Industry Research Note
Graphite

Q2 2018

MiFID II compliant*

Key themes

Recovering prices are driven by strengths in the steel industry, tightening Chinese environmental legislation and budding Li-ion battery demand

Traditional consumption is expected to plateau with electric economy growth as the main driver for future graphite pricing

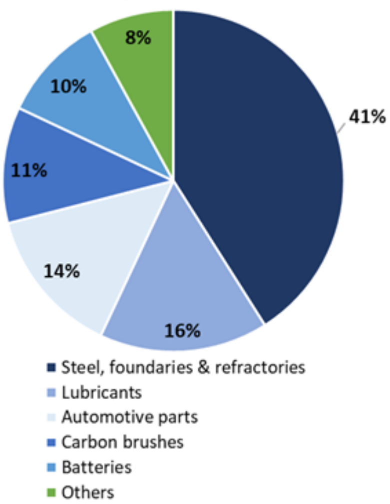
Expandable graphite demand accelerating to dominate future markets on stringent construction trends, drawing significant large-flake deposit pressure

Graphene R&D investment will drive an innovative technology sector

China to become net importer of natural graphite due to the war on smog and diminishing domestic ore quality

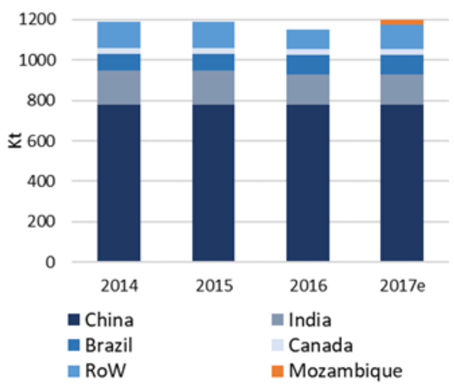
Future supply focus in Africa and Canada, targeting highest purity raw material

Graphite Markets



Consumption ~1 million tonnes

Graphite Production



Price Outlook

Graphite is an allotrope (a chemically similar, structural modification of carbon), exhibiting both metallic and non-metallic properties which favour a vast number of end-use markets. Further to traditional steel manufacturing, the unique qualities of graphite, including very high thermal and electrical conductivity, lend itself to innovative battery and emerging technologies.

Mined graphite is most commonly sold as a concentrate by private, direct negotiation, leading to opaque pricing structures. Pricing details are posted via minerals intelligence companies, for example '*Industrial Minerals*', who provide guideline quoted prices with respect to long-term trends after surveying industry participants. Most natural graphite is typically sold to traders who upsell to intermediary refiners, polishers and shapers before retailed to final customers. With China dominating the market, responsible for 67% production in 2017 (*source:* USGS), the Asian powerhouse nation is setting the global standard for the commodity's price.

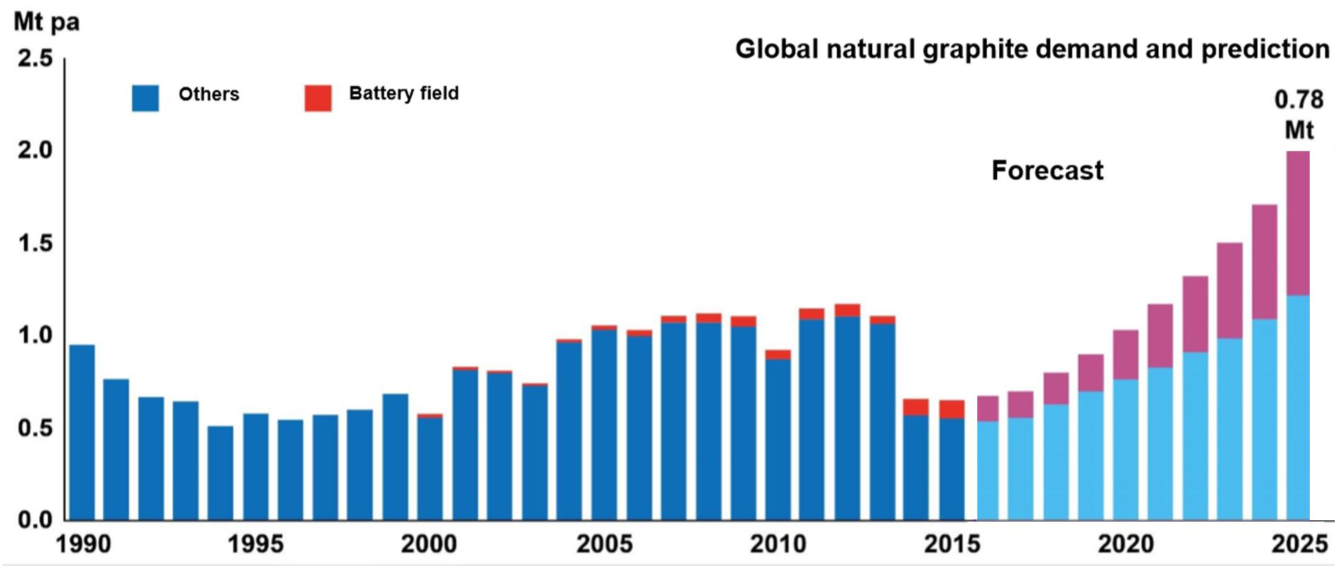
Graphite spot price benchmarks (US$/t 94-97% C) - early 2018

	Sieve Mesh	Graphite flake size (μm)	Price/t (US$)*
Amorphous Powder/Fine	-200	-75	~450
Small	-100/+200	+75	~850
Medium	-80/+100	+150	~1000
Large	-48/+80	+180	~1,200
Extra-large 'jumbo'	+48	+300	~1,950
Super jumbo	+35	+500	~3,500
Spherical (99.95% C)		~15	~2,800-2,900
Synthetic			~7,000 - 20,000

*Source: Northern Graphite, Walkabout Resources (Q2 2018), *approximate pricing for Q2 2018*

Table of Contents

Global natural graphite predicts growth in the field of lithium-ion batteries will be over 20% through 2025

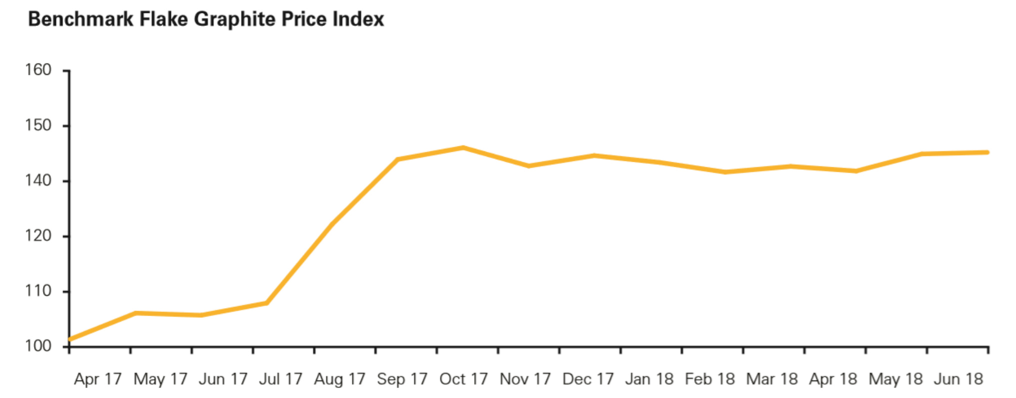


Source: Historical data from Roskill, forecast data from Canaccord (2016)

Price outlook cont.…

Graphite prices are determined as a function of particle (flake) size, carbon content (purity), crystallinity, downstream processing (i.e. spherical graphite), and target end-use. In general, higher grade graphite with increased and consistent flake sizes command higher prices, with early 2018 price ranges displayed in the above table. Upgraded and modified material for specialised applications - including expanded, spherical or synthetic graphite - may cost as much as $20,000/t (*source:* Northern Graphite Corp).

Despite environmental inspections across China's two main provinces of flake production – Heilongjiang and Shandong – creating near-term supply uncertainties, swelling new ex-China production is plugging shortfalls. Flake graphite prices stabilized during June with the reintroduction of limited Chinese production, however there remains a persistent lack of large flake availability which is driving preferential price appreciation. Benchmark Mineral Intelligence record 94-95%C grades (+50 mesh) climbing +1.4% to $1,875/tonnes on average (FOB China). The price outlook remains positive, as processing capacity limitations across China, coupled with the increased costs involved with those permitted to continue output, has created uncertainty among processors, forcing many to explore alternative supply options abroad (*source:* Benchmark Mineral Intelligence).



Source: Benchmark Mineral Intelligence

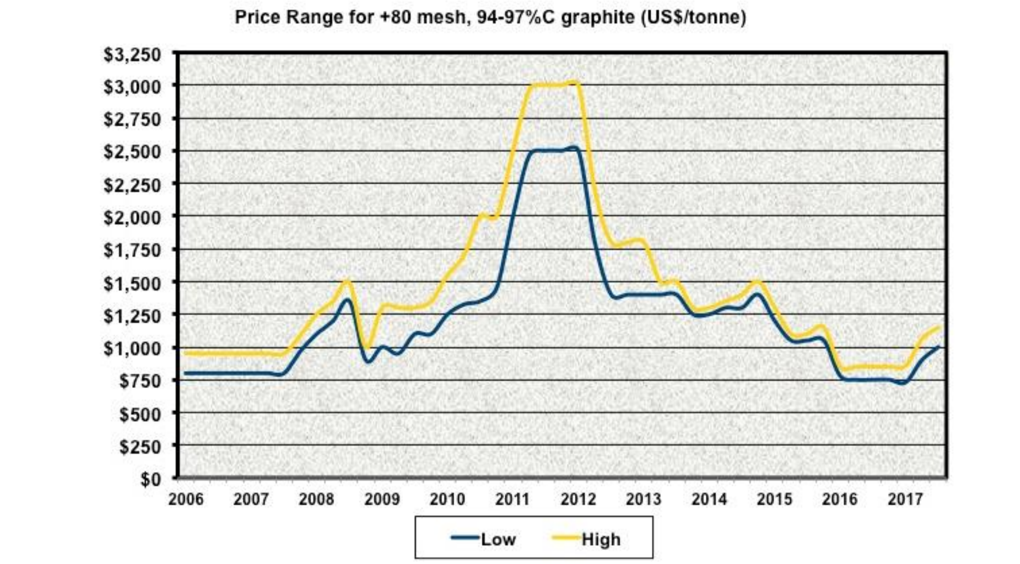
Mesh sizing

Mesh size refers to the number of openings in a single inch of screen. The higher mesh number equates to finer material. For instance, amorphous powder of size +400 mesh is equivalent to 400 grid squares across a single one inch of screen. The (+/-) symbol denotes the number of the mesh at which a graphite particle either remains/filters through.

Synthetic and value-add graphite

The creation of synthetic graphite in the late 1800's bifurcated the graphite market, with the synthetic form commanding higher pricing than naturally-occurring material. Manufactured by the application of high-temperature processing of amorphous carbon-bearing substances including petroleum, coal, natural and synthetic materials, the man-made material is generally 2-3x more expensive to manufacture.

Battery-purity product prices continued to rise through June 2018 in response to robust demand growth from anode producers throughout Asia. Prices for 15 micron uncoated spherical material (99.95% C) saw the biggest increases over the month, rising by 3% to an average of $3,400/t (*source:* Benchmark Mineral Intelligence).



Source: Northern Graphite

Historically the graphite industry found itself in a near-dormant state from the 1990's up to 2007, with minimal growth opportunities. However, since 2007 graphite prices display turbulent movements with a distinct peak in 2011/2012. The rapid price appreciation was consequent of the commodity super-cycle and a lack of finance for new mines during the industrialisation of emerging economies. New, high growth applications such as Lithium-ion batteries made immaterial impact on demand and consumption (*source:* Northern Graphite Corp).

Graphite prices are principally a function of the industrial sector with movements triggered by changes in economic sentiment in major markets. In 2012, prices retreated by 40-50% as a result of slower economic growth in China and the US and growing concerns over the Euro zone sovereign debt crisis. As prices contracted from 2012 highs and capital markets dried up, exploration and production activity in the sector significantly slowed, with major projects put on ice.

Environmental cuts

More recently, steadily improving fundamentals have allowed graphite prices to make robust recovery throughout 2017. Motivated to improve its air quality, China's environmental-designated production cuts led to tighter global graphite supplies, triggering the mineral's price to rebound off its bottom in October last year. Graphite prices are up 25-30% since the beginning of 2018 (*source:* Northern Graphite), with an improving market driven by a fall in output across China together with a rebound in demand from steel (refractories and recarburizer) and Li-ion battery growth. Fundamentals are strengthening for graphite producers, with the recent addition of production from Syrah Resources focusing on C1 production costs ~$400/t in concentrate (*source:* Syrah Resources).

Battery demand

Accelerating growth of the electric economy is expected to become the main driver for future graphite pricing. Positive momentum in battery demand is drawing value from its low 2017 base, with demand expecting 20% CAGR ("Compound Annual Growth Rate") for high-purity material markets through to 2020. Expanding battery demand is drawing higher intensity of graphite flake consumption, with 100% 2017 global production quantities required to support 2025 battery demand. Innovative R&D investment into graphene end-use markets also gives specialty value-add graphite products significant upside in prices as end-use markets advance from lab-scale testwork to commercialisation.

Critical raw material

Graphite has been earmarked as a mineral critical to both the economic and national security of the United States and the European Union. The list of 35 fundamental minerals in the US (27 in the EU) combine raw materials of high importance with high risk related to supply. Consequently, there is a strong emphasis on securing long-term supply of minerals that are not produced in substantial quantities domestically.

Market tightness presents buying opportunities

Global supply is being matched by a growing number of projects, with a particular focus on Africa and Canada, and import risk is expected to draw significant investment along the entire supply chain. While natural graphite ore output in 2017 indicates 200kt surplus, production inefficiencies associated with graphite upgrading result in 30-50% losses. However, with strong supply advancing from Syrah Resources and improving processing recoveries, the graphite **market should remain tight and reasonably well balanced**. Risks to sustained consumption from high-tech markets will enhance the competitiveness of offtake agreements, with a strong emphasis on procuring mineral from the highest-purity resources and sale products.

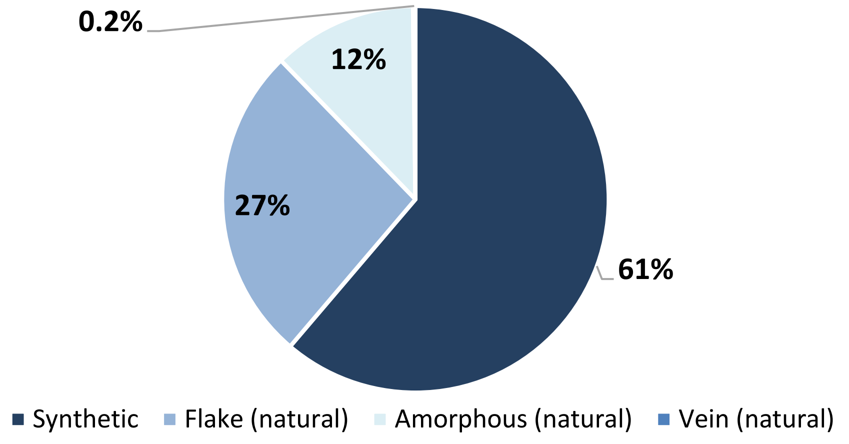
The price outlook remains positive, particularly with swelling battery capacity, and growing environmental legislation across China. Preferential growth in large flake prices, buoyed by the ongoing tightness in global production, is set to continue as industry participants report a lack of source availability. **This growing divergence of value across flake sizes is creating a strong investment case for companies with larger-flake distribution or value-added processing to expanded or spherical graphite products.**

Demand

Summary

Driven by traditional steel industry consumption and innovative lithium-ion battery demand growth has drawn global demand for graphite to ~2.5 million in 2017 (*source:* USGS); divisible into ~1 million tpa natural source and ~1.5 million tpa synthetic graphite.

Graphite market distribution (2016)

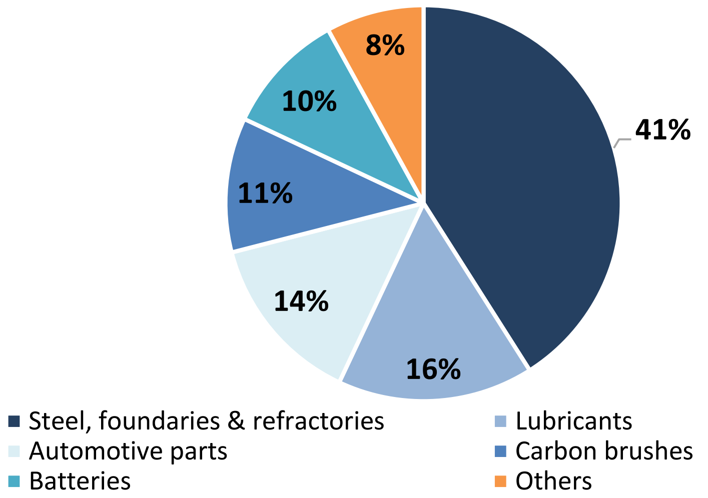


Source: Syrah Resources

Graphite is an industrial mineral with a myriad of applications in steel manufacture, refractories, automotive production, batteries, lubricants and nuclear power plants.

Traditional Demand

Graphite end-use market (2015)



Source: Statista

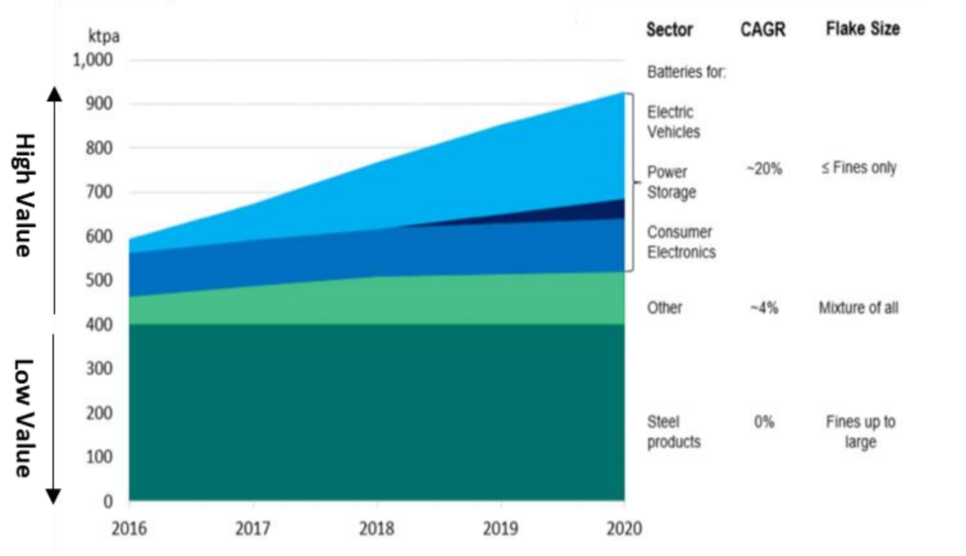
Steel

Historic graphite consumption has been dominated by the steel making industry, with 41% worldwide demand associated with the sector in 2015 (*source:* Statista). The addition of graphite at steel mill operations raises the carbon content of the manufactured steel to bolster its strength and rigidity under temperatures exceeding 3,600°C. Further, the graphite agent is self-lubricating and resistant to oxidation and chemical corrosion.

High-carbon steel is defined by metallurgists as iron composed of 0.8% - 2.11% carbon. As the carbon content rises, steel has the ability to become harder and stronger via heat treating, however some of the effects of elevated carbon levels include reduced weldability, ductility and impact toughness. Common applications include forging grades, rail steels, spring steels, wear resistant steels and high-strength bars.

The steel sector growth has deteriorated in recent years, contributing to depressed graphite prices. However, recent recovery has drawn a 5% global steel production rise in 2017, according to the World Steel Association. The demand for graphite in steelmaking is expected to plateau as China transitions from its industrialization phase and the economy moves to more sustainable economic expansion (*source :* Syrah Resources).

Natural flake graphite global demand forecast



Source: Syrah Resources

Further end-use markets target production of crucibles for holding molten metal, refractory lining for high-temperature furnaces and boilers, lubricants, automotive parts and carbon brushes, accounting for cumulative 41% demand in 2015.

Nuclear

Synthetic and high-purity flake graphite has long been used as a moderator of the nuclear fission reactors in nuclear plants. Generation IV nuclear reactors, like Pebble Bed Reactors (PBRs), have neither rods nor cooling towers but use graphite to coat uranium dioxide fuel particles. The graphite in the pebbles is a mix of 75% natural material and 25% synthetic (pyrolytic) graphite. China constructed the first prototype reactor, a small 20MW in mid-2011, with plans to expand from 2 commercial units to 30 by 2030 (*source:* Northern Graphite). The Asian nation ultimately plans to construct up to 300GW of reactors, with Pebble Bed Modular Reactors (PBMRs) forming a major part of the strategy. It is estimated that each PBMR requires 300 tonnes of graphite at construction, and a further 60-100tpa operating requirement. Given growing demand for power in rapidly developing markets, rising energy security concerns and carbon emission targets, nuclear energy has the potential to drive demand for specialist natural and synthetic graphite.

Lithium-ion Batteries

Global shift in policy and environmental legislations, sales momentum and swelling industry investment continues to support the rapidly advancing electric economy, underpinned by battery components consisting of specialty metals such as lithium, carbon, nickel, manganese and graphite. An escalating lithium-ion battery market now consumes about 25% of global graphite supplies (2017).

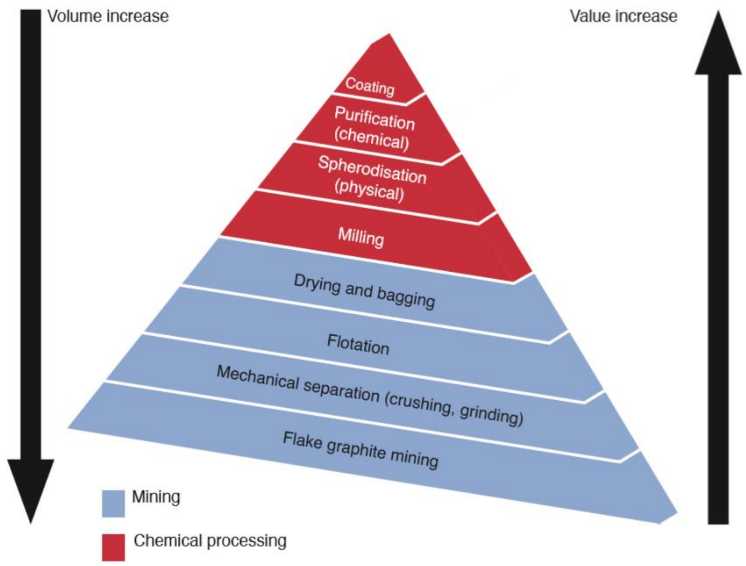
Battery-suitable material provides a high surface area and layered crystal structure making graphite an appropriate anode material into which the lithium ions are intercalated. With the most-stringent constraints focusing on purity, minimum commercial restrictions target 99.5% toc (“total organic carbon”). Consequently, ~55% lithium-ion anode material gravitates towards synthetic graphite (*source:* Battery University) due to its superior consistency and purity, with the balance of natural graphite supporting falling battery costs. This blend achieves the strengths of each form to manufacture lower cost, long-life, high-capacity EV batteries. Synthetic graphite for Li-ion sells for approximately $10,000/t compared to spherical natural graphite at ~$2,800/t (*source:* Northern Graphite).

Flake graphite processing

Natural flake graphite requires processing into spherical graphite (SPG) material in preparation for anode manufacture. The sequence of micronising, rounding, and purifying flake graphite generates SPG products focused on either coated (cSPG) or uncoated (uSPG) specifications. Historically, three tonnes of flake graphite concentrate translated into a single tonne of uSPG consequent of losses during the initial micronising and rounding stages; representing a major cost (*source:* Northern Graphite). **Processing improvements have enhanced industry yields to 40-50% and, in general, larger flakes are more effective.**

While the unpatented process was initially developed in Germany, Chinese manufacturers dominate commercial production and subsequent anode production. The basic sequence is outlined below.

Flake to spherical graphite process



Source: Industrial Minerals

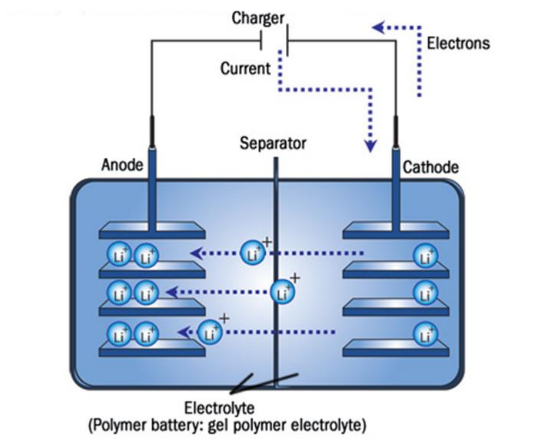
Spherical product final size varies between 5-20 microns depending on application. The round shape is necessary for uniform production during high speed manufacture, while also resulting in higher density batteries with better rate capacity and longer life (*source:* Northern Graphite). Stringent purification specifications for batteries requires the use of hydrofluoric and sulphuric acid to upgrade from ~94% toc to 99.95% toc. Processing costs increase with the addition of neutralizing agents to conform with environmental, health and safety practices.

Coating via application of pitch or asphalt substances and baking at over 1,200°C provides a hard carbon shell which protects the spheres from exfoliation and inhibits the ongoing reaction of electrolyte and graphite (*source:* Northern Graphite). A number of Chinese, Japanese and Korean firms produce cSPG, priced around $4,000-$6,000/t. Technology companies are investigating enhanced coatings for spherical graphite, with improved electrochemical performance achieved with silicon additions (*source:* Focus Graphite).

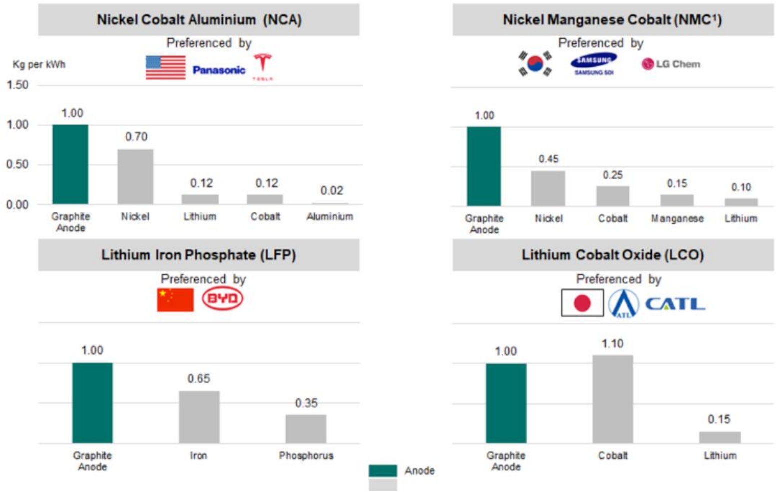
China has traditionally been the most competitive supplier of spherical graphite, capturing 100% of the natural anode material market, owing to historically low labour, power and raw material costs (*source:* Indmin). Blending Chinese export figures and domestic consumption, **annual natural SPG demand for flake graphite approximates to 60,000 tonnes per year. Assuming a 40% yield, battery flake feed totals 150,000 tpa, equivalent to 25% annual**

flake production (*source:* Norther Graphite). Eroding margins, significant Western R&D investment and evolving global demand is creating increasingly competitive non-Chinese firms.

Lithium-ion battery construction



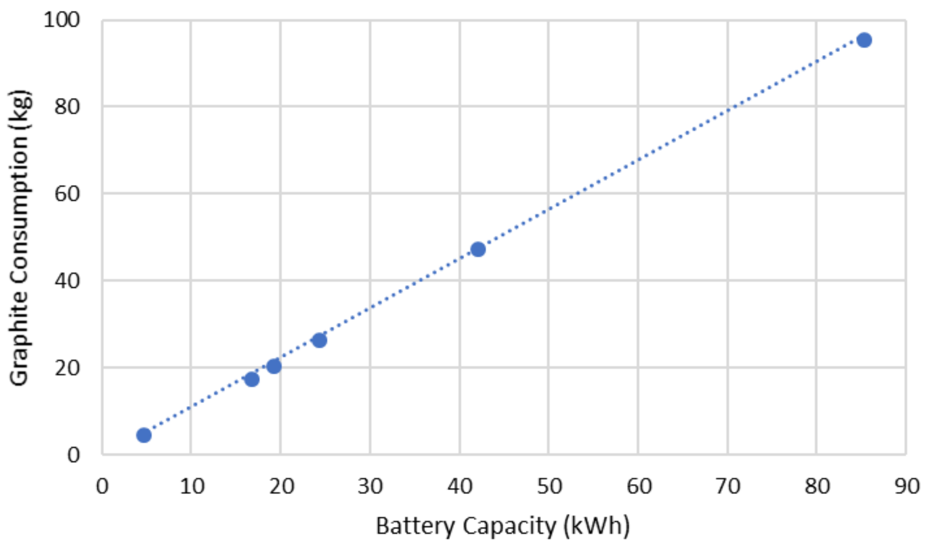
Graphite intensity for variable Lithium-ion battery technology (kg/kWh)



Source: How Stuff Works, Syrah Resources

The metal mass consumption per unit kWh is battery technology specific, with graphite dominating the breakdown of Nickel-Cobalt-Aluminium (NCA), Nickel-Manganese-Cobalt (NMC) and Lithium-Iron-Phosphate ("LFP") batteries. Typically, this can translate to ~55kg for a 50kWh EV battery.

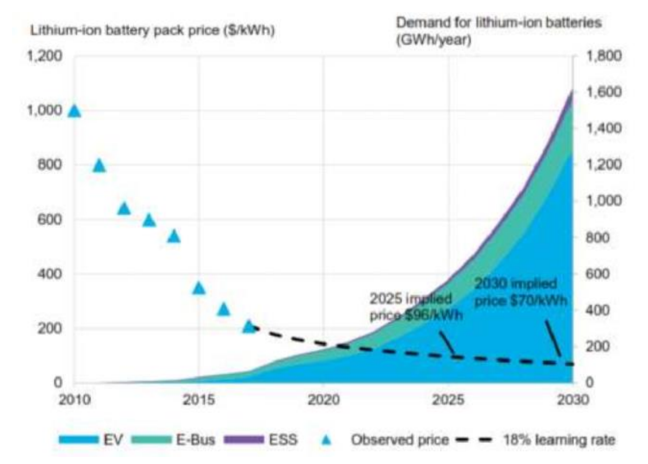
Electric Vehicle graphite consumption (Kg/kWh)



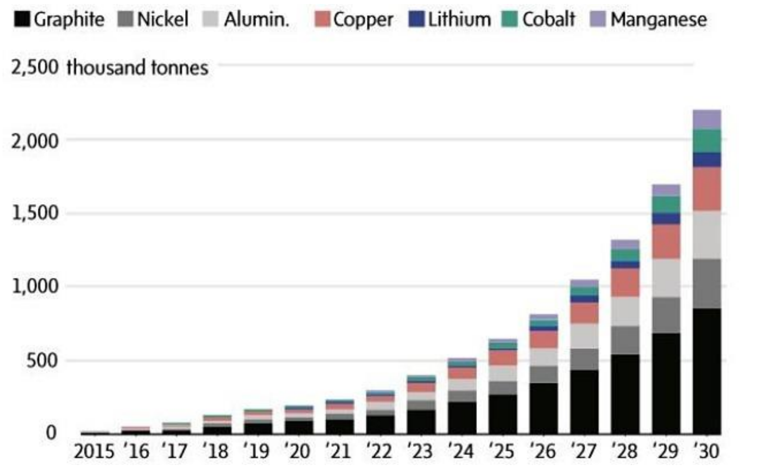
Source: Industrial Minerals Research Data (2014)

Whilst the growth of electric vehicle adoption remains in its infancy, it has huge implications for the automotive industry, traditional fuel demand, and battery metals. Falling LiB costs are drawing widespread application as all automotive companies announce a transition of models to hybrid, plug-in or all-electric vehicles, accelerating consumption requirements from ~60GWh in 2015 to ~1,600GWh by 2030 (*source:* Bloomberg New Energy Finance). For every million EVs, equivalent to 1.5% of global new vehicle sales, 100,000 tonnes of graphite is required (*source:* Northern Graphite).

Electric mobility is driving LiB global demand (2010-2030)



Consumption of metals in EV Li-ion batteries dominated by graphite (2015-2030). Battery demand will become the main driver influencing the graphite market

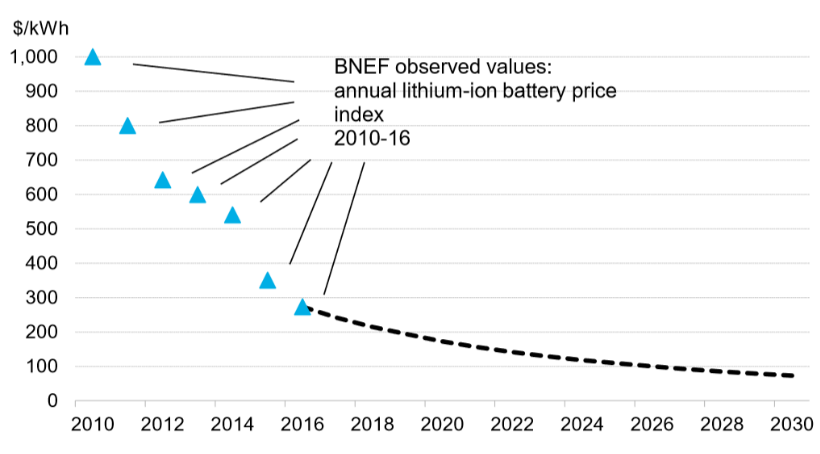


Source: Bloomberg New Energy Finance

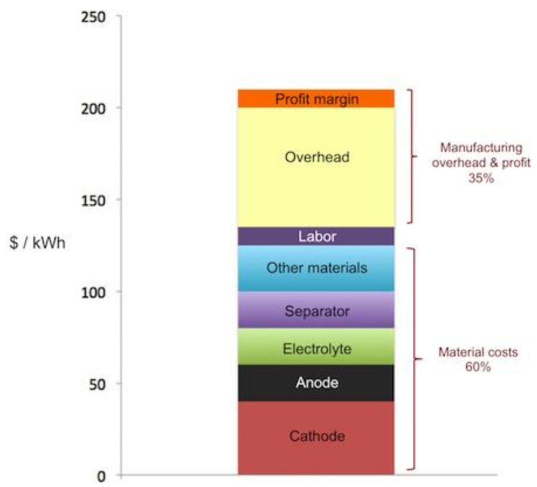
Projections for demand for electric vehicle lithium-ion batteries suggest the battery anode could devour as much as 691,875tpa by 2025, with the global industry absorbing more than 1.2mtpa of flake graphite (*source:* Benchmark); equivalent to 100% 2017 global supply.

Fundamental to forecast Li-ion battery growth are falling pack costs driving mass adoption. Bloomberg New Energy Finance Group observe that intense price competition is leading manufacturers to develop new chemistries in defense of variable raw material costs and reductions in production costs. The Group estimate producing a battery in a Korean manufacturing plant in 2017 costs ~$162/kWh, dropping to ~$74/kWh by 2030. Battery cost structure estimates material costs contribute an aggregate 60% total cost. While the intensity of graphite in Tesla's Model 3 is greater than lithium components, 72kg per vehicle compared to 48kg for lithium hydroxide (*source:* Benchmark Minerals Intelligence), anode costs are only associated with approximately 10% total (*source:* Qnovo).

Falling Li-ion battery pack costs ($/kWh)



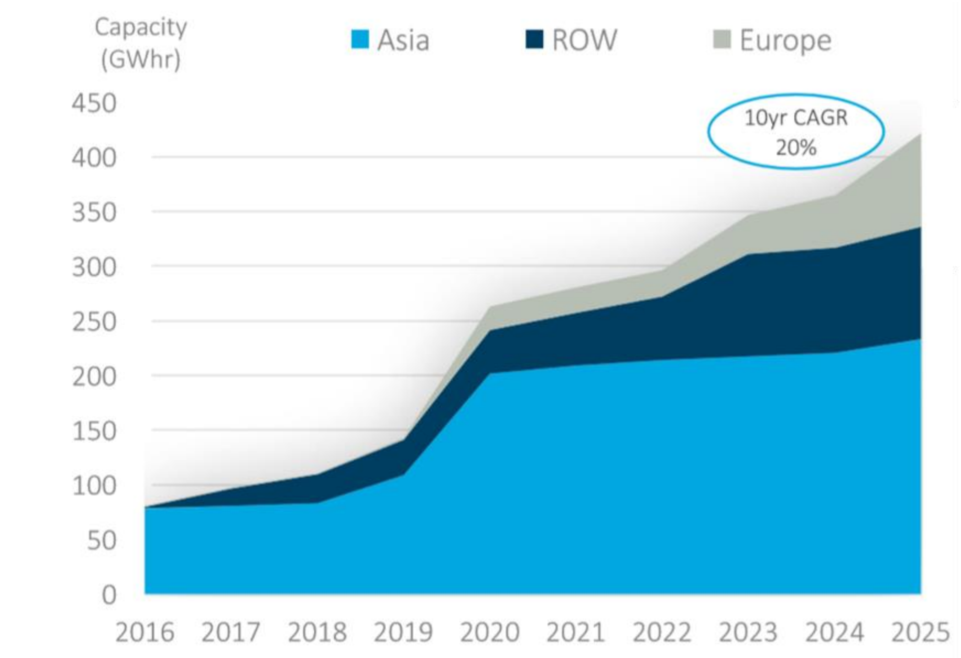
Li-ion battery cost breakdown



Source: Bloomberg New Energy Finance, Qnovo

To match expanding growth from the electric economy, global Li-ion cell production requires rapid acceleration forecast 20% CAGR. Manufacturing capacity from global battery gigafactories is set to more than quadruple from current levels of ~100GWh to ~420GWh in 2025 (*source:* Bloomberg). Asia are dominating the market, with production expected to total ~50% global by 2025.

Global lithium ion battery manufacturing capacity (GWh)

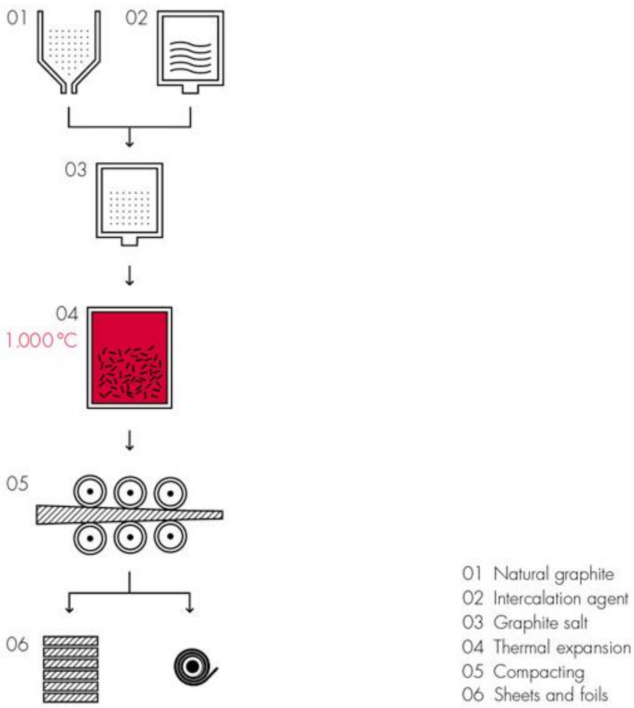


*Source: Bloomberg, Benchmark*2023, Avicienne, UBS*

Expandable graphite

One of the fastest growing markets alongside Li-ion batteries is expandable graphite, which is experiencing market tightness as a consequence of limited XL flake supply. Manufacture involves the treatment of XL flake graphite with dilute acid solution and rapidly applying heat to cause the flake to fracture. The resultant expanded 'intumescent' flake graphite can swell by a factor of 100x's in volume, lowering the bulk density and boosting surface area 10-fold (*source:* Asbury Carbons). The relationship suggests coarser flake graphite typically have higher expansion ratios than smaller flakes. The loose 'worms' of expanded graphite are subsequently compressed into foils and sheets without the use of any binder or filler.

Expanded graphite manufacturing sequence



Source: SGL Group

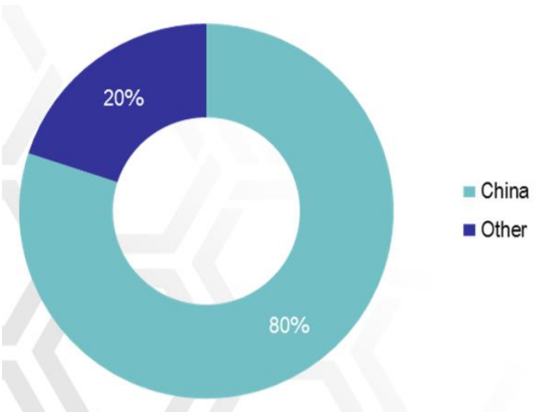
These pressed sheets are shaped and consumed in many applications including thermal management in consumer electronics, high end gaskets that are heat and corrosion resistant, fire retardants, smart building products, flow batteries and fuel cells (*source:* Northern Graphite).

Unique properties of expandable graphite include high-heat resistance, corrosion resistance, softness, compression resilience and radiation resistance (*source:* Graphex Mining). The product represents a specialist value-add product with premium expanded graphite foils consumed across electronic applications selling for up to US$50,000/t (*source:* Graphex Mining).

Improving building regulations in emerging economies, in particular China, are drawing higher consumption levels of expanded graphite. The market for flame retardant building materials is accelerating from a small, specialised sector, and could exceed battery applications. In the address at the 'graphite industry and graphite building materials conference' Group Vice President of China National Building Materials notes "*China needs 40 million tonnes of fire retardant building materials per annum, which will contain 5% expandable graphite"*. Updated legislation will require an equivalent to 2 million additional tonnes of expandable graphite to be drawn per year.

A global focus on flame retardants is driven in part by significant property damage and loss of life caused by large scale fires, most notably at the Tianjin Port, China in December 2015. Amendments to regulations mandate the use of flame retardant building materials in future construction for inner insulation and finishing exterior walls. Construction regulation review is underway across the globe following large-scale disasters, markedly London (Grenfell Tower), Dubai (Torch Tower) and Melbourne (Lacrosse Building).

China dominates global expanded graphite supply



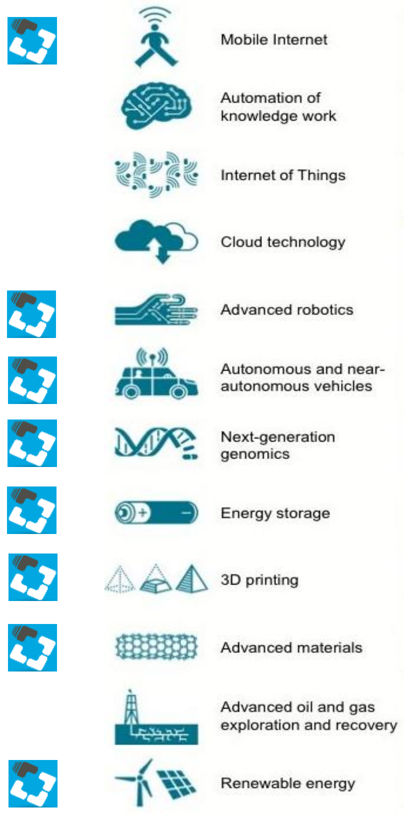
Flame retardant properties improves thermal efficiency

Source: Benchmark Minerals Intelligence, Graphex Mining

Growth in XL flake graphite supply needs to accelerate to match swelling demand, with aggregate 2017 natural flake production recording ~1mt. Graphex Mining highlight the current level of expandable graphite demand is more than 10x greater than existing natural graphite demand consumed by the Li-ion battery industry. The fire retardant market solely utilises more expensive coarse flake, giving significant value upside for global graphite projects with the preferential distribution towards XL flakes. Flame retardant polystyrene insulation foam supports heat retention and currently sells for ~US$2,625/t, indicating additional value capture from upgrading XL flake (*source:* Graphex Mining).

Benchmark Mineral Intelligence identify China as dominating supply, providing 80% of global output. However, diminishing coarse flake reserves across China is highlighting the crucial importance of developing projects outside of the Asian nation.

Disruptive technologies driven by material advances (*Talga symbol)*



Source: McKinsey Global Institute analysis, Talga Resources

Graphene

A rapidly emerging product derived from graphite is graphene. Rewarded with a Nobel Prize in Physics for pioneering work, researchers Prof. Andre Geim and Prof. Kostya Novoselov playfully isolated graphene during their "*Friday night experiments"* in 2004. The two-dimensional atomic layer of graphite displays properties favourable for innovative technology markets. Graphene is more robust than diamond, measuring the strongest discovered material equivalent to 40x gemstone strength. The material is also flexible, thin (1mm = 3 million sheets of graphene), lightweight, transparent and an excellent conductor of electricity, associated with electrical current density 10^6 greater than copper, and heat.

McKinsey Global Institute identified 12 potentially economically disruptive technologies, where advances will transform life, business and the global economy. Properties of graphite and graphene are expected to support at least 8 of these segments (indicated by Talga Resources symbol), giving robust outlook for consumption.

Properties encourage broad use with applications under investigation focusing on energy, electronics, high-strength bulk materials, carbon fibres, coatings, sensors and membranes for purifying water (*source:* Talga Resources). However, potential applications remain in the early development phase and due to high production costs and lack of scalability, have not yet been commercialised. China's Shandong Leadernano Tech was awarded the world's first graphene product certificate in July 2018. The award put the spotlight on the nations fast-growing market in the research and application of graphene. In 2017, 58% of the world's graphene patent applications were from China, according to a Ministry of Industry and Information Technology report. Growth across the future material markets is expected to accelerate as China lifts the limit on foreign investors' participation in graphite ore mining, providing a boon for the upstream graphene industry.

Graphene as a commercial product is typically marketed as either bulk powder or continuous thin film, with variable extraction methods targeting chemical vapour deposition (CVD), micromechanical exfoliation, epitaxial growth or carbon dioxide reduction. While no universal standards exist for graphene materials, classification can be defined on number of sheets:

Graphene definition and approximate offer price (2016)

	# sheets	Offer price (US$/kg)
- Graphene (monolayer)	1	~$750
- Few layer graphene (FLG)	2 - 5	~$100 - $250
- Multilayer graphene (MLG)	2 - 10	~$40 - $60
- Exfoliated graphite "graphene nanoplatelets" (GNP)	> 10	~$30 - $50

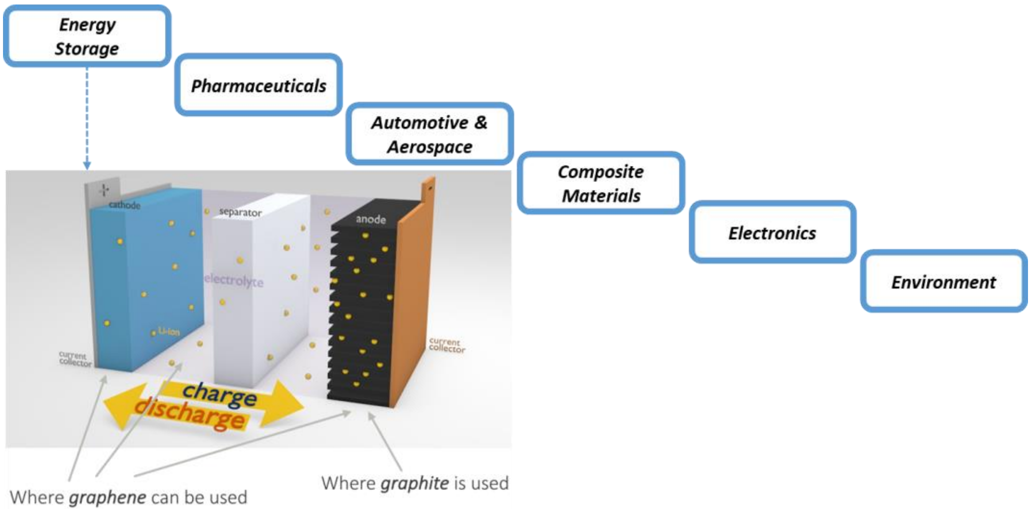
Source: Carbon Journal, fullerex

While nanomaterials broker Fullerex foresee the principal industrial segment as composites, consuming almost half bulk graphene market by 2024, the rapidly advancing electric economy is the major driver for the advanced material.

The addition of graphene in anode components can be utilised to double theoretical capacity to 740-780Ah/kg, compared to traditional natural or synthetic graphite. Combined to create a composite to overcome fundamental instabilities, graphene-phosphate based anodes can reach capacity of 1,400Ah/kg.

Gradually falling graphene costs, declining by approximately 8% per year to $165/kg by 2020 (*source:* Goldman Sachs), is leading to adoption by primary consumers of Lithium-iron-Phosphate (LFP) technology such as BYD and Guoxuan High-Tech. As a conductive additive, graphene LFP cathode demand could reach 164,400 tonnes by 2025 (*source:* Goldman Sachs).

Graphene end-market applications focused on lithium-battery sector



Source: Johnson Matthey

Further to LFP technologies, other next generation battery manufacturers are investigating preferential incorporation of graphene instead of graphite, including Samsung with their 'graphene coated silicon'. Cumulatively, the addressable market for graphene batteries by 2025 is forecast to rise to Rmb6.3bn (US$0.9bn) (*source:* Goldman Sachs).

The end-use market is receiving significant R&D funding, with the 'Graphene Flagship' initiative delivering Europe's biggest-ever research enterprise of €1 billion in a joint, coordinated research consortium. The group consists of over 150 academic and industrial research parties across 23 nations taking graphene from the realms of academic laboratories to market. In addition, the UK government are also funding £246 million into the '*Faraday Challenge*' initiative targeting superior battery technologies and promoting local supply chains.

Graphite applications

	Natural			Treated	Synthetic
	Amorphous	Vein	Flake	Expanded	
Refractories	+		+		+
Electrodes for electric arc furnaces	+		+		+
Carbon raisers in steel production	+	+	+		+
Construction (fillers, heat conductivity, heating systems, etc)			+	+	+
Batteries		+	+	+	+
Carbon brushes in automotives	+		+		+
Friction materials (brake linings, pads)	+		+		+
Lubricants	+	+	+	+	
Pencils	+		+		
Paint	+		+		
Graphite fibres, nanotubes & nanoparticles			+	+	+
Foil, seals, gaskets			+	+	
Electrical components, powder metallurgy, plastics & resins		+	+	+	+
Graphite grinding wheels		+			
Graphene			+		+
Catalysts	+		+		
Nuclear reactors			+		+

Source: SP Angel, Industrial Metals, Superior Graphite, Asbury Carbons

Graphene companies

Versarien plc (VRS LN) – this is an IP-led advanced engineering materials group that utilises proprietary technology to create innovative new engineering solutions. Versarien has been working with the WMG ("Warwick Manufacturing Group") and partner companies and scientists at the of Warwick and Cambridge to collaborate on the production of power storage devices such as batteries and supercapacitors using Versarien's proprietary Nanene graphene nano-platelets. The business was founded in 2011 and today has over 100 staff. Versarien recently received its first small initial order for Nanene product from a Chinese automotive battery manufacturer for technical evaluation. The company has number graphene businesses:

a) 2-D Tech – acquired from Manchester University in 2014, this business provides proprietary graphene powder using Versarien's patented production process. The company states that their product is very high quality: With 60% ≤5 layers and 90% ≤10 layers and 98% purity. In May 2018 Versarien announced that it was to collaborate with FTSE European manufacturer in examining formulations comprising existing polymeric packaging materials with graphene loading to assess the feasibility of these nanocomposites in packaging solutions. This to improve moisture performance, strength and to reduce weight. Versarien has also previously announced the sale of Nanene product for testing to be undertaken by a European tyre manufacturer. The company is working with E3D Online on trials to incorporate graphene into 3D printing.

b) Cambridge Graphene Limited – this Cambridge University spinout and in May 2017 Versarien, acquired a majority stake for £0.2m. The business recently launched Graphinks, a range of high performance, electrically conductive, graphene inks suitable for a wide range of printing processes, substrates and applications, including flexible electronics and antennas. The production process for Graphink was developed by the University of Cambridge.

The subsidiary also launched a partnership with the Flexibat consortium that has recently been awarded £1.2 million of grant funding from Innovate UK. Funding forms part of a £1.5 million project to develop and bring to market graphene enhanced, thin, flexible printed batteries for electronic wearable and IoT ("Internet of Things") devices.

c) Collaborative agreement with Zap&Go Ltd focuses on developing a new class of energy storage device incorporating Versarien's proprietary Nanene few layer graphene nano-platelets into Zap&Go's supercapacitor type devices. Research is targeting enhanced performance, specifically through increased electrical conductivity of supercapacitor cells.

Haydale Graphene Industries plc (HAYD LN) – was founded in 2010 and has developed a proprietary scalable plasma process to tailor nano-materials such as graphene. Haydale taking both mined organic fine powdered graphite and synthetically produced graphene and treats it with a plasma reactor process to improve material performance reducing impurities and improving quality. The company today has 11 reactors in 6 locations (UK, U.S. and Asia). The company has patents for its technology in Europe, USA, Australia, Japan and China.

Haydale is targeting markets such as conductive inks and coatings, polymer composites, sensors, battery and energy storage. Haydale has sold graphene into application including Graphene conductive adhesive to replace lead-based solder for aerospace; sensors in composites for real time defect sensing; and Gas Transition Piece (GTP) for National Grid UK. Haydale announced in June 2018 that it has been selected as one of the core Tier One partners of the University of Manchester's recently completed £60 million Graphene Engineering Innovation Centre.

Supply

Graphite Forms

Naturally forming carbon occurs in two polymer structures; graphite and diamonds. While sharing the same chemical composition, graphite is characterised with a two-dimensional, planar crystal structure whereas diamonds form three-dimensional lattices. In contrast to diamond, graphite is soft and malleable, greasy to the touch, and soils fingers and paper with colour ranging from grey to black.

The minerals form when carbon trapped in rocks become crystalline, with the distinctive hexagonal atomic array requiring intense pressure and temperature conditions. Geological formations are described as the highest grade of coal above anthracite, although it is an inappropriate form of fuel.

Natural graphite generally occurs as a consequence of the metamorphism (regional or thermal contact) of organic matter supported in sediment (*source:* British Geological Survey). As metamorphic grades increase, resulting from increasing temperature and pressure, carbonaceous material converts to 'amorphous' graphite. Graphite commonly occurs in one of three forms: microcrystalline or amorphous; crystalline lump or vein; and crystalline flake.

Characteristics differ between forms, summarised in the table below:

Natural graphite characteristics

	Amorphous	Vein	Flake
Description	Microcrystalline <70µm	Coarse crystals >4cm	Crystalline flakes: coarse >150µm; fine <150µm
Origin	Syngenetic: contact and/or regional metamorphism	Epigenetic: regional metamorphism	Syngenetic: regional metamorphism
Ore	Seams; folded and faulted	98%+ graphite; veins and fractures	5-30% graphite; strata-bound, tabular or lenses
Product grade	70-85% C	90-97% C	85-90% C
Major producers	China, North & South Korea, Austria	Sri Lanka	China, Brazil, India, Madagascar, Germany, Norway, Canada, Zimbabwe

Syngenetic – mineralogy forming at the same time as host rock

Epigenetic – mineralogy forming later than host rock

Source: Mineralogy and Petrology Group, British Geological Survey

1. **Amorphous (microcrystalline)** – formed of aggregates of fine graphite crystals which give the ore a soft, black, earthy appearance. Typically hosted by quartzites, phyllites and conglomerates, deposits are the least valuable and most abundant, supplying ~31% global graphite market. '*Amorphous*' gives reference to *'no visible crystallinity'* with particle size being finer than 40µm, which is similar to anthracite coal. In reality, all graphite is crystalline in structural formation, while the amorphous type is best described as microcrystalline or cryptocrystalline graphite. Amorphous graphite deposits occur in mineralised seams confined to a layer of strata. Typical deposit grades record 20-40%C. Elevated ash content also tends to be higher which complicates ore processing and impacts end-product purity. Commercial grades of economic amorphous graphite are between 70-85%C.

2. **Vein –** often called Sri Lankan or Ceylon graphite due to the unique commercial mineralogy from the island nation of Sri Lanka. Vein-type formations are found as interlocking aggregates of coarse and/or microcrystalline platy graphite. Mineralisation is restricted to veins and fissures results from the fluid-to-solid deposition process with graphitic carbon content of over 90%, with rare examples reaching 99.5%C. Vein thickness ranges from 1cm-2m, with grades declining from the high-purity core. Vein graphite production accounts for ~1% world output. The ore is easy to process, attracting the highest price of the natural depositions due to the wide number of applications. Commercial product purity typically ranges 90-95%C.

3. **Flake –** flat, plate-like crystals, ranging angular, rounded or irregular edges, disseminated throughout altered carbonaceous metasediments. Flake graphite deposits are typically strata bound, with individual beds or lenses ranging 30cm - >30m, while strike lengths may extend for kilometres. The British Geological Survey note ore bodies are normally tabular, occasionally lenticular, and occur locally as irregular bodies in the hinge zones of folds. Commercial deposits may host up to 90%C graphite, although 10-15%C is significantly more common. Flake ore bodies represent the most substantial deposit type, accounting for ~68% of the graphite market. Flake size is highly variable across deposits, with the range impacting the economic viability of formations.

While the market remains dominated with natural graphite supply, advances in synthetic manufacture methods are enhancing market capture. The man-made product typically formed either as electrographite or manufactured by the high-temperature treatment of amorphous carbon-bearing substances with primary feedstock including calcinated petroleum coke, coal tar pitch, or natural and synthetic organic materials containing carbon.

Heat treatment of around 2,300-3,000°C provides the mobility needed by carbon atoms to rearrange from an amorphous structure to a crystalline graphite lattice. Multi-stage processing of by-product material yields an upgraded product with hundreds of industrial applications.

Typical synthetic graphite has exceptional electrical and thermal conductivity with >99%C purity. While the product is associated with higher production costs, ranging double-triple standard pricing compared to its natural form, the material can be tailored to requirements for highly specialised end-market industries. In general, synthetic graphite is available in two basic forms:

1. **Electrodes (99.9% C) –** primarily created using the highest quality petroleum coke particles as a precursor. Electrode form products are almost exclusively utilised in metallurgical applications as a source of energy for melting steel and iron in an electric-arc furnace, refining certain types of ceramic materials, manufacturing chemicals and functions requiring a high-temperature, clean energy source. Electrode specifications are stringent, requiring high conductivity and contamination-free.

   Primary synthetic refers to graphite manufacture of granular powder utilising electrode processing. The special, high-cost hybrid form of synthetic graphite requires precise precursor material, specialised heat treating and milling to create specific shape product with precise properties including density. The product competes against natural flake graphite for high-end battery manufacturers for consistent and high-purity anode material.

2. **Graphite blocks (99.9% C) –** also known as 'isotropic graphite', graphite blocks offer differing micro particle structure, relying on isotropic-type coke and created through the cold isostatic pressing ("CIP") of micro particles. Graphite blocks overcome anisotropic properties of conventional graphite, with no differences in cross sectional direction properties. The highly reliable product is utilised in the semi-conductor industry, energy storage and the atomic power sector.

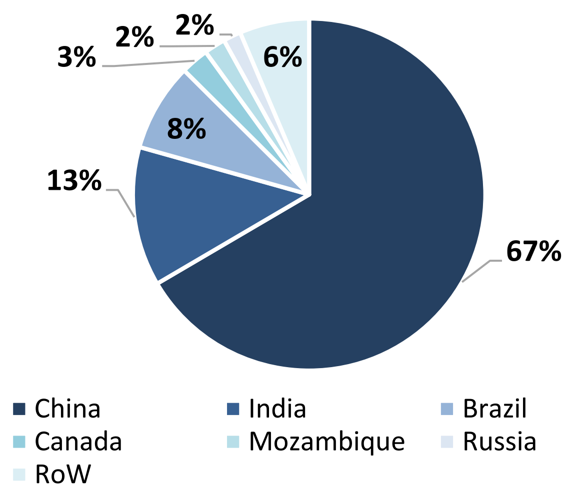
Secondary synthetic graphite represents a by-product yielded as a powder with marginally reduced purity (~99.6% C) (*source*: Reade) forming via machining. It is considered a lower cost product, with quality comparable to that of natural graphite, thereby competing in applications like brake linings, lubricants and carbon brush.

Global supply

Global mine production advanced 4.3% from 1.15 million tonnes in 2016 to 1.2 million tonnes in 2017 (*source:* USGS), with significant growth of output driven by new production across Africa and Canada.

Segmentation of production shows approximately 70% of supply is amorphous graphite and 30% flake. The Asian nation has minor large flake product, principally in the +200 mesh range, and is therefore dependent on ex-China supply for coarser natural graphite (*source:* USGS).

Global mine production 1.2 Mt (2017)



Evolving global graphite rounded production (2016-2017)

	2016	2017	Growth (Kt)	%
China	780	780		67%
India	149	150	+1	13%
Brazil	95	95		8%
Canada	30	30		3%
Mozambique	0	23	+23	2%
Russia	19	19		2%
RoW	76	75	-1	6%
Mine Supply, Kt	**1,150**	**1,200**	**+50**	

Source: United States Geological Society

Worldwide production recorded modest increases in output, as greenfield projects in Mozambique and Tanzania came online and began production. In particular 23,000 tonnes of new material was sourced from Mozambique, originating from two new main graphite players; Syrah Resources and Triton Minerals. This growth more than offsets decreasing output in Madagascar.

During 2017, China continued to dominate the market with production levels approximately 67% of the global graphite market. The long-standing market control stems from the 1990's where the Asian nation depressed prices to impede Western mining. Sustained oversupply applied significant downward pressure and put the competition out of business.

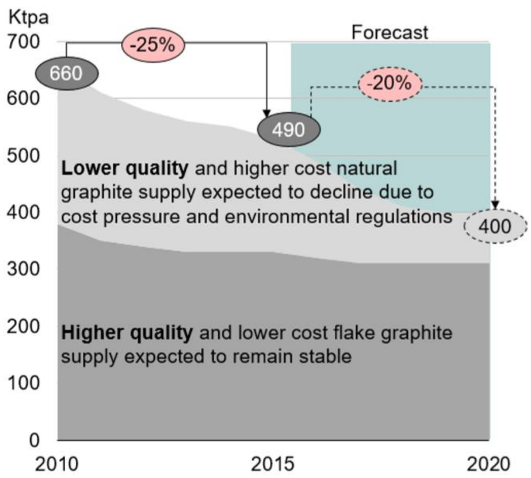
China pollution

China's government is waging a war on pollution, establishing a Ministry of Ecological Environment responsible for the compiling and implementation of policies, plans and standards, as well as ecological environment monitoring and law enforcement. The graphite processing sector is associated with air-quality and wastewater issues, with the nation announcing a crack-down on polluting flake graphite operations and consolidation of mines to 25 operations by 2020 in the dominant region of Heilongjiang. The Ministry is looking to establish great control over area mining rights and limit illegal operations.

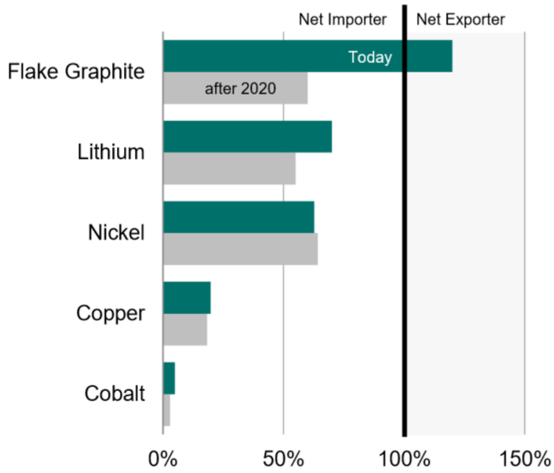
The Chinese government also introduced an Environmental Protection Law at the close of 2016 to tax producers that flout environmental measures; which came into effect in January 2018. The government is also conducting multiple rounds of inspections in the major producing province including Shandong. In an effort to curb pollution, inspectors reduced the supply of needle coke, a key feedstock material used for manufacturing graphite electrodes.

The cumulative impact of heightened environmental protection efforts is expected to apply downward pressure on future production figures from the Asian nation. In addition, domestic resource depletion is forecast to drive market flow from net exporters to net importers by 2020 (*source:* Syrah Resources). Long-term impacts on Chinese production will likely put pressure on global flake supply, increasing the reliance on ex-China output. China's switch from an exporter to importer of natural graphite will permanently and structurally alter the market dynamics.

China's declining domestic supply due to resource depletion and environmental preservation



China's transition to net importer of graphite places greater emphasis on investment and development of resources outside the Asian nation



Source: Syrah Resources, CRU, Metal Bulletin

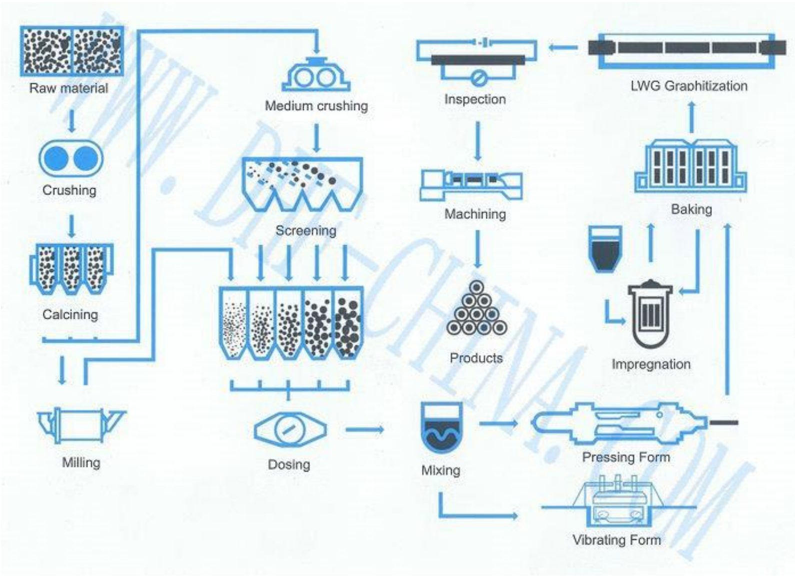
Mining and producing

Graphite mining operations are variable on ore mineralisation. Flake and amorphous graphite projects target open pit and underground methods depending on deposit geometry, while high-grade lump/vein graphite is exclusively mined using underground methods in Sri Lanka.

Key variables impacting processing methodology are grade, flake size and distribution, recoveries, and purity of graphite prior to chemical and thermal treatment.

Graphite processing initially involves primary crushing, grinding and beneficiation through multiple stages of froth floatation. Thermal treatment and acid leaching may be used to raise the carbon grade for industry and battery applications.

Example graphite electrode processing workflow



Source: DHF Ming Xiang

Preservation of flake sizes is fundamental to maintaining the most valuable ‘jumbo’ flakes, relying on maximizing the purity and minimising damage to the flake. Impurities in the graphite flake arise from two areas. The first is “mechanically” attached particles in the form of mineral grains stuck or “cold welded” to the surface of the flake. Floatation and milling is used to reduce these types of mineral impurities. The second form comes in an “intercalated” form. “Intercalated” means impurities like ash are located in “parting layers” between stacks of adjacent graphene layers. This ash cannot be removed by milling and floatation and, instead, chemical and thermal treating is used. The extent of ash “intercalation” varies across deposits. Typically, flake graphite is 85-90%C (balance 10-15% ash) in Madagascar, 90-97%C in Canada, and 90-96%C in China.

Excessive processing is expected to raise ore recoveries and purity of the concentrate but would reduce the graphite flake size and diminish the value of the final product. Crushing and grinding of ore and milling of the concentrate could potentially ‘grind’ the flakes.

Three primary commercial flake graphite sieve sizes preparing for additional grinding and processing are; -100 mesh, +100 mesh, and +50 mesh. This material may then be used as feed for production of different sizes material, from +32 mesh coarse flake to finely grind (3µm) powder.

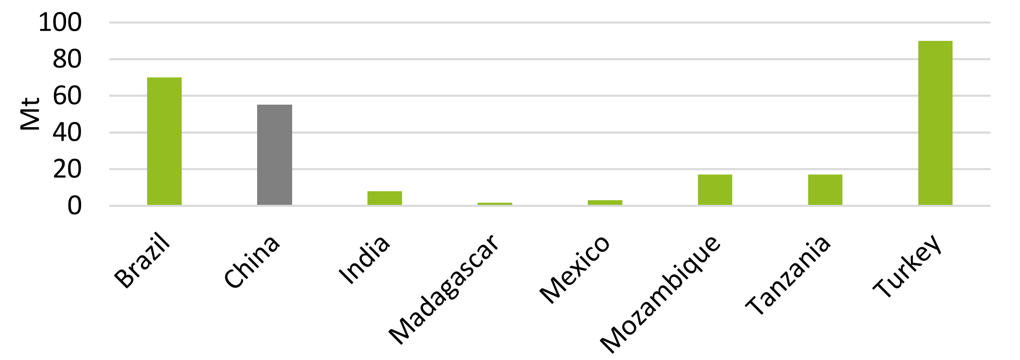
Subsequent purification of graphite adds to processing costs, with larger flakes (improved average carbon content) requiring less treatment to obtain material above 97%C. Lower carbon content amorphous and flake graphite is cheaper and offers reduced profit margins for ex-China producers that find strong competition from lower-cost operations in China. Producers of large flake graphite are set to perform better in the environment of depressed prices should China manipulate global availability.

The graphite industry is associated with minimal recycling, the abundance of available graphite inhibits increasing recycling efforts. Current efforts target refractory brick and linings, alumina-graphite refractories for continuous metal castings, magnesia-graphite refractory brick for basic oxygen and electric arc furnaces, and insulation brick.

Graphite producers

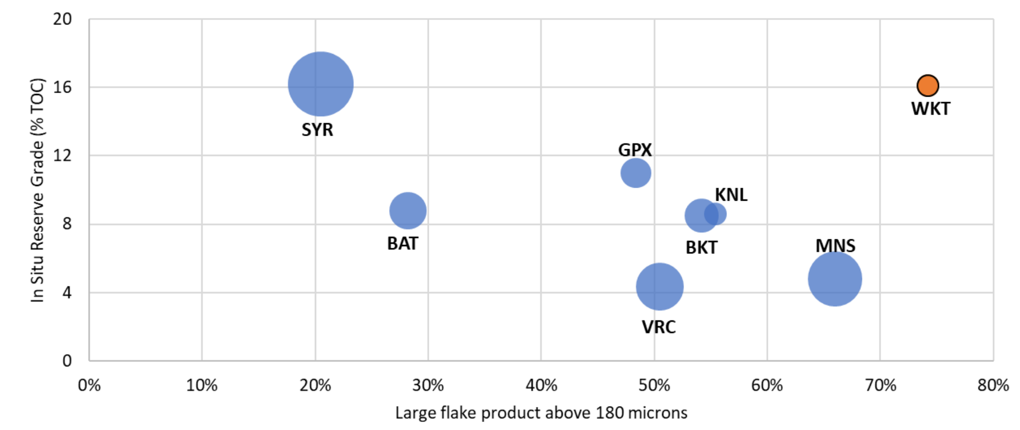
Designation to 'critical mineral' status and positive price momentum since 2005 has drawn substantial Western exploration and development of projects for fundamental future supply. Ex-China reserves equate to approximately 207 million tonnes recoverable graphite (262 million tonnes including China) (*source:* USGS). Major graphite provinces are Turkey and Brazil, however principal new deposits that are being developed focus on Africa, with companies targeting Madagascar, Mozambique, and Tanzania. There is also major exploration effort into Canadian graphite.

Worldwide graphite reserves (2017)



Source: United States Geological Survey

Africa-focused reserve grade and flake-size distribution



Source: Walkabout Resources (N.B. planned annual production targets reflected by the size of the bubble)

Madagascar

Bass Metals (BSM AU) – the acquired Graphmada large-flake graphite mine is currently undergoing optimisation work to improve cost-efficiency. Bought from Stratmin Global Resources in 2016, Bass Metals aim to ramp up annual production to 20,000 tonnes by 2019. The company is advancing its flagship project, while developing Lahorno and trial mining began at Mahefedok in January 2016.

NextSource Materials (NEXT.TO) (formerly Energizer Resources) - the Molo graphite project is one of the highest-grade flake deposits containing 22.44Mt ore at 7.02%C. NextSource are targeting commissioning and production in 2018, following an updated feasibility study detailing a fully modular, two-phased build methodology dramatically reducing CAPEX.

Mozambique

Syrah Resources (SYR AU) – Syrah Resources is advancing its Balama graphite project, hosting the largest graphite ore reserves in the world at 81.4Mt at 16.2% C. All major construction works were completed by November 2017, with remaining commissioning activities targeting the fines circuit and further optimisation. Syrah is aiming to produce 160,000-180,000 tonnes in 2018 and 250,000-300,000 tonnes in

2019 of graphite concentrate. Cruising altitude capacity targets 350,000 tonnes per annum graphite concentrate over the first 10 years of operation, accounting for 29% of 2017 global supply market.

Triton Minerals (TON AU) – through 80% majority interest in holding company Grafex Limitada, Triton holds six granted exploration licenses in Mozambique. The company's key focus is the Ancuabe project due to its recognised flake size distribution of jumbo and super jumbo graphite. In July 2017, Triton raised A$1.23 million via a strategic placement with Shandong Tianye Mining, its largest shareholder. The funding was utilised to produce the maiden Ore Reserve and Definitive Feasibility Study ("DFS") in December 2017. The 24.9Mt reserve at 6.2%C targets 60,000 tpa graphite concentrate.

Battery Minerals Limited (BAT AU) – diversified minerals exploration focusing on two graphite development assets, Montepuez and Balama, expected to come into production in late 2018 and 2021 respectively. Battery Minerals obtained US$30 million debt & equity funding for construction at Montepuez, with stage 1 producing ~50,000 tpa.

Tanzania

Kibaran Resources (KNL AU) – Kibaran Resources Limited's primary focus is to fast-track the Epanko graphite project into development, targeting 60,000 tpa from the 10.9Mt ore reserve at 8.6%C. The company is also progressing the 17.7Mt resource Merelani-Arusha and Tanga graphite projects, also in Tanzania.

Magnis Resources (MNS AU) – Australian-based company aiming for end-to-end supply chain in sourcing raw materials for integrated lithium-ion battery cell manufacture. Magnis are also developing the Nachu Graphite Project with high distribution toward natural flake graphite in the super jumbo, jumbo and large range. The 2016 Bankable Feasibility Study highlights 240,000 tpa nameplate concentrate capacity from Ore Reserves of 76Mt at 4.8%C.

Volt Resources (VRC AU) (formerly Mozambi Resources) - Volt are focused on the exploration of its wholly owned Bunyu graphite project, targeting 12-15 months to complete Stage 1 development. Their PFS study shows the company plans to develop 170,000 tpa graphite concentrate from the maiden JORC Reserves of 127Mt at 4.4%C.

Canada

Northern Graphite (CVE:NGC) – 100% interest in Bissett Creek deposit, aiming for commercial production from 28.3Mt Mineral Reserves by 2020. Almost 90% of production will consist of large and extra-large flake and battery grade graphite. The company is undergoing metallurgical testing investigating the potential to reduce capital and operating costs.

Focus Graphite (FMS:CN) – portfolio of 14 properties, with its flagship Lac Knife project focusing on Mineral Reserves of 7.9Mt at 15%C. The company have been targeting exploration, with a resource updated in Jan. 2017 increasing Measured and Indicated resources by 26%. The company is advancing development of a value-add industrial transformation plant which looks to further refine and optimise spherical and expanded graphite production. The process aims to produce 99.98%C using Continuous Thermal Purification.

Mason Graphite (TSXV:LLG) – 100% owned Lac Guéret property located in northeastern Quebec targeting 4.7Mt Mineral Reserves grading at 27.8%C, with 'in-pit' Mineral Resources beyond the project life of 25 years of 58.1Mt grading 16.3%C. Mason has received its main environmental permit and continues optimization work to achieve near-term production.

*Walkabout Resources

Stock Data

Ticker	WKT AU
Share Price:	A$0.13
Market Cap:	A$34.9m
	£19.6m

Price Chart

African focused energy minerals developer progressing its Lindi Jumbo Graphite project. The updated August 2017 DFS confirms highest Ore Reserve grade in Tanzania at 16.1% C. A resource upgrade drilling and trenching programme has commenced targeting a shallow 'ultra-high grade' portion of the Mineral Resource and conversion from Inferred to Indicated and/or Measured Resource Status. Exceptional flake distribution above 180µm in concentrate above 95% C delivers a higher weighted average basket price of $1,534/t.

- The company declare a 5Mt Reserve based on only 42% of the Measured and Indicated portion of the Mineral Resource, with plans to develop 40,000 tpa graphite concentrate with a high-grade feed to the plant of <300,000 tpa.
- The current Resource will support 20 years of production, the project can be expanded through upgrading of the Inferred Resource and treatment of the lower grade stockpiles (<16%C).
- Extensive metallurgical testwork indicates the Lindi Jumbo project concentrate contains 85% flake distribution above large 180µm, incorporating 25% super jumbo 500µm.
- The revenue associated with production of flake product large or higher rises over 85%. The company has achieved 75% HoA and MOU offtake for its 'Lindi Jumbo Premium Flake'.
- Further value can be achieved from expandable graphite and graphite foil manufacture, with expansion ratios up to 590cm^3/g; almost double Chinese averages of 250 cm3/g.
- Expanded graphite targets halogen-free intumescent flame-retardant materials for automotive, industry, construction, plastics, isolation etc. The non-polluting, low cost product reduces fume formation
- Flame retardant industry is expected to swell, as China and developing economies amend building regulations to incorporate compulsory standards in construction.

*Talga Resources

Stock Data

Ticker	TLG AU
Share Price:	A$0.13
Market Cap:	A$34.9m
	£19.6m

Price Chart

Vertically integrated technology minerals company with its own carbon sourced from multiple high-grade graphite projects in northern Sweden. The flagship 'Vittangi' graphite ore offers unique properties containing 25.5%C, allowing graphite and graphene to be liberated without crushing utilising exfoliation processing technology. While Talga are advancing manufacture in the exfoliation platform 1, partnerships with academic and industrial research groups target commercialisation pathways for graphene enhanced products.

- Currently offer ~30tpa ore capacity from Rudolstadt test plant in Germany for downstream products, with focus on 1,000-7,000tpa graphene base case.
- Innovative programs testing Talga micrographite and graphene in Li-ion anodes at leading global independent facility WMG, part of the University of Warwick's Energy Innovation Centre. Focusing on growing $24bn battery market.
- Battery scale-up pilot line incorporating battery characterisation laboratory, aggressive-testing changers and an electric/hybrid drive test facility.
- Talga forecast market potential as significant for graphene products. The construction sector is near-medium term target, currently estimated at $17bn, just for speciality metals.
- The Coatings sector is US$22bn, just for corrosion protection, and Talga's graphene provides an eco-friendly alternative to chromium-based coatings.
- The Carbon, Composites and Resins market is currently US$18bn and Talga product testing indicates enhancements to create stronger, lighter, more conductive products.
- The company is collaborating with industry leading partners including Heidelberg Cement, Netzwerk NanoCarbon, Jena Batteries, Chemetall, Cfaed, Zinergy, Haydale and the Cambridge Graphene Centre.

*SP Angel corporate clients with graphite assets

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