



## CHAPTER 20

# Commodity Marketing

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# Commodity Marketing

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The discussion of the marketing of key minerals in this chapter by industry colleagues builds on the framework discussed in Chapter 3 – Revenue Estimation, which considered the changing nature of the supply and demand sides of the markets for different minerals, particularly over the past half century. It also provided a summary of the recent value and overall character of most of these markets, before considering the process of net revenue calculations in mineral processing.

The minerals in this current chapter (listed alphabetically from antimony to zinc) include those where Australia is either a world-class producer, or where production is significant for the Australian economy. In reading the contributions that focus on specific minerals the reader may find it useful to refer to Tables 3.1, 3.2 and 3.3 (Chapter 3). Over the past decade, and also for a more extended period, the size, degree of competition and prices in these markets have changed, often in important ways.

As time has gone by, the range of information accessible for individual mineral markets has grown. Some of this is public-domain data that can be accessed either without cost, or very economically. By contrast, detailed market analysis of some of the less-prominent minerals typically requires the payment of significant fees to national or international companies or organisations, or alternatively for the individual to undertake considerable research. Several contributions in this chapter refer to a variety of companies that undertake such analysis, and relevant websites are listed in the references.

## ANTIMONY

*By Chris Gregory and John Nyvlt*

Antimony is usually mined in the form of either stibnite ( $\text{Sb}_2\text{S}_3$ ) containing 71.7 per cent Sb, but in some cases in the form of complex Sb-Pb  $\pm$  As minerals.

Antimony concentrates are sold in two forms: hand-picked ores, usually the product of prospectors or countries with low labour costs, or as flotation concentrates. The price of both forms is quoted by the *Metal Bulletin*, London (MB) in US\$ per metric tonne unit (mtu). An mtu is one tonne at one per cent; that is, one tonne of 60 per cent Sb concentrate contains 60 mtu. The MB quotes a high and a low price for antimony concentrates. In a falling market, or when customer demand is weak, the low price tends to prevail, while the high price is adopted as demand increases.

Antimony concentrate is usually sold dried in polypropylene bulker bags of 800 to 1400 kg net and shipped in container loads. Most sales are to northern-hemisphere smelters, and mainly to China, all of which produce either antimony oxide or metal.

The normal minimum acceptable concentrate grade is about 35 per cent Sb. Typical smelter payments are in the range of 55 per cent to 70 per cent of the full Sb content at the MB price, but with no smelting treatment or refining charges applicable. Payments at the higher end of the range are more likely for higher-grade concentrates and when the concentrate market is tighter and vice versa.

Penalty elements are arsenic, lead, bismuth, selenium, copper and mercury. The last four elements are not known to occur at significant levels in Australian deposits.

For sales to China, the maximum allowable arsenic level is 0.5 per cent As. Higher arsenic levels may be accepted by smelters in other countries, but the options are limited. Lead can be derived either from the ore or from other minerals (usually sulfides) and is removed along with agents used in flotation. The allowable lead level is 0.5 per cent Pb with penalties applying at a rate of US\$3 per dry metric tonne (dmt) per 0.1 per cent Pb above 0.5 per cent. The allowable level for Bi is 30 ppm with very high penalty rates at higher levels of \$1/ppm per dmt, or more, above 30 ppm Bi per cent. The allowable level for Se is 40 ppm, with typical penalty rates at higher levels of \$0.30/ppm per dmt, above 40 ppm Bi; up to 0.1 per cent Cu is allowable. Higher levels are unusual, but attract a penalty subject to negotiation. Penalty terms for mercury in concentrate can be severe.

The only co-product payments for stibnite concentrates are for gold. Appreciable silver in stibnite concentrates is rare. For concentrates of Pb-Sb minerals, payments for silver can be expected, at rates perhaps of 65 per cent of those applicable for silver in Pb concentrates.

For stibnite concentrates, most smelters are unable or unwilling to credit gold due to a lack of a gold recovery circuit; in China this is because of complex taxation issues related to gold. For the Chinese smelters that are able to recover gold, a payment is applicable only above a minimum content, which is typically 15 to 20 ppm Au. Payment in excess of the minimum is normally based on a steeply sliding scale rated with gold content.

The payment ratio may be as low as 25 per cent to as high as 90 per cent of the gold content at the full gold price. However, the very high payment ratios are only applicable for gold contents above 100 g/dmt.

The antimony market is dominated by China, although China increasingly needs to import concentrates, particularly from Canada, Australia, Tajikistan, Siberia, Thailand, Bolivia, Turkey and South Africa. In recent years, concentrate prices have been volatile due to the large swings in the international Sb metal price and changes in mine supply. Currently there is a resurgence of western-world mine supply and this trend is expected to continue as China depletes its ore resources. This trend is likely to be exacerbated by stricter Chinese environmental and safety controls being implemented on mining in their country. A prime end-use for antimony is as a flame retardant in textiles and polyethylene terephthalate (PET) plastics, for example in airline seats. There is also a growing use in semiconductor applications. Antimony continues to be used as an alloying metal, particularly as a hardener of lead.

## BAUXITE

*By Peter Bath and James Salter*

The characteristics and marketing of both bauxite ore and refined alumina are considered in this section.

### Bauxite and alumina characteristics

Almost all aluminium metal is derived from bauxite. Bauxite is chemically refined to pure aluminium oxide or alumina ( $\text{Al}_2\text{O}_3$ ) before it is electrolytically reduced to aluminium metal. Because electric power is a high-cost component, smelters are often found close to cheap power sources. Bauxite is generally found in tropical regions (eg Australia, Brazil, Guinea, Venezuela, Jamaica and Indonesia). Strategic placement of alumina refineries is, therefore, a key consideration within the industry. Generally, lower-cost refineries tend to be on or close to bauxite mines, but some bauxites are still traded over long distances.

Typical compositions of traded bauxites are outlined in Table 20.1. These bauxites are of sufficiently high grade to warrant transport.

Typically, tropical bauxite contains much of the alumina in the form of gibbsite  $\text{Al}(\text{OH})_3$ , which is sometimes described as trihydrate alumina,  $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ . Where this is the major form of alumina, the bauxite can be treated by a low-temperature digestion around  $150^\circ\text{C}$ . Bauxites from Jamaica, Brazil, Western Australia and the Northern Territory fall into this category.

Some bauxites contain significant amounts of alumina in the form of boehmite  $\text{AlO}(\text{OH})$ , which is sometimes written as monohydrate alumina,  $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . Bauxites containing significant amounts of boehmite require a high-temperature process (around  $230 - 280^\circ\text{C}$ ) to

TABLE 20.1  
Typical compositions of traded bauxites.

	$\text{Al}_2\text{O}_3$	$\text{SiO}_2$	$\text{Fe}_2\text{O}_3$	$\text{TiO}_2$	Loss on ignition (%)
Boke (Guinea)	59.5	1.6	5.7	3.6	29.7
Weipa (Australia)	54.6	5.6	12.0	2.6	25.0
Gove (Australia)	50.2	3.7	17.3	3.2	25.4
Trombetas (Brazil)	50.0	4.0	17.5	2.8	25.5

digest the bauxite. Bauxites from Weipa in Australia and Guinea require high-temperature plants.

In the refinery, bauxite is digested in hot caustic soda ( $\text{NaOH}$ ). The alumina is dissolved and impurity oxides of  $\text{Fe}_2\text{O}_3$  and  $\text{TiO}_2$  are separated and discarded as 'red mud'. Trihydrate alumina is recovered from the process by cooling and precipitation from the sodium hydroxide solution, which is recycled to digestion. The trihydrate alumina is calcined to produce the final alumina product.

Silica ( $\text{SiO}_2$ ) is usually present as kaolinite ( $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ ) and quartz ( $\text{SiO}_2$ ). Essentially all of the kaolinite will react with sodium hydroxide at either high or low temperature to form insoluble silicate compounds, which are discarded with the red mud. At high temperatures, a portion of the quartz reacts with sodium hydroxide and alumina.

Tropical bauxites also contain trace quantities (typically 0.1 - 0.3 per cent) of organic carbon. This also reacts with sodium hydroxide to form sodium carbonate, sodium oxalate and a variety of longer chain sodium organic compounds. The presence of these compounds increases the equilibrium solubility of the liquor and makes precipitation more difficult. Refineries processing tropical bauxites generally require some form of organics control.

To determine the value of a bauxite it is usually necessary to carry out laboratory autoclave digestions to simulate refinery conditions and gain an insight into likely refinery economics. Terminologies describing the properties of bauxite vary somewhat between companies, but the following tend to be followed in Australia and North America:

- total chemical alumina (TCA) – determined by wet chemical analysis or X-ray fluorescence (XRF), includes alumina in all mineral forms
- total available alumina (TAA) – total amount of alumina extracted by high-temperature autoclave digestion; the temperature is not specified by standards, but is usually over  $200^\circ\text{C}$ ; TAA allows for the loss of some alumina as complex silicates in



the red mud where the amount lost depends on the amount of silica in the bauxite

- trihydrate alumina (THA) – amount of alumina extracted in low-temperature autoclave digestion (140 - 150°C); the THA value generally corresponds to the amount of gibbsite in the bauxite, but again allowance is made for losses of alumina in the silicates precipitated in the red mud
- monohydrate alumina (MHA) – not determined directly, but obtained by difference according to the expression  $MHA = TAA - THA$
- total silica – total  $SiO_2$  present; reactive silica is the  $SiO_2$  present as kaolinite.

These properties are useful descriptive terminologies that relate to plant performance. However, people working in the industry now prefer to use true mineralogical definitions such as gibbsite and boehmite.

Some typical performances of bauxites in autoclave digestion are outlined in Table 20.2. As previously noted, the value of the bauxite is dependent on the silica level as well as alumina, but in these analyses emphasis has been placed on the amount of soluble silica present.

**TABLE 20.2**  
Mineralogical composition by autoclave digestion.

	TCA (%)	TAA (%)	THA (%)	Reactive $SiO_2$ (%)
Weipa	54.6	50.1	40.3	4.6
Gove	50.2	46.4	43.9	3.2
Trombetas	50.0	46.1	44.1	3.3
Darling Range (WA)	35.0	32.0	31.0	1.2

Note: TAA = total available alumina; TCA = total chemical alumina; THA = trihydrate alumina.

It is useful at this stage to comment on other bauxite types that are used in the industry. In Western Australia, the Darling Range bauxites are, at first sight, low-grade. Typically, they have only 35 per cent  $Al_2O_3$  and 20 - 25 per cent  $SiO_2$ . However, full mineralogical analysis shows that most of the silica is quartz, while most of the alumina is gibbsite. These bauxites may, therefore, be inexpensive to process in local refineries at low temperature (150°C) with very low sodium hydroxide losses. The Western Australian bauxites are, however, too low-grade to transport over large distances.

Not all bauxites are tropical, but the use of other types is declining. There is now little mining of bauxite in Europe, but some diasporic-type bauxite is mined in Greece. Similar diasporic bauxite is mined extensively in China. Diaspore is a hard rock form with the same essential formula as boehmite, which is  $AlO(OH)$  or  $Al_2O_3 \cdot H_2O$ . However, it is very hard to dissolve and requires temperatures in excess of 260°C, with

substantial lime addition. It is likely that imports of tropical bauxites will eventually replace diasporic.

The relative importance of various components varies with bauxite, refinery location and commodity prices. The following list can be taken as a rough guide to the main components of operating cost:

- bauxite costs – highly variable, depending on whether the bauxite is obtained from a nearby mine (and transported to the refinery by conveyor), or whether the cost of transport (shipping or slurry pipeline) has to be added
- sodium hydroxide makeup – required to balance losses to silica and carbon reactions and losses with the red mud and product; sodium hydroxide losses are determined by the reactive silica content of the bauxite and also by losses with liquor reporting to the red mud; the cost of sodium hydroxide is highly variable
- energy – required for steam raising (mainly for digestion) and calcination and as electricity for grinding and other motive power; in a low-temperature refinery it may be possible to cogenerate electricity and steam; for a refinery that cogenerates, a total energy consumption of 10 GJ/t alumina, including 200 kWh/t alumina for electricity, is a reasonable starting point; the source of energy depends on location
- labour costs – depend on location and workforce size; low labour cost locations also tend to have low labour productivity.

Other operating costs to be taken into account include:

- consumable and operating spares
- contract services
- lime – used for control of phosphorus
- other chemicals – flocculant (for the mud washing circuit) and water.

The rate at which red mud is produced depends on the TAA of the bauxite. This is measured by the 'mud factor' (tonnes of red mud solids per tonne of alumina). The mud factor is unlikely to be less than one; for Darling Range bauxites it is greater than three. Red mud is a toxic waste and must be contained. Availability of space for the red mud storage is a major consideration in selecting a refinery site. The containment must be continually enlarged, incurring ongoing capital costs.

Not all bauxite is converted to smelter-grade alumina. There are specialist markets in the following areas for around ten per cent of the world's bauxite:

- abrasives manufacture
- chemicals manufacture
- refractory manufacture
- steel fluxing
- water treatment.

All these areas have special technical requirements, but primarily a high alumina content is sought.



## Bauxite and alumina marketing

Australia is the largest bauxite producer in the world, accounting for around 30 per cent of the 231 Mt of bauxite produced worldwide in 2010 (Figure 20.1).

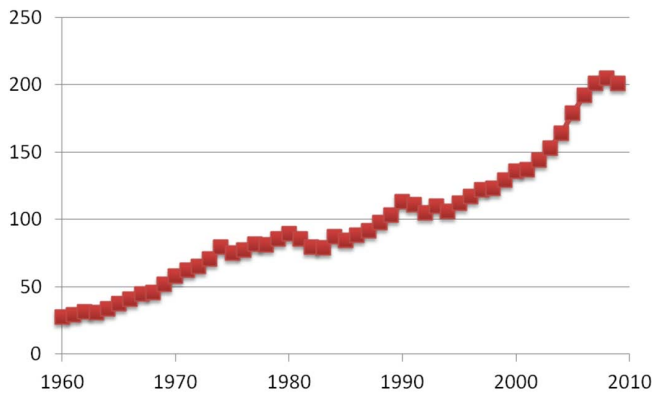


FIG 20.1 - World bauxite production (Mt) from 1960 to 2009.

Bauxite sold in bulk to alumina refineries is usually priced on the basis of long-term contracts. Contract prices are of two types:

1. formula prices within consortium refinery operations, such as Queensland Alumina Ltd (QAL) in Gladstone, Queensland
2. contract prices in the third-party market.

Because bauxite quality can vary, an average price for bauxite is not very meaningful and such information is not made public. However, it is understood that bauxite prices have generally increased over the past decade, and as an indication, prices for Australian bauxite may be US\$20 - 30/t on a free on board (FOB) basis.

For traded bauxites the lower limit on available alumina content is about 50 per cent, with an upper limit of about six per cent on reactive silica.

World production of alumina was estimated at 82 Mt in 2010. Contracts for the sale of alumina tend to be medium-term in nature. Contract alumina prices are not normally reported although spot prices on an Australia FOB basis fluctuated between US\$300 and US\$400/t in 2010. An indication of the price of alumina delivered in 2010 under long-term contracts would be US\$350/t FOB basis.

## COAL

*By Hugh K Babbage*

Coal exported from Australia is generally classified as hard (and semi-hard) coking, semi-soft coking, pulverised coal injection (PCI) or thermal coal. Coking and PCI coals are primarily used in steelmaking, while thermal coal is mainly used for power generation.

Coal is a high-volume bulk commodity. Geographic and infrastructure factors play substantial roles in determining its delivered cost to its end-users, with freight and other distribution costs often a significant

proportion of the total. As a result most Australian coal is sold in Asia, although coking and PCI coals also have strong markets in Europe and Brazil. Unlike many other bulk commodities almost all mines produce a coal with unique physical and chemical properties. Thus, most buyers, in particular of coking coal, will not generally interchange coal types at short notice. Coal is commonly sold on FOB, cost and freight (CFR) and cost insurance freight (CIF) bases. Asia is almost totally an FOB market.

Much of Australia's coal exports are sold under long-term buyer-seller relationships, often against long-term contracts. Contracts of this nature usually specify annual tonnages to be delivered, but allow for price renegotiation at various intervals, traditionally annual, now increasingly quarterly.

## Coking coal

Coke makers worldwide blend coals of different qualities to achieve desired coke properties. Generally, this requires the use of high-, medium- and low-volatile coals. Typically, high-volatile coals have plastic properties, which facilitate the agglomeration of coke, and also contribute gas to by-product circuits. Lower-volatile coals have higher coke yields and produce stronger cokes. Most coke oven operators target 24 - 26 per cent volatile matter for their feed blend. Coals in this medium-volatile range are highly rated as the blending requirement to achieve the desired final coke oven charge is reduced. These generalisations should be treated with care as coking coal customers have many different opinions and requirements, for example based on the types of equipment they use, their experience and local coals that are, or were historically, available to them.

The prime coking coals used by coke makers are the hard coking coals, typified by the well-known brands produced in Queensland's Bowen Basin and other parts of the world for the international market, mostly the USA and Canada. Hard coking coals have the highest price of all coal types and, reflecting their generally tight supply-demand balance, as well as the relatively small number of major producers, these prices have increased substantially over the past decade.

A subcategory of hard coking coal is semi-hard coking coal, a commercial category established by the Japanese steel mills (JSM) in the 1990s to formalise a price discount system to reflect negative quality differences against hard coking coals. In some cases, a semi-hard coking coal may simply be a recognised hard coking coal, but with higher ash or sulfur or some other quality deficiency. In other cases a semi-hard coking coal has coking qualities between those of hard and semi-soft coking coals.

Semi-soft coking coals traded internationally are mostly exported from Australia, mainly for use in Japan, Korea and Taiwan. They are typified by the

higher-volatile weaker-coking coals produced in the Hunter Valley of New South Wales, the so-called ‘Newcastle semi-soft coking coals’. They also include a range of coals of all volatile levels, but with poorer coking qualities. The Newcastle semi-soft coking coals can also usually be used as PCI coal and, when washed to produce a higher ash at higher yield, as thermal coals. This interchangeability of the end-uses of these coals sometimes affects pricing for both the semi-soft and thermal coal markets.

Typical specifications for coking coals include detailed proximate and ultimate analyses; coke strength data; fluidity and rank information; and other test results. Of particular importance are moisture level, coking properties, volatile matter, ash and sulfur contents. The volatile matter level determines the market segment in which the coal competes, and the ash, coking properties, sulfur and moisture contents determine a coal’s competitive value in its respective market segments. Coke makers often have a target coke strength after reaction (CSR), which typically forms part of any evaluation. Other properties, particularly phosphorus and alkali levels, can also affect a coal’s acceptability, more likely as a negative rather than a positive factor.

Coking coal pricing in Asia was, until recently, established by means of a formal annual negotiation process between the JSM and leading producers from Australia and Canada. This process focused on hard coking coal pricing and, once agreement was reached, the settlement level would be used to establish prices for semi-hard and semi-soft coals. However, over the past few years this annual pricing system has been changing. The most visible coking coal pricing mechanism is now based on quarterly pricing agreements between the JSM and the producers. A further shift to monthly pricing is being pursued. However, not all buyers and producers are in accord with these changes. A range of outcomes is now common, with buyers and sellers sometimes working with a combination of annual, half-yearly and quarterly agreements, and perhaps also including spot deals for top-up cargoes. A spot market for coking coal, once almost non-existent, has also developed in recent years, to the point of now being regularly reported in coal industry publications. While not yet in place, the establishment of a financial market for coking coal trade has been suggested.

Other Asian countries such as Korea, Taiwan and China traditionally follow Japanese coking coal pricing, although slight variations in specifications are often used to achieve relatively small discounts to the headline prices. Another significant Asian coking coal importer is India, which while generally following the Japanese steel mill prices for its longer-term contracted supplies, is also a major buyer through regular tenders. When the annual pricing system prevailed, and there was a very limited spot market, these tenders gave the

only meaningful insight into market pricing during a year; however, the tender results now closely follow the quarterly JSM pricing.

Coking coal sold into the European and Brazilian markets generally returns lower prices to Australian producers than in Asia, mainly due to the need to compete with US supply. As in the Asian market, each coal attracts a different price depending on its advantages and disadvantages as perceived by the buyer. However, traditional Asian market relativities are more loosely defined by European buyers.

### **Pulverised coal injection coal**

PCI coal is also used in the steelmaking industry, although in a different way from coking coal. Its use in significant quantities began in the late 1970s as a response to the oil shocks of that decade, replacing the fuel oil that had traditionally been injected into the bottoms of blast furnaces. The fuel oil provided fuel and heat in that part of the furnace and generated carbon monoxide as a reducing gas to work its way upwards, and facilitate the reduction of iron ore to liquid iron. Initially the coals used generally contained higher volatiles and such coals are still widely used. In particular Japan and Korea use the Newcastle semi-soft coking coals. However, in the 1990s blast furnace operators, particularly in Europe, began to increase PCI usage rates, recognising that one tonne of lower-cost PCI could replace up to 0.8 t of expensive coke, sometimes more. As these rates were pushed ever higher, this replacement ratio was maximised due to thermodynamic effects with the use of lower and low-volatile coals. This led to the creation of the mostly Australian-based low-volatile PCI business, mostly based on semi-anthracite and other heat-affected Queensland coals.

These low-volatile PCI coals are in demand worldwide, with Australian exports to east Asia, Europe and Brazil, often on the same vessels as coking coal products. A separate pricing category has evolved for these coals, related to semi-soft coal pricing. However, it is usually at a premium, recognising the higher value in use that the lower-volatile coals have, compared to using Newcastle semi-soft coal for PCI operations.

PCI coal buyers look for several specific quality parameters. Obviously volatile matter is a major factor, as is ash, which is preferred to be in-line with coking coal ash levels. As with coking coals, sulfur and phosphorus are required to be low, as these contaminants will end up in the hot metal. Many buyers also prefer PCI coals to have low crucible swelling number (CSN) so as to avoid potential blockage difficulties around the injectors. In general, while the energy level is required to be high, the low ash requirement usually ensures this to be the case.

### **Thermal coal**

Thermal coal is burned as an energy source, and most customers are electricity-generating utilities. Despite

the apparent market segregation, Asian thermal coal prices have in the past been influenced by coking coal prices, with the prevailing contract price generally following the trend established in the coking coal market. However, this has changed substantially over the past decade as a large proportion of business has become subject to relatively short-term tenders and even shorter-term spot deals. In parallel, the financial market for thermal coal has grown with many players active. These include producers, end-users, traders, banks and others, making a continuous market based on numerous supply and delivery points worldwide. Thus, the thermal coal market has been largely commoditised. Notwithstanding these developments, Asian utilities, notably in Japan, continue to purchase sizeable proportions of their supply under long-term contract arrangements, but with pricing on several period bases, including annual, biannual and quarterly, and referenced to the now-independent thermal coal market pricing mechanisms.

Australian thermal coal producers once sought markets in Europe for a proportion of their sales as a means of diversification, albeit at some cost relative to Asian pricing, as these sales were made in competition with supply from countries including South Africa, Colombia, USA and Russia. Little Australian thermal coal now finds its way to Europe, as most of the larger Australian producers now have their own inbuilt diversification through worldwide operations.

Australia's major thermal coal competitors are Indonesia, now the world's largest thermal coal exporter, and occasionally South Africa, USA, Russia, Columbia and Canada. China, once a significant thermal coal exporter, is now a net importer. Thermal coal is bought for its energy and its most important property is its energy level, commonly expressed in kcal/kg, MJ/kg or British thermal units (BTU)/lb. Thermal coal contracts are generally written with the price referred to an energy level base, usually with a pro rata price adjustment for the delivered energy level. As the moisture level has a direct influence on the net energy, customers typically prefer contracts written on an 'as received' basis, while producers, particularly of higher moisture coals, often favour 'air dried' contracts. Other physical and chemical properties that may influence a coal's suitability to a particular power utility, and hence the price that utility will pay, include ash content, volatile matter, sulfur, ash fusion temperatures and hardness. As with coking coal, each buyer's requirements are likely to be slightly different with regards to these properties.

### Coal property terms

Common terms used to describe coal properties are given in this section.

#### *Alkalis*

The most important alkalis in coal are sodium and potassium. They are undesirable in steaming coals

because they can give rise to fouling and slagging problems in boilers, although small additions can improve electrostatic precipitation performance. They are undesirable in coking coals because they tend to increase coke reactivity (ie rate of coke consumption) in the blast furnace.

#### *Ash*

Ash is the inorganic residue after the incineration of coal to constant weight under standard conditions. It is less than the mineral matter content because chemical changes occur during incineration. Most important differences are loss of water of hydration, loss of carbon dioxide and loss of sulfurous gases from sulfides.

#### *Ash fusion*

The ash fusion properties of laboratory-prepared coal ash are demonstrated by heating the ash in a mildly reducing or oxidising atmosphere. The temperature range generally used is 900°C to 1600°C. The temperatures that can be recorded are initial deformation temperature, softening temperature, hemisphere temperature and fluid (flow) temperature. Almost invariably the temperatures recorded under a reducing atmosphere are lower or equal to those recorded under an oxidising atmosphere. Of the characteristic temperatures the 'initial deformation' and 'flow' are generally the most difficult to reproduce.

#### *Coke strength after reaction*

The CSR is determined by a laboratory test designed to give an indication of the strength of coke after it is exposed to the reducing atmosphere of the blast furnace. Coke, after exposure to the high temperature and carbon dioxide atmosphere of the coke reactivity test (CRI), is tested in a tumbler device to determine its strength.

#### *Coking coal*

This is coal that, because of its characteristics, is suitable for carbonising to produce blast furnace coke. Important properties required technically to produce good coke include good coking and caking properties such as fluidity, dilatation and CSN, allied with an appropriate rank indicated by reflectance values around 0.9 - 1.5 per cent. Other properties that are important for commercial reasons are ash and moisture, which should be as low as possible. Sulfur and phosphorus contents are important because of their deleterious effects on pig iron.

#### *Crucible swelling number*

CSN is one of the most common simple caking tests. Finely crushed coal is heated rapidly in a crucible and the coke button obtained is compared with a series of standard profiles to give the CSN. Values range from zero (no caking characteristics at all) to 9 then 9+ (superior coking properties). The results obtained in



the test can be affected by oxidation, size distribution and moisture of the sample, and care should be taken in interpretation of results. In the USA, it is known as the free swelling index.

### *Fluidity*

Fluidity is the measurement resulting from a test using a Gieseler plastometer. Unpulverised fine coal is heated slowly and its fluidity is measured as it melts and passes through its plastic range. Results are expressed as maximum fluidity in dial divisions per minute (ddpm). The characteristic temperatures recorded include initial softening temperature, maximum fluidity temperature and resolidification temperature. The plastic range, which is the temperature range during which the coal is in its plastic state, is also important. All coking and caking tests are sensitive to oxidation, but the Gieseler test is by far the most sensitive. There are two types of Gieseler plastometers: automatic and manual. Manual equipment gives results that are 50 per cent to several times higher than those from the automatic equipment.

### *Gross calorific value*

The gross calorific value (GCV) is defined as the amount of heat liberated during laboratory testing when coal is combusted under standard conditions, with the temperature of starting materials and products being approximately 25°C. During combustion in boilers the GCV is never achieved because some of the products, most importantly water, are lost in the gaseous state with their associated heat of vaporisation. The maximum achievable calorific value under these conditions is the net calorific value. Calorific value (CV) is also known as specific energy and the gross and net CV are known as the higher and lower heating values in some countries. GCV can be expressed in many ways, the most common include kcal/kg, MJ/kg and BTU/lb.

### *Nitrogen*

Part of the organic material in coal contains nitrogen. Under certain combustion conditions a portion is emitted to the atmosphere as polluting nitrogen oxides unless removed from the flue gases.

### *Phosphorus*

Phosphorous is avoided in coking coal because it accumulates in the hot metal and gives undesirable properties to the resultant steel. It can also create problems during combustion as it forms hard phosphatic deposits inside boilers.

### *Rank*

Coals vary in composition and properties in accordance with the extent of alteration, or degree of coalification, of the original organic material from which they are derived. The concept of rank is used to indicate the

stage of alteration obtained by a particular coal: the greater the alteration, the higher the rank of the coal. Thus, lignites and sub-bituminous coals are low rank, while semi-anthracites and anthracites are high rank.

### *Sulfur*

Sulfur can be part of the carbonaceous material in coal, or part of the minerals present as sulfates or sulfides. It forms sulfur dioxide during coal combustion, which is a serious pollutant. Most countries regulate emissions to the atmosphere. Sulfur is undesirable in coking coal because it partly accumulates in the hot metal during steelmaking and requires desulfurisation to remove it if above 0.02 per cent.

### *Total moisture*

This is defined as the moisture in the coal as sampled and which is removable under standard conditions.

### *Volatile matter*

Volatile matter is defined as the loss in mass, less that due to moisture, when coal is heated under standard conditions and out of contact with air. This test is highly empirical and results are very sensitive to operating conditions. Results obtained from different standard methods will not necessarily give the same result. The US ASTM<sup>1</sup> method generally gives a higher result than other methods.

## **COPPER**

*By Albert de Sousa*

This section presents market factors for the production and pricing of copper and includes revenue calculations.

### **Market**

The main market for copper concentrates is made up of the world's custom copper smelters. Integrated smelters may also make some custom purchases. Custom smelters are those that purchase concentrates from third parties, while integrated smelters have a captured source or sources of concentrate feed. The delineation between integrated and custom smelters has become less clear in recent years as previously integrated smelters look for custom feed from time-to-time. Moreover, custom smelters may seek to achieve a degree of self-sufficiency through investment in mines or mining projects.

### **Refining technology**

Copper metal can be produced directly from copper oxide ore by acid leaching and solvent extraction-electrowinning (SX-EW). This section refers only to copper concentrates produced from sulfide ores. For information on SX-EW refer to Chapter 16 – Electrolytic Processes.

1. Formerly the American Society for Testing and Materials, it is now known as ASTM International. It provides the US equivalent of Australian Standards.

Copper sulfide concentrates are processed into copper metal and other by-products by using a variety of smelting methods, followed by electrowinning. Smelting methods include conventional reverberatory and converter systems; the Mitsubishi continuous process; the Noranda process; Outokumpu flash smelting; and Isasmelt technology. In addition, development of hydrometallurgical processes such as the Sherritt Cominco process, N-Chlo and CESL is continuing.

### Concentrate quality

The copper content of concentrates can generally vary between 18 and 38 per cent; most fall in the range of 20 - 30 per cent. The average grade of concentrate has fallen significantly over recent years: smelters that once achieved an average feed blend of about 31 - 33 per cent may now achieve a blend of about 27 - 29 per cent. The drop in grade has forced smelter operators to alter operations, which in some cases may have a material impact on their levels of metal recoveries (eg copper, gold, silver).

'Clean' concentrates (derived from porphyry orebodies) may carry virtually no lead and zinc (<0.5 per cent) or other deleterious elements in quantities harmful to the smelting and refining processes.

Most smelters will accept certain levels of deleterious or 'penalty' elements, which are subject to penalties being applied. Sensitivity to any given element will vary among smelters and may be governed by a number of factors, including local environmental considerations, trade regulations such as the World Trade Organization (WTO) and the smelter's overall exposure to the element in question from all supply sources.

Penalty elements of concern to smelters include lead, zinc, arsenic, bismuth, cobalt, nickel, mercury, antimony, chlorine and fluorine.

### Smelters

China has overtaken Japan as the geographic centre of primary copper production, although Japan still plays an important role in the custom concentrate market. Major smelters are also located in Korea, India and the Philippines. Custom smelters in Thailand and Port Kembla, Australia, have closed in recent years.

Australian concentrate is overwhelmingly destined for these Asian smelters, although shipments to European or other smelters are made, albeit at higher freight costs. The traded market for copper concentrate is generally undertaken in a cost insurance freight/cost and freight (CIF/CFR) basis with FOB sales in the minority.

Comprehensive lists of copper smelters are obtainable from commodity research companies such as CRU International Ltd, Wood Mackenzie and Bloomsbury Minerals Economics Ltd.

### Initial pricing estimate

As an example, historically the net smelter return was between 70 per cent and 80 per cent of the value

of the metal contained in the concentrate. However, a sustained period of strong metal prices has seen smelters' share of revenue fall to about five to ten per cent, or less in the case of concentrates with high precious metal contents.

### Detailed pricing estimate

For a more detailed estimate, each component of the smelter terms should be calculated. The structure of copper smelter terms is described below and a worked example is given in the section 'Example of revenue calculation'.

#### *Payable metals*

Typical payments for metals contained in copper concentrates include:

- copper – pay for about 96.5 - 96.75 per cent copper content subject to a minimum deduction of about 1.0 - 1.10 units
- gold – pay for gold content about 90 - 98.5 per cent with no minimum deduction; a detailed scale may be applied up to about 50 g/dmt
- silver – pay for 90 per cent of silver content subject to a minimum content of 30 g/dmt, or an outright deduction of about 10 - 20 g/dmt.

#### *Treatment and refining charges*

Smelter charges are typically a combination of separate treatment charge (TC) and refining charges (RC). Some sales contracts use a combined TC-RC. The TC is a fixed deduction per dmt of concentrate.

The RCs are based on the payable metal content for each respective metal (copper, gold or silver) The RCs and combined TC-RC are expressed in US cents per pound (US¢/lb) of payable copper. Price participation (PP) may also be included in the terms (see 'Price participation' below).

The combined TC-RC-PP is only poorly correlated to the copper price in the short-to-medium term. Other variables such as smelter capacity utilisation, exchange rates, acid credits and duties have significant effects on the final return to the smelter. One-off events, such as the impact of the tsunami on Japan's Onahama smelter, may result in short-term impacts to the prevailing trend.

As a rough indication, the combined TC-RC-PP ranges from US\$0.10 to US\$0.18/lb.

Prevailing market TCs-RCs are obtainable from publications by industry research bodies such as Wood Mackenzie (formerly Brook Hunt and Associates Ltd) and CRU International Ltd.

#### *Price participation*

A PP arrangement would increase or decrease the copper RC above or below an agreed trigger level. Historically, this trigger level was at a copper price of US\$0.90/lb. At other times, a neutral zone has been included at, say, between US\$0.80 and US\$0.90/lb.

Examples of PP terms are:

- if price >US\$0.90/lb, add ten per cent of differential in price to RC
- if US\$0.80/lb <price <US\$0.90/lb, no change
- if price <US\$0.80/lb, deduct ten per cent of differential in price from RC.

Therefore, at a copper price of US\$2.50/lb and a trigger of US\$0.90/lb, ten per cent of the price differential (ten per cent × \$1.60 = US\$0.16/lb) would be applied. A copper RC of, say, US\$0.07/lb would be increased to US\$0.23/lb.

A cap and/or a floor may also be applied, usually expressed in US¢/lb.

PP was eliminated from major market contracts in 2007, and at the time of publication it has not been reintroduced.

**Precious metal refining charges**

Refining charges may be imposed for precious metals. Typical formulas are:

- silver – US¢30 - US¢40/oz payable silver
- gold – US\$3.00 - US\$7.00/oz payable gold.

**Penalties**

Penalties are imposed for undesirable elements that increase the smelter’s costs. Typical penalty elements and formulas are shown below. All calculations are on a pro rata basis. For example, if the Pb grade is 2.5 per cent, the penalty would be (2.5 per cent - 2.0 per cent) × \$2.00 = US\$1.00/dmt concentrate. Some concentrates may be rejected by smelters because they contain a high level of a certain penalty element.

**Worked example**

A worked example of the calculation of the net smelter return (NSR) for a copper concentrate in US\$ is shown below.

**Concentrate specification**

Cu	28.0%
Au	25 g/dmt
Ag	40 g/dmt
As	3000 ppm
F	500 ppm
Pb	3.0%
Zn	4.2%
Bi	490 ppm
Sb	300 ppm
Hg	9 ppm

**Commercial terms**

Treatment charge	US\$70.00/dmt
Refining charge Cu	US\$0.07/lb
Refining charge Au	US\$5.00/oz (all ounces are troy oz equivalent to 31.1035 g)

Refining charge Ag	US\$0.40/oz
Penalties As	US\$2.00/dmt concentrate for each 1000 ppm above 2000 ppm
F	US\$1.00/dmt concentrate for each 100 ppm above 330 ppm
Pb	US\$1.50/dmt for each 1.0% above 1.0%
Zn	US\$1.50/dmt for each 1.0% above 3.0%
Hg	US\$0.20/dmt concentrate for each 1.0 ppm above 10 ppm
Bi	US\$2.00/dmt for each 100 ppm above 500 ppm
Sb	US\$0.50/dmt for each 100 ppm above 1000 ppm

Payable copper	96.5 per cent subject to a minimum deduction of 1.0 per cent unit
Payable gold	less than 1 g/dmt, then 0% equal to or more than 1 g/dmt, but less than 3 g/dmt, then 90.00% equal to or more than 3 g/dmt, but less than 5 g/dmt, then 94.00% equal to or more than 5 g/dmt, but less than 10 g/dmt, then 95.00% equal to or more than 10 g/dmt, but less than 15 g/dmt, then 96.00% equal to or more than 15 g/dmt, but less than 20 g/dmt, then 96.50% equal to or more than 20 g/dmt, but less than 30 g/dmt, then 97.00% equal to or more than 30 g/dmt, but less than 50 g/dmt, then 98.00% equal to or more than 50 g/dmt, then 98.25%

Payable silver	equal to or great than 30 g/dmt, then 90.00%
Prices	Cu US\$7000.00/t Au US\$1200.00/oz Ag US\$20.00/oz
Revenue	Calculated per dmt of concentrate Cu 28% less 1.0% unit = 27% × US\$7000 = \$1890/dmt Au 25.0 g/dmt × 97.00% = 24.25 g/dmt 24.25 / 31.1035 × US\$1200/oz = US\$935.59/dmt Ag 40 g/dmt × 90% = 36 g/dmt 36/31.1035 × US\$20/oz = US\$23.15/dmt

At 28 per cent copper content and a 96.5 per cent payable rate, the minimum deduction of 1.0 per cent unit will apply. If 96.5 per cent is applied, the payable content would be 27.02 per cent, which would not exceed the minimum deduction. Hence the minimum deduction must be applied.

**Total revenue** US\$2848.74/dmt

Treatment charge US\$70.00/dmt

#### Refining charges

Cu  $27\% \times 2204.6206 \text{ lb} = 595.25 \text{ lb} \times \text{US}\$0.07/\text{lb} = \text{US}\$41.67/\text{dmt}$

Au  $24.25 \text{ g} / 31.1035 \text{ g} = 0.78 \text{ oz} \times \text{US}\$5.00 = \text{US}\$3.90/\text{dmt}$

Ag  $36 \text{ g} / 31.1035 \text{ g} = 1.16 \text{ oz} \times \text{US}\$0.40 = \text{US}\$0.46/\text{dmt}$

For copper, each dmt has a weight equivalent of 2204.6206 lb avoirdupois. Refining charges are levied on payable metal quantities rather than analytical quantities.

#### Metal deductions

Cu  $1.0\% \times \text{US}\$7000 = \text{US}\$70.00/\text{dmt}$

Au  $0.75 \text{ g/dmt} / 31.1035 \text{ g} \times \text{US}\$1200/\text{oz} = \text{US}\$28.94/\text{dmt}$

Ag  $4 \text{ g/dmt} / 31.1035 \text{ g} \times \text{US}\$20/\text{oz} = \text{US}\$2.57/\text{dmt}$

#### Penalties deductions

As  $3000 \text{ ppm less } 2000 \text{ ppm (trigger)} = 1000 \text{ ppm}$   
 $1000 \text{ ppm} \times \text{US}\$2.00/1000 \text{ ppm} = \text{US}\$2.00/\text{dmt}$

F  $500 \text{ ppm less } 330 \text{ ppm} = 170 \text{ ppm}$   
 $170 \text{ ppm} \times \text{US}\$1.00/100 \text{ ppm} = \text{US}\$1.70/\text{dmt}$

Pb  $3.0\% \text{ less } 1.0\% = 2.0\%$   
 $2.0\% \times \text{US}\$1.00/1.0\% = \text{US}\$2.00/\text{dmt}$

Zn  $4.2\% \text{ less } 3.0\% = 1.2\%$   
 $1.2\% \times \text{US}\$1.50/1.0\% = \text{US}\$1.80/\text{dmt}$

Hg 9 ppm – not penalisable

Bi 490 ppm – not penalisable

Sb 300 ppm – not penalisable

**Total deductions** US\$225.04/dmt

**NSR** US\$2623.70/dmt

## DIAMONDS

*By Peter McCarthy*

Diamond is composed of carbon and is the hardest known substance – although it can be shattered by a sharp blow. Its high refractive index and power to disperse light gives diamond its brilliance and fire. If heated to bright red it will burn. The weight of diamond is measured in carats (one carat = 0.2 g). A one-carat cut and polished diamond is about 6.5 mm across.

## Australian deposits and types of mining

Australia's diamond production comes from the very large, low gem-quality-content Argyle deposit in the Kimberley region of north-western Australia. Relatively small resources of alluvial diamonds have been worked nearby in Smoke Creek. Several kimberlite pipes, with much higher gem-quality diamond content than Argyle, have been mined at Merlin in the Northern Territory.

The Argyle open pit mine has reached its economic pit limits. It is being redeveloped by its owner, Rio Tinto, as an underground block cave project that is scheduled to be operational in 2013. The project will extend the life of the mine until at least 2019. The Argyle mine has led the world in volume production of diamond, averaging annual production of 35 M carats (7000 kg), or about one-third of global production of natural diamonds. Production peaked in 1994, when 42 M carats (8400 kg) were produced. Of this quantity only five per cent is considered gem-quality, with the rest either near-gem quality or industrial grade; this is somewhat below world averages of about 20 per cent of mined diamonds qualifying as gem-grade.

## Applications

Diamonds are used as gems and for industrial purposes. Industrial diamonds are used to grind and shape machine tool tips, while diamond polishing powders and compounds are used for fine finishes on optical and other surfaces. Diamond grit and powder are used in some types of rock-drilling bits and for sharpening knives. Circular metal saw discs with a diamond-impregnated edge are used to cut grooves in roads and airport runways, and to cut concrete, building stone, bricks and shapes for furnace linings.

## Diamond categories

The Central Selling Organisation (CSO) (see section on 'Selling procedures') recognises some 2500 categories of diamonds, based on size, shape, colour, clarity and inclusions. However, four broad categories are recognised: gem, near gem (Indian good), industrial and crushing board.

## Initial project evaluation

There are no reliable short-cuts to the evaluation of a primary or alluvial diamond source. Selective bulk sampling is generally the first stage in determining whether the source is diamond-bearing or not. Depending on the geology, size and nature of the deposit the weight of the sample may vary from 300 to 1000 t.

## Detailed project evaluation

If the source is diamondiferous the next stage is to outline the orebody by close interval drilling, followed by further bulk sampling to recover some 2000 carats



of diamonds. This valuation is an essential step, as the value per diamond can be extremely variable, unlike most commodities where the unit value is normally uniform. At this stage the company would probably appoint a valuer who would value the diamonds recovered in conjunction with prospective buyers. The average grade of the orebody is less important in estimating revenue than is the dollar value per tonne. It may be possible to use microdiamonds as an indicator of the diamond content, but not the diamond value, of the deposit. Diamond valuers usually work confidentially and may be reluctant to have their valuations published for the purposes of raising funds.

### Selling procedures

For many years up to 80 per cent of the world market for rough diamonds was controlled by the London-based CSO and by de Beers. The CSO was formed in 1934 in response to cyclical price slumps and the total closure of diamond mines in South Africa during the Great Depression. It is now estimated that de Beers has a 55 per cent market share, with 45 per cent coming from its own mines. Discoveries in Russia, Australia, Zaire, Angola and Canada have eroded de Beers's virtual monopoly of the supply chain over the past 20 years.

When commencing a mining operation a sample parcel (excluding special stones) is agreed by the valuer and the CSO. This parcel accurately reflects the various categories into which the diamonds are sorted. The larger the diamond of equivalent colour and quality, the higher the price per carat. Gem diamonds over an agreed size and 'pinks' are negotiated individually by the valuer and the CSO. (Australian pink diamonds have developed an important niche in the international gem market). The balance is sorted in accordance with the sample parcel and agreed with the valuer. The CSO typically deducts ten per cent commission from the gross value of each shipment.

The majority of diamonds from the Argyle mine are sold as 'rough' or uncut stones. Between 1983 and 1996, most of the Argyle rough diamonds were sold through two sales agreements with de Beers. The first agreement (1983 - 1991) helped provide industry and investor confidence in the viability of the mine. It also gave the company time to gain expertise in the sorting and valuation of its diamonds, as well as in marketing them. Diamond industry analysis conducted during this period provided the foundation for marketing systems that were eventually developed. These were used to underpin the establishment of a competitive advantage for Argyle in the market place.

The processing of diamonds through the CSO system, from date of shipment to payment, averages 60 days. CSO pricing is confidential and is made available to only those people directly involved with valuing diamonds. Rough diamonds are sorted at the mine site into broad categories. In Western Australia a government royalty

of 7.5 per cent is levied on gross proceeds, less transport and selling expenses.

Sales from Argyle direct to the market from as early as 1983 provided verification for the rough diamond prices received within the contractual agreements. A direct sales office in Antwerp, Belgium, was opened in 1985, and a representative office in Mumbai, India, in 1989. In 1996, Argyle began to market its entire production of rough diamonds through its Antwerp office. In June 2002, the sales office in Antwerp was expanded to provide a centralised sorting, sales and marketing service to all diamond mines in the Rio Tinto Group.

## GOLD AND SILVER

*By David Woodford*

This section discusses the gold and silver market in Australia and indicates refining charges.

### Australian refineries

All gold and silver doré produced at mine sites in Australia is sent to the Western Australian Mint for refining. The Western Australian Mint, trading as 'The Perth Mint', is the only London Bullion Market Association (LBMA) accredited refiner in Australia.

The LBMA Good Delivery List is now widely recognised as representing the de facto standard for the quality of gold and silver bars, in large part thanks to the stringent criteria for assaying standards and bar quality that an applicant must satisfy in order to be listed. The assaying capabilities of refiners on the Good Delivery List are periodically checked under the LBMA's Proactive Monitoring program.

The main requirements to be considered for listing are normally that a refiner must:

- furnish evidence of their ownership structure and directors
- have a tangible net worth of at least STG£10 M equivalent
- have an established track record of at least three years of producing the refined metal for which the listing is being sought
- produce a minimum quantity of refined metal per annum – 10 t/a of gold and 30 t/a of silver
- provide, if required, a suitable letter of endorsement such as from the central bank or an acceptable commercial bank in their country of operation.

### Refining charges

Basic gold-silver doré is refined at a cost ranging between A\$0.50 and A\$1.50 per gross troy ounce, where gross troy ounce refers to the weight of doré received.

The refining charge is assessed against the quality of the doré and the competition to provide the refining service. This charge would normally cover the services

of melting, assaying, refining and providing bars accredited to the LBMA.

### *Doré quality, penalty charges and credits*

A refiner normally requires the doré to contain not less than five per cent gold and/or silver.

Should elements deleterious to the refining process be present within the doré then penalty charges may apply. The customer should obtain a clear definition from the refiner.

### *Precious metal return*

Refineries return between 99 per cent and 99.9 per cent of the gold and 95 per cent and 99 per cent of the silver contained in the doré bullion to the seller, with the balance retained to cover losses incurred in the refining process.

The metal return offered by the refiner varies according to the quality of the doré. A high gold content normally ensures a high gold return, and similarly for silver.

### **Metal pricing and settlement date**

Precious metal trading is based on London prices expressed in US dollars. A sale price is agreed on the day of refinery out-turn with settlement two business days later.

## **INDUSTRIAL MINERALS**

### *By Murray G Lines*

Industrial minerals are often referred to as the building blocks of many industrial products. This section examines the issues of revenue calculations and marketing of industrial minerals from a broad perspective. It addresses the industrial minerals sector as a whole, examining broad principles and pitfalls, but discusses some specific examples. This approach has been taken due to the diversity of the minerals making up this group. There are some 40 individual industrial minerals at present either in production in Australia, or being actively evaluated. Most of these have several end-product grades, in total comprising some hundreds of finished mineral products. Such a large number of minerals in the group precludes a detailed treatment in this chapter. Therefore, this chapter focuses on the issues that are central to the commercial assessment and viability of industrial mineral products as a whole, rather than presenting a detailed analysis of individual minerals.

The group of minerals classified as 'industrial minerals' has expanded somewhat over the past few decades. Although mainly comprising non-metallic minerals, industrial minerals include such metallic minerals as magnetite (used in coal preparation). Increasingly, specialist metals such as silicon, strontium, magnesium and titanium come within the

ambit of the industrial minerals classification because each of them is the product of industrial minerals silica, celestite, magnesite and ilmenite or rutile, respectively. Similarly, the range of industrial mineral products is widening as increasingly sophisticated applications in industry require more refined and innovative process technologies in the preparation of further processed and performance-oriented industrial mineral products.

At one end of the scale are the high-volume, low-value products such as salt, silica sand for the glass industry, and aggregates, limestone, gypsum and clays for construction materials. In the wide middle range are most industrial mineral products including talc, calcium carbonate and kaolin fillers, ceramic raw materials, heavy mineral sands, graphite, bentonite and magnesite. These are valued at one hundred to several hundred dollars per tonne. At the high-value end of the scale are fused and calcined minerals including fused alumina, fused silica, magnesia, zirconia, surface-modified fillers and rare earth elements, all of which command prices of over A\$1000/t.

Zircon has been the standout mineral sand during the past few years because Australia is the world leader in production (followed by South Africa), with a surge in volumes exported, mainly to China, and a seven-fold increase in pricing from \$400/t to approaching \$3000/t. The driver for this growth has been China's infrastructure boom, which needs zircon for ceramics and chemical industry (zirconia) products.

Spodumene, which is a key source of lithium, has also been an important mineral from an export perspective as the demand for lithium in electric car batteries is growing fast. Rare earth elements comprise another growth material and several projects are progressing. It is somewhat unfortunate that most of the value will be added overseas in Malaysia and China.

Although the diversity of industrial mineral products and applications is large, there are commercial issues common to the whole group that are crucial to the economic evaluation of industrial mineral projects. An appreciation of these is a prerequisite for the estimation of sales revenues capable of being generated from a project. Also, in the initial stages there is a need for 'broad-brush' revenue estimates to be calculated. However, the more complex the envisaged product or products and end-uses, the less applicable and accurate are generalised estimates of likely sales revenues.

### **Recent trends**

Australian industry has changed dramatically. There has been a move to offshore manufacturing (mainly to China) of products such as ceramic tiles, sanitary ware, glass products (including flat and some container glass), ceramic lampstands and many rubber products including auto tyres. This has meant a vast drop in local consumption of various industrial minerals such as talc, kaolin, feldspar, calcium carbonate and

magnesite over the past decade in particular. This has led to a rationalisation in the mining companies involved in mining and processing. Silica sand local consumption has remained flat, but this has been more than compensated for by the export of washed silica sand in bulk to overseas glass manufacturers and foundries around Asia. Many products that Australia now imports from Asia/China have had some inputs from Australian raw materials in one form or another, with silica sand as a major example. Australia now imports perhaps more than 70 per cent of its flat glass from overseas, although it is true that much of the silica component originally came from Australia.

### *Vertical integration within the region*

This is a worldwide trend involving a style of ownership and control. The supply chain from mine to market is constantly evolving where the supply chain shares a common owner. Australian industry integration with companies from Japan, South Korea and Indonesia, and most notably from China, has meant a trend for companies to source raw materials for use in overseas factories and locally. Toyota is an example. Usually each member of the supply chain produces a different product or service, and the products combine to satisfy a common goal – supplying high-quality products to the end-market in the most economic and logistically efficient way. This trend can be extended to suggest that Australian raw materials, including several key industrial minerals, are now part of the supply chain to Asian manufacturers.

### **Resource assessment**

Most deposits of industrial minerals differ from precious or base metal deposits. Unlike their metallic counterparts, it is rare that the product from one specific industrial mineral deposit is exactly the same as a product from a second deposit of the same mineral. Kaolin is a good example. Different kaolins can exhibit different properties, enabling kaolin from one deposit to be suitable for certain applications, and kaolin from another deposit suitable for others. Kaolin is a clay mineral that is white or near white, or it can be beneficiated to be white. Its use as a ceramic raw material is dependent on its firing properties and its ability to fire white or nearly white. Its use as an important industrial filler has developed due to its chemical inertness over a wide pH range, its covering capacity when used as a pigment or extender and its soft, and non-abrasive qualities. Its particle size distribution, colour, brightness and viscosity are usually subject to stringent specifications, especially in the paper industry in which it is used as a filler, and at higher purities and in a finer form as a coating compound. Coating grades of kaolin generally have the highest market values, suffer less competition from alternative products and are the most desirable for a potential producer to supply.

Extensive resource sampling and analysis are required to ascertain whether a particular deposit can be beneficiated to meet the various quality standards of the target industry application for a mineral. The type of deposit, and its mineralisation and chemistry, will have a major bearing on the selling price levels possible. Early in the project assessment it is necessary to identify whether material from a deposit can be suitably processed, economically transported to the end-user markets and, once there, gain an adequate degree of market share to sustain profitable production. As a general rule, it is advisable for a company examining a particular industrial mineral deposit to expend, in the first instance, the minimum funds on resource delineation and quantification. At an early stage the company should undertake a commercial prefeasibility study to assess the likely market viability of the project. This approach is recommended as it can prevent considerable (and perhaps unnecessary) expenditure if it is demonstrated that the products capable of being developed from the deposit would be unlikely to secure markets of sufficient size to sustain the proposed operation. A problem in many parts of Australia is the salinity of readily available artesian and groundwater. This makes it difficult to use as wash water as the sodium content affects its use in applications such as papermaking and ceramics.

### **Specifications, end-use and prices**

Several steps in industrial mineral project assessment need to be completed prior to quantifying revenue estimates. The selling prices obtainable for industrial mineral products vary quite widely from application to application, country to country and grade to grade. Unlike most metals, industrial minerals prices are not quoted on the London Metal Exchange (LME) or by similar international market mediating organisations. There are published prices for a cross-section of minerals in a few magazines such as the price-watch section in *Industrial Minerals*. However, these can be misleading as they may indicate pricing in Europe, USA or China, which is often markedly different from the Australian price envelope. Zircon is an exception, and a global price for the various ceramic-grade sands or flour and micronised opacifier grade now tends to be the same across world markets.

Prices are generally settled by negotiation between the supplier or the supplier's agent and the end-user.

The potential producer must be acquainted with the full range of products that theoretically can be processed from the as-mined mineral resource. As has been demonstrated previously for kaolin, the potential producer must ascertain whether suitable beneficiation or other downstream process routes can be cost-effectively applied to produce market acceptable grades.



In most applications consistency of specific properties in the day-to-day supply of raw materials is nearly as important as the specific properties themselves. End-users regularly vary component batch designs to accommodate specific raw material availability. For example, a flint glass manufacturer can tolerate a maximum level of total  $\text{Fe}_2\text{O}_3$  impurities not exceeding 0.01 per cent by weight. In one plant location a glass company may have access to a supply of extremely pure limestone with  $\text{Fe}_2\text{O}_3$  content considerably lower than 0.01 per cent. This enables that plant greater flexibility in the purchase of silica sand, so it can accept a higher iron oxide content in the sand. A potential glass sand producer with a high-quality product wishing to compete with the existing supplier in that market, with or without a transport cost advantage, needs to be aware of these detailed technical marketing considerations that exist in that localised market before they can determine likely selling prices and the possibility of obtaining a market share. Thus, the viability of the proposed silica operation may depend on the iron oxide level of the limestone supplied.

Similarly for ceramic and glass industries, the percentage of alumina, sodium and potassium oxides present in the feldspars or nepheline syenite can vary significantly in materials drawn from different supply sources. Batch design is varied to maximise the alumina content and the fluxing capacity of the soda and potash present in the feldspathic materials on offer. A lower alumina content in a soda feldspar (perhaps 16 per cent) than one of 23 per cent in a nepheline syenite will mean that greater quantities of the feldspar than syenite would be needed. This will directly affect the price able to be paid for such a feldspar. As mentioned above, ceramic production generally has now shifted away from Australian to Asian production. The strong Australian dollar in recent years means these finished products, although imported, are now cheaper than the previously locally manufactured goods. An example is that ceramic vanity units and toilet bowls are now around half the cost of previously locally made items. A problem with loss of manufacturing skills is still an ongoing issue.

In the paper industry a general rule is that a coating kaolin must consist of particles finer than  $2\ \mu\text{m}$ , whereas a filler can be coarser. Further processing of the coating-grade kaolin, for instance by calcination, could produce a premium-priced material with superior pigment extender qualities that can command selling prices up to A\$100/t higher than otherwise. In international kaolin markets, the high-volume, high-quality US producers tend to be the price leaders of paper coating-grade products, enabling an Australia producer of a regular brightness kaolin (86 ISO brightness) to achieve an FOB price of A\$140/t. A calcined kaolin of 94+ ISO brightness can command prices of A\$600/t. At the lower-quality filler-end of the paper market the prices

in Japan are dictated by the availability of cheaper talc and kaolin from China or by Indonesian kaolin, landing in Japan at around US\$150 - \$220/t at the time of writing. Whereas Australian producers can compete at the higher end of the market, they are unable to do so at the lower end.

However, in the Australian domestic ceramic industry, relatively untreated local kaolins sell for as low as A\$50/t, but can command prices up to A\$250/t for more highly processed products.

Other determinants of application, quality and, therefore, prices of industrial minerals in general include:

- brightness
- chemical purity
- colour
- crystal structure
- density
- inertness or reactivity
- ion exchange capacity
- Moh's hardness
- moisture content
- particle shape
- particle size
- particle size distribution
- pH value
- refractoriness
- thermal conductivity
- viscosity.

### Downstream processing

Production processes that can be used to achieve the prerequisite grades or product characteristics include:

- acid treatment
- air separation
- blending
- calcination
- crushing
- dry or wet screening
- drying
- flotation
- gravity separation
- magnetic separation
- milling-micronising
- selective surface coating.

End-user requirements dictate the form in which a product is sold and packaged. Examples are:

- bagged
- bulk
- calcined
- exfoliated
- fused

- granular
- pelletised
- powdered
- slurried.

These processes can add significant value to mineral products, thereby making them less transport-sensitive and capable of entering more specialised markets in more distant locations, at higher prices.

### Infrastructure and market logistics

For most industrial minerals, infrastructure and transport costs are the most significant determinants of successful market penetration. The lower the cost of the material, the greater the transport sensitivity. Thus low-value products in general need to be relatively close to the end-user, or in the case of export commodities, close to the port. In many cases the capacity of a particular mineral to be transported longer distances to the point of sale is determined by the location, quality and availability of competitive products. In some less-sophisticated applications, competitive products do not necessarily need to be the same mineral.

Trucking, shipping, processing and distribution logistics are central cost factors. Therefore, they are price determinants in the economic evaluation of most industrial mineral projects. Domestic road freight charges range from 12 ¢ to 15 ¢/t/km and, therefore, a 300 km trip can add A\$35 - A\$50/t to a producer's delivered costs. International shipping costs depend on the size of the transshipment, and will vary between US\$40 and US\$75/t for 20 t container lots to less than US\$20/t for bulk shipments of 10 000 to 25 000 t. The impact of these charges on revenue sensitivity is clear. Some silica exporters, such as Mitsubishi (Cape Flattery deposit), use their own fleet to carry the sand to overseas destinations including Japan, South Korea, Taiwan and the Philippines.

### Market, supply-demand and revenue

It is evident from this chapter that the evaluation of the commercial viability of industrial minerals projects is based on very different principles and premises from those of precious or base metal projects. Once the often-complex technical assessment of base metals has been completed, it is relatively easy to estimate at least the current selling prices for production from a gold or copper project. This is clearly not usually the case with industrial minerals projects, which are market driven, with peculiarities perhaps associated with one market area or one commodity grade and not another.

A commercial overview of an industrial minerals commodity and its current pricing can be obtained in the first instance from state mines departments' annual production statistics. It may be possible to discover the import and export situation, if applicable, from an analysis of import and export statistics published by the Australian Bureau of Statistics (ABS) or from

the Department of Foreign Affairs and Trade (DFAT). However, sometimes these data are aggregated with similar minerals and are, therefore, meaningless. Monthly and annual import and export statistics provide FOB values at the port of export and tonnages shipped. The Australian state of entry can also be established from these records. Most of Australia's trading partners produce similar statistics and it is sometimes possible to obtain these from overseas consulates or commercial offices.

For domestic production and prices of industrial minerals by foreign countries, statistics are put together by several organisations on a regular basis. These include *Industrial Minerals*, published by the *Metal Bulletin* – Euromoney Institutional Investor PLC, and various reports on industrial minerals published by Roskill. Both are based in the United Kingdom. At best these provide broad-brush facts and general industry trends.

It is essential to identify not only the current supply-demand balance but also emerging trends. It is essential to assess the likely emergence of a competitive mine or mines, not only in Australia, but in other countries when dealing with international markets. The market structure and supply-demand balance, as well as the dynamics of the suppliers and end-users, including possible equity or other commercial links between them, require a full understanding. The same is true for alternative products or technologies, which may mean the mineral is no longer used in its current material form or process. Growth trends and changes in demand, or the flattening in demand in mature markets, with concomitant growth in developing markets for the minerals or products in which they are used, need careful analysis.

The percentage of market share that can be successfully addressed, and the sharpness of the time curve of full market entry by the new producer is a matter of detailed market knowledge, analysis and judgement. It is the key to the accurate assessment of industrial mineral revenue flows.

In some instances international trading companies handling industrial minerals can be of assistance to a company wishing to examine selling prices and sales revenues of proposed mineral products, particularly in the assessment of overseas export-based market opportunities. However, the potential producer must be certain that the trading company being used has reason to act in the best commercial interests of a new supplier. This may mean the trading company does not have conflicting interests, for example equity or commercial links to potentially competitive alternative sources, or acts exclusively for one group of end-users. Such certainties are difficult to establish.

Specialist marketing advice is required to provide specific input and judgement into the commercial viability of the project. Such studies should focus on actual end-users in the targeted markets, and be based

on communication with the major companies using the minerals in question. Only then do specific issues emerge that determine the prices that can be obtained, the tonnage levels that are likely to be purchased and the resultant revenue flows. Many larger projects now include an overseas company as a partner, which ensures a base-load of export sales.

## IRON ORE

### *By Rio Tinto Iron Ore, Sales and Marketing*

Iron ore is the raw material used to make iron, which is refined and then alloyed with other metals to make steel. This section discusses the market and forms of iron ore products, and the pricing and packaging of iron ore products.

### Market

Iron ore may occur as a massive rock that must be broken into smaller lumps to facilitate handling, thereby creating some small particles. It may also occur naturally as a fine material or occur finely divided in rock that contains unwanted minerals such as silica.

Typically, iron ore is smelted in blast furnaces to produce impure iron. The blast furnace uses large volumes of preheated air. Solid inputs include iron-bearing burden in the form of lump, sinter and pellets, and coke as fuel and reductant. Unfortunately blast furnaces do not operate well when large quantities of fine material are placed or generated in the furnace. Consequently, fine material is separated from the raw feed before it is charged into the blast furnace. Iron ore fines are agglomerated into either pellets or sinter to make them suitable as blast furnace charge material.

Pellets are made by creating balls from very fine ore with a suitable binder. These are then heat-hardened into iron-bearing spheres of nominally 12 - 16 mm in diameter. Pellets may also contain fluxes to improve metallurgical properties.

Sinter is created by heating a mixture of iron ore, flux (eg limestone, dolomite and serpentine) and coke breeze or coal fines. The resulting fused iron-bearing sinter is then sized to produce lumpy sinter of 5 mm to 40 mm, which is suitable for blast furnace feed. Sinter smaller than 5 mm is reprocessed in the sinter plant.

The decision to sinter or pelletise the fine ore depends primarily on the physical characteristics, location and economics of the ore. Usually, very fine ore is pelletised and coarser ore sintered. Pellets can be transported and handled better because they degrade at a lower rate (ie break or abrade during transport, resulting in generation of fine material) than sinter.

Traded iron ore products usually have the following characteristics:

- fine ore – normally less than 10 - 12 mm and is
  - created as an adjunct of lump ore production

- deliberately crushed to create a more saleable product
- naturally occurring
- produced by a beneficiation process involving crushing and grinding the ore to a fine particle size
- lump – normally has a top size of 35 mm and a lower size of 5 - 6 mm, but with some quantity of fines less than 5 mm, which are generated during handling and transport
- pellet – very fine ores (concentrates) are difficult to handle, so are often made into pellets before shipment. Pellets may be produced with defined amounts of fluxes to meet blast furnace requirements.

Blast furnaces can run on any single type or combination of lump, sinter or pellets, provided the feed is suitable quality, is consistent and uniform and the furnace has a control system that can monitor and control the reduction process. Usually, though, furnaces run on a mixture of feed types. The relative cost and availability of pellets, lump and sinter are major considerations.

A blast furnace produces hot metal (liquid iron), which must be purified in a steel furnace (usually an oxygen converter) to make many different grades of steel for many end-uses.

A small amount of steel (approximately 6.5 per cent) is made from iron ore by a combination of direct reduction and electric arc furnaces. In this process the iron ore is 'metallised' in a direct reduction furnace, where the oxygen is removed from the hematite and magnetite in the solid state. The removal of much of the oxygen from the iron ore creates a 'sponge', so direct reduced iron (DRI) is occasionally referred to as 'sponge iron'.

DRI rapidly re-oxidises under certain conditions and must be passivated before shipment. The most common practice is to reduce the surface area by making it into hot briquetted iron (HBI).

Small quantities of iron ore are traded for such diverse end-uses as ballast and heat storage. Other applications are for making heavy concrete, sulfur-resistant cement, ferrite magnets, ceramics, pigments, foundry moulds and welding electrodes. Iron ore is an additive in the production of glass, fertilisers and jewellery, in food preservation and in manufacturing hand and foot warmers.

### Marketable product

For iron production (as a step in steel production) the iron content of the iron ore should be as high as possible (usually >60 per cent). The alumina ( $\text{Al}_2\text{O}_3$ ) and silica ( $\text{SiO}_2$ ) contents should be as low as possible ( $\text{SiO}_2 + \text{Al}_2\text{O}_3$  usually two to eight per cent in total), as should the phosphorus content (<0.1 per cent). Total content of alkalis, sulfur and other elements such as



titanium, copper, tin, zinc, lead, vanadium, fluorine, chlorine and manganese should all be low. There are limited markets for materials significantly outside these specification limits; for example, materials with high silica, phosphorus, manganese or alumina values.

Some of these elements have an adverse effect on iron and steel production costs (eg Si, Al, Ti, Zn and alkalis). Some have an adverse effect on steel quality (eg P, S, Ti, Cu, Sn and Pb) and some have an adverse effect on environmental quality.

Commercially traded iron ore must have chemical and physical properties, both absolute and consistent, that allow it to smelt predictably and as required in the blast furnace and be easily handled and transported. Above all, it must be uniform, reliable and competitively priced.

Before substantial quantities can be commercially traded, samples are required for laboratory tests (sample about 0.2 - 1 t) to determine pelletising quality, sintering characterisation in the case of fines as well metallurgical characteristics for lump, pellets and sinter. Full-scale plant trial testing (in the order of 10 000 - 100 000 t shipments) may also be required.

### Pricing

Iron ore is sold on the basis of its contained iron content and is either priced per iron unit, or at a price per dmt (\$/dmt) at an implied iron percentage.

The ore is either sold on a FOB basis, loaded at the seller's wharf on a vessel supplied by the buyer, or cargo-and-freight delivered to the buyer's wharf in a vessel supplied by the seller.

Currently pricing indices (\$/dmt) are the starting point for the majority of internationally traded iron ore. The index price is converted to an implied FOB cent per iron unit price by adjusting for freight and using the index's iron grade (typically 62 per cent).

A key theme to emerge over the past decade has been structurally stronger rates of growth among developing nations. This growth led to a dramatic increase in the demand for steel, resulting in the seaborne iron ore industry more than doubling over the last decade to 1.1 B t in 2011.

The speed of growth in the size of the iron ore market has also been matched by evolution in iron ore pricing, with a proliferation of contract methodologies and financial instruments. Spot market sales have become far more prevalent, and reliable liquid iron ore spot indices have appeared, with derivatives markets developing. A number of new trading entities, clearing houses and brokers have entered the market. They continue to do so, resulting in a variety of new channels for managing iron ore sales.

Product characteristics such as chemical composition, physical and metallurgical properties and relative delivered prices are major factors considered by buyers

to determine the value in use (VIU) of iron ore. The ore VIU is a key determinant in the negotiated pricing outcome for any iron ore.

### Packaging

Seaborne traded iron ore is usually shipped in dry bulk carriers, in the largest vessels that can service the shippers' and buyers' ports. Other transport methods such as rail, barges and road are widely used in certain regions to transport large volumes of iron ore.

### LEAD

*By Trevor Watters*

The main market for lead concentrates arises from the world's custom lead smelters. Integrated smelters may also make some custom purchases.

### Smelting technology

Blast furnace smelting is the most common extraction process for lead; this includes Imperial Smelting process (ISP) blast furnaces. Newer technologies include the Kivcet (Russian), QSL and Isasmelt processes. These new processes have been designed to handle more complex concentrates. In practice, commissioning has often been difficult or unsuccessful (eg Cominco's QSL smelter at Trail). However, as problems are overcome, these technologies should find more frequent application. Following smelting, refining is achieved using either the Parkes or Pattinson process, or electrolytic refining by the Betts process, which is the predominant method used in China.

### Concentrate quality

The majority of lead blast furnace smelters process lead sulfide concentrates of higher grade (>50 per cent Pb). Lower grade concentrate may be accepted if it is sold sufficiently discounted from higher quality concentrate, and market conditions permit. ISP smelters regularly process concentrate with <50 per cent Pb, but from the mine's perspective, it is frequently uneconomic to transport low-grade lead concentrates. ISPs are disappearing worldwide because of their high operating costs, so the producer is being pushed to higher-grade concentrates, albeit at lower recoveries.

Lead smelters penalise or reject concentrates with high levels of impurities such as antimony, bismuth, arsenic and mercury. There is a worldwide trend to place upper limits on penalty elements so that rejection of products is likely to be more common. For example, an upper limit of 0.5 per cent for arsenic in any concentrate has been implemented in China. In dedicated lead smelters, zinc and copper are not welcomed. High precious metal contents improve the value of concentrates significantly.

### Smelters

Comprehensive lists of lead smelters can be obtained from the International Lead Zinc Study Group



(ILZSG), or commodity research companies such as CRU International Ltd, Brook Hunt and Associates Ltd, Metals Minerals Research Services and Metal Bulletin Research, all of which are based in England. Table 20.3 provides a guide to the main smelters in the Asia-Pacific region. Some smelters are either partly or fully integrated with mining operations. Concentrates are also shipped from Australia to other regions, usually incurring higher freight costs. The major alternative destination is Europe.

### Initial pricing estimate

While lead concentrates may have consistently high lead contents, their penalty and precious metal contents vary widely. It is, therefore, very difficult to provide a simple estimation technique based on historical data across a range of mines.

The mines' share of the value of lead metal in a 65 per cent Pb concentrate varied between 45 per cent and 65 per cent over the decade prior to 1993. Currently, the negotiated smelter share for clean concentrate is low at 17 per cent.

### Detailed pricing estimate

For a more detailed estimate, each component of the smelter terms should be calculated. The structure of lead smelter terms is described below and a worked example is given in the section 'Example of revenue calculation'.

### Payable metals

Typical payments for metals contained in lead concentrates are shown below:

- lead – pay for 95 per cent of lead content subject to a minimum deduction of three units (industry standard)
- gold – pay for 95 per cent of gold content subject to a minimum deduction of 1.5 g/dmt

- silver – pay for 95 per cent of silver content subject to a minimum deduction of 50 g/dmt.

### Treatment and refining charges

A treatment charge (TC), expressed as a fixed deduction per tonne of dry treconcentrate, is applied. This includes the cost of refining the lead. Price participation is also included.

Historically, TCs have varied widely with the lead price. In addition, TCs for 'clean' concentrates may be significantly lower than for 'dirty' concentrates. This trend is increasing as environmental restrictions increase. Current TCs are best obtained from the *Metal Bulletin* or from traders, as TCs can be quite volatile. Spot sales are especially variable and currently sit at around 75 per cent of frame contracts.

### Price participation

This mechanism increases the TC as prices increase above a base price. It is rare for smelters to reduce the TC if prices fall below the base price. Again, PP can be volatile and should be confirmed from the market before assuming any figures for financial analysis.

### Precious metal refining charges

Refining charges are often included for silver and gold and can also vary considerably depending on current prices and demand.

Currently, market conditions are supporting large differences in TCs and RCs between high and low silver contents.

### Penalties

Penalties are imposed for undesirable elements that increase a smelter's costs. Typical elements and formulas are shown in Table 20.4.

TABLE 20.3  
Major lead smelters in the Asia-Pacific region.

Country	Smelter	Capacity 2010 (000 t/a Pb metal)	Company
Australia	Port Pirie	235	Nyrstar
	Mount Isa	240	Xstrata
Japan	Kosaka	25	Dowa
	Hachinohe	34	Hachinohe Smelting
	Kamioka	34	Mitsui
	Harima	30	Sumitomo
	Chigirishima	120	Toho Zinc
	Takehara	44	Mitsui
Korea	Kangwon	200	Korea Zinc
China	19 smelters	2240	Various

TABLE 20.4  
Typical lead concentrate penalty payments.

Penalty element	Typical formula (US\$/dmt concentrate)	Negotiable range
Arsenic	\$3.00 per 0.1% above 0.5%	Penalty \$2.00 - \$3.00 above 0.2% - 0.3%
Antimony	\$3.00 per 0.1% above 0.1%	Penalty \$2.00 - \$3.00 above 0.1% - 0.3%
Bismuth	\$2.00 per 0.01% above 0.03%	Penalty \$1.50 - \$2.50 above 0.03% - 0.05%
Mercury	\$1.00 per 10 ppm above 30 ppm	Penalty \$1.00 - \$1.50 above 10 - 50 ppm

Some concentrates may be rejected by smelters because they contain a high level of a particular penalty element. Arsenic is the only penalty element that has a standard rejection limit. However, it is likely that with increasing competitive and environmental pressures,

other elements may be subject to similar constraints. Any concentrate is potentially saleable depending on its quantity and the availability of other more favourable materials with which it can be blended. Clearly, dirtier concentrates can only be sold for lower returns than cleaner concentrates or at times when cleaner concentrates are in short supply.

**Example of revenue calculation**

A worked example of the calculation of the NSR for a lead concentrate in US\$ is shown below. This calculation is presented as a guide only and may not represent actual market conditions.

**Concentrate specifications – clean**

Pb	65%	Bi	0.12%
Au	3 g/t	As	0.08%
Ag	900 g/t	Sb	0.25%

Terms include:

- treatment charge = US\$250/dmt concentrate
- payable metals as in preceding section ‘Payable metals’
- refining charges
  - US\$4.00/oz payable gold
  - US\$0.30/oz payable silver
- PP as in preceding section ‘Price participation’
- penalties as in preceding section ‘Penalties’.

Metal prices	Conversions
Pb US\$2000/t = US\$0.91/lb	31.1 g = 1 troy oz 2204.6 lb = 1 t
Au US\$1500/troy oz	
Ag US\$30.00/troy oz	

**NSR calculation**

Payable metals	US\$/dmt
Pb	(0.65 × 0.95 = 0.6175) or (0.65 - 0.03 = 0.62) therefore, payable Pb = 61.75% 0.6175 (t payable Pb × US\$2000/t Pb = \$1235.00
Au	(3 × 0.95 = 2.85) or (3 - 1.5 = 1.5) therefore, payable Au = 1.5 g/t 1.5 g/dmt conc × (US\$1500/troy oz)/31.1 g/oz = \$72.35
Ag	(900 × 0.95 = 855) or (900 - 50 = 850) therefore, payable Ag = 850 g/t 850 g/dmt conc × (US\$30.00/troy oz) / 31.1 g/oz = \$819.90
<b>Total payment for metals</b>	<b>= \$2127.25</b>
<b>Treatment charge</b>	<b>= (\$250.00)</b>

**Price participation**

Assume 4% PP above US\$1500
Actual price = US\$0.2000/t
Base Price = US\$0.1500/t
Escalator = (2000 - 1500) × 0.04 =
US\$20/t concentrate = (\$20.00)

**Charges**

Au 1.5/31.1 oz payable Au/dmt × US\$4.00/oz = (\$0.19)
Ag 850/31.1 oz payable Ag/dmt × US\$0.30/oz = (\$8.20)

**Penalties**

Hg (0.12% - 0.03%) × \$2.50/0.01%	= (\$22.50)
As 0.08% < threshold of 0.1 %	= (\$0.00)
Sb (0.25% - 0.1%) × \$3.00/0.11%	= (\$4.50)

**Total deductions = (\$305.39)**

**NSR = \$1821.86**

**LITHIUM**

The primary source of lithium minerals is pegmatites. Lithium is also contained in subsurface brines, which are the main source of lithium chemicals. Brines have become the leading source for lithium carbonate production internationally due to lower production costs than mining and processing hard rock ores. Chile is the leading producer of lithium chemicals, with Argentina, China and USA also major producers. Australia and Zimbabwe are major producers of lithium minerals (USGS, 2011).

Australia has about five per cent of the world’s economic lithium resources, behind Chile which has about 75 per cent and Argentina with about ten per cent (Geoscience Australia, 2012).

Lithium is used in the manufacture of glass, ceramics, greases, pharmaceuticals and batteries. The demand for lithium has strengthened in recent years due to the increased use of rechargeable and non-rechargeable batteries in electronics and mobile devices as well as increased development of electric motors (USGS, 2011). However, production has also increased, and the leading producer in Chile lowered prices by 20 per cent in 2010 amid concerns of oversupply (USGS, 2011).

Global production of lithium was estimated to be 18 800 t in 2009 and 25 300 in 2010. These figures do not include US production, as this information has been withheld. World reserves of lithium are estimated to be 13 Mt (USGS, 2011).

The lithium industry expresses production and sales in terms of lithium carbonate equivalent (LCE) in tonnes. Lithium carbonate contains 40.40 per cent lithium oxide (Li<sub>2</sub>O). Annual demand for lithium in 2011 was approximately 23 000 t of lithium mineral or 122 000 LCE.

Australia remains one of the major producers of lithium minerals, with Talison Lithium’s Greenbushes

mine in Western Australia producing around 315 000 t/a of lithium concentrates (Ingham *et al*, 2011). A second phase of expansion has recently been approved, which will increase concentrate capacity to 720 000 t/a, making Talison Lithium the world's largest LCE producer at 110 000 t/a (*Industrial Minerals*, 2011). Lithium is also produced at Mount Cattlin in south-west Western Australia, and a mineral processing plant is being planned at the Mount Marion lithium project near Kalgoorlie, Western Australia (Geoscience Australia, 2012).

## Pricing

Indicative prices for lithium minerals and lithium carbonate are now published regularly in *Industrial Minerals*. The price of lithium minerals is traditionally compared with the price of lithium carbonate as a benchmark and a current lithium carbonate price of over \$4000/t was noted (*Industrial Minerals*, 2011).

As lithium minerals are relatively low-cost commodities, the cost of packaging, freight and storage form a significant part of the delivered price, making general comments on pricing difficult (USGS, 2011). A comparison of the relative prices of lithium minerals versus lithium carbonate on an equivalent lithium oxide basis is illustrated in Table 20.5.

TABLE 20.5

Prices of lithium minerals in US\$/lb lithium carbonate equivalent (source: USGS, 2011).

Material	Li <sub>2</sub> O (%)	Approximate price (US\$/t)	Date
Lithium carbonate	40.4	4300	Dec 2011 <sup>a</sup>
Spodumene concentrates	7.6	250 CIF China	Early 2011 <sup>b</sup>
Glass grade spodumene	5.0	380 - 430	Dec 2010 <sup>c</sup>

Note: a = Watts (2012); b = Green Leader (2011); c = USGS (2010); CIF = cost insurance freight.

## Applications

As noted above, traditional applications for lithium minerals include low thermal expansion glass ceramics, low expansion and fully vitrified ceramics, frits and glazes, fibreglass, bulk glass packaging, pharmaceuticals and high-quality perfume containers. More recently batteries have emerged as a major market for lithium, while the use of lithium as a flux in primary aluminium smelters has been declining.

## MAGNESITE

By Paul Rix

This section presents market factors of the different products derived from magnesite, and includes revenue calculations and pricing considerations.

## Market and product forms

Magnesium is the eighth most abundant element in the world and accounts for around two per cent of the Earth's crust. It is the third most abundant element found in sea water, averaging 0.13 per cent. Although magnesium is found in over 60 common minerals, only a few are of commercial importance. Magnesite (MgCO<sub>3</sub>), which has a theoretical maximum magnesia (MgO) content of 47.6 per cent, is the world's major source of magnesia.

Production of magnesite in 2010 was estimated at 24.6 Mt, with 55 per cent of output attributed to China; Europe accounted for a further 30 per cent. Magnesia production was 9.9 Mt, with China accounting for just over half of the supply. Russia was the next largest producer at 11 per cent. Australia produces three per cent.

When calcined at 800 - 1000°C, magnesite converts to caustic calcined magnesia (CCM), which in 2010 had a world market of approximately 2.5 Mt/a. It is used mainly in agriculture, animal health and fertiliser applications, accounting for approximately 1.2 Mt/a. Other important markets include water treatment, flame retardants and as an additive in steel manufacture. A new fast growing market for CCM is hydrometallurgy.

When magnesite is further calcined to 1600 - 2000°C, it forms a hard, dense product called sintered or dead-burned magnesia (DBM), which, in various formulations, is used for the manufacture of refractories. DBM represents 72 per cent of output by magnesia product and CCM, 20 per cent.

The world market for refractory DBM in 2010 was approximately 7 Mt/a, of which approximately 3.5 Mt/a was consumed by China, with a further 11 per cent by Russia.

Heated above 2800°C (in electric arc furnaces), magnesia melts. The resultant recrystallised electrofused magnesia (EFM) is used for high-quality refractories. Total demand for EFM in 2010 was approximately 750 000 t/a, with 90 per cent of this volume produced in China. A further 80 000 t/a was used in electric appliances for the manufacture of heating elements.

Chinese magnesia exports are currently the highest of any producing country, and they have shaped global supply over the last 20 years. However, over the last five years there has been a change in the dynamics of magnesia supply from China. Since 2005, Chinese exports to the world market have been limited by quotas imposed by the government; in 2010, the quota for all magnesia products was 1.2 Mt. This created shortages and rising prices for some grades of magnesia in 2010, in particular DBM and EFM.

The Chinese magnesia policy is driven by a desire to protect resources, particularly of higher-grade material; protect the environment; and increase the exports of value-added products such as refractories rather than raw materials. The Liaoning Provincial Government, the region accounting for 85 per cent of Chinese

magnesite reserves, has implemented strict controls on mining, and magnesite production is predicted to be kept at current levels over the next five years. There are also major constraints on energy sources in China, which can be a limiting factor on production, particularly for energy-intensive EFM.

### Marketable qualities

Each of the approximately 40 worldwide producers of refractory magnesia has a differentiable quality that derives its particular characteristics from the magnesia source (eg natural cryptocrystalline magnesite, natural microcrystalline magnesite, sea water or brine) and the subsequent processing methods used.

Broadly speaking the range of refractory sintered magnesias is divided into two qualities for brick grade (higher- or lower-grade) and a monolithics grade (lower quality). Monolithic refractories are all unshaped refractories; for example, castables, plastics and rammables. The elements determining quality are, in general terms, shown in Table 20.6.

The product must be dry and is typically sold as crushed lump (eg -30 mm) in bulk, loose bulk in container or in one metric tonne bulk bags in container.

With respect to EFM, the MgO contents vary from 99 per cent MgO down to 95 per cent MgO. Most other properties are the same, with the exception of grain bulk density  $>3.50$  g/cm<sup>3</sup> and periclase crystal size (PCS)  $>1000$ .

### Pricing

All refractory magnesia is sold on a per-tonne basis, and is typically priced in US\$; however, customers in Europe are now more likely to require pricing in Euro, and some pricing is also in Japanese Yen. Elsewhere pricing is always US\$.

Because magnesias are technically differentiated products, there is no single terminal market price. Prices are negotiated on an annual basis between sellers and buyers, or on a spot basis where the price will be set for a particular shipment or a number of deliveries over a shorter time frame from one to three months.

An indication of the current market prices is published in the monthly *Industrial Minerals* magazine. However, prices reported frequently refer to recent deliveries, which may have been fixed many months prior to delivery and would not reflect the current price at the time of publication.

In continental Europe, while sellers generally price on a delivered basis to the customers' works throughout Europe, all prices are referenced back to an FOB Rotterdam basis.

Over the last decade, refractory magnesia price trends have been quite volatile in nominal terms, with fluctuations from the trend corresponding to the fortunes of the steel industry and/or the Chinese Government's export policy on minerals in force at the time. Currently the Chinese Government limits the volume of magnesia that it allows to be exported to 1.23 Mt/a by way of a licensing system. Nominal prices over the last decade are shown in Table 20.7.

TABLE 20.7  
European prices for various grades of magnesia.

Magnesia quality	European price (US\$ FOB Rotterdam)
High-quality electrofused (>98% MgO)	500 - 1200
Lower-quality electrofused (<97% MgO)	300 - 850
High-grade DBM	250 - 675
Monolithics-grade DBM	150 - 500
CCM (90%)	150 - 450

Note: CCM = caustic calcined magnesia; DBM = dead-burned magnesia.

### Revenue calculations

The most important issue in estimating revenues from a magnesia project is to understand the product quality contemplated. This quality can then be priced by comparison with similar existing qualities in the market. This requires a comprehensive understanding

TABLE 20.6  
Impurities that determine the quality of refractory magnesia.

	High-grade	Low-grade	Monolithics-grade
Purity (% MgO)	96.5 min	95 - 96	90 - 92
SiO <sub>2</sub> (%)	0.8 max	0.5 - 2.0	3 - 5
CaO (%)	2.7 max	1.0 - 3.0	3 - 5
Fe <sub>2</sub> O <sub>3</sub> (%)	0.3	<1.0	<1.0
Lime/silica ratio	2.5 to 1 min	<2.0	1 to 1
Grain bulk density	>3.40	<3.3	N/A
Mean PCS (µm)	110	<100	N/A

Note: N/A = not applicable; PCS = periclase crystal size.



of refractory magnesias and/or the application targeted for the CCM grade contemplated and competitive forces in the market. The services of an expert consultant or marketing agent would be necessary for this purpose by a newcomer to the industry, as there are no organised markets or exchanges for magnesia. All marketing is typically done through agents or directly between producer and consumer.

Gross revenue is a simple product of tonnage times price. Net revenue (eg FOB producer's works in Australia) is then simply derived by deducting the realisation costs.

### Packaging and transport

EFM and DBM are typically shipped in bulk in parcels of 3000 - 12 000 t, which constitute a part cargo on a 'handy size' (typically 15 000 - 40 000 t) dry bulk vessel. It can also be sold bulk loose in container, in one-metric-tonne bags in containers, or sized according to customer requirements (eg 1 - 3 mm, 3 - 5 mm) and packed in one-tonne bulker bags.

## MANGANESE

*By Peter McCarthy*

This section presents market factors for the different products derived from manganese and includes revenue calculations and pricing considerations.

### Demand

Carbon steelmaking accounts for approximately 87 per cent of end-user demand for manganese generally as manganese alloy. Manganese is non-substitutable in the steelmaking process: it acts as a deoxidising and desulfurising agent and thereby ensures steel is tough and hard without making it brittle. Demand for manganese is inextricably linked to the fortunes of the steel industry. Steady growth in demand is expected, particularly from China and India.

Additionally, manganese is used in the dry cell battery industry, in manganese chemical production and as an additive in unleaded petrol. Electrolytic manganese dioxide (EMD) is used almost exclusively in the production of dry-cell batteries.

An emerging application is in lithium-manganese dioxide (LMO) cathodes for large-format lithium ion batteries for electric power storage for electric vehicles. This could become a substantial demand over the next decade.

### Markets

The global production of manganese ore in 2011 was estimated at 16.54 Mt of contained manganese compared with an estimated output of 16.4 Mt of contained manganese in 2010. BHP Billiton Ltd, which controls some 15 per cent of world manganese ore output, forecasts a nine per cent per annum increase in its manganese production through to 2020 (Roskill, 2012).

Most manganese ore destined for consumption in the steel industry is sold to smelters and used to produce manganese alloys, which are on-sold to steelmakers.

A significantly lesser amount is sold to steelmakers for direct addition purposes. Some grades of steel require the addition of high-purity manganese metal, which is produced by electrochemical processes. Ningxia Taiyuan Manganese is the single largest producer of pure electrolytic manganese metal in the world from its Chinese operations. The chemical and battery industries generally purchase direct from the ore producer.

### Pricing

There is no general publication of ore pricing factors relative to the chemical and battery industries. Price determination depends on individual negotiation with the end-user, based on purity and the application of the product.

For alloying and steelmaking manganese, ore pricing is generally related to manganese content with price adjustments applied for minor elements levels. Prices are quoted in US\$ per dry metric tonne unit (dmtu) of manganese (US\$/dmtu).

A simple revenue assessment is:

$$\text{tonnes} \times \text{Mn content} \times \text{price}$$

where:

$$\text{Mn Content} = \% \text{Mn}$$

$$\text{Price} = \text{US\$/dmtu for Mn in ore}$$

For example, 10 000 t, with 45% Mn grade at price of US\$5.50/dmtu would be calculated as follows:

$$10\,000 \times 45 \times 5.5 = \text{US\$}2\,475\,000$$

A preliminary assessment of price can be obtained from sources that publish manganese pricing data and sometimes industry analysis, including the following websites: Mineral Prices, Metal Prices, InfoMine, Metal Pages, Metal Bulletin and FerroAlloyNet (see references for full details of websites).

To a large extent, material value is determined by whether the ore is oxide, carbonate or silicate type.

Determination of ore type can be arranged through an accredited mineral laboratory although simple assessment for the better-known manganese minerals (eg psilomelane, rhodonite, pyrolusite and rhodochrosite) can be made through reference to any handbook on ore mineralogy and applying a series of simple tests for colour, hardness, density, streak and other properties. A more complete mineralogical analysis requires X-ray diffraction (XRD) or electron microscope analysis, or both.

The type of ore will determine both market acceptance and revenue range. Carbonate ores generally command lower prices than oxide ores, while silicate ores command lower prices again.

For battery use the ore must be of the dioxide type. Battery activity is associated with manganese minerals that have defect crystal structures. XRD analysis is needed to determine the presence or otherwise of these minerals.

High-quality manganese dioxide is produced by electrochemical processing of various ore types for the high-grade battery market. These processes are complex and demand extensive purification steps. Before any assessment of value can be made, the specific needs of the individual producers must be ascertained.

Determination of chemical analysis is required before evaluation can proceed past very preliminary levels. Acceptance in the marketplace of manganese ore is dependent on the chemical and physical characteristics of the ore. By way of illustration, the following criteria are required for alloying and steelmaking:

- manganese – >44% Mn is preferred, but lower grades have become acceptable with increasing demand
- iron – for ferromanganese production, a higher iron content can be acceptable; for silico-manganese production, a lower iron content is desirable
- silica – for ferromanganese production, a higher silica content is not desirable; for silico-manganese production, a higher silica content is desirable
- alumina – should be minimised
- phosphorus – of major concern and >0.1% is generally unacceptable
- sulfur and alkalis – demand consideration
- manganese to iron ratio – >6.5 to 1 is preferred, much lower may be acceptable
- sizing – lumpy commands a higher value as fines require agglomeration or sintering
- heavy metals – not favourably received and environmentally sensitive.

Chemical industry requirements are:

- manganese – of principal importance, the higher the better
- silica/alumina ratio – lower is better
- phosphorus – not so important
- sizing – not critical, since it is ground before use.

Battery industry requirements are:

- battery activity of the ore is the single most important factor and can only be determined by actual test over time
- MnO<sub>2</sub> – principal constituent
- heavy metals – required to be minimal particularly nickel, cobalt, copper and molybdenum
- sizing – not critical, since it is ground before use.

Once the chemical composition is known, a further preliminary evaluation is made by comparison with known ore types and the price levels they command.

In common with other minerals, relative pricing is also influenced by non-technical factors such as the country of origin, the reputation of the producer, the size of the reserves and the consequent potential for long-term supply. Failure to meet basic criteria in any of these aspects could result in considerable discounts to the selling price. Examples of manganese ore specifications in lots offered for sale can be found at the Alibaba website.

### Transport

There are no constraints on manganese ore transport other than economic considerations.

Shipment of manganese ore is, almost without exception, in bulk parcels. Packaging is a rarity rather than normal.

### Product specifications

There are numerous grades of manganese ore required by consumers. These grades differ depending on the end-use of the manganese.

Lump ore is used for alloying and steelmaking. Low-grade lump is typically 36 per cent Mn minimum, high-grade metallurgical lump may be up to 54 per cent Mn, while either may be high Fe or low Fe. Chemical specifications typically range as given in Table 20.8.

TABLE 20.8  
Typical chemical specifications for manganese ore.

Component	Range (%)
Manganese (% Mn)	36 - 54
Iron (% Fe)	4 - 20
Silica (% SiO <sub>2</sub> )	4 - 20
Alumina (% Al <sub>2</sub> O <sub>3</sub> )	1 - 8
Phosphorus (% P)	0.03 - 0.17

Sizing can vary depending on individual customer requirements. However, an acceptable indicative range would be 90 per cent between 6.7 mm to 75 mm.

### MINERAL SANDS<sup>2</sup>

*By Zayn Marlowe and Sue Fitzgerald*

Mineral sands refer to concentrations of heavy minerals (HM) in an alluvial, old beach or river system environment. However, when looking at the industry as a whole, it is normal to include all the producers of titanium raw materials, which encompasses operations based on the mining and processing of primary 'hard

2. Note that this information was compiled in November 2011 and may not reflect current industry trends or costs.

rock' deposits of ilmenite. The mineral sands industry is oriented principally towards the supply of titanium raw materials (titanium feedstocks) for the production of titanium dioxide (TiO<sub>2</sub>) pigment and titanium metal. The other major product of the industry is zircon, which most producers consider a co-product of their titanium mineral production. Zircon typically makes up a relatively low proportion of production from most mineral sands operations, but has a high value comparable to the other heavy minerals.

### Titanium minerals

Titanium minerals ilmenite, rutile and leucoxene as well as titanium slag and synthetic rutile are all used principally as feedstocks for the production of white TiO<sub>2</sub> pigment, which accounts for almost 90 per cent of the world's consumption of titanium minerals. The remainder is used in the production of titanium metal, fluxes for welding rods and as a metallurgical flux in iron and steelmaking. Demand for titanium feedstocks has, therefore, been historically linked with that of TiO<sub>2</sub> pigment.

TiO<sub>2</sub> pigment is used predominantly in the production of high-quality surface finishes to impart opacity, brightness and whiteness. TiO<sub>2</sub> extends the life of the medium it is incorporated into, absorbing and reflecting ultra-violet radiation that would otherwise accelerate the decomposition of the medium. However, the main attribute of TiO<sub>2</sub> is that it improves the aesthetic appearance of the product and is, therefore, considered to be a quality-of-life product with consumption generally increasing as disposable income increases.

### Feedstock

Titanium is the ninth most abundant element in the Earth's crust and occurs naturally in a number of minerals; those of greatest commercial importance are ilmenite, rutile and leucoxene.

Ilmenite (FeTiO<sub>3</sub>) is the most abundant titanium mineral with naturally occurring ilmenite having a TiO<sub>2</sub> content ranging from 35 per cent to 65 per cent, depending on its geological history. Ilmenite may contain iron oxides, which can lower the TiO<sub>2</sub> content to less than the theoretical level, as shown in Table 20.9.

Rutile is composed essentially of crystalline titanium dioxide and, in its pure state, would contain close to 100 per cent TiO<sub>2</sub>. Naturally occurring rutile contains minor impurities, and commercial concentrates of the mineral typically contain 94 - 96 per cent TiO<sub>2</sub> (Table 20.10).

Leucoxene is a natural alteration product of ilmenite, with TiO<sub>2</sub> content ranging from 65 per cent to more than 90 per cent (Table 20.11). In practice, the distinction between 'altered ilmenite' and leucoxene is largely arbitrary and is principally commercially based. Some leucoxene may also be termed 'tertiary' ilmenite.

**TABLE 20.9**  
Typical ilmenite analysis.

Typical analysis	Unit	Primary ilmenite	Secondary ilmenite
TiO <sub>2</sub>	%	48 - 54	58 - 64
Fe(t) as Fe <sub>2</sub> O <sub>3</sub>	%	35 - 50	30 - 35
Cr <sub>2</sub> O <sub>3</sub>	%	<0.1	<0.4
Al <sub>2</sub> O <sub>3</sub>	%	<1.0	<1.5
SiO <sub>2</sub>	%	<1.0	<1.2
U + Th	ppm	<100	>100 - 400

Note: Fe(t) = total Fe.

**TABLE 20.10**  
Typical rutile analysis.

Typical analysis	Unit	Rutile
TiO <sub>2</sub>	%	93 - 96
Al <sub>2</sub> O <sub>3</sub>	%	<1.0
SiO <sub>2</sub>	%	<1.0
ZrO <sub>2</sub>	%	<1.0
V <sub>2</sub> O <sub>5</sub>	%	<0.6
U + Th	ppm	<100

**TABLE 20.11**  
Typical leucoxene analysis.

Typical analysis	Unit	Leucoxene 70%	Leucoxene 90%
TiO <sub>2</sub>	%	70 - 75	90 - 92
Al <sub>2</sub> O <sub>3</sub>	%	1.0 - 2.5	0.6 - 1.1
Fe <sub>2</sub> O <sub>3</sub>	%	16 - 20	1.4 - 3.5
CaO	%	0.02 - 0.06	0.01 - 0.03

### Zircon

Zircon (ZrSiO<sub>4</sub>) is the most important economic mineral of zirconium. It is commonly found in alluvial deposits in conjunction with other HM; most typically titanium minerals, in which it can represent up to 30 per cent of the mineral suite.

The element hafnium occurs naturally with zirconium and, in zircon, is normally present as about one to two per cent of the mineral composition (as HfO<sub>2</sub>). Because zirconium and hafnium have very similar chemical properties, they are difficult to separate. The convention in the industry is to express zircon quality in terms of the combined zirconium and hafnium content. Typically, ZrO<sub>2</sub> and HfO<sub>2</sub> represent around 66 per cent of commercial zircon concentrates. Often the combined content is shown simply as the percentage of ZrO<sub>2</sub> (Table 20.12).



**TABLE 20.12**  
Typical zircon analysis.

Typical analysis	Unit	Premium	Standard
ZrO <sub>2</sub> + HfO <sub>2</sub>	%	66	65
TiO <sub>2</sub>	%	<0.15	0.15 - 0.25
Fe <sub>2</sub> O <sub>3</sub>	%	<0.08	0.10 - 0.20

The other commercial mineral of zirconium is baddeleyite, which is not a product of the mineral sands industry, although it does compete with zircon as a raw material for the extraction of zirconia (ZrO<sub>2</sub>). Baddeleyite typically contains approximately 98 per cent ZrO<sub>2</sub>; however, this mineral contributes less than one per cent to the total of zirconium minerals currently extracted.

The prime drivers of zircon demand are in the end-use sectors of:

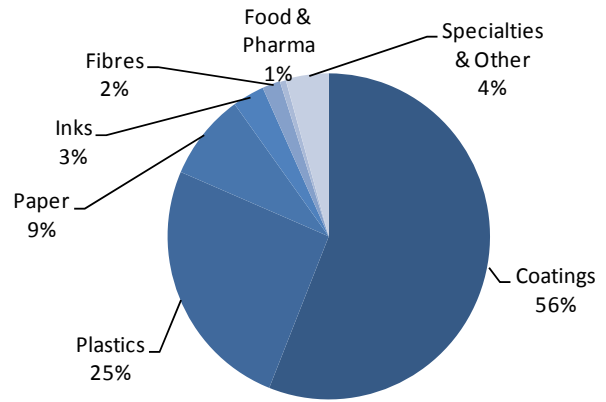
- ceramics
- refractories, foundry sand and the relatively minor TV glass market
- specialty chemicals and materials.

The ceramics industry is the major driver for zircon demand. Within the sector, growth in zircon consumption will be largely determined by intensity of use in ‘gres porcellanato’ tiles and the rate of urbanisation in the industrialising nations. Zircon, when finely ground and incorporated into ceramic glazes and tile bodies, imparts a brilliant white to the ceramic. Zircon is also used as the base material for many of the colours used in ceramic glazes. Global tile manufacture has been growing rapidly for the last 15 years, especially in China.

Demand for zircon is driven by end-use applications, based on its unique properties, which include opacity, wear resistance, chemical and thermal stability and useful electrical properties.

**Demand and supply**

The paint and coatings sector is the largest consumer of TiO<sub>2</sub> pigment, averaging around 56 per cent of total pigment consumption in 2010 (Figure 20.2). The plastics sector accounted for 25 per cent, while the remaining 20 per cent was mostly used in the production of paper, paper laminates and inks. Most TiO<sub>2</sub> pigment is used in the architectural coatings segment. Demand for architectural coatings is driven by factors such as home sales, new construction (residential and commercial), home maintenance and government spending on urban development. Demand is largely seasonal, with most activity in the northern hemisphere’s late spring and early summer – when decorative coatings are most in demand. In 2000, China accounted for 11 per cent of global TiO<sub>2</sub> demand. By 2010, that figure rose to 21 per cent.



**FIG 20.2 - Global TiO<sub>2</sub> demand by end-use sector**  
(source: ©TZMI).

**TABLE 20.13**  
Geographic distribution of global titaniferous feedstock production (per cent TiO<sub>2</sub> units) (source: ©TZMI).

Geographic region	2006 (%)	2007 (%)	2008 (%)	2009 (%)	2010 (%)
Australia	26	26	25	23	20
South Africa	20	20	20	22	19
North America	19	17	17	13	14
China	11	10	9	9	10
India	6	6	6	8	9
Norway	6	6	6	7	6
Other	12	14	16	19	22

As can be seen from Table 20.13, the largest feedstock-producing country in the world in 2010 was Australia, with 20 per cent of the world’s supply (net of beneficiated ilmenite), followed by South Africa with 19 per cent. Canada produced 13 per cent of global feedstock supply, solely from Rio Tinto Fer et Titane’s operations, followed by China and India, accounting for 12 per cent and nine per cent, respectively.

In the short-term, new supply is expected to come from a limited number of greenfields projects as well as from several brownfields expansions. However, this extra capacity will not be enough to avoid supply deficits forecast in the short-to-medium term.

TZMI expects feedstock demand to continue to grow at strong rates in the coming years. The supply deficits that have developed in the industry have had a significant impact on pricing of feedstocks. The pricing dynamics have changed, with control now in the hands of producers. In this uncertain climate, although it is obvious that prices are headed in an upward direction, it is difficult to determine how much they will rise by. Once long-term contracts have run their course, there will be more short-term contracts and peak pricing occurring in spot sales.

With consumers competing to secure sufficient feedstock going forward, there will be more upward price pressure. Rising operating and fuel costs and strengthening local currencies have also had an impact on feedstock producers.

TZMI expects significant price increases in bulk rutile, sulfate ilmenite and chloride ilmenite in the next few years.

In the last five years, there has been a significant lack of investment across the mineral sands industry as a whole, primarily as a result of low profit margins compounded by the effects of the global financial crisis (GFC). The current buoyant market has seen increased investor interest in the mineral sands industry overall. However, the first new supply to come on-stream is not expected until 2013. In light of the depletion of existing mature orebodies, the volume of new supply will not be enough to balance the supply-demand equation in the medium- to long-term.

## NICKEL

*By Mark Selby and David T White*

The characteristics and marketing of commercially available nickel ores and intermediates are considered in this section.

### Market

This section presents market factors affecting the world nickel market, including nickel mine production, processing and consumption.

### Mine production

Total 2012 world mine production was approximately 1.5 Mt of nickel. The major producing countries are Russia, Canada, New Caledonia, Australia, Indonesia, Cuba, Brazil, China, Colombia, South Africa and the Philippines. Significant new production is coming online in Madagascar and Papua New Guinea.

Sulfide ore sources dominated in the 20th century, even though world reserves of sulfides represent only 30 per cent of total resources. Historically, nickel was largely produced in integrated operating facilities with relatively little custom smelting. Until the 1970s, nickel production was dominated by the large integrated operating complexes owned by Norilsk, Inco, Falconbridge, SLN, Western Mining and Outokumpu. As production from the mines associated with these complexes began to decline and with development of smaller scale nickel orebodies, nickel intermediate flows began to increase. These have been complemented in recent times by production of nickel intermediates from laterite orebodies using pressure acid leach processing technology. These intermediates can be processed in facilities that have historically processed nickel sulfide materials. With laterite pressure acid leaching projects coming online, increases in ferronickel production

through expansions and new projects and development of nickel pig iron production in China, nickel sourced from laterites now makes up just over 50 per cent of primary nickel produced.

### Processing

A variety of technologies have been developed for processing sulfide and laterite ores.

#### Sulfide ores

Sulfide ores, formed at depth by volcanic processes, are generally higher in grade and usually associated with other elements such as copper and precious metals.

Sulfide ores are concentrated, smelted and refined to remove impurities and extract valuable elements other than nickel. The final metal product can be in the form of a cathode, pellet, briquette or powder.

#### Laterite ores

Laterite ores are near-surface deposits formed when nickel is concentrated in oxide and silicate minerals as a result of the breakdown of ultramafic rocks by surface weathering processes, usually in tropical climates.

A nickel laterite ore profile is simplistically divided into two ore types. The upper horizon consists of a limonite component with high iron, low magnesium and variable silica, containing low to medium nickel grades. The lower horizon contains low iron, high magnesium and high silica and is generally known as saprolite. Higher nickel grades are typical of this horizon. The quantity of each ore type varies significantly between orebodies.

Limonite ores are generally processed by either the Caron reduction roast ammonia leaching process, or the pressure acid leaching process. The Yabulu refinery near Townsville is an example of the Caron process. Other operating plants of this nature are in Cuba and Brazil.

The Murrin Murrin and Ravensthorpe operations in Western Australia are examples of the pressure acid leaching process. Other operating plants of this type are in Cuba, the Philippines, New Caledonia, Madagascar and Papua New Guinea.

Saprolite ores are typically processed by the reduction kiln – electric furnace (RK-EF) process to produce ferronickel. There are no plants of this nature in Australia. Worldwide, it is the dominant form of nickel production from laterite ores. There are significant operations in New Caledonia, Japan, Indonesia, Colombia and Brazil.

A significant development since 2004 has been the emergence of nickel pig iron production in China, using imported ore. This now accounts for over 15 per cent of the world's nickel production. This uses a similar smelting route to the RK-EF process, but typically with smaller and often existing equipment. The nickel content (six to ten per cent) is much lower than ferronickel (20 - 35 per cent) and phosphorous

and sulfur impurities are much higher. Nevertheless, at times of high iron ore and nickel prices, the ability to supply an already molten iron-nickel alloy to a nearby stainless steel mill can make this process competitive.

### Marketable products and consumption

Nickel is a versatile metal and is used in a number of end-products including stainless steel production (58 per cent), metal alloy products (21 per cent), plating (11 per cent) and foundry, chemicals, coinage and miscellaneous uses (ten per cent). Consumption trends have changed over the last ten years, with the proportion of nickel in stainless steel decreasing due to substitution, elimination and development of new lower nickel content duplex stainless steels.

In alloy applications nickel is typically used to add strength and/or corrosion resistance, particularly at higher temperatures and more challenging operating conditions. Nickel is used for plating where its appearance and ability to interact with layers of chromium provide a very strong and distinctive finish. Nickel powders are used in metallurgical applications and batteries. A small but traditional use of nickel has been in rechargeable batteries, first nickel-cadmium, then nickel metal hydride. Lithium ion batteries, which contain little nickel (but contain cobalt, a co-product of nickel refining) have replaced nickel-containing batteries in many uses such as mobile phones and laptop computers.

The major consuming countries are those with well-developed industrial bases and include the rapidly growing Asian economies: Japan 13 per cent, USA 13 per cent, China 26 per cent, European Union 30 per cent and other Asia 14 per cent. This too has shown a major shift in recent years, with the growing dominance of Chinese consumption.

Nickel demand growth has typically correlated well with industrial production and averaged approximately four per cent per annum from 1960 until 2000, with demand in periods accelerating or decelerating generally in-line with global industrial production. Rapid demand growth in China since 2000 would have driven global growth rates to over five per cent annually, based on historical relationships with industrial production growth, but shortages in supply and the resultant spikes in nickel prices led to substantial substitution, forcing demand growth from 2000 to 2010 to below three per cent annually, in-line with available supply.

Brook Hunt (2010) forecasts that global nickel consumption will increase to 2.1 Mt in 2016 and three per cent thereafter to 2.85 Mt in 2025. The two main consumption sectors, stainless and nickel-based alloys, are expected to grow strongly in the future. Primary nickel demand in stainless steel is projected to increase to just over 2 Mt by 2025. The bulk of this growth is expected to be supported by the continued expansion of the Chinese stainless steel industry.

### Price assumptions

Like most metals, nickel prices are determined by the level of demand and the structure of the cost curve. The 90th percentile of the cost curve has tended to be a good determinant of long-term pricing, and the 70th percentile of the cost curve is a good indicator of the short-term floor for metal prices. In nickel, the fourth quartile of the cost curve has become increasingly dominated by nickel pig iron production from China, using imported ore from the Philippines and Indonesia. Because the nickel content of the ore is low (1.0 - 2.0 per cent nickel) and it requires substantial amounts of energy (either electricity or coke) to process, it faces severe cost pressures when energy and labour costs increase, and as the Chinese currency strengthens.

### Marketing sulfide ores

A number of nickel producers in the Kambalda area of Western Australia sell nickel sulfide ores to the BHP Billiton Kambalda nickel concentrator. This is as a result of long-term back-to-back agreements on the purchase of mines and ore deposits from Western Mining in the late 1990s and early 2000s.

It is understood that the price under long-term agreements of this nature can be of the order of 55 to 60 per cent of LME nickel, delivered to concentrator.

Nickel laterite pressure acid leaching facilities typically have some capacity to process the oxide or supergene component sitting above the sulfide orebody. Pricing would be expected to be in the order of ten to 20 per cent of LME nickel, depending on grade.

### Marketing sulfide concentrates

While it is theoretically possible to trade in ore, it is much more common to deal in nickel concentrate. As a value-added product, nickel concentrate offers a number of global marketing opportunities for an Australian producer.

Apart from BHP Billiton's nickel smelter near Kalgoorlie, Western Australia, potential sulfide nickel concentrate customers include smelters in Canada (Xstrata and Vale, Sudbury, Ontario), Finland (Norilsk, Harjavalta), China (Jinchuan and others) and Brazil (Votantim, Fortaleza). There may be other potential customers in Southern Africa and Russia. Brief profiles of selected smelters are provided in the subsections below.

#### *Xstrata*

The Xstrata smelter, located in Falconbridge, Sudbury, Ontario, currently treats concentrates produced by Xstrata's operations located in the Sudbury Basin (the bulk coming from the new Nickel Rim South mine), Quebec (Raglan), Western Australia (Cosmos) and from third parties.



The smelter treats concentrates by a partial oxidising roast, followed by electric furnace smelting. Matte produced by the Falconbridge smelter is shipped to the Nikkelverk refinery in Norway. Overall cobalt recovery through the smelter and refinery is approximately 70 per cent.

### Vale

Vale's main smelter is located at Copper Cliff, Sudbury, Ontario. The smelter uses oxygen flash smelting to treat concentrates. Matte produced at the smelter is processed at the nearby Copper Cliff nickel refinery, Clydach in Wales, or converted to nickel oxide for further processing to utility nickel at a number of locations in Asia.

It is expected that the planned hydrometallurgical refinery at Long Harbour near St John's, Newfoundland, will process concentrates from other Vale operations, as well as the Voisey's Bay mine.

### Boliden/Norilsk

Boliden currently operates the Harjavalta nickel flash smelter in Finland. Output from the smelter is refined at the adjacent Norilsk-owned Harjavalta nickel refinery. Harjavalta processes significant quantities of third-party concentrates and other nickel-containing intermediates.

### Jinchuan

Jinchuan operates an integrated smelting and refining facility in Gansu Province, China. It uses flash smelting, electric smelting and Ausmelt furnaces in three separate lines. The smelter currently has a capacity of approximately 120 000 t/a of contained nickel, while the refinery has a capacity of around 150 000 t/a of contained nickel. Significant quantities of nickel concentrate feed to the smelter and nickel matte feed to the refinery comes from third-party sources.

### Concentrate quality

Typically, a concentrate purchase contract specifies a minimum nickel content, and may stipulate maximum levels of such deleterious elements as magnesium, arsenic, lead, selenium, tellurium and chlorine. Depending on the levels of copper and cobalt present these may be payable elements.

The magnesium content (expressed as magnesium oxide, MgO) of nickel concentrates is an important factor, because of its effect on the slag chemistry of the smelting operation, with higher MgO containing concentrates requiring high smelting temperatures. The absolute MgO content and the metal (nickel, iron) to MgO ratio are important in determining the marketability of nickel concentrates, but ranges vary, depending on the type of smelter and blended concentrate quality.

Other factors for nickel concentrates are the sulfur and iron contents (the fuel for the smelter). If the sulfur

and iron contents are low, flash smelters may have limited capacity to blend these types of concentrates.

While some gold and platinum group elements (PGE) may also be present, these are generally at low levels in Australian concentrates, so are not regarded as payable elements. Table 20.14 shows an example of a theoretical sulfide nickel concentrate delivered to BHP Billiton's Kalgoorlie nickel smelter.

**TABLE 20.14**  
Specifications of a theoretical sulfide nickel concentrate.

Element or property	Value
Ni	10% (minimum acceptable 9%)
Cu	0.4%
Co	0.5%
MgO	6.5% (maximum acceptable 7%)
Fe	33%
S	33%
As	300 ppm (maximum acceptable 400 ppm)
Se	10 ppm (maximum acceptable 50 ppm)
Pb	5 ppm (maximum acceptable 50 ppm)
Cl	100 ppm (maximum acceptable 0.5%)
H <sub>2</sub> O	<0.3% (ie if delivered in pressurised tankers in dry powder form)
Sizing	80 per cent passing 200 mesh (75 µm)

Concentrates are smelted into nickel matte, which is then either refined into nickel metal, or on-sold to custom refiners.

### Concentrate purchase terms

The recoverable or 'payable' nickel contained in concentrates normally has as its 'reference price' the LME quotation, which is cash or three-month, or a combination of these. The payable units of nickel are either paid for at the reference price less appropriate cost deductions, or at a percentage of the reference price, possibly with provision for minimum deductions in the event of low prices, plus a price bonus clause to cover times of high reference prices. Copper and cobalt similarly have a payable content, to which the LME reference price is applied.

The typical price for nickel concentrates is approximately 65 to 75 per cent of the LME nickel price. Unlike the copper industry, the volume of transactions in the nickel industry, combined with the wider range of nickel concentrate specifications relative to copper, has resulted in a lack of 'benchmark pricing' and standard penalties in nickel concentrate terms. A sample calculation is shown in the section on 'Examples of revenue calculation'.

Nickel concentrates with high levels of impurities, such as magnesium and arsenic, may have values as low as 50 per cent of LME, if buyers can be found. Laterite pressure acid leach operations sometimes have capabilities in this area, due to the impurity elimination steps inherent in these processes.

### Sulfide matte

Nickel matte is generally traded under long-term contracts from smelters to custom refiners.

Basic pricing of nickel mattes is understood to be in the range of 85 to 92 per cent of LME nickel, depending on impurities and by-product credits.

The apparently high smelting margin relative to concentrate terms is due to a combination of relatively high operating and sustaining capital costs for nickel smelters and additional refining capacity relative to smelting capacity.

Similarly, refining margins relative to matte terms are modest due to by-product credits for copper, cobalt and precious metals and the existence of tariff structures in a number of countries. This improves the refining margin relative to importation of finished nickel metal.

### Laterite ores

There is a significant international trade in nickel laterite ores. Mines in New Caledonia, Indonesia and the Philippines supply ore to smelters in Japan, China, South Korea and the Yabulu refinery near Townsville Queensland.

It is understood that the value of smeltable saprolite ores containing around two per cent nickel is approximately 30 per cent of the LME nickel price. The value of high-iron limonite ore containing around 1.5 per cent nickel and 0.1 per cent cobalt is approximately 20 per cent of LME nickel, with some credit for cobalt possible, depending on market conditions.

### Intermediates

Other intermediate nickel concentrates and products are discussed in this section.

#### *Mixed nickel-cobalt sulfide*

Mixed nickel-cobalt sulfides (often termed MSP or Mixed Sul) are produced from a variety of processes, including as:

- co-products from refining of nickel laterites by the Caron reduction roast - ammonia leach process, with a nickel to cobalt ratio of 2 - 3 to 1
- co-products from refining of nickel mattes, with a nickel to cobalt ratio of 1 to 1
- intermediates from leaching of nickel sulfide ores or concentrates, with nickel to cobalt ratios of around 30 - 50 to 1

- intermediates from pressure acid leaching of nickel laterites, typically with nickel to cobalt ratios of around 10 - 15 to 1, reflecting the ratio in the ore.

The sulfide precipitation process is selective for base metals over most other impurities, so will generally contain only nickel, cobalt, copper and zinc. Copper and zinc can often be selectively removed ahead of nickel and cobalt precipitation. The main 'impurity' is sulfur.

Total base metals content can be as high as 64 per cent (dry basis) on a sulfide precipitated from an acid leach solution, and around 40 per cent from an ammonia solution. Moisture contents are similarly diverse, at around 15 per cent in filtered product from an acid precipitated sulfide, to as high as 50 per cent from material precipitated from alkaline ammonia solutions.

These intermediates are processed directly in refineries, so intrinsically have a value closer to that of a matte than a nickel sulfide concentrate. They have higher levels of sulfur and lower levels of by-products than mattes, so effective conversion costs may be higher.

Perhaps as important, they are not widely traded, so transparent pricing is difficult to establish.

It is understood that where sales have been made, the value is in the range of 80 to 85 per cent of LME nickel for both nickel and cobalt content.

#### *Mixed nickel-cobalt hydroxide*

Mixed nickel-cobalt hydroxides (often termed MHP) are produced as intermediates from acid leaching of nickel laterites, with nickel to cobalt ratios generally a reflection of the ratio in the ore. Nickel content is typically 40 to 48 per cent on a dry basis, with moisture contents of 40 to 60 per cent. A high-quality MHP that has been pressure filtered may have a nickel content on an 'as shipped', or wet, basis of 25 per cent.

MHP has higher manganese and magnesium impurities than MSP, but lower sulfur levels. As a result of the manganese and magnesium impurities, fewer refineries are capable of processing this intermediate than MSP. In addition, moisture levels of around 50 per cent mean that transport costs to an off-site refinery can be quite significant. Drying can have a significant effect on the chemical characteristics of MHP, making refining problematic.

As it is a relatively new intermediate in commercial terms, with the limited refining opportunities discussed above, the market in MHP is still developing. Shorter-term contracts are believed to be in the range of 67.5 to 72 per cent of LME nickel, with the longer-term upper limit currently believed to be around 75 per cent of LME. This may increase to 75 to 80 per cent over time, if more refining options become available.

It should also be noted that upstream impurity removal is critical for the reduction of iron, chromium and aluminium to levels that do not affect refining operations.

In addition to refining options, the potential for adding to RK-EF operations as a supplemental feed has also been investigated.

### Basic carbonate

Nickel carbonate may be produced as an in-process intermediate in the Caron reduction roast - ammonia leach process, as practised at the Yabulu refinery and other similar operations, or by adding sodium carbonate (soda ash) to nickel sulfate solutions.

It may be sold from time-to-time if there is a downstream bottleneck in production. The approximate price is estimated at 85 per cent of LME nickel. It is generally suitable as refinery feed.

### Oxide sinter

Nickel oxide sinter is produced either by oxidising nickel sulfide matte or as an in-process intermediate kiln product from the Caron process.

There is a specialised market in this product, generally into Japan, South Korea and China, for conversion to nickel metal for direct feed to stainless steel melting.

The price is approximately 95 per cent of LME nickel, and like nickel sulfide matte, is influenced by the tariff structure in these countries.

## Examples of revenue calculation

Examples of cost calculation for smelter terms and for NSR are given below (reproduced from first edition).

### Smelter terms for concentrates

The following is an example of typical smelter terms for nickel concentrates. Terms vary from smelter to smelter.

#### Delivery

Free-on-truck (FOT) Kambalda, Western Australia, as wet concentrate containing approximately eight to ten per cent H<sub>2</sub>O.

#### Nickel payment

Pay for 89 per cent of the nickel content, less a TC of US\$200/t of concentrate and a refining charge of \$0.75 per pound of nickel, at the lower of the LME cash and three-month prices (the 'reference price') for the quotational period.

Deduct ten per cent of the amount by which the reference price exceeds the long-term price expectation; today approximately US\$8.00/lb.

#### Copper payment

Where the copper content exceeds 0.5 units, pay 70 per cent of the lower of the LME Grade A cash and three-month prices for the quotational period. Deduct a refining charge of 7.5 ¢/lb.

#### Cobalt payment

Where the cobalt content exceeds 0.25 units, pay for 50 per cent of the metal content at the lower end of the

producer price and the mean of the free market range, as published in *Metal Bulletin* less a refining charge of \$3/lb.

#### Quotational period

This will be the fourth month following the month of delivery of concentrate, for all payable elements.

#### Deductions

All deductions will be escalated for fuel oil, and Consumer Price Index changes are for:

- penalties
  - arsenic – for each 10 ppm As over 200 ppm, a penalty of A\$1/dry tonne will be levied
  - magnesia – for each one per cent MgO over five per cent MgO, a penalty of A\$6/dry tonne will be levied
  - other – if any other elements are found to have a detrimental effect on nickel production, the parties will negotiate appropriate penalties in good faith
- marketing charge – a charge of US\$0.10/lb payable nickel will apply.

#### Payment

A provisional payment equal to 70 per cent of the estimated value will be made at the end of the month following the month of delivery

Final payment will be made at the end of the fifth month following the month of delivery.

#### Weighing, sampling and assaying

Buyer's weights and moisture determinations will be final.

Sampling is to be carried out in lots of not more than 600 wet tonnes. Assays will be exchanged between buyer and seller. Splitting limits will be 0.2 per cent Ni, 0.1 per cent Cu, 0.05 per cent Co, 0.5 per cent MgO and seller's As assay will be not more than ten per cent from the buyer's assay.

#### Calculation of net smelter return

The following example of the calculation of NSR is based on the smelter terms quoted in the preceding calculation.

**Specification** – assume that the specification given in the section 'Marketing of sulfide concentrates' applies.

**Metal prices** – assume:

Ni	US\$9.00/lb
Cu	US\$3.00/lb
Co	US\$12.00/lb

**Exchange rate** – assume US\$0.90 = A\$1.00

#### Nickel payment

Payable nickel = 10% × 89% = 8.9% payable Ni  
= 196.21 lb payable Ni/dmt

Reference price percentage of reference price =  
 Payment for nickel = 196.21lb @ US\$9.00  
 = US\$1 765.89/dmt  
 Less treatment charge of \$200/t  
 Less refining charge of \$0.75/lb  
 $\$0.75 \times 196.21\text{lb} = \$147.16$   
 Less price participation  
 $(\$9.00 - \$8.00) \times 10\% = \$0.10/\text{lb} \times 196.21\text{lb} = \$19.62$   
 Payment for nickel = \$1765.89 – \$200 – \$147.16 – \$19.62  
 = \$1399.11/dmt

**Copper payment**

Copper content fails to meet the minimum content of 0.5 per cent; therefore, no payment for copper content.  
 Payment for copper = \$0/dmt

**Cobalt payment**

As cobalt content exceeds 0.25%, then payable Co = 50%  
 = 0.5% × 50% = 5.51 lb payable Co/dmt

Reference price = US\$12.00/lb

Less refining charge of \$3.00/lb

= \$9.00/lb of payable Co

Payment for cobalt = 5.51 lb @ US\$9.00 = **US\$49.59/dmt**

**Total payment for metals = US\$1432.17/dmt**

Converted @ US\$0.90 / A\$/1 = **A\$1609.67/dmt**

**Less deductions**

Arsenic penalty = 300 ppm – 200 ppm

= 100 ppm @ A\$1/dmt for each 10 ppm

= 1.00 = 10 × A\$1 = A\$10.00/dmt

10

MgO penalty = 6.5% – 5%

= 1.5% @ A\$6/dmt for each 1%

= 1.5 × A\$6 = A\$9.00/dmt

**Total deductions = A\$19.00/dmt**

**NSR, FOT Kambalda = A\$1590.67/dmt**

**PHOSPHATES**

*By Peter McCarthy*

Sources of phosphates are phosphate rock, guano, cave earth of organic origin and basic slag (the slag resulting from basic hearth steel production). Phosphate rock is by far the most important source, with an estimated world production of 191 Mt in 2011 (USGS, 2012). USGS (2012) estimates that phosphate rock production capacity will increase by nearly 20 per cent, from 215 M (short) tons in 2011 to 256 M (short) tons in 2015, with most of the increases occurring in Africa. Australian production was an estimated 2.7 Mt in 2011.

Phosphate rock is usually very fine grained, in which the phosphate mineral is a member of the fluorapatite-chlorapatite-hydroxyapatite series, with the general formula  $\text{Ca}_5(\text{PO}_4\text{CO}_3)_3(\text{F},\text{OH},\text{Cl})$ . The major constituents in apatite are 50 per cent to 55 per cent CaO and 38 per cent to 42 per cent  $\text{P}_2\text{O}_5$ . The term 'collophane' is used for the cryptocrystalline variety of apatite. Rock phosphate grades are quoted as per cent tricalcium phosphate, referred to as bone phosphate of lime (BPL) or triphosphate of lime (TPL) equivalent to 2.185 × % $\text{P}_2\text{O}_5$ .

Phosphate rock is the basic material used in all phosphorus fertiliser production. It typically contains 12 - 17 per cent phosphorus and is usually beneficiated to remove clay and other impurities. Following beneficiation, the phosphate rock is finely ground and treated with acid. Single superphosphate is produced by reacting phosphate rock with sulfuric acid and is a relatively low-grade fertiliser. Phosphoric acid is produced by a two-stage closed-circuit reaction, with phosphate rock and sulfuric acid (90 - 93 per cent) as the raw materials and calcium sulfate (gypsum) as a by-product. Filtration removes the gypsum to leave green, wet-process or merchant-grade phosphoric acid containing about 22 per cent phosphorus (International Fertilizer Industry Association, 2010). Phosphoric acid is an intermediate product in the production of high-grade fertilisers such as triple superphosphate, monoammonium phosphate (MAP) and diammonium phosphate (DAP). Triple superphosphate is produced by reacting phosphoric acid with phosphate rock and MAP and DAP are produced by reacting phosphoric acid with ammonia.

The Australian market for phosphate fertiliser is around 350 000 t as phosphorous, which is equivalent to 4 Mt of superphosphate (Chemicals Australia Consultants, undated). Locally manufactured superphosphate provides around 75 per cent of Australian phosphates (as phosphorus), with the balance by imports of ammonium phosphates. Imports of phosphate fertiliser are almost entirely as ammonium phosphates. Australia has significant phosphate resources, some with good export potential. There is no substitute for phosphorus in agricultural use.

There is a lead-time involved in shipping fertilisers from overseas suppliers to Australia, which can cause problems of oversupply or undersupply if real demand varies from forecasts made by the importers. Domestic fertiliser prices are determined by the international price, the exchange rate and the costs of shipping, storing and handling.

Due to the lead-times from origin to Australia and the effect of inventory and the seasonal demand pattern, the rate at which international price changes are reflected in Australia varies considerably. The rate is primarily driven by competition between the various manufacturers and importers. As domestic



production competes with imported product, or could be sold on the world market at international traded prices, the international market determines the Australian domestic price for both imported and locally manufactured fertilisers.

Sales of phosphate rock are generally by annual contract with consumers, with minimum rock grades of about 30 per cent  $P_2O_5$  (approximately 66 per cent BPL). Rocks with an analysis of 32.5 to 35 per cent  $P_2O_5$  (70 to 77 per cent BPL) fetch a premium price. The grade of phosphate rock is usually specified within a BPL range (68 - 70 per cent BPL), with the contract price based on one end of the range. At the time of shipment the grade of the rock is determined and the base contract price is adjusted to reflect the actual analysis.

In January 2012, the price of phosphate rock (Morocco), 70 per cent BPL, contract, free-alongside-ship (FAS) Casablanca was US\$203/dmt. Varying typically between US\$20 and US\$30/t between 1960 and 2005, the price surged to US\$430/dmt in 2008, but then fell to around US\$90/dmt by July 2009. Since then it has risen steadily (World Bank, undated). Al Rawashdeh and Maxwell (2011) provide a longer-term view of the industry's market framework.

In addition to  $P_2O_5$  grade, the price of rock is adjusted downwards when the silica content exceeds six per cent and is generally unsaleable when it exceeds nine per cent unless it can be blended with lower silica rocks. High silica levels are not detrimental to the process of phosphoric acid production per se, but increase the load on filters in the phosphoric acid plant, thereby reducing overall plant throughput. Fully integrated plants using high-silica feed are designed with larger capacity filters, although this obviously comes with a capital cost penalty.

Most sales contracts contain price penalty conditions, which are effective when the combined  $Fe_2O_3$  and  $Al_2O_3$  analysis, commonly termed  $R_2O_3$ , exceeds three per cent. The base price of the rock is usually decreased for each per cent  $R_2O_3$  that the actual analysis is above three per cent. Fractions of  $R_2O_3$  are pro rata.

Sales contracts usually contain indicative analyses of  $P_2O_5$ ,  $Fe_2O_3$ ,  $Al_2O_3$ , carbonate, chlorine, fluorine, silica, sulfides, magnesium, sodium, potassium, uranium and cadmium. The presence of carbonates is undesirable as they consume sulfuric acid during processing. The presence of the elements from chlorine to potassium inclusive may have a deleterious effect on subsequent processing, but this effect is somewhat dependent on the process and the plant design. If the gypsum from the phosphoric acid manufacture is to be used for plasterboard manufacture, the  $U_3O_8$  content must be below legislated limits. Cadmium in the rock is carried through to the fertiliser and into the food chain. The cadmium content of fertilisers is limited by legislation in most countries. Rock with cadmium content less than

10 ppm will be more readily sold. With the exception of  $P_2O_5$ ,  $Fe_2O_3$  and  $Al_2O_3$ , there are usually no penalty conditions for other elements present except that if they exceed certain limits the shipment may be rejected.

Phosphate rock is sold in bulk. Moisture and sizing are usually the only physical properties in the sales contract. Moisture levels are required to be as low as possible and generally less than three per cent. The sizing specification is dependent on the processing method and the design of the plant. The sizing specification is commonly 100 per cent -5 mm, but may be as coarse as 25 mm.

The quality of phosphoric acid, the intermediate product in the production of solid fertilisers, is primarily determined by the minor element ratio (MER) of the acid. MER is a measure of impurities in the acid and is defined as  $(\%Al_2O_3 + \%Fe_2O_3 + \%MgO)/\%P_2O_5$ . The MER determines the uptake of nitrogen when the acid is ammoniated. DAP has a strictly defined composition of 18-46-0 nitrogen-phosphorus-potassium (N-P-K) whereas MAP can have a variable composition with typical values of 10-50-0 to 12-52-0. A MER of 0.08 is considered to be the maximum acceptable for solid fertiliser production. A MER of 0.04 would be ideal for the production of DAP and 0.06 for the production of MAP. Some level of MER is required to promote granulation.

Approximately 4.7 Mt of phosphoric acid is traded each year, with India at 2.3 Mt the largest importer (International Fertilizer Industry Association, 2010).

## TANTALUM

*By Gippsland Limited*

One of the denser elements, tantalum is related to niobium and vanadium and shares many of niobium's chemical and physical characteristics. Discovered in Sweden over 200 years ago, tantalum was not isolated until 1820, and then only as an impure metal. It was not until 1905 that a pure metal suitable for working was achieved. Its desirable properties are high electrical capacitance, high melting point and excellent resistance to chemical attack. More than 130 species of tantalum-niobium minerals exist, but only a few (tantalite, microlite, wodginite, euxenite and polycrase) are used by the tantalum industry as raw materials. Tantalite, in the form of  $(Fe,Mn)(Ta,Nb)_2O_6$ , is the most important mineral for tantalum extraction (*Mining Journal*, 2010).

### Pricing

The pricing unit is a pound unit of tantalum pentoxide ( $Ta_2O_5$ ). Tantalum prices are expressed as US\$/lb  $Ta_2O_5$ .

### Applications

About half of the tantalum consumed each year is used in the electronics industry, mainly as powder and wire for capacitors, owing to tantalum's particular

ability to store and release electrical energy. This allows components to be exceptionally small. They are, therefore, favoured in space-sensitive, high-end applications in telecommunications, data storage and implantable medical devices. Tantalum is also used for electronic sound filters and as a barrier against copper diffusion in semi-conductors.

Tantalum carbide's hardness makes it ideal for cutting tools. Tantalum is highly biocompatible. Its low mechanical strength means it is generally used as a coating on stronger substrates, such as stainless steel. Applications range from stents supporting blood vessels to plates, bone replacements, suture clips and wire. Tantalum also goes into the manufacture of superalloys, imparting strength and high-temperature resistance against cracking for use in aerospace and energy generation.

The use of tantalum in high-temperature alloys for the aircraft industry is assured for the foreseeable future as these alloys cannot easily be substituted once they are engineered and tested into the designs. Its corrosion resistance makes tantalum useful in the chemical industry, generally as a lining to pipes, tanks and vessels. Tantalum oxide increases the refractive index in lens glass.

### Resource distribution

Tantalum resources are widespread, with the most important known resources found in Brazil and Australia (Table 20.15). Other significant sources are China, the Democratic Republic of Congo (DRC), Ethiopia, Mozambique, Nigeria, Russia and Rwanda. Tantalum is also produced in Brazil, Malaysia and Thailand as 'tin slag', a by-product of tin mining and smelting.

Tantalum raw materials are also being explored and/or produced in Canada, Colombia, Egypt, Namibia,

Saudi Arabia, South Africa, Tanzania, Venezuela and Zimbabwe. The level of production in these countries varies from exploration deposits to active artisanal mining and inactive major mines.

The most likely resource base is a measure that balances the strictness of Proved Resources (Indicated + Measured) with the broader availability of Inferred Resources and 'advanced exploration targets'. The large figure that would be provided by the latter is reduced by ignoring early exploration projects and discounting other resources according to level of exploration, mineralogy and grade quality, while including operating (or currently closed) mines or those having reached feasibility study status.

Total resource information must be used cautiously, however, as tantalum and niobium invariably co-occur in tantalite minerals, and the relative weight proportion of tantalum to niobium in any particular setting significantly affects the commercial viability of tantalum extraction. At present, only mineral resources where tantalum is a significant constituent are considered potentially commercially exploitable.

Tantalum minerals with over 70 different chemical compositions have been identified. Those of greatest economic importance are tantalite, microlite and wodginite; however, it is common practice to name any tantalum-containing mineral concentrate as 'tantalite' primarily because it will be processed for the tantalum values and is sold on that basis. The minerals are concentrated by physical means at or near the mine site to increase the percentage of tantalum oxide and niobium oxide by weight.

The concentrates are transported to the processing works for chemical processing. Tantalum mineral concentrates may contain from two to more than five different tantalum-bearing minerals from the same mining area. The sale of tantalum mineral concentrates is based on a certified analysis for the tantalum oxide ( $Ta_2O_5$ ) they contain, with a typical range from 20 per cent to 60 per cent, depending on the mine source.

The structure of the supply side of the tantalum industry has undergone dramatic changes since the start of the GFC, a process that is continuing; current producing countries are limited to Brazil, Malaysia, Thailand, Russia, DRC, Rwanda, Ethiopia, Mozambique and Nigeria.

### World production

The tantalum market is supplied from a number of sources (Table 20.16). Primary mineral production from both conventional and artisanal sources typically makes up about 60 per cent of total supply. The balance comes from tin slags and synthetic concentrates produced from tin slags (typically about 20 per cent) and from scrap and inventory. The relative proportions provided from each source from time-to-time vary with overall market

TABLE 20.15

Most likely tantalum resource base (source: Tantalum and Niobium International Study Center, undated).

Source	'000 lb	Proportion (%)
South America	285	40
Australia	145	21
China and South-east Asia	73	10
Russia and Middle East	69	10
Central Africa	63	9
Other Africa	47	7
North America	12	2
Europe	5	1
Total	698	100

**TABLE 20.16**  
World tantalite production, showing Ta<sub>2</sub>O<sub>5</sub> contained in different sources.

	2005	2006	2007	2008	2009
Concentrate ('000 lb Ta <sub>2</sub> O <sub>5</sub> )	3000	1700	2100	2100	500
Other concentrates ('000 lb Ta <sub>2</sub> O <sub>5</sub> )	220	380	440	470	430
Tin slag ('000 lb Ta <sub>2</sub> O <sub>5</sub> )	500	480	350	490	390
Total	3720	2560	2890	3060	1320

demand. In general terms, the volume of tantalum provided to the market from secondary sources is dependent on tin smelter production in Thailand, for which supply is relatively inelastic. Likewise, in general terms, the supply of tantalum from scrap is dependent on the overall level of tantalum use and, to a lesser extent, tantalum prices. This supply is also relatively inelastic. As a result, the supply of tantalum from primary mine production has a significant bearing on the satisfaction of overall demand and pricing. In turn, tantalum is a rare material, and primary mine production is satisfied by a small number of producers.

The market for tantalum raw materials is dominated by two tantalum material processors (Cabot and HC Starck of Germany), which together produce around 80 per cent of the world's requirements for refined products such as tantalum metal powder, tantalum oxides and carbides and tantalum metal. The traditional dominance of Cabot and HC Starck could be challenged in the future by emerging Chinese entrants and increased activity by other smaller processors.

Before 2009, supply was dominated by two large primary producing mines (Greenbushes and Wodgina in Australia) and from tantalum-containing tin slags from Thaisarco's Thailand tin smelting operations. Lesser contributions came from mines in Brazil, Canada, Mozambique and Ethiopia, with the Wodgina and Greenbushes operations accounting for typically around 50 per cent of the primary tantalum raw material production.

In the immediate aftermath of the GFC, the demand for processed tantalum products contracted as both demand for end-use products contracted and as end-users depleted their inventories. Simultaneously, the major tantalum raw material processors sought to reduce their raw material inventories and thus there was a sharp contraction in primary tantalum material demand. Processor raw material inventories were believed to have amounted to as much as two years' raw material requirement at the start of the GFC.

As a result, lack of demand led to severe curtailment on the supply side, with the closure of the Greenbushes

and Wodgina mines in Australia (December 2008) and the Tanco mine in Canada (April 2009) as well as other, smaller producers such as Marropino in Mozambique (April 2009). More recently the passage of the US 'conflict minerals' law in July 2010 aimed at curtailing the supply of tantalum-containing minerals from conflict areas, particularly the DRC, and is also thought to have had a significant effect on primary tantalum supply.

Progressive improvement in the demand for processed tantalum materials since 2009 has been satisfied largely by inflexible secondary supply of Thai tin slags, drawdown of large supply chain inventories held by processors (which have been progressively depleted) and (until July 2010) a significant primary material contribution from 'conflict' sources. This increasing end-user demand did not flow-through to demand for primary tantalum raw materials, and of the four major producing mines that previously dominated the supply of primary materials, only one (Marropino in Mozambique) tentatively returned to production (April 2010). Marropino is presently thought to produce around 300 000 lb/a Ta<sub>2</sub>O<sub>5</sub>, but has a limited easily exploitable resource inventory.

Global Advanced Metals, which owns the Greenbushes, Wodgina and Tanco mines and the Cabot processing facility, previously announced its intention to recommence production from its Wodgina mine at a rate of 700 000 lb/a Ta<sub>2</sub>O<sub>5</sub>. However, there appears to be no prospect of a restart of the Greenbushes and Tanco mines.

The Mibra mine in Brazil (owned by Metallurg International Resources) has the capacity to produce 300 000 lb/a although current production is thought to be about 100 000 lb/a. Additional operating mines are the Kenticha mine (Ethiopia Mineral Development Enterprise) in Ethiopia, Lovozero mine in Russia, Yichun mine in China and Pitinga mine (Parapanema) in Brazil.

Prior to the GFC, worldwide annual consumption of tantalum was estimated to be between five and seven million pounds (as Ta<sub>2</sub>O<sub>5</sub>). As a result of the global economic recession and supply chain inventory destocking, Roskill estimates that world consumption of tantalum fell in 2009 to three million pounds of Ta<sub>2</sub>O<sub>5</sub>, a 40 per cent drop from 2008.

The 2009 global supply of tantalum fell 30 per cent from 5.4 M lb of Ta<sub>2</sub>O<sub>5</sub> in 2008 to 3.64 M lb. While demand is expected to recover to pre-GFC levels, primary supply is quite inflexible and not expected to recover until, and unless, one or more of the closed operations is recommissioned and unless a significant new source is developed.

Roskill (2009) states that 'there are mounting fears in the tantalum market that serious (supply) shortages are looming'.



## Transparency and traceability

It is in the interest of the tantalum industry to maintain a stable and reliable supply of raw materials in order that this high technology market can continue to grow with confidence. The Tantalum-Niobium International Study Center (TIC) supports the industry as a whole, taking instruction from the executive committee, which is composed of volunteers from a broad cross-section of the industry including mining, trading, processing and refining, electronics manufacture and metal recycling. Where necessary, the committee's actions are subsequently endorsed by a vote at the annual General Assembly. As a voice for the entire industry, the TIC cannot support the individual views of a minority of members, as it is duty bound to follow the wishes of the majority. Central Africa (chiefly DRC and Rwanda) and Nigeria were very minor sources in the mid-2000s.

However, renewed interest in this area (not least because of the passage of legislation recently in the USA) highlighted the need to implement a system of traceable supply due to the association of the conflict in the DRC with the supply of raw materials. For a decade, the TIC has stated its commitment to, and members' requirement of, 'lawful and ethical trade practices'. However, by 2008 this position was felt to be insufficient, and the TIC set up the Working Group on Tantalum and Niobium Mining (WGTNM) in January 2009 to study how best to achieve a transparent and traceable supply chain that would simultaneously support and promote the legitimate activities of the artisanal miners that make up the bulk of mining production in developing countries.

## Marketing

Most tantalum-bearing raw materials are sold on long-term contracts, although there is some spot market activity. Prices are a matter of negotiation between buyer and seller and are not made public. The world's main tantalite processors are, in order, Cabot (USA), HC Starck (Germany) and Ningxia Orient (China). There are no official or published prices, as tantalum is not traded on any metal exchange, although tantalum spot prices are freely published online (Metal Pages, undated).

In volume terms, only a very small proportion of tantalum-containing raw materials is traded on the spot market, with most bought and sold under long-term agreements. Accordingly the spot price should not be regarded as a reliable guide to long-term contract prices, which may be higher or lower than the prevailing published spot prices.

The spot market price has increased from approximately US\$38/lb in December 2009 to over US\$120/lb in 2010 and for much of 2011. Since October 2011, the price has moved down to around US\$100/lb.

## TIN

*By Peter Kettle*

This section discusses effects of smelter terms and charges, and concentrate grades, on tin pricing.

### Smelter terms and charges

Tin smelter terms depend on many factors; however, contracts are generally structured under four main headings:

1. smelting charge (sometimes referred to as treatment charge), which includes the smelter's costs and margins
2. unit deductions, which reflect recovery losses throughout the smelting process
3. penalties or costs associated with removing impurities
4. payment terms, which include the timing and amounts of payments.

Smelting charge generally includes all of the smelter's consumables, labour and overheads along with an expected return from the capital. As a large percentage of the operating costs is also related to the energy price including electricity, oil, gas and anthracite costs, some contracts include a rise-and-fall clause linked to the prevailing oil price. Terms can also include a cost reduction for volume and can include price participation (PP) where the smelter is paid less at lower tin prices and the supplier pays more at higher prices.

Unit deductions are associated with the loss of tin within the smelting process. In general, the lower the quality of concentrate the higher the deduction, as lower-quality concentrates will generate higher volumes of slag and will, therefore, result in more tin being lost. In addition, higher quantities of iron and tungsten in the concentrate attract higher unit deductions as these elements can result in the formation of excessive quantities of hardhead (iron-tin alloy) in the smelting process, and as a result carry more tin into the slag.

A base unit deduction is usually based on a minimal deduction at a specified concentrate grade to reflect tin losses in the process and will increase or decrease if the grade is lower or higher. The base deduction ranges between 1.5 per cent and 2.5 per cent and is usually referenced to a concentrate grade of 60 per cent  $\pm 0.05$  per cent to 0.1 per cent per one per cent variance. Additional deductions for iron and tungsten are based on the combined percentage of Fe + W in the concentrate above a certain limit (free limit).

Penalty charges relate to the costs associated with removing impurities such as arsenic, sulfur, copper, lead, zinc, bismuth, antimony, nickel, cobalt, chloride, fluoride and silver. Most contracts have a minor free limit after which penalties are paid.

There are generally no credit payments received for tin concentrates, with the exception of tantalum, which



some smelters will pay credit for if they are able to recover the contained tantalum into a saleable final tin slag.

Payment terms will vary from smelter to smelter and have become less favourable over the last several years as a result of tightening credit markets. Provisional payments are available after the loading of material onto a ship and with the delivery of bills of lading, assays and other specified documentation. Provisional payments are similar to trade finance and can, therefore, attract an interest charge on the basis that it reflects an early payment. Provisional payments can be up to 85 per cent of the contained tin less the anticipated smelting and penalty charges.

Other payment terms include various provisional payments on delivery to the smelter's port, or to the smelter's works. Final payments are provided at settlement, which is approximately three to five weeks after arrival of concentrate at the smelter's works.

Some smelters may also offer a toll treatment option where the supplier of concentrates pays all of the smelting costs and penalties and receives metal at the point of settlement.

### Pricing

For provisional payments the price received is based on a provisional price that is derived from either a spot price on the day of shipment, or on the average price a week or two prior to shipment. This price is then adjusted, based on the final prices received when the metal has been deemed as sold.

The tin price received is priced on one of two markets: LME or the Kuala Lumpur Tin Market (KLTM). There is also a Chinese market price; however, at this stage for various reasons it is not very common to be used in concentrate sales contracts. The most common is the LME, which can consist of spot cash prices or three-month settlement prices, while the KLTM price is a single settlement price each day. The pricing mechanism used to determine the final tin price received can vary depending on the smelter. The most common is the average price of tin over a period related to the arrival of concentrates at the smelter. This could be the average price over two weeks from the time of arrival, or the average price over four weeks, which may be the combined average price over the two weeks prior to and two weeks after arrival. Some smelters offer the ability to spot price the tin on the market at any time over a specified period, with some limits on daily pricing volumes. Others offer a combination of prices such as spot or three-month. Others still may insist on pricing on the lowest of the four quoted LME tin prices, that is, bid and offer for cash and three-month settlement.

Most concentrate contracts are also on a CIF basis, with the supplier paying the insurance and freight.

### Concentrate grades

In general, most concentrates consist of tin oxides as  $\text{SnO}_2$ , which in its pure form is approximately 78 per cent. Traditional smelting feed concentrates range between 45 and 75 per cent concentrate grades. However, some smelters can accept concentrate grades as low as 30 per cent tin at substantial discounts. Material containing less than 30 per cent tin can be treated through a tin fuming process route; however, globally there are very few tin fumers that have been established to take third-party concentrates, and terms would be very specific.

The only surviving tin smelter in Australia is owned by Global Advanced Metals and is located at Greenbushes in Western Australia. This small electric furnace smelter has operated periodically and is used to recover small quantities of tin from the mining of tantalite ore at the Wodgina and Greenbushes mines in Western Australia. The closest smelters to Australia are on Bangka and Belitung islands in Indonesia. The largest of the Indonesian smelters, near Mentok on Bangka Island, is operated by PT Timah. Combined with a new smaller plant on Kundur Island, this company has a total smelting capacity of about 65 000 t/a of high-grade gravity concentrates. PT Koba Tin has modern tin smelter on the southern end of Bangka Island capable of treating at least 35 000 t/a of high-grade gravity tin concentrate. In addition, on both Bangka and Belitung Islands, numerous other smaller privately owned tin smelters treat domestically produced tin concentrates.

The nearest toll and custom smelters to Australia are located in Malaysia and Thailand. Malaysian Smelting Corporation operates a large smelter at Butterworth Malaysia, based on the use of up to five reverberatory furnaces; the smelter has a nameplate capacity of some 50 000 t/a of refined tin. Thailand Smelting and Refining Company Limited (Thaisarco Limited) operates a toll and custom tin smelter and large refinery on the south-eastern corner of the island of Phuket in Thailand. This smelter consists of reverberatory furnaces and two small submerged arc electric furnaces and has a nameplate capacity of about 35 000 t/a of refined tin, although recently Thaisarco has operated mainly as a refiner and tin product manufacturer. Other possible destinations for concentrates from Australian mines might be Chinese smelters such as Yunnan Tin and Yunnan Chengfeng, or the Funsur smelter in southern Perú. Table 20.17 shows typical penalty amounts in tin concentrates and Table 20.18 shows the leading tin smelters and refiners.

### Example of revenue calculation

#### Concentrate specification (dry)

Sn	54.0%	S	2.5%	Fe	6.2%
$\text{WO}_3$	1.8%	As	0.4%	Zn	0.05%
Cu	0.3%	Mn	1.2%		

All calculations are in US dollars.

TABLE 20.17  
Penalty amounts in tin concentrates.

Penalty element	Free limit	Typical formula (\$US/t concentrate)
Sulfur	<0.5%	Sliding scale \$2 at 1% S, \$10 at +2.5%
Arsenic	<0.1%	\$120 - \$150 per 1% pro rata
Lead/bismuth, antimony, fluorine/chlorine	<0.01%	\$90 - \$120 per 1% pro rata
Copper	<0.02%	\$300 - \$500 per 1% pro rata
Zinc	<0.02%	\$90 - \$120 per 1% pro rata
Iron and manganese	<2.5% combined	Unit deduction 10% of combined
Tungsten (WO <sub>3</sub> )	<1%	Unit deduction of 10% of content

TABLE 20.18  
Leading tin smelters and refiners (source: ITRI).

Country	Company	Plant location	2010 refined tin production (t)	Comments
Belgium	Metallo Chimique	Beerse	9945	Secondary smelting and refining as part of copper recycling plant
Brazil	Taboca (Minsur)	Sao Paulo	1123	Capacity about 20 000 t/a. Own mine supply currently restricted. May be converted to slag treatment in future
Bolivia	EM Vinto	Oruro	11 520	State-owned company treating local medium-grade concentrates. Capacity expanding in 2012
	OMSA	Oruro	3423	Treats medium and low-grade concentrates from local mines
China	Yunnan Tin	Gejiu, Yunnan and Chenzhou, Hunan	59 180	Main smelter is Ausmelt unit in Gejiu. Treats own and purchased concentrates
	Guangxi China Tin	Laibing, Guangxi	14 300	Treats own and purchased concentrates. Capacity expanding in 2012
	Yunnan Chengfeng	Gejiu, Yunnan	14 155	Custom smelter treating primary and secondary material
	Gejiu Zi-Li	Gejiu, Yunnan	9000	Custom smelter
	Jiangxi Nanshan Tin	Nankang, Jiangxi	6000	Custom smelter treating primary and secondary material
	Other companies	Various	52 000	Primary and secondary production
Indonesia	PT Timah	Mentok and Kundur	40 413	Main plant at Mentok, Bangka Island. Treats own and purchased concentrates
	PT Koba Tin	Koba	6644	Capacity about 25 000 t/a, but feed restricted. Treats own and purchased concentrates
	Private smelters	Various	10 000	Crude tin production >50 000 t. More than 30 independent smelters with combined capacity of about 60 000 t/a have export licences. Most tin is sent for final refining elsewhere in Asia
Malaysia	Malaysia Smelting Corp	Butterworth	38 737	Leading global custom smelter and refiner, mainly treats medium- and high-grade concentrates and Indonesian crude tin
Peru	Minsur	Ica	36 052	Integrated Ausmelt smelter with some spare capacity
Thailand	Thaisarco	Phuket	23 505	Global custom smelter with capacity of about 35 000 t/a. Has focused recently on custom refining of Indonesian crude tin

Note: The smelters listed individually accounted for 78 per cent of estimated refined tin production in 2010. Smelters not listed are mainly small units treating local concentrates in China, Indonesia and Brazil.

**Tin price** \$25 000  
**Smelter charge** \$500 +\$5 per 1% below 55% Sn,  
 -\$5 per 1% above 55% Sn

**Tin unit deductions**

1.8 units ± 0.05 units < > 60% Sn minimum of 1.4 unit deduction

1.8 units + (60% – 54% Sn) × 0.05 units = 2.1 units  
 Fe + Mn = 6.2% + 1.2% = 7.4%

Unit deduction 7.4% less 2.5% free limit = 4.9 × 10%  
 = 0.49 units

WO<sub>3</sub> = 1.8% less 1% free limit = 0.8% × 10% = 0.08 units

Total unit deductions = 2.67

**Penalties**

Sulfur 2.5% = \$10/t

Arsenic 0.4% less free limit 0.1% = 0.3 × \$150 = \$45

Zinc 0.05% less free limit 0.02% = 0.03 × \$120 = \$3.60

Copper 0.3% less free limit 0.02% = 0.28 × \$500 = \$140

Total penalties = \$198.60

**Total payment**

Payable tin metal 54% Sn – 2.67 units = 51.33%

51.33% Sn × \$25 000 = \$12 832.50

Less smelting charge \$500 + \$5 = \$505

Less penalties \$198.60

Total payment = \$12 128.90/t concentrate

**TUNGSTEN**

*By Grant Brock*

Tungsten is marketed as different products including oxide concentrates, ammonium paratungstate (APT), tungstic acid, sodium tungstate, tungsten metal powder, ferrotungsten and tungsten carbide powder. Comprehensive information about tungsten is compiled by the International Tungsten Industry Association (ITIA), which was formed in 1988. Current price information can be obtained from *Metal Bulletin* and *Minor Metals*.

Products produced on mine sites can include mineral concentrates as well as intermediates such as APT. Intermediate products command significantly greater prices and so provide an incentive for primary mine sites to produce them. APT is the principal tungsten raw material traded on the open market and varies in grade from 88 to 99.95 per cent WO<sub>3</sub>. When further processed, APT is usually calcined to yellow (WO<sub>3</sub>) or blue (WO<sub>3-x</sub>) oxide and reduced to tungsten powder by hydrogen in high-temperature furnaces.

Tungsten ores, concentrates, intermediates and products are sold in metric tonne units (MTU) of WO<sub>3</sub>.

Historically, China has been the major producer of tungsten concentrates, commanding approximately 90 per cent of the world market. With low production

costs, China could flood the market and force higher-cost Western miners to cease production. However, in 2003, the Chinese Government abolished export incentives, introduced production and export quotas and increased export tariffs. This has significantly increased the price of APT from US\$45/MTU to US\$450/MTU in 2011, and has provided the opportunity for new producers to enter the market. Yet with many years of inactivity outside of China, it will take some years for new sources to come into production.

A typical scheelite-wolframite concentrate requires a grade of 65 - 75 per cent WO<sub>3</sub> and may have the specifications given in Table 20.19.

**TABLE 20.19**  
 Typical scheelite-wolframite concentrate grade.

Element	Grade (%)
W (as WO <sub>3</sub> )	65% minimum
Sn	0.5% maximum
P	0.05% maximum
As	0.2% maximum
S	0.75% maximum
Cu	0.4% maximum
Mo	0.04% maximum

The value of a tonne of tungsten concentrate containing 70 per cent WO<sub>3</sub> is calculated as follows:

Number of MTUs/t of concentrate = 70  
 Selling price per MTU = US\$140  
 Hence, value = US\$140 × 70 = US\$9800/t

For APT concentrate the grade of the concentrate varies between 88.5 and 99.99 per cent WO<sub>3</sub>, particle size of 30 - 70 µm and bulk density of 1.83 - 3.35 g/cm<sup>3</sup>. Maximum impurity content of APT is given in Table 20.20.

The value of one tonne of APT containing 95 per cent WO<sub>3</sub> is calculated as follows:

**TABLE 20.20**  
 Maximum impurity content of ammonium paratungstate.

Element	(%)	Element	(%)	Element	(%)
Al	0.001	Fe	0.001	Pb	0.0007
As	0.001	K	0.0005	S	0.007
Bi	0.001	Mn	0.0007	Sb	0.0005
C	0.001	Mg	0.0007	Si	0.001
Ca	0.0005	Mo	0.002	Sn	0.0003
Co	0.0005	Na	0.001	Ti	0.001
Cr	0.0010	Ni	0.0007	V	0.001
Cu	0.0005	P	0.0007	Zn	0.001

- number of MTUs/t of concentrate = 95
- selling price per MTU = US\$425
- hence, value = US\$425 × 95 = US\$40 375/t

The major markets for tungsten include China, USA, Europe and Japan. The major uses are in cemented carbides, steels and alloys, milling products and high-temperature electrical applications.

## URANIUM

Natural uranium concentrates of Australian origin can be exported to all countries that comply with Australia's uranium export policy and they are subject to the Customs (Prohibited Exports) Regulation 1958.

Direct exports can also occur to other countries that satisfy the definition of 'recipient country': one or more countries that satisfy all of the following requirements:

- there is in force, between the country and the United Nations International Atomic Energy Agency (UN IAEA), an agreement for the application of safeguards, and unless the country is a nuclear weapon state, an additional protocol to that agreement
- there is in force, between the country and Australia, an agreement relating to the application of safeguards in relation to nuclear transfers between Australia and that country and administrative arrangements pursuant to that agreement
- the country is a party to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) (London, Moscow and Washington 1 July 1958) and has not given notice of its intention to withdraw from that treaty.

Therefore, exporting only to 'recipient countries' accords with the Australian Government's policy only to allow the export of uranium to countries that observe the NPT and that are committed to non-proliferation and nuclear safeguards. Non-nuclear weapons states must have an additional protocol in place with the IAEA. This means that:

- Australia exports its natural uranium ore concentrates to conversion facilities meeting the above requirements
- sales of Australian-produced uranium can only be made to countries that meet the above requirements.

Nuclear power generating facilities can be readily identified in most countries as being either state- or privately-owned. Marketing activities involve making a direct approach to the fuel buying divisions within potential customer utilities (as would be done in selling steaming coal) and entering into sales contracts that, apart from mutually acceptable commercial terms, must provide for:

- Australian Government approval of the commercial terms before the sales contract can come into force

- all shipments being made in accordance with bilateral safeguards agreements administered by the Australian Safeguards and Non-Proliferation Office (ASNO), in conjunction with the nominated government safeguards authority in the country operating an approved conversion facility as nominated by the customer, in accordance with the terms and conditions of the applicable sales contract.

In order to ensure safe and secure transport, natural ore concentrates are packed in 200 L steel drums securely stowed within standard 20 ft shipping containers. Transport and handling must conform to the international standards for low-level radioactive material as per the Regulations for the Safe Transport of Radioactive Material (TS-R-1) published by the IAEA, and the International Maritime Dangerous Goods (IMDG) Code.

Uranium concentrates are usually sold on the basis of account-to-account ('book') transfer at converters from the account of the seller to the account of the buyer.

There are several intermediate process steps between the production of 'yellowcake' (uranium oxide concentrate ( $U_3O_8$ )) and the fabrication of fuel assemblies for use in nuclear power reactors. In summary, these comprise:

- refinement of yellowcake ( $U_3O_8$ ) into uranium trioxide  $UO_3$
- conversion of  $UO_3$  into uranium hexafluoride ( $UF_6$ )
- enrichment of  $UF_6$  from its natural level of about 0.7 per cent  $^{235}U$  to 3.0 to 4.5 per cent  $^{235}U$ , which is the enrichment level used in nuclear fuel
- transport of enriched  $UF_6$  to a fuel fabrication plant where it is converted to uranium dioxide ( $UO_2$ ) powder and pressed into small pellets that are inserted into thin zircalloy or stainless steel tubes to form fuel rods; the rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of a nuclear reactor.

Suppliers generally enter into agreements with conversion facilities, which include weighing, sampling and analysis. Agreements also include provisions for the storage of the concentrates ahead of book transfers. Converters impose penalties on suppliers if delivered concentrates fail to meet the converters' impurity limits. Typical specifications are given in Table 20.21.

The power utilities purchase either the U or  $U_3O_8$  component of the delivered uranium ore concentrate. Rather than simply delivering dried ammonium diuranate, suppliers can reduce their overall cost per pound of delivered U by adding a calcination step into the process between precipitation and packaging. Calcination drives off all of the ammonia and reduces the overall moisture content. Installing a calciner is a capital-intensive cost that for small producers can prove difficult to justify.



Utilities generally contract with converters, enrichers and fabricators directly for the provision of those services.

Uranium concentrates have been traditionally sold under medium- to long-term contracts (three to ten years) to utility customers in accordance with the international safeguards regime. Intermediaries such as brokers and traders have taken a higher profile in the uranium market in recent years.

Prices under long-term contracts are either negotiated annually or are based on formulas referencing long-term and/or spot price indicators. Spot prices are

published weekly by two established organisations, Trade Tech and UxC. Long-term prices are published monthly by the same organisations.

Other commercial matters such as delivery terms and payments terms are resolved by mutual agreement between buyers and sellers.

### UF<sub>6</sub> conversion surcharges

The uranium concentrate specifications and surcharges in Table 20.21 have been established for UF<sub>6</sub> conversion services. When uranium concentrates fail to meet the specifications designated as 'standard concentrates', surcharges are assessed for any deviations up to the 'maximum limit concentrates' specification according to the surcharge schedule.

**TABLE 20.21**  
Typical uranium ore concentrate specifications.

Element	Standard concentrates (%)	Maximum limit concentrates (%)
U	75	65% minimum
As	0.01	0.04
Ba	0.01	0.04
B	0.005	0.10
Cd	0.01	0.04
Ca	0.05	1.00
CO <sub>3</sub>	0.20	0.50
Cr	0.01	0.04
F	0.01	0.10
Br, Cl, I	0.05	0.10
Fe	0.15	0.50
Pb	0.01	0.04
Mg	0.02	0.50
Hg	0.01	0.04
H <sub>2</sub> O	1.00	2.00
Mo	0.10	0.30
PO <sub>4</sub>	0.10	1.00
K	0.20	1.00
Se	0.01	0.04
SiO <sub>2</sub>	0.50	2.00
Ag	0.01	0.04
Na	0.50	3.00
SO <sub>4</sub>	1.00	4.00
Th	0.10	0.50
Ti	0.01	0.05
<sup>234</sup> U	56 µg/gU	62 µg/gU
V	0.10	0.75
Zr	0.01	0.50
Zr	0.01	0.50

### ZINC

*By Bill Wise*

Zinc concentrates and production are presented in this section with an example of a net smelter return calculation.

### Market

It is generally forecast that global production of refined zinc metal in 2012 will be in excess of 14 Mt for the first time, with China the dominant producer at about 42 per cent of this figure. Other Asian countries (including Japan) will produce another 21 per cent, putting the Asian total at a remarkable 63 per cent. Worthy of mention are Europe at 17 per cent, North America and Latin America each at seven per cent and Oceania at about 3.6 per cent.

Smelters sell their metal to local customers in the first instance for logistical reasons, and then export as necessary, with freight costs a major criterion in customer selection. The dominant immediate use of zinc is in galvanising. Diecastings, brass, rolled zinc and zinc compounds are also useful outlets for the main end-users, which includes construction, transport, machinery, equipment and consumer durables industries.

The zinc smelters are in turn the customers of the mines. Many indeed are also zinc miners themselves to provide feed to their smelters, but also to mitigate the fluctuation of profit contributions between the two. The simple axiom is that miners, as principal risk takers, do better than smelters at high prices, and so integration between mines and smelters reduces the amplitude from year to year. The top five zinc mining companies, with about 27 per cent of global zinc mined (Xstrata, Hindustan Zinc, Teck, China Minmetals and Glencore) are also among the top ten zinc smelter companies, producing 17.4 per cent of global refined zinc. The major custom smelter, which is not significantly integrated with mines, is the Korea Zinc Group. It produces over 1 Mt/a of refined zinc (and a range of by-products), making it the largest single purchaser of zinc concentrates among producers.

Apart from miners selling zinc concentrates directly to zinc smelting companies (custom or integrated with their own mines), another significant group of customers is the base metal commodity trading companies. Glencore and Trafigura are the two largest and have an enormous book of zinc and other base metal concentrates each year. Other smaller, but nonetheless experienced, trading companies also exist. The larger trading companies also buy and sell refined zinc and other metals, and occasionally invest directly in mine and smelter ventures, often subject to controlling all or part of the production offtake.

### Concentrate supply and demand

Many analysts agree that, due to inevitable mine closures and continuing robust demand for zinc (and, therefore, zinc concentrate), significant new zinc mine production will be needed in the near future. Asian smelter capacity is anticipated to increase in India, South Korea, Uzbekistan and especially China, where seven new smelters are expected by 2025. This suggests that new zinc mine production will be needed by 2015–2016, possibly rising to an extra 8 Mt of zinc concentrate by 2020.

### Frame contracts and spot contracts

Contracts to buy and sell zinc concentrates are normally based on an agreed tonnage over a calendar year or years, with terms negotiated and agreed on an annual basis. These are known as frame contracts, and have the advantage that both parties are certain of the sale and purchase well before the agreed delivery date. Occasionally the brick method is used to minimise any significant changes in terms from year to year. For example, the applicable treatment charge may be the arithmetic mean of that agreed in the current year, and that earlier agreed for the previous year, and so on for every year of the contract.

Spot contracts, on the other hand, are deals made at short notice, often to fill an unforeseen requirement of a smelter, which invariably aim to maintain an optimum level of production. In such cases involving a ‘distressed buyer’, the spot deal is likely to provide a better return to the miner than a frame contract. However, if a miner sets aside tonnage to sell on the spot market at a later time, it risks not being able to find a suitable buyer when the time comes, and so the ‘distress’ is with the miner. Trading companies, with intimate knowledge of the market and/or short-term commitments to satisfy, are usually interested participants when spot tonnage becomes available. Strong demand in China in recent years has resulted in an atmosphere of healthy trading in the Chinese spot market, with those selling in this manner achieving improved returns compared to frame contracts.

### Smelter technology

The extractive metallurgy of zinc from concentrates is dominated by two main technologies: the electrolytic

zinc process and the reduction of zinc oxides by carbon at elevated temperatures, of which the ISP is dominant. Smelters using these different technologies competed strongly during the last 40 years of the 20th century. However, the ISP has now been largely phased out as a primary smelter since the electrolytic process gained dominance because of its superior product, higher efficiency and lower cost structure. The only niche for the ISP today is for the treatment of relatively cheap low-grade mixed zinc and lead concentrates, which cannot be handled by an electrolytic plant, and for the treatment of secondary materials. Another factor contributing to its decline has been the continued development of mineral dressing and the resultant improvement in separation of zinc and lead into high-grade concentrates. These two smelter technologies are summarised below.

#### *Electrolytic process*

The electrolytic process has been applied to the recovery and refining of copper since 1865, and by 1915 the importance of solution purification in attempts to electrolyse zinc sulfate solutions to produce zinc was becoming understood. A significant number of experimental or small commercial electrolytic zinc plants built in North America, Europe, Japan and Australia prior to 1920 pioneered many of the basic features of the electrolytic process. These features have remained unchanged since that time, albeit with a number of significant improvements. These key steps, stripped to basics are:

- roasting – changes standard feeds from sulfides to oxides
- leaching – dissolves zinc in the roasted concentrate (calcine) to form a solution suitable for purification and electrowinning
- purification – removes elements that contaminate zinc, or reduce current efficiency during electrolysis
- electrolysis – discharges zinc ions from the purified zinc sulfate electrolyte and deposits them at the aluminium cathode in an open electrolytic cell, also using a lead anode
- melting and casting – melts the cathode zinc and casts it into various moulds for marketing.

#### *Imperial Smelting process*

During the 1920s, the electrolytic process was not universally favoured because of the high cost of electricity, and a new process based on carbothermic reduction was sought, leading to the zinc blast furnace. Development was slow until integration with the lead splash condenser to overcome zinc condensation in 1950, which was followed by the construction of these ‘blast furnace-condenser system’ plants around the world to replace old retort plants. The overall process was named the Imperial Smelting process (ISP). The ISP involves preparing of sinter from sulfide concentrates then feeding it with preheated coke to a blast furnace.

There carbon combustion takes place and zinc oxides in the sinter are reduced in the gas stream at the top of the furnace. The gas stream is directed to a splash condenser chamber through which molten lead is continuously circulated, scrubbing out zinc and cooling the gas. The lead flows with zinc to a settling bath where zinc floats to the surface and is separated at 98.6 per cent zinc content, which is adequate for batch steel sheet galvanising, but not for other uses such as continuous galvanising and alloy diecasting. New Jersey Zinc Company developed refining technology for zinc produced from retort processes, which became an integral part of ISP plants, thus improving zinc quality significantly. Slag from the sinter and lead bullion are tapped at the bottom of the furnace. Any precious metals report to the bullion.

### Technical aspects of concentrates

Most viable zinc mines have orebodies containing between four per cent and 20 per cent zinc, which may also contain commercial quantities of other minerals such as silver, lead, copper and gold. The ultimate viability of a mine is largely dictated by the head grade of the ore and the metal recovery achieved into commercially attractive concentrates. Therefore, the basic aim of primary metallurgy is to recover valuable metals into their respective concentrates and to optimise the grade of the concentrate, often expressed as a position on a grade-recovery curve. This is a complex and movable balance involving both primary and by-product concentrates, dictated by overall economics of the mine, metal prices and marketing pressures, including logistics costs.

Each orebody is unique and requires customised processing and reagents to optimise separation and concentration efficiency, usually involving two main steps:

1. size reduction by crushing and grinding to liberate and separate individual mineral grains from one another
2. selective physiochemical separation by froth flotation to form separate metal concentrates.

Each final zinc sulfide concentrate has unique physical and chemical characteristics, but is generally treated by the market as a commodity, and generally has compositions falling within traditionally accepted ranges and limits set by electrolytic zinc plants, as shown in Table 20.22.

Impurity elements must be eliminated from the electrolytic process and if present in quantities in excess of the normal process capabilities, may attract a financial penalty from the buyer. Such elements and limits include iron eight to ten per cent, carbon one per cent, magnesium 0.3 per cent, arsenic 1000 g/t, antimony 1000 g/t, mercury 100 g/t, nickel 100 g/t and germanium 50 g/t. Other elements that are totally unmanageable by electrolytic smelters in excessive amounts include lead over three to four per cent,

TABLE 20.22  
Typical zinc sulfide concentrate specifications.

Element	Range (%)
Zn	48 - 56
S	30.5 - 32.5
Fe	1.5 - 10.0
Pb	1.0 - 3.0
Cu	0.10 - 1.5
Cd	0.15 - 0.30
Ag	10 - 200 g/t
Au	0 - 2 g/t

silica over three to four per cent, copper over two per cent, manganese over 0.4 per cent, and lead + copper over three per cent. Feeds to ISP smelters have no limits on lead, and copper can be significantly higher than two per cent, but limits still apply to silica, arsenic, bismuth and antimony. Silver and gold are recovered into lead bullion with ISPs, but report to low-value residues in the electrolytic process, which limits the ability to pay for them in concentrate feed. Some typical penalty payments applicable to both electrolytic and ISP smelters, depending on market conditions, are given in Table 20.23. They are payable pro rata.

TABLE 20.23  
Penalty payments for electrolytic and Imperial Smelting Process smelters.

Element	Payment
As	Up to \$2.00 per 1.0 per cent above 0.2 per cent
MgO	\$1.50 per 0.1 per cent above 0.3 per cent
Hg	Up to \$2.00 per 10 ppm above 50 ppm
Fe	\$1.50 per 1.0 per cent above 8.0 per cent
Mn	\$1.50 per 0.1 per cent above 0.5 per cent
SiO <sub>2</sub>	Up to \$2.00 per 1.0 per cent above 2.5 per cent

A common means of overcoming problems inherent with impurities or other elements occurring in zinc concentrates in excessive quantities is to blend concentrates. This dilutes the offending elements to acceptable levels and increases the value of the blended concentrate. This can be done at the mine site, by traders in warehouses, or by smelters at the smelter site, depending on circumstances. Finding the right 'home' for concentrates is an important part of marketing and sales, as unusual qualities (such as very low iron levels) can have special value to a smelter obliged, for example, to consume large quantities of internally produced 'high-iron' material, especially where residue disposal is a serious problem or cost.



## Pricing

Simply expressed, the traditional structure of the formula that determines the selling price of zinc concentrates to electrolytic smelters is based on a payment for 85 per cent of the contained zinc, at an agreed 'prevailing' price, less a TC.

Normally, the relevant zinc price is the LME cash settlement price (expressed in US\$) averaged over an agreed calendar month. This month is known as the quotational period (QP) and relates to the time of arrival of the carrying vessel at the discharge port. A common QP is the month after the month of arrival (MAMA), but other months are often agreed as an alternative. Custom smelters usually prefer a QP that provides a form of 'natural hedge' on price by allowing time for the concentrate to be converted to marketable metal and sold about the same time as the QP, under which the payment for concentrate is made.

Payment for 85 per cent of the contained zinc originated at the time of horizontal retorts early in the 20th century, when metal recoveries were limited to this figure. Electrolytic smelters were also limited by an inability to extract zinc from the zinc ferrite formed during roasting until the development of the jarosite and goethite processes in the late 1960s, when 95 per cent recovery became common. Today the better smelters recover 97 per cent to 99 per cent of contained zinc. This notwithstanding, the basic metal payment of 85 per cent has remained unchanged, but with a qualifying allowance of eight percentage units in the relevant concentrate. Hence today the metal payment is the lesser of either the total zinc content less eight percentage units, or 85 per cent of the contained zinc. Therefore, at a zinc concentrate grade of 53.3 per cent, the above alternatives have similar effects, but below 53.3 per cent the buyer would deduct eight percentage units and pay for the remainder. Above 53.3 per cent the buyer would pay for 85 per cent of contained zinc. At lower grades (where an eight unit deduction continues in full) this formula gives rough recognition to the fact that metal losses by the smelter are determined by the quantity of residues, and hence are proportional to concentrate volume irrespective of zinc content.

A significant feature of the formula is that the smelters are apparently 'gifted' a quantity of zinc metal free of charge, referred to as 'free metal', always equivalent to at least eight percentage units of contained zinc. This represents a significant addition to smelters' financial returns, but is also somewhat recognised in negotiation of the TC, which is almost invariably lower than actual smelter costs. However, it genuinely provides smelters with a vested interest in higher zinc prices, which to some extent can be influenced by overall supply of refined zinc from the world's smelters. This is one reason miners have been prepared to retain this otherwise outdated price formula. Another positive feature of the free metal is that smelters have an incentive to maximise

recovery of zinc metal, as improvements in this area are not shared with the miners. Finally, old habits die hard, and both buyer and seller have long experience negotiating in this manner, and can easily follow trends from year to year, while the traditional formula remains.

The TC is the main negotiable item and in some long-term frame contracts is the only item renegotiated from year to year. It no longer reflects smelter costs in any way, and in times of surplus concentrate supply, the TC tends to be higher (favouring the smelter), while in times of concentrate shortage it tends to be lower (favouring the miner). While each concentrate is unique and representatives of mines and smelters conduct their individual negotiations in private, it is not unusual for benchmark TCs to become known through the commercial literature and by other means, during the period when mines and smelters come together to negotiate terms for a new calendar year (quaintly termed the 'mating season'). Benchmark TCs are invariably established by the larger mines and smelters, and equally invariably used as a guide by other participants in the industry. The TC is set at an LME 'basis' price, which is usually close to the prevailing price, or a forecast of the average price for the upcoming year. Using an approximation of 2011 benchmark terms as an example, a TC may be expressed as 'US\$230/dmt of concentrate at a basis price of US\$2500 per metric tonne of refined metal'. The TC remains linked to movements in the LME zinc price by being deflated or inflated by agreed fractions of the subsequent movement of the zinc price above or below the basis price. For example, the above TC could be subject to an inflator of six cents per dollar between \$2500 and \$3000, and three cents per dollar above \$3000 to \$3500. The corresponding deflator could be four cents per dollar between \$2500 and \$2000, and two cents per dollar below \$2000 to \$1500. As a consequence, if the relevant zinc price during the QP was \$3000 instead of the basis price of \$2500, the TC paid by the mine would be \$260 instead of \$230.

Silver is the only other metal commonly paid for in zinc concentrates, and usually on the basis of 'deduct 90 grams and pay for 90 per cent of the remainder', which reflects the smelter's recovery of silver into a lead-silver residue.

The ISP produces both zinc and lead metal. It normally uses a bulk concentrate of mixed zinc and lead, but alternatively can use a blend of standard zinc and lead concentrates as feed. Standard terms for low-grade and bulk concentrates provide a greater percentage of free metal to the smelter, but also reduce metal output and profitability due to the increased formation of slag, zinc losses in the slag and energy costs to heat and melt the slag. Therefore, a balance needs to be struck between lower-cost raw materials and consequent lower zinc production (throughput versus output), resulting in an optimum-grade mixed feed. Bulk concentrates with a high zinc + lead content tend to be the most popular



among ISP smelters. Terms for bulk concentrates are a changing mix of the terms for standard zinc and lead concentrates. Some current examples of metal payments are:

- zinc – 80 per cent, minimum deduction eight units
- lead – 95 per cent, minimum deduction three units
- silver – deduct 90 g and pay for 90 per cent of remainder (if silver content is below 200 g/t, deduct 50 g and pay for remainder)
- gold – deduct 1 g and pay for 70 per cent of remainder.

The treatment charge for bulk concentrates for ISPs is commonly above the comparative TC for standard zinc concentrates, depending on the percentage mix of contained zinc and lead and various market conditions.

### *Other aspects of concentrate sales*

Of the matters not touched on in former sections, two of the more important commercial items involve the logistics of transporting the concentrate from the mine to the receiving smelter, and the sampling and assaying of the concentrate in a manner that ensures that payment is made on the basis of an accurate assessment of the actual mineral values contained in the material.

It is customary for the seller to arrange and pay for transport and insurance of the zinc concentrate to the contractual delivery point, which is usually an agreed shipping port near the smelter. The buyer is normally responsible for arranging and paying for the discharge of the concentrate from the hold of the carrying vessel. The seller usually presents bills of lading, a certificate of insurance, a provisional weight and assay certificate and a provisional invoice to the buyer promptly after shipment. This commences the process leading to payment for the concentrate. On receipt of the documents the buyer is normally required to immediately make a provisional payment equal to 90 per cent of the provisional value of the shipment, based on prices on the last market day prior to the bill of lading.

Insurance is for 110 per cent of the provisional value of the cargo and made in favour of the buyer once the buyer assumes 'risk'. This is normally when the cargo passes the ship's rail on loading. Title usually passes to the buyer on receipt of the provisional payment by the seller.

Weighing, sampling and moisture determination are carried out in a standard manner immediately after discharge of the concentrate at the buyer's port. The seller may be represented at this process by a professional supervisor from a company that specialises in this work, nominated by the seller. Deliveries are normally divided into sample lots of 500 wet metric tonnes (wmt), and sublots of 100 wmt for moisture determination. A sample is taken from each lot, and normally divided into five parts – one each for buyer and seller, one held for

an umpire (if required) and two held in reserve by the nominee of the seller. Each lot is weighed, sampled and moisture determined at the point of discharge. Samples from each lot are assayed independently by the buyer and seller for payable metals and for those impurities that incur a penalty. The results of assays are exchanged simultaneously between buyer and seller, and if the results are within the contractual level of difference, the arithmetic mean is taken as the agreed assay for final invoicing purposes. If the results are outside the contractual level of difference, the parties may agree on a figure, or alternatively have an independent umpire laboratory determine the result.

A final payment is made by the buyer covering the balance of the price after deducting the provisional payment, on receipt of the seller's final invoice, based on discharge weights, agreed assays and prices known at the conclusion of the QP. On occasion, because of a drop in metal prices, the buyer may receive a refund of part of the provisional payment, but usually the final payment is a positive figure. Occasionally a second provisional payment is made if final details are not known 60 days after the arrival of the carrying vessel at the port of discharge.

### **Example of mine and smelter returns**

Using the TC and zinc basis price details outlined for zinc concentrates in the section 'Pricing', and taking a typical concentrate with 52 per cent zinc content sold to an electrolytic smelter (without payable silver or penalty elements), the zinc metal payment per dmt of concentrate will be 52 per cent less eight units = 44 per cent of \$2500 or \$1100. The TC of \$230 is deducted, so the net concentrate payment to the mine is \$1100 – \$230 = \$870/dmt. All calculations are in US dollars.

The smelter's return is the value of the metal sold less the cost of the concentrate purchased. Assuming 97 per cent zinc recovery, the value of the metal sold is  $52 \times 97$  per cent = 50.44 per cent multiplied by the zinc price of \$2500 = \$1261. The smelter return is, therefore,  $\$1261 - \$870 = \$391$ /dmt of concentrate consumed, or \$775/t of zinc recovered. However, smelters normally sell refined zinc metal to customers at a premium to the LME cash settlement price, which varies depending largely on supply-demand at the buyer's location. A premium of US\$0.04/lb is not unusual, which increases revenue by about US\$88/t of metal sold. Smelter revenues are also boosted by the recovery and sale of by-products such as sulfuric acid, lead-silver residues and various minor elements when their value exceeds the cost of separation. Miners do not seek a payment for sulfur in zinc concentrates, despite the smelter revenue from sulfuric acid being considerable. Recognition is given to the fact that acid production requires considerable capital investment on the part of the smelter, and also avoids what may otherwise be a difficult disposal problem.

Calculations relevant to the purchase and sale of standard zinc concentrates to an electrolytic smelter (in US\$) are given below.

#### Assumptions

- Concentrate grade – Zn 52 per cent, Ag 190 g/t, Fe 9 per cent, As 0.7 per cent, Hg 70 ppm, Mn 0.6 per cent.
- Metal payments – Zn pay for 85 per cent, subject to a minimum deduction of eight percentage units. Ag deduct 90 g and pay for 90 per cent of the remainder.
- Prices during the QP – Zn \$3100/t, Ag \$30/troy oz (31.1035 g/troy oz); therefore, Ag = \$0.9645/g.
- Treatment charge – \$230/dmt basis \$2500. Upscale – add 6¢/\$1 to \$3000, add 3¢/\$1 above \$3000 to \$3500. Downscale – deduct 4¢/\$1 to \$2000, deduct 2¢/\$1 below \$2000 to \$1500.

#### Penalty elements

- Fe = penalised at \$1.50/1 per cent above eight per cent.
- As = penalised at \$2.00/1 per cent above 0.2 per cent.
- Hg = penalised at \$2.00/10 ppm above 50 ppm.
- Mn = penalised at \$1.50/0.1 per cent above 0.5 per cent.

#### Metal payments made by smelter

- Zn = the lesser of either  $0.52 \times 0.85 = 0.442$ , or  $0.52 - 0.08 = 0.44$ . Therefore, payment per dmt is for 52 per cent less eight units = 44 percentage units at \$3100/t = \$1364.
- Ag = deduct 90 g from 190 g = 100 g, 90 per cent of which is payable at \$0.9645/g = \$86.80.
- Total metal payments made by smelter = Zn \$1 364 + Ag \$86.80 = \$1450.80/dmt

#### Treatment charge paid by mine

- TC = \$230 at the basis zinc price of \$2500/t; escalation payable is:
- 6¢/\$1 between \$2500 and \$3000 =  $6¢ \times 500 = \$30$ , add 3¢/\$1 above \$3000 to \$3100 =  $3¢ \times 100 = \$3$ . TC payable by mine at a zinc price of \$3100 is, therefore,  $\$230 + \$30 + \$3 = \$263$ .

#### Payments by mine for penalty elements

- 9% Fe penalised at \$1.50/1% above 8% =  $1 \times \$1.50 = \$1.50$
- 0.7% As penalised at \$2.00/1% above 0.2% =  $0.5 \times \$2.00 = \$1.00$
- 70 ppm Hg penalised at \$2.00/10 ppm above 50 ppm =  $2 \times \$2.00 = \$4.00$
- 0.6% Mn penalised at \$1.50/0.1% above 0.5% =  $1 \times \$1.50 = \$1.50$
- Total payment by mine for Fe, As, Hg and Mn content is, therefore, \$8.00/dmt of concentrate.

#### Summary of payments

The cost to the smelter is \$1364 for contained zinc, add \$86.80 for contained silver, deduct \$263 as a TC and deduct \$8 for contained penalty elements.

**Net payment = \$1179.80/dmt of concentrate.**

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