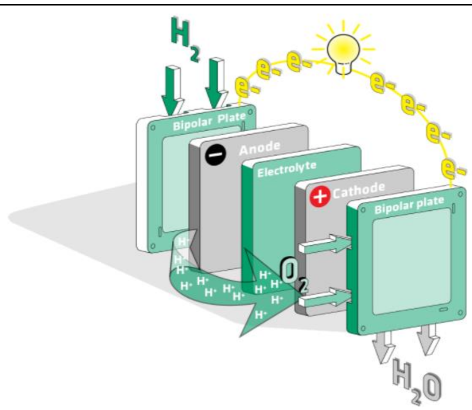


Source: IEA NZE, Credit Suisse estimates

Hydrogen Fuel Cells

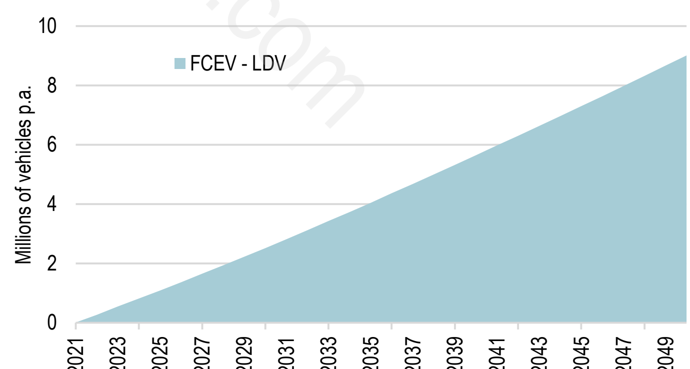
- **Hydrogen fuel cells work like an electric battery:** The cell converts chemical energy into electrical energy using the movement of charged hydrogen ions across an electrolyte membrane to generate current. There they recombine with oxygen to produce water – a fuel cell's only emission, alongside hot air.
- **Graphite is used as the bipolar plates in fuel cells.** Bipolar plates sandwich most of the components within a fuel cell, performing multiple functions. These plates distribute fuel and gas into the plate, prevent gases and moisture from leaking out of the plate, remove heat from the active electrochemical portion of the cell, and conduct currents between cells. As fuel cells are stackable the battery capacity can be increased, with the bipolar plates also responsible for electrical conductivity between the plates of the fuel cells.
- **High purity natural graphite:** The graphite used in bipolar plates must be processed specifically for fuel cells and batteries, as other forms of graphite don't provide all of the traits needed. Natural flake graphite is usually the raw graphite and needs to be mechanically / chemically processed and thermally purified to reach the necessary carbon levels for industrial applications. Like battery anode graphite, fuel cells require the highest purity graphite. Most conventional high volume stationary cells use etched graphite block which uses a pure natural graphite blend which is ~80%+ of the plate material contents (plates are 40% of the mass of the fuel cell). Most auto fuel cells are coated stainless steel (no natural graphite), or pressed graphite foils (using expanded natural graphite).
- **Alternatives to graphite unclear.** Stainless steel may be used for bipolar plates due to its mechanical strength and corrosion resistance lifespan. However, stainless steel lacks sufficient thermal and electrical conductivity for efficient operation. Gold can be used but is too expensive. Low-quality graphite offers the thermal and electrical conductivity that is required for efficient operation but doesn't last as long as high-quality fuel cell grade, as it's prone to premature corrosion due to impurities. Research has shown that investing in high-quality graphite is more cost-effective when the lifespan of fuel cells is taken into account, establishing it as the benchmark material for fabrication of bipolar plates.
- **How much graphite is used in a hydrogen fuel cell?** In 2020, FCEVs made up a very small share of the global stock of total vehicles (<0.01%) and of electric vehicles (0.3%). However, the FCEV market is beginning to take off, catalysed by developments in Asia and the United States. More than 40 000 FCEVs were on the road globally by the end of June 2021. Under IEA's NZE there is a large increase in the uptake of FCEVs reaching 15 million HCEVs on the road by 2030.

Figure 30: Bi-polar plates sit in-between fuel cells



Source: SuperiorGraphite.com

Figure 31: Demand for hydrogen FCEVs in new car sales under NZE

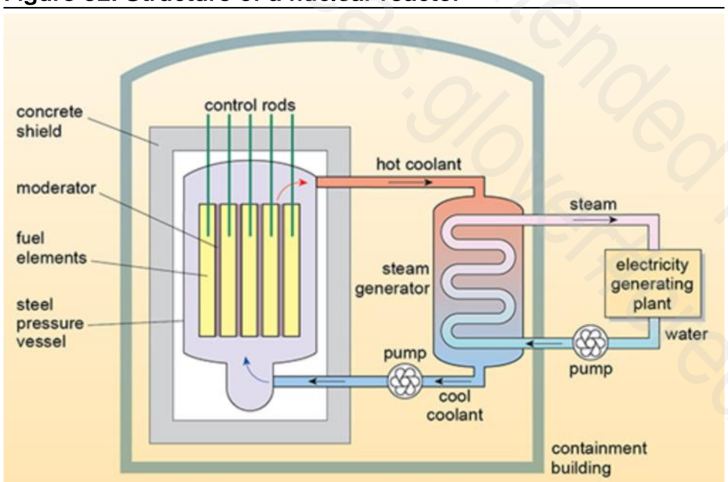


Source: IEA NZE, Credit Suisse estimates

Nuclear

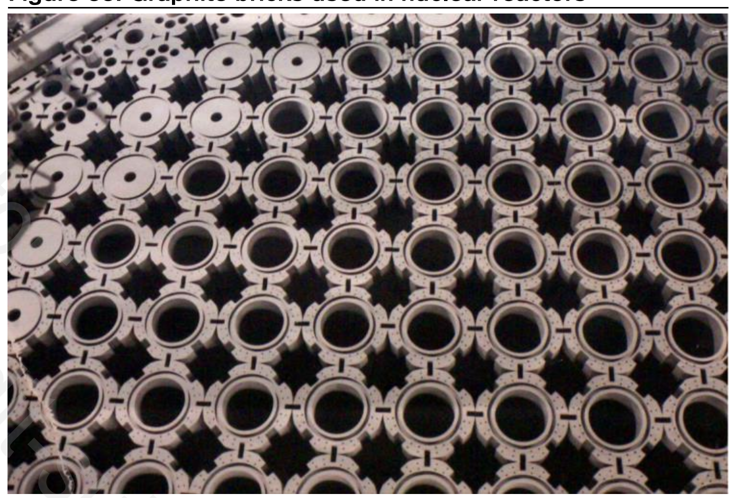
- **Graphite has been used in nuclear energy since the conception of the technology:** Due to its favourable properties, graphite can be used in a range of nuclear applications including as a moderator, reflector, fuel-channel sleeve, thermal column, fuel matrix, and control-rod material, but by far the greatest use has been as a moderator.
- **Graphite moderators:** Graphite bricks can be used in the core of nuclear reactors. Graphite bricks act as a moderator to reduce the speed of neutrons and allow the nuclear reaction to be sustained. It also acts as an important safety function by providing the structure that removes heat from the fuel and where the control rods used to shut down the reactor are inserted. The main types of graphite-moderated nuclear power reactors are Uranium Naturel Graphite Gaz reactors (UNGG) in France, advanced gas-cooled reactors (AGR) in the UK, RBMK in Russia and Pebble-bed reactors (PBR).
- **Synthetic graphite is used to make nuclear graphite:** Nuclear grade graphite is typically made from synthetic graphite due to the high purity standards and need to be porous and polycrystalline. However, a recent study in China showed how natural flake and microcrystalline vein graphite can be purified to meet nuclear grade standards.

Figure 32: Structure of a nuclear reactor



Source: The Open University

Figure 33: Graphite bricks used in nuclear reactors



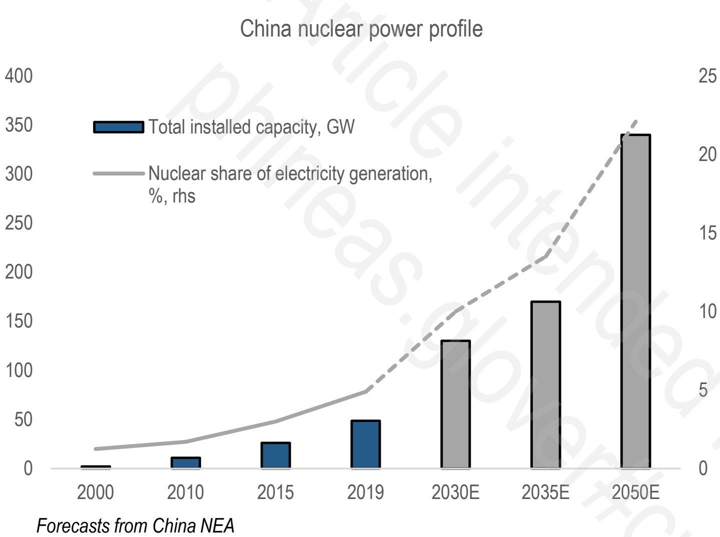
Source: EDF

- **Around 20% of nuclear reactors today use graphite..:** Three different types of materials are commonly used as moderators in nuclear reactors today: light (regular) water, heavy water (deuterium oxide), and solid graphite. Graphite is, in theory, a better moderator than light water. Yet, light water is currently more appealing because graphite is susceptible to degradation and require complicated waste management.
- **…but use has declined significantly:** The popularity of graphite as a moderator has declined significantly in the late 20th and 21st centuries, mainly because the graphite moderator is almost always the life-limiting component of the reactor. Over time, cracks and weight loss can appear in the brinks and they are unable to be replaced or repaired. Another issue is the residual public fear of graphite-moderated nuclear reactors due to the fact that the Chernobyl nuclear explosion occurred in an RBMK. This fear is grounded in a key distinction between graphite-moderated reactors and light-water-moderated reactors. It is predicted that the graphite use in nuclear will continue to decline.
- **New technology may see resurgence in graphite demand in nuclear power:** A PBR is a graphite-moderated, gas-cooled nuclear reactor. It uses graphite ‘pebbles’ containing fuel particles. PBRs have been flagged for potential future growth in nuclear power generation technology due to its modular and scalable design. Currently there is limited commercial demonstrations of PBRs. However in 2021, China officially turned on the first

two units of its PBR, Shidaowan, with a current thermal capacity of 500 MW. Now it has plans to further scale up the Shidaowan site to eventually host 16 more PBRs. There are already plans underway to design and build a 600MW PBR. Yet this is the only confirmed PBRs in China's nuclear pipeline at this point.

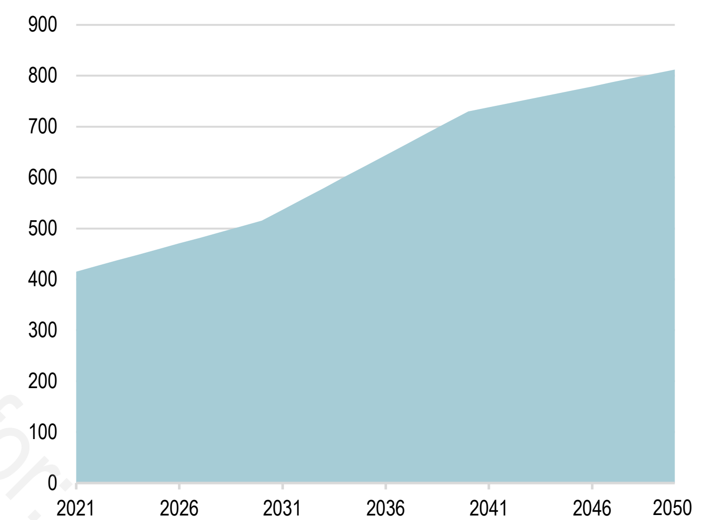
- **How much graphite is used in nuclear energy?** There is limited data on the amount of graphite used in different nuclear applications as it is heavily dependent on the design. However we did find rough calculations for the graphite usage in PBRs. For a 110MW design, over 330k pebbles are required, which is the equivalent of 80.2 tonnes of graphite. And, the reactor requires 350 new pebbles every day, or 85kg of graphite per day.

Figure 34: China to more than double nuclear power capacity in the next eight years



Source: China NEA, Credit Suisse research

Figure 35: Nuclear power capacity under IEA NZE (GW)



Source: IEA, Credit Suisse research

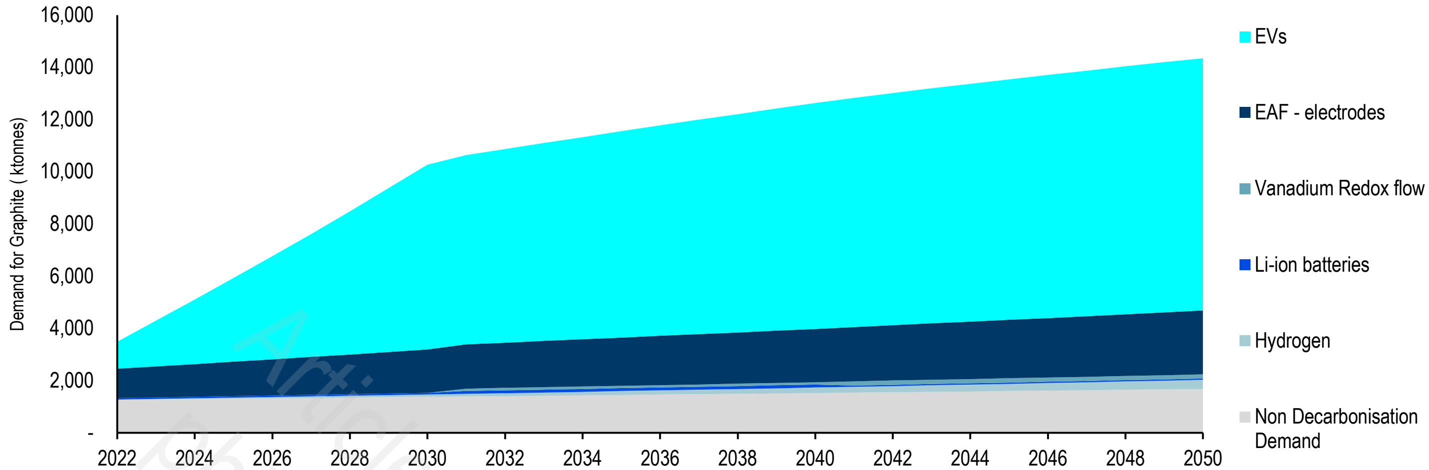
Climate Transition Framework - Graphite

Demand opportunity from decarbonisation

Using the CS Super Materials demand model, we have estimated potential demand for graphite up to 2050. Our analysis draws references from both a high growth scenario under Net Zero, where graphite is widely used across all of its decarbonisation applications, and a low growth scenario, in which graphite is used in EVs, grid batteries and EAFs. Under a high growth scenario, demand for graphite could be 5.3x greater than current levels by 2050 with, by this time, over 85% of demand coming from decarbonisation technologies. Graphite therefore has major applications under a Net Zero world and is classified as a **High Impact Material.**

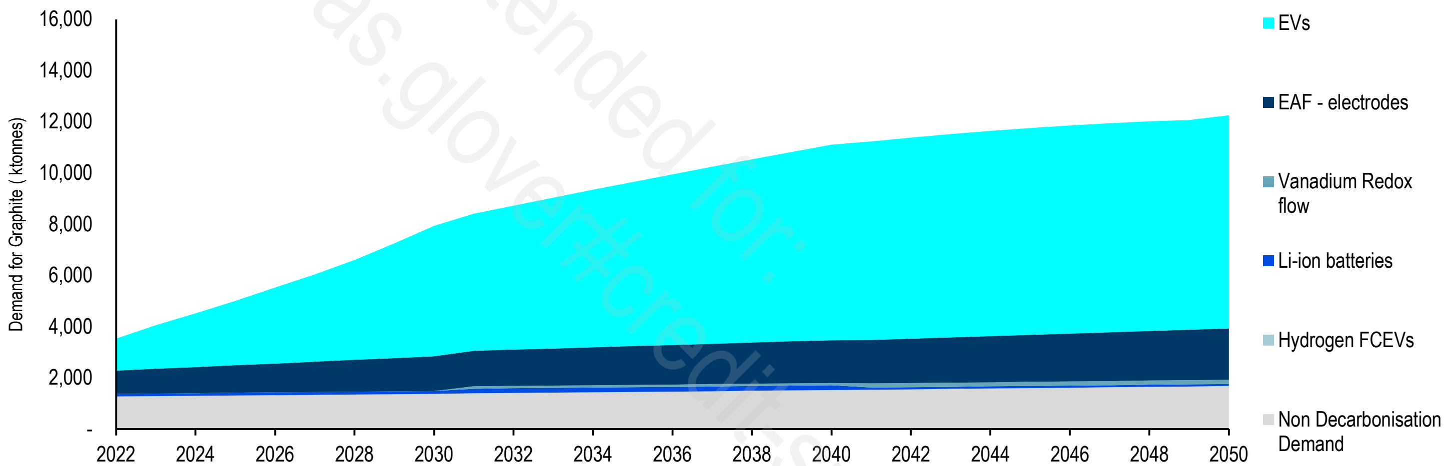
- **EVs:** Under IEA NZE, the share of EVs (including BEVs, PHEVs and FCEVs) in new car sales increases from 4% in 2020 to 64% in 2030 and reaches 100% in 2050. Graphite is currently the only battery anode materials used in Li-ion batteries and with an intensity of 1.2kg/kWh, and assuming 64kWh per EV, there is approximately 76.8kg per EV. However, there are nascent alternative technologies that could replace graphite anodes. These include all solid state batteries (ASSBs) and increased silicon content in anodes. Under **our low graphite demand** scenario we assume ASSBs increase to 10% of new car sales by 2040 and 30% by 2050 and silicon reaches 10% of anode materials by 2040 and 20% by 2050. This results in annual graphite demand in graphite-anode EVs increasing from 1,035kt in 2022 in 3.2m EVs to 5,091kt in 2030 in 41m EVs and reaches 8,300kt by 2050 in 67m EVs. **Under our high graphite demand case**, we assume ASSBs only reach 20% of sales by 2050 and silicon reaches 10% of the anode. This results in annual graphite demand from EVs rising to 9,525kt by 2050 in 77m EVs.
- **Grid Storage:** Similar to EVs, graphite is used in Li-ion energy storage batteries, with1.2 kg of graphite per kWh of storage. Under the IEA NZE, there is over 3 TWh of storage by 2050. We use the same assumption under both the low and high demand, where graphite demand in 2022 is 70kt, rising to 156kt in 2030 and 120kt in 2050.
- **EAF:** Graphite is used in the electrode and as refractory material in EAFs. Electrodes are consumed at 2-3kg per tonne of steel produced. Under the IEA NZE, EAF becomes the dominate form of steelmaking, through scrap-based EAF, hydrogen direct reduced iron EAF (H-DRI EAF) and iron ore electrolysis EAF. In 2022, 24% of steel is produced with EAF; this grows to 38% by 2030 and 72% by 2050. Under the low case, this corresponds to graphite demand rising from 865kt in 2022 to 1,360kt in 2030 and 2,000kt in 2050. Under the high case demand increases to 1,661kt in 2030 and 2,446kt in 2050.
- **Hydrogen FCEVs:** Graphite can be used as the bipolar plates in hydrogen FCEVs, however it is not the only option. Metals like titanium and platinum can perform the same function. Today, hydrogen vehicle manufacturers Toyota and Hyundai use metal plates rather than graphite. In the low growth scenario, we assume there is no graphite used as bi-polar plates and in the high scenario we show the extremes of demand by assuming all bipolar plates are made from graphite. Therefore under the high growth scenario, demand in 2030 is 89.11kt and reaches 346kt in 2050.
- **Vanadium Redox Batteries:** Under IEA NZE, redox batteries grow to 15% of total energy storage by 2040 and 27% by 2050. As 3 tonnes of graphite is used per MW, we use the same assumption under both low and high demand cases, where graphite demand from VRFBs is 0 in 2022 and grows to 90.2kt by 2040 and 160kt in 2050.
- **Non decarbonisation demand:** All other graphite demand is assumed to grow at 1% CAGR to 2050, rising from 1,269kt in 2020 to 1,374kt in 2030 and 1,677kt in 2050.

Figure 36: Annual graphite demand – high case



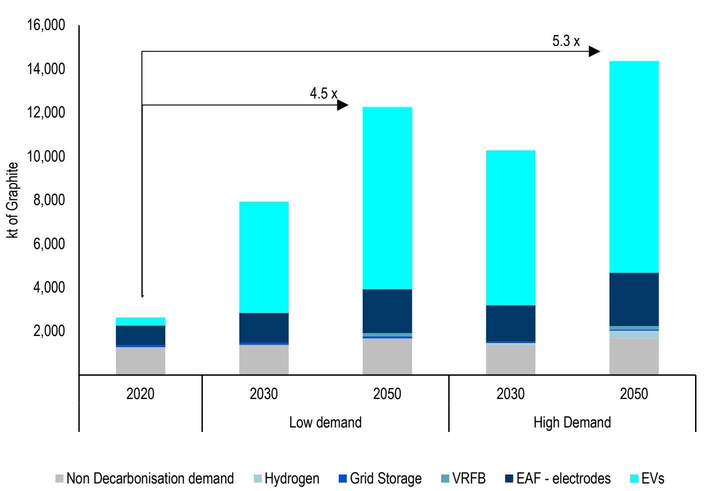
Source: Credit Suisse

Figure 37: Annual graphite demand – low case



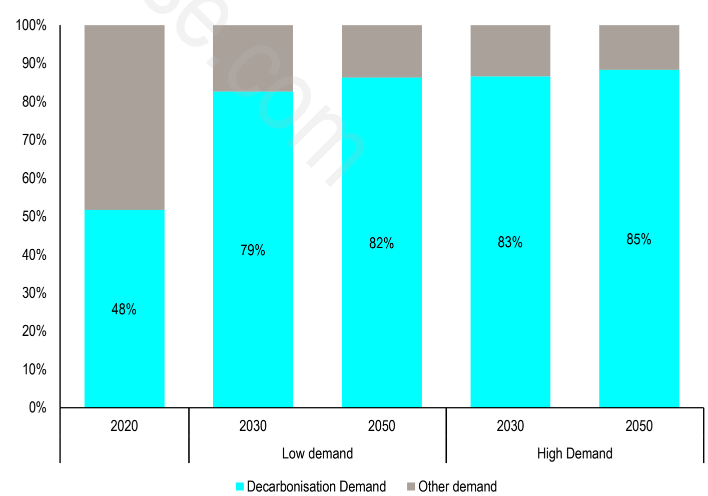
Source: Credit Suisse

Figure 38: Annual demand in 2050 to be 4.5x to 5.3x greater



Source: Credit Suisse

Figure 39: Decarbonisation demand



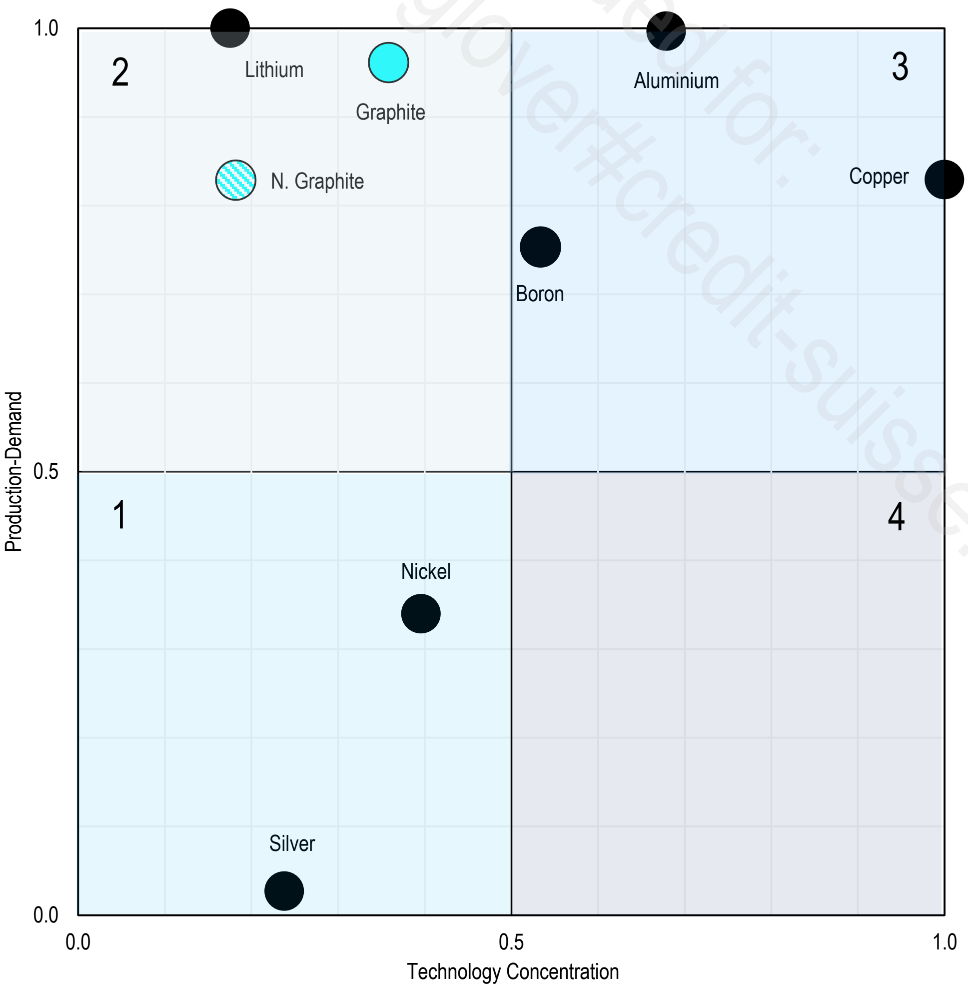
Source: Credit Suisse

Graphite: a high impact transition material

Using the CS Super Materials demand model, we review the attractiveness of graphite against the CS Production-Demand Index and the Technology Concentration Index. Overall, Graphite scores 0.96 on the production–demand index and 0.36 on the technology concentration index, placing it in quadrant 2, as a **High Impact Material. High-Impact Materials** that fall in quadrant 2 are important because, although they feature in a smaller number of technologies, their level of future demand is much greater than 2020 production levels. However, changes to the technologies used may have big implications for overall levels of demand. They are predominantly (but not exclusively) materials used in energy storage technologies.

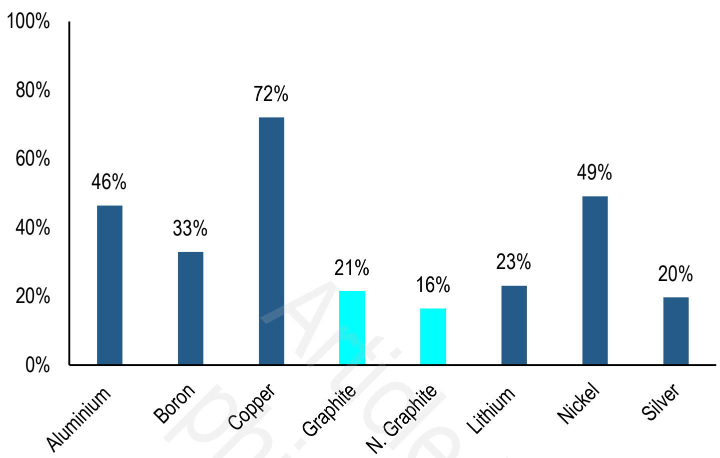
- **Production-Demand Index:** Graphite scores 0.96 on the production demand index. Underpinning the score is the relative increase in demand from decarbonisation applications. As we model both a high growth and low growth scenario for graphite, we take the midpoint to assess performance under the production-demand index. As a result, the relative increase in demand in 2050 is 4.3x greater than production in 2020.
- **Technology Concentration Index:** Graphite scores 0.36 on this index. This is driven by its involvement in decarbonisation solutions that contribute 21% of emission reduction under Net Zero. However, graphite demand is mainly concentrated in EVs, which is 74% of total demand under both the low and high scenario, giving it a higher relative level of technology concentration.

Figure 40: Production-Demand and Technology Concentration Index



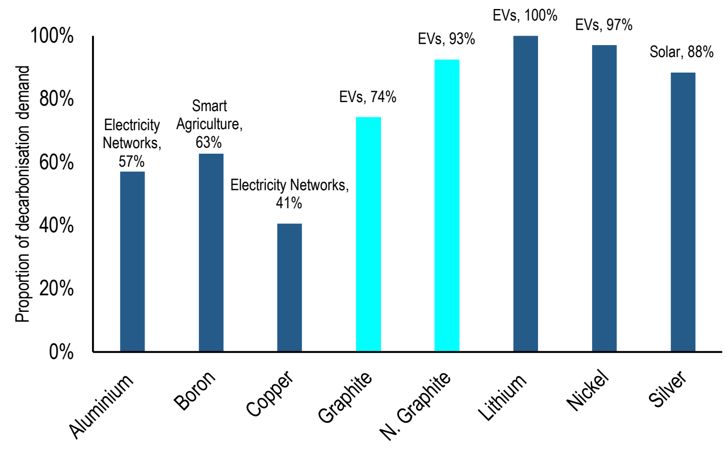
Source: Credit Suisse - Super Materials Demand Model

Figure 41: Coverage – proportion of emissions reduction technologies that Super Materials supply by 2050



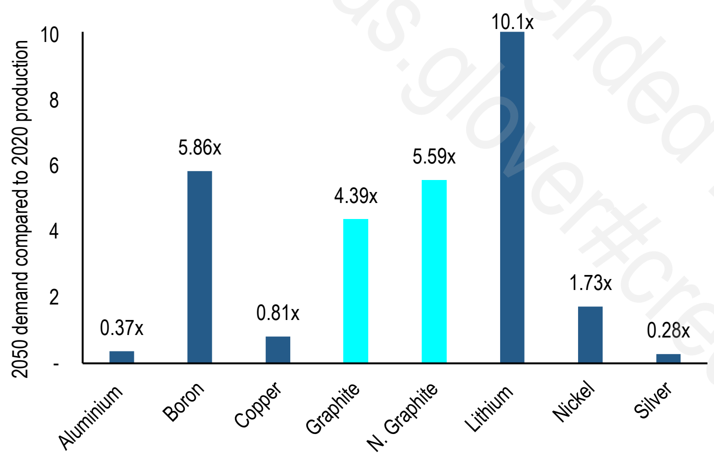
Source: Credit Suisse - Super Materials Demand Model

Figure 42: Concentration – proportion of demand for Super Materials that come from a single end use by 2050



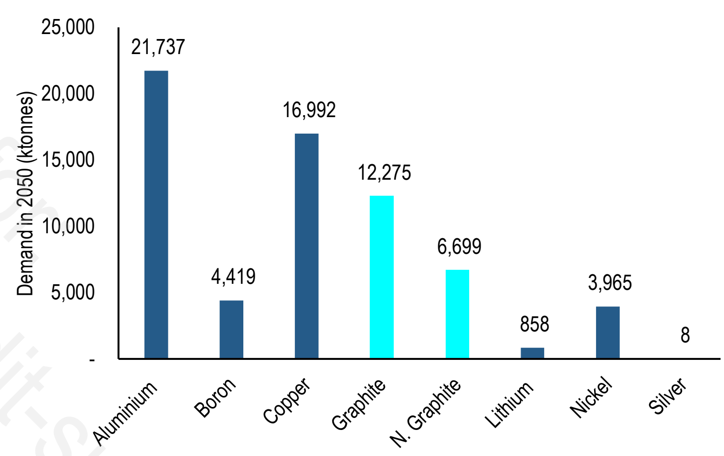
Source: Credit Suisse - Super Materials Demand Model

Figure 43: Relative demand 2020-2050



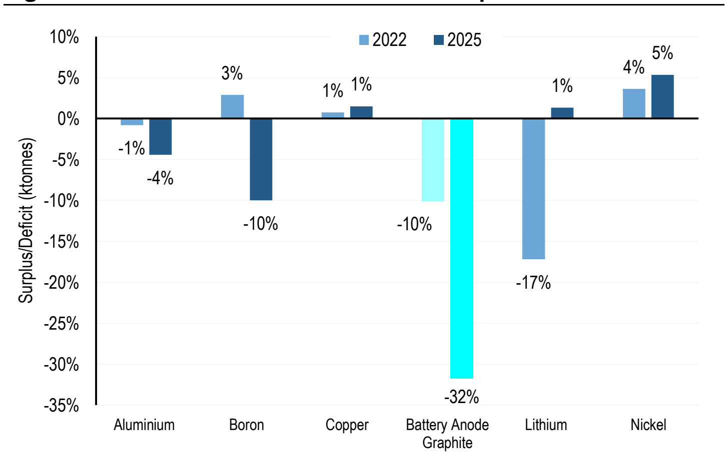
Source: Credit Suisse - Super Materials Demand Model

Figure 44: Absolute Demand by 2050



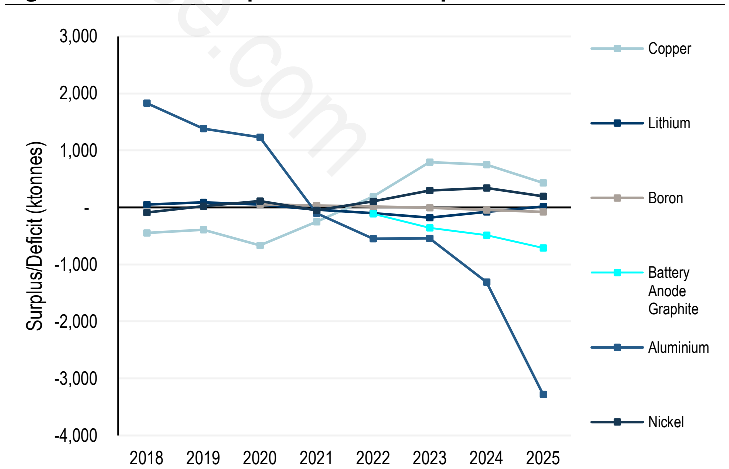
Source: Credit Suisse - Super Materials Demand Model

Figure 45: 2022E vs 2025E forecasted surplus/deficit



Source: Credit Suisse - Super Materials Demand Model; CS commodities

Figure 46: Climate super materials surplus/deficit balance



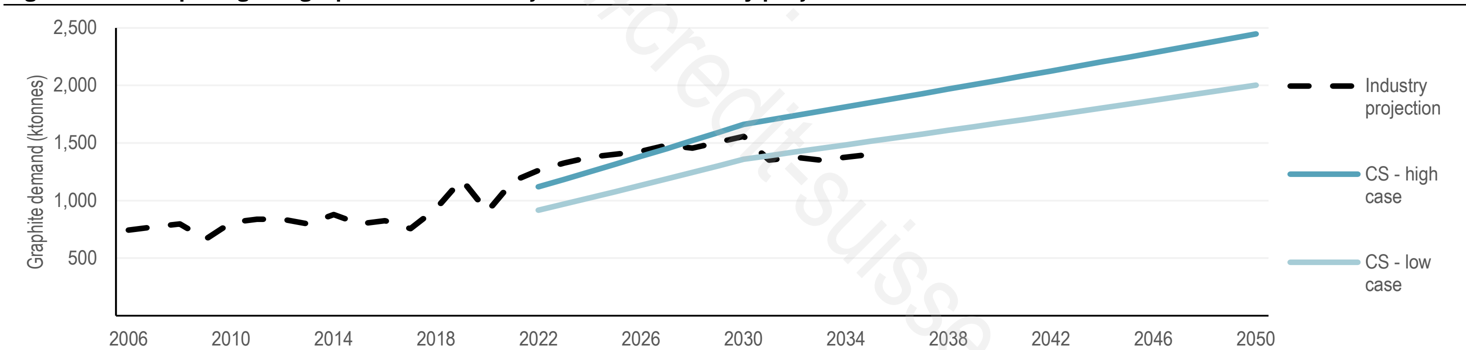
Source: Credit Suisse - Super Materials Demand Model; CS commodities

Comparing demand trajectories

Throughout our research, we were unable to find a complete demand forecast for all end uses for both natural and synthetic graphite. However, we believe it is important to reference other demand trajectories to see how our model differs to the market. As steel and EVs are the two single biggest end markets for graphite, we were able to find comparisons for them.

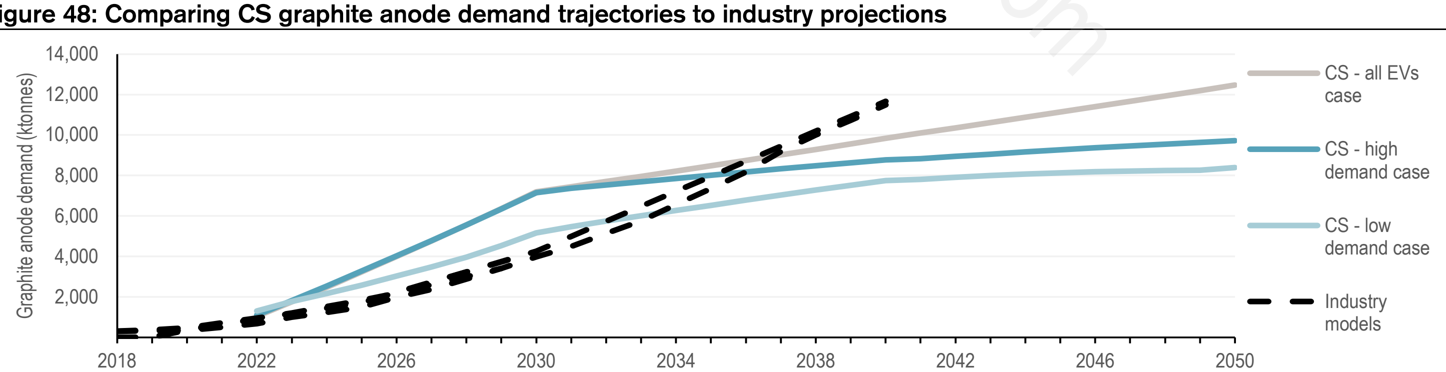
- **EAF electrodes:** CS graphite high and low case demand trajectories from EAF electrodes traverse the lower and upper bounds of the industry consensus projection from 2026 to 2030, but is then substantially higher from 2030 onwards (Figure 47). This is due to our use of the IEA's more aggressive EAF penetration rate assumption under its Net Zero scenario, under which the EAF's total share of streel production rises from 24% currently to 38% in 2030 and 72% in 2050.
- **EVs:** Our high demand trajectory from EVs differs substantially in the short-medium term. We attribute this to the accelerated uptake assumptions under the IEAs NZE scenario where EV penetration in new car sales increases from 4% in 2022 to 64% by 2030. This is also supported by the observation that our low demand case, with lower short-medium term EV penetration rates, is closer to industry projections. Post 2035, our demand scenarios are then lower than the industry projections, which we attribute to our inclusion of penetration rates for alternative battery technologies, including ASSBs and silicon anodes.
- **EVs – *all graphite*:** To further show the impact of these assumptions, we include an alternative *CS-all EVs case*, which assumes that there is no ASSB or further penetration of Si anodes, and instead all batteries have graphite anodes. This results in the demand being closer to the industry's 2035 value (Figure 48). This suggests that industry forecasts may be under-estimating growth in EVs in the short to medium-term but under-estimating the potential for new battery technologies to incrementally erode graphite demand.

Figure 47: Comparing CS graphite demand trajectories to industry projections for EAF electrode demand



Source: Credit Suisse

Figure 48: Comparing CS graphite anode demand trajectories to industry projections

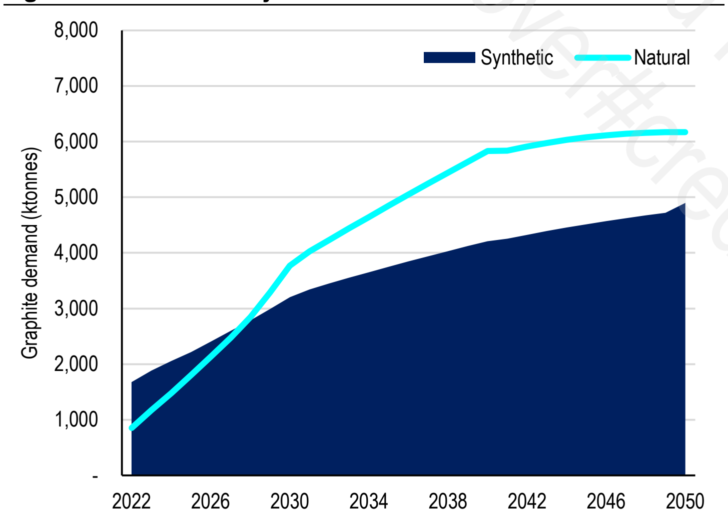


Source: Credit Suisse

Natural vs synthetic demand in decarbonisation

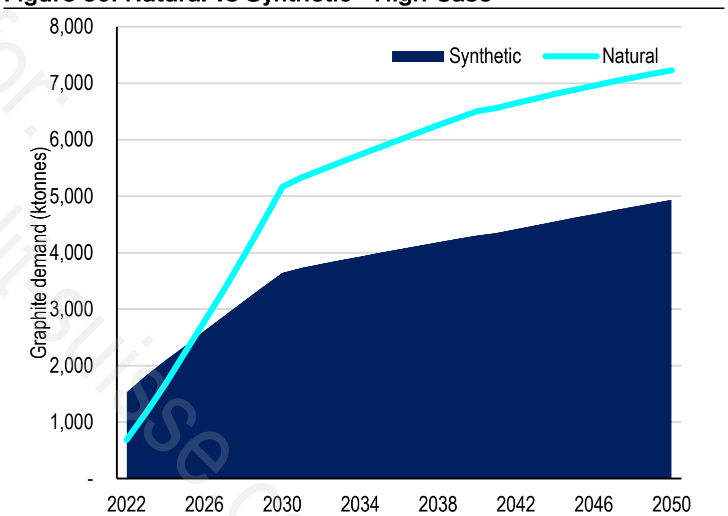
- **Natural Graphite:** Under decarbonisation applications, demand for natural graphite quickly surpasses synthetic by 2026. Natural graphite demand is expected to be 680kt in 2022. Under our low case, demand increases to 3,767kt by 2030 and continues to grow to 6,168kt in 2050. Under our high case, demand reaches 5,169kt by 2030 and continues to grow to 7,229kt by 2050. This is due to the growth in electric vehicles and the increased penetration of natural graphite anodes.
- **Synthetic Graphite:** Historically, the largest decarbonisation demand source for synthetic graphite was EAF electrodes, which has grown in line with economic growth at a CAGR of 1%. Under both demand scenarios, synthetic demand also rapidly increases to 2030. While EAF proliferation in steel-making results in an increase in demand beyond economic growth, the largest share of growth results from the increase in demand from EVs.
- **Battery grade graphite inputs vs raw materials:** When we discuss the demand for graphite battery anodes, we need to acknowledge this is a finished, processed product. As synthetic is produced from raw inputs, natural graphite is also processed to create the batter-anode material. As highlighted, 2.2 tonnes of natural graphite is typically required to create 1 tonne of finished anode material. We show this relationship in Figure 51 below, where the proportion of battery anode materials made from natural graphite is extrapolated to get the raw material equivalent. We highlight that we have accounted for this in all our demand modelling so that we calculated the total demand for raw natural graphite rather than the amount required by the processed battery anode.

Figure 49: Natural vs Synthetic - Low Case



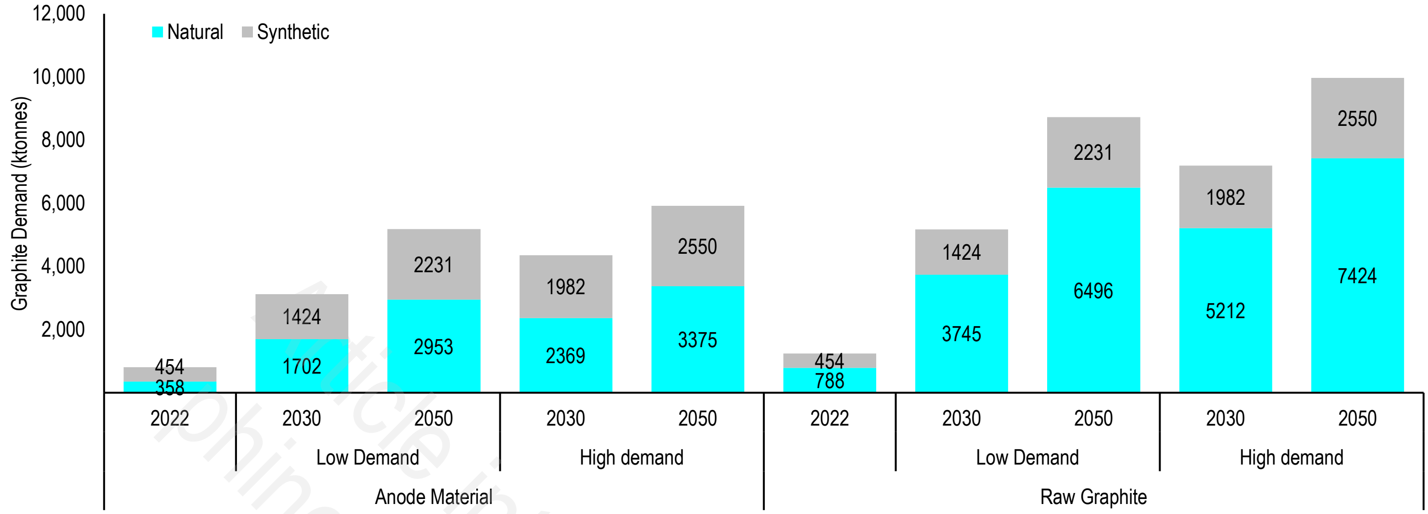
Source: Credit Suisse estimates

Figure 50: Natural vs Synthetic - High Case



Source: Credit Suisse estimates

Figure 51: Graphite demand for EVs, comparing anode material to raw inputs - 1 tonne of natural graphite anode material requires 2.2 tonnes of raw graphite

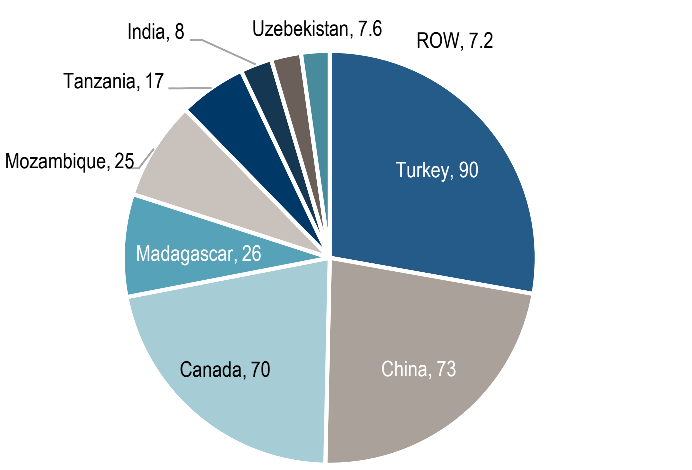


Source: Credit Suisse

Supply-demand dynamic

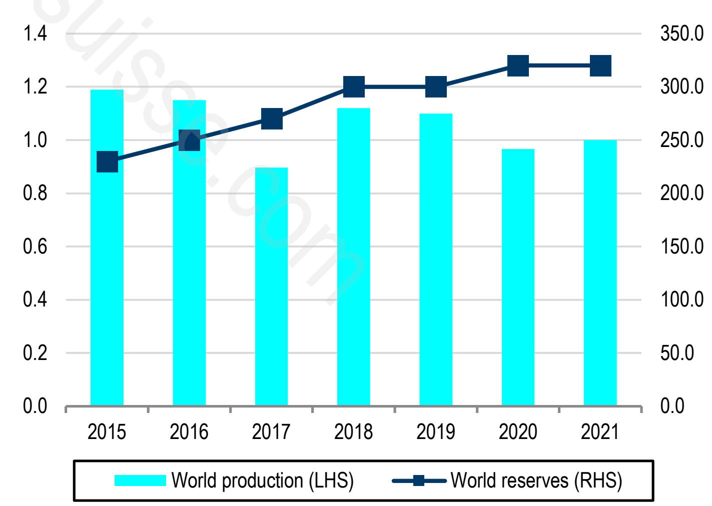
- **Global graphite market amounted to around 2.8mn tonnes in 2020**, of which synthetic graphite accounted for 57% (1.6mn t) and natural graphite 43% (around 1.2mn t). Out of this natural graphite, flake material was around 68% (820,000t), amorphous 31% (373,000t), and vein 0.5% (6,000t).
- **There is no shortage of reserves.** Currently there is over 320mn tonnes in natural graphite reserves. China has 20% of the reserves (70 mt), but there significant reserves in Africa which, so far, have been shown to exhibit larger flakes. There is also existing clumps in Europe, Asia, USA and Australia.
- **China dominates the graphite-battery value chain.** Currently, 73% of natural graphite extraction and 61% of synthetic graphite production occurs in China. All natural graphite processing, or graphite spherification, also occurs in China due to the low cost and environmental regulations. Further upstream, 83% of anode production and 73% of battery cell manufacturing occurs in China.
- **Similar story for EAF graphite electrodes**. China is the biggest producer and consumer of graphite electrodes, followed by the EU and Japan. Whereas, the major countries that import graphite electrodes are the USA, Russia, Iran and Turkey. There are concerns that China's new focus on decarbonisation may further constrain the EAF electrode market. In 2020, EAF production in China was 10% of total steel output. In February 2022, China set a target for EAF production to reach 15-20% of primary steel production by 2025.
- **Geographic diversification**: At present, investments into spherical graphite milling and purification equipment do not justify the returns. Yet, both the EU and the US have declared graphite as a critical mineral. In US 100-day review into supply chains specifically called out the importance of lithium and graphite and the need for the US to secure reliable and sustainable supplies (100-day review, page 9). For the EU, graphite remains on its official critical minerals list due to its medium supply risk (link here). There is also a push globally from battery and EV manufacturers to diversify their supply chains and secure more sustainable sources of supply.

Figure 52: Graphite reserves by country (Mt)



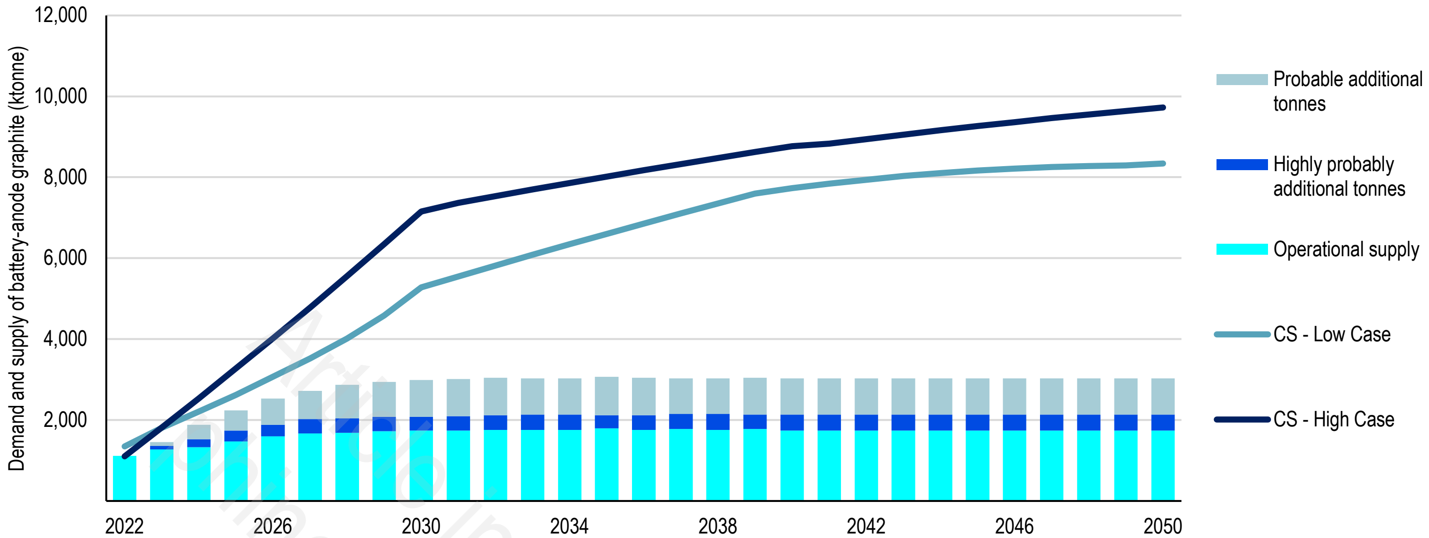
Source: USGS 2021

Figure 53: Production vs Reserves (million metric tons)



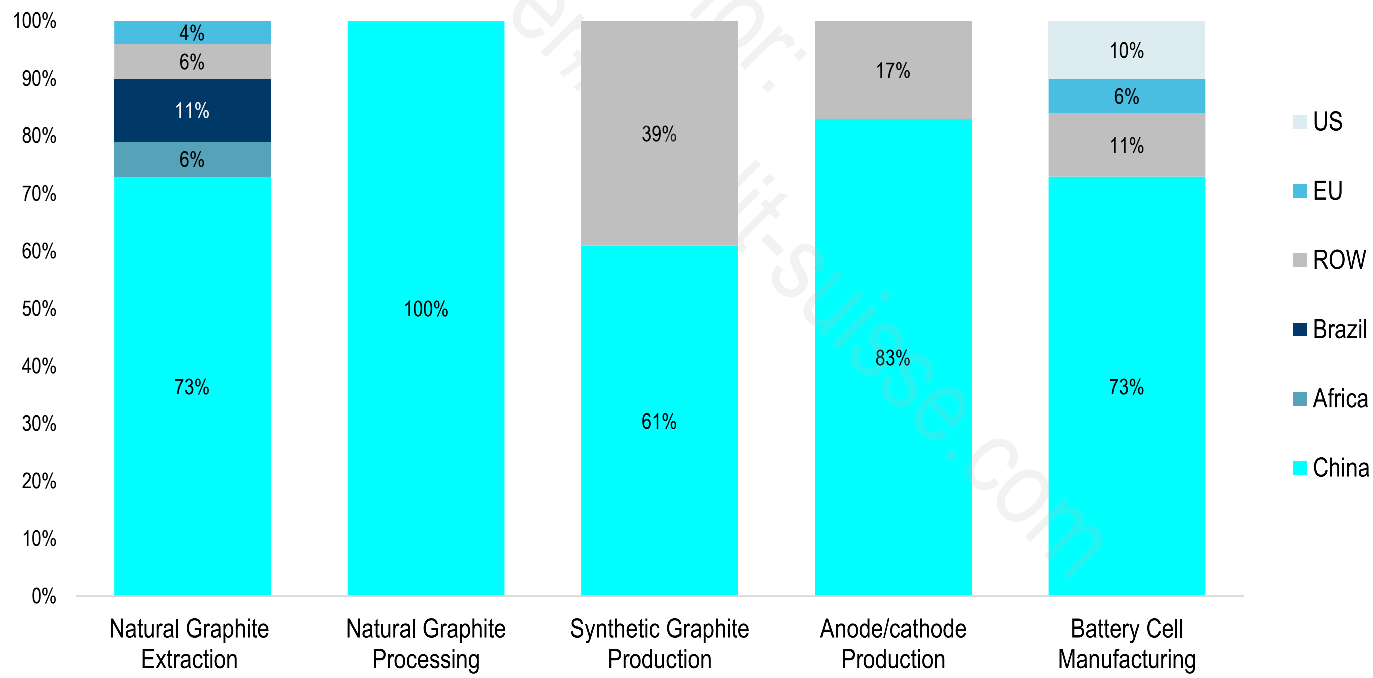
Source: USGS

Figure 54: CS demand estimates for battery anode graphite vs the supply of processing capacity



Source: Benchmark Mineral Intelligence, Credit Suisse estimates

Figure 55: Geographic concentration of the graphite anode value chain



Source: Benchmark Mineral Intelligence, Credit Suisse estimates

Supply cost as driver of price

There is no standard quoted price for natural graphite. "Market" prices are obtained by direct negotiations between large buyers and sellers. Flakes of different sizes sell for different prices. Larger flake size commands higher prices, and there is also a premium for purity. According to Northern Graphite, the costs in the different steps to manufacture spherical graphite (SPG) used in battery anode materials have direct implications on pricing.

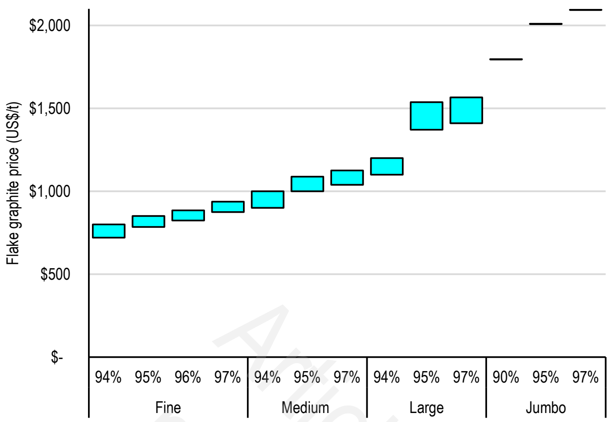
- **Raw material small flake** graphite cost $500/t in China though are increasing. Given losses in the micronising and rounding step, are estimated at $1,250/t.
- **Micronising and rounding** flake graphite costs $1,000/t.
- **Purifying** micronised and rounded material using hydrofluoric and sulphuric acid to produce uncoated SPG (uSPG) costs $300/t in China. However, water, neutralising agents, as well as proper environmental/safety standards can increase costs to $1,000/t.
- **Combined**, the cost of uSPG in China is around $2,500/t plus tax, depreciation, transport and other costs. The selling price is roughly $3,000/t.
- **Coating**: To make the battery anode material, the next step is coating, covering uSPG with a hard carbon shell at a cost of $1,000/t. Selling price of this coated spherical graphite (cSPG) is $4,000-6,000, but is also increasing.
- **"re-graphitising" natural graphite** is a possible additional step to mimick the synthetic manufacturing process, in order to increase the cycle life of natural graphite. Heat treatment costs as much as $2,500-3,000/t.
- **uSPG costs differ on IP**: Samsung, LG and Hitachi charge $8,000-$12,000/t for cSPG which reflects the cost and complexity of the process and the value of their IP.

The average flake price increased by 19% in 2021… This has been due to environmental, power and shipping/Covid disruptions in China but the trend is continuing in 2022, with tightening availability, uncertain output expectations, as well as delayed shipments. For example, Syrah Resources reported rising demand and sales prices over 2021Q4, but its flake graphite output was down 48% QoQ due to limited availability of containers. The Russia / Ukraine conflict has worsened the situation. Volt Resources, which holds a 70% controlling interest in the Zavalievsky graphite business in Ukraine, has had to halt production as expected.

..and 38% since Nov 2021. Latest data from Fastmarkets shows that graphite flake 94% C, -100 mesh, fob China increased 38% since November 2021 to $830/t on 24 March, the highest since price assessment commenced 3.5 years ago. The corresponding cif Europe price has increased 19% over the same period to $885/t, also the highest.

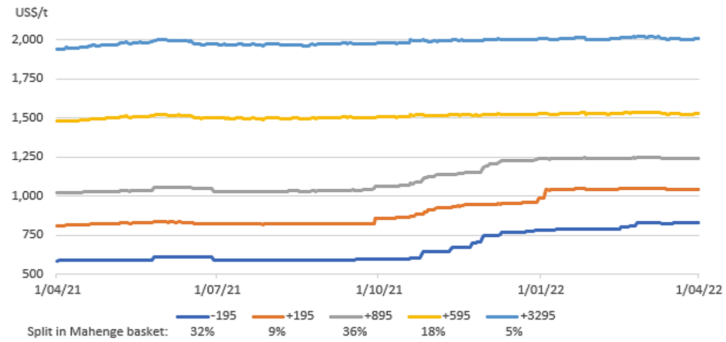
High barriers to entry sustain high prices: We believe that future pricing downgrades of natural-based anode material supply face potential risk given the current high barriers to entry and the unfunded status of various natural graphite new entrants. Moreover, anode material production is fairly bifurcated with graphite mining, processing and purification (to SPG product), and coating (to CSPG product) often done by different companies due to varying specialties. Moving forward, industry participants are looking at ways to vertically integration to eliminate some of the costs that arise from this bifurcated supply chain.

Figure 56: Prices for natural flake graphite, China FOB 94% C



Source: RefWin, AsianMetals, ICC Sino, Wood Mackenzie, Credit Suisse estimates

Figure 57: Graphite prices for Black Rock's Mahenge products



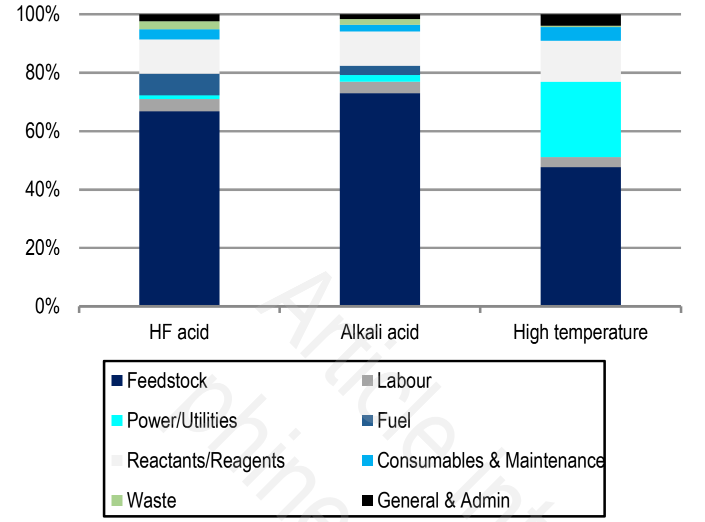
Source: RefWin, Asian Metals, ICC Sino, Black Rock Mining

80% of spherical graphite is made using chemicals with high HSE concerns: Currently 80% of spherical graphite is produced through hydrofluoric acid (HF) processing of flake graphite concentrate. But due to environmental and health & safety concerns, many companies started looking for alternative purification methods which usually involve high temperature thermal treatment, chlorine, alkaline reagents or some combination of them. The alternatives are still less popular though, for cost and other environmental reasons. An emerging question is whether the battery and auto sector pay a premium for zero-/low-HF materials.

Graphitisation is crucial, but increasingly energy intensive… Graphitisation is the crucial step in synthetic graphite production. It is the heating of amorphous carbon for a prolonged period of time to up to 3000°C, which rearranges the atomic structure to achieve an ordered crystalline structure. This process is energy- and emissions-intensive (consumes >12,000 kWh/t), and accounts for 55% of synthetic graphite anode production costs. The electricity cost is around 60% of this, hence many Chinese companies have built graphitisation plants in regions where electricity is cheaper, like Inner Mongolia and Sichuan (but with higher emissions intensity).

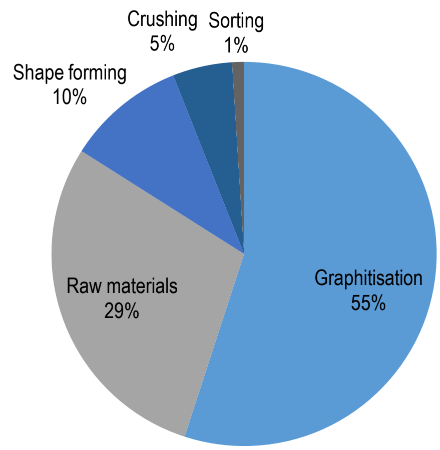
… and has been affected by the recent energy crunch. The energy crunch has therefore had a large impact on the output of synthetic graphite, due to the volatility of price increases. Efforts to contain energy consumption/carbon emissions and manage air pollution continue to put pressure on synthetic graphite production. The price differential between synthetic and natural graphite widened further as a result, leading to a shift to more readily available and cheaper natural graphite. Another important consideration over the longer term is that raw material waste from the O&G industry needed for synthetic graphite production (e.g. pet coke) may become more expensive and scarcer as the industry shrinks.

Figure 58: Spherical graphite production costs by process type



Source: Wood Mackenzie

Figure 59: Synthetic graphite anode production costs by process type



Source: Huaan Securities, Credit Suisse estimates

Graphite mining lead times and qualification are critical

Compared to other transitional minerals, mining lead time for natural graphite appears to be average-to-short. However, despite the growing capacity in the pipeline (around 1.5 Mtpa planned capacity from first stage flake projects), there are rising concerns that lengthy (but critically important) **product qualification** processes will delay the ramp-up of approved supply.

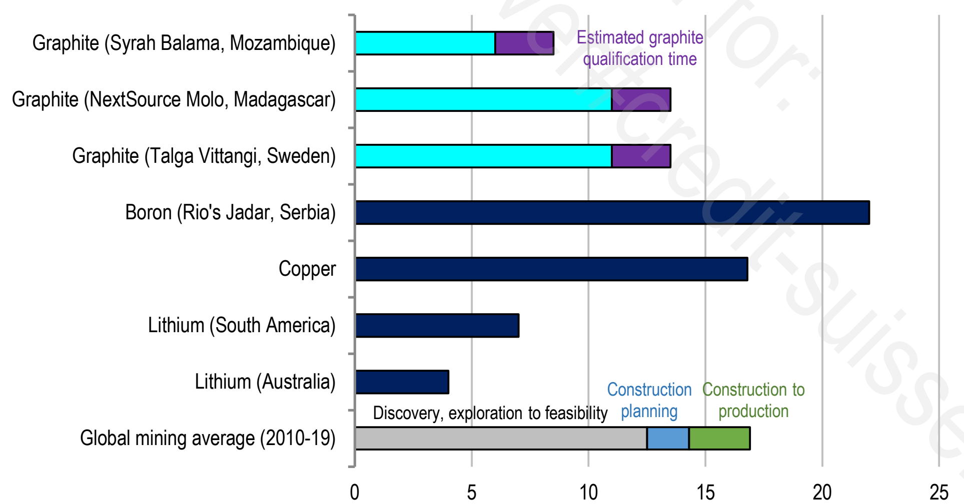
- **Product qualification is the most time intensive stage, taking up to 2-3 years to get it right...** Spherical graphite is not a standardized product but rather sold on long term contracts with buyers after extensive product qualification. Typically there are three stages of qualification, first there is traditional raw material QA/QC period that takes 4-6 months. Then prospective new sources of anode material (particularly if used in EV batteries) must undergo extensive product qualification and testing with cell manufacturers that can take up to 2 years (if production tweaks need to be made), or at best 12-18 months. Additional downstream qualification at the vehicle level is also required and can take up to a year. For example, qualification took a little over 3 years before Black Rock Mining and Posco could finalise offtakes agreements.

- **… And it is qualification that makes graphite supply sticky.** This time is taken to test whether the anode material is compatible with other battery cell components and whether safety and performance standards are met. It takes longer if the material supplier needs to tweak production. The lengthy qualification process implies that anode material often is not interchangeable between suppliers, particularly for Tier 1 battery manufacturers (required status for EV production) that have typically longer qualification timelines with more stringent demands and therefore will source material from two to three suppliers with the same anode material supplier/spec used for each specific battery cell production line. To facilitate this process, Syrah built a product qualification plant in the US to accelerate its ability to meet customer qualification. The necessity for such a plant shows the potential delay that qualification requirements can cause, and demonstrated the risk to production supply forecasts and by extension pricing.

- **The anode material needs to work *with* the cathode material.** Cell manufacturers must ensure the new prospective material supply has material properties that "work" with other battery cell components like the cathode and electrolyte to ensure the battery cell meets performance and safety thresholds. In particular it means monitoring the impurity levels of the entire system, e.g. if the anode material has high levels of a specific impurity that also happens to be present in the cathode material supply, then this could breach impurity thresholds as well. This means that battery manufactures need consistency in the graphite quality but also the impurities it presents.

- **NextSource took 11 years…** For NextSource, its Molo deposit is one of seven surficial graphite trends discovered and drill tested in 2011. Initial production from the mine is planned for 2022. The steps that NextSource took from discovery to production shed light on the complexity of the process. Since discovery in 2011, resource delineation, drilling and trenching on the Molo took place in 2012. A maiden Indicated and Inferred Resource was stated in the same year, which formed the basis for the Preliminary Economic Assessment published in 2013. Another phase of exploratory drilling and sampling was in 2014, which provided data to support the positive Full (Bankable) Feasibility Study released in 2015. NextSource released an updated Feasibility Study in 2017, and a further update in 2019 that outlined a phased development approach starting with Phase 1 – 17 ktpa. Initiation of technical study for an expanded Phase 2 was announced in 2021 (from 45 ktpa to 150 ktpa). Finally, 2022-24 will see initial mine production, anode facility production and Phase 2 expansion.
- **… others took 7-10 years from exploration to production.** The exploration of Syrah's Balama operation in Mozambique commenced in 2011 with first production in 2017. NextSource (Molo) and Talga (Vittangi) are taking longer (~11 years). Talga acquired Vittangi in 2012 and has undertaken multiple mining trials. Production (together with its anode project) is expected to reach commercial stage in 2023-24.

Figure 60: Mining lead times (years)



Source: Company data, IEA, S&P Global (2020), S&P Global (2019a) and Schodde (2017). NB: Global average values are based on the top 35 mining projects that came online between 2010 and 2019

Natural vs synthetic

- **Natural graphite has a higher energy capacity and is less expensive, yet, has a lower lifecycle and less balanced performance.** Spherical graphite made with natural graphite for anodes has a higher power capacity and is less expensive than synthetic graphite. Natural graphite is approximately half the cost of synthetic partly because the production process uses less electricity. Auto makers generally prefer synthetic graphite given superior battery longevity and faster charge turnaround. Consistency of natural graphite could also be lower with more side reactions. We emphasise that this is a generalisation, as factors like grain size, surface area, and processing could play a key role in shaping the different qualities of the graphite product. A mix of both is preferred.

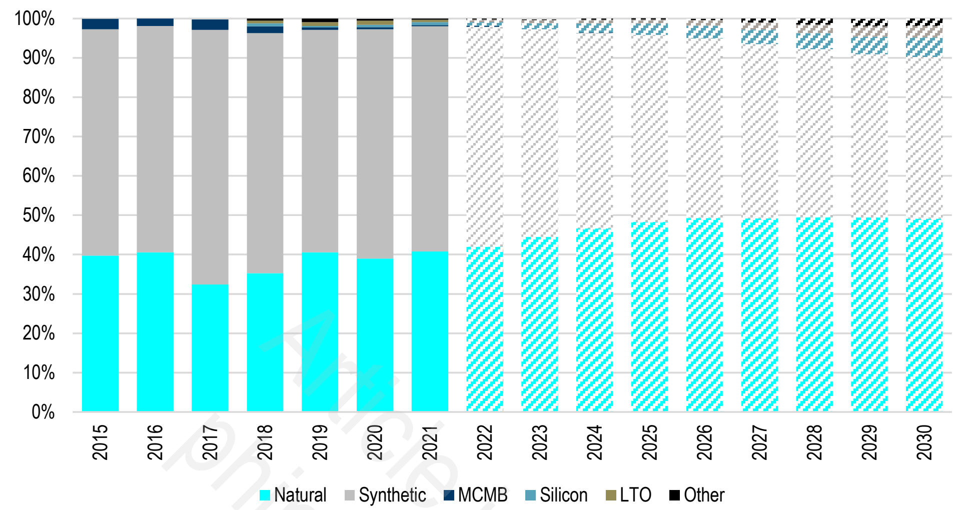
- **Battery manufacturers have sought to solve the problem.** There are a few methods to increase the lifespan of natural graphite. Firstly using a CVD coating process which subjects the spherical graphite to a high temperature treatment, to "re-graphitizing" the graphite and mimic the synthetic manufacturing process. This repairs defects in the natural crystalline structure. Another way is to blend natural and synthetic graphite to take advantage of the high capacity of natural graphite and the longer lifecycle of synthetic. Reports indicate that LG, Hitachi, Samsung, and its partner BTR use a combination of these solutions, but the companies do not disclose this IP. But it is generally understood that their EV batteries are 40-60% natural graphite.

- **Natural graphite production generally has lower emissions intensity:** The carbon emission embedded in 1 tonne of natural graphite anode material is 5.3 t CO2eq, and mainly comes from raw coal and electricity, which is 24% and 21% of total respectively (Gao et al, 2018). In comparison, the production of synthetic graphite is more energy-intensive, which has led operators to seek the cheapest power sources. This has tended to be coal-heavy, thereby increasing carbon and other emissions (NOx, SOx, PM10). Most of the impact is the result of the graphitisation and roasting processes, in addition to calcined petroleum coke production. Some of these effects can be reduced if natural gas/renewable energy is used instead. In terms of natural vs. synthetic graphite, a consolidated information source showed that natural graphite production emits 1-2 t CO2/t from the conventional mining process, compared to 4.9 t CO2/t in synthetic graphite production (Ecoinvent v3.1; GREET, 2018; Dai et al, 2019). Some recent studies have suggested underestimation of environmental footprint in the literature. We flag an estimate of 9.6 t CO2eq/t of global warming potential in the life cycle of natural graphite anode material made in China (Engels at al, 2022) and 20.6 t CO2eq/t for synthetic graphite production (Surovtseva at al, 2022). Minviro estimated that the emissions intensity of natural and synthetic graphite production in China is 16.8 and 17 t CO2eq/t respectively.

- **Natural vs synthetic market share:** Currently 58% of battery anode material is made from synthetic graphite and 39% from natural graphite. In 2030, it is projected that 41% of anode material is from synthetic graphite, 49% from natural graphite and 10% from other sources. The IEA states that natural graphite is expected to continue to account for the majority of market share even as artificial graphite could replace natural graphite for reasons of improved purity and hence energy density.

- **The availability of cSPG will be the limiting factor to a higher mix shift, not demand.** This is partially a function of limited high-grade domestic Chinese natural graphite production growth availability for CSPG feedstock (China has increased flake graphite imports in recent years) and is also prioritizing synthetic graphite anode production. This is further exacerbated by the broadly unfunded status of ex. Asia new entrants currently and non-trivial anode material process development paths to meet stringent downstream quality/safety standards.

Figure 61: Anode market share



Source: Benchmark Mineral Intelligence, Credit Suisse estimates

- **Natural to disrupt synthetic**: The rising synthetic graphite costs due to the energy crunch and controls in China and the better environmental performance of natural graphite product manufacturing (increasingly powered by renewables) will lead to natural graphite taking a larger share of the market, in our view. Moreover, there are exciting innovations that can reduce the environmental damage of natural graphite processing. Urbix is an example of a company that uses proprietary methods for the environmentally conscious purification of natural graphite. Its low-temperature, non-oxidative purification technique avoids the use of hydrofluoric acid and the huge energy consumption often required. With its patented refinement techniques, Urbix's battery grade graphite purports to outperform synthetic anodes, possessing a longer cycle life and greater energy density at significantly lower cost. Further penetration of such technology would clearly benefit natural graphite demand.

Graphite anodes to remain dominant

As we've discussed, and reflected in our demand modelling, next-gen batteries like ASSBs and increased silicon doped anodes are potential disruptors to the graphite-dominated anode market. However, graphite has advantageous characteristics that make it difficult to displace, in our view.

- **Silicon doping will increase but is capped at c. 10%.** Currently, 20% of battery anodes use 5% silicon blending. We expect to see a greater uptick of silicon blending with graphite but largely capped at 10% silicon/90% graphite blends (and 15-20% silicon at most). Adding silicon to graphite anode material increases energy density, but there is a limit before battery safety/life is compromised.
- **ASSBs have higher energy density but higher cost.** The benefits of ASSBs are higher energy density, a lower volume/weight requirement and improved battery safety. However, when we translate this to the passenger EV market, it really means that an ASSB-powered EV can travel longer distances than current battery chemistry, meaning it can go further between charges. Currently, the average EV can travel around 314km or 2-3 hours before needing a charge. For road-trippers, typical driving behaviour is for trips to be no longer than 3 hours before a stop is needed (e.g. stretch, eat, bathroom breaks and refresh etc). Based on these behavioural patterns, there does not appear to be a strong basis to travel further than that between the current charge patterns (assuming a charger is available). Therefore, for a high price point and a potentially underutilized function, ASSBs are unlikely to dominate this end-market, in our view.

- **Qualification hurdles prevent these alternatives from being viable for at least another decade.** While next-gen battery start-ups are developing prototypes for EVs in the coming years as planned, follow-on material qualification processes will still take up to five years. The manufacturability and cost competitiveness (vs. LIBs at massive scale by this time) must also be viable to warrant large-scale production, which would take a couple years to scale-up. We see next-gen battery commercialization at scale by the latter half of the decade, at the earliest.

Circular economy potential

The recovery and recycling of Li-ion batteries has focused on the most economically valuable materials, i.e., nickel, cobalt, lithium, manganese, copper, and aluminum. It has been estimated that retired batteries could supply 60% of cobalt, 53% of lithium, 57% of manganese, and 53% of nickel globally in 2040, under optimal conditions (Dunn et al, 2021). But given the mass of graphite is ~15-20% of EV batteries (~10% of economic value), some argue that graphite recycling should be actively pursued for environmental reasons (as much as 456,000 tons of graphite were used for lithium ion batteries in 2020).

- **The rate of natural graphite recycling is currently only 3% (EU).** In China, it has been estimated that less than 40% of the materials contained in a battery can be recycled given the current organization of the battery life cycle, meaning that 70% of the nickel, 67% of the cobalt, 77% of the lithium and as much as 95% of graphite were lost in 2016 (Song et al, 2019). Technical challenges include, among others, spent graphite containing undesired metal impurities and organic electrolytes, and that the structure of graphite is usually damaged during charging/discharging cycles. As a result, spent graphite is mostly abandoned or incinerated, posing environmental risks via particulate contamination and GHG emissions.

- **There are emerging recycling technologies.** Graphite recycling technologies explored in the literature are broadly grouped under two types: (1) hydrometallurgical methods based on acid–base leaching processes (for example using acids HCl or H2SO4), or (2) pyrometallurgical processes where graphite is treated under temperatures above 1000 °C so that the residual metals, metal oxides, and binders are gasified and the graphite structure is repaired. There is currently an increasing number of pilot studies on novel recycling methods, with the aim of producing high purity regenerated graphite with favourable characteristics in morphology and structure. That said, we are still at a very early stage of productive or scalable recovery of graphite.

- **Hydro- and pyrometallurgical methods each have different environmental issues:** Hydrometallurgical methods can cause heavy metal pollution whereas pyrometallurgical methods can lead to human/ecotoxicity, eutrophication, ozone depletion given the use of inert gases/VOC release. Initial suggestions have been put forward to improve the environmental performance of these treatments, for example optimizing the amount of acids used, and using renewable energy for additional energy input.

- **Recovered graphite does not quite compete with virgin materials**: On electrochemical performance, studies show that regenerated graphite could efficiently work at cycling rates up to 0.5–1C, although the damaged structure cannot compete with the performance delivered by virgin graphite at high rates. The C-rate measures the charge and discharge rates of a battery. 1C means a fully charged battery rated at 1Ah should provide 1A for an hour. The same battery discharging at 0.5C releases 0.5A for two hours. 2C discharges 2A in 30 minutes.

- **Within a closed loop, high grade recycled graphite can potentially be reused as battery anode material / green electrodes**. There are other possible open loop applications for circular graphite, including in high-tech industries like bipolar plates, as well as downgraded applications like heat exchangers / semiconductors, or as reducing agent in pyrometallurgical processes. Another increasingly discussed option is the recycling of graphite waste into high quality graphene products which offer different physical, chemical and biological properties compared to graphite. There is what is called “green” graphite electrodes, with companies like Coidan Graphite recovering used and damaged electrodes and reconditioning them. This saves energy required in electrode manufacturing and reduces graphite waste.

Impact intensity

China's Ministry of Industry and Information Technology published an updated Guiding Document for the Graphite Industry in 2020. The main purpose of the document is to ensure effective utilization of graphite resources, optimize industry structure, promote technological innovation, and improve environmental protection. Given the dominance of China in the graphite industry and the relevance of the document to many aspects of environmental impact, we provide a summary here and then discuss more generally the key findings from the literature, with regard to emissions and energy intensity, water, biodiversity and waste:

- **Processing technology and equipment**: Safe, efficient and advanced mining methods and equipment should be used. The recovery rate of open-pit/underground mining should not be less than 92%/75%. Construction shall comply with the Code for Green Mine Construction in the Non-metallic Mining Industry. Energy-saving and environmentally friendly technologies should be used, such as more crushing/less grinding, shorter grinding and flotation processes, larger crushing and grinding equipment and vertical mills etc. Minimum beneficiation recovery rates are set for different grades of raw ore. Minimum yields are set for different graphite products.

- **Product quality**: Quality management system based on specified standards should be implemented, e.g. GB/T 3518 for flake graphite, GB/T 3519 for microcrystalline graphite.

- **Energy, water and other resource consumption**: Maximum energy intensity is specified for each type of graphite product, ranging from 100kg standard coal / tonne for cryptocrystalline graphite, to 1,000kg standard tonne for high-purity graphite made using the high temperature method. Those listed as key energy-consuming units should submit a report on energy consumption and saving progress. Recycling of water should be increased and be above 80-90%. Tailings should be used where possible.

- **Environmental protection**: Graphite projects should strictly implement the environmental impact assessment system to control pollutants. Smoke and dust generating processes like material transport, crushing, grinding should be equipped with dust suppression and removal facilitates. Exhaust gas released should meet corresponding emissions standards. There are also requirements on noise control and water treatment and discharge. Protection of soil and groundwater needs to be enhanced. Solid waste should be treated and disposed of properly.

- **Work safety, occupational health and social responsibility**: Enterprises must comply with all relevant laws and regulations, such as the Safety Production Law, Mine Safety Law, Regulation on Safe Production License, Code for Design of Tailings Facilities, and Law on the Prevention and Control of Occupational Diseases. Accountability systems, risk management processes, and relevant training should be in place.

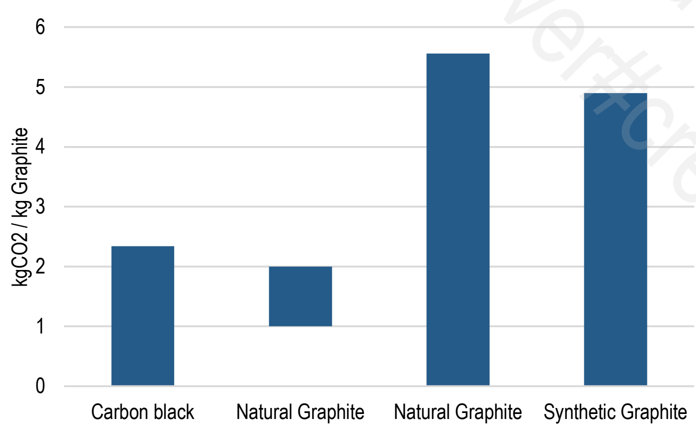
Emissions and energy intensity

- Mining (open-pit) contributes less CO_2 per tonne of battery-grade graphite compared to subsequent production stages, especially the purification step that uses acids and other chemicals. A study estimated that the life cycle energy consumption of 1 tonne of natural graphite anode material is 112 GJ, of which the processing stage contributes 42%, coke oven gas 32% and raw coal account 23% of energy consumption in the whole life cycle (Gao et al, 2018).

- The same study found that the carbon emission embedded in 1 tonne of natural graphite anode material is 5.3 t CO2eq, and mainly comes from raw coal and electricity, which is 24% and 21% of total respectively. In comparison, the production of synthetic graphite is more energy-intensive, which has led operators to seek the cheapest power sources that tend to be coal-heavy, thereby increasing carbon and other emissions (NOx, SOx, PM10). Most of the impact is the result of the graphitisation and roasting processes, in addition to calcined petroleum coke production. Some of these effects can be reduced if natural gas/renewable energy is used instead.

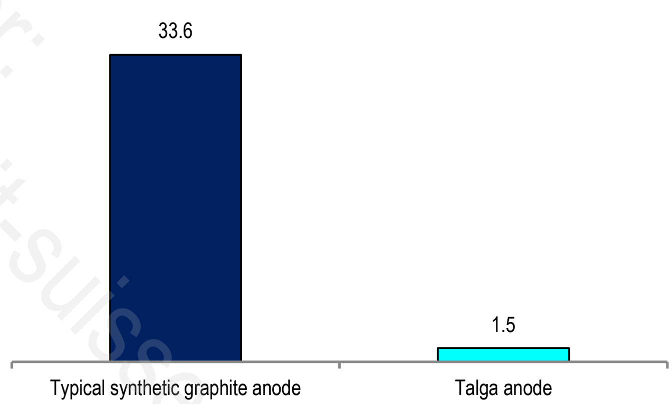
- We note that recent findings showed that the true emissions-intensity of producing battery-grade graphite can be as much as 10x higher than database values, depending on the energy and material inputs (e.g. coal-based grid in Inner Mongolia). For instance, a 2022 life cycle assessment showed that the production of 1 tonne of natural graphite anode material has a global warming potential of around 9.6 t CO2eq (Engels at al, 2022). Another recent study on synthetic graphite yielded 20.6 t CO2eq and 45.9 GJ per tonne, also suggesting an underestimation in prior literature (Surovtseva at al, 2022). Corporate level assessments of 'cradle-to-gate' emissions intensity is increasing. An example is Novonix finding that its flagship GX-23 synthetic graphite anode product has 60% lower CO2 emissions in its life cycle compared to that made in facilities in the Inner Mongolia and Heihlongjiang Provinces of China.
- In terms of natural vs. synthetic graphite, a consolidated information source showed that natural graphite production emits 1-2 t CO2/t from the conventional mining process, compared to 4.9 t CO2/t in synthetic graphite production (Ecoinvent v3.1; GREET, 2018; Dai et al, 2019). Minviro estimated that the emissions intensity of natural and synthetic graphite production in China is 16.8 and 17 t CO2e/t respectively. Different results shown in Figure 62 came about because studies could adjust the system boundary, cover different impact categories, or treat co-products in different ways. The high China synthetic anode carbon footprint comparison in Figure 63 is quoted by Talga, based on Eurostat and EEA data, with the intention of demonstrating the low emissions intensity of its Talnode®-C produced in Sweden.

Figure 62: Emissions intensity of anode material used in battery LCA studies (recognising inconsistent methodology)



Source: Minviro, Credit Suisse

Figure 63: LCA shows Talga anode production emits 96% less CO2 compared to typical synthetic graphite anode (t CO2eq/t)



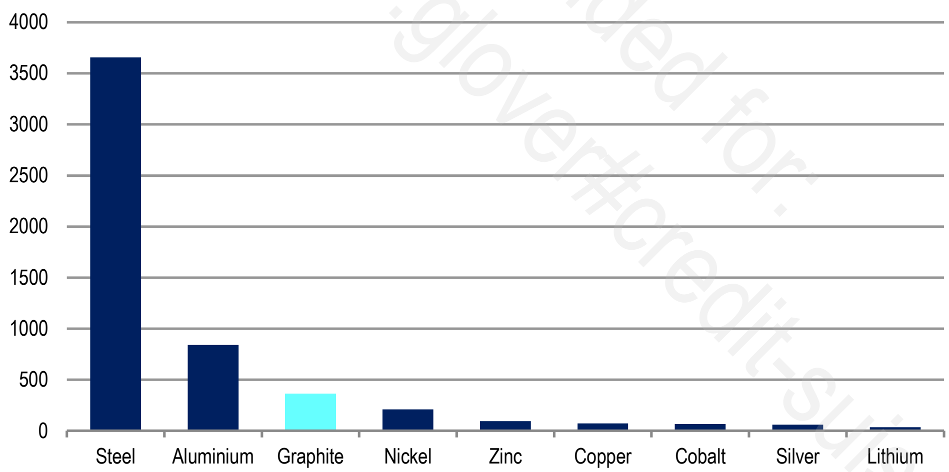
Source: Talga Group, Credit Suisse estimates

- The latest trend is using renewable energy. Nouveau Monde, for instance, plans to leverage Quebec's low-cost hydropower to provide carbon-neutral, high-purity anode material to the battery market. They will use carbon offsets to lower remaining fossil fuel exposure. The focus of Talga Group is building an integrated graphite anode facility in Sweden running on 100% renewables, to produce ultra-low emission coated anode for Li-ion batteries. Anode-grade graphite produced from Northern Graphite's Bissett Creek mine has a carbon footprint of 9.5 t CO2eq/t, much lower than synthetic production in China. Increased electrification and use of hydropower could further lower carbon emissions. Overall, this highlights the need for a company specific approach to emissions intensity and impact.
- World Bank assessed the cradle-to-gate global warming potential of different minerals used in energy technologies (Figure 64). Steel, the highly emissions-intensive material produced in large volumes, is included for reference. Its cumulative carbon footprint under

the 2-degree scenario is 3655 Mt CO2eq through 2050. Excluding steel, aluminium has the highest footprint (843 Mt CO2eq), as solar PV is expected to be the most widely deployed renewable energy technology under that scenario, accounting for 87% of total aluminum demand. Graphite is second at 364 Mt CO2eq, given it is almost exclusively used to manufacture anodes used in most battery technologies. According to S&P, in 2022 alone, the graphite that will be needed to make the estimated 9.5mn new EV will in total generate 11.2 Mt CO2eq during production.

- Given the increase in decarbonisation/ESG commitments from downstream auto OEMs and battery makers on fostering a sustainable supply chain, how the more carbon-intensive minerals, such as graphite, are produced will face increased scrutiny. Toyota, for example, set a 2030 milestone to reduce CO2 emissions by 25% or more throughout its entire vehicle life cycle compared to 2013 levels, by working with suppliers, energy providers, infrastructure developers, governments and consumers. LG Energy Solution said ESG evaluation of all raw material suppliers will be conducted by 2023. The battery maker is cooperating with suppliers to reduce greenhouse gas emissions during production and transportation of raw materials.

Figure 64: Cumulative global warming potential from extraction and processing of minerals from cradle-to-gate for energy technologies through 2050 under the 2-degree scenario (Mt CO2eq)



Source: World Bank, Credit Suisse estimates

Water intensity

Data on the water impact of graphite production is very limited, partly because water management can be highly specific to local circumstances. For example, for Syrah Resources' Balama graphite operation in Mozambique, the amount of water withdrawn from raw water sources (Chipembe Dam and groundwater boreholes) in the past few years was well below licensed withdrawal volumes. A recycled water target of 60% was instituted in March 2021, which was on average achieved in the months that followed. Good governance is maintained over the Balama tailings storage facility with zero non conformances on the quality of water discharged (~359,000m3 in 4Q21), and a permanent discharge license application is in progress.

Biodiversity

It was reported that graphite plants discharge pollutants into air and water. Inhaling particulate matter/dust can cause an array of health impacts, including heart attacks and respiratory ailments. During the mining process, dissolution of iron sulphide and other minerals in the deposit can cause acid mine drainage. The purification process can be highly toxic and polluting particularly if environmental regulations do not demand proper management. Effects more broadly on biodiversity, like most mining operations, are project-specific. For example, the proposed Munglinup Graphite Project of Mineral Commodities and Gold Terrace could clear up to 350ha, directly impacting the ecological linkage values of the remnant vegetation corridor of Munglinup River, and indirectly isolating the remaining native vegetation. Other key environmental factors for the project include terrestrial fauna, inland waters and social surrounds, which are subject to detailed assessments. The impact of land use transformation can have effects on biotic production, erosion potential, groundwater regeneration, infiltration reduction and physico-chemical filtration.

Waste

For natural graphite, flotation as a refining method leads to tailings, which have to be disposed. The composition depends on the mine. Tailings occupy a large amount of landfill and can also lead to serious pollution. However, it is also possible to use them for other purposes such as replacement of sand in concrete, depending on the composition. In the case of the Munglinup Graphite Project, it was determined that tailings are non-acid forming, contain 26-46% clay minerals, with low levels of molybdenum and selenium, and hydrocarbon consistent with diesel. Therefore it was concluded that Munglinup tailings present a low risk to surface and groundwater quality. The purification of battery-grade anode products uses hydrofluoric acid and other chemicals, which create waste after neutralisation, which needs to be recycled or dumped. Broadly for the mining industry, the Global Industry Standard on Tailings Management published by International Council on Mining and Metals is recognised as the current best practice.

Climate Transition Framework Summary

Below is the summary of our assessment of Graphite within our CS Climate Transition Super Materials framework. A complete description of each of the assessment elements and methodology can be found in the Appendix.

Figure 65: Climate Transition Assessment Framework - Graphite

Factor	Value	Comment
1. Demand Opportunity in decarbonisation		
Production-Demand Index	0.96	**High impact material** Important because, although they only feature in a small number of technologies, their level of future demand is much greater than 2020 production levels. However, changes to the technologies used may have big implications for overall levels of demand
Technology Concentration Index	0.36	
2. Supply-Demand dynamic		
Reserves and production	320mn tonnes in natural graphite reserves.	
Rate of supply *Ratio of committed mines: Demand*	N/A	
Production lead times	~6-11 years	Based on main Syrah/NextSource/Talga projects in Africa/Europe. Lead time shorter than the global mining average. See Figure 52.
Geographic concentration of production	China	The majority of the natural and synthetic graphite value chain is based in China
3. Circular Economy		
End of life recycling rates	3% (EU)	The recovery and recycling of Li-ion batteries has focused on the most economically valuable materials, i.e., nickel, cobalt, lithium, manganese, copper, and aluminum.
Recycled content rates	Minimal	Very early stage for scalable recovery. e.g. "Green" graphite electrodes: companies like Coidan Graphite recovering used and damaged electrodes and reconditioning them.
4. Impact Intensity of Production		
Absolute emissions impact	364 Mt CO2eq through 2050	Based on World Bank cradle-to-gate global warming potential of minerals used in energy technologies. Graphite is behind to steel and aluminium.
Emissions intensity of production	Natural: 1-2 t CO2/t Synthetic: 4.9 t CO2/t	Highly dependent on energy and material inputs. Emissions in a life cycle assessment (LCA) of anode material production can be much higher.
Energy intensity / cost	Natural graphite anode material LCA: 112 GJ/t	Based on Gao et al (2018). Coke oven gas and raw coal are main energy consumers.
Water intensity of production	Limited comparable quantitative information / plant-specific.	
Water pollution	Limited comparable quantitative information. During the mining process, dissolution of iron sulphide and other minerals in the deposit can cause acid mine drainage. The purification process can be highly toxic and polluting.	
Biodiversity	Limited comparable quantitative information / location-specific. There could be impacts on vegetation, terrestrial fauna and social surrounds.	
Waste	Limited comparable quantitative information / plant-specific. Tailings waste needs to be handled. Harm would depend on the share of hazardous/non-hazardous waste, and whether the waste is stored/recycled/incinerated/sent to landfill.	

Source: Credit Suisse

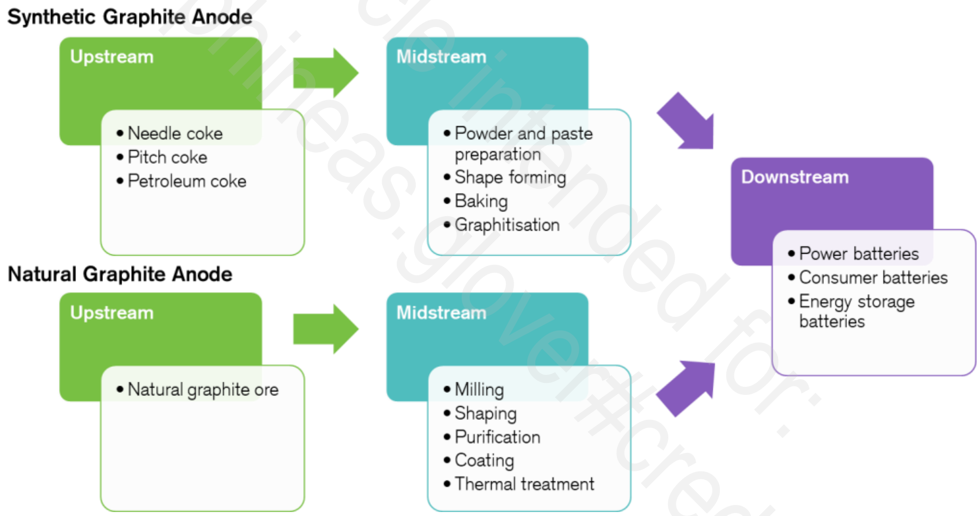
Value Chain and Stock Exposures

The upstream of Li-ion battery anode materials is mainly petroleum coke, needle coke, pitch coke and other chemical products, or primary graphite.

The midstream is the manufacture of final specification anode materials, and the downstream is the application in power batteries (e.g. NEV), consumer batteries (e.g. cell phones) and industrial energy storage batteries (solar PV). The anode materials produced are supplied to battery manufacturers, and are ultimately applied in these downstream battery sectors.

For the production of graphite electrodes for EAF steelmaking, the value chain is similar to that of a synthetic graphite Li-ion battery anode, starting with needle coke as the main raw material and undergoing similar midstream processes before final electrode manufacturing (graphite electrodes are currently made with synthetic graphite).

Figure 66: Value chain of Li-ion battery anode materials sector

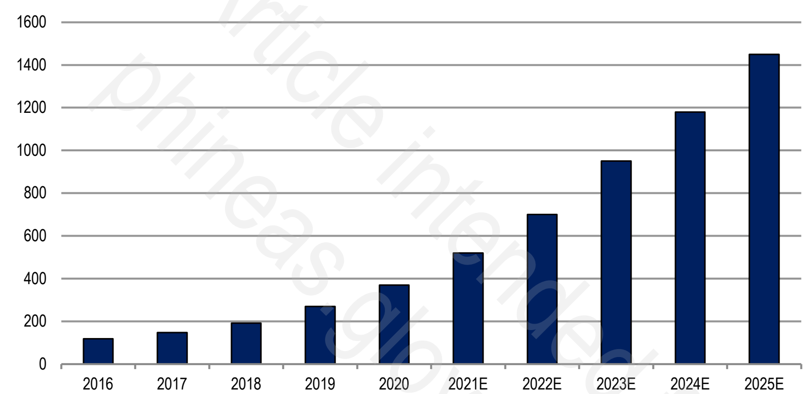


Source: Credit Suisse

Synthetic graphite: China dominates

Prior to 2000, Li-ion anode material supply was dominated by Japan. With technological improvements and scale, Chinese companies have caught up. Between 2016 and 2020 China's sales of anode materials grew at a CAGR of 33% from 118,000 t to 370,000 t reaching 70% global market share. Driven primarily in the near term by the growth in the NEV market in and outside China, China's domestic Li-ion battery industry, and therefore the anode materials industry, is undergoing rapid expansion. According to GaoGong Lithium Battery Research Centre, the market size in China is expected to reach 1,450,000 t in 2025, maintaining a similar CAGR of the past five years. ~80% of this is synthetic graphite, and natural graphite makes up the rest.

Figure 67: China anode materials market volume ('000 t)



Source: GGII, Credit Suisse

- **Upstream coke producers**: Needle / pitch / petroleum coke is the upstream raw material for synthetic graphite production. Needle coke is the material input to graphite electrodes in electric arc furnace steelmaking, as well as synthetic graphite anodes used for lithium-ion power batteries. Major producers include US-based Phillips 66 and GrafTech International, Japan-based C-Chem (Nippon Steel), ENEOS, Petrocokes Japan (Sumitomo Corp), India-based Graphite India, HEG Limited and Indian Oil. In China, while there are many smaller producers, major listed companies include Fangda Carbon New Material, Baotailong New Materials, Henan Yicheng New Energy, China Risun Group, and Sinopec Shanghai Petrochemical. Several coke companies are subsidiaries of major national oil & gas / iron & steel firms, for example Jinzhou Petrochemical is owned by Petro China and Baowu Carbon Material Technology, a subsidiary of China Baowu Steel Group.

- **The value chain is still evolving**: We emphasise that the classification of companies in the supply chain is not precise given increased vertical integration across the sector. This applies across the whole value chain. For instance, POSCO Chemical and Mitsubishi Chemical are both coke suppliers, but they also make graphite-based anode materials for lithium-ion batteries and therefore are grouped under anode material suppliers in the later section. Among coke producers, GrafTech, C-Chem, Fangda, HEG and Graphite India appear to have a bigger focus on supplying coke to make synthetic graphite electrodes used in EAF steelmaking. Japanese firms Showa Denko and Tokai Carbon are also major producers of graphite electrodes globally.

- **China carbon peaking favouring natural graphite**: While most of the anode materials volume is synthetic graphite, we expect the power rationing policy in China will help boost consumption of natural graphite. This is because the production of synthetic graphite consumes a large amount of electricity. As of late 2021, artificial graphite production has seen cuts between 10 and 50% in different regions since the policy rollout. Battery companies started to increase the use of natural graphite for anode materials. We expect the increase in natural graphite consumption to continue as China continues to decarbonise.

Figure 68: Synthetic graphite coke producers - stock exposures summary

Company	Ticker	Business description
Phillips 66	PSX	Phillips 66 is an energy manufacturing and logistics company with midstream, chemicals, refining, and marketing and specialties businesses. Phillips 66 is the only producer and marketer of all grades of green and calcined specialty petroleum coke, serving the steel, lithium-ion battery, aluminum, titanium dioxide and specialty carbon/graphite product industries. It is the leading worldwide producer of premium needle cokes.
C-Chem / Nippon Steel	5401.T	C-Chem, a subsidiary of Nippon Steel, develops a variety of carbon-based products and fundamental chemicals from coal tar. Among other applications, pitch coke is in the synthetic graphite electrodes required for iron reproduction and in leading edge semiconductors and solar cells.
GrafTech International	EAF	Operates in industrial materials, comprised of two product categories, graphite electrodes and petroleum needle coke products. Graphite electrodes are an industrial consumable product used primarily in EAF steel production. Petroleum needle coke is a crystalline form of carbon derived from decant oil, which is a raw material used in the production of graphite electrodes.
ENEOS	5020.T	Mainly engaged in the energy business, oil and gas development business, and metal business. High purity coke and artificial graphite anode material for lithium-ion batteries are delivered by its High Performance Materials division.
Petrocokes Japan / Sumitomo Corporation	8053.T	Petrocokes Japan, a subsidiary of Sumitomo Corporation, manufactures petroleum needle coke applied in mineral resources, energy, chemical & electronics.
Fangda Carbon New Material	600516.SS	Principally engaged in the production and sales of graphite and carbon products. Main products include ultra-high power, high power and common power graphite electrodes, microporous carbon bricks, semi-graphite carbon bricks, aluminum carbon bricks, isostatic graphite products, special graphite products, biological carbon products and carbon composite materials.
Baotailong New Materials	601011.SS	Principally involved in the production and sales of coke. The Company's other products include slack coal, crude benzene, methanol, refined wash oil, pitch blending components, needle coke, graphene and downstream products.
Kaifeng Pingmei New Carbon Materials Technology / Henan Yicheng New Energy	300080.SZ	Henan Yicheng New Energy operates two segments: Kaifeng Carbon and Pingmei Longji. The Kaifeng Carbon segment is mainly responsible for R&D, production and sales of graphite electrodes. The Pingmei Longji segment is responsible for the production and sales of battery chips.
Sinopec Shanghai Petrochemical	600688.SS	Principally engaged in processing crude oil into synthetic fibers, resins and plastics, intermediate petrochemicals and petroleum products.
China Risun Group	1907.HK	Mainly engaged in coking products and fine chemical products business. The Refined Chemicals segment principally includes carbon material chemicals, alcohol-ether chemicals and aromatic chemicals.
HEG Limited	HEGL.NS	Engaged in manufacturing and exporting graphite electrodes. The Company's segments include Graphite electrodes (including other carbon products) and Power. The Graphite electrodes are used in steelmaking through the Electric Arc Furnace (EAF) route. The Power generation is comprised of two thermal power plants and a hydroelectric power facility for its graphite electrode.
Graphite India	GRPH.NS	Manufactures graphite electrodes, graphite equipment's, steel, glass reinforced plastic pipes and tanks.
Indian Oil Corporation	IOC.NS	Indian Oil Corporation's segments mainly include Petroleum Products and Petrochemicals. Coke can be applied in electrodes for electrometallurgical industries, in synthetic graphite, aluminium anodes etc.

Source: Company data, Refinitiv Eikon, Credit Suisse

Figure 69: Synthetic graphite coke producers - stock exposures financials (as at 1 Apr 2022)

RIC	Company	Rating	Market Cap (US$ Bn)	PE (x)		EV/EBITDA		Sales growth		EBITDA growth		Key HOLT metrics			ESG (Refinitiv)	
				2022	2023	2022	2023	2022	2-yr growth	2022	2-yr growth	Quality	Momentum	Valuation	ESG Score	ESG Momentum
PSX	Phillips 66	O	41.6	11.1	10.8	6.7	6.5	15%	3%	14%	7%	29	73	63	84	20%
5401.T	Nippon Steel	NC	16.0	5.5	6.0	4.9	4.9	8%	1%	-1%	0%	10	69	89	59	8%
EAF	Graftech International Ltd.	O	2.5	5.3	5.5	5.3	4.8	13%	7%	4%	1%	97	14	77	46	12%
5020.T	ENEOS Holdings	NC	11.9	5.9	6.4	4.7	4.6	9%	5%	-12%	-6%	17	43	93	67	9%
8053.T	Sumitomo Corp	NC	21.5	6.7	7.4	13.6	13.6	5%	1%	1%	-1%	21	91	86	61	5%
600516.SS	FangDa Carbon	NR	5.1	18.4	11.4	16.0	9.6	32%	35%	61%	74%	48	76	54	29	10%
601011.SS	BNMC	NR	1.4	na	na	na	na	na	na	na	na	na	na	na	na	na
300080.SZ	YCNE	NR	1.5	na	na	na	na	na	na	na	na	na	na	na	na	na
600688.SS	Sinopec Shanghai Petrochemical	U	4.8	14.3	14.3	7.8	7.7	8%	5%	-12%	-6%	31	22	55	62	60%
1907.HK	China Risun	NR	2.4	4.5	3.4	na	na	26%	23%	na	na	na	na	na	na	na
HEGL.NS	HEG	NR	0.7	5.5	4.9	na	na	25%	21%	42%	27%	27	16	84	na	na
GRPH.NS	Graphite India	NR	1.3	10.0	8.3	na	na	37%	25%	173%	84%	27	25	81	na	na
IOC.NS	Indian Oil Corpn	NR	15.1	5.7	5.6	5.7	5.6	17%	9%	-4%	0%	49	53	70	71	13%

Source: Credit Suisse HOLT®, Credit Suisse Research, Refinitiv Eikon

Natural graphite: lower carbon intensity

Outside China, there are a number of emerging natural graphite miners stepping up to supply this critical material. These include Syrah Resources, Black Rock Mining, Talga Group, Triton Minerals, Leading Edge Materials, NextSource Materials, among others. Most of these more upstream operators have certain things in common: First, their main graphite projects are in the development/ feasibility stage. Second, they capitalise on the growth in natural graphite demand mainly in anodes. Benchmark Mineral Intelligence projects that by 2030 natural graphite anodes will represent half of total demand. Flake graphite demand for lithium-ion batteries is expected to grow from 0.2mn/t in 2020, to 1.1mn/t in 2025 and 2.9mn/t in 2030.

- **Significantly lower carbon intensity**: Importantly, these companies expect to produce graphite with less environmental impact. For example, Leading Edge Materials forecasts that 1 tonne of natural graphite anode material (coated spherical purified graphite) from natural graphite extracted at its Woxna Graphite mine has cradle-to-gate impact of 1.8 tonnes CO_2eq. This is 85-90% lower than current market dominant Chinese alternatives producing synthetic graphite. The significant factor is access to hydropower as the main electricity source. Talga Group's main focus is building an integrated graphite anode facility in Sweden running on 100% renewable electricity, to produce ultra-low emission coated anode for greener Li-ion batteries. Others are trying to find ways to achieve lower emissions to remain competitive. For example Northern Graphite engaged Minviro, which estimated that by powering the mining fleet with natural gas rather than diesel, and replacing the planned natural gas fired generating plant with hydro power, the global warming potential of the main Bissett Creek project could be reduced by more than half, from 2.2 kg of CO_2eq/kg of graphite produced to 1.0 kg/kg. Total carbon footprint of the manufactured anode materials (7.3 kg CO_2eq/kg) could also be less than half of that of Chinese producers (16.8-17 kg CO_2eq/kg).
- **Natural graphite value chain still evolving**: In terms of positioning across the supply chain, Talga will feed flake graphite ore from its Vittangi Project to an in-house downstream processing facility, producing a coated graphite anode product to be sold to lithium-ion battery cell manufacturers. Syrah aims to be vertically integrated, from mining and concentration in Mozambique, to milling/shaping and purification to produce an anode precursor, and making the active anode material via carbon coating and thermal treatment in Vidalia, Louisiana. For Leading Edge Materials, the planned output is coated spherical purified graphite, made with existing mine reserves. NextSource adopted a partnership approach (within the Tesla supply chain), allowing it to get immediate access to established spheroidisation and coating technology IP for OEMs and provide OEMs a proven anode solution using non-Chinese sources graphite. Last year, POSCO acquired a 15% stake in Black Rock Mining. Black Rock signed an offtake deal with POSCO that effectively de-risks the Mahenge project.
- **Vertical integration driven by economics**: Coated spherical graphite sells for >$6,500/t, uncoated spherical graphite for >$3,000/t, while flake graphite supply is priced at >$1,200/t. Some identified a valuation differential as well between miners that adopt an integrated battery anode material strategy and those that do not, for example Triton Minerals. Triton has a target production of 60,000 tonnes of high purity, large flake, graphite concentrate per annum, primarily used for the expandable market (flame retardants and building products), unlike the others that focus on the EV opportunity with more downstream reach. Having said that they have a Binding Offtake Agreement for up to 10,000 tonnes of graphite concentrate with Chinese graphite specialist and battery anode manufacturer Yichang Xincheng Graphite. Other than Triton, miners like Black Rock Mining, Volt, and Evolution Energy Materials have lower degrees of integration into the downstream processing stages.

Figure 70: Natural graphite - stock exposures summary

Company	Ticker	Business description
Syrah Resources	SYR.AX	Engaged in its flagship Balama natural flake graphite operation in Mozambique (ramping up) and a downstream battery active anode material project in the United States (Phase 1 under construction and fully funded, with Tesla off-taker).
Black Rock Mining	BKT.AX	Owns one of the largest JORC-compliant flake graphite resources globally in Tanzania. Differentiated global graphite exposure due to backing by tier-1 anode producer, POSCO as major shareholder and offtaker, and has achieved product qualification.
Talga Group	TLG.AX	Engaged in the production of battery anodes and graphene additives. The Company is focused on graphite exploration, research and development in Sweden, Germany and the United Kingdom.
Nouveau Monde	NOU.V	Focused on developing a fully integrated source of carbon-neutral battery anode material in Quebec, Canada for the lithium-ion and fuel cell markets. It owns interest in the Matawinie graphite property and a battery material plant.
NextSource Materials	NEXT.TO	Mining and value-added processing of flake graphite and other critical minerals. The company is capable of producing coated and spheronized graphite that is used for the manufacturing of battery anodes. Projects include Molo Graphite Project and Green Giant Vanadium Project in Madagascar.
Triton Minerals	TON.AX	Engaged in developing graphite projects in the Cabo Delgado region of Northern Mozambique.
South Star Battery Metals	STS.V	Engaged in developing the Santa Cruz Graphite Project in Southern Bahia, Brazil.
Gratomic	GRAT.V	Focused on mine to market commercialisation of graphite products, and exploration of assets primarily in Canada and Namibia.
Graphite One	GPH.V	Focused on producing anode material for the lithium-ion electric vehicle battery market and energy storage systems, and is evaluating the graphite resources on its Graphite Creek Property near Nome, Alaska.
Northern Graphite	NGC.V	Holds interests in the Bissett Creek Project, which is located between the towns of Deep River and Mattawa, Ontario.
Mason Graphite	LLG.V	Engaged in exploration and evaluation of the Lac Gueret graphite property located in Quebec, Canada.
Focus Graphite	FMS.V	Developing high-grade flake graphite deposits to supply battery-grade graphite. Projects include Lac Knife and Lac Tetepisca.
Haida Graphite	/	Owns one of the most important bases for crystalline flake graphite in China. Products include natural flake graphite, graphite carburising agent, spherical graphite, expandable graphite, graphite lead core, alkaline battery, graphite sheet, high purity graphite.
Magnis Energy Technologies	MNS.AX	Three core areas of focus: battery technologies, gigafactories and graphite. The company has ownership interests in two LIB cell gigafactories in Endicott, New York and Townsville, Australia. It also holds a graphite deposit in south east Tanzania (Nachu Graphite Project), with high distribution towards natural flake graphite in the super jumbo, jumbo and large flake categories.
Leading Edge Materials	LEM.V	Involved in the exploration and development of resource properties in Sweden/EU with operations in Canada. Projects include Woxna Graphite mine (Sweden), Norra Karr HREE project (Sweden) and Bihor Sud Nickel Cobalt exploration alliance (Romania).
EcoGraf	EGR.AX	EcoGraf's businesses include battery products (spherical graphite production in Australia for battery anode makers), battery recycling (purification tech) and Epanko Graphite Project (natural flake in Tanzania).
Renascor Resources	RNU.AX	Focused on the exploration and evaluation of economically viable deposits containing graphite, gold, copper and other minerals. The Company has a portfolio, holding interests in key mineral provinces of South Australia. Its projects include the Siviour Battery Anode Materials Project, Carnding Gold Project, Marree Project, Olary Project and Eastern Eyre Project.
Volt Resources	VRC.AX	Mines graphite, gold and other minerals in Africa and holds a 70% controlling interest in the Zavalievsky Graphite business in Ukraine. Volt is also developing its wholly owned Bunyu Graphite project in Tanzania, as well as gold exploration in Guinea.
Mineral Commodities	MRC.AX	Segments: Mineral sands mining & production (Tormin Mineral Sands project, South Africa), Mineral sands exploration (Xolobeni Mineral Sands project, South Africa), Graphite mining & production (Skaland, Norway) and Exploration activities, Australia.
Greenwing Resources	GW1.AX	Produces graphite, advanced materials and lithium. The Company's projects include Graphmada Graphite project (Madagascar), Millie's Reward (Madagascar) and San Jorge lithium brine project (Argentina).
Evolution Energy Minerals	EV1.AX	Owns and controls 100% of the Chilalo coarse flake graphite project, located in south-eastern Tanzania.
Walkabout Resources	WKT.AX	Focused on discovering and developing a range of products, such as graphite, gold, base metals, and lithium. Its projects include the Lindi Jumbo Graphite project (Tanzania), Eureka Lithium project (Namibia), and United Kingdom project.
Battery Minerals	BAT.AX	Engaged in graphite projects, Montepuez and Balama, in Mozambique. The company is also advancing its gold/copper projects in Australia.
Tirupati Graphite	TGRT.L	Integrated specialist graphite and graphene producer. Operations include mining and processing in Madagascar, graphite processing in India, and a graphene and technology R&D center to be established in India.

Source: Company data, Refinitiv Eikon, Credit Suisse

Figure 71: Natural graphite - stock exposures financials (as at 1 April 2022)

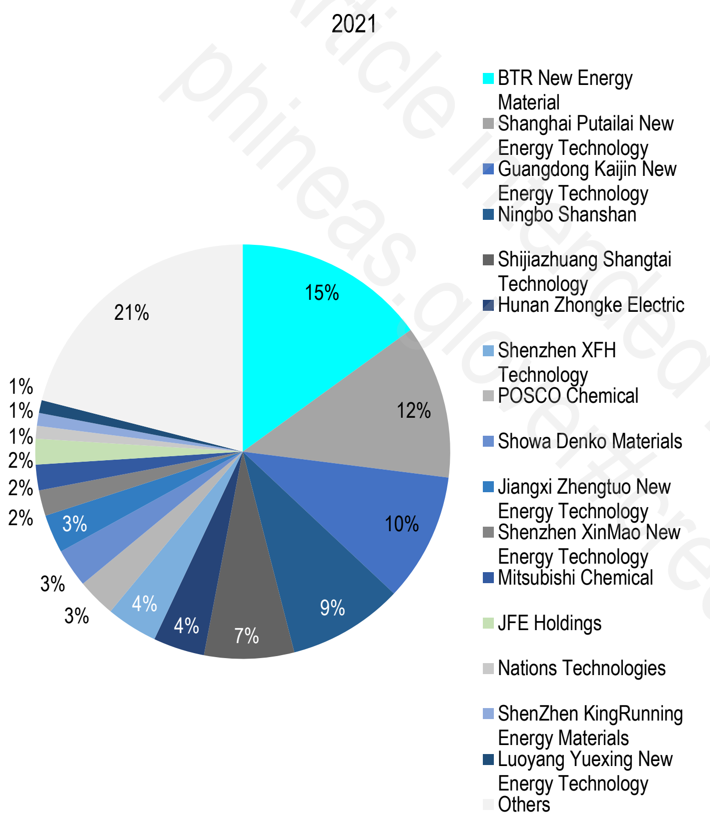
RIC	Company	Rating	Market Cap (US$ Bn)	PE (x)		EV/EBITDA		Sales growth		EBITDA growth		Key HOLT metrics			ESG (Refinitiv)	
				2022	2023	2022	2023	2022	2-yr growth	2022	2-yr growth	Quality	Momentum	Valuation	ESG Score	ESG Momentum
SYR.AX	Syrah Resources	N	0.9	na	29.9	42.6	11.1	377%	158%	na	na	24	91	75	50	26%
NOU.V	Nouveau Monde	NR	0.4	na	na	na	na	na	na	na	na	na	na	na	na	na
TLG.AX	Talga Group	NR	0.4	na	9.3	na	na	13811%	5293%	na	na	na	na	na	na	na
TON.AX	Triton Minerals	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
LEM.V	Leading Edge Mat	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na
NEXT.TO	NextSource	NR	0.3	na	na	na	77.3	na	na	na	na	na	na	na	na	na
GRAT.V	Gratomic	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na
GPH.V	Graphite One	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na
NGC.V	Northern	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na
LLG.V	Mason Graphite	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na
FMS.V	Focus Graphite	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
MNS.AX	Magnis Energy	NR	0.4	na	na	na	na	na	na	na	na	na	na	na	13	8%
BKT.AX	Black Rock Min	NR	0.2	na	na	na	na	na	na	na	na	na	na	na	na	na
EGR.AX	Ecograf	NR	0.2	na	na	na	na	na	na	na	na	na	na	na	na	na
RNU.AX	Renascor Res	NR	0.4	na	na	na	na	na	na	na	na	na	na	na	na	na
VRC.AX	Volt Resources	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
MRC.AX	Mineral	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
GW1.AX	Greenwing Rsrcs	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
EV1.AX	Evolution Energy Minerals	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
WKT.AX	Walkabout	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na
BAT.AX	Battery Minerals	NR	0.0	na	na	na	na	na	na	na	na	na	na	na	na	na
TGRT.L	Tirupati Graphite	NR	0.1	na	na	na	na	na	na	na	na	na	na	na	na	na

Source: Credit Suisse HOLT®, Credit Suisse Research, Refinitiv Eikon

Anode material suppliers: competition growing

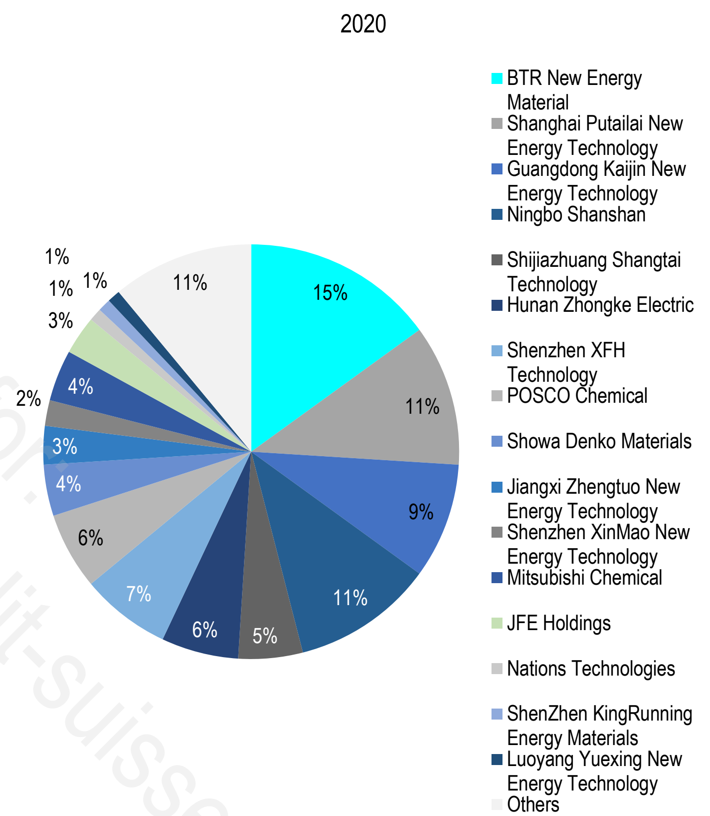
In 2021, the top seven anode material suppliers were all Chinese, in the order of BTR New Energy Material (BTR), Shanghai Putailai New Energy Technology (Putailai), Guangdong Kaijin New Energy Technology (Kaijin), Ningbo Shanshan (Shanshan), Shijiazhuang Shangtai Technology (Shangtai), Hunan Zhongke Electric (Zhongke), and Shenzhen XFH Technology (XFH). Together they account for c. 60% of global market share. Major players outside China include POSCO Chemical from South Korea, and Showa Denko Materials, Mitsubishi Chemical and JFE from Japan, each of which supplies 2-3% of the market. From 2020 to 2021, we can see that Chinese companies further increased market share against foreign competitors.

Figure 72: Global market share of Li-ion anode material (2021)



Source: SPIR, Credit Suisse

Figure 73: Global market share of Li-ion anode material (2020)



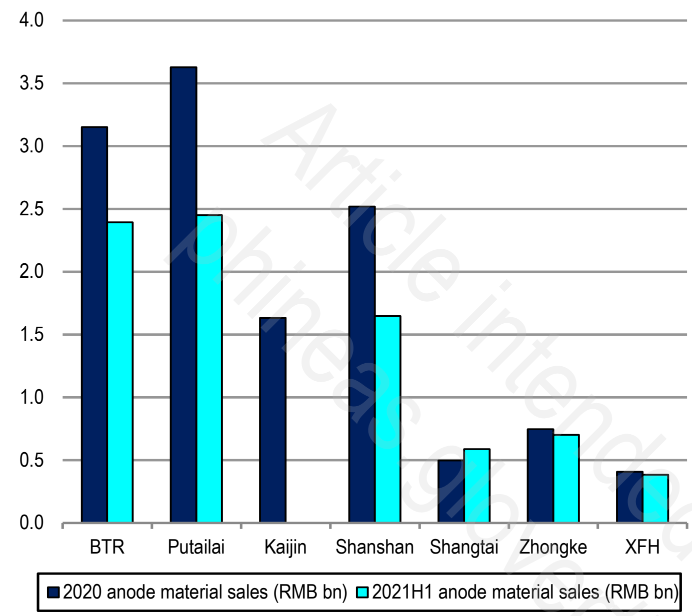
Source: SPIR, Credit Suisse

In terms of sales revenue/volume, we are seeing robust growth based on the latest 2021H1 data. 2021H1 revenue is at least 70% of 2020 revenue for the largest Chinese firms (noting generally H2 had higher business activity). Shangtai even recorded higher 2021H1 revenue and volumes than full year 2020. By volume, the largest firm BTR shipped ~75,000 t in 2020 and ~62,000 t in 2021H1. By sales, the largest firm Putailai made RMB~3.6bn and ~2.5bn respectively for 2020/2021H1.

On the input side, the anode makers buy mainly petroleum/needle coke (synthetic) and flake graphite (natural). These firms sit in the midstream of the anode supply chain. For BTR, for example, the upstream raw materials account for >60% of operating costs. Long-term cooperation with suppliers is a priority. The upstream appears to be less concentrated than the downstream battery manufacturing sector though in China. Top five clients make up 63% of BTR's revenue. This figure is 22% for the top five suppliers as a proportion of costs.

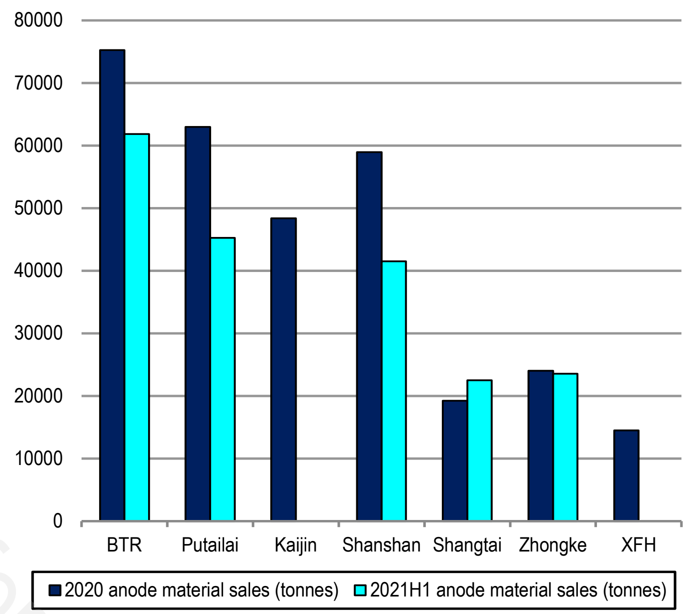
In terms of market structure, natural graphite material supply is dominated by BTR, followed by XFH. Share of natural graphite anode in Li-ion battery is currently at around 20% of total, but is expected to rise given power consumption control in China. The policy is also likely to reduce outsourcing of the energy-intensive and increasingly expensive graphitization process.
Compared to natural graphite, the synthetic graphite anode material market is less concentrated. The top three suppliers are Putailai, Shanshan and BTR.

Figure 74: Anode materials sales revenue of top Chinese firms



Source: Company data
*Kaijin data unavailable for 2021H1

Figure 75: Anode materials sales volume of top Chinese firms



Source: Company data
*Kaijin and XFH data unavailable for 2021H1

Figure 76: Graphite anode material suppliers - stock exposures summary

Company	Ticker	Business description
BTR New Energy Material / China Baoan Group	835185.BJ / 000009.SZ	Products include lithium battery cathode materials, natural graphite, artificial graphite and silicon-based anode materials. 60%+ market share within natural graphite. Top 3 in synthetic graphite.
Shanghai Putailai New Energy Technology	603659.SS	Focuses on lithium-ion battery's key materials and automation equipment, with comprehensive coverage of lithium-ion battery anode materials, automation coating equipment, separator coating, aluminium laminated film and other services. Leader in synthetic graphite (20% market share).
Guangdong Kaijin New Energy Technology	/	Specialises in researching, producing and selling anode materials. Top 5 in synthetic graphite.
Ningbo Shanshan	600884.SS	Since its A-share listing in 1996, Shanshan has transformed from the first listed apparel company in China to a leader in the new energy industry. Its business covers lithium-ion battery materials, battery system integration (including lithium-ion capacitors, power battery packs), and energy management services. Top 3 in synthetic graphite.
Shijiazhuang Shangtai Technology	/	Specialises in R&D, production, processing and sale of lithium-ion battery anode materials and graphitised coke. The company is also one of the few domestic lithium-ion battery anode material manufacturers that integrates the whole industry chain from raw material grinding, graphitisation processing to finished anode materials production. Top 5 in synthetic graphite.
Hunan Zhongke Electric	300035.SZ	Magnetoelectric equipment enterprise that also provides anode material solutions for high energy density lithium batteries.
Shenzhen XFH Technology	300890.SZ	Supplier of lithium battery anode materials, covering traditional graphite anode materials such as natural graphite, artificial graphite, and composite graphite, and new types of silicon carbon, titanium, and graphene energy materials. Second largest natural graphite producer behind BTR.
POSCO Chemical	003670.KS	Battery and chemical materials manufacturing arm of Posco Group, producing battery materials, advanced chemical materials and basic industrial materials. POSCO Chemical develops and supplies natural graphite and low-expansion anodes. It is diversifying into artificial graphite, silicon and lithium metal.
Showa Denko Materials	4004.T	Advanced materials company supporting the Information and Communication, Mobility (including plastic molded products, brake parts, powder metal products, anode materials), High Performance Materials, and Life Sciences sectors. Hitachi Chemical became a subsidiary of Showa Denko in 2020.
Jiangxi Zhengtuo New Energy Technology	/	State-level enterprise that integrates the research and development, production and sale of graphite anode materials for lithium batteries.
Shenzhen XinMao New Energy Technology	/	Main business is development of lithium ion battery anode graphite material, positioning for mid- to high-end of the market.
Mitsubishi Chemical	4188.T	Engaged in the functional products, healthcare and materials business applied in a wide range of applications, e.g. petrochem, environment, auto, electronics, building, energy, food. The anode material unit provides formulated anode materials for lithium-ion batteries, made from either natural or artificial graphite.
JFE Holdings	5411.T	JFE Chemical supplies high-grade products for a broad range of industrial applications. It reforms spherical natural graphite to create high-performance anode materials.
Nations Technologies / Shenzhen Sinuo Industrial Development	300077.SZ	Shenzhen Sinuo is a subsidiary of Nations Technologies. Sinuo's main business is lithium ion battery anode materials development and sales.
ShenZhen KingRunning Energy Materials	/	A national high-tech enterprise that focuses on industrial development and sales of anode materials for lithium-ion batteries.
Luoyang Yuexing New Energy Technology	/	A lithium-ion-based technology solution provider, mainly involved in the R&D, production, and sale of lithium-ion battery anode materials.
Novonix	NVX.AX	Operates through three segments: Graphite Exploration and Mining, Battery Technology, and Battery Materials. Its anode materials business, PUREgraphite, has developed an environmentally friendly process to produce lower-cost graphite anode material for lithium-ion batteries in the United States.
Tokai Carbon	5301.T	Engaged in the manufacture and sale of carbon products. The Company operates in the following business segments: Carbon Black, Graphite Electrode, Fine Carbon, Industrial Furnace and Related Products. Anode Material is a new division that has a lot of growth potential.

Source: Company data, Refinitiv Eikon, Credit Suisse

Figure 77: Graphite anode material suppliers - stock exposures financials (as at 1 April 2022)

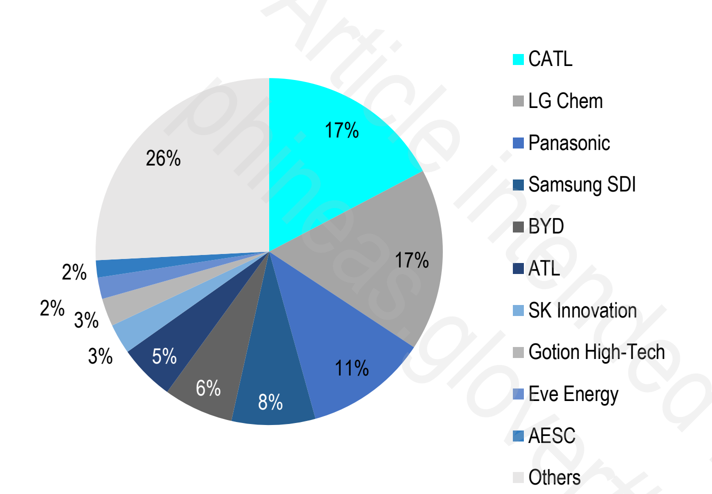
RIC	Company	Rating	Market Cap (US$ Bn)	PE (x)		EV/EBITDA		Sales growth		EBITDA growth		Key HOLT metrics			ESG (Refinitiv)	
				2022	2023	2022	2023	2022	2-yr growth	2022	2-yr growth	Quality	Momentum	Valuation	ESG Score	ESG Momentum
000009.SZ	China Baoan Grp	NR	4.6	18.9	12.3	na	na	40%	38%	na	na	23	48	34	na	na
603659.SS	Shanghai Putailai New Energy Tech.	NR	15.6	37.1	26.3	28.0	20.0	57%	49%	59%	50%	67	93	25	1	na
600884.SS	Ningbo Shanshan	N	9.5	16.4	12.8	11.7	9.5	16%	20%	17%	20%	19	43	66	na	na
300035.SZ	HNZK Electric.	NR	3.6	28.1	18.9	na	na	81%	62%	95%	73%	na	na	na	na	na
300890.SZ	XFH Technology	NR	0.8	26.9	17.7	na	na	26%	28%	61%	52%	na	na	na	na	na
003670.KS	Posco Chemical	NR	7.6	61.3	44.4	32.6	24.1	23%	32%	24%	32%	32	29	9	51	1%
4004.T	Showa Denko	NC	3.5	9.8	6.6	5.8	5.5	-3%	2%	2%	8%	37	19	82	64	9%
4188.T	Mitsubishi Chem	NC	9.4	7.5	7.5	6.0	5.7	8%	5%	2%	2%	12	57	47	61	0%
5411.T	JFE Holdings	NC	7.9	5.1	5.7	5.5	5.7	7%	1%	-2%	-3%	10	52	90	70	4%
300077.SZ	Nations Tech	NR	1.8	na	na	na	na	na	na	na	na	31	66	8	na	na
NVX.AX	Novonix	NR	2.3	na	na	na	75.9	314%	262%	na	na	27	35	36	5	na

Source: Credit Suisse HOLT®, Credit Suisse Research, Refinitiv Eikon

Li-ion battery-makers

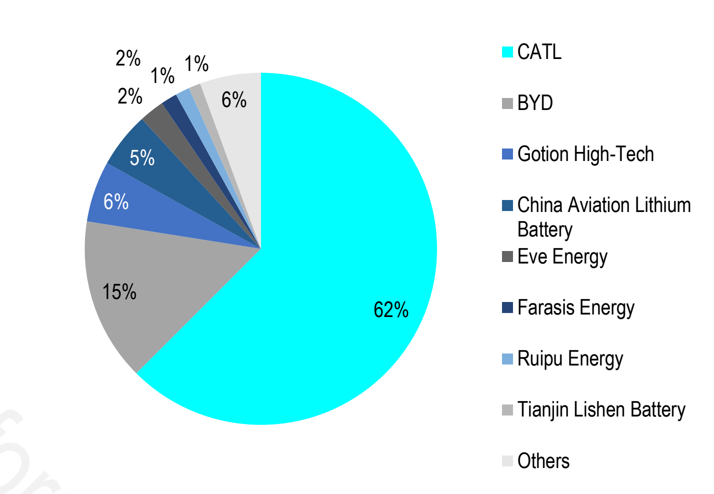
Who are the major customers of the top Chinese anode makers? Most count CATL as one of them, if not the largest. For example, Shangtai derived 79%/58% of anode sales/total sales from CATL in 2020. Similarly, for Kaijin, 60% of sales in 2020 came from CATL, which increased to 66% in 2021H1. This is somewhat expected given the market structure of downstream battery markers: CATL accounts for 17% of global Li-ion market and as much as 63% of China's power battery market. Other major customers of anode makers include BYD, Gotion High-Tech, Tianjin Lishen Battery, LG Chem, China Aviation Lithium Battery, Panasonic, SK Innovation, and Samsung SDI.

Figure 78: Global Li-ion battery market share (2020)



Source: GGII, Credit Suisse

Figure 79: China power battery market share (2020)



Source: GGII, Credit Suisse

Alternative downstream applications

The graphite electrode industry primarily supplying to EAF steel producers is fairly consolidated, particularly outside of China. The largest global producers are companies mentioned above, Showa Denko, GrafTech, Fangda, Tokai Carbon and Graphite India.

Use of graphite in hydrogen fuel cells is identified as an emerging growth market by some graphite suppliers, quoting the US Geological Survey that "fuel cells have the potential to consumer as much graphite as all other uses combined." The Schunk Group, an international technology group supplying high-tech materials such as carbon, technical ceramics, sintered metal and various machines/systems, is committed to this opportunity. It developed bipolar plates for the fluctuating Proton Exchange Membrane Fuel Cell (PEMFC) and Direct Methanol Fuel Cell markets. More than 700,000 plates were produced to date. Its bipolar plates have a very high proportion of graphite, which achieves high electrical conductivity, corrosion resistance, mechanical strength and flexibility.

Entegris Poco Materials says its graphite is the only graphite portfolio recommended by the Fuel Cell and Hydrogen Energy Associations testing protocols, providing advanced materials for bipolar plates and subassemblies that improve fuel cell reliability. The company also provides graphite for use in modern fission and fusion reactors. Its graphite grades are highly uniform, which enables efficient and long-lived energy production.

Research on graphite-made bipolar plates in fact started years ago. We identified a 2009 US Department of Energy-funded programme led by GrafTech, whose goal was to develop the next generation of high temperature PEMFC bipolar plates. NeoGraf Solutions, previously owned by GrafTech, provides GrafCell flow field plate and gas diffusion layer fuel cell components manufactured from expanded natural graphite.

Figure 80: Graphite electrode producers - stock exposures summary

Company	Ticker	Business description
Showa Denko KK	4004.T	Comprehensive chemical company with six business segments: Petrochemical, Chemicals, Electronics, Inorganic Materials, Aluminium, Others. The Inorganic Materials segment is engaged in the manufacture and sale of graphite electrodes, ceramics and fine ceramics.
GrafTech International	EAF	Operates in industrial materials, comprised of two product categories, graphite electrodes and petroleum needle coke products. Graphite electrodes are an industrial consumable product used primarily in EAF steel production. Petroleum needle coke is a crystalline form of carbon derived from decant oil, which is a raw material used in the production of graphite electrodes.
Fangda Carbon New Material	600516.SS	Principally engaged in the production and sales of graphite and carbon products. Main products include ultra-high power, high power and common power graphite electrodes, microporous carbon bricks, semi-graphite carbon bricks, aluminum carbon bricks, isostatic graphite products, special graphite products, biological carbon products and carbon composite materials.
Tokai Carbon	5301.T	Engaged in the manufacture and sale of carbon products. The Company operates in the following business segments: Carbon Black, Graphite Electrode, Fine Carbon, Industrial Furnace and Related Products.
Graphite India	GRPH.NS	Manufactures graphite electrodes, graphite equipment's, steel, glass reinforced plastic pipes and tanks.
SGL Carbon	SGCG.DE	Manufacturer of products and solutions based on carbon fibers and specialty graphites. It operates through three segments: Composites-Fibers & Materials, Graphite Materials & Systems and Corporate/Research.
HEG Limited	HEGL.NS	Engaged in manufacturing and exporting graphite electrodes. The Company's segments include Graphite electrodes (including other carbon products) and Power. The Graphite electrodes are used in steelmaking through the Electric Arc Furnace (EAF) route. The Power generation is comprised of two thermal power plants and a hydroelectric power facility for its graphite electrode.
Nippon Carbon	5302.T	Mainly engaged in the manufacture and sale of carbon products, including artificial graphite electrodes, impervious graphite, isotropic high purity graphite, graphite products for equipment, general carbon fiber and graphitic fiber, lithium-ion battery negative-electrode materials. It also has a Silicon Carbide Product segment.
Kaifeng Pingmei New Carbon Materials Technology / Henan Yicheng New Energy	300080.SZ	Henan Yicheng New Energy operates two segments: Kaifeng Carbon and Pingmei Longji. The Kaifeng Carbon segment is mainly responsible for R&D, production and sales of graphite electrodes. The Pingmei Longji segment is responsible for the production and sales of battery chips.
Jilin Carbon / Sinosteel Engineering & Technology	/	Jilin Carbon is owned by Zhongze Group. Products include graphite electrodes, carbon fibers, special carbon products, electrode pastes and others. The products are widely used in metallurgy, chemical industry, machinery, electronics, medical treatment, scientific research and new materials fields.
Dan Carbon	/	Main product range is involved with varieties of RP (regular power), HP (high power) and UHP (ultra-high power) graphite electrodes, graphite blocks and special heterogeneous graphite and other carbon products. Products sold all over the China domestic markets and globally.

Source: Company data, Credit Suisse estimates

Figure 81: Graphite electrode producers - stock exposures financials (as at 1 April 2022)

RIC	Company	Rating	Market Cap (US$ Bn)	PE (x)		EV/EBITDA		Sales growth		EBITDA growth		Key HOLT metrics			ESG (Refinitiv)	
				2022	2023	2022	2023	2022	2-yr growth	2022	2-yr growth	Quality	Momentum	Valuation	ESG Score	ESG Momentum
5301.T	Tokai Carbon	NC	2.0	9.8	8.0	na	na	16%	12%	38%	25%	30	12	71	57	24%
4004.T	Showa Denko	NC	3.5	9.8	6.6	5.8	5.5	-3%	2%	2%	8%	37	19	82	64	9%
EAF	Graftech International Ltd.	O	2.5	5.3	5.5	5.3	4.8	13%	7%	4%	1%	97	14	77	46	12%
600516.SS	FangDa Carbon	NR	5.1	18.4	11.4	16.0	9.6	32%	35%	61%	74%	48	76	54	29	10%
GRPH.NS	Graphite India	NR	1.3	10.0	8.3	na	na	37%	25%	173%	84%	27	25	81	na	na
SGCG.DE	SGL	NC	0.8	17.6	12.1	9.1	7.1	4%	5%	1%	13%	7	35	11	69	7%
HEGL.NS	HEG	NR	0.7	5.5	4.9	na	na	25%	21%	42%	27%	27	16	84	na	na
5302.T	Nippon Carbon	NC	0.4	11.2	8.4	na	na	12%	11%	45%	32%	24	21	51	na	na
300080.SZ	YCNE	NR	1.5	na	na	na	na	na	na	na	na	na	na	na	na	na

Source: Credit Suisse HOLT®, Credit Suisse Research, Refinitiv Eikon

APPENDIX

Credit Suisse's Climate Transition Super Materials Series

The growing need for transition materials

Society is in the midst of a major climate transition to lower carbon technologies and clean energy. The efforts of an ever-expanding number of countries, industries and companies to reduce emissions to Net Zero requires the deployment of a wide range of new climate technologies. The growth in the technologies critical for this climate transition will, in turn, be dependent on a wide range of critical minerals and specialty materials.

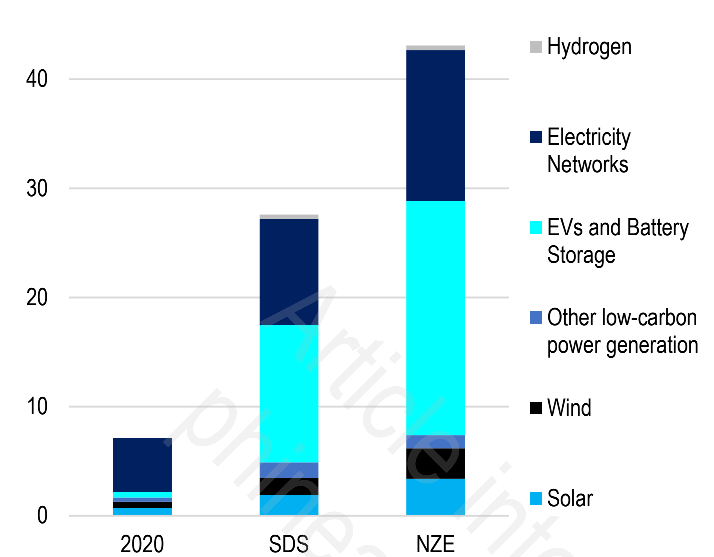
Low-carbon technologies, particularly solar and wind, and enabling infrastructure, such as electricity transmission and distribution, are significantly more mineral intensive vs fossil fuel technologies. A typical EV requires 6x the mineral inputs of a conventional car, and an onshore wind plant requires 9x more mineral resources than a gas-fired power plant (IEA). Since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% (as renewables have risen).

Under a Net Zero scenario, production of graphite, lithium, and nickel will need to be significantly ramped up by more than 8-11x by 2050 - from 2021 levels - to meet demand from climate technologies. Moreover, these projections do not include the associated infrastructure needed to support the deployment of technologies. According to IEA and World Bank modelling, today's supply and investment plans for many critical minerals fall well short of what is needed to support the much needed and accelerated deployment of these technologies.

This, of course, creates risks and opportunities for investors. There has been a great deal of focus on modelling the demand for core energy transition materials such as copper, aluminum, lithium, nickel and cobalt. However, there is in fact a broader range of materials with demand exposure not to only the energy transition, but the climate transition. In this new report series, we expand on the concept of assessing the role of *critical minerals* in the energy transition, to outlining a framework for assessing all investment opportunities under the concept of Climate Transition Super Materials.

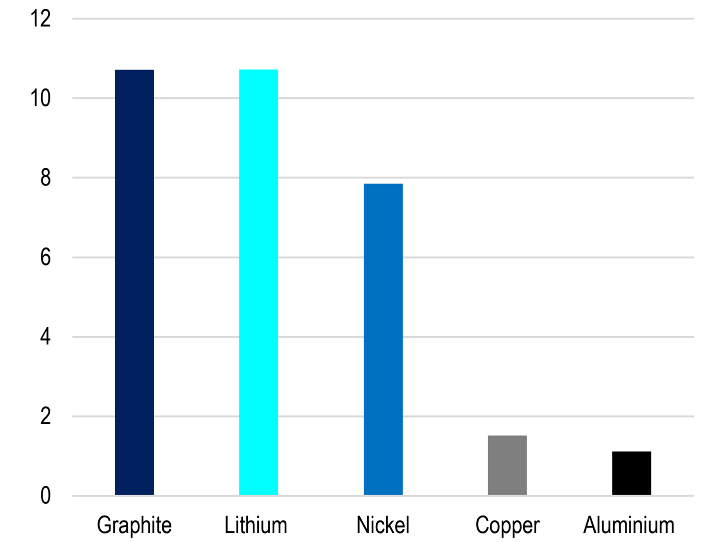
This will, for example, include materials critical for enabling emissions reductions in all sectors necessary for reaching Net Zero, from fertilisers and technologies which will increase agricultural yields, building and industrial energy efficiency to light-weighting and decarbonising transport. Crucially, this expanded concept will also include materials crucial for capturing or removing carbon from the atmosphere, thereby assessing bio or geo-based materials with unique carbon sequestering properties.

Figure 82: Growth in demand to 2040 by clean energy technologies for critical minerals by scenario (Mt)



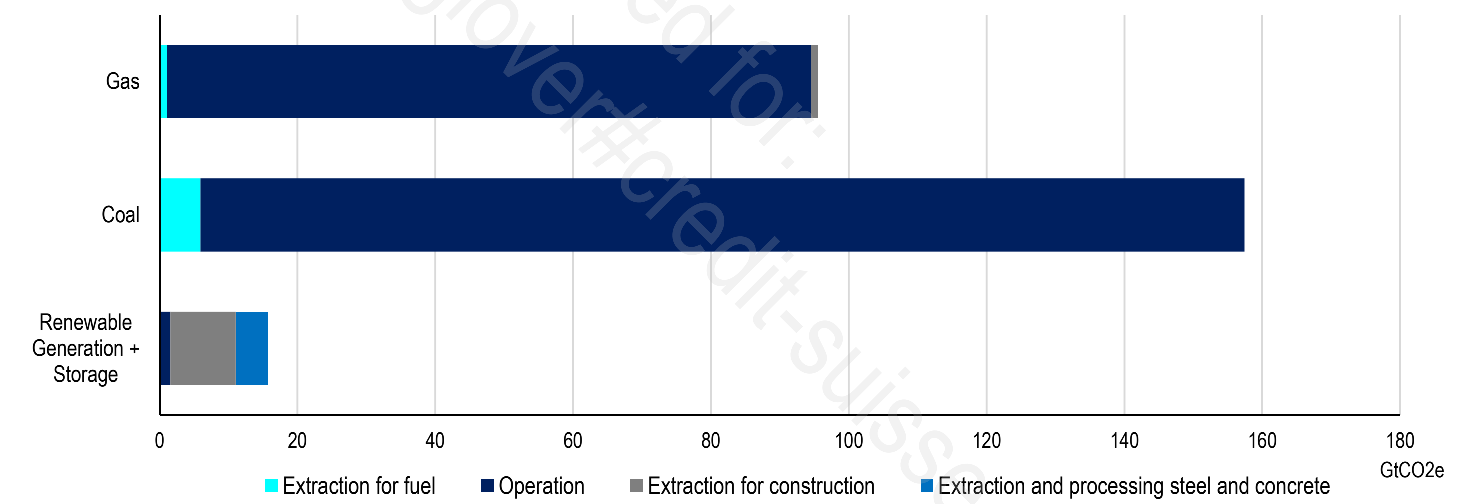
Source: IEA, Credit Suisse estimates

Figure 83: Growth of selected metals & minerals under the IEA's Net Zero by 2050 (Index - 2021 = 1)



Source: Credit Suisse Super Materials Demand Model, IEA NZE Scenario

Figure 84: Cumulative GWP to 2050 from "Cradle to Gate" of renewables and energy storage vs fossil fuels under a 2DS



Source: World Bank, Credit Suisse estimates. NB: Global Warming Potential (GWP); Cradle to Gate includes mineral extraction, processing and operation

The climate transition super materials framework

- **Demand opportunity from decarbonisation**: Building on modelling work undertaken by the World Bank to assess demand growth for critical minerals, we have developed a Climate Super Materials Demand Model that captures a broader range of low carbon technologies. This is made up of two equally weighted components: 1) **The Production-Demand Index** captures the scale to which production must increase to meet demand from energy technologies and includes by relative and absolute demand; and 2) **The Technology Concentration Index** captures how cross-cutting or concentrated in the decarbonisation technologies the minerals are in the model. Finally, we also review the extent to which efficiency improvements could impact demand.

- **Supply-demand dynamic**: Here, more traditional supply metrics are incorporated such as reserves and production and committed mine production vs primary demand. However, we also consider this in the context of the average lead times from discovery to production, to see how much actual production could lag growing demand. Finally, we also assess the geographic concentration of production. For example, in the cases of lithium, cobalt and rare earth elements, the world's top three producers control well over three-quarters of global output (IEA).
- **Circular economy**: Recycling relieves the pressure on primary supply. For bulk metals, recycling practices are well established, but this is not yet the case for many climate transition materials such as lithium and rare earth elements. Emerging waste streams from clean energy technologies (e.g. batteries and wind turbines) can change this. The amount of EV batteries reaching the end of their first life is expected to surge after 2030, at a time when mineral demand is set to still be growing rapidly (World Bank). We therefore also assess Super Materials on both current End of Life Recycling Rates and the percentage of New Product made using Secondary Materials recovered.
- **Impact intensity of production:** Finally, we consider a broad range of environmental factors to consider the relative attractiveness of different materials based on the impact of production and refining methods. This includes the global warming potential of the production, such as through assessment of Cradle to Gate Emissions and Emissions Intensity per Tonnes of Production. Energy intensity of production through assessment of Energy Share in Mining Cash Cost and Electricity Cost in Total Refining. Finally we review water consumption and pollution, biodiversity and waste risks.

Figure 85: Climate transition super materials framework

Factor	Units	Method	Explanation
1. Demand opportunity in decarbonisation			
Production-Demand Index	0-1	Compares the relative and absolute increases in demand between 2021 and 2050. Scoring 1 means highest growth in demand and scoring 0 means low growth in demand. For more information see pg 7-8.	Captures the scale to which production must scale up to meet demand from energy technologies and includes by relative and absolute demand.
Technology Concentration Index	0-1	Compares the use of the material across decarbonisation technologies. A value of 1 is given to the most cross-cutting material, namely copper, with all other materials index to copper. For more information see pg 7.	Captures how cross-cutting or concentrated in the decarbonisation technologies the minerals are in the model.
Efficiency improvements	%	What efficiency improvements are expected in key technologies	To understand how R&D and technical developments in end use markets may affect future demand forecasts for the material.
2. Supply-Demand dynamic			
Reserves and production	tonnes	Tonnes of material produced in 2020 and known reserves	To understand the current supply context
Rate of supply	%	Ratio of committed mine production and primary demand	Indicator of over or under supply for the material
Production lead times	years	Global average lead times from discovery to production	Captures how much actual production could lag growing demand.
Geographic concentration of production	%	Percentage breakdown of production	Supply concentration risk, disruption
3. Circular Economy			
End of life recycling rates	%	The percentage of material that is recovered at the end of a products life and recycled into new material	To understand how recycling of the material may interact with demand and whether the material is exposed to the circular economy thematic.
Recycled content rates	%	The percentage of a new product that is made using secondary (recycled) material	
4. Impact Intensity of Production			
Absolute emissions impact	MtCO2e	Total cumulative emissions from Cradle to Gate for end market technologies	To understand the total impact of the use of the material in decarbonisation and global warming potential.
Emissions intensity of production	tCO2e/ tonne	Emissions intensity of material production, where possible breakdown by Mining and processing	
Energy intensity / cost	GJ/tonne	Energy intensity/cost in mining and/or refining	
Water intensity of production	m3 / tonne	Water used in production	To understand the significance of water usage in production and whether the material is exposed to the access to water and/or water scarcity thematic
Water pollution	kgP-eq/kg CTUeco/kg	Freshwater eutrophication potential Freshwater ecotoxicity	
Biodiversity	N/A	Qualitative assessment of the known biodiversity impacts of mining and/or producing the material	
Waste	tonnes/yr	Tailings per mined output Waste of inputs per output	To understand the waste streams and whether the material is exposed to the circular economy and/or pollution thematics.

Source: Credit Suisse

How do we model the demand opportunity from Net Zero

To support our Climate Transition Super Materials series, we have built a supporting Climate Super Materials Demand Model. The model takes material usage, technology deployment and policy inputs to calculate the demand for different super materials by climate technologies in 2050. The core inputs to the model include:

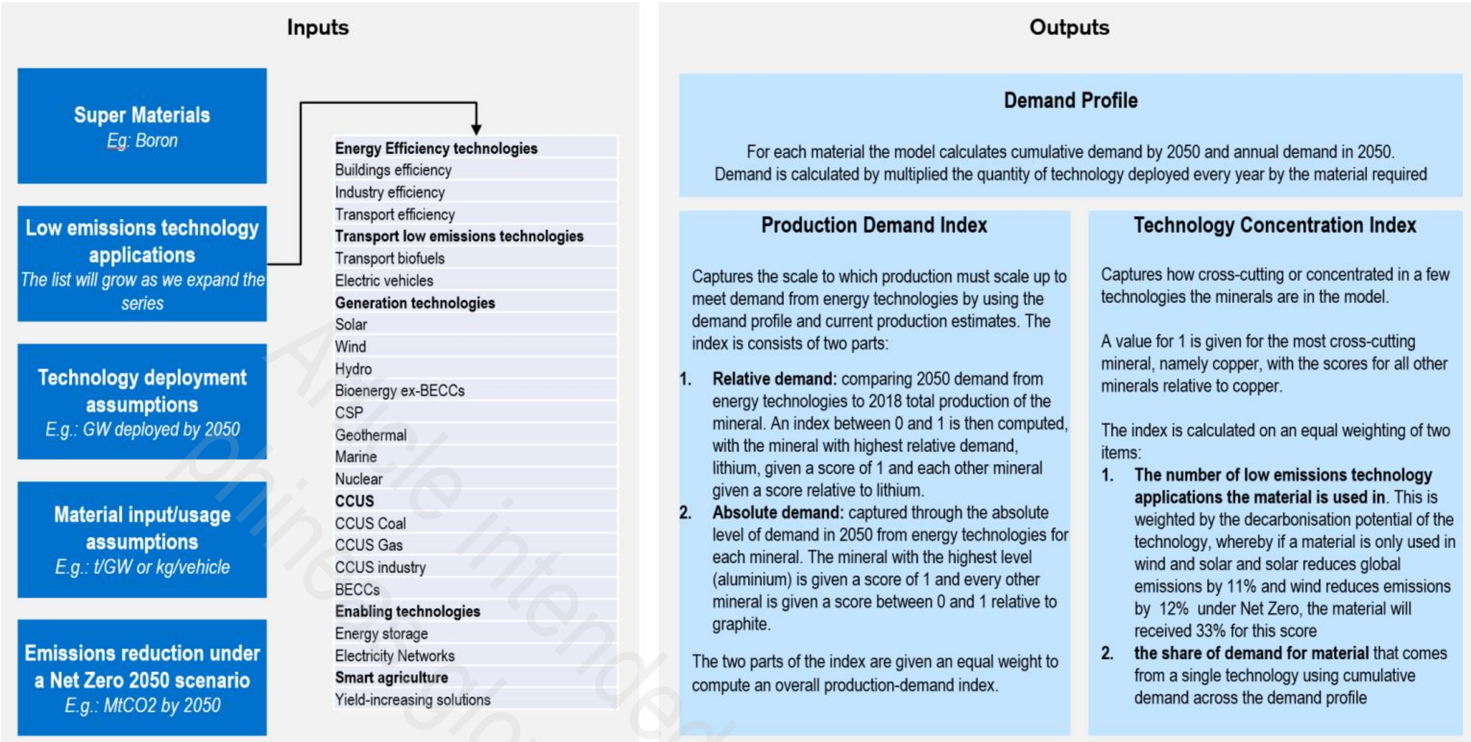
- **Technology**: the required climate technology deployment under the IEA Net Zero (NZE) scenario, and the absolute emissions reduced from the deployment of the technology.
- **Material usage**: estimates the minerals required for each low emissions technology from a broad literature review.

To understand the demand profile and compare the opportunity between materials, we have adapted the methodology used in the World Bank report *Minerals for Climate Action,* with the key difference being that the model incorporates a broader range of climate technologies. We use two indices to size the demand opportunity. These are the Production-Demand Index and the Technology Concentration Index, both of which are calculated using the CS model.

- **The Production-Demand Index** captures the scale to which production must increase to meet demand from energy technologies and includes relative and absolute demand.
- **The Technology Concentration Index** captures how cross-cutting and concentrated in the decarbonisation technologies the minerals are in the model.

We graph the two outputs along a matrix to show the comparison and relative attractiveness of different Super Materials. In addition to Boron, as part of this initiation report, we also graph six other prominent Super Materials to show the context, including aluminium, copper, graphite, nickel, silver and lithium.

Figure 86: CS Climate Super Materials Demand Model Schematic

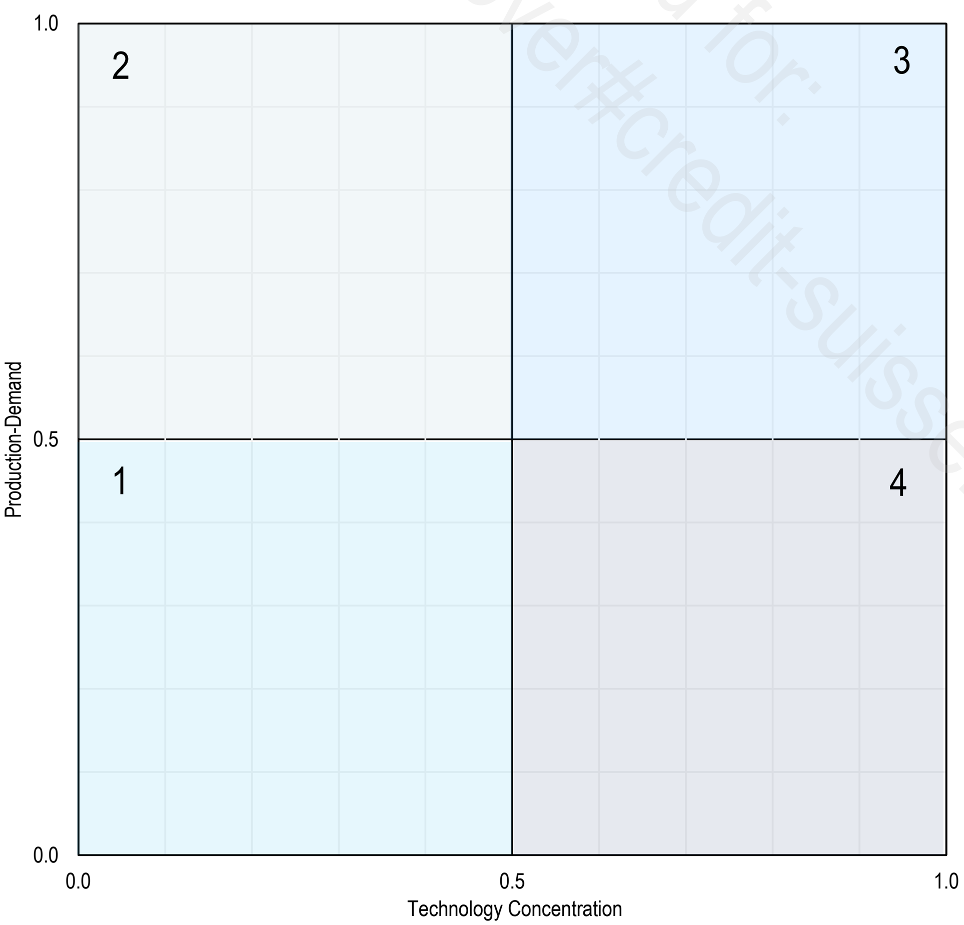


Source: Credit Suisse, World Bank

As a result of the indices, we create a demand opportunity matrix with four quadrants, see Figure 87. Materials that fall in the same quadrant share similar demand profiles, including:

1. **Medium-Impact Materials:** Materials that fall in quadrant 1 have lower demand from decarbonisation. These minerals feature in only a small range of decarbonisation applications and the anticipated increases in demand is a smaller percentage of 2020 production levels. This is not to say that these minerals are not important to the deployment of particular sub-technologies.
2. **High-Impact Materials:** Materials that fall in quadrant 2 are important because, although they only feature in a small number of technologies, their level of future demand is much greater than 2020 production levels. However, changes to the technologies used may have big implications for overall levels of demand. They are predominantly (but not exclusively) materials used in energy storage technologies.
3. **High-Impact, Cross-Cutting Materials:** Materials that fall in quadrant 3 are critical because the demand from 2020 production levels increases significantly, yet their use is also widespread across a variety of technologies, like aluminium and copper.
4. **Cross-Cutting Materials:** The materials in quadrant 4 are important because while their overall demand from energy technologies relative to production (in percentage) is not as dramatic as that for materials in quadrants 2 or 3, they are used across a wide variety of technologies and are not dependent on one specific technology. Therefore, the demand for these minerals will exist no matter which technologies or sub-technologies are deployed and win market share.

Figure 87: Demand opportunity matrix structure



Source: World Bank, Credit Suisse

Companies Mentioned *(Price as of 11-Apr-2022)*

BNMC (601011.SS, Rmb4.33)
BYD Co Ltd (002594.SZ, Rmb233.0)
BYD Co Ltd (1211.HK, HK$220.8)
Battery Minerals (BAT.AX, A$0.009)
Black Rock Min (BKT.AX, A$0.26)
China Baoan Grp (000009.SZ, Rmb9.93)
China Risun (1907.HK, HK$3.84)
Contemporary Amperex Technology Co., Limited (300750.SZ, Rmb459.0)
EVE Energy (300014.SZ, Rmb70.3)
Ecograf (EGR.AX, A$0.56)
Entegris (ENTG.OQ, $109.32)
FangDa Carbon (600516.SS, Rmb7.92)
Farasis Energy (Gan Zhou) Co., Ltd. (688567.SS, Rmb23.29)
Focus Graphite (FMS.V, C$0.08)
Graftech International Ltd. (EAF.N, $9.4)
Graphite India (GRPH.NS, Rs579.5)
Graphite One (GPH.V, C$1.89)
Greenwing Rsrcs (GW1.AX, A$0.39)
Guoxuan High-Tech Co Ltd (002074.SZ, Rmb29.58)
HEG (HEGL.NS, Rs1377.2)
HNZK Electric. (300035.SZ, Rmb27.5)
Hitachi (6501.T, ¥5,849)
Hyundai Motor Company (005380.KS, W179,500)
Indian Oil Corpn (IOC.NS, Rs128.85)
JFE (5411.T, ¥1,636)
JX Holdings (5020.T, ¥449)
Jinrui Mineral (600714.SS, Rmb13.18)
LG Chem Ltd. (051910.KS, W510,000)
LG Energy Solution (373220.KS, W425,000)
Leading Edge Mat (LEM.V, C$0.52)
Magnis Energy (MNS.AX, A$0.465)
Mason Graphite (LLG.V, C$0.58)
Mineral (MRC.AX, A$0.13)
Mitsubishi Chemical (4188.T, ¥785)
Nations Tech (300077.SZ, Rmb20.36)
NextSource (NEXT.TO, C$3.6)
Ningbo Shanshan (600884.SS, Rmb24.47)
Nippon Carbon (5302.T, ¥4,130)
Nippon Steel & Sumitomo Metal (5401.T, ¥2,065)
Northern (NGC.V, C$0.76)
Nouveau Monde (NOU.V, C$8.03)
Novonix (NVX.AX, A$6.24)
POSCO (005490.KS, W286,000)
Panasonic Holdings Corporation (6752.T, ¥1,130)
Phillips 66 (PSX.N, $84.25)
Porsche (PSHG_p.DE, €83.12)
Posco Chemical (003670.KS, W126,500)
Renascor Res (RNU.AX, A$0.305)
Rio Tinto (RIO.L, 6138.0p)
Rio Tinto (RIO.AX, A$117.5)
SGL Carbon SE (SGCG.DE, €5.105)
SK Innovation (096770.KS, W206,500)
Samsung Electronics (005930.KS, W67,900)
Samsung SDI (006400.KS, W585,000)
Shanghai Putailai New Energy Technology (603659.SS, Rmb135.0)
Showa Denko (4004.T, ¥2,350)
Sinopec Shanghai Petrochemical (600688.SS, Rmb3.42)
Sinopec Shanghai Petrochemical (0338.HK, HK$1.61)
Sth Star Battery (STS.V, C$0.18)
Sumitomo Corp (8053.T, ¥2,044)
Syrah Resources (SYR.AX, A$1.55)
Talga Group (TLG.AX, A$1.52)
Tesla Inc (TSLA.OQ, $1025.49)
Tokai Carbon (5301.T, ¥1,084)
Toyota Motor (7203.T, ¥2,102)
Triton Minerals (TON.AX, A$0.031)
Volt Resources (VRC.AX, A$0.02)
Walkabout (WKT.AX, A$0.25)
XFH Technology (300890.SZ, Rmb42.09)
YCNE (300080.SZ, Rmb4.13)

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