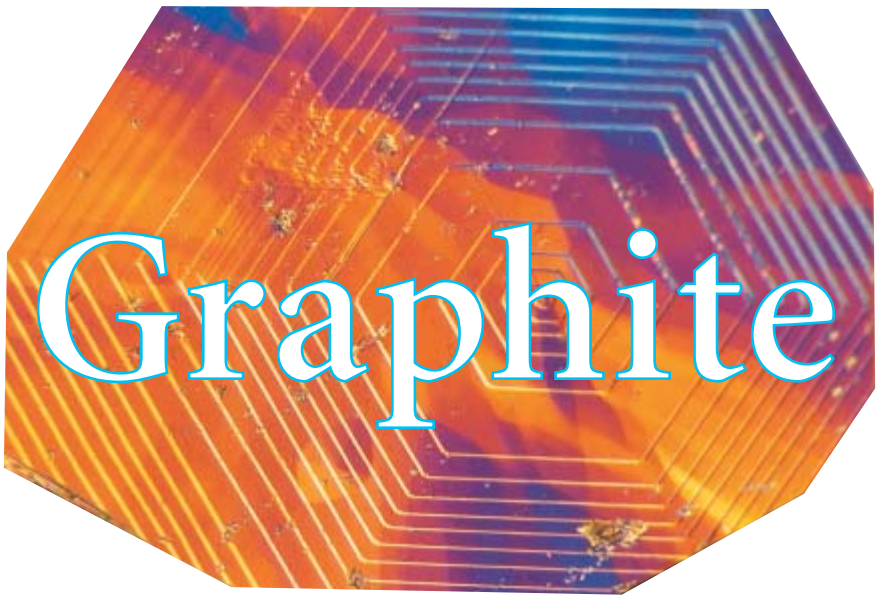


High-tech supply sharpens up

by Penny Crossley, *Assistant Editor*

From its unassuming beginning as the "lead" in a pencil, graphite has become an $8,000m. industry. The applications for this slippery, conductive material keep evolving, and look set to make graphite a material for the future. Production has suffered some setbacks in the last few years, but the search for increased purity and volume by graphite consumers means that new processing technology and capacity is coming on-stream. While there is a demand for the higher value material in certain sectors, there is also the risk of an overcapacity if purification technology continues to be added at its current rate.

A graphite operation can take many years to become profitable, even with a reliable source in a steady economy. In 1998, the graphite industry, and particularly flake production, became weighed down by overcapacity. In the following years, two mines in Africa closed, a Sino-US j-v foundered, and two planned projects in Australia were abandoned.

For those operations that clung on – despite a weak refractory market and pricing pressure from Chinese material – the next few years could bring a reversal of fortunes. One optimistic prediction is that the demand for high quality, high carbon graphite could increase to more than 100,000 tpa for just two applications – batteries and fuel cells.

Graphite is prized for its conductivity, inertness and light weight – properties that coincide perfectly with the trend towards products that are lighter, stronger, more resilient and longer lasting. Graphite has become synonymous with quality and performance in sports equipment, and the new generation of electrical and electronic goods. Yet the demand for graphite by more traditional markets – refractories, engineering materials, lubricants and pencils – has not abated at the expense of high-tech applications. In the case of refractories, foils and automotive parts, the market is increasing.

While natural graphite usually has to be purified and upgraded, synthetic graphite can be engineered that has 99.9% and higher carbon. The global market for this high-grade synthetic material is reportedly 50,000 s.tpa. Technology now

Properties and structure

Graphite and diamond are the two dimorphs of carbon. Diamond's cubic lattice arrangement makes it extremely hard and transparent. Graphite, however, has carbon atoms arranged in a layered lattice structure ordered in hexagonal and rhombohedral form. A low coefficient of friction between the planes allows them to slide over each other and gives graphite its lubricating properties.

Natural graphite forms from the metamorphism of organic carbon or carbonaceous rocks, and is found in three commercial varieties: crystalline flake, microcrystalline (or amorphous), and crystalline vein (or lump). All graphite is malleable, absorbent, chemically inert, has high electrical and thermal conductivity, and excellent refractory properties.

Flake graphite is the most widely mined variety, and generally has better conductivity and oxidation resistance than amorphous graphite. Amorphous graphite is not really amorphous at all – it is highly crystalline, but the crystals are only visible under the microscope. The concentration of carbon is high, usually more than 70%. Vein graphite is the rarest form of graphite, and is only found in significant amounts in Sri Lanka. It is highly crystalline and with carbon concentrations of more than 97%, cannot be purified further.

Title photo: graphite crystal showing growth spirals, courtesy of John Jaszczak, Associate professor, Michigan Technological University, USA

Table 1. Graphite and its applications

	Natural			*Treated*		*Synthetic*
	Crystalline flake	**Micro-crystalline/ amorphous**	**Crystalline vein/lump**	**Exfoliated/ expanded**	**Colloidal**	
Applications	Batteries Carbon pans Carbon brushes Catalysts Coatings Crucibles Foil Flame retardants Friction materials Fuel cells Lubricants Pencils Plastics + resins	Carbon additives Coatings Friction materials Lubricants Pencils Refractories	Batteries Lubricants	Batteries Coverings Foil Flame retardants Gaskets Insulation Lubricants Paint Seals	Batteries Carbon resistance film Catalysts Conductive suspensions Lubricants Metal alloys Mould release agents	Batteries Carbon additives Electrodes Fuel cells Heating systems
Producers	China India Brazil Canada Mexico Norway Zimbabwe Madagascar	Austria China Czech Republic North Korea Mexico	Sri Lanka	India Switzerland	India Ukraine	Austria Japan Switzerland USA

allows natural graphite material to be upgraded to more than 99.5% carbon.

China has introduced capacity for purifying graphite fines at low cost, and already it seems that there is sufficient material to satisfy the market. The price of graphite has been falling for the past six years – with the exception of flake graphite, which showed a slight increase over the last six to nine months. Demand for expanded and pulverised flake graphite in high performance batteries grew, and the price of the material has stabilised.

There are only two locations where graphite mining produces flakes without producing fines – Madagascar and one location in Brazil. As the demand for flakes grows, producers are being left with excess fine material (–80 mesh and smaller), which is used in the more traditional applications such as lubricants and pencils. The only current growth market for graphite fines is in its purified form in alkaline batteries. This market is growing at a fairly modest 5-6% per year, but if more companies continue to acquire purification technology at today's rate, there is likely to be an overcapacity situation bringing prices down within the next two years. In order to regain some stability, the graphite market may need to look towards consolidation.

Grease containing graphite
Source: Graphit Kropmühl

Growth markets

Purification techniques have improved to the point that even low-quality graphite can be used in high-tech applications, which were once the domain of synthetic material. At present, boosting natural graphite purity to match the performance offered by synthetic material comes with little or no cost advantage. However, the cost-performance ratio of natural graphite is improving all the time. Many consumers are choosing the marginally poorer performance – but noticeable cost incentive – of purified natural graphite, for all but the most demanding applications.

"Traditional" graphite applications like pencils, refractories, hot metal forming and lubricants still use the natural material because the purity required does not merit the higher cost of synthetic graphite. Chinese graphite is commonly used in these lower-grade applications. Graphite foils require large flakes and a high capacity of expansion, and natural sources such as Lac-des-îles, Quebec offer these properties.

The steel industry is a big consumer of graphite – both in refractories such as mag-carbon bricks,

and as electrodes in electric arc furnaces (EAFs). The industry as a whole is picking up after the slump of early 1999, when steel prices hit their lowest levels ever, and production in the first half of 2000 rose by 11%. For graphite, further demand will come from the electric arc route of steel production. Between 1985 and 1999, the proportion of EAF steel increased from 25% to 34%. It is expected to increase further to 40% by 2005 – and in North America, the share of EAF steel is already at 45%.

Developments in graphite foil have created potential for the use of graphite as a flame retardant. As regulations have halted the use of asbestos FRs, replacements such as vermiculite and perlite have come into use. Graphite's resistance to heat, flexibility and light weight make both natural and synthetic varieties suitable alternatives, and research is ongoing to ensure it complies with building regulations.

Fuel cells – power from thin air

When fuel cells were used to power the Gemini and Apollo space missions in the 1960s, few would have thought that one day we would be using the same technology to run vehicles, static power stations and electrical devices back on Earth. Forty years ago the technology was prohibitively expensive, and only NASA could afford to use it. But now, the search is on to find a clean, renewable source of power, and fuel cells seem set to become future sources of energy. Graphite forms a crucial part of fuel cell technology, and some predictions show the consumption of graphite in fuel cell electrodes could reach 80,000 tpa in just two to three years' time.

Fuel cells convert hydrogen into electricity by an electrochemical reaction. The hydrogen molecules break down into protons and electrons in the cell's graphite anode – protons are then conducted through the electrode while the electrons travel through an external circuit and generate electricity. At the graphite cathode, the electrons and protons recombine with oxygen from the air, and produce water. Just like an engine, the cell keeps providing power as long as the fuel (hydrogen) is supplied. But unlike a normal engine, only water, heat and electricity are produced – no pollutants are created.

Already, the USA, Canada, Germany and Japan are aggressively promoting fuel cell development. The cost of fuel cells is still too high for commercial vehicles, and the price per unit needs to drop by around $1,500 before they will be viable. If fuel cell production takes off anywhere, it is likely to be in the USA's west coast, where car manufacturers have been instructed to produce a percentage of environmentally sound cars within the next few years. DaimlerChrysler has pledged to have a commercially viable fuel cell vehicle available in 2004, and trials of fuel cell buses, taxis, bicycles and wheelchairs have already begun. Fuel cells may be incorporated into stationary power stations by 2002.

Superior Graphite's ThermoPURE™ products are used to produce alkaline batteries

Table 2. Selected world production of graphite

Country	Production (1999 estimates)	Comments/grades
China	220,000	
India	145,000	run of mine
	25-30,000	finished
Brazil	61,400	marketable
Mexico	43,000	amorphous
	1,000	flake
Ukraine	>40,000	capacity
Czech Republic	30,000	amorphous + flake
Canada	25,000	flake
North Korea	25,000	
Madagascar	12,000	flake
Austria	12,000	amorphous, flake + synthetic
Norway	8,000	flake
Sri Lanka	6,000	crystalline vein
Sweden	3-4,000	flake
World total	**480,000**	**including primary + secondary synthetic**

Source: USGS and industry estimates

Batteries – the Li-ion's share

The global demand for graphite used in battery systems may double to more than 25,000 tpa in the next five to seven years. This demand will be spread between the two main consuming sectors – alkaline batteries and lithium-ion batteries. Both synthetic and highly purified natural graphite are used in the Li-ion and alkaline cells.

In alkaline batteries, graphite – until now dominantly synthetic graphite – is the conductive material in the cathode. Graphite purification technology is now more efficient, and it has become possible to improve the conductivity of most natural graphite to the point where it can be used in batteries. The decision whether to use synthetic or natural graphite then becomes a balancing act between performance and price. Essentially, natural graphite can be upgraded to the purity of synthetic graphite, but the cost of the two types would be comparable. However, for a small decrease in quality and performance, natural graphite can be used at a significant cost advantage. Expanded natural graphite can match the performance of synthetic graphite, but at more than double the cost.

Some of the key producers in the alkaline battery market have recently lost market share to lower cost manufacturers. This kind of competition will make the battery producers turn to the raw materials suppliers in order to cut costs, which may open the market for Chinese producers. In some cases, the non-graphite components of alkaline batteries have improved enough to allow lower quality graphite to be incorporated while producing the same performance.

The growth of the Li-ion market could be more influential for the graphite market, as the demand swells for mobile energy

Table 3. Physical & chemical properties of Liumao flake graphite, with specifications

	Specifications %	Typical %
Chemical analysis		
Fixed carbon	95.00 min	95.66
Ash	5.00 max	4.79
Volatiles	–	0.55
CaO	6.00 max	0.54
MgO	–	0.09
Fe_2O_3	–	0.96
Al_2O_3	–	0.76
SiO_2	–	2.41
Physical specifications		
Moisture	–	0.30
Sized	Minus 100 mesh (150 microns)	100%

Source: Nanchuan Minerals Group Co. Ltd

storage systems – systems that are used to power portable consumer products such as phones, computers and cameras. As well as the industry growing as a whole, the consumption of graphite per cell is set to increase. Around 95% of all Li-ion batteries are manufactured in Japan, and most Japanese producers use a specialist meso-carbon product (MCMB) in the positive electrode of the cells. MCMB is very expensive, and efforts are being made by graphite producer *Timcal Group* of Switzerland to replace the material with synthetic and natural graphite. Timcal has developed a compound of rounded "potato-shaped" graphite particles, which stores and expels Li-ions as the battery charges and discharges.

World production

China continues to be the world leader in graphite production, accounting for around a third of the market. The top five producers of natural material – China, India, Brazil, Mexico and the Czech Republic – account for about 80% of total production (*see Table 2*).

While Africa and Australia have seen operations close or planned projects abandoned, Canadian production is set to increase, and several European producers have plans for market and capacity expansions. The USA and Switzerland are the dominant producers of synthetic grades, and Sri Lanka still corners the market for crystalline vein graphite.

Asia

China

As with so many other minerals, China leads the world with proven reserves, processing, and exports of graphite. Production of graphite in 1999 was around 220,000 tonnes. China is the most rapidly advancing economy in the world – for the past 14 years, its growth rate has been almost 10% a year. As the government is focused on privatisation, it now comes second to the USA in drawing foreign investment. Shanghai is thought to be the best future business centre in the world, and Beijing to be the sixth.

China has a huge growing market for mobile communications, and so the predicted demand for Li-ion batteries is strong. Western car manufacturers are also making massive investment in China – £900m. in the case of German-based Volkswagen over the next few years – to modernise production of cars and components at its Chinese operations. While the number of passenger cars in China in 1999 was 586,517 units, this is expected to grow to over 1m. units in the medium term, and so demand for graphite as clutch facings, friction pads and carbon brushes will soar.

China is holding on to its low-cost production, and its competitive prices for graphite remain difficult for most other producers to match. Quality requirements in China are increasing, and as the economy strengthens, the domestic demand for high-grade graphite will grow.

Liumao – US j-v abandoned

The country's most significant producer is the *Jixi Liumao Graphite Mine* of Heilonjiang Province – accounting for around 50% of total output. The Liumao mine is thought to be the largest graphite mine in Asia, and one of the largest in the world, with estimated reserves of 350m. s.tons, and production of around 36,000 tpa *(see Table 3*).

The mine has been in operation since 1936, and in October 1997, *Integrated Carbonics Corp*., based in Nevada, USA, acquired the rights to pursue a joint-venture with Liumao Graphite Mine to be called *Liumao ICC Graphite Products Ltd*.

The purpose of the j-v was to produce higher-value products than those previously produced at the site – such as high-purity graphite, expandable graphite, graphite sheet – and to export to world markets. ICC became an 80% equity partner in the project, contributing 80% of the construction costs of $28m. However, at the end of 1999, ICC abandoned its graphite assets as part of a reorganisation of the company and the ICC name ceased to exist.

ICC's other venture in China, a 55% stake of the j-v company, *Yichang Integrated Carbonics Company Ltd* also folded. This j-v was established with *Yichang Hengda Graphite Group* at the end of 1998, as part of ICC's campaign to establish itself as a quality value-added producer in China. This gave ICC mining rights to a 6m. tonne proven and probable graphite deposit in Yichang county. The deposit grades over 13%, and produces medium and high carbon graphite concentrate.

Also on site was an 8,000 tpa flotation, mining and concentrate production facility. Yichang Integrated Carbonics also had a 1,000 s.tpa graphite foil operation; a 15,000 s.tpa screening and classification plant; a 98-99% high purity plant and a 1,000 s.tpa expandable graphite plant.

On 14 December 1998, ICC announced its plans to build a fluorographite and Li-F battery plant through the Yichang j-v – the first of its kind in China – this project has also been relinquished.

Hunan – amorphous grades

Hunan Lutang Graphite Mine, in the Beihu district of Chenzhou city, is China's richest reserve of amorphous graphite. Over 1,500 employees work in mining, ore dressing and processing – producing 55,000 tpa of graphite ball, grain and powder. The mine's export department – *Hunan Lutang Graphite Foreign Economic Relations and Trade Co.* – exports more than 20,000 tpa to more than 20 countries, including the USA, Germany, Japan, South Korea, and Taiwan.

Lutang brand graphite is divided into two types – WT (limitation to iron) and W (no limitation to iron). There are

eight grades, with sizes of 325, 200 and 100 mesh. The content of cryptocrystalline scales in the raw graphite is over 70%. It contains little iron and sulphur and has high refractoriness, conductivity and plasticity. Applications for Lutang amorphous graphite include pencils, welding rods, graphite emulsions, desulphurising agents, lubricants and electrodes.

Shandong – Qingdao mines

The Qingdao region of Shandong is a hive of graphite activity. *Qingdao Asian Minerals Co. Ltd*, based in Qingdao, Shandong province has a mine in Pingdu and a nearby plant in Jiaozhou. The company has the capacity for 5,000 tpa of graphite, with carbon content between 90 and 99%. Five sizes are produced, and are sold to the refractory brick, paint and battery industries of Japan, Australia, the UK, Belgium, Spain, Indonesia, Turkey and Taiwan.

In Laixi, Shandong province, *Qingdao Graphite Co. Ltd* – formerly *Shandong Nanshu Graphite Mine* – operates four surface mines and 13 plants. The company produces 6,000 tpa of natural, high carbon flake graphite (capacity for 8,000 tpa); 600 tpa expandable graphite (capacity for 1,000 tpa); 400 tpa graphite emulsion (capacity for 600 tpa); and 400 tpa of superfine graphite powder (capacity for 500 tpa). As well as the raw graphite grades, Qingdao Graphite Co. produces 500 tpa of graphite shapes, 100 tpa of graphite energy-saving products, and 200 tpa of graphite sealing materials.

Also with a mine in Qingdao is *Non-Metals Inc.*, the Tucson, Arizona-based US firm that produces some 30,000 tpa of Chinese graphite. Non-Metals also operates a graphite mine in Jixi City, Heilonjiang province. Some 70% of Non-Metals' output is for refractory applications; another 10% is used in gaskets.

In March 2000, *Graphit Kropfmühl AG (GKAG)* of Hauzenberg, Germany completed a joint-venture contract that gave it a 60% share in *Qingdao Kropfmühl Graphite Co. Ltd*. This provides GKAG with long-term access to high quality graphite, and a platform for expanding its market share in the Asian market – particularly in Japan and South Korea, and for battery applications.

Processors and traders

The largest integrated carbon producer in China is *Jilin Carbon Plant*, in Jilin City. Its production capacity is 100,000 tpa of carbon products, of which 46,000 tpa is for graphite electrodes. In terms of sales, the plant produces 29% of China's graphite electrodes, and exports to the USA, Japan, Germany, South Korea and South East Asia. Graphite powder, electrode paste, anodes, and special shaped products are also manufactured.

China Graphite Carbon Sales, based in Liaoning province, is the exporting subsidiary of *Liaoyang Carbon Group (LCG)*, one of China's leading graphite electrode manufacturers. LCG produces 20,000 tpa of graphite products, including flake, amorphous, expandable, micronised and flexible grades, filling rings, winding sealing gaskets, braided foils, compounded sheets, crucibles, coatings and lubricants. The products have been exported to the USA, the UK, Germany, Japan, South Korea, Brazil and Pakistan for the past 20 years.

India

Although India is one of the world's largest producers of graphite, the industry still seems to be in its infancy when the immense undeveloped potential is considered. The country's large reserves mean that there is significant opportunity for growth, and India is starting to explore added-value markets in earnest.

The diversity of graphite applications, and the ongoing depression in some industries means that there is still a surplus of certain grades. However, as the steel, refractories, and automobile markets take off, the vast majority of India's graphite is being sold. The most important graphite applications in India today are mag-carbon and other refractories, crucibles, pencils, and foundry facing.

Domestic demand has increased since the lethargic market of 1998, when the steel industry – the major consumer of graphite electrodes – was in the midst of a depression. Several manufacturers of graphite products closed; more managed a lucky escape.

In March 1998, the commerce ministry confirmed preliminary dumping duties on the import of graphite electrodes from the USA, Austria, France, Germany, Italy, Spain, China and Belgium. It maintained that electrodes originating in, or exported from, these countries were arriving in India below the normal value, and causing material injury to the domestic industry. In the 1998 budget, the government also set a 4% additional customs duty on the electrodes, though some companies doubted the healing effect these measures alone would make.

But now, in 2000, the outlook for India's graphite industry looks much more positive. Recognising the country's natural potential, foreign investment is coming to India with a view to fully exploiting the reserves, and wringing more value from the raw material.

From Ukraine, the *Gas Institute* and the *Zavalye Graphite Plant* are collaborating with India's *International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI)* to convert natural graphite into high-value exfoliated material. The consumption of graphite in car parts is also set to increase. *Hyundai*, *Ford* and *General Motors* are to make a presence in India – other foreign car producers are expected to follow.

The use of graphite in the steel industry is also rising in India. Application of mag-carbon and aluminium-carbon refractories has increased, and capacity expansions of graphite electrodes for electric arc furnaces are underway.

HEG Ltd, a *LNJ Bhilwara Group* company announced in July 2000 that it would be making a capital outlay of Rs. 55m. ($1.2m.) to expand graphite electrode production at the Mandideep plant near Bhopal. The capacity will be increased from 22,000 tpa to 30,000 tpa, probably by July 2001. The company's export volume is also expected to increase from 15,147 tonnes in the period 1999-2000, to 18,000 in the period 2000-2001.

Prices for the higher value grades, such as expandable and colloidal graphite are currently higher in India than in countries where this market is better developed. But the cost should start to come down as the technology required to process these grades is introduced more extensively. For almost all other grades, India's pricing matches international levels.

Sambalpur – industry hub

Many of India's graphite producers are based in Sambalpur, Orissa state. *M/s Agrawal Graphite Industries (AGI)*, and its sister concern *M/s Gandhamardan Graphite Udyog*, are mine owners, producers and exporters of natural crystalline graphite flakes and powders for Indian markets.

The companies operate four mines throughout the state – at Temrimal, Gandabahali, Malisira and Mahanilaha. AGI has two plants, one near Checherbeng in Bolangir district, and one near Mundapala in Nuapara district. Gandhamardan's single plant is near Menkamunda, Bargarh district.

In the last five years, AGI has doubled its capacity to 9,600 tpa. Production now stands at 6,600-7,200 tpa of natural

crystalline graphite with carbon content between 45 and 97%, and six sizes from –400 mesh BSS to +100 mesh BSS.

AGI says that it is constantly adding capacity for the production of different graphite grades for Indian and export markets. Over the next two years, the company is likely to triple its capacity, and it hopes to start exporting its graphite by 2001.

AGI's different grades find use in magnesia-carbon bricks, carbon and clay-bonded crucibles, lubricants, pencils, foundry coating and fluxes, carbon brushes, mechanical seals, mud chemical for drilling purposes, dry cell batteries, gaskets, brakes and paints.

Also based in Sambalpur is *GR Graphite Industries*. GR owns a mine in Dudukamal, Balangir, which outputs 18,000 tpa of graphite, and a plant in Belpara, Balangir, which has a capacity of 10,000 tpa of graphite flakes and powder. GR's graphite ranges from 70-97% carbon content, and applications include carbon bricks, refractories, pencils, brake lining and batteries.

Lakshminarayan Makhanlal Co. owns two graphite mines in Balangir. The larger Tureikela mine has a crude output of 12,000 tpa; the Gargarbahal mine has an output of 8,000 tpa. The company's plant, in Belpara, Balangir, has a capacity of 4,800 tpa and actually produces 4,500 tpa of 80-95% carbon graphite for use in refractories, foundries, steel plants, lubricants and pencils.

ARCI – expands and adds value

ARCI, based in Hyderabad, is an Indian R&D facility for advanced materials and processing technologies that has joined forces with the Ukrainian Gas Institute and Zavalye Graphite Plant to add value to India's graphite. ARCI has developed a unique process for the exfoliation of natural graphite flakes – currently at a pilot scale of 5kg/h.

The process involves chemical intercalation followed by thermal treatment, and results in volume expansion of up to 300 times the graphite's original volume. The fluffy, vermicular graphite powder can be rolled into flexible sheets or pressed into shapes. The graphite can withstand high temperatures and pressures, and is used in vehicle gaskets, seals for vacuum furnaces and in the chemical industry, thermal insulation, fire retardant, and for removing oil spills. ARCI's collaboration with the Gas Institute will also see the transfer of the technology for production of colloidal graphite.

Tamilnadu Minerals Ltd (TAMIN) has a lease over 2.4km^2 of graphite-bearing land in the Sivaganga district of Tamilnadu, southern India, with reserves of around 3m. tonnes. The company's plant produces around 200 tpd of beneficiated graphite flakes for the manufacture of refractory bricks, crucibles and carbon brushes. ARCI has undertaken a consultancy with TAMIN, with the intention of improving the quality and yield of the beneficiation plant. The flakes from the TAMIN plant will be the raw material for a new plant to be built at Sivaganga, which will use ARCI-Zavalye technology.

The Indian/Ukrainian collaboration has also signed a memorandum of understanding with *M/s Pasumpon Graphite Ltd* of Chennai, for the transfer of technology and production of various value-added products from exfoliated graphite.

GIL – electrodes in demand

Graphite India Ltd (GIL) is planning to up its graphite electrode production capacity, in light of positive trends in the global market. Price increases are expected by January 2001, and with the healthier state of the steel industry, GIL sees potential for growth – particularly in export markets.

GIL has an installed capacity of 21,900 tpa – for electrodes, anodes, and other graphite items – divided between its two plants at Bangalore and Durgapur. However, the company has been operating below capacity since the slack demand for the electrodes in 1998. Inventories have now been worked down, and GIL plans to operate at full capacity in the 2000-2001 period. The management has not yet revealed the scale of the proposed capacity increases.

In March 2000, GIL was in the news in connection with a criminal conspiracy lawsuit that has become known to the Indian courts as "the Graphite case". Three public officials – former electricity minister R. Balakrishna Pillai, former Kerala State Electricity Board chairman P Kesava Pillai, and former power secretary G Gopalakrishna Pillai – have been charged with abusing their positions by illegally selling electricity to GIL between June 1985 and April 1986. This came at a time of acute power shortage in Karntaka, and allowed GIL to derive pecuniary benefits of over $4m.

Sri Lanka

Sri Lanka is the world's only significant source of crystalline vein graphite, which occurs in the west and south-west parts of the island. The veins are thought to have formed from the assimilation of limestone and dolomite by igneous magma. The estimated reserves are of the order of 50,000 tonnes, with inferred reserves of 400,000 tonnes. The graphite is of medium to high carbon content and requires little upgrading for use in lubrication, pencils, and electromotive brushes.

Sri Lanka has over 600 mines, the two largest being Bogala and Kahatagaha. By the middle of 2000, Germany's Graphit Kropfmühl (GKAG) had acquired 80% of the shares in *Bogala Graphit Lanka Ltd*, Sri Lanka's largest producer, from the state of Sri Lanka.

Bogala Graphit mines, processes and exports around 6,000 tpa of graphite from the Bogala mines in the Kegalle district. Around 40% of the graphite has carbon content between 90 and 99%, and is in great demand for electrotechnical applications worldwide. The company has access to inferred reserves of 63,000 tonnes.

PERC, the *Public Enterprises Reform Commission* of Sri Lanka, recognised that capital investment was required to modernise processing equipment, and to introduce more efficient methods of upgrading graphite. As the quality of graphite from China improves, Sri Lanka's graphite industry needed to add value to its material in order to remain competitive.

At the end of 1999, GKAG also acquired 100% of *Branwell Graphite Ltd* – the UK's leader for sales of high-grade graphite. Branwell, as well as being a specialist in the high-grade field, has many years of experience in Sri Lanka.

North and South America

Brazil

Brazil's largest graphite producer – *Nacional de Grafite Ltda (NGL)* – is also the largest producer of natural crystalline graphite in the world. NGL is headquartered in São Paolo, but has its operations in the graphite centre of Brazil, in the state of Minas Gerais.

NGL has been producing graphite for more than 60 years. Its first mine was founded in Itapecerica, then in 1972, the Pedra

Azul deposit was identified. In 1994, NGL found graphite occurrences in the city of Salto da Divisa, where the company has now established a third mine.

NGL's average output is 40,000 tpa – 50% of which is exported. Production in 1999 amounted to 42,000 tonnes. When the Salto da Divisa deposit was first discovered, NGL's plan was to produce 40,000 tpa from this deposit alone. But by 1996, the company had decided to scale down production to 10,000 tpa in order to concentrate on extracting large, high-value flakes for refractories, particularly for North American markets.

In 1997, NGL became the world's largest supplier of graphite for battery applications. Other grades are sold for the manufacture of refractories, lubricants, ferrous metals and automotive parts.

Other Brazilian graphite producers include *Mamore Mineração e Metalurgia Ltda*, owned by metals holding company *Paranapanema SA*. Mamore mines and processes graphite in Maiquinique, Bahia, for chemical lubricants, pencils, foundries and steelmaking. The company's output is around 1,500 tpa of graphite containing 75-99.7% carbon.

Brazil's production of high value purified graphite has increased, and the country is now able to supply the battery market at a lower cost than certain synthetic grades.

Mexico

Mexico has two graphite-producing regions – the states of Sonora and Oaxaca. Sonora graphite is associated with Triassic coal beds – the Barranca deposits – that were converted to graphite in the Palaeocene. This graphite is amorphous, primarily for metallurgical industries, and the reserves amount to some 60m. tonnes. Mexico's largest graphite producer, *Grafitos Mexicanos SA* is active in this region. Mexico's other graphite deposits are small by comparison, crystalline, and formed during the metamorphism of Precambrian rocks.

The leading supplier of Mexican graphite is the Detroit, US-based *Cummings-Moore Graphite Co.*, a subsidiary of *Asbury Carbons*. Although, being part of Asbury, Cummings-Moore has at its disposal supplies of graphite from around the world, Mexican graphite has been the company's mainstay since 1923.

Cummings-Moore holds stakes in three subsidiaries of *Grafimex SA de CV* – 25% in *Grafitos Mexicanos SA*; 49% in *Grafitera de Sonora SA de CV*; and 49% in *Grafitos Industrializados Mexicanos SA de CV*. Together with the other two subsidiaries – *Minera Moraguirre SA de CV* and *Minera Jecho SA de CV*. Grafimex owns eight mines in south-east Sonora.

At the plant in Estación Torres, Grafimex produces over 24,000 tpa of graphite with carbon content between 70 and 85%. Some 60% is for steel making, and 30% is for refractories.

Superior Graphite Co., based in Chicago, USA, is the 100% owner of *Grafito Superior SA de CV*, based in Hermosillo, Sonora. Superior began to develop mining in Mexico in 1945, after the company's mine in Alabama closed, and Superior was forced to find a cost-effective alternative. Grafito Superior now produces some 10,000 tpa of graphite from three mines in Covalmar, Santa Clara and Rio Mayo, Sonora. Around 50% is consumed by the domestic Mexican market.

A comparatively smaller producer is *Grafito de Mexico SA de CV*, based in Mexico City. The company is owned by kaolin producer *Caolines y Minerales SA de CV*, and mines and processes flake graphite in Telixtlahuaca, Oaxaca state. Grafito de Mexico produces three grades – for mag-carbon bricks, pencils, lubricants and brake linings.

USA

The USA has no indigenous natural graphite production, although in 1999 its production of electrodes and synthetic graphite reached 267,000 s.tons. US graphite processors and producers source graphite worldwide – ICC and Non-Metals Inc. have operations in China, and Superior Graphite and Asbury Carbons source Mexican material.

The US consumption of graphite in 1999 was 34,600 s.tons, an increase of around 26% on 1998. Around 50% of this was consumed by four major industries – refractories, brake linings, lubricants, and foundries. More than 50% of total graphite consumption was of crystalline graphite, which as well as refractories, was used in batteries and other thermal and electrical conductivity applications.

Around 80% of the imports to the USA come from China, Mexico, Canada, Madagascar and Brazil. Sri Lanka supplies the USA with lump graphite, and other imports come from Germany, India, and Japan.

Asbury Carbons, based in Asbury, New Jersey is the world's largest graphite processing and producing company, with operations in the USA, Canada and Mexico. Asbury imports graphite from mines around the world, but the only mines owned by the company are in Mexico, through Cummings-Moore Graphite.

In 1998, the output of Asbury's 10 processing subsidiaries was over 150,000 s.tons of graphite and other carbon-related products, for refractory, friction, lubricants, powder metallurgy, gaskets, pencils, castings, brushes, rubber and plastics. The majority of Asbury's sales are to North America, but it exports its products to South America, Europe, Asia and many other parts of the world.

Superior Graphite Co. is based in Chicago, Illinois, where it also has three plants for the production of graphite and graphitic carbons, speciality products, and lubricants for the railroad industry and metal forming. Like Asbury, Superior sources Mexican graphite, from its Grafite Superior SA de CV operations. As well as producing amorphous, crystalline vein and flake graphite, Superior manufactures synthetic graphite and carbon.

Superior's plant in Russellville, Arkansas, produces Ark® electrodes for the iron and steel industries, and in August 2000, was one of 25 US manufacturing plants to be named "America's Best Plants" by *IndustryWeek* magazine. Since 1995, the Russellville plant has achieved a 54.3% increase in annual sales per employee. The plant serves North and South American, European, Asian and Middle Eastern markets.

Superior's brand of carbon additives, Desulco®, is produced in a 55,000 tpa capacity plant in Hopkinsville, Kentucky, and in Sundsvall, Sweden. The Sundsvall plant was opened in 1994 to serve Europe, Asia, Africa and South America. Superior first produced Desulco® in 1987, and in the following seven years produced 375,000 s.tonnes of the product.

In July 1999, Superior added a third furnace at Sundsvall, taking capacity of Desulco® from 17,000 to 25,000 tpa. The expansion in Sweden was intended to take some of the pressure of producing Desulco® away from the Hopkinsville plant, and allow for more ThermoPURE® – thermally purified natural and synthetic graphite – to be produced in Kentucky.

Canada

Since July 1999, *Stratmin Graphite Inc.*, Canada's sole graphite producer, has been part of Swiss-based *Timcal Group* – the graphite division of Imerys. Timcal falls within Imerys' ceramics and specialities division. Stratmin is based in Montreal, and mines and purifies natural flake graphite in Lac-des-Îles, Quebec.

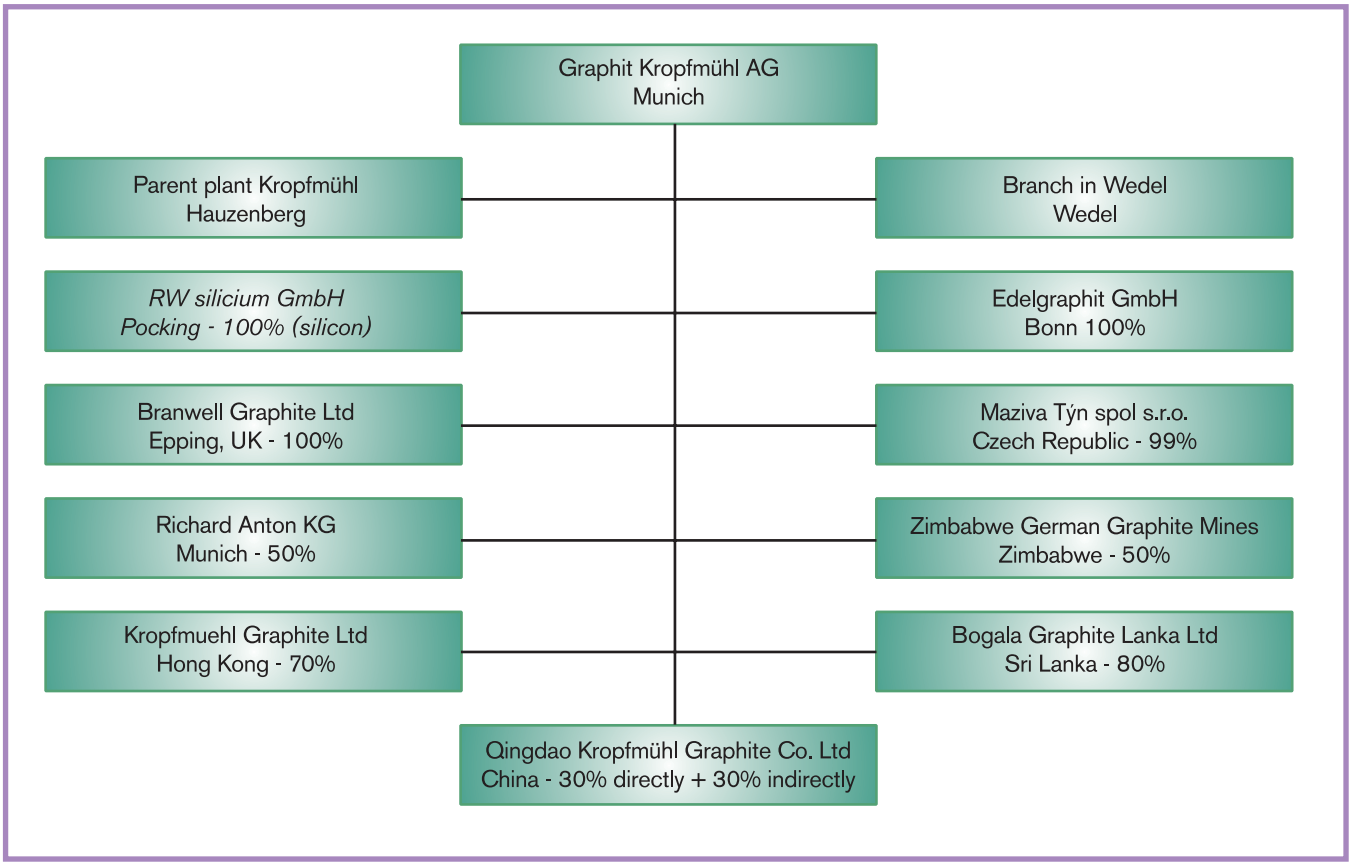


Figure 1: Structure of Graphit Kropmühl AG as of 31 May 2000

Stratmin produces flake graphite with carbon content 90-98%, which has high anisotropy, compressibility and conductivity. The purification process is used to increase the quality of some of the natural flakes to 95-98%. The higher grade, processed graphite finds more applications than natural graphite in the fields of engineering materials. The main use for all of Stratmin's grades is in refractories and foils – such as gaskets, flame retardants, and fuel cells.

Stratmin is soon to be joined in graphite production by Vancouver-based *IMP Industrial Mineral Park Mining Corp.* IMP was founded in 1996 to develop the Black Crystal graphite ore body in south-central British Columbia, which was discovered by IMP's former principal. Construction of the plant began in 1997, but was put on hold when the company ran into financial difficulty.

Black Crystal holds inferred resources in the region of 88m. tonnes. The graphite formed from the partial metamorphism of limestone that acts as the host rock. The large flakes (80-20 mesh) and high purity (95-99%) of the ore meant that IMP overcame its cashflow problems, and has just completed a major equity financing programme that has generated more funds than required.

Lac-des-Îles, Quebec: Stratmin's natural graphite operations

IMP expects trial production in the middle of 2001, and full production during the third quarter of 2001. The company will initially process 300,000 tpa, and expects recovery of 12-15,000 tpa. Depending on the market, IMP will probably increase this to 600,000 tpa in year two or three of the project. The next phase of development will be to perform further processing at a local foil plant.

IMP has not yet decided on which applications, or geographic regions, to market the graphite, but the company is confident that the markets do exist for the Black Crystal graphite. The most important markets are likely to be export markets, and the most important applications will probably be electrodes, particularly for fuel cells.

Another potential graphite source in Canada is the Kearney, Ontario graphite mine, formerly owned by Pittsburgh, US-based *Applied Carbon Technology Inc (ACT)*. Production halted at the Kearney mine in 1994 because of financial problems and low graphite prices. ACT disposed of the mine in March 1999 to *International Graphite Inc. (IGI)*, and subsequently changed the company's mission to that of a merchant bank. ACT acquired *Merchant Capital Group Ltd* in July 2000, and renamed itself *Merchant Capital Group Inc. (MCGI)*. MCGI – now the full owner of ACT – will retain its US-based graphite processing operations, *Applied Carbon Technology (America) Inc.*

Africa

Madagascar

Graphite is Madagascar's twelfth most important commodity by value, and the island's most important industrial mineral resource. Graphite has been used by the Malagasy people for hundreds of years – before the island became a French colony – who made crucibles from the mineral for the manufacture of weapons. The production volume has changed little since about 1945 – averaging around 12,000 tpa – and the main consuming market is still refractories.

The majority of the graphite mines are in the Manampotsy district on Madagascar's east coast. Other rich deposits are found in the Ambatolampy and Ampanihy districts. The graphite flakes are generally large, and occur in irregular veins in weathered metamorphosed schists and gneisses. The natural weathering and leaching has increased the purity of many of the deposits.

All the Madagascan graphite companies are based in the country's capital, Antananarivo. The largest producer is the Gallois mine, near Toamasina, which accounted for two thirds of the 14,500 tonne production in the bumper year of 1998. Madagascar's biggest exports go to the UK, the USA, and Germany, although sales to the USA are likely to decrease with the advent of more production in Canada.

Madagascar's installed capacity is much greater than the 12,000 tpa average production, but the island is in need of investment to update and rejuvenate many operations. With the recent failure of graphite mines in Mozambique and Tanzania, the Madagascan industry is working hard to convince foreign importers and investors of the island's potential.

Société Minière de la Grande Ile (SMGI), based in Paris, France and Antananarivo, is one such Madagascan graphite company either looking for partners or to sell its mine. Its reserves are of the same size – around 100,000 tonnes – and genesis as the Mozambique and Tanzania mines, but considerably closer to a port. SMGI claims that with an investment of around $2m., the mine could produce 8-10,000 tpa of high-quality graphite flake, grading 95-98% carbon. At present the mine produces around 2,160 tpa up to 95% carbon, for refractories and batteries. The processing operations have a treatment capacity of 20 tpd of finished product.

The largest producer of Malagasy graphite, *Etablissements Gallois*, has three mines in Antsirakambo, Marovintsy, and Ambalafotaka on Madagascar's east coast. Gallois produces some 10,000 tpa and has been active in the industry since the early 1900s. The company's plant and transit department are located in Toamasina, the island's main port.

Mozambique

The Ancuabe Graphite Mine, and its 10,000 tpa capacity processing plant, is located in northern Mozambique, and has been on care and maintenance since late 1999. *Kenmare Resources PLC* of Ireland owns 78% of the project – the balance is held by the Government of Mozambique (13%), and the Commonwealth Development Corp. (9%). The mine's owners are seeking a new investor to restore the project to production.

The mine began operation in 1994, producing high-grade flake graphite – Kenmare Flake – for foil, crucibles, refractories and batteries. The weathered orebody allows for easy removal of the graphite, and preserves the large size of the flakes.

The distributor of Kenmare Flake, Chicago-based Superior Graphite, decided to terminate its distribution contract in 1999, and withdrew its working capital. This created a significant funding deficiency that hastened the move to care and maintenance.

Since 1997, the mine has experienced problems with its power generation systems, which led to production levels that fell short of expectations. Improvements were made in 1998, when larger alternators were brought in that incorporated filters to remove conductive graphite dust. The power situation should improve further within the coming two years, when the Mozambique government extends the power grid to the mine.

Tanzania

In early 1998, the Merelani graphite operation finally closed after coming on-stream in July 1995. When the operations folded, Merelani was owned by London-based *Phoenix Minerals Ltd*, through the Tanzanian subsidiary *Graphtan Ltd*, but the original owner was the UK's *Samax Resources Ltd*. Merelani was struggling to operate to the full 15,000 tpa capacity of the plant, and stopped shipments of its coarsely crystalline, refractory grade flake graphite in February 1998. The reasons for closure are believed to be a lack of due diligence into the markets for Merelani graphite.

In December 1998, with Graphtan in receivership, *African Gem Resources Ltd (Afgem)* of Johannesburg, South Africa, bought the mining lease for the Merelani mine, but with the intention of solely producing tanzanite, the USA's second most popular gemstone.

Europe

Austria

After the Czech Republic and Ukraine, Austria is Europe's third largest natural graphite producer, with production at around 12,000 tpa. The country consumes around 30,000 tpa, the most important applications by volume being refractories – although there is a definite demand for higher quality grades to cater to new markets.

Grafitbergbau Kaisersberg GmbH operates a mine and processing plants in St Stefan ob Leoben, with capacity at 12-15,000 tpa. Grafitbergbau produces micro-crystalline, flake and synthetic graphite, with an emphasis on micronised grades from 2-70µ. The carbon content varies between 45 and 99% and can be used for most graphite applications. Recent developments have been in the fields of expandable graphite and graphite for plastic.

Grafitbergbau's sales to its major markets – Austria (25% of total sales), the EU, USA, Asia and Eastern Europe (75% of sales combined) – are increasing. Micronised grades will continue to be the most valuable sector for the company, which has plans to extend production.

Czech Republic

Graphite in the Czech Republic formed from the regional metamorphism of sandy sediments rich in organic matter, and is mainly found in the Southbohemian Moldanubicum and Moldavian-Silesian region. Deposits can be amorphous, crystalline, or a combination of the two. Production in 1999

Table 4. Specifications of natural flake graphite from Woxna's deposits in Edsbyn, Sweden

	80-160/92 medium	-75/90 powder	Medium/fine 90	160/92 coarse
Size specifications	Max 20% <75µ (200 mesh) Max 20% >150µ (100 mesh)	Max 20% >75µ (200 mesh)	Max 45% <45µ Min 80% <150µ	Min 80% >150µ (+100 mesh)
Carbon specifications	92% min	90% min	90% min	92% min
Moisture	Max 0.5% H_2O	Max 0.5% H_2O	Max 0.5% H_2O	0.5% H_2O
Typical analysis				
Ash	7%	8-10%	8-10%	6%
Carbon	93%	90-92%	90-92%	94%
Sulphur	0.23%	0.30%	0.30%	0.14%
Moisture	0.15%	0.35%	0.35%	0.15%
Bulk density	500 kg/m^3	420 kg/m^3	420 kg/m^3	550 kg/m^3
Typical ash analysis				
SiO_2	46.8%	45.7%	45.7%	46.6%
CaO	0.29%	2.2%	2.2%	0.29%
K_2O	6.5%	4.3%	4.3%	6.4%
MnO_2	0.057%	0.088%	0.088%	0.077%
P_2O_5	0.030%	0.10%	0.10%	0.044%
LOI	0.2%	0.3%	0.3%	0.2%
Al_2O_3	25.8%	21.5%	21.5%	25.2%
Fe_2O_3	13.8%	20.7%	20.7%	14.1%
MgO	5.1%	3.5%	3.5%	5.2%
Na_2O	0.31%	0.43%	0.43%	0.25%
TiO_2	0.62%	0.93%	0.93%	0.61%
S	0.02%	0.03%	0.03%	0.02%

Source: Woxna Graphite AB

regained 1996 levels of around 30,000 tonnes, after two years of lower output. There are 16 deposits of graphite in the Czech Republic, four of which are exploited, and hold total reserves of just under 15m. tonnes.

Mining companies include *Grafit AS Netolice* and *Grafitové doly Staré Mesto s.r.o. Maziva Týn spol. s.r.o.* is the Czech specialist for graphite micronising and lubricants, and was acquired in 1999 by Germany's Graphit Kropfmühl AG. GKAG will utilise Maziva's location as a springboard into the markets of eastern Europe.

Germany

Like the USA, Germany lacks any indigenous production, but is home to some major international players in the graphite industry. Total graphite consumption in 1999 was some 30,000 tonnes, mainly in the fields of refractories, friction and batteries – a market that is thought to be the most important for the German graphite industry in the future.

Graphit Kropfmühl AG (GKAG) is based in Munich, and has a processing plant in Kropfmühl, Hauzenberg, but has subsidiaries in the UK, Czech Republic, Zimbabwe, Hong Kong, Sri Lanka and China, as well as elsewhere in Germany (see Figure 1). GKAG's slogan is "we refine the future" – the company claims to have the most advanced production techniques for refining raw materials (silicon as well as graphite) for the high-tech industries.

GKAG has entered into its participations and long-term contracts to ensure global sourcing and constant pricing on raw materials. In 1999, with the acquisition of Branwell Graphite Ltd and Maziva Týn, GKAG became the leading European producer. The company's belief is that internationally operating high-tech producers need a raw material refiner who is also a global player.

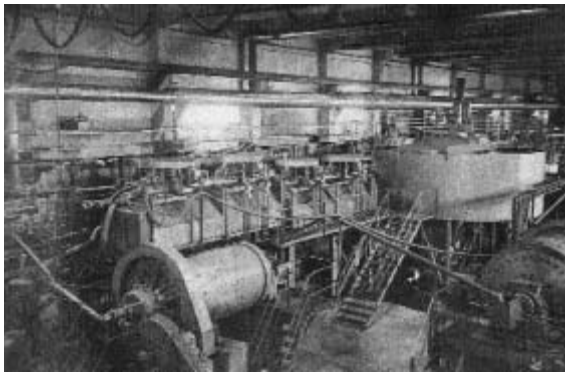
GKAG's graphite business is now divided into three separate fields. The high-grade graphite business is represented by the parent plant in Kropfmühl, Edelgraphit GmbH, Branwell and Maziva Týn. Richard Anton KG and the plant in Wedel take care of the commodity grades, and the ventures in Zimbabwe, China and Sri Lanka provide the raw materials.

In the automobile industry, GKAG's graphite is used in brake linings, and in aircraft and power plants it forms high-temperature material for turbines. Some 16% of sales are to the electrical industry, where graphite is used in carbon brushes for electric motors. Another 12% of sales is for the communications industry, such as rechargeable batteries for computers and mobile phones. Communications and automobiles are the two sectors in which GKAG predicts greatest growth.

Georg H Luh GmbH, based in Walluf, sources graphite from its single source in Norway, where it owns 45% of Skaland Grafitverk AS. It has a capacity of 10,000 tpa of natural microcrystalline graphite from -200 to +50 mesh, with a carbon content between 70% and 98%. Georg H Luh markets its graphite worldwide for refractories, crucibles, friction material and other applications. The company has made developments in flotation, to increase yield to 98% and higher.

NGS Naturgraphit GmbH is a Leinburg-based firm that offers consultancy to the worldwide graphite industry. Its fields of expertise include groundwork, planning, realisation, control and supervision. It has been involved with many of the world's biggest graphite operations and producers, including Stratmin, Woxna, Skaland, Bogola, Lakshminarayan, Sivaganga, Merelani, Ancuabe and Liumao.

Skaland Grafitverk's operations, Norway



Norway

Norway is a minor market for graphite, with average consumption over the last three years at just 140 tonnes. The country's leading graphite producer is *Skaland Grafitverk AS*, which is jointly owned by *James Durrans & Sons Ltd* of the UK (45%), Georg H Luh of Germany (45%) and *Berg Industri Selskap AS* of Skaland (10%).

Skaland is on the island of Senja, off the coast Norway some 200km north of the Arctic Circle. The mine produces 40,000 tpa of crystalline graphite flake and powder, and the plant has a capacity of 9,000 tpa. In 1999, the output was 7,900 tonnes of four graphite grades: fine powder, and fine, medium and coarse flakes with carbon contents between 85 and 97%.

In the last five years, plant upgrades have increased the yield of the coarse flake graphite, and increased carbon levels from an average of 90-92% to an average of 96%. Skaland Grafitverk's principal markets are for refractories and friction products, in Germany, the UK, France, Spain, Italy, Turkey, Egypt, Greece, Venezuela and Finland.

For the future, Skaland Grafitverk is looking towards expansion in the friction industry. The company is undertaking preliminary drilling on a deposit in nearby Traelen, which is indicated to host very high purity large graphite flakes.

Sweden

Sweden has a graphite industry of relatively modest size, producing 3-4,000 tonnes in 1999, and consuming around 1,000 tonnes. Traditional use of graphite is in powder metallurgy and foundry applications, but as Ericsson, and other players in the mobile communications industry thrive, graphite producers are also turning their attention to high-tech markets.

Woxna Graphite AB, based in Edsbyn, in the central part of Sweden, formed in 1993 as a joint venture between *WGAB*, *MIRAB Mineral Resources AB* and *Svenska Mineral AB*. It is now the full subsidiary of *Tricorona Mineral AB*, the Gothenburg-based producer of minerals for the refractory, metallurgical, ceramic and paper industries.

Woxna owns four graphite deposits around Edsbyn, which it acquired from the State Mining Property Commission in 1993, with total reserves of over 10m. tonnes. Production of flake graphite concentrate began in late 1996. The plant's initial capacity was some 8-10,000 tpa, and it made use of equipment from WGAB's gold mine in Harnäs, which had closed shortly before. In 1998, Woxna invested SEK17m. ($1.83m.) to raise capacity to 12,000 tpa.

Woxna now produces 5-6,000 tpa coarse, medium and powder grades of flake graphite with 90-94% carbon. The main applications are mag-carbon and special refractories, crucibles, foundry and brake lining in the UK, Germany, Italy, Benelux, Sweden, Spain and Turkey. Woxna is looking to expand into markets for high purity graphite, and is investigating the use of graphite in fuel cells and Li-ion polymer batteries. The company also has ongoing R&D programmes with the enrichment development company *Minpro AB*.

US graphite major Superior Graphite is also active in Sweden with its carbon additives plant in Sundsvall, on the Gulf of Bothnia.

Switzerland

In July 1999, the *Timcal Group*, based in Bodio, southern Switzerland, formed from the operational merger of all the graphite activities of Imerys. This included *Timcal Ltd* and its subsidiaries – producers of synthetic graphite products – with Stratmin Graphite Inc. of Canada, which operates the Lac-des-Îles natural graphite mine in Quebec. Timcal's natural and synthetic graphite processing operations in Changzhou, China *(Changzhou Timcal Graphite Corp. Ltd)* were also combined into the new organisation.

The merger allows the new Timcal to offer the full range of synthetic and natural graphite products worldwide. The group's total capacity for its Timrex natural and synthetic graphite products is around 40-50,000 tpa; with another 5-10,000 tpa capacity for Rollit graphitic lubricants.

Timcal Ltd formed in 1994 when *Lonza G+T* was acquired by *Mircal*, a subsidiary of Imerys' forerunner Imetal. In April 1998, Timcal took over as Stratmin's graphite agent in Russia and Europe from *Damrec*.

The 1999 merger allowed for rationalisation of production, R&D, sales and marketing. These functions were integrated in Bodio in April 2000, at the site of Timcal's synthetic graphite manufacturing and natural graphite processing plant. Two new divisions, Timcal Japan and Timcal Deutschland were created to control sales in the key markets of Japan and Germany.

In the first year after the merger, Timcal reported a 25% increase in sales. The group regained market share in the mobile energy sector, and improved sales of engineering materials, refractories and foils. The hot metal forming sector remained fairly stable. Excellent growth was seen in the refractories sector, as the industry recovered from a difficult period. Some of Timcal's customers who defected to source graphite from Mozambique and Tanzania also returned to the group after the closure of the African projects.

In the Li-ion battery market, Timcal supplies both natural and synthetic graphite. The graphite is processed into rounded "potato-shaped" particles for use in the batteries. Timcal is proceeding with the first production and expects the sector to become huge.

Timcal also hopes to enter the emerging market for graphite flame retardants. The FRs, again manufactured from Stratmin's natural graphite, are working technically, and Timcal is now looking for an outlet either with a building materials company, or

internally within the Imerys group.

Timcal believes the most promising future for graphite lies in the fuel cell industry. Fuel cell graphite must be of exceptionally high conductivity and very lightweight. Timcal is well-placed with both its natural and synthetic graphite to participate in this market and is already in partnership with car and fuel cell manufacturers.

Since the operational merger with Stratmin, Timcal has become more active in the natural graphite-consuming industries. The large flakes from Lac-des-îles have a high capacity for expansion and are well-suited to foil applications.

Over the last two years, Timcal has developed new graphite products for several industries:

- Special graphite with improved electrical conductivity for high performance alkaline batteries
- Expanded graphite for alkaline batteries
- Potato-shaped graphite for Li-ion batteries
- Graphite dispersions for coating cans, TVs and cables
- High specific surface graphite for catalyst supports
- Large particle size graphite and special cokes for friction applications
- High purity graphite for diamonds

Timcal plans to develop its operations in China, and is looking for new sources of natural graphite and to expand its existing processing operations. The company expects that any activity in China will be in the lower value end of the natural graphite market – refractories and pencils for instance – but it recognises that as processing technology improves, it is becoming possible to achieve high grades of graphite by purifying lower quality natural graphite. Timcal has been approached by a number of Chinese producers and is in the process of evaluating the best partnership.

Ukraine

The Zavalye graphite field in Ukraine's Kirovograd region has been producing graphite since the 1930s, and three periods of subsequent reconstruction have taken the capacity of the plant up to 40,000 tpa. The deposit, covering 50km^2, is worked by *Zavalyevsky Graphite Combine*, which produces more than 10 grades of graphite and one grade of abrasive garnet concentrate as a co-product of mining.

The Zavalye field has reserves of 6,418,000 tonnes, grading 5-7% graphite. The ore, kaolinised gneiss, is being extracted from the Yugo-Vostochny quarry, and processed on-site. It is beneficiated by flotation, and treated with soda ash or caustic soda at high temperature to remove impurities. Some of the chemically pure graphite is micronised and converted to colloidal graphite and lubricating fluids. Other applications include casting graphite for drilling, crucible graphite for refractories, battery graphite for high quality galvanic cells and low-ash graphite for the manufacture of artificial diamonds.

Further west, the Burtynske deposit is a crystalline graphite-bearing biotite gneiss, with total inferred resources of 1,000m. tonnes spread over four plots. The yield in the concentrate varies from 88-90%, and the graphite can be used for steel additives, graphitisers, crucibles, gun powder, batteries and lubrication.

Australia

The Australian graphite industry is in limbo, with projects on hold or abandoned. The 14,000 tpa high-grade flake Uley graphite mine, owned by *Eagle Bay Resources NL* of Perth, has been on care and maintenance since a drop in graphite prices in 1993. Eagle Bay were close to finalising a joint-venture agreement with *Harbin Liumao Carbon Technical Development Co. Ltd (HLC)* of China for the development of the project, but negotiations fell through in the final stages.

HLC, the world's largest producer of flake graphite, had agreed to refurbish the Uley plant for a production trial, and would earn a 33.3% stake in the project if the trial generated commercial production. Eagle Bay's former partner, *Mining Project Investors Ltd* withdrew from the project in 1997, after a dispute over compliance to earning conditions.

The Uley deposit is close to Port Lincoln in South Australia, and has 387m. tonnes of reserves, grading 7.4% graphite. Eagle Bay believes that with an upgrade of A$6m., the Uley plant could produce 20,000 tpa of graphite. Eagle Bay has also identified a method of producing a 99.9% carbon graphite grade from the fines discarded by coarse flake processing. The company is evaluating the possibility of processing the high-carbon graphite into electrodes for the aluminium and steel industry. This would add a high-value dimension to the existing production.

Since 1993, *Gwalia Consolidated Ltd* – part of Perth-based *Sons of Gwalia Ltd* – had been considering developing the Munglinup graphite deposit near Ravensthorpe, Western Australia. Gwalia was waiting for the market to improve before pursuing the 11,000 tpa operation, but when by June 2000 conditions had not recovered sufficiently, Gwalia relinquished its interest in the project. IM