GRAPHITE

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The graphite market improved during 2000, but only in terms of the weaknesses lessening. The present major graphite end uses, mostly related to steelmaking, had a better than average year. Easily the best news, however, was the rapid progress towards implementation of two major new end uses for graphite: in fuel cells and in Li-ion batteries. Supply should be adequate, considering China and the shuttered operations in various parts of the world.

Graphite prices, as quoted in *Industrial Minerals,* continued unchanged through 2000 and into early 2001; for example, large crystalline flake (94% C) was US$570-750/t and large crystalline flake (90% C) was US$480-US$550/t. The US Geological Survey (USGS) average prices for crystalline flake (US imports) show a small increase from US$540/t in 1999 to US$550/t in 2000, but this could reflect that 2000 is based on only partial year data, or could reflect proportionally more 94% C flake imports in 2000. The USGS Mexican amorphous price rose from US$225/t in 1999 to US$230/t in 2000.

Demand

Several potentially important new end uses for natural graphite have emerged, one being the use of graphite electrodes in fuel cells, and the related use of graphite foil in the Ballard fuel cell. While fuel cells have been a clean source of very expensive electricity for decades, mostly for use by NASA in space projects, those costs have been dropping significantly with the advent of new technology. The newer Ballard fuel cell uses graphite foil as a flexible graphite material for flow field plates for its proton exchange membrane.

At the end of 2000, UCAR International announced its progress in the installation of a US$9 million process line to make the material, tradenamed Grafcell, and a related material trademarked eGraf. The Grafcell will go to the new fuel cell plant of Ballard Power Systems that is just coming onstream, with the product destined for the automotive market. The use of fuel cells in automotive vehicles in places like California may be close, perhaps resulting in quantities of graphite being used that would double or triple total current US consumption.

The use of eGraf, like the use of Grafcell, could also be a high growth market for natural graphite. eGraf is the most highly conductive thermal interface product available, and is used in computers, telecommunications equipment, and other electronic devices to aid the cooling of chip sets and other heat generating components.

Some synthetic graphite may also be used in fuel cells. SGL Carbon has agreed to develop low-cost injection-moulded graphite plates for proton-exchange membrane fuel cells for H Power Corp. Graphite is used in the bipolar plates, papers and gas diffusion layers in the fuel stack of such cells. The fuel stack now uses expensive machined graphite plates, and accounts for 40% of the manufacturing cost. Use of injection-moulded plates will reduce the cost of this stack by as much as 90%.

Another important, and growing, end use for graphite is in batteries, particularly the new Li-ion battery. Graphite has been used in batteries for a long time, beginning with dry cells, and then going to alkaline batteries. In the older batteries, graphite is usually displaced by cheaper forms of carbon. Alkaline batteries, on the other hand, are a good moderately growing market for high-

purity fine graphite, where the electrically-conductive graphite is used as the cathode. The lightweight rechargeable Li-ion batteries power cameras, computers and cellphones, all rapidly growing in popularity, and have technical advantages over battery alternatives such as the nickel metal hydride battery.

Production of the Li-ion batteries is rapidly increasing and is projected to continue to do so through 2010. This battery is currently being produced only in Japan, but plants are being built in Mexico, Korea and China. The Li-ion battery currently uses a special very expensive meso carbon product as the cathode. The Timcal Group of Switzerland, a graphite producer, has developed a cheaper compound of 'potato-shaped' graphite particles for use in the cathode of this battery, which functions by storing and expelling Li-ions as the battery charges and discharges.

In addition to these promising end uses, plus the promising expanded graphite and graphite foil end use mentioned in last year's article, there are a number of steady (and much older) end uses, such as the use of natural graphite in pencils. Most of the graphite used in pencils is fine crystalline flake and not a high-purity item. The graphite is mixed with varying amounts of clay (the more the clay the harder the pencil lead) to form a paste that is extruded, baked to dryness, and kiln-fired into a finished pencil lead. Rising pencil exports from countries like China are leading to a shrinkage of the pencil industry in North America and Europe.

Another old, but important, use for graphite, but with a high-tech twist, is its use as a lubricant. Both natural and synthetic graphite is used as a lubricant, when added to a water or hydrocarbon base, and sometimes in the form of a colloid. The recent growth in availability of high-purity natural graphite has been beneficial, because its use cuts the amount of grit in the lubricant. Graphite is a useful lubricant because it maintains its stability and lubricating properties at very low and very high temperatures.

There are two significant older steel-related end uses for natural graphite. The faster growing one is its use in powdered metal production (the metal is almost entirely steel). The graphite is blended with the metal (steel) powder and lubricates the dies during compacting, reduces metallic oxides during sintering while adding carbon content to the steel product being formed, and serves as a lubricant during pressing. The slower growing one is its use by (mostly ferrous metal) foundries, almost all as foundry facings. A foundry facing or mould wash is a water-alcohol or hydrocarbon-based graphite paint applied to the inside surface of a mould, where it dries before the molten metal is poured in, and afterwards eases the separation of the cooled metal casting from the mould.

Most graphite is marketed to the steel industry, either directly or indirectly. For example, natural graphite is mostly used in refractories and other items that are in turn used to make iron and steel, and synthetic graphite is used as electrodes in electric steel-making furnaces and as a powder (along with some natural graphite) added to molten steel to raise the carbon content. Therefore, the outlook for steel determines the outlook for graphite.

World steel prices have risen since the all-time low in early 1999, and world production rose even more. It is quite likely that the rapid weakening in the US economy in late 2000 and early 2001 will eventually lead to dropping steel prices and then cutbacks in output, even though US steel makers raised prices in late February 2001 in response to what they consider stronger upcoming demand. Any cutbacks in US steel output, and associated graphite consumption, will probably be accentuated by the recent trend to import semi-finished steel and finish it in the US. Steel output in the US during 2000

was up 3% over 1999, and world output in 2000 was probably up about 5% over 1999.

The major graphite-using countries in 2000 were Japan and China (possibly in an almost dead heat), then the US, Germany and the Republic of Korea, according to statistics that are more incomplete than those of last year. Japan took another big jump in its consumption of graphite other than flake and powder in 2000. The US graphite consumption as measured by imports appears to have increased very slightly.

Japanese imports of crystalline flake and powder graphite in 2000 preliminarily totalled 42,200 t, compared with 34,696 t in 1999. Japanese imports of natural graphite other than flake and powder in 2000 preliminarily totalled 103,000 t, compared with 76,919 t in 1999.

Supply

The Liumao graphite mine was again China's largest fine flake graphite producer, accounting for about 36,000 t in 2000. The Hunan Lutang graphite mine produced 55,000 t of amorphous graphite and derivative products, and exports around 20,000 t of its output. Shandong Province has two major graphite-producing centres: one in Qingdao resulting from the activities of Qingdao Asian Minerals Co., and the other in Laixi resulting from the four mines and 13 plants of Qingdao Graphite Co. Ltd.

In mid-October 2000, UCAR International Inc. signed a letter of intent with Jilin Carbon Co. to produce and market ultra-high power graphite electrodes in China. The production joint venture will use renovated capacity at Jilin Carbon's main operation in Jilin City and complete capacity underway at its Changchun site, and have a 20,000 t/y capacity that can be expanded to 30,000 t. Jilin Carbon presently produces graphite electrodes, plus other graphite and carbon products. UCAR will supply cash and technical assistance and receive a 25% ownership stake in the production facilities. The marketing will be done by a separate 50/50 venture. China has the world's largest market for graphite electrodes.

Integrated Carbonics Corp. (ICC) had two joint ventures, one with Liumao Graphite to build an expanded graphite, graphite foil, and high-purity graphite plant, and one with Yichang Hengda Graphite Group to build a fluorographite and Li-F battery plant. These both ended when ICC abandoned its graphite plans and assets as part of a reorganisation.

Now that the Indian steel industry is recovering from its recession, natural graphite production is also rising. The industry is still centered around Sambalpur, Orissa State. Graphite electrode production is also picking up, and HEG Ltd (LNJ Bhilwara Group) is planning to expand its Mandideep plant near Bhopal to 30,000 t.

Brazil continued to have a high level of flake graphite production, preliminary data indicating a little increase in total production from 1999. Nacional de Grafite Ltda. accounted for about two thirds of Brazilian production, coming from its three mines and associated plants in Minas Gerais State; production from its Salto da Diviso mine has been scaled back to the 10,000 t/y level in order to obtain a higher proportion of large flakes in its product.

Canadian exports of graphite rose in 2000; with sales to the US rising to 14,900 t in 2000 from 12,600 t in 1999, the rest of the exports being relatively minor. As the result of an internal reorganisation, Stratmin Graphite Inc. is now part of the Timcal Group, a Swiss firm.

There has been some activity among Canadian junior mining companies interested in graphite. IMP states that it has overcome financing problems that stopped it in 1997 and proposes to develop a graphite mine in southern British Columbia that would produce 12,000 t to 15,000 t of flake graphite product, perhaps at full capacity in latter 2001.

Quinto Technology Inc. (former Quinto Mining) announced that it is developing high-purity expandable and micronised graphite products to be produced at Portland, Ontario, for high end applications such as fuel cells and graphite foil. Preceding this, it bought Microgrinding Technologies, a firm that specialised in fine and ultrafine milling services and equipment, as part of its effort to move beyond being a miner and producer of basic materials.

Mexican graphite exports to the US rose to 14,600 t in 2000 from 13,100 t in 1999. This was mostly in amorphous graphite connected with older traditional uses such as lubricants, firebricks and gunning and ramming mixes. Also included in the exports were minor amounts of fine crystalline flake. The largest source of Mexican graphite is Asbury Carbons, through three subsidiaries of its Cummings-Moore Graphite subsidiary that own eight amorphous graphite mines in southeast Sonora State. Next largest is Superior Graphite Co. through its subsidiary Grafito Superior SA de CV, which has three amorphous graphite mines in Sonora. There is also a small producer of flake graphite in Oaxaca State, Grafito de Mexico SA de CV.

The Skaland operation in Norway probably increased its production substantially in 2000, based on import figures for Germany through mid-year. Woxna Graphite AB's operation in Sweden was again operating, but the import figures for Germany through mid-year 2000 show a minimal amount. *Industrial Minerals* has quoted a Norwegian production of 8,000 t in 1999, and Sweden a production of 5,000 to 6,000 t in 2000.

Asbury Carbons Inc. bought Dixon Ticonderoga Co.'s graphite operations, which includes its plant in New Jersey and its Southwestern Graphite operation in Texas.

The joint venture negotiations between the present owners of the Uley crystalline flake graphite operation in South Australia, on care and maintenance since 1993, and Harbin Liumao Carbon Technical Development Co. Ltd (HLC) of China, the world's largest crystalline flake producer, were suspended in mid-2000, apparently due to issues about water supply and Aboriginal claims. HLC was to manufacture and ship all new processing equipment to Uley, and do some plant refurbishing and make a production trial.

Zavalievsky Graphite Combine, the Ukraine's principal producer of flake graphite, is attempting to increase product output by removing overburden at its mine, rebuilding its screening equipment, adding new separation equipment and buying new equipment for its 99%C graphite line. This is all badly needed, since the production of the operation in 1997 was only 4,500 t, a fraction of its Soviet output of around 30,000 t.

The last part of the US-Canadian price-fixing suit brought by North American steel producers against world graphite electrode producers in 1997 was finally ended in late 2000 when SGL Carbon made a C$12.5 million settlement with the Canadian Government. This was in addition to the fines it and UCAR International paid previously.

The most significant development in synthetic graphite shapes was the decision by UCAR International Inc. to broaden its business alliance with Pechiney in graphite cathodes, and its reconfiguring graphite cathode production from the US to its plant in Brazil. UCAR will contribute this Brazilian plant, which will produce only graphite cathodes, to its joint venture with Pechiney which is titled Carbone Savoie SAS and its present French graphite cathode plant; Pechiney will contribute cash to upgrade the Brazilian plant. The graphite cathodes will be used in aluminium smelting in high amperage electrolysis potlines, and have been displacing the previously used older cathode types.

SGL Carbon raised its ownership to 75% in a Polish graphite and carbon electrode manufacturer, Zaklady Elektrod Weglowych

SA. It will make technical improvements in the plant to bring it up to company standards. SGL Carbon already has a Polish graphite-carbon subsidiary with a plant at Nowy Sacz.

Outlook

Graphite suppliers had a better 2000 than was expected, and 2001 might even be slightly better despite the observed weakening in the US economy in late 2000 and early 2001. This takes into account only the present major graphite uses, which are mostly related to steel production. Two new and potentially significant end uses, in fuel cells and in Li-ion batteries, have also emerged and might start taking significant tonnages of graphite in fairly short order. Supply should be adequate to handle any such expansion in demand; Chinese graphite was easily available in 2000 and should continue to be, and there are always the shuttered operations in Australia, Mozambique and even Tanzania.

Graphite Information

There were four significant advances in the provision of graphite information during 2000. First, the author of this article opened a free website for graphite (www.basicsmines.com/graphite), which will be updated with news, statistics and current market outlooks. Second came publication, by *Industrial Minerals* in November 2000, of a comprehensive article on graphite. This covered the major supplying nations, some major consuming nations, and some promising new end use markets. A third advance was the publication by FT Energy of an '*Executive Commodity Report*' on graphite. Fourth, as heralded in last year's *Annual Review* article, the USGS published production statistics on synthetic graphite for 1999. The USGS noted that the US produced a total of 267,000 t valued at US$817 million; for more details, and an evaluation, go to www.basicsmines.com/graphite Issue 1, which has a link to the USGS website for the complete set of statistics. The USGS will produce a similar set of statistics for the year 2000, probably available in September 2001.