



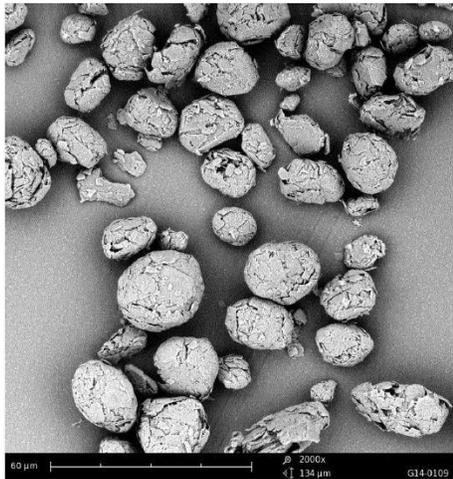
ABOUT SPHERICAL GRAPHITE (“SPG”)



Spherical graphite is manufactured from flake graphite concentrates produced by graphite mines and is the battery anode material (“BAM”) used in lithium ion batteries (“LiBs”). The first part of the process consists of micronizing, rounding and purifying flake graphite to produce uncoated (“uSPG”).

**XL/XXL flake graphite concentrate
(95%C purity)**

Micronizing involves reducing the flakes in size to approximately 10 to 15 microns. A human hair is about 70 microns in diameter. This is done in a step by step process as the flakes move through a cascading series of jet mills. They are crushed by impact, collision, friction and shearing using a high speed rotating plate and classified to separate the target size range which then goes into the next mill.



Once the final target size has been achieved, the micronized graphite is then “rounded” which essentially involves rolling the flakes up like a snowball in similar mills (with different “beaters” on the plates), again using a cascading, step by step approach. SPG has been described as a “clenched fist” or a “cabbage” like structure. The final size varies between 5 and 20 microns depending on the application. The round shape is necessary for the spheres to be spread thinly and uniformly during the high speed LiB manufacturing process. The round shape also results in better packing, i.e. a higher density in the battery, more active sites for the lithium to intercalate into the graphite (better rate capacity) and a longer life. For these reasons, micronized, “unrounded flakes” are not used in batteries.

(uncoated spherical graphite)



ACM grinding plate, sharp edge beaters are used for size reduction, round edges for spheronizing

A plant can consist of 15 to 20 mills in series. The process does not scale well so higher production means more mills, not bigger mills. The cost of micronizing and rounding is about US\$1,000/t. It is essentially electricity and wear parts as it is not labor intensive. Micronizing and rounding are not high technology. They are done using milling systems which can essentially be bought off the shelf in China. There are suppliers outside of China but they are more expensive.

A Chinese SPG Plant



Due to losses during the micronizing and rounding stages, three tonnes of flake graphite concentrate are required to produce one tonne of SPG and this represents a major cost. The waste is essentially powder and dust which has little value. Industry yields have improved to 40 per cent or more and Northern and some other companies have reported yields in excess of 50 per cent. Small flake graphite (less than 100 mesh) is used to make SPG because it is cheap and readily available. Medium and large flake can also be used but prices for these grades are higher and it does not make economic sense to turn them into SPG. Small flake graphite currently sells for approximately \$500/t in China so raw material costs to produce one tonne of SPG are \$1,250 based on a 40 per cent yield.

Most flake graphite can probably be made into SPG but that does not mean it would be commercially used. Some concentrates are better than others. Concentrates with low bulk density translate into a battery with lower energy density and are not preferred. Also, concentrates with a high percentage of fines will result in a low yield of SPG.

Micronized and rounded material is then purified from approximately 94%Cg to 99.95%Cg using hydrofluoric and sulphuric acid as impurities affect battery performance. (Cg means carbon in graphitic form as opposed to carbon atoms which are tied up in the molecular structure of other minerals). Wet chemical purification is a low cost process in China, approximately US\$300/t. However, large quantities of water are required to rinse the graphite and the costs of neutralizing agents and proper environmental and health and safety practices with respect to handling HF can increase costs to US\$1,000/t. This is one of the reasons almost all uSPG is produced in China.

The HF process can be used in the west but HF is a very nasty substance and the costs are substantially higher. This has led many companies to look for alternative purification methods which usually involve high temperature thermal treatment, chlorine, alkaline reagents or some combination of them. A number of junior graphite companies have announced purification processes but it

remains to be seen whether any of them have real solutions that can match the low capital and operating costs of the Chinese. This is a big issue with respect to developing a competitive SPG supply in the west. It also highlights that green electric vehicles have a component in their batteries which may not be so green.

Not only does SPG have to be 99.95 per cent pure but there are strict requirements with respect to the remaining impurities, i.e. less than 50 ppm Fe or S and almost no metallic elements. Most, but probably not all, graphite concentrates can achieve these specifications but it is a function of cost. The Chinese demand a starting purity of 94% Cg, or better yet 95% Cg, and it must be cost efficient to get to 99.95% Cg. A number of junior graphite companies will produce at least some concentrates which are less than 94 per cent Cg and therefore not suitable, at least by Chinese standards.

The cost of producing uSPG in China is therefore about US\$2,500/t plus various taxes, depreciation, transportation and other costs. The selling price is approximately US\$3,000/t making it a low margin business despite inexpensive raw material costs, low labour rates and weak environmental regulations. uSPG is essentially a commodity that is sold to battery anode material manufacturers. Producing it would be the first step for any junior graphite developer wanting to enter this market. Almost all is currently manufactured in China and there is excess capacity. However, it is likely that the substantial projected growth in EV demand will lead to higher prices which are needed to build capacity in the west. The challenges are a purification technology and cost competitiveness with the Chinese. All car manufacturers want to be green but they are phobic about cost control and are not willing to pay a premium to achieve it.

Coating is the next step in producing BAM. For common batteries used in small devices the spheres are coated with a thin layer of pitch or asphalt and baked at over 1,200°C. This covers the uSPG with a hard carbon shell that protects the sphere from exfoliation and degradation during expansion and contraction with charging and discharging. It also inhibits the ongoing reaction of the electrolyte with the active graphite inside the sphere itself. Both of these processes reduce battery capacity and life. This type of coating adds about \$1,000 to the cost and selling prices are in the range of US\$4,000 to \$6,000/tonne for coated SPG or “cSPG”.

Anode material made with natural graphite has a higher capacity and is less expensive than synthetic graphite. As a result, natural graphite has been largely used in small devices which helped fuel the substantial growth in the three C market, cell phones, cameras and computers. However, the cycle life of natural graphite is lower than synthetic. If your cell phone battery only has 50 or 60 per cent of its original capacity after three or four years you don't care much because you will be buying the latest offering from Samsung or Apple. However, a Tesla has to have 80 per cent of its battery capacity after eight years. The value of the car is in the battery. This has lead BAM manufacturers to seek ways to increase the cycle life of natural graphite. There are three.

The first is using a CVD coating process. The second is subjecting the SPG to very high temperature heat treatment, essentially “re-graphitizing” the graphite and mimicking the synthetic graphite manufacturing process. This repairs defects in the graphite crystal structure which is where breakdowns occur during charge and discharge cycles. Heat treatment is \$2,500-3,000/t and is the largest single cost in producing BAM. The third is blending natural and synthetic graphite to take advantage of the strengths of each.

Three companies (LG, Hitachi and Samsung, and its partner BTR) have developed the technology to control expansion and extend the cycle life of natural cSPG using these processes and the result is longer life, high capacity EV batteries. The recipes are a closely guarded secret but it is generally believed that their EV batteries are 40 to 60% natural graphite and that the ratio will increase because natural graphite is cheaper, higher capacity and works better with Si. (advanced EV batteries are being doped with small amounts of Si which has a much higher storage capacity than graphite. However, Si experiences very large volume changes on charge/discharge which breaks down the anode faster, particularly with synthetic graphite, severely limiting the amount that can be used). Also, at some point the Chinese will develop or “borrow” the technology to blend and will switch from using mainly synthetic graphite in EV batteries to using a blend.

cSPG prices charged by these companies are US\$8,000-\$12,000 per tonne which reflects the cost and complexity of the process and the value of their IP. This IP is a barrier to any junior graphite companies that want to develop cSPG for the EV market. A second is that the cSPG then has to go through a rigorous and extensive, multi year qualification process to actually be used in batteries. The quality and safety of their batteries are paramount and it will be a long time before a Tesla would buy cSPG directly from a small graphite producer.

The Chinese micronize, round and purify graphite to produce uSPG. The graphite has to have a good yield on rounding, be economical to purify, not contain any deleterious impurities and meet other technical specifications. **Not all graphite mines produce suitable concentrates!** Chinese uSPG is then sold to companies like Hitachi which does the heat treatment, coating and blending and is responsible for product consistency and quality. Hitachi sells BAM to Tesla and Panasonic who make LiBs and EVs. That is the supply chain junior graphite “wannabies” have to break into.