

## **Revenue Calculations and Marketing**

The following is taken from the AusIMM publication -"Cost Estimation Handbook" Monograph 20, 1993. It was not available electronically so, to minimise the size of the file, it had to be scanned into Word format and then converted to a PDF. It is intended to update the selling terms and conditions. If anyone can help with this please contact Peter Tilyard ([peter.tilyard@riotinto.com](mailto:peter.tilyard@riotinto.com))

# **CHAPTER 16**

## **REVENUE CALCULATIONS AND MARKETING**

**Peter J Lewis**

**Peter J Lewis & Associates Pty. Ltd, Sydney, N.S.W.**

After graduating in Mineral Technology from the Royal School of Mines, London in 1963 he gained operating experience with Mount Isa Mines and Mogul of Ireland. From 1970 to 1985 he was employed by Consolidated Gold Fields Ltd., London, latterly as Group Metallurgist, on work mainly associated with new mine developments in Europe, the USA and the Middle East. He joined Elders Resources Ltd., Sydney in 1986 with whom he was Manager-Metallurgy and where he was responsible for metallurgical development and design at the Selwyn and Red Dome mines in Queensland. Since 1990 he has been practising as an independent consulting metallurgist and has worked on assignments throughout Australia and in New Zealand, PNG, Indonesia and the Philippines.

**Bindle, Ken J.** -Manager Marketing Services, BHP Manganese, Melbourne, Victoria

**Boyle, Glen O.** -Senior Mine Geologist, New England Antimony Mines N.L., Hillgrove, N.S.W.

**Breen, Thomas A.E.** -Managing Director, Status Resources Australia, Sydney, N.S.W.

**Chanroux, Christian** -Managing Director, Transamine Services Ltd., London, U.K.

**Codner, Anna** - Senior Trader, Metals and Minerals Division, Minemet Australia Pty. Ltd., -Sydney, N.S.W.

**Cotton, Michael** -Marketing Director, Western Australian Mint, Perm, W.A.

**Cuninham William H.** -Manager ~ Intermediate Products. Marketing, W.A. Operations, Western Mining Corporation Limited, Perth WA

**Davies, Warren** -Manager Marketing, Energy Resources of Australia Ltd., Sydney, N.S.W.

**Dennis, John W.** -Distribution Superintendent, Queensland Phosphate Ltd., Melbourne, Victoria

**Haigh, Michael** -Technical Marketing Manager, Gwalia Consolidated Ltd., Perm, W.A.

**Hohnen Murray A.** -Manager, External Relations, BHP Australia Coal Ltd., Brisbane, Queensland

**Greville, Andrew J** - Marketing Manager Asia, Americas and Thermal Coal, BHP Australia Coal Ltd., Brisbane, Queensland.

**McDonald, Ian** -Manager, Liaison & Analysis, BHP Iron Ore Ltd., Perth, W.A.

**Milne David** -Manager, Resource Utilisation, Comalco Minerals & Alumina, Brisbane, Queensland

**Rickleman Neil**- Senior Business Analyst, Business Analysis, Comalco Minerals and Alumina, Brisbane, Queensland

**Scotford, Rodney F.** - formerly Marketing Manager, Metalliferous Mining Division, Peko Wallsend Ltd., Sydney, N.S.W. (now Manager, Sales & Analysis, Energy Resources of Australia Ltd., Sydney, N.S. W.)

**Vogel, Arnold** - formerly General Manager Marketing, Pancontinental Mining Ltd., Sydney, N.S.W. (now Corporate Finance Department, Bankers Trust Australia Ltd., Sydney, N.S.W.)

**Wilson, Peter C.** -Manager Marketing, Pancontinental Mining Ltd., Sydney, N.S.W.

# Chapter Contents

Introduction (P.J. Lewis)	328
Antimony (G.O. Boyle)	332
Bauxite (D. Milne and N. Rickleman)	332
Coal (M.A. Hohnen and A.J. Greville)	334
Copper (P.C. Wilson and C. Chanroux)	337
Diamonds ( <i>The AusIMM</i> )	340
Gold and Silver (M. Cotton)	340
Industrial Minerals ( <i>7:A.E. Breen</i> )	342
Iron Ore ( <i>I. McDonald</i> )	344
Lead (P.C. Wilson and C. Chanroux)	346
Lithium (M. Haigh)	348
Magnesite (A. Vogel)	350
Manganese (K.J. Bindle)	351
Mineral Sands (A. Codner)	352
Nickel ( <i>W.H. Cunningham</i> )	356
Phosphates (J. W. Dennis)	358
Tantalum (A. Vogel)	359
Tin (P.J. Lewis)	360
Tungsten ( <i>R.F. Scotford</i> )	363
Uranium ( <i>W; Davies</i> )	363
Zinc (P.C. Wilson and C. Chanroux)	364

# Introduction

By P.I. Lewis, with assistance from P.C. Wilson and A. Vogel

For the economic evaluation of any mining project it is essential to determine a realistic value of the revenue derived from the sale of products. This applies at all stages of project evaluation through to the final feasibility study. In estimating revenue the following factors must be considered: process plant recovery; product quality; product prices; commercial sales terms; and the cost of getting the product to the market.

In general terms, the net revenue received by the mine is the payment made by the buyer less the realisation costs, where the latter includes freight, insurance, marketing, and other selling costs. This relationship is often expressed as (Vogel and Grey, 1990):

$$AMV = NSR - RLZ$$

where,

AMV = at mine value, which is the actual value of the product after all deductions are made (it can also be expressed as AMR, at mine revenue);

NSR = net smelter return, which is the payment received by the mine after the smelter, refiner, or buyer has deducted all their charges (it can also be expressed as NSV, net smelter value);

RLZ = the total realisation costs.

The payment (NSR) received from the buyer varies considerably in terms of the gross value of the valuable constituent and often can be surprisingly low. For example, the NSR for base metal concentrates can vary from 95% to as little as 40% of the gross value of metal contained in the concentrates, depending on the metal involved and the grade of the concentrate. The percentages for the AMV can be considerably less once realisation costs are taken into account, particularly for mines in remote locations.

This chapter deals with the estimation of revenue derived from a variety of mineral products. Realisation costs and general matters related to smelter terms and the sale of products are discussed first. Then guidance is given on how to calculate the NSR for various mineral products, which are arranged in alphabetical order.

## Realisation Costs

Realisation costs comprise the sum of all transportation, insurance, superintendence, assaying and marketing costs.

**Transportation costs** cover all freight costs associated with the delivery of the product to the buyer, whether it be by road, rail, sea or air, and invariably it is the main component of total realisation costs.

The basis for delivery of the product to the buyer can vary considerably and is defined by one or other of the terms given in Table 16.1.

For more detailed explanations of these, and other terms, reference should be made to the *handbook Incoterms*, which is published

Term	Definition	Explanation
FOB	Free on board.	Loaded at seller's port at seller's cost on vessel supplied by buyer. Buyer responsible for insurance, sea freight and discharging costs at buyer's port.
FOBST	Free on board stowed and trimmed.	As for FOB, but costs of stowing and trimming cargo in vessel paid by seller.
FOT FOR	Free on truck/or transport. Free on rail.	Synonymous terms as 'truck' refers to rail wagon. Seller responsible for hiring trucks and loading, including weighing. Buyer responsible for all costs and risks thereafter.
FAS	Free alongside ship.	Seller responsible for placing cargo alongside vessel. Buyer responsible for loading vessel, export clearances and permits, and all subsequent costs and risks.  Synonymous terms. Delivered to buyer's nominated depot at seller's expense. Usually used where no overseas shipment occurs.
FID	Free into depot.	Seller responsible for all FOB costs plus sea freight and insurance. Buyer responsible for unloading at arrival port and all subsequent costs.
FIS	Free in store.	
CIF	Cost, insurance, freight.	As for CIF, but seller is also responsible for unloading cost. Buyer responsible for all subsequent costs.
CIFFO	Cost, insurance, freight, free out.	As for CIF, but buyer is responsible for insurance cost.
C&F or CFR	Cost and freight.	

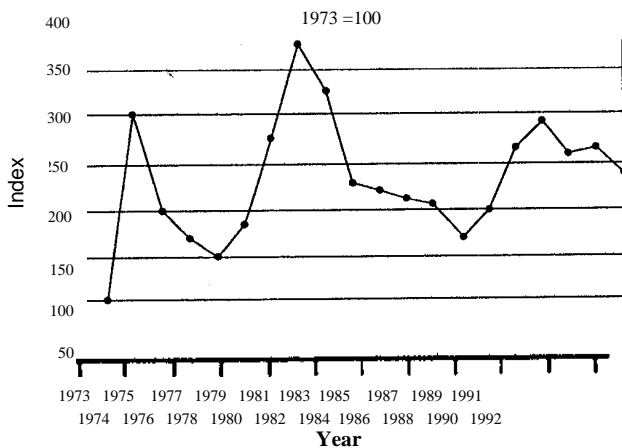
Table 16.1 - Definition of Delivery Terms

by the International Chamber of Commerce, Canberra, ACT.

Many products are sold on a simple FOB basis. That is, on board the buyer's vessel at the mine's port. Others, particularly base metal concentrates, are sold on a CIF basis, where the mine is responsible for all costs up to the berthing of the ocean-going vessel at the quay of the buyer's port. The buyer is responsible for all subsequent costs. Thus, transportation costs can comprise a variety of components, including:

- actual road, rail, air or sea freight costs;
- loading, unloading and transference costs;
- storage costs at the rail head or the mine's port;
- port and harbour dues;
- superintendence costs associated with rail and ship loading; .documentation costs;
- costs of special containers.

Clearly, transportation costs are quite specific to each mine and its market. International ocean freight rates on any route are influenced by the worldwide balance of supply and demand for freight space. Figure 16.1 illustrates the volatility of ocean freight rates over time, as measured by a worldwide general cargo index.



**Figure 16.1** -General Ocean Freight Rate Index  
(Vogel and Grey. 1990 -Updated)

Typical 1992 freight costs to deliver concentrates in bulk from an Australian port are shown in Table 16.2.

Destination	Cargo Size (wmt)	Cost (US\$/wmt)
Japan, Korea	5,000	\$28 \$22
	15,000	\$32 \$28
Europe (delivered Antwerp)	5,000	
	15,000	

**Table 16.2** -Typical 1992 Sea Freight Rates

Shipment costs by container are significantly higher. Currently, it costs A\$2000 to A\$4000 to ship a 20 tonne container from Australia to Europe.

Specific forecasts for ocean freights are best sourced from specialised bulk cargo ship brokers.

Road and rail freight costs are estimated on the basis of quotations from road transportation companies and State Government railways.

There are a number of consultants who specialise in the estimation of total transportation costs and, for definitive studies, the use of these to determine the most cost-effective transportation method is recommended.

**Insurance costs** are based on the estimated NSR that will be received for each shipment. For base metal concentrates, all risks insurance typically costs 0.06% to 0.12% of the insured value, depending on the amount insured and the age of the vessel. The insured value is customarily 110% of the NSR.

**Superintendence costs** are those associated with the witnessing, on the mine's behalf, of the weighing and sampling of the product either on discharge of the vessel or on delivery at the buyer's works. Superintendence is optional, but it helps to ensure that these procedures, on which final payment is made, are performed accurately. A number of international companies provide specialist superintendence services around the world. The cost per tonne of product is usually small, typically US\$0.50 per tonne concentrate.

**Assaying costs** are those associated with the contractual analysis of the sampled product, and are normally minor. Typical sampling and assaying procedures are discussed in the next section.

**Marketing costs** are those associated with identifying, securing and retaining the best customers for the full product output. For some mine products which are sold into complex and competitive markets they can be substantial and this may require the mining company to set up its own marketing team. Marketing costs also include the arrangement of optimal transportation and all the associated documentation, particularly in the case of sea freight.

There are specialist international marketing and trading companies, which can provide complete marketing services as agents on behalf of the mining company. The use of these companies is dependant on the mining company's assessment of the market locations, the marketing situation, and its own marketing capabilities. The fee or commission for use of a marketing agent is a matter of negotiation. It will depend on a number of factors, for example the nature of the market, technical complexity, volume and value of the product, and the term of the agency. As a guideline, however, an agent's marketing fee is in the range of 1.0 to 2.0% of the NSR.

### Assaying and Sampling

The sale of all mineral products and the subsequent calculation of NSR is based on the weighing, sampling and assaying of each shipment either upon discharge of the vessel or as it is received at the buyer's works. The procedures used to determine the final assays on which NSR calculations are based vary depending on the mineral products. However, the standard procedure for base metal concentrates is as follows.

The smelter contract normally specifies the tonnage increments (or lots) into which each shipment will be sub-divided for weighing, sampling, moisture determination and assaying purposes. The sample from each lot is carefully divided, normally into four. One sub-sample is analysed by the buyer and one sub-sample by the seller or their respective nominated representatives.

Once the analyses are available they are exchanged simultaneously. If any of the analyses do not agree within pre-determined limits (called "splitting limits") a third sub-sample is sent to an umpire for analysis. Usually, a number of umpires are used in rotation, the list being agreed between buyer and seller.

Once the umpire's analysis becomes available the final settlement assay is determined, usually by averaging the results of the umpire assay and whichever of the buyer's and seller's assays is closest to that of the umpire.

### Concentrate Sales: General Considerations

It is tempting to believe that the market will be prepared to accept whichever concentrate grade optimises plant recovery. After all, smelters may have the appropriate technology to process such a grade and other mines may be selling a similar or even a less acceptable grade. This is unfortunately not always the case. To understand the factors that make a concentrate attractive to a buyer and, therefore, command a higher purchase price, it is useful to look at the following factors from the smelter's viewpoint.

### Integration with Concentrate Producers

Where mines and a smelter are owned in part or full by the same organisation, preference is usually given to concentrates from the mines associated with the smelter. The quality and quantity of the concentrate produced by the integrated mines will thus affect what concentrates are acceptable for the balance of the smelter feed. Partly or non-integrated smelters that rely on concentrate purchases from the international market are referred to as "custom smelters".

### Feed Mix

Custom smelters seek the blend of concentrate feed stocks that optimises their plant efficiency, profitability and the environmental constraints under which they are operating. The shipping/delivery programme must be planned to ensure that a consistent feedstock is able to be blended from the range of contracted supplies. Each shipment, therefore, determines the desirability of subsequent purchases. A particularly "dirty" concentrate shipment will require a subsequent large volume of very clean concentrates to dilute the undesirable elements in the dirty concentrate. Thereby, further purchases of dirty concentrates are precluded until the first quantity is consumed.

### Reliability of Supply

The supply of and demand for concentrates have been historically volatile. Smelters need to be sure that they have a consistent supply of concentrates that maximises their output at minimum cost. Consequently, smelters prefer customers whose supply is less likely to be interrupted by natural (eg. weather), socio-political (eg. strikes, wars) or economic factors (eg. closure due to high costs and poor prices). Usually smelters reduce the supply

risk by buying from a range of suppliers.

In addition, smelters enter into long term contracts with reliable suppliers to further stabilise the quantity and quality of concentrates that are delivered in any particular year. Concentrates supplied under long term contracts may be supplemented with one-off or "spot" purchases at any time.

### Smelter Contracts

Table 16.4 (Lewis and Streets, 1978) shows the most common clauses that are included in smelter contracts. Although those listed apply specifically to the sale of base metal concentrates, many of the clauses are used in contracts covering the sale of any mineral product. Some contracts include all the clauses listed in Table 16.4, plus a few others peculiar to the circumstances of either the smelter or the mine; others contain only the more important clauses.

### Payment Terms

Other than the clauses dealing with treatment charges and other deductions, the ones which affect the NSR and cash flow are those which define the payment terms ie. the 'quotational period', the 'valuation' (price basis), the 'currency conversion', and the 'payment or settlement' clauses. Payment terms are negotiable, varying according to market conditions. A typical cashflow is shown in Table 16.3.

Event	Date
Ship loads and departs	20-Mar
Bill of lading (B/L) date	
Arrives main port of smelter	04-Apr
Provisional payment (90% of provisional value is paid on arrival at the smelter, based on prices in week prior to B/L date)	06-Apr
Quotational period (OP): 2 MAMA (2 months after month of arrival at smelter)	June
Final payment (Final value based on the average price over the OP, less provisional payment)	15-Jul

Table 16.3 -Typical Cashflow for Smelter Payments

### Revenue Calculations and Marketing

The objective of the remaining sections of this chapter is to provide guidelines for the calculation of the NSR for various mineral products. The diverse nature of these products and their ultimate uses means that in many cases, other than for base metal concentrates and precious metals, the provision of guidelines is by no means straightforward. In these instances, calculation of the NSR to an acceptable degree of accuracy can only be done once indicative purchase terms are obtained from potential buyers.

Section or Clause	Information Given
Preface	Names and addresses of contracting parties. Agreement that both parties will abide by terms and conditions of contract.
Definitions	Appropriate conversion rates. Precisely defines any parameters used repeatedly in contract.
Duration and period	Specific dates between which contract will apply. Usually defines whether contract applies to mine's production or shipments.
Quantity	Minimum and maximum monthly or annual tonnages. Alternatively, stated as total mine production over period, in which case seller normally agrees to advise buyer of its future production on quarterly, half-yearly or annual bases.
Material or quality	Typical analyses of concentrate, with ranges for more important assays. Maximum and minimum assays acceptable to smelter and, if these tolerances are exceeded, whether this will involve rejection of the delivery or renegotiation of terms.
Delivery	Methods of transporting, packing and where deliveries will be made. By whom freight, insurance and loading/unloading charges will be paid.
Shipment	Rate of shipment and size of vessel. Can also cover rate of loading/unloading; associated overtime payments; demurrage and despatch money; ships' agents; shipping documents; method of stowage; port dues and charges.
Valuation	Unit deduction or percentage metal paid for. Metal price that will apply (eg. LME, Penang, U.S., etc.). Price deduction or refining charge. Payments for credit elements.
Quotational period	Specific period during which deliveries will be priced (often combined with 'valuation' clause). Usually quoted as the average price in a specific month after the month in which the product is delivered.
Treatment charge or deductions	Treatment charge. Refining charge (can also be in separate clause). Other charges, eg for sampling.
Penalties or impurities	Tolerance levels and payments for penalty elements.
Escalation	Basis and method of escalation. Charges to which escalation will apply.
Payment or settlement	Timing, conditions, documentation, currency and methods for provisional and final payments by buyer to seller.
Weighing, sampling and Moisture determination	At whose cost and by whom shipments will be weighed and sampled for assay and moisture determination (normally this is done at buyer's works and expense, but seller is given right to be represented). Size of sampling lots.
Assays	Splitting of samples for assay by buyer and seller; exchange of assays; assay splitting limits; conditions for utilising umpire assays and basis for agreement of final assays.
Currency, conversion or exchange rate	Basis for conversion of currency. Can also include section stating how charges will change if exchange rates vary outside specified limits.
Insurance	Type, value and period of insurance cover; by whom it will be paid and beneficiary.
Force majeure	Conditions under which contract can be suspended by either party and procedure to be adopted. Period of continuous suspension after which contract may be cancelled.
Loss of vessel	Conditions and liabilities governing total or partial loss of a shipment (often incorporated in force majeure clause).
Title and risk	Precise moment when concentrate becomes property of buyer.
Tariffs, taxes or duties	By whom any taxes, duties or tariffs will be paid.
Licences	Licences necessary for contracts to be effective.
Fair operation, revision	Circumstances, not covered elsewhere in the contract, which will allow either party to renegotiate contract so that it remains fair to both parties; and procedure to be adopted if this clause is invoked.
Arbitration	Basis for settling any disputes or differences.
Applicable law	Country under whose law the contract will be governed and construed.
Notices	Procedure and rules governing submission of formal notices concerning terms of contract.
Successors and assigns	Whether contract can be passed on to successors and assignees.
Termination	The circumstances under which the seller or buyer will be entitled to terminate the contract.

**Table 16.4 -Smelter Contract Clauses**



## Antimony

by G.O. Boyle

Antimony is mined in the form of either stibnite ( $\text{Sb}_2\text{S}_3$ ) containing 71.7% Sb or as berthierite ( $\text{FeSb}_2\text{S}_4$ ) containing 59% Sb. Usually berthierite is only a minor component of the ore.

Antimony concentrate is sold in two forms: hand picked ore, usually the product of prospectors or countries with low labour costs, or as flotation concentrates. The price of both forms is quoted on the London Metals Exchange (LME) in \$US per metric tonne unit (mtu). A metric tonne unit is 1 tonne at 1 % ie. one tonne of 60%Sbconcentrate contains60mtu. The LM Equotesa 'High' and a 'Low' price for antimony concentrates. On 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 1000 kg weight and shipped in container loads. The majority of sales are to northern hemisphere smelters which produce either antimony oxide or metal.

The normal minimum acceptable concentrate grade is 60% Sb with upscale payments for higher antimony contents. Typical upscale payments range from 0.5% to 1 % of the base price for each 1 % increase in Sb above 60% Sb in concentrate. Penalty elements are arsenic, lead, mercury, selenium, nickel and bismuth. The last three are not known to occur at significant levels in Australian deposits.

The normal allowable arsenic level is from 0.2% to 0.6% As with penalties in excess of the agreed limit. The typical penalty is \$US 0.05 per 0.05% As above the contractual level.

Lead can be derived either from the ore or from a reagent used in the flotation process. The allowable lead level is 0.3% to 0.4% Pb with penalties applying at a similar rate to arsenic.

Most smelters specify a combined allowable arsenic plus lead level rather than specifying them separately.

Only a small number of smelters regard selenium as a penalty element. Selenium may occur in atomic substitution for antimony and is particularly difficult to detect. There is no known method of reducing the selenium level. Selenium levels in Australian concentrates are usually less than 30 ppm.

The preferred maximum level for mercury is 20 ppm. Since many antimony deposits contain significant mercury this can be a problem. Penalty terms for mercury in concentrate can be severe.

The maximum applicable moisture content is usually 8%  $\text{H}_2\text{O}$  although some smelters demand lower levels. The penalties applied by the smelter, coupled with the freight cost of moisture, make it worthwhile for the producer to limit the moisture content.

The only credit payments are for gold and silver.

Most smelters will credit gold only above a minimum which is typically 15 to 20 ppm Au. Payment in excess of the minimum

is normally based on 20% to 40% of LME prices. This gives every encouragement to remove gold and silver from the concentrate. At New England Antimony Mines both gravity separation and an acid thiourea leach method developed by the company are used to reduce the gold level of the antimony concentrate.

The antimony market is dominated by two suppliers, China and Bolivia. In recent years the concentrate price has been reasonably static as a result of more sophisticated marketing by the major producers but this translates to a decreasing price after inflation. Western antimony mines are striving to produce higher grade concentrates which result in a more secure market and lower freight costs. One of the prime end uses for antimony is as a flame retardant in textiles and plastics where there are several alternative chemicals. This tends to put a cap on price rises as the economics of alternative substitutes become attractive. Antimony continues to be used as a hardener of lead, particularly in lead-acid batteries. The demand in this application is directly dependent on world economic factors with demand falling during recessionary periods.

## Bauxite

by D. Milne and N. Rickleman

### Bauxite and Alumina Characteristics

Practically all aluminium metal production is derived from bauxite. The bauxite is chemically refined to pure aluminium oxide or alumina ( $\text{Al}_2\text{O}_3$ ) before being 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, 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 the bauxite mines but there are still some bauxites that are traded over long distances.

Typical compositions of traded bauxites are outlined in Table 16.5. These bauxites are of sufficiently high grade to warrant transportation.

The main value of bauxite lies in its alumina ( $\text{Al}_2\text{O}_3$ ) content, but silica ( $\text{SiO}_2$ ) is an undesirable impurity which offsets the value of the bauxite. A system of bonus/penalty payments is common in the industry and is based on alumina and silica levels but these payments are generally confidential.

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

In the refinery, bauxite is digested in hot caustic soda (NaOH), whereby the alumina is dissolved and impurity oxides of Fe<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> are separated and discarded as "red mud". The alumina is recovered from the process by cooling and precipitation from the caustic solution, which is recycled to digestion. During the course of the process insoluble silicate compounds are discarded with the red mud and take with them valuable caustic soda and alumina. The amount of caustic soda lost is generally proportional to the amount of silica present. There is no fixed upper silica level but 6% SiO<sub>2</sub> represents, in practice, an upper limit. Similarly, for alumina, the lower limit is about 50% for a traded bauxite.

An alumina refinery operator must, therefore, consider the following issues, amongst others, when sourcing bauxite feedstock:

- how much alumina can actually be extracted from each tonne of bauxite;
- whether a high or low temperature process is required for the bauxite, as is explained below;
- how much caustic soda is lost in the process

To adequately cover these issues, the operator must understand the mineralogical composition of the bauxite as well as the chemical analysis. Typically, tropical bauxite contains much of the alumina in the form of gibbsite, Al(OH)<sub>3</sub>, which is sometimes described as trihydrate alumina, Al<sub>2</sub>O<sub>3</sub>·3H<sub>2</sub>O. Where this is the major form of alumina the bauxite can be treated by a low temperature digestion around 150°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, AlOOH, which is sometimes written as monohydrate alumina, Al<sub>2</sub>O<sub>3</sub>·H<sub>2</sub>O. Bauxites containing significant amounts require a high temperature process (around 230-250°C) to digest the bauxite. Bauxites from Weipa in Australia and Guinea require high temperature plants.

Silica minerals consist primarily of kaolinite (Al<sub>2</sub>O<sub>3</sub>·2SiO<sub>2</sub>·2H<sub>2</sub>O) and quartz (SiO<sub>2</sub>). Essentially all of the former dissolves at either high or low temperature while only a proportion of quartz dissolves in a high temperature plant and none at all in a low temperature refinery.

To determine the value of a bauxite it is usually necessary to carry out laboratory autoclave digestions to simulate refinery conditions and to 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.

**TCA** is total chemical alumina, which is determined by wet chemical analysis (or XRF) and includes alumina in all mineral forms.

**TAA** is the total available alumina and refers to the total amount of alumina extracted by high temperature autoclave

digestion; the temperature is not specified by standards but is usually over 200°C. The TAA allows for the loss of some alumina as complex silicates in the red mud. The amount lost depends on the amount of silica in the bauxite.

**THA** is trihydrate alumina and refers to the 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 on the red mud.

**MHA** refers to monohydrate alumina. It is not determined directly but is obtained by difference according to the expression **MHA=TAA-THA**.

The above are useful descriptive terminologies which relate to plant performance, but those 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 16.6. 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.

It is useful at this stage to comment on other bauxite types which are used in the industry. In Western Australia, the Darling Range bauxites are, at first sight, low grade. Typically they have only 35% Al<sub>2</sub>O and 20-25% SiO<sub>2</sub>. 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 caustic soda losses. The WA 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 little mining of bauxite in Europe now, 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 ie. AlOOH or Al<sub>2</sub>O·H<sub>2</sub>O. However, it is very hard to dissolve and requires temperatures in excess of 260°C with substantial lime additions. It is likely that imports of tropical bauxites will eventually replace diasporic.

Other issues of economic importance in refining bauxite, which have an impact on the value of the bauxite, are the:

- disposal of red mud
- handling characteristics and dustiness
- amount of crushing required
- rate of dissolution.

A large refinery will typically produce more than a million tonnes of red mud each year. Bauxites with high iron oxide contents will, of course, produce more mud than others.

	<b>TCA</b>	<b>TAA</b>	<b>THA</b>	<b>Reacted SiO<sub>2</sub></b>
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

**Table 16.6** -Mineralogical Composition by Autoclave Digestion

Not all bauxite is converted to aluminium metal. There are specialist markets in the following areas for around 10% of the world's bauxite:

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

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

## Bauxite and Alumina Marketing

In 1992 Australia accounted for around 38% of the 111M tonnes of bauxite produced worldwide.

Bauxite sold in bulk to alumina refineries is usually priced on the basis of very long term contracts. Contract prices are of two types: formula prices within consortium refinery operations ego QAL -Gladstone; and, 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 as an indication, prices in the low to high quality range may be 1992 US \$12 -35 per tonne.

World production of alumina is estimated at 40M tonnes in 1992. Contracts for the sale of alumina tend to be medium term in nature. Contract alumina prices are not normally reported although spot prices fluctuated between US \$135 -175 per tonne in 1992. An indication of the long term contract average would be US \$190 -275 per tonne.

---

## Coal

---

by M.A. Hohnen and A.J. Greville

### Introduction

Coal exported from Australia is generally classified as hard coking, soft coking, semi-soft coking (including pulverised injection coal) or thermal. Coking and thermal coal exhibit different price structures and trends, and as such will require separate explanation.

Coal is a globally distributed resource with billions of tonnes of undeveloped reserves. Coal suppliers are generally pricetakers in markets dominated by Japanese purchasing bodies. In addition, purchasers world-wide have pursued diversification and investment policies for many years that have distorted prices and created artificial differentials in many markets.

Coal is a low value, high volume, bulk commodity. Geographical, political and infrastructure barriers play an enormous part in determining its delivered cost. For central Queensland coals delivered to the European market, the realisation costs routinely reach 50% of the contract price. Unlike other bulk commodities, almost all mines produce a coal with unique physical and chemical properties. As a rule most customers will not interchange coal types at short notice. Coal is commonly sold on FOB, CFR and CIF bases. Asia is almost exclusively an FOB market, while Europe is a mixture. Customers in several countries are constrained by government regulations which specify the terms for repayment, the shipping company to be used and the types of coal that can be purchased.

These factors, and many not mentioned, combine to make the international coal trade a complex business environment. Prospective coal producers generally seek bankable long term commitments from customers before investing the large amount of capital required to build a new mine. Recently commissioned Australian mines have sought long term contracts for approximately 70% of their production prior to entering production. Contracts of this nature specify a minimum tonnage but allow for annual re-negotiation of the price. The prevalence of long term supply relationships and the desire of customers to diversify lines of supply have meant that there is not a prevailing "world" price for coal. Having said this, there are some indicators which will determine approximately what a customer is likely to pay for an Australian coal. These indicators are summarised below.

### Coking Coal

Coke makers world-wide blend coals of different qualities to achieve the desired coke properties. Since many of the properties of coal are not additive, the blending results are difficult to predict, and the technical aspects of coke making are beyond the scope of this section. Generally high, medium and low volatile coals are blended to achieve optimum coke properties. Typically, high volatile coals contribute gas to by-product circuits and improve blend fluidities, while low volatile coals have a higher coke yield and produce stronger cokes. Most coke oven operators have a target of 24-26% volatile matter in feed. 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 different opinions and requirements, based on their level of sophistication, the type of equipment they use, and their previous experience.

### Japanese/Asian Market

Goonyella coal delivered to the Japanese steel mill (JSM) market has, over the years, emerged as a price benchmark for the price of coking coal. It fits into the mid-volatile range discussed above, and has traditionally been the highest priced Australian coal purchased by the JSM. Several other coals now attract the same price as Goonyella, including Oaky Creek, Gordonstone and Tahmoor from Australia. Other Australian coking coal prices lie in the range from 0 -15% less than the Goonyella price. The extent of the "discount" is related to the coal properties.

Typical specification sheets for a coking coal include detailed proximate and ultimate analyses, coke strength data, fluidity and rank information and other test results. Any property considered undesirable by the purchaser, obviously, increases the extent of the discount below the Goonyella price.

Of paramount importance are moisture level, coking properties, and ash, sulphur and volatiles analyses. The volatile level determines the market segment in which the coal must compete, and the ash, coking properties, sulphur and to a lesser extent moisture, determine a coal's competitive value in the respective market segment. Coke makers often have a target CSR (Coke Strength after Reaction), and this typically forms part of any evaluation. Other properties, particularly phosphorus and alkali level, can have an enormous impact on a coal's acceptability

more likely as a negative rather than a positive factor. The oven wall pressure (OWP) exerted by a coal during the coking process has recently emerged as a critical issue to some coke makers who are attempting to extend the life of their coke ovens.

Recent attempts by Australian suppliers to negotiate a premium above the Goonyella price with the Japanese have been unsuccessful, despite more attractive ash levels. Politics, history and tradition have played a large part in determining relative prices, and these factors are difficult to combat

Table 16.7 shows a sample of the general specifications and 1993 JSM prices for Australian and other coking coal.

Developed east Asian countries such as Korea, Taiwan and the Peoples' Republic of China traditionally follow Japanese pricing. Other developing nations, such as India, price on the ability of the imported coals to improve the properties of the domestic coals which form the base of the coke oven feed.

## European and Mediterranean Markets

Coking coal sold into the European market generally returns lower margins to Australian producers than the Asian market, due to the differential freight costs. As in the Japanese market, each coal will attract a different price depending on its advantages and disadvantages as perceived by the buyer. Traditional relativities are more loosely defined in the European market, and the absence of a powerful buying conglomerate has led to the existence of some small inter-country price differentials.

Much of the coal supplied by Australian producers into Europe is sold on a CFR basis. This makes the return achieved by the supplier more difficult to interpret from published contract prices, than is the case with Asian FOB contracts. Freight rates can range from US\$9.00 to US\$20.00 per tonne from Australia to Europe, depending on the size of the vessel, the prevailing bunker fuel

price, the loading and discharge ports, loading and discharge rates, the cargo transfer requirements and other factors.

In recent years the annual Japanese price outcome has set the trend in European contract discussions. This was seen in 1992 when the negotiated US\$0.50 price reduction in Japan was widely accepted in Europe. In the late 1980's and early 1990's the net FOB return on Australian coals into Europe has become closer to the FOB return for Asian markets, due in part to the demand for low OWP coals to help nurse additional life from ageing European coke ovens. This has increased the value of Australian coals to European customers in comparison to the lower delivered price, but high OWP, American coals.

Table 16.8 shows some typical 1991 European and Mediterranean FOB prices for imported coking coal.

Current coking coal prices are published regularly in *Coal Week International* (McGraw Hill) on an FOB basis for all the world's major export locations. These figures are indicative and are not always accurate.

## Thermal Coal

Thermal coal is burned as an energy source and most customers are electricity generating utilities. Despite the apparent market segregation, thermal coal prices have in the past been dominated by coking coal prices, with the prevailing contract price generally following the trend established in the coking coal market. The traditional coking to thermal coal price differential has narrowed over the past fifteen years as the combination of oil price shocks and nuclear power plant accidents has increased the desirability of coal as a power generating option. Market analysts are forecasting a rapid expansion of the seaborne thermal coal trade in the 1990's. However, most are predicting short to medium term oversupply due to the new capacity coming on stream.

Coal Type	Country	VM (%)	Ash (%)	TS (%)	CSN	Price US\$/tonne (@8% moisture)
Goonyella	Australia	25.0 - 27.0	8.9	0.55	8	49.30
Oaky Creek	Australia	29.5	8.5	0.8	8	49.30
Tahmoor	Australia	28.0	8.8	0.4	6	49.30
Riverside	Australia	22.5 - 24.5	9.8	0.58	8	48.80
Wollondilly	Australia	27.8	8.9	0.4	5	48.80
Balmer	Australia	19.0 - 22.0	9.0	0.4	6-8	49.30
Fording - MV	Australia	26.0 - 28.0	8.0	0.5	6-8	49.30
Hampton Farrell	U.S.A	33.0 - 34.0	7.5	0.85	6-8	46.21
Bailey	U.S.A	36.2 - 38.0	67.5	1.62	7-9	44.18

Abbreviations:	<b>VM</b>	Volatile Matter
	<b>TS</b>	Total Sulphur
	<b>CSN</b>	Crucible Swelling Number
	<b>JFY</b>	Japanese Fiscal Year

**Table 16.7** -JFY 93 JSM Coking Coal Prices (FOB)

Coal Type	Country	Buyer	Buyer Country	VM (%)	Ash (%)	TS (%)	CSN	Price (\$US/tonne)
South Blackwater	Australia	Eregli	Turkey	28.8	6.2	0.44	7	48.50
Island Creek	USA	Cockerill	Belgium					54.25
Sundial	USA	SSAB	Sweden	29-30				54.45
Pittston	USA	ILVA	Italy	31				52.00
Peak Downs	Australia	Ensider	Algeria	21	9.7	0.55	9	47.50

**Table 16.8** -1991 European and Mediterranean Coking Coal Prices (FOB)

The prevailing world price for thermal coal is significantly influenced by the annually negotiated Japanese utility price and settlements made by major power utilities such as GKE in the Netherlands. Thermal coal is primarily an energy source, and as such its most important property is its energy level, commonly expressed in kcal/kg, MJ/kg or BTU/lb. Thermal coal contracts are generally written with the price referring to an energy level "base" 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 often favour "air dried" contracts.

Other physical and chemical properties that may influence a coal's suitability to a particular energy utility, and hence the price that utility will pay include ash content, ash fusion temperatures, sulphur, nitrogen levels and volatile matter. As with coking coal, each customer's requirements are likely to be slightly different with regards to these properties.

The current Japanese utility price is regularly quoted in publications such as the *International Coal Report* (Financial Times) and *The Coal Observer* (Donaldson, Lutkin and Jenrette), together with recently negotiated spot sales and prevailing ocean freight rates.

## Glossary of Coal Property Terms (from GWC Coal Handbook)

### Ash

Ash is the inorganic residue after the incineration of coal to constant weight under standard conditions. It is less than the mineral matter because of the chemical changes occurring during incineration, with the most important differences being loss of water of hydration, loss of carbon dioxide, and loss of sulphurous gases from sulphides.

### Ash Fusion Properties

The ash fusion properties of laboratory prepared coal ash are demonstrated by the heating of the ash in a mildly reducing or oxidising atmosphere. The temperature range generally used is 900°C to 1600°C, and the temperatures which can be recorded are initial deformation temperature, softening temperature, hemisphere temperature and fluid (flow) temperature.

Almost invariably the temperatures recorded under reducing atmosphere are lower or equal to those recorded under

oxidising atmosphere. Of the characteristic temperatures the 'initial deformation' and 'flow' are generally the most difficult to reproduce.

### 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 in the blast furnace.

### Coke Strength After Reaction (CSR)

The CSR is determined by a laboratory test designed to give an indication of the strength of coke after being 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, is tested in a tumbler device to determine its strength.

### Coking Coal

This is coal which, because of its characteristics, is suitable for carbonising to produce blast furnace coke. Important properties required technically to produce good coke are good coking and caking properties (such as fluidity, dilatation, and crucible swelling number) allied with an appropriate rank (indicated by reflectance values around 0.9 -1.5%).

Other properties which are important for commercial reasons are ash and moisture (which should be as low as possible), and properties which are important because of the deleterious effects on pig iron are the sulphur and phosphorus contents.

### Crucible Swelling Number (CSN)

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 crucible swelling number. Values range from 0 (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 as it melts and passes through its plastic range its fluidity is measured. Results are expressed as **maximum fluidity** in dial divisions per minute (ddpm). The characteristic temperatures recorded are 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. The manual equipment gives results which are 50% to several times higher than that from the automatic equipment.

## Gross Calorific Value

The gross calorific value is defined as the amount of heat liberated during laboratory testing when coal is combusted under standardised conditions, with the temperature of starting materials and products being approximately 25°C. During actual combustion in boilers the gross value 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. Gross calorific value 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 the polluting nitrogen oxides unless removed from the flue gasses.

## 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 by the formation of 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 of lowrank, while semi-anthracites and anthracites are of high-rank.

## Sulphur

Sulphur can be part of the carbonaceous material in coal or part of the minerals present as sulphates or sulphides. It forms sulphur dioxide during coal combustion which is a serious pollutant, with

most countries having regulations regarding emissions to the atmosphere. It is undesirable in coking coal because it partly accumulates in the hot metal during steelmaking and requires desulphurisation to remove it if above 0.02%.

## 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 very empirical and results are very sensitive to operating conditions. Results obtained from different standard methods will not necessarily give the same result. The ASTM method generally gives a higher result than other methods.

---

## Copper

---

by P .C. Wilson with assistance from C. Chanroux

## The Market

The main market for copper concentrates is the world's custom copper smelters. Integrated smelters may also make some custom purchases.

## Refining Technology

Copper metal can be produced 'directly' from copper oxide ore by acid leaching and solvent extraction-electro winning (SX-EW). This section refers only to copper concentrates produced from sulphide ores. For information on SX-EW refer to Chapter 9.

Copper sulphide concentrates are processed into copper metal and other by-products by smelting (using a variety of 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. The Noranda and Isasmelt processes are designed to handle 'dirtier' concentrates but in practice these technologies are still being developed. In addition, development of hydrometallurgical processes (eg. Sherrin Cominco Process) is continuing.

## Concentrate Quality

The copper content of concentrates varies between 18%-38%. Most fall in the range 28%-34%. 'Clean' concentrates (eg. Escondida, Ertsberg -derived from porphyry orebodies) carry virtually no lead and zinc <0.5%). Smelters may accept concentrates with lead contents as high as 6% if the concentrate is sold at a sufficient discount to higher quality concentrate. In an oversupplied market, this material becomes unsaleable unless protected by a reliable contract. Copper smelters penalise or reject material with high contents of arsenic, bismuth, mercury, flourine, chlorine, nickel and cobalt. High precious metals contents (usually gold) will enhance the value of concentrates.

## Pricing

### Quick Estimate

Historically the Net Smelter Return has been 70%-80% of the value of the metal contained in the concentrate. This excludes concentrates with unusually high precious metal content or penalty element payments.

### Detailed 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 are shown below:

Element	Payable Metal Content
Copper	Pay for 96.5% of copper content subject to a minimum deduction of 1.10 units
Gold	Pay for gold content less 1 g/dmt (negotiable range of deduction 1 to 1.5 g/dmt)
Silver	Pay for 90% of silver content subject to a minimum deduction of 30 g/dmt.

### Treatment and Refining Charges

Smelter charges are usually a combination of a separate treatment charge (TC) and a separate refining charge (RC), or a combined TC/RC. The treatment charge is a fixed deduction per dmt of concentrate. The refining charge is based on the payable metal content. The RC and combined TC/RC are expressed in US cents per pound 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. Other variables such as smelter capacity utilisation, exchange rates, acid credits, and duties have significant effects. One-off events (eg. the closure of the Bougainville copper mine)

may result in trends opposite to the normal pattern.

As a rough indication, the combined TC/RC/pp (in US\$/lb) is approximately 17-23% of the copper price (in US\$/lb). This applies to long term contracts for standard grade clean concentrates (28% Cu). Spot terms are more volatile. Current TC/RC's are obtainable from the *Metal Bulletin* or from traders.

### Price Participation

The price participation formula increases the TC/RC as the copper price increases and reduces the TC/RC as the price decreases, above and below agreed base prices. A 'neutral zone' is normally included.

Typical current price participation terms are shown below:

- if the price > US\$0.90/lb, a 10% of increase in price to TC/RC;
- if the price < US\$ 0.90/lb and > US\$0.80/lb, no change;
- if the price < US\$ 0.80/lb, deduct 10% of decrease in price from TC/RC.

### Refining Charges for Precious Metals

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

Silver	US¢25-35 per oz payable silver
Gold	US\$3-6 per oz payable gold.

### Penalties

Penalties are imposed for undesirable elements that increase the smelter's costs. Typical penalty elements and formulae are shown in Table 16.9. All calculations are on a pro rata basis. For example, if the Pb grade is 2.5%, the penalty would be  $(2.5\% - 2.0\%) \times \$2.00 = \text{US}\$1.00/\text{dmt}$  concentrate.

Some concentrates may be rejected by smelters because they contain a high level of a penalty element. There are no standard 'rejection limits' for the penalty elements as any concentrate is potentially saleable depending on its quantity and the availability of other more favourable materials. Clearly, 'dirtier' concentrates can only be sold for lower returns than cleaner concentrates or at times when cleaner concentrates are in short supply.

Penalty Element	Typical Formula (US\$ per tonne concentrate)	Negotiable Range
Zinc	\$2.00 per 1.0% above 2.0%	Above 2% -5%
Lead	\$3.00 per 1.0% above 2.0%	Above 2% -5%
Arsenic	0.1% above 0.2%	Above 0.1% -0.2%
Antimony	\$3.00 per 0.1% above 0.05%	Above 0.05% - 0.2%
Bismuth	\$2.00 per 0.1% over 0.01%	Above 0.01% -0.03%
Fluorine	\$1.00 per 100 ppm above 150 ppm	Above 150 - 300 ppm
Mercury	per 10 ppm above 5 ppm	Above 5 - 20 ppm
Chlorine	\$0.50 per 100 ppm above 500 ppm	Above 500 - 1000 ppm
Cobalt+Nickel	per 1.0% above 0.5%	Above 0.5% -1.0%

Table 16.9 -Typical Copper Concentrate Penalty Payments

### Example of Revenue Calculation

A worked example of the calculation of the NSR for a complex copper concentrate in US\$ is shown below:

#### Concentrate Specifications

Cu	28%	Pb	3.0%	Bi	0.07%
Au	3 g/t	Zn	4.2%	Sb	0.03%
Ag	80 g/t	Hg	4ppm		

#### Terms

- Combined treatment/refining charge = US\$25.00 cents per pound payable copper;
- Payable metals as in preceding section "Payable Metals";
- Refining charges:
  - US\$4.00 per ounce payable gold;
  - US\$0.30 per ounce payable silver;
- Price participation as in preceding section "Price Participation";
- Penalties as in preceding section "Refining Charges for Precious Metals".

#### Metal Prices

		Conversions
Cu	US\$ 2,250.00/tonne = US\$1.02/per pound	31.10 g = troy oz
Au	US\$ 380/troy oz	2204.6 lb = tonne
Ag	US\$4.00/troy oz	

#### NSR CALCULATION

Payable Metals	US\$/dmt
Cu (0.28 x .0965 = 0.270) or (0.28 -0.011 = 0.269) Therefore payable Cu = 26.9% 0.269 [t payable Cu/dmt conc] x 2,250 [US\$/tCu]=\$605.25	
Au 3 -1. [g/t] = 2 g payable Au /dmt conc 2 [g/dmt] /31.10 [g/troyoz] x 380 [US\$/oz]	= \$24.43

Ag (80 x 0.90 = 72)  
or (80 -30 = 50)  
Therefore payable Ag = 50 g/dmt conc  
50 [g/dmt] /31.10 [g/troy oz] x 4.00 [US\$/oz] = \$6.43

Total Payment for Metals	= \$636.11
Treatment Charge/Refining Charge 0.269 [t payable Cu/dmt conc] x 2,204.6 [lb/t] x 0.25 [US\$/lb]	= (\$148.26)
Price Participation (1.021 -0.90) [US~/lb] x (0.269 x 2204.6) [lb payable] x 0.10	(\$7.18)
Refining Charges Au 2/31.10 [oz payable Au/dmt conc] x 4.00 [US\$/oz]	(\$0.26)
Ag 50/31.10 [oz payable Ag/dmt conc] x 0.30 [US\$/oz]	(\$0.48)
Penalties	
Pb (3.0% -2.0%) x \$2.00/1 %	(\$2.00)
Zn (4.2% -2.0%) x \$2.00/1%	(\$4.40)
Hg 4 ppm < threshold of 5 ppm	(\$0.00)
Bi (0.07% -0.01 %) x \$2.00/0.1 %	(\$1.20)
Total Deductions	= (\$163.78)
Net Smelter Return	= \$472.33

### Copper Smelters

Comprehensive lists of copper smelters are obtainable from commodity research companies such as CRU International Ltd., Brook Hunt & Associates Ltd., Metals Minerals Research Services and Metal Bulletin Research, who are all based in England. Table16.10 shows 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 a variety of other geographic regions, usually incurring higher freight costs.

Country	Smelter	Capacity 1993 ('OOOtpa copper metal)	Company
Australia	Mount Isa	210	MIM Holdings
	Port Kembla	80	Southern Copper
Japan	Tamano	150	Hibi Kyodo Smelting Co Kosaka
	Kosaka	66	Smelting & Refining Mitsubishi
	Naoshima	194	Nippon
	Saganoseki	305	Onahama Smelting & Refining
	Onahama	234	Sumitomo
	Niihama	192	Pasar
Philippines	Leyte	150	
Korea	Onsan	150	Lucky Metals

#### Indonesia

Table16.10 -Major Copper Smelters in the Asia Pacific Region



---

## Diamonds

---

by The AusIMM, in consultation with Argyle Diamonds and Normandy Poseidon Ltd

### Australian Deposits and Types of Mining

Currently Australia has two commercial diamond sources. The Argyle diamond mine which is mined by open cut methods and the Bow River mine, 26km downstream from Argyle which is a standard open cut alluvial mining operation. At Argyle the lamproite is crushed prior to screening while at Bow River the material is only screened prior to heavy media and X-Ray Sortex separation.

### Diamond Categories

The Central Selling Organisation (CSO), controlled by De Beers of South Africa, recognises some 2,500 categories of diamonds based on size, shape, colour, clarity and inclusions. However, four broad categories are recognised which are gem, near gem (Indian good), industrial and crushing board.

Argyle has only about 5% gem stones, while the Bow River Mine produces about 20% gem stones, including a small minority of high value "Pinks".

### Initial Evaluation of the Project

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 1,000 tonnes.

### Detailed Evaluation of the Project

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 2,000 carats of diamonds. This valuation is an essential step, as the cost 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 ego the CSO.

The average grade of the orebody is less important in estimating revenue than is the dollar value per tonne. For instance, the Argyle pipe grade is exceptionally high at 6 carats per tonne but the average value per stone is only about \$10.00 per carat. In contrast, the Areador alluvial deposit in West Africa has a grade of 0.1 carats/tonne but an average stone value of about \$300.00 per carat.

### Selling Procedures

Most mines choose to sell rough diamonds through the CSO. This ensures that there is a regular outlet at stable prices. During a strong market better prices may be obtained by selling directly to the market, however in recessionary times large stocks can accumulate. The processing of diamonds through the CSO system (from date of shipment to payment) averages 60 days.

Besides being a producer approximately 80% of the trade in rough diamonds passes through the CSO. In order to stabilise the price the CSO purchases rough diamonds and releases quantities to the diamond trade according to the level that the market will bear. The CSO recently introduced quotas for some producers. This practice enables prices to be maintained through depressed periods which differentiates diamonds from the pricing of other commodities. CSO pricing is confidential and is made available to only those persons directly involved with valuing diamonds.

Rough diamonds are sorted at the mine site into broad categories. They are then prevalued by a Western Australian Government representative as a control against final valuation on which a royalty of 7.5% is levied on gross proceeds less transport and selling expenses. The diamonds are then shipped to Europe.

When commencing a mining operation a sample parcel (excluding special stones) is agreed by the Valuer and the CSO which 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 deducts 10% commission from the gross value of each shipment.

---

## Gold and Silver

---

By M. Cotton

### Australian Refineries

All gold and silver doré bullion produced at mine sites in Australia is sent to refineries for toll refining.

Refiners normally prefer to handle doré bars no larger than 500/600 ozs in weight. Anything heavier can create health and safety concerns for the handler.

The Australian refineries are:

- Australian Gold Refineries -Perth and Kalgoorlie\* (A division of the Western Australian Mint), who refine approximately 60% of all Australian sourced doré.
- Johnson Matthey Ltd -Melbourne\*, who refine approximately 30% of all Australian sourced doré.
- Golden West Refining Corporation -Perth.
- Harrington's Limited\* -Melbourne.

(\* Denotes companies accredited by the *London Bullion Market Association*.)

To gain London Bullion Market accreditation the refiner must qualify under the criteria of experience, processor of significant volumes and net tangible worth. The refiner only qualifies after having had independent testing carried out on its capability to assay and melt to the highest standard. Once accredited, the refiner's 'stamp' or 'mark' is accepted by all major world gold dealers and provides assurance to the holder of its product as to quality thus ensuring optimum saleability.

### Refining Charges

Basic gold-silver doré bullion is currently refined at a cost ranging between A\$0.70 -1.00 per gross ounce, where gross ounce refers to the actual 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 the provision of bars accredited to the London Bullion Market Association.

### Dore Quality, Penalty Charges and Credits

A refiner normally requires the dore to contain not less than 70% gold and/or silver.

Should elements deleterious to the refining process be present within the doré then penalty charges apply. The most common deleterious elements are iron, lead, tellurium and nickel. The application of penalty charges or the rejection of the doré shipment depends on the refining method used by the refiner. The customer should enquire of the refiner to obtain a clear definition.

A precious metals refiner pays for platinum group metals if these are contained within the doré in commercial quantities.

### Precious Metal Return

Refineries return between 99.8% and 99.95% of the gold and 95% and 99% 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\$ and normally converted to A\$. A sale price is normally fixed on the day of refinery outturn with settlement two business days later.

## Revenue

The revenue obtained from the sale of bullion is calculated by the following formula:

$$[(RW \times RAg \times PMRg \times Pg) + (RW \times RAs \times PMRs \times Ps)] - [RC \times GW] - [PC] + [C]$$

Where:

RW	= the refiner's, or outturn, weight expressed in ounces.
RAg and RAs	= the refiner's, or outturn, assays of gold and silver, respectively.
PMRg and PMRs	= the precious metal returns for gold and silver, respectively, expressed as decimals.
Pg and Ps	= the metal prices for gold and silver, respectively, expressed in A\$ per ounce.
RC	= the refining charge, expressed in A\$ per ounce.
GW	= the actual gross weight of doré received, expressed in ounces.
PC	= the penalty charges.
C	= any credit payments.

The determination of the outturn weight and assays varies between refineries. However, typically the seller's doré bullion is separately receipted, weighed, characteristics recorded, and then melted. Dip samples are taken during the melt and applied to a dual stream assay procedure to obtain the outturn assays. The weight after the melt is the outturn weight.

The melting and assaying process is normally completed within three complete working days after receipt of the dare bullion.

### Toll Refining and Metal Accounts

Most Australian gold producers require their bullion to be refined on a toll basis.

Metal Accounts are established by the refiner for 'toll' refining services on behalf of the seller. These accounts represent a record of unallocated deposits, transfers and withdrawals expressed in metal rather than monetary value.

Once the gold and silver have been credited to the Metal Account of the seller or its nominees the metals can be sold or applied to meet existing financial commitments.

---

# Industrial Minerals

---

by T .A.E. Breen

## Introduction

This section on industrial minerals examines the issues of revenue calculations and marketing from a broad perspective. It addresses the industrial minerals sector as a whole, examining broad principles and pitfalls, but provides some specific examples in the course of discussion. 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 a chapter such as this, and therefore this section focuses upon 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 20 years. Although mainly comprising non-metallic minerals, the spectrum of industrial minerals includes such metallic minerals as magnetite (used in coal preparation). Increasingly, specialist metals such as silicon, strontium, magnesium and titanium come within the ambit of industrial minerals classification due to the fact that each of them is the product of such industrial minerals as 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 is the majority of industrial mineral products such as talc, calcium carbonate and kaolin fillers, ceramic raw materials, heavy mineral sands, graphite, bentonite and magnesite, 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 earths, all of which command prices of over A\$1,000 per tonne.

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, and 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.

## Resource Assessment - A Key to Revenues

Most deposits of industrial minerals differ from precious or basemetal deposits in that 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 of this phenomenon. Different kaolins can exhibit different properties enabling kaolin from one deposit to be suitable for certain applications whereas a kaolin from another deposit may be suitable for others. Kaolin is a clay mineral which is white or near white, or 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 specification, 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 are those which 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 is required to ascertain whether a particular deposit can be beneficiated to meet the various quality standards of the industry application for which it is being targeted. The type of deposit, its mineralisation and chemistry, will have a major bearing upon the selling price levels able to be obtained. Early in the project assessment it is necessary to identify whether material from the deposit in question 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 amount of funds on resource delineation and quantification, and at an early stage undertake a commercial pre-feasibility study to assess the likely market viability of the project. This approach is recommended as it can prevent considerable (and perhaps unnecessary expenditure) in the ground should it be demonstrated that for commercial and market considerations the products capable of being developed from the deposit under assessment would be unlikely to secure markets of sufficient size to sustain the proposed operation.

## Specifications, End-use Applications and Prices

There are several steps in industrial mineral project assessment which need to be completed prior to quantifying revenue estimates. The selling prices obtainable for industrial mineral products vary quite widely from application to application, from country to country, and from grade to grade. Unlike most metals, industrial minerals prices are not quoted on the London Metal Exchange or by similar international market mediating organisations.

They 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 basic "as mined" mineral resource, and as has been demonstrated previously with respect to kaolin, 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 Fe<sub>2</sub>O<sub>3</sub> impurities not exceeding 0.01 % by weight. In one plant location a glass company may have access to a supply of extremely pure limestone with an Fe<sub>2</sub>O<sub>3</sub> content considerably lower than 0.01 %. This enables that plant to have greater flexibility in the purchase of silica sand, being able to accept a higher iron oxide content in the sand than would otherwise have been the case. 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, would need to be aware of these detailed technical marketing considerations which exist in that localised market before being able to determine likely selling prices and the possibility of obtaining a market share. Thus the viability of the proposed silica operation may depend upon the iron oxide level of the limestone being supplied.

Similarly in respect to the ceramic and glass industries, the percentage of alumina, sodium and potassium oxides present in the feldspars nepheline syenite available can vary significantly in materials drawn from different supply sources, with batch design being 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%) compared with one of 23% in a nepheline syenite will mean that greater quantities of the feldspar would need to be used compared to the syenite. This will have a direct bearing on the price able to be paid for such a feldspar.

In respect to the paper industry a general rule is that a coating kaolin must consist of particles finer than 2µ, 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 enabling it to command selling prices up to A\$100 per tonne higher than otherwise would be the case. In international kaolin markets, the high volume, high quality USA producers tend to be the price leaders of paper coating grade products enabling an Australian producer of a kaolin of regular brightness (86 ISO Brightness) to achieve an FOB price of A\$140 per tonne. A kaolin of 88+ ISO Brightness can command prices of A\$240 per tonne. 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\$100-US\$110 per tonne 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 per tonne but can command prices up to A\$250 per tonne for more highly processed products.

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

particle size	density
particle size distribution	thermal conductivity
particle shape	colour
Mohs' hardness	brightness
chemical purity	ion exchange capacity
moisture content	inertness/reactivity
refractoriness	pH value
crystal structure	viscosity

## Downstream Processing

Production processes, which can be utilised to achieve the pre-requisite grades or product characteristics, include:

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

End user requirements dictate the form in which a product is sold and packaged, examples of which are:

granular	slurried
powdered	bagged
pelletised	bulk
fused	calcined
exfoliated	

The processes identified above 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, which in some less sophisticated applications do not necessarily need to be the same mineral.

Trucking, shipping, processing and distribution logistics are central cost factors and therefore price determinants in the economic evaluation of most industrial mineral projects. Domestic road freight charges range from 8 cents to 12 cents per tonne/kilometre, and therefore a 300 km trip can add A\$25-\$35 per tonne to a producer's delivered costs. International shipping costs depend on the size of the transshipment, and will vary between US\$100-\$200 per tonne for 20 tonne container lots to less than US\$25 per tonne for bulk shipments of 10,000 to 25,000 tonnes. The impact of these charges on revenue sensitivity is clear.

## Market Identification, Supply - Demand Dynamics and Revenue Flows

It is evident from the foregoing that the evaluation of the commercial viability of industrial minerals projects is based on very different principles and premises to that of precious or base metal projects. Once the often complex technical assessment of the latter has been completed, it is a relatively easy process to estimate at least what the current selling prices for production from a gold or copper project will be. This is clearly not usually the case with industrial minerals projects, which are market driven, with peculiarities perhaps associated with one market area, 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 Department's 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. However sometimes this data is aggregated with similar minerals and is therefore meaningless. Monthly and annual imports and export statistics are kept, and 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.

In respect to the 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, and various reports on industrial minerals published by Roskill, both 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, and to assess the likely emergence of a competitive mine or mines, not only in Australia, but in other countries if one is 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 obviate the need for the mineral in question to be used in the material or process which is the current focus of its use. 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 the new supplier, and

not have conflicting interests, for example equity or commercial links to potentially competitive alternate sources, or to one group of end-users, to the exclusion of others. 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 upon actual end-users in the targeted markets, and be based on communication with the major companies using the minerals in question. Only then do the specific issues emerge that determine the prices which can be obtained, the tonnage levels that are likely to be purchased, and the resultant revenue flows.

---

## Iron Ore

---

by I. McDonald

### Market

Iron ore is primarily used as a raw material in the production of steel.

Iron ore may occur as a massive rock which must be broken into smaller lumps to facilitate handling, thereby creating some fine ore; or naturally as a fine material; or finely divided in a silica host rock from which it must be extracted by a beneficiation process which usually entails crushing and grinding the ore to a fine powder.

About 1 billion tonnes of iron ore in its various forms are produced worldwide each year. Most of this ore is used in steelmills which own or control the iron ore mines. Some 400 million tonnes of iron ore, however, are internationally traded.

The "captive" ore business is concentrated in the previously centrally planned economies of eastern Europe, CIS, the People's Republic of China, and also the USA. The internationally traded iron ore business is highly competitive, with vigorous and growing trade between major iron ore miners in Brazil, Australia, India, South Africa, Canada, Sweden and Venezuela, and steelmills in Europe, Asia and the USA. The international trade is growing at about one percent per year, while the "captive" trade is decreasing.

Typically, iron ore is smelted in blast furnaces using pre-heated air as a medium and coke as a reductant. Unfortunately blast furnaces do not perform well when processing large quantities of fine material. Consequently, fine material is separated from the raw feed before it is charged into the blast furnace, and is agglomerated into either pellets or sinter to make it suitable as charge material. Pellets are created by balling very fine ore with a suitable binder, then burning the resultant balls into spheres of nominally 16-20 mm diameter. Pellets may also contain fluxes to aid smelting. Sinter is created by burning a mixture of iron ore and flux (eg. limestone, dolomite, serpentine.) and then breaking the resultant "cake" into "fist sized" pieces.

The decision to sinter or pelletize the iron ore depends primarily upon the physical characteristics of the ore. Very fine ores are usually pelletized; coarse ore is usually sintered. Pellets usually travel and handle better (ie. yield less [me material] than sinter.

Traded iron ore products are usually:

\***Fine ore**, which is;

- naturally occurring;
- created as an adjunct of lump ore production;
- deliberately crushed to create a more saleable product;
- the product of a beneficiation process which necessitates crushing and grinding the ore to a fine particle size.

\***Pellet**: very fine ores are difficult to handle so are often made into pellets before shipment.

\***Lump**: usually this has a top size of 30 mm, and a lower size of 6 mm, but with some quantity of fines less than 6 mm which is created as the material is handled.

Blast furnaces can run on any combination of lump, sinter or pellets or anyone alone, provided the feed is suitable in quality, consistent and uniform, and the furnace has a control system which can monitor and control the reduction process. Usually, though, furnaces run on a mixture of feed types.

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

A small (3% of world total), but growing amount, of steel 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, i.e. the oxygen is removed from the hematite and magnetite molecules while the material is in a 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 and must be passivated before shipment. The most common practice is to seal the surface by making it into hot briquetted iron (HBI).

The steel industry also uses iron ore in minor quantities as a de-carburiser and coolant in electric arc furnaces and oxygen converters. There is no specific international trade in iron ore for this particular end use, requirements being taken from stock held for traditional ironmaking.

Finely ground magnetite ore is commonly used as heavy medium in coal washeries. The trade in this material is a separate exercise to the trade in steelmaking raw materials. It is outside the scope of this discussion and is covered in the Industrial Minerals section of the chapter.

There are small quantities of iron ore traded for such diverse end uses as ballast, for making heavy concrete, making sulphur resistant cement, ferrite magnet production, ceramics, an additive in foundry moulds, an additive in glass production, welding electrodes, pigment production, ferro-alloy production, fertiliser additives, heat storage, jewellery, food preservation and 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 over 60 percent). The alumina and silica content should be as low as possible (usually 2 to 8 percent in total), as should the phosphorus content (less than 0.1 %). Total content of alkalis, sulphur 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

These specification limits, e.g. those with high silica, high phosphorus, high manganese, high CaO/MgO, high alumina values.

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

The ore must have physical properties which allow it to handle easily and smelt predictably and easily in the blast furnace.

Above all, it must be uniform, reliable and competitively priced, with the buyer being ready in many cases to off-set less desirable qualities in return for price concessions.

Before substantial quantities can be sold, samples are required for laboratory tests (200 litre drum sample), sinter pot tests (say 10-20 tonnes), and full scale plant tests (10-100,000 tonnes).

The form of these tests is dictated by the buyer, and only if all the tests indicate suitability, and if concurrent geological/engineering studies indicate a competitive, reliable, uniform and consistent supply, will purchases be made.

## Pricing

Iron ore is usually sold in USA currency expressed as US cents per dry tonne unit or per dry long ton unit. A 'unit' is one percent iron. To convert price per unit to price per tonne, the unit price is simply multiplied by the dry percentage iron in the ore.

The ore is sold on an FOB basis (that is, loaded at the seller's wharf on a vessel supplied by the buyer), or CFR (delivered to the buyer's wharf in a vessel supplied by the seller).

Very little ore is sold on a 'spot' basis. Most is sold on long term contract with annual quantities varying slightly in line with contract terms, but with prices being re-negotiated each year.

Prices are set in annual negotiations between the major Australian producers and the Japanese steel mills. Concurrent negotiations are usually conducted between major Atlantic Basin producers and major European steel mills. Such settlements fix a "bench mark" for prices that year.

Typically, in Asia, the price is settled for standard Australian fine ore ex. BHP Iron Ore or Hamersley Iron, with a 'lump' premium to cover the extra value recognised for lump ore.

Other buyers and sellers settle quickly on the basis of typical and pre-agreed 'quality' merits or demerits.

The major pellet buyers negotiate a blast furnace 'pellet' premium with pellet producers in Sweden, Canada, South America and elsewhere, and later a 'direct reduction pellet' premium is also agreed. These agreements become industry standard for the year.

Prices are negotiated on a calendar year basis for the European market and on a year commencing 1 April basis for the Asian market. In the event of prices not being agreed before the start of the period, it is common to continue shipping and issue provisional invoices.

Agreement on price is rapidly published in the trade journals.

*Metal Bulletin* and *The Tex Report*, followed by the financial press in Australia and Japan.

## Packaging

Iron ore is usually shipped in dry bulk carriers, in the largest vessels which can service the shippers' and buyers' ports.

Freight costs are a significant part of the delivered cost of iron ore and must be minimised for successful business to be conducted.

---

## Lead

---

by P .C. Wilson with assistance from C. Chanroux

### The Market

The main market for lead concentrates is 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 (including Imperial Smelting Process (ISP) blast furnaces). Other, 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 fire refining, or electrolytic refining by the Betts process.

### Concentrate Quality

The majority of lead blast furnace smelters process lead sulphide concentrates of fairly high grade (>50% Pb). Lower grade concentrate may be accepted if it is sold at a sufficient discount to higher quality concentrate and the timing is right. ISP smelters regularly process concentrate with Pb <50% but, from the mine's perspective, it is frequently uneconomic to transport low grade lead concentrates.

Lead smelters penalise or reject concentrates with high levels of impurities such as antimony, bismuth, arsenic and mercury. In dedicated lead smelters, zinc and copper are not welcomed. High precious metal contents improve the value of concentrates significantly.

### Pricing

#### Quick 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% Pb concentrate varied between 45% and 65% over the decade prior to 1993.

#### Detailed 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:

Element	Payable metal content
Lead	Pay for 95% of lead content subject to a minimum deduction of 3 units (industry standard)
Gold	Pay for 95% of gold content subject to a minimum deduction of 1.5 g/dmt
Silver	Pay for 95% of silver content subject to a minimum deduction of 50 g/dmt.

### Treatment Charges

A treatment charge (TC), expressed as a fixed deduction per tonne of concentrate, is applied. This includes the cost of refining the lead. A price participation (pp) as discussed in the section "Price Participation" is also included.

Historically, treatment charges have varied widely with the lead price. In addition, TC's for 'clean' concentrates may be significantly lower than for 'dirty' concentrates by, approximately US\$50/dmt. This trend is increasing as environmental restrictions increase. Current TC's may be obtained from the *Metal Bulletin* or from traders.

### 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.

A typical escalator for the treatment charge is:

*If the price is above a base of US¢251lb, increase the TC by US\$3.00 per dmt for every US¢1lb greater than US¢251lb.*

### Refining Charges for Precious Metals

Refining charges are often included for silver and gold. These are typically:

- Gold US\$3.00 -6.00 per oz of payable gold content
- Silver US~ 25 -35 per oz of payable silver content.

### Penalties

Penalties are imposed for undesirable elements that increase the smelter's costs. Typical elements and formulae are shown in Table 16.11.

Some concentrates may be rejected by smelters because they contain a high level of a penalty element. There are no standard 'rejection limits' for the penalty elements as any concentrate is potentially saleable depending on its quantity and the availability of other more favourable materials. Clearly, 'dirtier' concentrates can only be sold for lower returns than cleaner concentrates or at times when cleaner concentrates are in short supply.

Penalty Element	Typical Formula (US\$ per dmt concentrate)	Negotiable Range
Arsenic	\$3.00 per 0.1% above 0.1%	Penalty: \$2.00 -\$3.00 Above: 0.2% -0.3%
Antimony	\$3.00 per 0.1% above 0.1%	Penalty: \$1.50 -\$2.50 Above: 0.03% -0.05%
Bismuth	\$2.00 per 0.01 % above 0.03%	Penalty: \$2.00 -\$3.00 Above: 0.1% -0.3%
Mercury	\$1.00 per 10 ppm above 30 ppm	Penalty: \$1.00 -\$1.50 Above: 10 -50 ppm

**Table 16.111** -Typical Lead Concentrate Penalty Payments

### Example of Revenue Calculation

A worked example of the calculation of the NSR for a lead concentrate in US\$ is shown below:

Ag (900 x 0.95 = 855)  
or (900 -50 = 850)  
Therefore payable Ag = 850 g/t  
850[g/dmt conc] x 4.00 [US\$/troy oz]/31.1 [g/oz] = \$109.32

#### Concentrate Specifications

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

#### Terms

- Treatment charge = US\$190 per dmt concentrate;
- Payable metals as in preceding section "Payable Metals";
- Refining charges:
  - US\$4.00 per ounce payable gold
  - US\$0.30 per ounce payable silver
- Price participation as in preceding section "Price Participation";
- Penalties as in preceding section "Penalties".

#### Metal Prices

Pb	US\$ 507/tonne = US\$ 0.23 per lb
Au	US\$ 380/troy oz
Ag	US\$ 4.00 /troy oz

#### Conversions

31.1 g = troy oz
2204.6 lb = tonne

### NSR CALCULATION

#### Payable Metals

Pb (0.65 x 0.95 = 0.6175)  
or (0.65 -0.03 = 0.62 )  
Therefore payable Pb = 61.75%  
0.6175 [t payable Pb/dmt] x 507 [US\$/t Pb] = \$313.07

Au (3 x .95 = 2.85)  
or(3-1.5=1.5)  
Therefore payable Au = 1.5g/t  
1.5 [g/dmt conc] x 380 [US\$/troy oz]/31.1 [g/oz]= \$18.33

#### US\$/dmt

**Total Payment for Metals** = **\$440.72**

**Treatment Charge** = (\$190.00)

#### Price Participation

Actual price = 0.23 [US\$/lb]  
Base Price = 0.25 [US\$/lb]  
Therefore no adjustment to TC = (NIL)

#### Refining Charges

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

#### Penalties

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

**Total Deductions** = (\$225.39)

**Net Smelter Return** = \$215.33

### Lead Smelters

Comprehensive lists of lead smelters can be obtained from the ILZSG (International Lead Zinc Study Group) or commodity research companies such as CRU International Ltd., Brook Hunt & Associates Ltd., Metals Minerals Research Services and Metal Bulletin Research, who are all based in England. Table 16.12 shows 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 a variety of other geographic regions, usually incurring higher freight costs. The major alternative destination is Europe.



Country	Smelter	Capacity 1993 ( '000tpa lead metal)	Company
Australia	Port Pirie	210	Pasminco
	Mount Isa	240	MIM Holdings
	Cockle Creek	35	Pasminco
Japan	Kosaka	14	Dowa
	Hachinohe	34	Hachinohe Smelting
	Kamioka	34	Mitsui
	Harima	32	Sumiko ISP
	Chigirishima	84	Toho Zinc
Korea	Onsan	80	Korea Zinc

**Table 16.12** - Major Lead Smelters in the Asia Pacific Region

## Lithium

by M. Haigh

Consumption of lithium minerals as raw materials for the glass, ceramic and metallurgical industries in 1992 was estimated to be 82,000 tonnes (or 12,000 tonnes lithium carbonate equivalent, LCE). A further 120,000 tonnes (or 16,000 tonnes LCE) were used in the production of lithium chemicals.

The lithium industry expresses production and sales in terms

of lithium carbonate equivalent (LCE) in tonnes. Lithium carbonate contains 40.40% lithium oxide ( $\text{Li}_2\text{O}$ ). There are three major producers of lithium minerals. Gwalia Consolidated Ltd in Western Australia and Tantalum Mining Corporation (TANCO) in Manitoba, Canada are processors of spodumene ( $\text{LiAlSi}_2\text{O}_6$ ), whereas, the largest producer of petalite ( $\text{LiAlSi}_4\text{O}_{10}$ ) is Bikita Minerals in Zimbabwe, who also have the capacity to produce a small amount of spodumene as a by-product.

The typical and guaranteed chemical and particle size analyses of available lithium minerals are shown in Tables 16.13 and 16.14, respectively.

	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Li}_2\text{O}$	$\text{Fe}_2\text{O}_3$	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	$\text{TiO}_2$	$\text{CaO}$	$\text{P}_2\text{O}_5$	$\text{MnO}_2$
Gwalia Consolidated Ltd Spodumene Concentrate	62.50 (min)	25.00 (min)	7.50 (min)	0.10 (max)	0.35 (max)	0.15 (max)	0.02 (max)	0.10 (max)	0.25 (max)	0.05 (max)
Gwalia Consolidated Ltd Fine Spodumene Concentrate	62.50 (min)	25.00 (min)	7.30 (min)	0.15 (max)	0.25 (max)	0.30 (max)			0.30 (max)	
Gwalia Consolidated Ltd Glass Grade Spodumene	75.20 (typ)	18.60 (typ)	4.80 (min)	0.13 (max)	0.30 (typ)	0.23 (typ)		0.10 (typ)	0.08 (typ)	
Tanco Spodumene Concentrate		25.00 (typ)	7.25 (min)	0.07 (max)	0.30 (typ)	0.20 (typ)			0.25 (typ)	0.05 (typ)
Tanco minus 200 Mesh, Spodumene		25.00 (typ)	7.10 (min)	0.12 (max)	0.30 (typ)	0.20 (typ)			0.35 (typ)	0.06 (typ)
Tanco Glassmaker's Spodumene		25.00 (typ)	6.80 (min)	0.10 (max)	0.35 (typ)	0.25 (typ)			0.20 (typ)	0.07 (typ)
Bikita Petalite	76.70 (typ)	17.10 (typ)	4.20 (typ)	0.03 (typ)	0.50 (typ)	0.25 (typ)				
Bikita Spodumene Concentrate	64.60 (typ)	26.50 (typ)	7.10 (typ)	0.07 (typ)	0.17 (typ)	0.16 (typ)				
Bikita Glass Grade Spodumene	75.00 (typ)	19.10 (typ)	4.80 (typ)	0.03 (typ)	0.40 (typ)	0.13 (typ)				

**Table 16.13** - Analytical Specifications of Commercial Lithium Minerals

### Nominal Screen Size (microns)

Production Identification	850	710	500	425	355	300	250	212	180	150	125	106	90	75	53	45	38	24	12
	(% Wight Retained)																		
Gwalia Consolidated Ltd Spodumene Concentrate			Nil					1.00 (typ)	2.9 (typ)		24.2 (typ)		23.0 (typ)	10.3 (typ)		21.5 (typ)	17.1%		- 45µm
Gwalia Consolidate Ltd Glass Grade Spodumene	Nil	0.15	11.6 (typ)		29.8 (typ)		37.2 (typ)		17.4 (typ)			3.2 (typ)	0.1 (typ)	0.55% - 90µm					
Gwalia Consolidated Ltd Fine Spodumene Concentrates											1.0 (max)			90-95% - 75µm					
Tanco Spodumene Concentrates			0.1 (max)	Nil		1.0		4.0		13.0		22.0		12.0		48%			- 75µm
Tanco Glassmakers Spodumene			0.1 (max)											45% max - 75µm					
Tanco - 200 Mesh Spodumene												Nil		3.0	4.0		25.0	34.0	26.0 (8% - 12µm)
Bikita Petalite	52#, 80#, 200#, 326# particle size available on request.																		
Bikita Spodumene Concentrate	52# particle size available on request																		
Bikita Glass Grade Spodumene	52# particle size available on request																		

**Table 16.14** – Particle Size Specifications for Commercial Lithium Minerals

Material	%Li <sub>2</sub> O	Approximate Price Seller's Warehouse	Price (US\$ per Ib LCE)
Lithium Carbonate	40.4	US\$ 1.96/lb	1.96
Spodumene Concentrates	7.6	US\$ 385.00/t	0.93
Glass Grade Spodumene	5.0	US\$ 185.00/t	0.66
Petalite	4.2	US\$ 239.00/t	1.04

**Table 16.15** -Prices of Lithium Minerals in US\$ per Ib LCE

## Pricing

The prices for lithium minerals and lithium carbonate are published regularly in *Industrial Minerals*.

The price of lithium minerals is traditionally compared with the price of lithium carbonate as a benchmark. Lithium carbonate is produced by Cyprus Foote Mineral Company, headquartered in Pennsylvania, USA and FMC Corporation, Lithium Division in North Carolina, USA.

Effective from November 2, 1992, the Cyprus Foote Mineral Company announced that the price of lithium carbonate technical grade, as quoted in the *American Metal Market* (Volume 100, Number 195), would be US\$1.96 per pound.

As lithium minerals are a relatively low cost commodity, the cost of packaging, freight and storage are a significant part of the delivered price making general comments on pricing difficult. Nonetheless, the lithium minerals industry has contained price increases over the past 4 years to 2 -4%. A comparison of the relative prices of lithium minerals versus lithium carbonate on an equivalent lithium oxide basis is illustrated in Table 16.15.

## Applications

Traditional applications for lithium minerals are low thermal expansion glass ceramics, low expansion and fully vitrified ceramics, frits and glazes, monochromatic and colour TV components, fibreglass, bulk glass packaging and high quality perfume containers.

## Magnesite

by A. Vogel

### The Market and Product Forms

Naturally occurring magnesite (MgCO<sub>3</sub>) is the world's most important commercial source of magnesia (MgO -magnesium oxide) and other magnesium-based products.

World production of magnesite is approximately 23 million tpa, of which an estimated 16 million tpa is produced in the CIS, China and North Korea.

Only an estimated 300,000 tpa of magnesite is used in its uncalcined form (as MgCO<sub>3</sub>) in various plastics, paper, pigment, and horticultural applications, as well as a feedstock for magnesium metal production.

Magnesite when calcined at 700-1,000°C converts to caustic calcined magnesia (MgO), which has a world market of approximately 1 million tpa, mainly as an industrial neutralant, in paper and plastics manufacture, as a fertilizer and in animal feedstuffs, and as a feedstock for electrofused magnesia.

When magnesite is further calcined to 1,500-2,000°C, it forms a hard, dense product called sintered or dead-burned magnesia which, in various formulations, is used for refractories.

The world market for refractory dead-burned magnesia is approximately 9 million tpa, of which approximately 5 million tpa is consumed by the CIS, China and North Korea.

Of the "western world" 4 million tpa consumption, approximately half is derived from natural magnesites; the other half is "synthetic" magnesia extracted from seawater and brines.

Heated above 2,800°C (in electric arc furnaces), magnesia melts. The resultant recrystallised electrofused magnesia is used for high quality refractories (with a western world market of approximately 150,000 tpa) and in electrical appliances as an insulator (approximately 80,000 tpa).

Approximately 70% of all magnesia-based refractories are consumed in the steel industry, with the balance going mainly into the cement, non-ferrous metals and glass industries.

## Marketable Qualities

Each of the more than 40 worldwide producers of refractory magnesia produces a differentiable quality, which derives its particular characteristics from the magnesia source (ie. natural cryptocrystalline magnesite, natural microcrystalline magnesite, seawater or brine) and the subsequent processing methods employed.

Broadly speaking the range of refractory magnesias is divided into two qualities: brick grade (higher quality) and monolithics grade (lower quality). Monolithic refractories are all unshaped refractories eg. castables, plastics, and rammables.

The elements determining quality are, in general terms:

	Brick Grade	Monolithics Grade
Purity (% MgO)	>95	<95
Iron	< 1 % Fe <sub>2</sub> O <sub>3</sub>	-
Lime/silica ratio	,>2:1	<2:1
Bulk specific gravity	>3.3	<3.3

The product must be dry and is typically sold as crushed lump (eg. minus 30 mm) in bulk, or otherwise sized and bagged, the latter usually for electro fused magnesias.

## Pricing and Price References

All refractory magnesia is sold on a per tonne basis, and is priced in DM or £ sterling in Europe, Yen in Japan, A\$ in Australia, and typically US\$ elsewhere.

Because magnesias are technically differentiated products, there is no single terminal market price. Prices are negotiated on an annual basis between sellers and buyers. An indication of the current market prices is published in the monthly *Industrial Minerals* magazine. This reference is for brick grade (high grade) magnesia CIF United Kingdom market, expressed in £/tonne.

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

Over the last decade, refractory magnesia price trends have been relatively flat in nominal terms, with fluctuations from the trend corresponding to the fortunes of the steel industry. An indication of the flat nominal prices over the last decade is:

Magnesia Quality	European Price (DM/t CIF Rotterdam)
High quality electrofused (> 97% MgO)	1000 -1500
Lower quality electrofused (< 97% MgO)	700 -1000
Brick grade dead-burned	500 -800
Monolithics grade dead-burned	200-500

## 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 to similar existing qualities in the market. This requires a comprehensive understanding of refractory magnesias, applications and competitive forces in the market. An expert consultant or marketing agent would be required for this purpose by a newcomer to the industry. There are no reliable shortcuts.

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

## Packaging and Transportation

Dead-burned magnesia is typically shipped in bulk in parcels of 3,000 -10,000 tonne, which constitute a part cargo on a "handy size" (typically 15,000 -40,000 tonnes) dry bulk vessel.

Electrofused magnesia is sold in sized fractions according to customer requirements (eg. 1-3 mm, 3-5 mm, etc.) and packed in 1-tonne bulker bags. These are shipped in standard 20-foot containers, with up to 20 bags per container..

---

## Manganese

---

by K.J. Bindle

### Demand

The principal use of manganese is in steel production, generally via manganese alloy addition during the refining process. As such, demand is inextricably linked to the fortunes of the steel industry.

Additionally, manganese is used in the dry cell battery industry and in manganese chemical production.

### Markets

The majority of manganese ore destined for consumption in the steel industry is sold to smelters and used to produce manganese alloys, which are onsold 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.

The chemical and battery industries generally purchase direct from the ore producer.

### Valuation

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

For alloying/steelmaking, manganese ore pricing is generally related to manganese content with other elements having no significant influence. Prices are quoted in US\$ per dry tonne unit of manganese, ie.: US\$/dmu.

**Simple revenue assessment** would be:

Tonnes x Mn Content x Price

where:

Mn Content = %Mn

Price = US\$/dmu

**A preliminary assessment of price** can be obtained from authoritative journals which regularly publish manganese pricing data, eg.: *Metal Bulletin*, *TEX Report*, *Industrial Minerals* and *Metals Week*. The order of accuracy would depend upon material grading but could be generally said to be around 80%-90%.

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

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

The type of ore will determine both market acceptance and revenue range. Carbonate ores generally command lower prices than oxide ores, whilst 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. Previous conventional wisdom was that battery activity required the presence of the mineral nsutite, but more recently the minerals vernadite and todorokite have been identified with battery activity. To determine the presence or otherwise of these minerals requires access to XRD analysis.

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 market place of manganese ore is dependent upon the chemical and physical characteristics of the ore. By way of illustration, the following criteria are required.

#### alloying/steelmaking

- Manganese
  - 48%Mn preferred
- silica
  - for ferro manganese production, a higher content of silica may be acceptable
- alumina
  - should be minimised
- phosphorus
  - of major concern
  - >0.1% is generally unacceptable
- sulphur/alkalis
  - demand consideration
- manganese to iron ratio
  - >6.5:1 is preferred
- sizing
  - lumpy commands a higher value as fines require agglomeration/sintering
- heavy metals
  - not favourably received
  - environmentally sensitive

#### chemical industry

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

#### battery industry

- 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>
  - the 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, and the size of the reserves and 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.

## Transportation

There are no constraints to manganese ore transportation 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 upon the end use of the manganese.

Generally speaking, Metallurgical Lump is the benchmark grade for the alloying/steelmaking applications. Indicative chemical specifications for this grade are as follows:

Manganese	48 -50	% Mn
Iron	4 -10	% Fe
Silica	4 -7.5	% SiO <sub>2</sub>
Alumina	1 -6	% Al <sub>2</sub> O <sub>3</sub>
Phosphorus	0.03-0.10	% P

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

---

## Mineral Sands

---

by A. Codner

### Titanium Minerals

Approximately 92% of world titanium mineral production is consumed in titanium dioxide pigments which are used in paints and high quality colouring agents to enhance the colour of paper and plastics. Other applications are the production of titanium metal for the aerospace industry, steel deoxidisers, welding rod coatings and ceramics. All titanium feedstock is

derived from either rutile or ilmenite. Rutile, at approximately 95% TiO<sub>2</sub>, is the premier raw material and has suffered from potential scarcity at times. However, ilmenite (50 to 60% TiO<sub>2</sub>), a combination of iron and titanium oxides in varying ratios, is found in large quantities worldwide. It can be enriched to form synthetic rutile at 90% TiO<sub>2</sub>.

The economics of pigment production favour the use of higher grade feedstocks, but there are pigment producers who retain the ability to use raw ilmenite depending on the relative price between high and low grade TiO<sub>2</sub> bearing material.

Pigment is produced by the chloride and sulphate processes. Ilmenite is divided into two categories, rock ilmenite and beach sand ilmenite. The former has a high alkali content (> 1%), whereas the latter is usually very low in alkalis and, for this reason, is the preferred source for the chloride and sulphate processes. Traditionally, the chloride and sulphate processes have used ilmenite concentrates, beneficiated ilmenite, or acid soluble high TiO<sub>2</sub> content slags. Natural and synthetic rutile cannot be used in the sulphate process, because rutile is insoluble in sulphuric acid. Other than iron and titanium oxides, nearly all commercial ilmenites contain only about 3-4% of other oxides.

### Rutile Concentrate

The main analyses which must be guaranteed are the TiO<sub>2</sub>, ZrO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub> contents. Sizing is also important as some consumers prefer fine and others coarse grained material, depending upon the particular application. Some examples of the analyses of rutile concentrates available on the market are shown in Table 16.16.

No penalties are imposed, perse, if the TiO<sub>2</sub> content is below the standard 95% minimum. However, the producer must guarantee the quality which will be marketed.

### Ilmenite concentrate

Examples of the analyses of ilmenite concentrates available on the market are shown in Table 16.17.

Usually a standard grade ilmenite concentrate has a minimum 50% TiO<sub>2</sub> content which is suitable for application in the welding electrode industry. Ilmenite concentrates from beach sands operations, which have grades of 48-51 % TiO<sub>2</sub> are also used for synthetic rutile manufacture and blast furnace hearth linings.

### Leucoxene

Leucoxene is a generic name covering a range of alteration products derived from the natural leaching of iron from ilmenite. With increasing alteration the mineral suite is:

Ilmenite	(52%-60% TiO <sub>2</sub> )
Secondary Ilmenite	(60%-62% TiO <sub>2</sub> )
Leucoxene	(85%-92% TiO <sub>2</sub> )

Uses of leucoxene concentrate are similar to those for rutile, with the pigment and welding electrode industries being the main users. A typical concentrate analysis is shown below.

	Guaranteed	Typical
TiO <sub>2</sub>	88% min	90-91%
Fe <sub>2</sub> O <sub>3</sub>	5% max	2.0%
ZrO <sub>2</sub>	2.7% max	1.0%
P		0.05%
S		0.02%

	East Coast Australia	West Coast Australia	India
<b>Guaranteed analyses</b>			
TiO <sub>2</sub>	96.0% min	95.0% max	95.0% min
ZrO <sub>2</sub>	1.0% max	1.0% max	
Fe <sub>2</sub> O <sub>3</sub>	0.5% max	1.0% max	
<b>Typical analyses</b>			
TiO <sub>2</sub>	96.20%	95.80%	96.40%
ZrO <sub>2</sub>	0.75%	0.34%	1.10%
Fe <sub>2</sub> O <sub>3</sub>	0.35%	0.94%	1.10%
SiO <sub>2</sub>	0.70%	0.42%	1.10%
Al <sub>2</sub> O <sub>3</sub>	0.35%	0.19%	
Cr <sub>2</sub> O <sub>3</sub>	0.20%	0.15%	
V <sub>2</sub> O <sub>5</sub>	0.70%	0.43%	
CaO	0.05%	<0.02	
MgO	0.05%	0.02%	

**Table 16.16** - Analyses of Rutile Concentrates

	East Coast Australia	Malaysia	India
<b>Guaranteed analyses</b>			
TiO <sub>2</sub>	50.00% min	60.00% min	58.00% min
Total Fe	32.00% min		
Cr~3	0.40% max		
Al <sub>2</sub> O <sub>3</sub>	0.65% max		
<b>Typical analyses</b>			
TiO <sub>2</sub>	50-51%	63.10%	60.00%
Total Fe	32-34%	31.90%	25.50%
Cr <sub>2</sub> O <sub>3</sub>	0.27%	0.06%	0.13%
Al <sub>2</sub> O <sub>3</sub>	0.59%		0.10%
MnO	1.05%		0.40%
MgO	0.90%	2.20%	0.60%
CaO	0.03%	0.25%	
SiO <sub>2</sub>	0.49%	1.79%	0.90%
ZrO <sub>2</sub>	0.13%	0.06%	0.40%

**Table 16.17** - Analyses of Ilmenite Concentrates

## Zircon

Zircon is noted for its high temperature insulation properties and has a wide range of high technology applications, which are listed below.

- Refractories  
Refractory bricks and blocks in glass furnaces and in hearths containing molten metal. Refractory material for dies used in extruding materials.
- Foundries  
Foundry sands. Facings on foundry moulds. Refractory paints for coatings on outside of foundry moulds. Steel foundry ladles.
- Nuclear Reactors  
Hafnium-free metal for fuel cladding and structural materials. Engineering ceramics. Glazes, especially for tiles.
- Chemical Processing  
Zirconia. Zirconium metal and compounds.
- Ceramics  
Opacifying agents in frit formulations and glazes. This application requires zircon sand to be processed into flour or micronised (ultra fine) particles sized less than 5 microns.
- Others  
Abrasives. Water repellents. Alloying agents;. Glass polishing.

The processing of zircon concentrates into a micronised product has traditionally been the domain of a small number of companies in Australia and Europe. They purchase concentrates from various supply sources, and resell the micronised product to ceramic manufacturers.

For ceramics, a premium quality zircon concentrate is preferred, above 65% ZrO<sub>2</sub>, with minimal levels of Fe<sub>2</sub>O<sub>3</sub> (0.04 to 0.05%). Typical zircon concentrate specifications and their applications are given in Table 16.18.

## Monazite and Other Rare Earths

Monazite is a rare earth thorium phosphate containing nearly 70% combined rare earths (including about 1.5% yttrium oxide), with a predominance of cerium. Xenotime usually occurs with monazite and is rarely separated from the concentrate prior to sale. Monazite is usually sold directly to processors as concentrate with 55-60% REO (Rare Earth Oxides), including thorium oxide. However, monazite from Brazil and India is only sold as an intermediate mixed compound. Xenotime concentrate, the main source of yttrium, is often chemically upgraded to 60% Y<sub>2</sub>O<sub>3</sub> before shipment.

A typical monazite concentrate specification is shown below.

### Sulphuric acid solubles

Rare Earth Oxides	57.0 -60.0%
ThO <sub>2</sub>	5.0 -6.8%
P (as P <sub>2</sub> O <sub>5</sub> )	27.0 -28.0%

### Sulphuric acid insolubles

ZrO <sub>2</sub>	2.0 -8.0%
TiO <sub>2</sub>	0.0 -0.8%
Others	1.0 .5 -3.0%

## Marketing

The mineral sands industry has traditionally suffered from fluctuating commodity prices but, by negotiating long term contracts and investing in downstream processing, a more diversified and dependable marketing strategy can be developed.

One of the most significant features of the Australian industry over the last five years has been the emphasis on value added production, including upgrading ilmenite to synthetic rutile, and

Quality Parameter	East Coast Australia	West Coast Australia
	Premium	Standard
ZrO <sub>2</sub> (+HfO <sub>2</sub> )% min	66.0	65.5
TiO <sub>2</sub> % max	0.1	0.2
Fe <sub>2</sub> O <sub>3</sub> % max	0.05	0.1
Typical Applications	- Glass refractories - Zircon silicate - High quality ceramics	- Steel refractories - Ceramics - Foundries ceramics

Quality Parameter	South African Standard	Chinese Standard
	ZrO <sub>2</sub> (+HfO <sub>2</sub> ) % min	65.0
TiO <sub>2</sub> % max	0.3	0.5
Fe <sub>2</sub> O <sub>3</sub> % max	0.3	0.5
Typical Applications	- Basic refractories - Foundries -Foundries	- Blender

**Table 16.18** - Analyses of Zircon Concentrates and Their Uses

the production of TiO<sub>2</sub> pigments and micronised zircon on site.

Whilst supply/demand factors govern the market price, market competitiveness is the critical factor which governs sales volume. The West Australian and South African standard grade zircon concentrates have similar analytical characteristics, however a higher proportion of the South African material is sold. The far lower cost of production and labour in South Africa compared to Australia, cheaper freight rates, and at times an unfavourable A\$/US\$ exchange rate, can render the Australian material uncompetitive even though the quality of the material may be acceptable.

Prices for rutile, zircon, ilmenite and mon31ite concentrates are published in A\$ per tonne (FOB/FID) for various grades of product twice weekly in the *Metal Bulletin*, and monthly in *Industrial Minerals*. The prices quoted should be used merely as a guideline.

A more accurate indication of market prices can be obtained by conferring with existing producers. There is no cartel as such, but producers tend to quote in line with each other so that there is some stability within the market place. In extremely competitive times, this is not always the case. Alternatively, an experienced merchant trading house can give indications of prices being quoted to consumers and an overall view of the direction in which the market is heading.

Marketing of any mineral sands product is complex and dependant on a number of factors, primarily:

- production rate;
- quality;
- production and delivery costs;
- availability;
- reliability.

In the majority of cases producers sell to three or four consumers on a long term basis. If market conditions are strong, producers can also trade a certain proportion of production on the open market. In some instances, products have been sold at five times

above the actual long term contractual pricing, although this situation tends to be somewhat shortlived.

Long term contracts encompass various factors. The contract can range from a fixed quantity per annum over 3-5 years duration with annual price renegotiations, to fixing of quantity and pricing for one year only. Some consumers are more conservative in their approach and prefer to price each consignment at the time shipment is made in accordance with the market price ruling at the time of delivery. This means that in times of rapidly rising prices they pay a higher price than those consumers who prefer to price on an annual basis, and vice versa. It is not uncommon in weak market conditions to have annual contracts with price renegotiations on a half yearly basis.

For annual contracts, tonnages can vary from 5,000 to 20,000 tonnes with the amount mutually agreed between the producer and consumer. Where tonnages are suitable for bulk shipments, the basis for pricing and delivery is either FOBST or CIFFO.

The transportation basis is negotiable between the producer and consumer. Some consumers may wish to charter their own vessel, in which case the producer must ensure material is available and ready for loading at the designated time.

For small quantities (eg. 20 tonne container loads) the producer, if supplying directly to the consumer, normally sells on a CIF basis. Alternatively, if the producer is selling to a merchant trading house, sales are on a FOB basis, making it the responsibility of the trading house to arrange and co-ordinate the freight and insurance. In this instance, the producer has to arrange delivery of the container to a designated wharf or depot.

Container shipments consist of material packed in either 1 or 2 tonne bulker bags or in approximately 40 kg multiwall paper bags, with pallet shrinkwrapping optional. In all cases the bags are shipped on pallets. Container shipments are more applicable to consumers within the foundry, refractory, welding electrode, and ceramic industries.

The majority of mineral sands producers have their own marketing department and do not conclude sales agreements with



merchant trading houses, particularly for large bulk tonnage contracts. However, trading houses do have an important role to play in the overall marketing scene. For example, there are many places where the producer may not wish to be directly involved because of communication difficulties, payment delays and, at times, failure to take delivery. These areas include India, Pakistan, the Middle East and Eastern Europe. Another example is those marketing areas where the total quantity consumed is significant, but where a large proportion of sales is in small lots. In this case a warehouse stockpile is set up and a local marketing agent is employed to make direct producer/consumer transactions from Australia more cost effective.

---

## Nickel

---

by W.H. Cunningham

### The World Market for Nickel

#### Mine Production

Total 1991 world mine production was approximately 900,000 tonnes of nickel. The six largest producers were CIS (212,000 t), Canada (193,000 t), New Caledonia (115,000 t), followed by Australia (69,000 t), Indonesia (62,000 t) and Cuba (43,000 t).

Of the total, some 60% is mined from sulphide orebodies with the balance from laterite ores. However, current known world reserves of sulphides represent only 30% of total resources. 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. Sulphide ores, formed at depth by igneous processes, are generally higher in grade and usually associated with other elements such as copper and precious metals.

#### Processing

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

Oxide ores are dried, roasted, calcined and refined into ferro-nickel or nickel oxide. Alternatively, by adding sulphur the ores can be reverted to the sulphide-process stream.

#### Consumption

Nickel is a versatile metal and is used in a number of end products including stainless steel production (65%), metal alloy products (18%), plating (8%), and chemicals, coinage and miscellaneous (9%). The major consuming countries are those with well developed industrial bases, namely Japan 180,000 tonnes, USA 130,000 tonnes and Germany 80,000 tonnes. CIS consumption is probably around 120-150,000 tonnes per annum.

#### Marketing of a Sulphide Nickel Concentrate

Whilst 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 Western Mining

Corporation's (W.M.C.) nickel smelter at Kalgoorlie, W A, potential sulphide nickel concentrate customers are mainly in Canada. They include Inco's Sudbury (Ontario) and Thompson (Manitoba) smelters, Falconbridge's Sudbury smelter and Sherritt Gordon's Fort Saskatchewan (Alberta) refinery. Outside Canada, there is Outokumpu's Harjavalta smelter in Finland, and there may be potential customers in Zimbabwe, Russia and China.

Typically, a concentrate purchase contract specifies a minimum nickel content, and may stipulate maximum levels of such deleterious elements as magnesia, arsenic, lead, selenium and chlorine.

Depending on the levels of copper and cobalt present these may be payable elements.

Whilst some gold and platinum group metals (PGM's) may also be present, these are generally not regarded as payable elements.

Set out below is an example of a theoretical sulphide nickel concentrate, delivered to WMC's Kalgoorlie nickel smelter:

#### Specification:

Ni	10% (min. acceptable 9%)
Cu	1%
Co	0.5%
MgO	6.5% (max. acceptable 7%)
Fe	33%
S	33%
As	300 ppm (max. acceptable 400 ppm)
Se	10 ppm (max. acceptable 50 ppm)
Pb	5 ppm (max. acceptable 50 ppm)
Cl	100ppm (max. acceptable 0.5%)
H <sub>2</sub> O	< 0.3% (ie. if delivered in pressurised tankers in dry powder form)

#### Sizing:

80% passing 200 mesh (75 micron)

In the case of WMC's Kalgoorlie smelter, concentrates must be dried prior to delivery, either by the supplier, or by WMC at one of its dryer facilities, at either Kambalda or Leinster.

The concentrates are smelted into nickel matte, which is then either railed in bulk to WMC's Kwinana Nickel Refinery in Perth for refinery into nickel metal, or bagged in two-tonne bulker bags for containerisation and export to overseas customers for refining.

#### Nickel Concentrate Purchase Terms

##### General

The recoverable or "payable" nickel contained in concentrates normally has as its "reference price" the London Metal Exchange quotation, either spot (cash), 3-month, or a combination thereof. 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, and a price bonus clause to cover times of high reference prices.

Copper and cobalt similarly have a "payable" content, to which a "reference price" is applied.

The London *Metal Bulletin* or the USA *Metals Week* publications are the standard reference sources for price data, with the former probably the main one.

## Example of Smelter Terms

The following is an example of typical smelter terms. It should be noted that terms will vary from smelter to smelter.

### Delivery

FOT Kambalda, W A, as wet concentrate, containing approx. 8-10% H<sub>2</sub>O.

### Nickel Payment

Pay for the nickel content less 0.7 units, less 3% of balance, at 65% of the lower of the [LME cash and 3 month prices (the "reference price") for the quotational period, as published in *Metal Bulletin*, less US\$10¢/lb payable nickel marketing charge. For each US\$ 0.50 by which the reference price exceeds US\$ 3.50/lb, increase the share of the reference price to the seller by 1%, to a maximum of 70% of the reference price, at US\$6.00/lb reference price.

In the event that the reference price is less than US\$ 2.80/lb, a minimum deduction of US\$ 0.98/lb of payable nickel shall apply.

### Copper Payment

Pay for the copper content less 0.5 units, at 45% of the lower of the LME Grade A cash and 3 months prices for the quotational period, as published in USA currency in *Metals Week*.

### Cobalt Payment

Where the cobalt content exceeds 0.25 units, pay for the full content at 15% of the lower of the Producer Price and the mean of the free market range, as published in *Metal Bulletin*.

### Quotational Period

This shall be the 4th month following the month of delivery of concentrate, for all payable elements.

### Deductions

All deductions shall be escalated for fuel oil and consumer price index changes.

- Drying charge: a charge of A\$ 25 per dry tonne shall be levied for the drying of nickel concentrate at Kambalda.
- Penalties:
  - Arsenic: for each 10 ppm As over 2() ppm, a penalty of A\$1 per dry tonne shall be levied.
  - Magnesia: for each 1 % MgO over 5% MgO, a penalty of A\$6 per dry tonne shall be levied.
  - Other: if any other elements are found to have a detrimental effect on nickel production, the parties shall negotiate appropriate penalties in good faith.
- Marketing charge: a charge of US \$0.10/lb payable nickel shall apply.

## Payment

- A provisional payment, equal to 700/0 of the estimated value, shall be made at the end of the month following the month of delivery.
- Final payment shall be made at the end of the fifth month following the month of delivery.

### Weighing/Sampling/Assaying

Buyer's weights and moisture determinations shall be final.

Sampling is to be carried out in lots of not more than 600 wet tonnes. Assays shall be exchanged between buyer and seller. Splitting limits shall be 0.2% for Ni, 0.1% Cu, 0.05% Co, 0.5% MgO, and seller's As assay shall be not more than 10% from buyer's assay.

### Example of Calculation of Net Smelter Return

The following example of the calculation of Net Smelter Return is based on the smelter terms quoted in the preceding section.

**Specification:** assume that the specification given in "Marketing of a Sulphide Nickel Concentrate" above applies.

**Metal Prices:** assume    Ni US\$3.75/lb  
   Cu US\$1.05/lb  
   Co US\$12.00/lb.

**Exchange Rate:** assume US\$0.75 = A\$1.00

### Nickel Payment

Payable Nickel            = 10% - 0.7% = 9.3% x 0.97  
   = 9.021 % payable Ni  
   = 198.88lb payable Ni/dmt

Reference Price            Percentage of reference price  
   = 65% +  $\left( \frac{\text{US\$3.75} - 3.50}{0.50} = 0.5\% \right)$   
   = 65.5% of US\$3.75/lb  
   = US\$2.45625/lb of payable Ni  
  
   Less marketing charge of US\$0.10  
   = US\$2.35625/lb of payable Ni

Payment for nickel = 198.88lb @ US\$2.35625  
   = **US\$468.61/dmt**

### Copper Payment

Payable Copper            = 1.0 - 0.5 = 0.5% payable Cu  
   = 11.021b payable Cu/dmt

Reference Price            = 45% of US\$1.05/lb  
   = US\$0.4725/lb of payable Cu

Payment for Copper = 11.021b @ US\$0.4725 = **US\$5.21/dmt**

### Cobalt Payment

As Cobalt content exceeds 0.25%,  
 then payable Co = 0.5%  
 = 11.02 lb payable  
 CO/dnlt  
 Reference Price = 15% of US\$12.00/lb  
 = US\$1.80/lb of payable Co

Payment for Cobalt = 11.021b @US\$1.80 =: **US\$19.84/dmt**

**Total Payment for Metals =US\$493.66/dmt**  
 Converted @ US\$0.75/A\$/1 =**A\$658.21/dmt**

### Less Deductions

Drying Charge =**A\$25.00/dmt**

Arsenic Penalty = 300 ppm -200 ppm  
 = 100 ppm @ A\$1/dmt for each 10 ppm  
 =  $\frac{100}{10} = 10 \times A\$1$  =**A\$10.00/dmt**

MgO Penalty = 6.5% - 5%  
 = 1.5% @ A\$6/dmt for each 1 %  
 = 1.5 x A\$6 = **A\$9.00/dmt**

**Total deductions = A\$44.00/dmt**

**Net Smelter Return, FOT Kambalda =A\$614.21/dmt**

## Phosphates

by I.W. Dennis

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 world production of 156 million tonnes in 1990. This rock is usually very fine grained, in which the phosphate mineral is one of the members of the fluorapatite-chlorapatite-hydroxylapatite series, with the general formula  $C_3s(PO_4)_3(F, OH, Cl)$ . The major constituents in apatite are 50 to 55% CaO and 38 to 42%  $P_2O_5$ . The tenn colophon is used for the cryptocrystalline variety of apatite. Rock phosphate grades are quoted as per cent BPL or per cent TPL (Bone Phosphate of Lime or Tri Phosphate of Lime) equivalent to  $2.185 \times \%P_2O_5$ .

Phosphate rocks for the Australian market are supplied predominantly from open cut workings on Nauru Island. Other sources of rock for Australia are Morocco and the USA. In the period 1986-90 Australia imported annually between 824,000 and 2,222,000 tonnes of phosphate rock of which approximately 75% had a grade of greater than 78 BPL.

Australia has significant phosphate rock reserves near Mount Isa in Queensland and near Laverton in Western Australia. A major portion of the resources in the Mount Isa area are held by Queensland Phosphate Limited, and CSBP 8Ild Farmers Ltd. hold the resources near Laverton at Mount Weld.

A wide range of phosphorus chemicals are made from phosphate rock, but only the manufacture of fertiliser, the principal use of phosphate rock in Australia, is considered in this section. Located in Australia are thirteen single superphosphate plants, four triple superphosphate plants and four phosphoric acid plants. Most of the single superphosphate plants are in operation but the triple superphosphate and phosphoric acid plants are only operated when their products are cost competitive with imports. Single superphosphate is produced by reacting phosphate rock with sulphuric acid and is a relatively low grade fertilizer. Phosphoric acid is produced by a two stage closed circuit reaction, with phosphate rock and sulphuric acid being the raw materials and calcium sulphate (gypsum) a by-product. Phosphoric acid is an intermediate product in the production of high grade fertilizers such as triple superphosphate, mono ammonium 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.

Sales of phosphate rock are generally by annual contract with consumers, with minimum rock grades of about 30%  $P_2O_5$  (approx. 66% BPL). Rocks with an analysis of 32.5 to 35%  $P_2O_5$  (70 to 77% BPL) obtain a premium price. The grade of phosphate rock is usually specified within a BPL range (ie. 68-70 %BPL) with the contract price being 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. For rock with a grade of 68-70 %BPL, the 1991 68 %BPL base price FOB USA Gulf varied between US\$34.50 and US\$38.50/t. Similarly, for a rock with a grade of 72-74 %BPL, the 1991 72 %BPL base price FOB USA Gulf varied between US\$39.00 and US\$44.00/t. The base price is increased or decreased by US\$1.00/t for each percent variance from the base grade. Fractions of BPL are pro rata.

The price is determined by the free market. An accepted source of price and market information is *Green Markets* published weekly by Pike and Fischer of the USA.

Most sales contracts contain price penalty conditions which are effective when the combined  $Fe_2O_3$  and  $Al_2O_3$  analysis, commonly termed R203' exceeds 3%. The base price of the rock is usually decreased by US\$2.00/t for each percent R203 that the actual analysis is above 3%. Fractions of R203 are pro rata.

Sales contracts usually contain indicative analyses of  $P_2O_5$ ,  $Fe_2O_3$ ,  $Al_2O_3$ , carbonate, chlorine, fluorine, silica, sulphides, magnesium, sodium, potassium, uranium and cadmium. The presence of carbonates is undesirable as they consume sulphuric 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 plaster board manufacture the rock should have less than 60 ppm  $U_3O_8$ . Cadmium in the rock is carried through to the fertilizer and into the food chain. The cadmium content of fertilizers is limited by legislative control in a number of countries and this practice is expected to become more widespread. Rock with a cadmium content of less than 10 ppm will become more readily sold. With the exception of  $P_2O_5$ ,  $Fe_2O_3$  and  $Al_2O_3$  there are usually no penalty conditions in respect of 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 3%. The sizing specification is dependent on the processing method

and the design of the plant. The sizing specification is commonly

100% minus 5 mm but may be as coarse as 25 mm.

## Tantalum

by A. Vogel

### Market

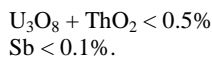
Tantalum is used in electronic capacitors (50%), tantalum-carbide cutting tools (25%), chemical process equipment (15%), ballistic projectiles and aerospace super-alloys. The world market is relatively small, totalling about 2.5 million lbs Ta (equivalent to about 3.0 million lbs Ta<sub>2</sub>O<sub>5</sub>) per annum. The world's tantalum consuming industries are located mainly in the USA, Japan and Germany.

### Marketable Product

While a number of economic tantalum minerals may be concentrated into saleable form (eg. microlite, wodginite, tantalite), the industry refers to all natural concentrates generally as "tantalites".

Saleable tantalite should contain >25% Ta<sub>2</sub>O<sub>5</sub> and will generally always contain some Nb<sub>2</sub>O<sub>5</sub> depending on the economic minerals present. If the Nb<sub>2</sub>O<sub>5</sub> content exceeds the Ta<sub>2</sub>O<sub>5</sub> content, the concentrate is regarded as a columbite. The Ta<sub>2</sub>O<sub>5</sub> plus Nb<sub>2</sub>O<sub>5</sub> content is referred to as the combined oxides ("C.O."). The higher the C.O., the higher the price per lb Ta<sub>2</sub>O<sub>5</sub> contained in the tantalite. This is because the Nb<sub>2</sub>O<sub>5</sub> content of the concentrate is not paid for; instead its value is included in the price paid per lb of Ta<sub>2</sub>O<sub>5</sub>.

Undesirable impurities in tantalite are U<sub>3</sub>O<sub>8</sub>, ThO<sub>2</sub> and antimony. As a guideline they should be:



Most processors reject concentrates at levels above these limits, however, there are exceptions.

Tantalite concentrates should be dry, free-flowing granular particles, typically minus 3 mm in size.

Tin is frequently an accessory metal in tantalite gravity concentrates, usually in the form of cassiterite or wodginite. Tin will attract a credit payment only if it is physically separable, present in relatively high concentration (eg. 10-20% SnO<sub>2</sub>) and tin prices are relatively high. Otherwise, tin is neutral in value and can in some instances attract a penalty if the cassiterite physically "locks up" grains of tantalum minerals and thereby reduces the yield of tantalum in downstream processing.

## Pricing and Price References

Tantalum in all raw materials is priced in US\$ per pound of contained Ta<sub>2</sub>O<sub>5</sub>.

Tantalites are differentiable products (ie. each concentrate is unique in chemistry and mineralogy) and therefore there is no terminal market, as for commodities. Pricing is therefore reached by negotiation between buyers and sellers.

Two types of pricing exist: spot market pricing in which traders are active, and long term contract pricing, which pertains to the majority of direct sales between primary producers (miners and tin smelters) and processors (who extract tantalum and niobium via hydrofluoric acid leaching followed by solvent extraction).

Processors are located in the USA, Germany, Austria, Thailand, Brazil, CIS, China and Japan.

- Two sources of published indicator prices exist:
  - Metal Bulletin
  - Metals Week.

Both publish "editorial" indicator prices, ie. the editors periodically contact industry participants to gauge the prices at which transactions are made. The *Metal Bulletin* has a worldwide scope, and takes into consideration both spot and long term prices. The specification for their quote is "25-40% Ta<sub>2</sub>O<sub>5</sub> basis 30% Ta<sub>2</sub>O<sub>5</sub> CIF; max 0.5% U<sub>3</sub>O<sub>8</sub> + ThO<sub>2</sub>". This means that the quote reflects typical tantalites (25-40% Ta<sub>2</sub>O<sub>5</sub> content) but is benchmarked for a 30% Ta<sub>2</sub>O<sub>5</sub> concentrate. It is based on CIF European port, with U<sub>3</sub>O<sub>8</sub> + ThO<sub>2</sub> at maximum of 0.5%. By industry convention, this quote is also based on 60% Ta<sub>2</sub>O<sub>5</sub> + Nb<sub>2</sub>O<sub>5</sub>.

*Metals Week* tends to have a USA-focus and reflects spot prices in that market, and is less frequently referred to by the international industry.

## Revenue Calculations

Typical steps are:

- Lookup the *Metal Bulletin* ("MB") price range (eg. US\$3034/lb Ta<sub>2</sub>O<sub>5</sub> CIF). The low to mid-point of the range tends to reflect 60% Ta<sub>2</sub>O<sub>5</sub> + Nb<sub>2</sub>O<sub>5</sub> clean concentrates. The high end reflects very high grade (eg. 75% Ta<sub>2</sub>O<sub>5</sub> + Nb<sub>2</sub>O<sub>5</sub>) concentrates.
- Adjust the MB price according to the C.O. (Ta<sub>2</sub>O<sub>5</sub> + Nb<sub>2</sub>O<sub>5</sub>) content of the concentrate at a rate of US\$0.20 per 1 % C.O. above and below 60% C.O. (This is an indicative adjustment rate only; it is subject to negotiation).
- Deduct from the adjusted price any expected penalties for high U<sub>3</sub>O<sub>8</sub> + Ta<sub>2</sub>O<sub>5</sub> or high Sb. Different processors will have different thresholds for these impurities. Penalties could be up to US\$3.00/lb of contained Ta<sub>2</sub>O<sub>5</sub>, and are determined by negotiation.

## Example

Assume a 10 tonne parcel of gravity concentrate has the following analysis:

- 30% Ta<sub>2</sub>O<sub>5</sub>
- 25% Nb<sub>2</sub>O<sub>5</sub>
- 0.3% U<sub>3</sub>O<sub>8</sub> + ThO<sub>2</sub>
- 100 ppm Sb

- a) MB price: say US\$30-34/lb Ta<sub>2</sub>O<sub>5</sub>
- b) Deduct US\$1.00/lb (ie. US\$0.20/lb per 1% C.O. below 60% C.O.) from the mid-point of the MB range i.e. \$32-\$1 = US\$31/lb CIF.
- c) Impurities are well below limits, therefore there is no penalty.
- d) Hence, NSR = 10,000 kg x 0.30 x 2.204 x \$31.00 = US\$204,972 CIF
- e) Allow for ocean freight to Europe (for example), insurance, weighing, sampling and assay, and freight forwarding: in total typically A\$4,000-A\$8,000 (1992) for a 10 tonne lot.

## Packaging and Transportation

Tantalites should be packed in lock-top steel drums, without liners and strapped to pallets.

Shipments to overseas markets are made in standard ocean containers.

## Tin

by P. J. Lewis with assistance from Renison Goldfields Consolidated Ltd., Sydney, NSW and Hatch Associates Ltd., Hull, England.

## Smelter Terms and Charges

Tin smelter terms, by comparison with other base metals, are highly complex and the payment received by the mine is dependent on many factors, some of which include:

- the grade of concentrate produced;
- the tonnage;
- the smelter with which terms are being negotiated.

It cannot be stressed too highly, that due to the above factors every tin smelting contract is different.

The percentage of actual tin in concentrate paid for by the smelter after all deductions and charges are made can vary between about 95% for 70% Sn concentrate, down to 80 to 85% for 35% Sn concentrate.

All tin smelter terms can be represented by the following general formula, but many smelters omit one or more of the factors:

$$[M - (D + d[M_B - M] + y[P_B - P] + x)] \cdot [P - (r \pm e)] - [(T \pm e) + t(M_B - M)] = \text{NSR}$$

where:

- M is the actual concentrate assay;
- M<sub>B</sub> is the base concentrate assay;
- D is the base unit deduction;
- d is the variable unit deduction based on concentrate assay;
- y is the variable unit deduction based on metal price;
- x is the unit deduction based on specific penalty elements;
- (D + d[M<sub>B</sub> - M] + y[P<sub>B</sub> - P] + x) = total unit deduction = D<sub>T</sub>;
- M - D<sub>T</sub> = payable metal content = M<sub>E</sub>;
- P<sub>B</sub> is the base metal price;
- P is the actual metal price;
- r is the refining charge or price deduction;
- [P - (r ± e)] = effective metal price = P<sub>E</sub>;
- T is the base treatment charge;
- t is the variable treatment charge;
- e is the escalation factor;
- NSR is the net smelter return or the actual payment made by the smelter to the mine per tonne concentrate.

## Base Concentrate Assay (M<sub>B</sub>)

Tin concentrates in the range 30 -75% Sn are commercially produced and sold. This represents a much wider range of concentrate grades than for any of the other base metals but most major smelters are capable of accepting concentrates over the whole of this range.

Despite this, all tin smelter terms are tailored to the grade of concentrate and, as indicated in the above formula, the unit deduction and treatment charge are normally based on a specified base concentrate assay (M<sub>B</sub>) and decrease and increase as the actual assay varies above and below this base assay.

With few exceptions the same base assay is applied to both the unit deduction and treatment charge variations.

Normal values of M<sub>B</sub> are:

- 70 to 75% Sn for high-grade concentrates;
- 50 to 60% Sn for medium-grade concentrates;
- 30% Sn for low-grade concentrates.

In some cases only the unit deduction or treatment charge are varied with grade, but not both.

## Unit Deduction (D<sub>T</sub>)

The payable metal content is obtained by deducting one or all of the following from the actual assay:

- the base unit deduction (D);
- the variable unit deduction based on concentrate assay (d);
- the variable deduction based on metal price (y);
- deductions based on specific penalty elements (x).

Because the values of D, d, Y and M<sub>B</sub> differ from smelter to smelter, the total unit deductions that may be applied to any specific grade of concentrate can vary considerably. However, those terms with the highest unit deductions have the lowest treatment charges and vice versa. Most base unit deductions lie in the range 1.5% to 2.5%.

Where the actual concentrate assay ( $M$ ) is above the base concentrate assay ( $M_B$ ), the effect of the variable unit deduction ( $d$ ) is to reduce the total unit deduction ( $D_T$ ). For this reason, a minimum value for  $D_T$  may be specified.

### Refining Charge or Price Deduction ( $r$ )

Normally, 100% of the price is applied, but in a few cases either a straight monetary deduction from the price is made or a refining charge, expressed in units of currency per kilogram of payable tin, is deducted.

### Treatment Charge

The treatment charge is made up of the basic treatment charge ( $f$ ) and, in most cases, a variable treatment charge ( $t$ ) related to concentrate grade. Both components are expressed in units of currency per tonne of concentrate. 1992 treatment charges were about A\$350 per tonne concentrate (including an energy surcharge, if applicable), but were highly dependent on concentrate grade and contract tonnage.

### Escalation

Escalation is either fixed for a specific period or cost-indexed. The same escalation factor is used for both the treatment charge and any price deduction that may be applied.

### Penalties

When in excess of specified tolerance levels, penalties for undesirable elements are applied in two ways: either a charge is made per unit present or, usually for iron and wolfram only, an additional deduction is made from the tin content. In the latter case the deductions are normally made before calculating the variable unit deduction ( $d$ ), but not necessarily so.

Typically, 10% of the iron content above 2 to 2.5% Fe and about 25% of the wolfram content above 2.5 to 5%  $WO_3$  are deducted from the tin assay.

Of the other elements, those shown in Table 16.19 are most frequently penalised.

In all cases the penalty is calculated pro-rata to the actual percentage above the tolerance level. Other elements which may be penalised are fluorine, cobalt, nickel and cadmium.

Penalty charges vary considerably between smelters and depend on the environmental guidelines under which they are operating and the grade of concentrate being sold.

### Credits

Unlike other base metals, credit payments for other elements in tin concentrates are not made.

### Tin Price

The London Metal Exchange (LME) is recognised as the international medium for setting prices for tin, and the LME price is normally used. However, some contracts can be based on the Kuala Lumpur Tin Market (KTLM) tin price. The KLTM price is available via AAP Reuters either electronically or over the telephone. The Australian dollar price equivalent is published in the *Financial Review* and the *Daily Commercial News*. The LME price is published in the *Financial Review*.

The KL TM is a bid and sell market. The bids are assembled at the market by 10.00 a.m. each morning from the purchasers of tin metal, in descending order in terms of price and quantity, and then compared against the tin metal that is available for sale. The market price is then determined by what quantity can be absorbed. Contracts are then issued to the successful parties and these contracts provide for delivery of tin metal "Ex-Smelter" normally within 60 days, which allows for the receipt of concentrates and their conversion into metal.

### Smelters

Australian tin concentrates are normally sold to smelters in S.E. Asia.

The world's tin smelters are shown in Table 16.20. Some of the smaller smelters listed only treat concentrates produced at their own mines.

Element	Typical Tolerance Level (%)	Typical Penalty per 1% Above Tolerance Level (A\$ per tonne concentrate)
Lead	0.01 to 0.02	100 to 275
Antimony	0.01 to 0.02	100 to 275
Bismuth	0.01 to 0.02	100 to 275
Copper	0.02	100 to 175
Zinc	0.02	100 to 175
Arsenic	0.01 to 0.05	150 to 175
Sulphur	1.0	5 to 6

Table 16.19 -Tin Concentrate Penalty Elements

Country	Company	Production (tpa tin metal)	Average Concentrate Grade (% Sn)
Argentina	Estansa	400	40 -45
Australia	Greenbushes	1,200	N/A
Belgium	Metallo-Chimique	3,000	20 -50
Bolivia	Empresa Metalurgica de Vinto	14,500	N/A
	Fundicion de Estano	5,000	N/A
	Fundicion Hormet	1,000	N/A
Brazil	Corumbatai	4,800	N/A
	Cia Estanifera do Brasil	6,000	60
	SNA	5,000	N/A
	SNC	600	N/A
	Best Metais e Soldas	6,000	55
	Mequimbras #	1,500 to 2,000	N/A
	Bera do Brasil	4,800	66
	Cia Industrial Fluminense	2,400	41
	Parapanema	20,000	N/A
	Burma	Myanma Oil Corp.	1,000
China	State Tin Corps at:		
	Guangxi	6 to 12,000	40-45
	Hunan	100	40-45
	Jiongxi	100	40-45
	Yunnan	10,000	40-45
Hong Kong	Mainland Metals	7,200	55-60
Indonesia	PEL	30,000	72
Korea Rep.	TIM	3,000	40 -70
	Kimetal	1,500	72
Malaysia	Korea Mining & 1)melting	25,000	64
	Datuk Keramat Malaysia	26,000	71
Mexico	Smelting Corp. Metales Potosi	6,400	N/A
	S.A. Estano Electro Fundidora	6,000	N/A
	de Estano	1,200	N/A
Nigeria	Makeri Smelting Co. # Societe	N/A	73
Rwanda South	Miniere du Rwanda	2,000	N/A
Africa	ISCOR #	1,000	66
	Rooiberg Tin Zaaipplaats Tin	2,000	58
	Mining	500	N/A
Spain	Estanos de Zamora S.A.	4,000	N/A
	Metalurgica del Noroeste	7,000	N/A
Thailand	Thaisarco	14,000	73
	Thai Pioneer Enterprise	6,000	N/A
USSR (former)	State Tin Enterprise	30,000	N/A
Zimbabwe	Kamativi Tin Mines	2,100	63

N/A = Not available

# = Temporarily closed or operating at low levels in mid-1993

Production rates fluctuate; those shown are approximate only.

**Table 16.20** - Location of Tin Smelters (1993)

## Tungsten

by R.F. Scotford

An indication of the value of a tungsten concentrate can be obtained from prices published regularly in the *Metal Bulletin*. Prices are expressed CIF Europe per metric tonne unit (mtu) of WO<sub>3</sub> content.

As at April I, 1991, the *Metal Bulletin* specification for wolframite ore was as follows:

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 *Metal Bulletin* ceased publication of a scheelite quotation (minimum 70% WO<sub>3</sub>) in April 1992 due to the low volume of scheelite traded relative to that of wolfram ore. A combined price for wolfram and scheelite is currently published.

By way of example, the value of a tonne of tungsten concentrate containing 70% WO<sub>3</sub> is calculated as follows:

Number of mtu's per tonne of concentrate	= 70
European selling price per mtu	= US\$60
Hence, value = US\$60 x 70	= US\$4,200

China has dominated trade in tungsten concentrates over the past ten years, resulting in a continual decline in Western world tungsten concentrate production and the closure of most Western world mines.

China has also increased production and sale of up-graded and intermediate tungsten products such as ferrotungsten and ammonium paratungstate (APT). These products from China have been often sold at prices close to or even below the equivalent price of tungsten concentrates. This has resulted in the closure of almost the entire Western world capacity for ferrotungsten production and the closure of most non-Chinese APT plants.

## Uranium

by W. Davies

Uranium concentrates of Australian origin can only be exported to utilities operating nuclear power plants in those countries with which the Australian Government has entered into a bi-lateral nuclear safeguards agreement to ensure strict adherence to the Nuclear Non-Proliferation Treaty and maintenance of global security.

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

Australian Government approval of the commercial terms before the contract can come into force and (ii) shipments only being

made in accordance with bi-lateral safeguards agreements. These are administered by the Australian Safeguards Office in conjunction with the nominated government safeguards authority in each customer country. To ensure safe transport, concentrates are packed in 210 litre drums and shipped in lots in standard shipping containers. Transport and handling must conform to the international standards for low level radioactive material.

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

There are several intermediate process steps between the production of yellowcake and the fabrication of fuel assemblies for power reactors. In simple terms, these comprise:

- refining yellowcake (tr uranium oxide, U<sub>3</sub>O<sub>8</sub>) to nuclear grade uranium-trioxide (UO<sub>3</sub>);
- conversion of uranium trioxide to uranium hexafluoride (UF<sub>6</sub>);
- enrichment of uranium hexafluoride from the natural level of about 0.7 % U-235 to 0.3-4.0% U-235, the enrichment level used in nuclear fuel.

Suppliers are charged a penalty if the uranium concentrates supplied do not conform to the specifications required by uranium converters (refer to the typical specifications in Table 16.21) after being weighed, sampled and assayed at the supplier's cost. Thus quality merit/demerits do not constitute a marketing tool. The cost of conversion, enrichment and the manufacture of fuel rods are paid for by the buyer.

Uranium concentrates have been traditionally sold under medium to long term contracts (3-10 years) to utility customers in accordance with the international safeguards regime. Of late, intermediaries such as brokers and traders have taken a higher profile in the uranium market (particularly in the USA) with the market share for spot purchased material rising to as much as 30% of the total volume of uranium concentrate consumed annually in the Western world.

Prices under long term contracts are either negotiated annually or are based on formulae made up of a basket of long term and spot price indicators. Spot prices are published monthly by two established trading organisations, Nuexco of the USA and Nukem of Germany.

Long term price indicators are typically either:

- the price published annually by the Euratom Supply Agency, which is an organisation within the European Atomic Energy Community, this being the weighted average price for all deliveries of uranium concentrates made to members of the European community under medium and long term contracts for the preceding year; and/or
- the price published by the United States Department of Energy, this being the weighted average contract price for foreign uranium concentrates purchased by USA utilities for the preceding year.

In recent years the pricing provisions under contracts with USA utilities in particular have been based on the spot price with movements in that price constrained by floor and ceiling price provisions.

Commercial matters such as prevailing market prices, usual delivery terms and payment are, as for other minerals, well known among industry participants and are also reported on by trade journals involved in the nuclear fuel cycle (eg. Nuexco and Nukem monthly reports, *Nuclear Fuel*, and *UX Report*).



	“Standard Concentrates”	“Maximum Limit Concentrates”	Surcharge Schedule (\$/lb U)
Uranium (U)	75.00%	65.00% min.	None
Vanadium (V2O5)	0.10%	0.75% max.	Reject
Phosphorus (PO 4)	0.10%	1.00% max.	None
Halides (Cl,Br,s,l)	0.05%	0.10% max.	None
Fluorine (F)	0.01 %	0.10% max.	None
Molybdenum (Mo)	0.10%	0.30% max.	
Sulphur (S04)	3.00%	12.00% max.	\$0.01
Iron (Fe)	0.15%	1.00% max.	None
Arsenic (As)	0.01 %	0.04% max.	None
Carbonate (CO3)	0.20%	0.50% max.	None
Calcium (Ca)	0.05%	1.00% max,	None
Sodium (Na)	0.50%	7.50% max.	Reject
Boron (B)	0.005%	0.10% max.	None
Potassium (K)	0.20%	3.00% max.	Reject
Titanium (Ti)	0.01 %	0.05% max,	None
Zirconium (Zr)	0.01 %	0.50% max.	None
Silica (SiO2)	0.50%	2.50% max.	\$0.02
Magnesium (Mg)	0.02%	0.50% max.	None
Water (H2O)	2.00%	5.00% max.	None

**Table 16.21** -Typical Uranium Concentrate Specifications

### UF<sub>6</sub> Conversion Surcharges

The uranium concentrate specifications and surcharges in Table 16.21 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,

### Zinc

by P.C. Wilson and C. Chanroux

#### The Market

The main market for zinc concentrates is the world's custom zinc smelters. Integrated smelters may also make some custom purchases.

In turn, zinc smelters sell zinc metal to fabricators, galvanisers and other users. Hence demand for zinc concentrates is a derived demand based on demand for zinc metal and zinc smelting capacity and utilisation.

#### Smelter Technology

Zinc concentrates are processed into zinc metal and other by-products by two predominant technologies: (i) the electrolytic

process (roast - acid leach - electrowinning from sulphide solution); and, (ii) the Imperial Smelting Process (ISP smelters) which treats mixed lead/zinc concentrates.

#### Concentrate Quality

Due to the high purity requirements for the electrolyte in the electrolytic process, only high grade concentrates (Zn >50%) with combined Cu+Pb<3% are acceptable. Other elements such as antimony, arsenic, chlorine, cobalt, fluorine, nickel, selenium, tellurium and tin can be deleterious to electrolysis, even in trace amounts in the electrolyte, and may therefore attract significant penalties or outright rejection of concentrates by the smelter.

While ISP smelters can accept clean high grade concentrates, they require a certain proportion of lead in their feedstock and can recover copper and other payable metals. ISP smelters therefore usually purchase bulk zinc-lead concentrates. Penalties and rejection may be imposed if the arsenic, antimony or tin contents are too high.

#### Pricing Quick Estimate

Historically, the Net Smelter Return has usually been 40%-60% of the value of the total zinc metal contained in the concentrate. This excludes concentrates with unusually high precious metals or penalty element payments.

## Detailed Estimate

For a more detailed estimate, each component of the smelter terms should be calculated. The structure of zinc smelter terms is described below and worked examples are given in the section "Examples of Revenue Calculations".

### Payable Metals

Typical payments for metals contained in zinc concentrates are shown in Table 16.22. Payments for gold are not normally made.

### Treatment Charge

A treatment charge (TC), expressed as a fixed deduction per tonne concentrate, is applied. This includes the cost of refining the zinc. A price participation (pp), as discussed in the section "Price Participation", is also included.

For high grade concentrates (>54%Zn), the TC (including price participation) can be roughly estimated by correlation to the zinc price using the following formula (Vogel and Grey, 1990):

$$TC = \text{zinc price} \times 17.5\%$$

Variation from this average should be confirmed using reports from the *Metal Bulletin*.

TC's for ISP smelters normally attract additional treatment charges of around US\$15-US\$35 per dmt concentrate.

### Price Participation (pp)

The price participation mechanism increases the TC as the price increases above, and reduces the TC as the price decreases below, an agreed base price. The escalators and base price are negotiable. Typical current pp terms are:

- Base zinc metal price of US\$1250/tonne zinc.
- For every US\$1.00 above US\$1250, increase TC by US\$0.12/dmt concentrate.
- For every US\$1.00 below US\$1250, decrease TC by US\$0.07/dmt concentrate.

### Refining Charges for Precious Metals

A refining charge may be imposed for silver. Typically this is US\$ 30-35 per oz payable silver.

### Penalties

Penalties are imposed for undesirable elements that increase the smelter's costs. Typical penalty elements and formulae are shown in Table 16.23.

Some concentrates may be rejected by smelters because they contain a high level of a penalty element. There are no standard 'rejection limits' for the penalty elements as any concentrate is potentially saleable depending on its quantity and the availability of other more favourable concentrates. Clearly, 'dirtier' concentrates can only be sold for lower returns than cleaner concentrates or at times when cleaner concentrates are in short supply.

## Examples of Revenue Calculations

Worked examples of NSR calculations in US\$ for an electrolytic smelter and an ISP smelter are shown below.

### Example 1

Electrolytic Smelter; High Grade Concentrate

Concentrate Specifications:

Zn	55.0%
Ag	160g/t
Cd	0.15%
As	0.4%
Hg	40ppm
Fe	9.0%

Element	Payable Metal Content	Negotiable Range
Zinc	Pay for 85% of the zinc content subject to a minimum deduction of 8 units Pay	Industry standard
Silver	for 70% of the silver content after deducting 3 oz	Deduction: 3 -5 oz Pay for: 60% -80/0
Cadmium	Pay for 70/0 of the cadmium content less a refining charge of US\$2.00-2.50 per lb payable cadmium. This calculation may yield a negative value, ie. cadmium may be penalised.	
ISP smelters use the formulae shown above except that the minimum deduction for zinc is 7 units. For the additional metals they are able to recover, the following formulae are typical:		
Lead	Pay for 95% of the lead content subject to a minimum deduction of 3 units	
Copper	Pay for 25% of the copper after deducting 1.5 units	Deduction: 1.5 -2.0 units
Gold	Pay for 70% of the gold content after deducting 1g/dmt	Deduction: 1 -2 g/dmt Pay for: 60% -80%

**Table 16.22** - Payable Metals in Zinc Concentrates

Penalty Element	Typical Formula (US\$ per tonne concentrate)	Negotiable Range
Arsenic	\$1.50 per 0.1% > 0.2%	Threshold: 0.1% -0.3% Penalty: \$1.50 -\$2.50 per 0.1 %
Magnesia	\$1.50 per 0.1% > 0.3%	Threshold: 0.20% -0.50% Penalty: \$1.50 -\$2.50 per 0.1%
Mercury	\$1.00 per 10 ppm > 20 ppm. Alternatively a flat penalty, if above 150 ppm, of US\$15-20 per dmt	Threshold: 20 -30 ppm
Iron	\$1.50 per 1% > 8%	Threshold: 8% -10% Penalty: \$1.50 -\$2.50 per 1 %
Manganese	\$1.50 per 0.1% > 0.5%	Threshold: 0.5% -1.0% Penalty: \$1.00 -\$2.00 per 0.1 %
Silica	\$1.50 per 1% > 2.5%	Threshold: 2% -4% Penalty: \$1.50 -\$2.50 per 1 %

Other elements that may be penalised include nickel plus cobalt (if above 200 ppm combined), selenium (if above 0.01%), fluorine and chlorine. Penalty rates are negotiable.

**Table 16.23** -Typical Zinc Concentrates Penalty Payments

Metal Prices	Conversions	Refining Charges
Zn US\$1,100.00/tonne	31.1g = troy oz	Ag 2.14 [oz payable Ag/dmt] x 0.30 [US\$/oz] = Cd (\$0.64)
Ag US\$4.00/troy oz	2204.6 lb = tonne	2.315 [lb payable Cd] x 2.50 [\$/lb payable] = (\$5.79)
Au US\$380/troy oz		
Cd US\$1.30/lb		
<b>Terms</b>		<b>Penalties</b>
<ul style="list-style-type: none"> <li>Treatment charge = US\$194.00 per dmt concentrate;</li> <li>Payable metals as in preceding section "Payable Metals";</li> <li>Refining charges: <ul style="list-style-type: none"> <li>US\$0.30 per ounce payable silver;</li> <li>US\$2.50 per pound payable cadmium;</li> </ul> </li> <li>Price participation as in preceding section "Price Participation";</li> <li>Penalties as in preceding section "Penalties".</li> </ul>		As (0.4% -0.2%)/0.1% x \$1.50 (\$3.00) Hg (40 -20)/10 x \$1.00 (\$2.00) Fe (9.0% -8.0%)/1.0% x \$1.50 (\$1.50)
		<b>Total Deductions</b> = (\$196.43)
		<b>Net Smelter Return</b> = \$326.84

### NSR CALCULATION

Payable Metal	US\$/dmt
Zn (0.55 x 0.85 = 0.4675) or (0.55 -0.08 = 0.470) Therefore payable Zn content = 46.75% 0.4675[t payable Zn;dmt] x 1,100[US\$/tZn]	
Ag 160 [g/t]/31.1 [g/oz] -3 [oz] = 2.14oz payable = \$514.25	
Ag 2.14 [oz payable Ag ] x 4.00 [US\$/oz] x 0.7	
Cd (0.0015 x 0.7) x 2204.6[lb/tonne] = \$6.01	
= 2.315lb payable Cd	
2.315 [lb] x 1.30 [US\$/lb] = \$3.01	
<b>Total Payment for Metals</b>	= \$523.27
<b>Treatment Charge</b>	=( \$194.00)
<b>Price Participation</b> (US\$1250-US\$1100) x 0.07	= \$10.50

### Example 2

#### ISP Smelter; Zinc/Copper/Lead Bulk Concentrate

##### Concentrate Specifications:

Zn 40.0%	As 0.4%
Ag 160g/t	Hg 40 ppm
Cu 6.0%	Fe 9.0%
Pb 15.0%	

##### Metal Prices

Zn US\$1,100.00/tonne
Ag US\$4.00/troy oz
Cu £1,190/tonne
Pb US\$522/tonne

##### Conversions

31.1 g = troy oz
2204.6lb = tonne
US\$1.80 = £1.00 sterling

##### Terms

- Treatment charge = US\$219.00 per dmt concentrate;
- Payable metals as in preceding section "Payable Metals";
- Refining charge US\$0.20 per ounce payable silver;
- Price participation as in preceding section "Price Participation";
- Penalties as in preceding section "Penalties".

## NSR CALCULATION

### Payable Metals

US\$/dmt

Zn (0.40 x 0.85 = 0.340)  
 (0.40 - 0.07 = 0.330)  
 Therefore 33.0% payable Zn content  
 0.33 [t payable Zn/dmt conc] x 1,100 [US\$/t Zn] = \$363.00  
 Ag 160 [g/t]/31.1 [g/oz] -3 [oz] = 2.14oz payable Ag  
 2.14 [oz payable Ag ] x 4.00 [US\$/oz] x 0.7 = \$6.01  
 Cu (0.06-0.015) x 0.25 x 1,190 [£/t] x 1.80 [US\$/£] = \$24.10  
 Pb (0.15 x 0.95 = 0.143)  
 (0.15 - 0.03 = 0.120)  
 Therefore 12% payable Pb content  
 0.12 [t payable Pb/dmt conc] x 522 [US\$/tPb] = \$62.64

**Total Payment for Metals = \$455.75**

**Treatment Charge = (\$219.00)**

**Price Participation (US\$1250 -US\$ 1100) x 0.07 = \$10.50**

### Refining Charge

Ag 2.14 [oz payable Ag/dmt] x 0.30 [US\$/oz] = (\$0.64)

### Penalties

As (0.4% -0.2%)/0.1% x \$1.50 (\$3.00)  
 Hg (40 -20)/10 x \$1.00 (\$2.00)  
 Fe (9.0% -8.0%)/1.0% x \$1.50 (\$1.50)

**Total Deductions = (\$215.64)**

**Net Smelter Return = \$240.11**

### Zinc Smelters

Comprehensive lists of zinc smelters can be obtained from the ILZSG (International Lead Zinc Study Group) or commodity research companies such as CRU International Ltd., Brook Hunt & Associates Ltd., Metals Minerals Research Services and Metal Bulletin Research, who are all based in England. Table 16.24 shows 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 a variety of other geographic regions, usually incurring higher freight costs. The main alternative destination is Europe.

Country	Plant	Production Capacity 1993 ( '000tpa zinc metal)	Company
<b>Electrolytic</b>			
Australia	Risdon	220	Pasminco
	Port Pirie	40	Pasminco
Japan	Annaka	143	Toho Zinc
	Kamioka	63	Mitsui
	Hikoshima	84	Mitsui
	Akita Iijima	106	Mitsubishi
	Mikkaichi	156	Akita Zinc
		100	Nippon
Korea	On san	190	Korea Zinc
<b>ISF</b>			
Australia	Cockle Creek	81	Pasminco
Japan	Harima	85	Sumiko ISP
	Hachinohe	101	Hachinohe Smelting

**Table 16.24** - Major Zinc Smelters in the Asia Pacific Region

## References

- Anon, 1991. *Australian Heavy Minerals Industry*, Vol.21, No.8, Australian Mining Weekly
- Anon, 1997. Background and Overview – Investment Strategies in the Mineral Sands Industry, Australian Mineral Economics Pty Ltd, Chapter 1
- Court, K., 1986. *Value Added in the Mineral Sands Industry*, Australia: A World Source of Ilmenite, Rutile, Monazite and Zircon Conference, The Australasian Institute of Mining and Metallurgy, Perth, Australia.
- Hayes, W.B., 1986. *Titanium Minerals -Marketing Factors from a Users Viewpoint*, Australia: A World Source of Ilmenite, Rutile, Monazite and Zircon Conference, The Australasian Institute of Mining and Metallurgy, Perth, Australia.
- Grulleman, W., 1990. *Zircon: Supply and Demand in the 1990's*, 9th Industrial Minerals International Congress, Sydney, Australia.
- *GWC Coal Handbook* 1991, George Waterhouse Consultants, Tallington, Lincolnshire, U.K.
- Lee, H.Y., 1986. *Role of Titanium Slags and Upgraded Ilmenite on TiO<sub>2</sub> Feedstock Supply and Demand*, Australia: A World source of Ilmenite, Rutile, Monazite and Zircon Conference, The Australasian Institute of Mining and Metallurgy, Perth, Australia.
- Lewis, P.I and Streets, C.G., 1978. *An analysis of base-metal smelter terms*, Proceedings of the Eleventh Commonwealth Mining and Metallurgical Conference, Hong Kong, Institution of Mining and Metallurgy, London.
- Vogel, A. and Grey, C.A., June 1990. *Lead and zinc smelting charges*, Mining Industry Capital and Operating Cost Estimation Conference, The Australasian Institute of Mining and Metallurgy, Sydney Branch.