ABOUT SPHERICAL GRAPHITE ("SPG")

Spherical graphite is manufactured from flake graphite concentrates produced by graphite mines and is the anode material used in lithium ion batteries ("LiBs"). SPG can be sold as either a coated ("cSPG") or uncoated ("uSPG") product. Uncoated SPG is made by micronizing, rounding and purifying flake graphite. Almost all natural, uSPG is currently manufactured in China due to low costs and weak environmental regulations. It is essentially a commodity which sells for approximately US$3,000 per tonne. There is substantial excess capacity in China and margins are very low despite inexpensive raw material costs, low labour rates and their weak environmental regulations. However, LiB growth projections could lead to substantially higher prices.

Historically, three tonnes of flake graphite concentrate were required to produce one tonne of uSPG due to losses during the initial micronizing and rounding stages and this represents the major cost. Industry yields have improved to 40-50% and Northern and some other companies have reported yields in excess of 50 per cent. Generally, the larger the flake size the higher the yield.

Flake graphite between 100 and 150 mesh in size ("small flake") 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 at current prices. Flake concentrates smaller than 150 mesh in size are generally not used because yields decline and purification becomes more difficult.

The flakes must be reduced in size to about 40 microns, and rounded which essentially involves rolling them up like a snowball. They have also been described as a "clenched fist" or a "cabbage" structure. The final size varies between 5 and 20 microns depending on the application. A human hair is about 45 microns. The round shape is necessary for them to be spread thinly and uniformly during the high speed manufacturing process. The round shape also results in a higher density in the battery, better rate capacity and longer life. For these reasons, micronized, "unrounded flakes" are not used in batteries.

The micronized and rounded material is then purified from approximately 94%C to 99.95%C using hydrofluoric and sulphuric acid as impurities affect battery performance. On its own, wet chemical purification is a low cost process but large quantities of fresh water are required to rinse the graphite. Costs increase if neutralizing agents are added and proper environmental and health and safety practices are followed. This is one of the reasons almost all uSPG is produced in China. It will be very difficult and challenging to use HF in the west and companies planning on manufacturing SPG must have an alternative.

Thermal purification can be used but it is very expensive and air emissions are a problem. Northern has developed a proprietary hybrid purification process that does not involve the use of strong acids. Northern's flake concentrate has a highly ordered, pristine crystal structure without large quartz grain impurities which are difficult to remove. The process will probably not work on graphite concentrate from all deposits.

Coating is the final stage in producing SPG. It is not one simple step. cSPG for common batteries in small devices is made by coating the spheres with a pitch or asphalt substance and baking it at over 1,200^{O}C. The coating is essentially a hard carbon shell which protects the sphere from exfoliation and inhibits the ongoing reaction of the electrolyte with the graphite which reduces battery capacity and life. A number of Chinese, Japanese and Korean companies produce cSPG and prices are in the range of US$4,000 to $6,000/tonne.

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 accounts for the substantial growth in battery demand. However, synthetic graphite has better rate capability and better cycle life. Because battery life is much more important in an EV than it is in a cell phone for example, EV batteries have been made from synthetic graphite which costs from $10,000 to $20,000/t. More recently, three companies (LG, Hitachi and Samsung) have developed the technology to control expansion and extend the cycle life of natural cSPG to meet the rigid requirements of the EV market. This has enabled them to blend natural and synthetic graphite to take advantage of the strengths of each and to manufacture lower cost, long 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 as natural cSPG manufacturing processes improve. cSPG prices from 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.

Many other companies with substantial resources and experience are attempting to duplicate their results, so far without success. Eventually, this technology will become a commodity but at present, it represents a significant barrier to junior graphite companies that wish to enter the cSPG EV market.

Companies wishing to sell cSPG to the EV market must also go through a rigorous and extensive qualification process to actually have their product used in batteries. The suitability of flake concentrates for use in making SPG, and the various processes for making SPG, are first tested in coin cells which are a relatively quick and inexpensive means of evaluating their performance. However, coin cells are inadequate to fully qualify a new material with a battery company. Full qualification requires extensive life and durability testing in real LiBs (such as 18650 cells or pouch cells), including industry standard calendar and cycle life testing and standard lot-to-lot quality control and process control analysis. Such testing procedures are well documented and are available at the USCAR website: (http://www.uscar.org/guest/article_view.php?articles_id=86). No junior graphite company has yet reached this stage.

Coin cells provide basic information on battery capacity, first cycle efficiency and cell life. The theoretical maximum capacity for natural graphite is 372mAh/g. However, there is a loss of capacity on the first charge/discharge cycle ("irreversible capacity" loss) which is a necessary thing. It is caused by the formation of a solid electrolyte interface ("SEI") layer around the graphite due to the reaction of the graphite with the electrolyte. The formation of the SEI insulates and protects the anode from the high reducing potentials that exists in an LIB when charged to voltages of up to 4.35V. Typical SEI layer formation results in a first cycle efficiency of 92-94% for anode materials. The first cycle efficiency of the anode must be balanced with the cathode. Currently the best choice of cathode for automotive applications are NMC and NCA which have first cycle efficiencies of about 94%. Since the first cycle efficiency of the cathode and anode need to be balanced, it is both undesirable and likely impractical to develop a graphite material with a first cycle efficiency higher than 94%. Reports of first cycle efficiencies of up to 99% demonstrate a lack of understanding of LiB chemistry and how LiBs actually work.

Exports of natural SPG from China are running at about 3,000 tonnes per month. If Chinese domestic consumption is included, Northern estimates that annual natural SPG demand for flake graphite is now in the order of 60,000 tonnes. Assuming a 40% yield of SPG from flake concentrate, battery demand for flake graphite is approximately 150,000 tpa which is about 25 per cent of annual flake graphite prodcution.