EDISON

Graphite for batteries

Value in natural graphite

Metals & mining

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As growth in electric vehicle and power storage accelerates, so in turn, it will require large amounts of the carbon allotrope graphite to meet an estimated 22% CAGR in battery graphite demand linked to construction and full utilisation of battery manufacturing facilities worldwide. In this note we address the complexity of graphite resources, their development, market dynamics, product pricing, and provide an introductory view of Volt Resources ahead of the release of its Namangale Project Pre-Feasibility Study due in Q416. Volt is an ASX-listed junior with a resource well positioned to deliver a high-quality natural graphite feedstock to battery manufacturers. In this report, we pay attention to the use of natural graphite in batteries – the strongest driver to growth in demand.

Volt's Namangale resource suited for battery making

Volt Resources has a very large resource of 446Mt at 5.01% Total Graphite Carbon (TGC) at its Namangale project in Tanzania. While this headline resource grade is relatively low compared to resources elsewhere, it hides the true value of graphite resources in the proportion it carries in the large to super-jumbo graphite flake size categories – those prized for battery application. Further, preliminary metallurgical test works have indicated a high-TGC % carried through into each size fraction (eg between 98.6% and 99.6% TGC in the super-jumbo size category). This should bode well for total processing costs (and margins) as simple crushing and flotation provides the purity required for battery anode applications and avoids potentially harmful chemicals required for some graphite purification processing.

High-purity, high-cost synthetic vs natural graphite

Graphite is sold in two forms: high-cost and high-purity synthetic and lower-cost variable-purity natural. Synthetic graphite's high purity makes it an important graphite source for use in energy storage. However, its high cost and, arguably, environmentally unfriendly process inhibits the ability of, for example, electric vehicle manufacturers to bring costs and hence prices to a level that allows for mass adoption. Synthetic graphite currently trades in a range of c US$10,000/t to US$20,000/t dependant on purity, whereas natural, battery-grade sources fetch in the region of US$5,000/t. Pricing is, however, opaque, with the market employing long-term offtake contracts for battery and strategic end uses (military and nuclear), in addition to shorter-term contracts and spot sales into broader industrial markets.

Potential CAGR 22% on battery factory uptake

We have taken a view of potential growth in battery manufacturing capacity worldwide and the resultant effect it could have on graphite demand. If all the major battery factories are built as expected and fully utilised they would require an additional c 750kt by 2022, representing an Li-ion battery-demand CAGR of 22%. This is obviously dependent on a high rate of electric vehicle sales, both in the West and, importantly, Asia. This demand is in addition to current global graphite supply of c 2.3Mt (both natural and synthetic types, split roughly 50/50) which, excluding electric car demand, is still expected to grow at c 2-4% across each of its other main applications.

Companies in this report

Archer Exploration
Black Rock Mining
Energizer Resources
Graphex Mining
Hexagon Resources
Kibaran Resources
Magnis Resources
Mason Graphite
Metals of Africa
Sovereign Metals
Syrah Resources
Triton Minerals
Volt Resources
Walkabout Resources

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This report was produced on behalf of Volt Resources, a research client of Edison Investment Research

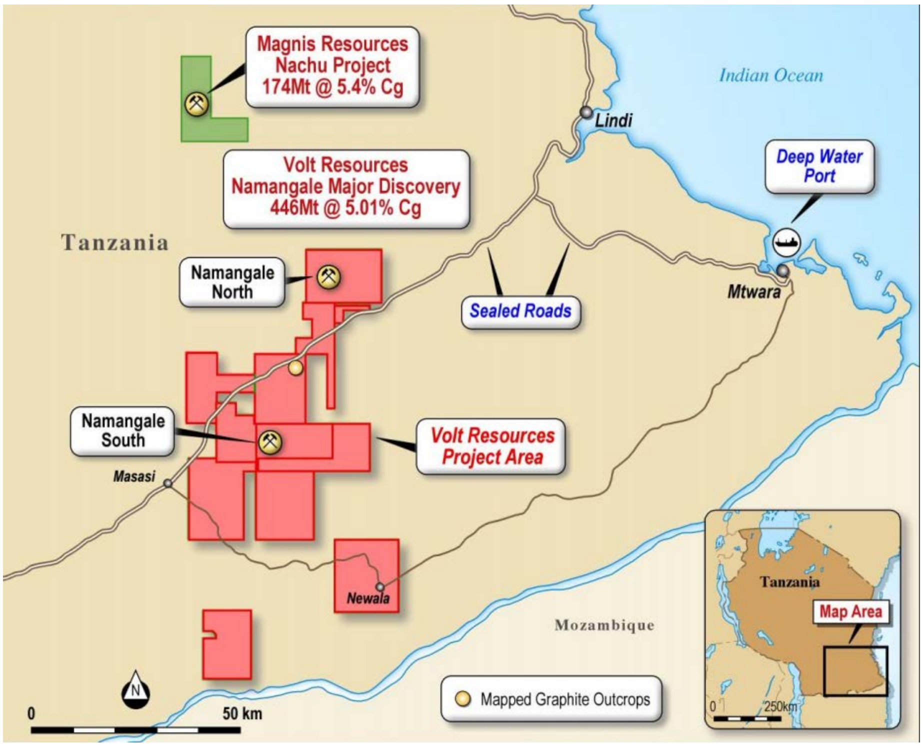
Volt's Namangale well suited for battery manufacturing

Volt Resources (formerly Mozambi Resources) holds tenements over ground containing graphitic carbon in Tanzania. Its flagship project is Namangale in Tanzania – located 50km from Magnis Resources' (BFS-stage) Balama Graphite Project (ASX:MNS, market cap: A$320m).

Namangale's lower grade hides true value of high-purity & large flake size

Namangale is a project that has recently seen a 108% increase in its total resource, which now stands at 446Mt at 5.01% TGC. Importantly, the resource carries a significant portion in the highly valued jumbo to super-jumbo size categories. Contained in the project's previous resource estimate of 214.4Mt, Volt stated that the proportion in the super-jumbo, jumbo and large flake sizes totalled 81.3%. However, this figure is based on one sample, and so a representative figure on the whole mineral resource will be stated in the upcoming PFS and as such could be lower. This size factor however, is highly important for the potential use of the resource in the manufacture of lithium-ion batteries, a market which is expected to see double-digit growth on the back of the anticipated high growth in the electric vehicle market (see Graphite uses and demand on page 10). This growth is anticipated in the West as well as probably the most important region for future demand, Asia. In our view, Asian countries (especially China) are likely to want to side-step the politically sensitive issues surrounding smog generated in part by the internal combustion engine. Further, Volt has reported that at the largest super-jumbo flake size it has managed to achieve a TGC content of 96.5% and 99.6%, from a simple sieving and flotation of the milled graphite ore. This bodes well for processing this highly valued size fraction into battery-grade material (anode-quality graphite requires purity of at least 99.9%), as purification costs are somewhat reduced. The effect of Namangale's larger flake size categories on its processing costs will be addressed in our full initiation report on Volt Resources following the release of its PFS.

Exhibit 1: Volt's Namangale project areas and resource size relative to Magnis Resources



Source: Volt Resources

Pushing Namangale towards production

As a means to expedite development of its flagship Namangale project, Volt has formed a team of mining engineers earlier than usual in the project development process to manage the necessary pre-development assessments and technical studies required to confirm the economic viability of the project – the first meaningful report being a pre-feasibility study (PFS) due in Q416. In this PFS report we expect to see the size and scope of the project for the first time, with a reasonable (c ±25% accuracy) assessment of operating and development capital costs. Further, the PFS will crucially provide a signed-off ore reserve estimate which will provide a clear indication of the portion of the resource that will be economically viable to mine. This is especially important for mining products that have no open market (see below), as the commercial sensitivity of offtake agreements may mean that the investor is not exposed to specific product pricing data. A reserve signed off by a competent person under JORC 2012 guidelines (a mining engineer), should therefore provide confidence over that portion of the resource that is defined as economically viable to extract using confidential graphite product prices.

Getting MoU agreements in-place – Chinese tech companies on board

Crucially, as graphite sells via bi-lateral, long and short term agreements between producer and end-user, Volt has agreed three memorandums of understanding with three Chinese end-users of graphite. These were signed with Optimum Nano, Huzhou Chuangya and Shenzhen Sinuo. All of these companies operate in the lithium-ion battery market and could be seen as an endorsement of Namangale's high resource value attributed to its higher than average proportion of battery-applicable larger graphite flake sizes. The MoUs are currently non-binding and require conversion into commercial offtake agreements before project financing can be obtained and future Namangale revenues are guaranteed.

The combined total graphite offtake contained in these non-binding MoUs amounts to 100kt per annum. The total annual output of graphite from Namangale is likely to be 180,000tpa, and will be presented in the upcoming PFS on the project.

Magnis Resources – a proxy for a medium-term re-rating of Volt?

Notable for being located adjacent to the north of Volt's Namangale project areas (see Exhibit 1) is the Nachu project owned by ASX-listed Magnis Resources. This company has a market cap of A$320m (at 27 October 2016) and yet has a resource 39% of the size of Volt's Namangale resource. Nachu has a comparable TGC grade of 5.4% vs Namangale's 5.0%. However, Magnis's Nachu project is much further advanced than Namangale, with a bankable feasibility study completed in March 2016, a demonstrable flow sheet design to produce a battery-grade spherical graphite product and all regulatory and environmental permits finalised. On the basis of this resource size (gross tonnage) differential alone, it would suggest that Volt's shares could see a considerable re-rating when it achieves the same level of development as Nachu – a timeline that Volt has, as stated previously, sought to expedite. Magnis Resource's current market cap of A$262m compares with Volt's current market capitalisation of A$70m.

Namangale's development needs to marry battery factory construction

Volt's stated development timeline will see the release of a PFS on Namangale in Q416, following which it will complete a bankable feasibility study. Subject to option conversions, the company could be fully funded to complete these studies. Dependent on a more accurate estimate of costs than is usually required by a PFS (ie ±25%), Volt could complete a BFS on Namangale in about one year's time. It is not wholly uncommon for mining companies to incorporate BFS accuracy into their PFSs to help shorten development timelines. The importance of expediting development for graphite (and lithium) is to be ready to supply feedstocks for the anticipated ramp-up in battery manufacturing production. This ramp-up, based solely on available published timelines for factory development, is likely to occur by the end of the decade, although it is heavily dependent on real demand for electric vehicles.

Basket prices: Flake size drives margins

As graphite has a varied set of prices and uses, it is important to understand the potential basket price that any particular graphite resource can yield. To attempt to understand the differences in resource values among a broad selection of graphite companies we have taken size distribution data to split up resources and applied some graphite price assumptions. The outcome of this analysis is that the greater the proportion of larger flake sizes, the higher the basket price that can be achieved. Further, any resource that has a meaningful proportion in the jumbo and super-jumbo size categories is particularly valuable, especially as these resources are best suited to feed into the highest (forecast) growth battery manufacturing sector. One word of caution, however: size distribution data is not standardised and we have, in certain instances, been required to arbitrarily split size distribution data so that they fit into the particle size ranges given in the following exhibit. Further, we take no account of the negative operating cost implications of any deleterious materials present in the resources analysed and the effect these materials could have on the purity of the end product. This latter point is critical to what end market the graphite can be used in.

The size categories and prices used to provide our estimate of each resource's basket price are given in the following exhibit:

Exhibit 2: Illustrative graphite prices by flake size

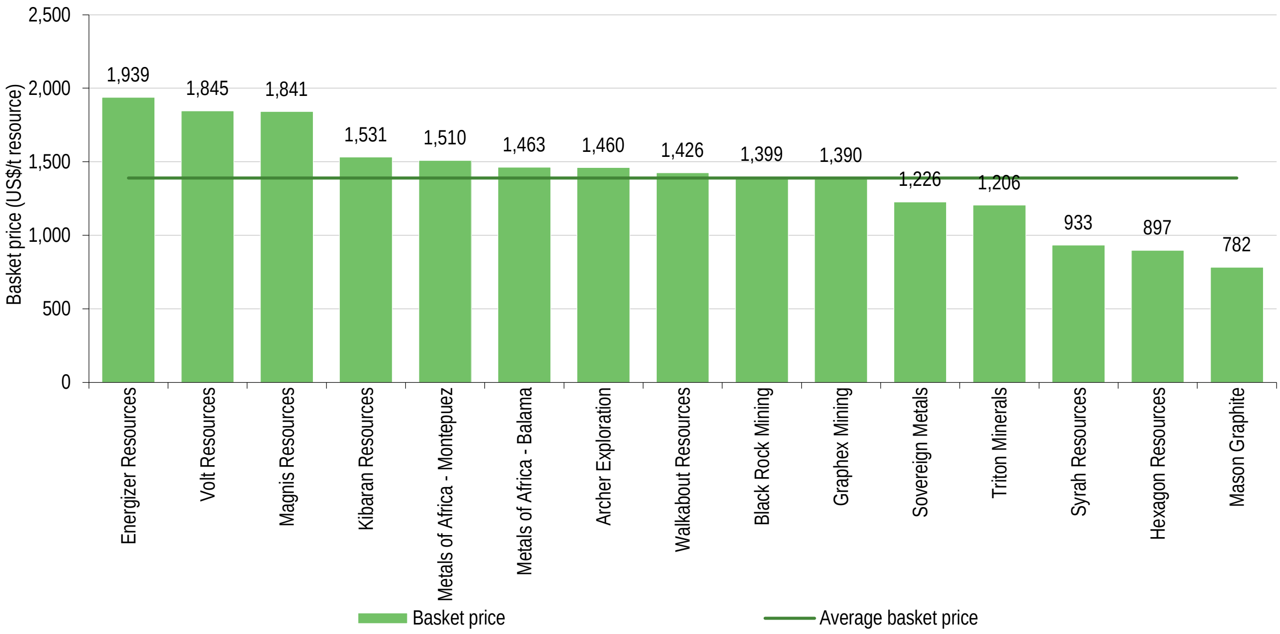
	Microns	Mesh (µm)	2018 forecast (US$/t)	Price source
Super-jumbo	>500	<35	4,000	Magnis BFS 97-98%
Jumbo	300-500	35	2,500	Benchmark 2018
Large	180-300	50	1,600	Benchmark 2018
Medium	150-180	80	1,250	Benchmark 2018
Fine	75-150	100	700	Estimate
Amorphous	<75	>200	500	Estimate

Source: Company data, Edison Investment Research

The basket prices estimated are given in Exhibit 3 below. What is evident is although the range is broad (US$782/t for Mason Graphite and US$1,845/t for Volt Resources, based on our estimates, to US$1,939/t for Energizer Resources), the end markets each company will deliver its products into are starkly different. To use Energizer and Mason as examples, the former intends to develop its project such that its primary end-user will be the energy storage sector, whereas Mason Graphite has considerable management expertise on board (via its appointment of ex-Imerys graphite personnel) to cement its position as a supplier of high-quality graphite products for a very broad set of industrial applications, all of which are high growth in their own right (see Exhibit 8). We do note that Mason is undertaking a feasibility study into battery-grade graphite and how the size distribution of the resource is not dominated by the larger graphite flake sizes used for this application. However, while management is key to any successful mine development (and especially so in these highly technical commodities), when we view these basket prices next to the estimated cash cost of production given in available feasibility studies, the higher the basket price, the greater the gross margin. For example, for the two companies compared, Energizer estimates a cash operating cost in its 2015 feasibility study of US$353/t and Mason, also in a 2015 feasibility study, estimates US$495/t. These provide for estimated gross margins of 87% for Energizer and 37% for Mason. Therefore we can at least say that the greater the proportion of larger flake sizes, the more likely the prospect of increased project gross margins, though we stress again that this analysis makes no comment as to the purity of the end product.

We also point to Volt having the highest estimated basket price versus any of its Tanzanian peers (eg Magnis Resources, Kibaran Resources, Metals of Africa). However, with Volt's cash cost estimations not yet available (due in its upcoming PFS), further analysis is required to comment on the potential gross margins achievable from the sale of Namangale graphite.

Exhibit 3: Edison estimate of graphite basket prices by company



Source: Company data, Edison Investment Research

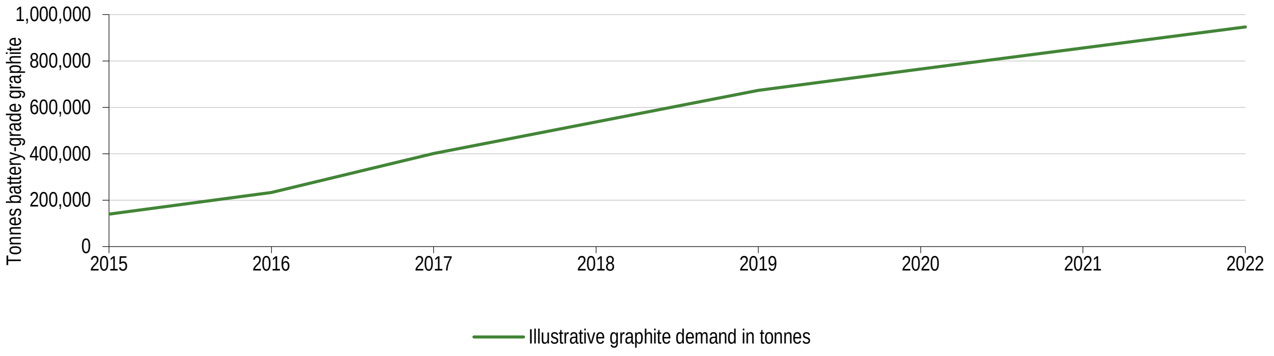
Illustrative future battery-graphite demand

Lithium is the best-known component of a lithium-ion battery. As mentioned previously, however, the amount of graphite that is included as the anode component is far more than lithium. Elon Musk has stated that his batteries are more graphite-nickel than lithium. And while this statement was made when a media frenzy circled over Tesla about the potential supply-side constraints of future lithium production and the potential impacts on future car production, the statement speaks of none of the supply-demand dynamics in the lithium market, or, for that matter, either the graphite or nickel markets.

We have previously performed an illustrative analysis of the future potential demand for lithium carbonate based on the assumptions for planned and under-construction battery manufacturing facilities worldwide (see source note for methodology). Taking this approach and revising it for the graphite component in batteries, we present the potential growth for battery-graphite demand. Note that graphite has many varied uses and the supply-side constraints envisaged in China (which, as already stated, accounts for some 66% of total global natural graphite supply), plus the increasing domestic demand in that country for its own burgeoning electric vehicle industry, provide further support for non-Chinese supply development. Further, Syrah Resources states that the preferred feedstock required for battery manufacture is that of the -100 mesh product type. Therefore while we consider the development of natural graphite resources is key to driving down end-use costs, synthetic graphite demand may be needed to fill shortfalls in natural graphite supply.

On the basis that approximately three tonnes of feed-stock natural graphite yields one tonne of spherical coated graphite for use in battery manufacture, and that one kilogramme of spherical coated graphite can produce 1KWh of power, the following illustrative demand profile arises:

Exhibit 4: Illustrative battery-graphite demand based on projected ramp-up in battery manufacturing capacity



Source: Edison Investment Research

The timeline is based on our understanding of battery factory development, as detailed in the aforementioned note written on behalf of our client Rare Earth Minerals. It represents an illustrative CAGR of 22%.

Graphite

In this section we present a brief overview of the graphite industry. At a point where technology changes and environmental concerns point to a strong increase in demand, there are limited opportunities to invest in quoted entities. Free market producers (China controls the majority of the market) are based largely in India and Brazil. Key demand drivers lie in increasing battery use, as well as fire retardants and increasing steel demand. This note pays special attention to the use of natural graphite in battery manufacture.

Graphite is manufactured and sold in two forms, natural and synthetic. Natural graphite is allotrope of carbon and currently mainly used for industrial purposes (such as a refractory agent, lubricant or in fire retardant materials). Its formation in nature is varied, with metamorphic occurrences the most voluminous and the most common deposit type mined. Graphite can also be produced synthetically from derivative hydrocarbon products.

Synthetic graphite offers the highest purity, and comprises 25% (according to Roskill) of the feedstock used for the manufacture of energy storage devices and batteries; it is also the highest cost due to the enhanced level of processing and purification needed to achieve a very high-purity and consistent (ie >99.9%) product. The high cost of synthetic graphite provides economic motivation to switch to a high-purity battery grade product derived from natural sources. The latter is priced at c US$5,000/t, whereas a synthetic battery grade graphite product can cost as much as US$20,000/t from certain, mainly Chinese, producers.

The natural graphite market in 2014 was roughly 1.2Mt (USGS data), around 10 times the market for lithium carbonate (c 110kt for the same period, USGS data). The largest demand, around half of the total, is from steel and refractory industries. The fastest growing demand is in batteries, currently around 8-10% of demand. The prospects for growth in lithium-ion batteries are much discussed. Perhaps less so is the potential for graphite, very much a part of the lithium ion growth story in that the ratio of graphite to lithium in a lithium-ion battery is said to be typically 10:1 (source: Talga Resources website).

The development of graphite deposits is relatively complicated compared to the established development methods and processing techniques associated with conventional base and precious metal deposits. This complexity is derived from the compositional variations of the in-situ mineral resource, along with the complexity of, and varied set of, end-products and uses. Therefore, to understand the viability, both technical and financial, of a natural graphite deposit requires the careful assessment of the following points:

- Purity – the higher the carbon content, the lower the level of impurities present, which is critical to what end-use the graphite can be used for.
- Porosity – internal impurities require far higher energy levels to liberate and remove them.
- Crystallinity – crystallinity aids energy storage through the trapping of electrons.
- Particle size – the larger the size, the lower the surface area, and therefore the lower the surface area for impurities to bond to.

The specific graphite type desired in high-end applications is termed 'flake' and falls into the size range of >106 microns and above. Below this and graphite is termed amorphous and is used primarily in industrial applications.

The benefits of graphite can be summarised as:

- It is a very good conductor of electricity and heat.
- It has the highest natural strength and stiffness of any material.
- It is one of the lightest of all reinforcing agents.
- It can maintain its strength and stability to temperatures above 3,600°C.
- It is a highly lubricating material.
- It is chemically inert.
- It is highly corrosion resistant.

Graphite market supply

Graphite is not traded on an open market, unlike copper, nickel or gold. Instead graphite is sold directly from the mine to the end-user via bilateral contracts. These contracts or offtake agreements are typically of at least one year duration, although it is normal for graphite producers to keep stocks and client lists in case spot-purchases are required.

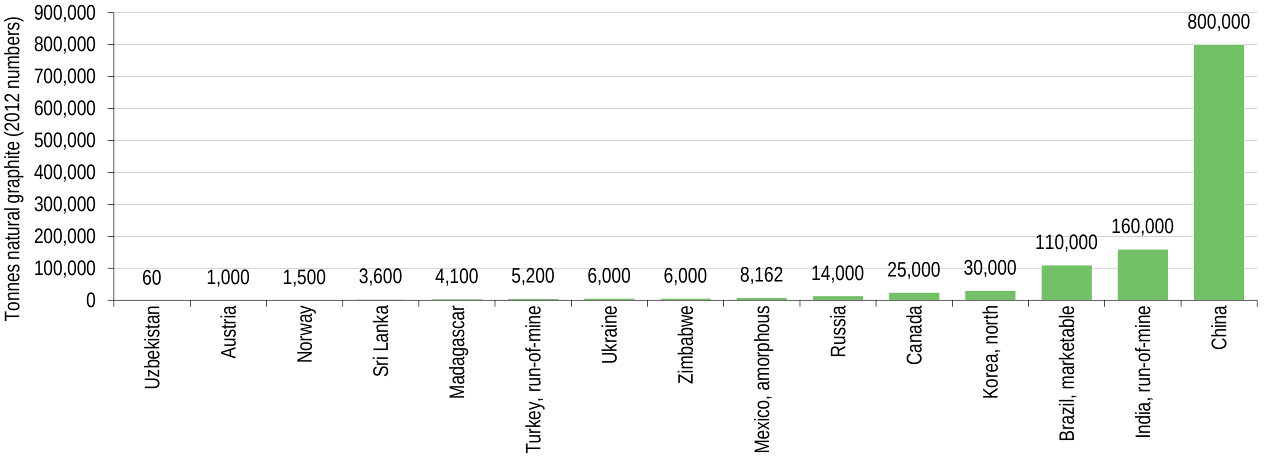
Where a producer offers a range of resource ranging from lower-value amorphous to large flake graphite sizes – ie graphite likely to be used for predominantly lower-value industrial applications where particle sizes and purity are less important – it is likely to supply to a broad network of customers.

However, the situation is different for those companies with a larger portion of their resources containing the large to super-jumbo particle sizes, as these are more likely to serve the fast-growing electric vehicle markets. In our view, these companies are likely to be able to secure multi-year offtake contracts to guarantee revenues and provide a stable Western supply, outside the dominant and increasingly protectionist China.

Global supply dominated by China

China accounted for c 68% of global supply of natural graphite production in 2012. Other notable producers include India (14%) and Brazil (9%), and interestingly North Korea (3%), according to United States Geological Survey (USGS) data.

Exhibit 5: Natural graphite production data by country in tonnes, 2012



Source: USGS

China's protectionist policies on strategic materials

China has imposed protectionist policies and tariffs on metals that are deemed strategic for many years. During 2011 at the height of the rare earth element (REE) 'bubble', the US, EU and Japan filed a complaint with the World Trade Organisation (WTO) claiming China was in breach of its obligations. At the time China used a system of tariffs and export quotas to regulate the flow of REEs to outside markets. China's argument for imposing these tariffs and quotas was that they were necessary to "protect human, animal, or plant life or health".[1] This could be viewed as consistent with China's messaging at the time about the environmental damage caused by its domestic REE industry, especially in connection with the illegal production of these metals. However, it should also be noted that China imposed no restrictions on the consumption of its REE metal supply by its domestic market.

In July 2016 the US, in isolation this time, launched a further action against China at the WTO relating to China's export duties on nine key raw materials: antimony, cobalt, copper, graphite, lead, magnesia, talc, tantalum and tin.

These actions point to the vulnerability of markets in the context of China's dominance in the supply of strategic raw materials. We see considerable parallels with what happened with REEs to graphite and we conclude there is potential for China, which controls some 66% of global graphite supply, to impose greater controls on this commodity. This is especially meaningful as China could potentially become globally dominant in electric vehicle production, and could also become a major constructor and user of pebble-bed nuclear reactors. Similarly, China may also become a dominant manufacturer and user of fire retardants (in which expandable-graphite is an important component) as it modernises its infrastructure and potentially brings its health and safety regulations closer to Western standards.

Other factors that support development of non-Chinese graphite mines include an increasing global environmental awareness and political willingness to reduce production from highly polluting mines.

At present China imposes a 20% export duty on graphite products.

Graphite uses and demand

Graphite uses are wide ranging and graphite products are varied with, consequently, a wide range of selling prices. Pricing reflects particle size (in general the greater the size, the higher the value)

[1] InvestorIntel, 27 April 2015 article.

and purity levels (>99.9% total graphite content [TGC] purity is required for high-end and technology uses).

Particle size is crucial as the larger the graphite particle, the less surface area there is for impurities to attach; impurities are mainly ash present as a silicate mineral. It should be noted that to attain the highest purity graphite product for high-end technology uses, impurities within the graphite lattice need to be removed also.

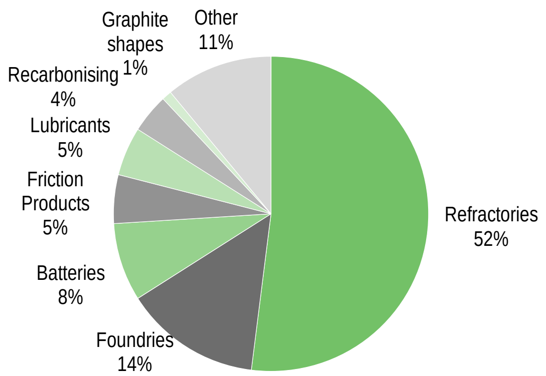
Exhibit 6: General graphite uses, size classification, carbon purity requirements and prices

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: Volt Resources presentation

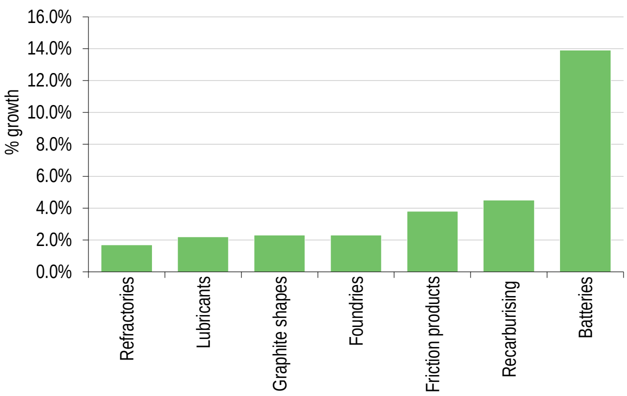
The following exhibits were created from a Roskill presentation by Suzanne Shaw, titled *Natural graphite: Raw material trends to 2020*. They provide a succinct view of graphite usage and growth rates per end sector, with battery technology central to future growth (Exhibit 8).

Exhibit 7: Graphite uses



Source: Roskill presentation by Suzanne Shaw, *Natural graphite: Raw material trends to 2020*

Exhibit 8: Graphite % growth per annum, by use



Source: Roskill presentation by Suzanne Shaw, *Natural graphite: Raw material trends to 2020*

Types of natural graphite and their formation

Graphite is produced either synthetically or mined in its natural form and used in a wide range of industrial applications. The main uses in the US in 2015 were for electrodes, brake linings, foundry operations, lubricants, as a refractory agent and in the manufacture of steel (see Exhibit 6).

As stated previously, graphite is an allotrope of carbon (along with diamond, the synthetically manufactured Buckminster fullerene and the newly discovered '2D' graphene). It is found in nature, largely as a result of metamorphism of sedimentary carbon compounds and also in association with quartz and other silicate minerals. Typical metamorphic settings that provide the appropriate environment for graphite formation include:

- Regional metamorphism where shales and limestones that were created at the boundaries of convergent plate margins were subjected to heat and pressure. Under these circumstances, tiny flakes of graphite form in the rock, and where these flakes are in abundance can be economic to mine. Mining includes the crushing of the host of the rock to liberate the graphite particles, and then processing using gravity separation or froth flotation techniques, with the resultant product called ‘flake graphite’.

- Coal seam metamorphism. With coal being the organic source, which is subjected to further heat and pressure, a type of amorphous graphite is formed. The process by which amorphous graphite forms is down to heat and pressure destroying the organic molecules of coal and by volatizing the oxygen, hydrogen, nitrogen and sulphur components already present in the coal seam. This volatization results in an almost pure form of carbon that then crystallises to form mineral graphite.
- Hydrothermal vein-type graphite (also known as ‘lump’ graphite) is a less important (in terms of ore deposit size) and rarer form of graphite. Hydrothermal activity can create an environment where the carbon compounds within a rock change into graphite, which is then remobilized and deposited as veins along with other hydrothermal mineral assemblages. As with other precipitated minerals (eg salts), this form of graphite has a well-defined crystalline form and can be, as long as an economic deposit is available, preferred for use in electronic applications. However, being in vein form, economic occurrences of this graphite type are extremely rare and flake graphite is generally mined and used for electronic applications.

Graphite is also found in igneous settings, as tiny particles in basalt flows and alkaline igneous rocks such as syenite. It can also form in pegmatites, a rock type that forms from the residual melt fluids of intrusive magmatic bodies, and in some iron rich meteorites.

Synthetic graphite

Graphite can also be formed via synthetic processes, from the heat-treatment of petroleum coke (the solid non-volatile carbon residue left after the distillation and cracking of petroleum) or coal tar pitch. This type can be known as highly-ordered, or highly-oriented, pyrolytic graphite. Heat treatment is in the range of 2,500 to 3,000 degrees centigrade. At these temperatures any impurities, critically metal (eg vanadium, pyrite or pyrrhotite can be found in association with graphite in the ground), are driven off leaving a high-purity graphite product. The heat treatment process can be extremely effective in purifying graphite and currently synthetic graphite is the dominant graphite type in the manufacture of anodes for batteries. However, the high cost of production, among other things, guides to a high sale price, which has negative effects on the cost of battery production, a key economic hurdle in bringing the cost of electric car manufacturing down to a level that allows mass adoption. The high cost of synthetic graphite production is a key economic impetus to the development of new natural graphite sources for use in battery production and energy storage in general.

Understanding graphite resource data

The reporting guidelines for natural graphite resource data are more complex than for conventional metals, for instance copper and gold. This is due to the complex and varied set of end-product characteristics that are required to understand the economic viability of mining a deposit. For example, just providing grade and tonnage numbers is not sufficient, and purity and size distribution data are usually required to bring graphite resource reporting in line with Australasian Joint Ore Reserves Committee (JORC) 2012 and NI 43-101 guidelines.

Graphite resources are first stated in terms of total graphite content (TGC), usually expressed as a percentage. The TGC of a resource is the equivalent to a gold resource’s grams per tonne grade. However, as the following section explains, TGC should not be used in isolation. The sole use of TGC values (along with tonnage numbers) is advised against in the JORC 2012 code for mineral resource and ore reserve reporting, as the two values alone cannot adequately state the economic viability of a deposit at the resource definition stage. The 2012 JORC code was revised from the

2004 edition so that a clearer understanding of a mineral resource's potential economic viability can be assessed in greater detail before an ore reserve is calculated. A key excerpt from the 2012 code provides a clear explanation of why greater knowledge of a graphite resource is needed.

Key excepts from the JORC Code 2012, Clause 49

Clause 49 of the JORC Code 2012 relates to industrial minerals, of which graphite is one such constituent mineral type. The following (bullet point) excerpts have been taken from the JORC 2012 code, and highlight the degree of complexity involved in the estimation of a mineral class that is very attuned to the end-product being sold. This is obviously a key component of understanding the myriad of product classes and purities, which govern the ultimate price received and drive the value of a graphite project:

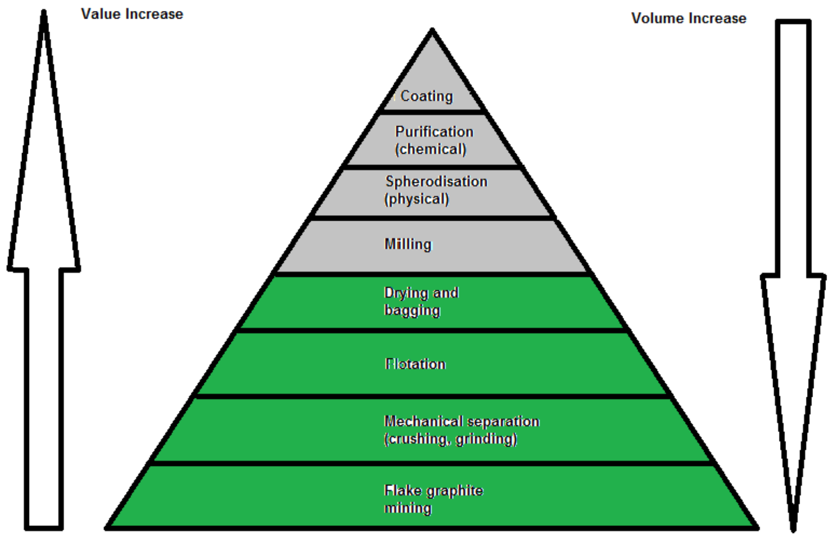
- "For minerals that are defined by a specification, the Mineral Resource or Ore Reserve estimation must be reported in terms of the mineral or minerals on which the project is to be based and must include the specification of those minerals."
- "Assays may not always be relevant, and other quality criteria may be more applicable. If criteria such as deleterious minerals or physical properties are of more relevance than the composition of the bulk mineral itself, then they should be reported accordingly.''
- "It may be necessary, prior to the reporting of a Mineral Resource or Ore Reserve, to take particular account of certain key characteristics or qualities such as likely product specifications, proximity to markets and general product marketability."

Taking the above three points into consideration, graphite mineral resources should be reported at least in terms of purity and flake size distribution, in addition to TGC and tonnes. We would also consider that key deleterious components such as the ash content and any significant metals should also be stated. Mineral resource tonnes and TGC are key metrics for assessing flake graphite projects, although these projects also require attributes such as product flake size and product purity to be evaluated; product flake size and product purity are intimately linked to the end markets they feed into. Flake graphite is defined primarily according to size distribution, with a number of terms such as fine (sometimes described as amorphous) small, medium and large defined in the marketplace.

Processing: Purity, not just grade, is king

Graphite purity is very important, especially to the production of graphite anode material for use in batteries. Understandably, any presence of metalliferous minerals in a graphite end-product can prevent its use in electronic applications, as metal will create electrical shorting with very undesirable effects on battery performance. By virtue of its geological formation, numerous other minerals can be found in association with graphite. For example, the largest (by market value) pure natural graphite producer is ASX-listed Syrah Resources (ASX: SYR). Syrah has a very large deposit, called Balama, located in Mozambique. The Balama deposit contains a large vanadium component, derived from an organic plankton source. The presence of vanadium alongside graphite requires purification such that no vanadium reports to the end-graphite-product and the risk of creating a short-circuit in electrical applications is removed. The purification process is one of the largest cost components, if not the largest, to natural graphite production and a key component and risk to any graphite project or company valuation.

Exhibit 9: Graphic showing relationship between graphite value, volume and processing



Source: Industrial Minerals website. Note: Grey shaded sections relate to processing, green to mining.

The most common deleterious components of a graphite resource comprise silicate minerals, and the level of impurity is usually recorded as the ash content and is measured by calculating the mass of ash left after burning a sample of graphite. Also found in association with graphite are the minerals pyrite and pyrrhotite (iron sulphides) as well as the metal vanadium. And while raising the cost of graphite purification, economic metals can provide an additional revenue stream to the graphite producer. For example, the production of vanadium for sale from Syrah's Balama project provides a relatively low (to the value of the contained graphite) value by-product revenue stream (vanadium pentoxide currently fetches US$4.3/lb and has risen 79% from a multi-year low of US$2.4/lb seen in January 2016).

Graphite processing and the importance of flowsheet design

As stated previously, the processing of graphite depends upon the level of contaminants present in the resource and the physical characteristics of the graphite (ie particle size, surface area and shape). The first stages of processing are not dissimilar from conventional crush and grind, sizing and sorting techniques found at typical metalliferous mines. The crushing and sizing of graphite requires the use of the lowest energy ball and rod type milling equipment to liberate the graphite from the host or gangue rock. As little pressure as possible needs to be exerted on the graphite ore during crushing, especially when the larger flake types are present and the inherent value in this size fraction (due to their higher-natural purity) needs to be preserved.

Once a homogenised ground and sized graphite product is made, a secondary phase of processing takes places to remove any unwanted impurities. The typical tolerances for a selection of typical impurities within graphite are given in the following exhibit:

Exhibit 10: Technical index giving thresholds for a high purity graphite product

Parameter	Value	Unit/limit	Parameter	Value	Tolerance
Fixed carbon content	99.96%	min	Tap Density (g/ml)	0.96	±0.05
Ash content	0.04%	max	SSA (m2/g)		±0.25
Moisture	0.10%	max	D10 (micron)		±1.0
pH	5.5-7	no.	D50 (micron)		±0.5
Fe (ppm)	≤35	ppm	D90 (micron)		±1.0
Ca (ppm)	≤25	ppm	D-Top (micron)		
S (ppm)	≤15	ppm			
Si (ppm)	≤45	ppm			
Ni (ppm)	≤5	ppm			
Zn (ppm)	≤10	ppm			
Cr (ppm)	≤5	ppm			
Al (ppm)	≤15	ppm			
Cu (ppm)	≤5	ppm			

Source: Kibaran Resources announcement dated 27 September 2016

When graphite requires the greatest levels of purification, that is, when the end graphite product is going to be used as a battery component or for other high-end technology uses (eg fuel cells, solar cells, semiconductors, LEDs or pebble-bed nuclear reactors), a greater amount of grinding is likely to be required to liberate any intercalated impurities within the graphite's crystal lattice structure.

After this extra stage of grinding (if it is required), a phase of chemical purification, which is usually highly toxic, is undertaken. This toxic processing treatment requires high-level environmental monitoring, control and adequate planning at the project design stage.

Size fraction analysis

The size fraction analysis of graphite concentrates produced from graphite deposits indicates a general decreasing graphite concentrate grade with decreasing particle size. The reason for this relationship is that smaller size fractions need greater mechanical manipulation to remove impurities from smaller flakes than from larger flake sizes. The rise in energy costs is exponential as flake size decreases, and this is a key cost input that requires accurate estimation during a graphite project's feasibility and planning stages. Removal of impurities and purification methods are assessed in the laboratory, with the end goal being the creation of a full demonstrable flow sheet. With the process flow sheet design completed, and the general sequence of processing methods understood to remove impurities, a further stage of flow sheet optimisation is usually performed. This optimisation stage would seek to optimise the concentrate grade at smaller flake and particle sizes by the design and inclusion of secondary cleaning circuits (including high-shear grinding technology) for the optimisation of graphite grades at various particle and flake sizes.

In conclusion, size fraction analysis is usually completed after a scoping study level of assessment. As such, any scoping study that is based on preliminary metallurgical test work may significantly over- or underestimate the graphite concentrate grade. Further, the reader should note this as a critical risk when viewing graphite deposit viability before adequate metallurgical test works have been completed. This is very similar to understanding the viability of rare earth element deposits, where a demonstrable flow sheet, which may take many years to refine and get right (not so likely with graphite by virtue of it being only one element to refine, and therefore technically more simple to process), is critical to understanding the capital requirement of developing an asset, as well as the operating cost structure that is so crucial to understanding a project's economic viability.

Listed graphite producers

This note is intended as an overview of the graphite industry and we are not, at this point, providing individual company analyses. However, we set out in Exhibit 11 below the largest global quoted graphite entities ranked by market cap.

Exhibit 11: Graphite resource companies ranked by market cap (US$)

Name	Ticker	Market cap (000s U$)	EV (000s)	Project name (s)	Country	Ownership (%)	Development stage
Syrah Resources	A:SYR	815,362	668,995	Balama	Tanzania	100	Under construction
Magnis Resources	A:MNS	245,355	239,853	Nachu	Tanzania	100	FS
Mason Graphite	C:LLG	85,476	92,008	Lac Gueret	Canada	100	FS & FS underway on battery grade graphite
Zenyatta Ventures	C:ZEN	58,876	58,552	Albany	Canada	100	PEA
Volt Resources	A:VRC	54,643	53,812	Namangale	Tanzania	100	PFS due Q416
Hexagon Resources	A:HXGX	48,190	47,798	McIntosh	Australia	100	PFS
				Geumam	S. Korea	100	Inferred Resource/Expl. Targets
				Taewha	S. Korea	100	Inferred Resource/Expl. Targets
				Samcheok	S. Korea	100	Inferred Resource/Expl. Targets
Talga Resources	A:TLG	42,337	38,007	Nunasvaara	Sweden	100	Resource stage
				Jalkunen	Sweden	100	Resource stage
				Raitajarvi	Sweden	100	Resource stage
Black Rock Mining	A:BKT	33,766	31,866	Mahenge	Tanzania	100	PFS underway
Beowulf Mining	L:BEM	29,072	27,261	Five early-stage exploration projects	Sweden	100	Exploration stage
Kibaran Resources	A:KNL	28,157	24,609	Epanko	Tanzania	100	BFS
Metals Of Africa	A:MTA	23,871	22,742	Montepuez	Tanzania	100	Resource stage/Conceptual Study
				Balama Central	Tanzania	100	Resource stage/Conceptual Study underway
Energizer Resources	C:EGZ	20,531	20,401	Molo	Madagascar	100	FS
Sovereign Metals	A:SVMX	15,135	14,321	Duwi	Malawi	100	Scoping Study
Graphite One Resources	C:GPH	13,562	12,605	Graphite Creek	Alaska, USA	100	Resource stage
Alabama Graphite	C:ALP	12,059	11,667	Coosa	USA	100	PEA
Nouveau Monde	C:NOU	10,624	10,646	Matawnie	Canada	100	PEA
Northern Graphite	C:NGC	10,026	9,173	Bissett Creek	Canada	100	BFS, Expansion Case PEA
Focus Graphite	C:FMS	9,407	9,274	Lac Knife	Canada	100	FS
				Lac Tetepisca	Canada	100	Pre-resource stage
				Lac Guinecourt	Canada	100	Pre-resource stage
Bass Metals	A:BSM	8,528	8,922	Graphmada	Madagascar	100	In production
Armadale Capital	L:ACP	7,696	7,696	Mahenge-Liandu	Tanzania	100	Maiden resource by end 2016
Walkabout Resources	A:WKTX	6,049	5,874	Lindi	Tanzania	Eventual 70% (JV farm-in)	Pre-resource stage
Archer Exploration	A:AXEX	5,047	3,764	Eyre Peninsula Graphite Projects	Australia	100	Resource size defined

Source: Company data, Thomson Reuters, Edison Investment Research. Note: Priced at 26 October 2016.

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