India

Neutral *(no change)*

Non Ferrous

Graphite Anode: Natural versus synthetic

- Graphite is a critical mineral used in the anode for lithium-ion batteries (LiB). 1 GWh of LiB requires 1.2kt of graphite.
- However, both natural and synthetic graphite can be used to produce the anode material, with synthetic graphite currently having an 80% market share.
- Our analysis shows that natural graphite method of anode production will be able to maintain or slightly improve natural graphite's market share by CY30F.

There are two ways to make graphite anode - natural and synthetic

1kWh of typical lithium-ion battery storage requires ~1.2kg of graphite. Despite being one of the most abundant elements, graphite still has a scaling issue. Two types of graphite are used in lithium-ion batteries – naturally-mined flake graphite processed into spheres, and synthetic graphite produced from petroleum coke and tar pitch at a very high temperature. Synthetic graphite anode production can be over four times more carbon-intensive than natural graphite anode production, as due to the usage of energy and fossil fuels as a feedstock, it needs needle coke as one of its raw materials.

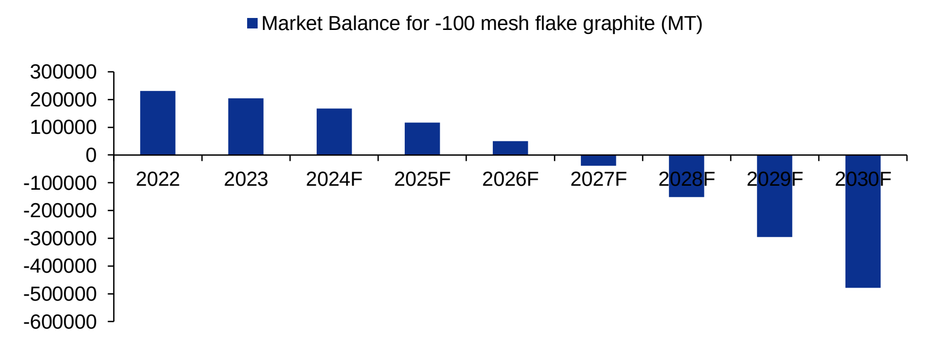
Synthetic/natural graphite anode have their respective benefits

Currently, natural graphite has a higher capacity, but a lower cycle life and energy density compared to artificial graphite. Natural and synthetic graphites are not necessarily interchangeable for use in lithium-ion batteries. Generally, natural graphite possesses a higher degree of crystalline order at the nanometer scale. However, the high degree of crystalline order is more susceptible to exfoliation (degradation) over many cycles. Practically, the result is slower charging times, as battery charging is the intercalation (lithiation) step of the graphite. Synthetic graphite also currently swells less than natural graphite during the charge/discharge cycles, which is a desirable attribute for a longer cycle life.

Natural graphite to improve its market share marginally by CY30F

We have graphite mine production data from CY94. Over a period of 29 years, graphite mine production has shown an annual CAGR of only 2%. Anyway, new mines take time to start production, and, on an optimistic note, we expect this CAGR to be 6% till CY30F. For CY22, the annual mine production of graphite was 1,300,000tpa. Out of this, flaky graphite production was close to 1,200,000tpa. However, we must understand that the raw material feedstock for a natural graphite anode is mined flake graphite. This is then separated by size, with the small-to-medium mesh material being the optimal size for battery material processing. The material at this mesh size represented only 49% of the total global market of 1.2mt of flake graphite i.e. close to 0.6mt. On performing an analysis, we realized that even if annual production of natural graphite posts an annual CAGR of 8%, which is a very optimistic estimate as in various studies it has been found that rarely metals grow at a CAGR of more than 6%, there will be natural graphite shortage by FY27F. Hence, natural graphite will maintain or marginally improve its market share of 20% in battery anode materials.

Figure 1: Market balance if graphite grows at an 8% CAGR and maintains market share



SOURCE: INCRED RESEARCH, COMPANY REPORTS

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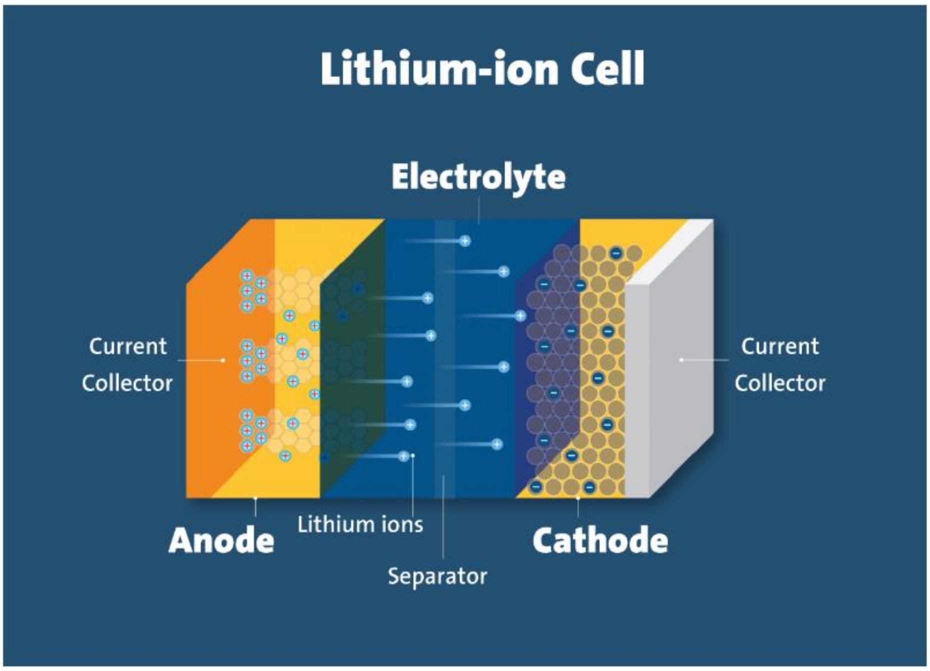
Graphite Anode: Natural versus synthetic

Graphite has become a key material for the manufacture of anodes in lithium-ion batteries, with about 1.2kt of graphite used to generate 1GWh of energy. However, there is a twist in the tale here. Lithium-ion battery anodes can be manufactured using both synthetic and natural graphite. Both have their own advantages and disadvantages, but whether natural or synthetic graphite will triumph in the long run remains the key question.

How does a simple lithium-ion battery work ›

- A battery is made up of an anode, cathode, separator, electrolyte, and two current collectors (positive and negative). The anode and cathode store lithium. The electrolyte carries positively charged lithium ions from the anode to the cathode and vice versa through the separator. The movement of lithium ions create free electrons in the anode, which creates a charge at the positive current collector. The electrical current then flows from the current collector through a device being powered (cell phone, computer, etc.) to the negative current collector. The separator blocks the flow of electrons inside the battery.
- While the battery is discharging and providing an electric current, the anode releases lithium ions to the cathode, generating a flow of electrons from one side to the other. When plugging in the device, the opposite happens: lithium ions are released by the cathode and received by the anode.
- The two most common concepts associated with batteries are energy density and power density. Energy density is measured in watt-hours per kilogram (Wh/kg) and is the amount of energy a battery can store with respect to its mass. Power density is measured in watts per kilogram (W/kg) and is the amount of power that can be generated by the battery with respect to its mass. To draw a clear picture, think of draining a pool. Energy density is like the size of the pool, while power density is comparable to draining the pool as quickly as possible.

Figure 2: Simple diagram explaining the working of a lithium-ion cell



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Two ways to make graphite anode - natural and synthetic

1kWh of typical lithium-ion battery storage requires ~1.2kg of graphite. Despite being one of the most abundant elements, graphite still has a scaling issue. Two types of graphite are used in lithium-ion batteries – naturally-mined flake graphite processed into spheres, and synthetic graphite produced from petroleum coke and tar pitch at a very high temperature. Synthetic graphite anode production can be over four times more carbon-intensive than natural graphite anode production, as due to its use of energy and fossil fuels as a feedstock, it needs needle coke as one of its raw materials. Let's go into both these types of graphites one by one.

Natural graphite

Graphite has a layered, planar structure with carbon atoms arranged in a honeycomb lattice. It's because of this unique structure that graphite has such a stellar combination of properties; for example, it's flexible, highly refractory, chemically inert and has high thermal and electrical conductivity. Those characteristics allow graphite to be used in a variety of places, including brake linings, foundry operations, lubricants, refractory applications, and steelmaking. However, not all types of graphite are suitable for all applications. Indeed, there are three main types of graphite, and in many cases specific applications require one type.

- **Flake graphite**: It occurs as isolated, flat, plate-like particles with either hexagonal or angular edges. Flake graphite is found in metamorphic rocks, such as limestone, gneiss, and schist, and is distributed uniformly throughout the body of the ore or in concentrated, lens-shaped pockets. This is the graphite typically used in the anode material for lithium-ion batteries. Flake graphite comes in four basic sizes: jumbo, large, medium, and fine. Each size of the flake has its own uses.
- **Amorphous graphite:** It is found as an extremely small, crystal-like particles in beds of mesomorphic rocks like coal, slate and shale, and its carbon content depends on that of its parent material. While amorphous graphite is one of the less popular types of graphite, it has its uses as well. Amorphous graphite is used in the refractory industry to manufacture crucibles, ladles, molds, nozzles, and troughs that can withstand very high temperatures, particularly the casting of steel. Indeed, the electrodes used in many electrical metallurgical furnaces, including the electric arc furnaces used in steel processing, are manufactured from this type of graphite.
- **Vein graphite:** Also referred to as lump graphite, it is believed to have hydrothermal origins and occurs in fissures or fractures, appearing as massive platy intergrowths of fibrous or needle-like crystalline aggregates. Vein graphite is believed to originate from crude oil deposits that through time, temperature and pressure were converted to graphite. Graphite in this form is found all over the world but is only currently mined in Sri Lanka. Of the different types of graphite, vein graphite is considered the rarest. Vein graphite is used in advanced, thermal, and high-friction applications such as car brakes and clutches. It can also be used in much the same way as flake graphite, as it shows great performance in applications that require high thermal and electrical conductivity.

Figure 3: Different types of natural graphite

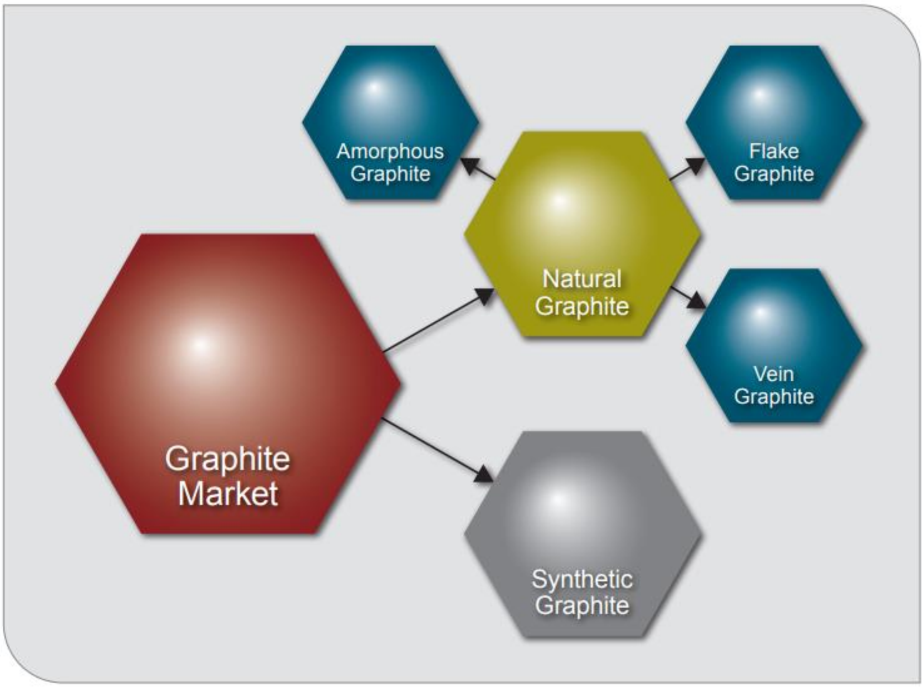

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Figure 4: Production mix between different types of graphite

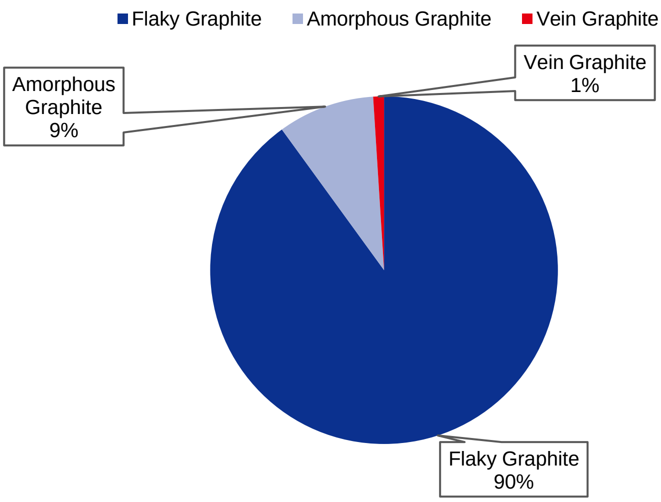

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Figure 5: Flake size and price range of different types of flaky graphite

Classification	Flake size (microns)	% TGC	Applications	Price range (US$/t)
Super-jumbo	>500	97-99	Nuclear reactors, aerospace, advanced materials and other specialised and niche applications	4,000-6,000
Jumbo	300-500	97-99	Expandable graphite, composites and electronics	2,500-3,000
Large flake	150-300	>99	Spherical graphite, battery applications	2,500-3,000
Flake	106-150	>99	Spherical graphite, battery applications	2,500-3,000
Large flake	150-300	94-97	Industrial uses	800-1,100
Flake	106-150	94-97	Industrial uses	500-800
Amorphous	<106	94-97	Industrial uses	300-500

SOURCE: INCRED RESEARCH, COMPANY REPORTS

Figure 6: Natural graphite annual mine production data.

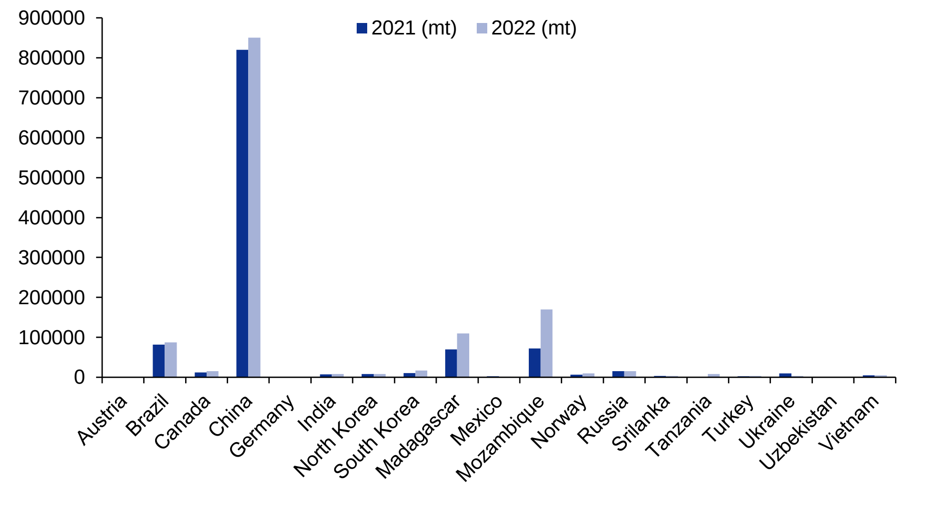

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Figure 7: Global reserves of natural graphite, by country - China & Turkey account for a major portion

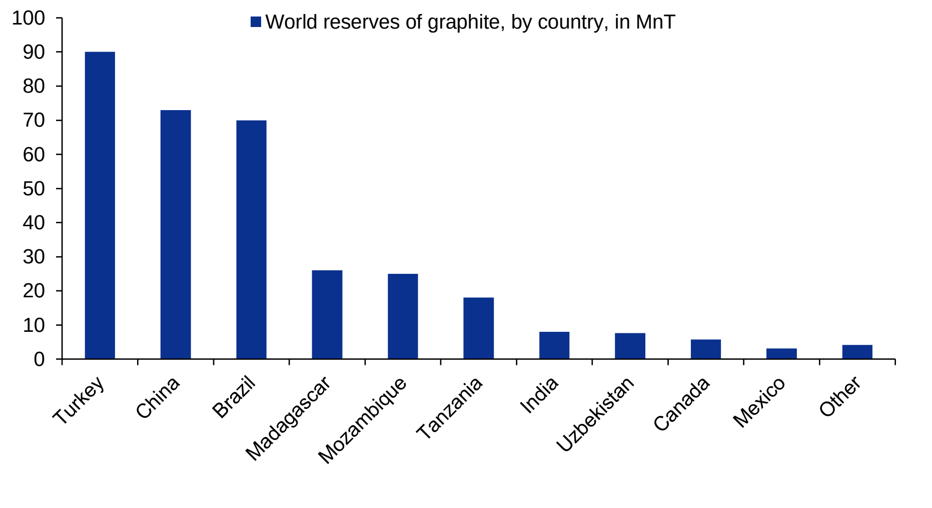

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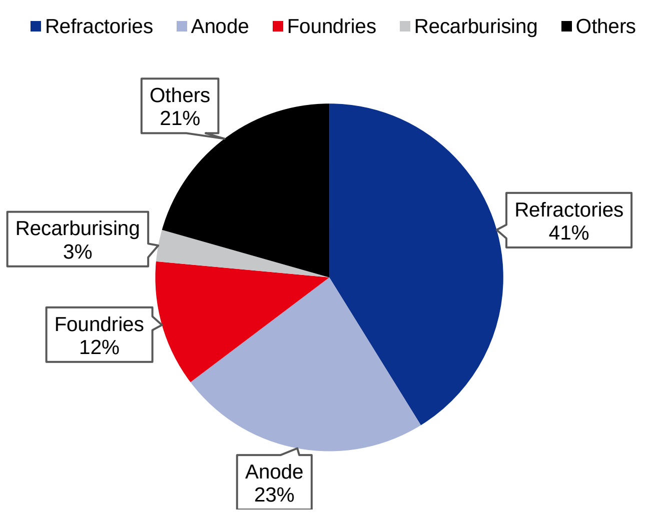
Figure 8: Natural graphite's key applications - percentage breakup



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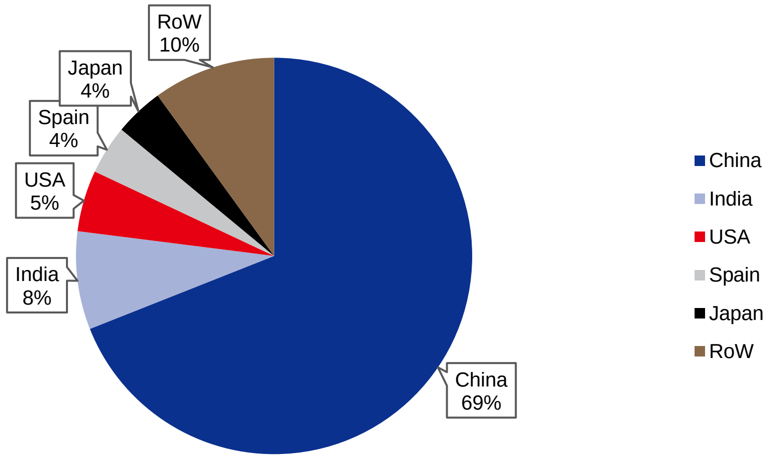
Synthetic graphite

Synthetic graphite is a product manufactured by high-temperature treatment of amorphous carbon materials. In most instances, the primary feedstock used for making synthetic graphite is calcined petroleum coke and coal tar pitch. It must be noted that synthetic graphite uses a fossil fuel derivative as its feedstock and hence, has a higher carbon footprint compared to natural graphite.

Figure 9: Supply chain of synthetic graphite is relatively more diversified



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However, synthetic graphite has a worse carbon footprint

For natural graphite, two-thirds of carbon emission come from the spheroidization process, in which China has a monopoly currently. Spheroidization is a process in which graphite particles are mechanically rounded. This leads to the loss of some material but yields improvement in the performance of the anode. Although natural graphite is associated with lesser carbon emission, it is not without its own ESG and supply chain concerns.

China produced 68% of natural graphite last year, with most of this concentrated in the Heilongjiang province, which shuts in the winter season every year as temperatures drop too low for the machinery and the personnel to operate. A major source of natural graphite outside China, in the short term, is Mozambique, which currently accounts for 10% of mined graphite. According to forecasts, 96% of Mozambican graphite in 2025F will be mined in the northern Cabo Delgado province which, since 2017, has been the site of attacks by an Islamist state-linked insurgency group. Earlier this month, Triton Resources, an Australian-owned graphite miner, said that two of its staff members were killed after an attack by insurgents. The company also suspended personnel and logistics movement on a primary transport route in the province following the attack. Nearly 70% of graphite mining in Europe takes place in Russia and Ukraine, and the Ukraine war could impact the stability of Europe's graphite production. Madagascar is another alternative graphite supply source to China, accounting for nearly 10% of supply currently. However, the region suffers from cyclones, one of which halted operations at a graphite mine in the country earlier this year. Climate change has made these cyclones more severe, and it is likely that they will get more destructive going ahead.

Figure 10: Synthetic graphite has a worse carbon footprint than natural graphite

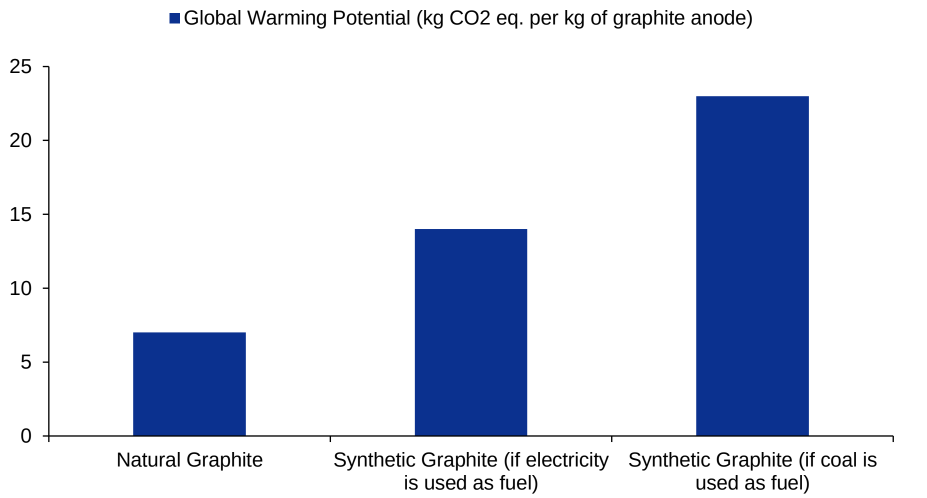

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Figure 11: Material inputs per tonne of synthetic graphite

Inputs	Calcination	Carbonization/ Baking	Graphitization
Material inputs (ton/ton of SG)			
Green petroleum coke	1.108		
Coal tar pitch		0.205	
Energy inputs (mmBtu/ton of SG)			
Natural gas	13.566	11.091	
Electricity	1.507		7.711
Process emissions (g/ton of SG)			
CO	14,067	2,482	17,866
NO_X		229	
CH_4	155,740	73.9	
CO_2	13,062		

SOURCE: INCRED RESEARCH, COMPANY REPORTS

Graphitization vs spheroidization ›

In layman's terms, graphitization is associated with the manufacturing of graphite anode using synthetic graphite whereas spheroidization is associated with the manufacturing of graphite anode using natural graphite.

Figure 12: Manufacturing of anodes via natural and synthetic graphite

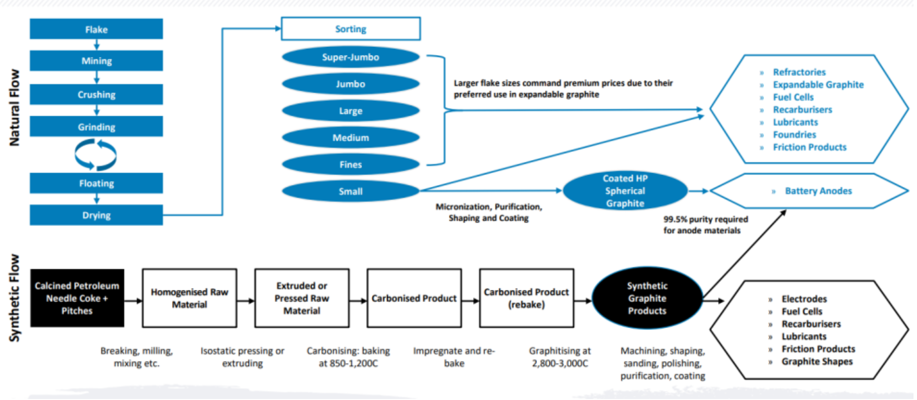

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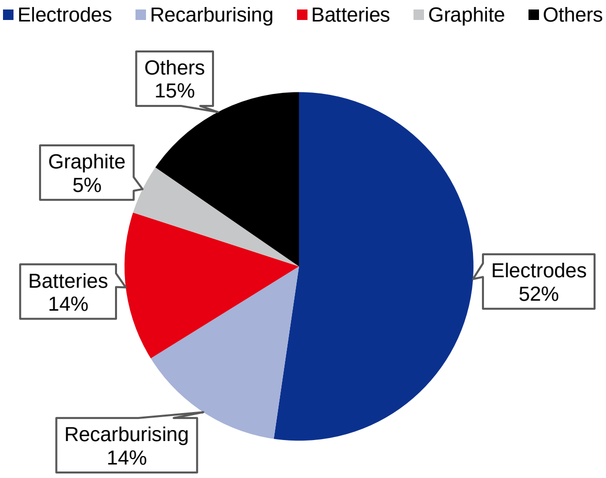
Figure 13: Electrodes used in electric arc finance, or EAF steel manufacturing process remains the principal usage of graphite



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Comparison between synthetic and natural graphite

Historically, natural flake graphite was not able to match the performance characteristics of synthetic graphite. However, recent technological breakthroughs have improved the cycle life, energy density and product consistency of natural graphite while maintaining the significant relative cost advantage and improved environmental footprint. Currently, natural graphite has a higher capacity, but it has a lower cycle life and energy density compared to artificial graphite. Natural and synthetic graphites are not necessarily interchangeable for use in lithium-ion batteries. Generally, natural graphite possesses a higher degree of crystalline order at the nanometer scale. The quantity of lithium ions that fit in the structure gives a gravimetric capacity closer to the theoretical one. However, the high degree of crystalline order is more susceptible to exfoliation (degradation) over many cycles. Also, because lithium ions can only enter the lattice structure through the edges of the graphite and not directly through the planes, the process of electrochemically inserting lithium ions can be slower. Practically, the result is slower charging times, as battery charging is the intercalation (lithiation) step of the graphite. Accordingly, the rate capability of natural graphite is generally lower than synthetic graphite. Synthetic graphite also currently swells less than natural graphite during charge/discharge cycles, which is a desirable attribute for a longer cycle life.

Figure 14: Synthetic graphite captures a major market share in the battery anode material space

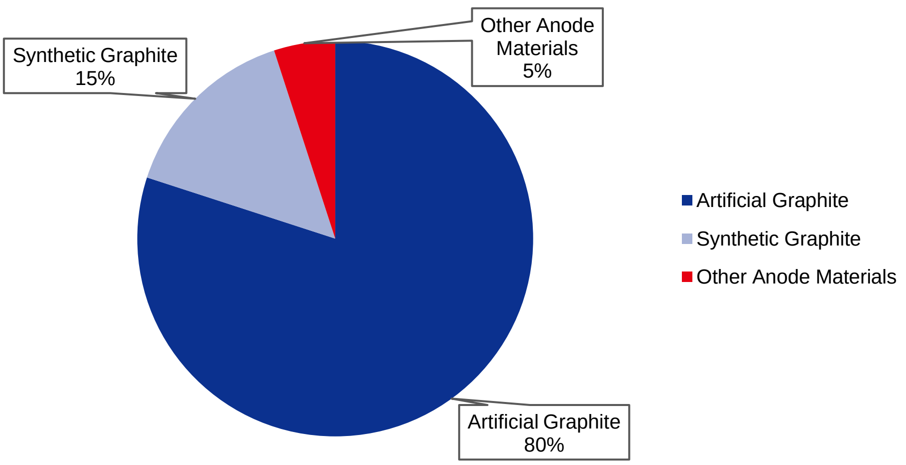

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Figure 15: Comparison between natural vs. synthetic graphite

Properties/Parameters	Natural Graphite (NG)	Synthetic Graphite (SG)
Source of production	Ores within ground	Carbon precursors (e.g., petroleum coke, coal tar pitch)
Production cost	Relatively low	Relatively high
Purity	Low	High
Quality	Low	High (better thermal stability, lower thermal expansion)
Performance in LIBs	Relatively low (anisotropic orientation of crystals)	Relatively high (isotropic orientation of crystals ensures superior lithiation/de-lithiation kinetics)
Capacities	High (due to higher domain size)	Low (due to smaller domain size or more inter-domain interfaces)
Cycle life	Short	Long

SOURCE: INCRED RESEARCH, COMPANY REPORTS

Mathematical model to project graphite demand and supply

We have graphite mine production data from CY94. Over a period of 29 years, graphite mine production has shown a CAGR of only 2%. However, there has been a slight ramp-up in its production in recent years. But still, new mines take time to start operations and on an optimistic note, we expect this CAGR to be 6% till CY30F. For CY22, the annual mine production of graphite was 1,300,000tpa. Out of this, flaky graphite production was close to 1,200,000tpa. But we must understand that the raw material feedstock for a natural graphite anode is mined flake graphite. This is then separated by size, with the small-to-medium mesh material being the optimal size for battery material processing. The material at this mesh size represented only 49% of the total global market of 1.2mt of flake graphite i.e. close to 0.6mt. On performing an analysis, we realized that even if annual production of natural graphite grows at a CAGR of 8%, which is a very optimistic estimate as in various studies it has been found that rarely metals grow at a CAGR of more than 6%, plus natural graphite has a 30-year CAGR of only 2%, and so there will be natural graphite shortage by FY27F. Hence, in our view, natural graphite will maintain or marginally improve its market share of 20% in battery anode materials.

Figure 16: Market balance for natural graphite, provided its production grows at a CAGR of 8% and maintains current market share of 20%.

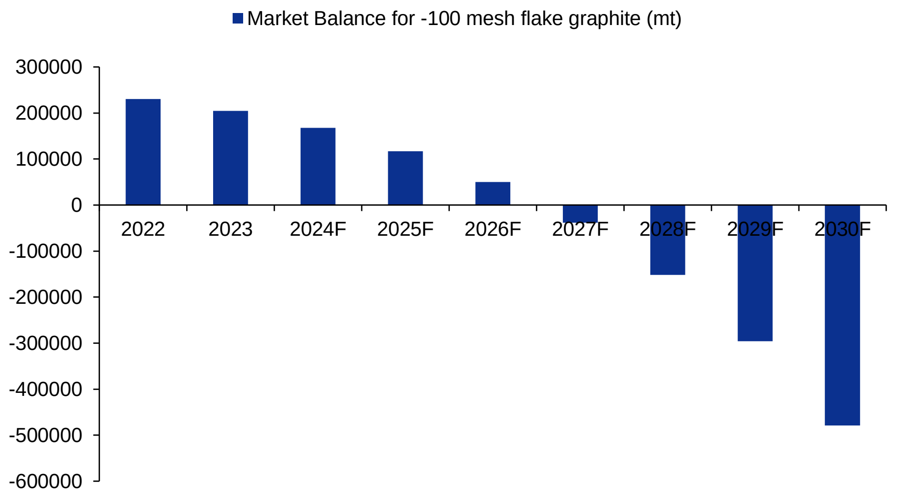

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Figure 17: There will be sufficient natural graphite by CY30F only if the production grows at a CAGR of 14%, which doesn't look probable.

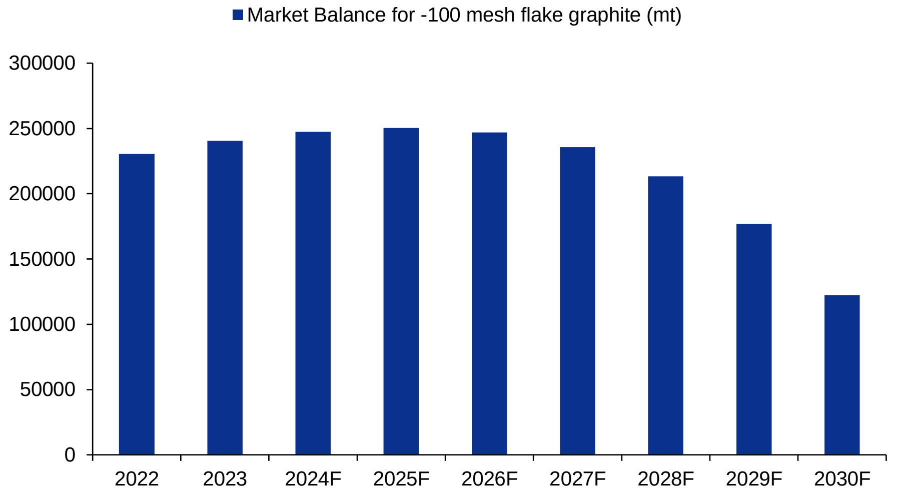

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Figure 18: For our calculations, we have assumed LiB market growing at a CAGR of 20% and it will be at 3TWh by 2030F

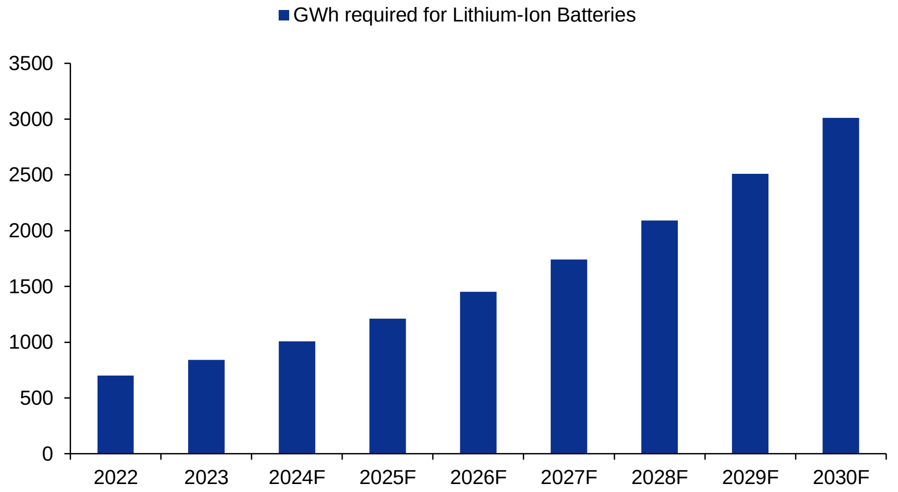

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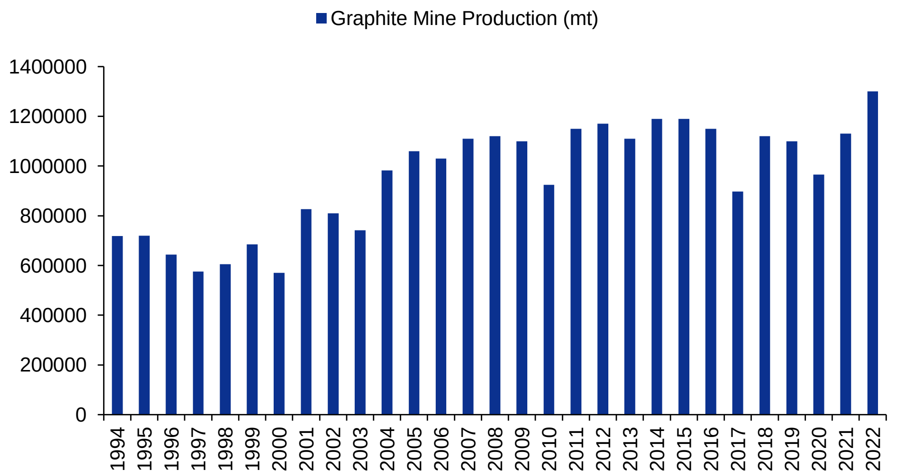
Figure 19: Historically, graphite production maintained a CAGR of only 2% over 30 years



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