# 1.0 INTRODUCTION

In 1779, Peter Woulfe examined the mineral now known as wolframite and concluded it must contain a new substance. Scheele, in 1781, found that a new acid could be made from tungsten (a name first applied around 1758 to a mineral now known as scheelite). Scheele and Berman suggested the possibility of obtaining a new metal by reducing this acid. The de Elhuyar brothers found acid in wolframite in 1783 that was identical to the acid of tungsten (tungsten acid) of scheelite, and in that year they succeeded in obtaining the element by reduction of this acid with charcoal. The metal is obtained commercially by reducing tungsten oxide with hydrogen or carbon.

Pure tungsten is a steel-grey to tin-white metal. Very pure tungsten can be cut with a hacksaw, forged, spun, drawn, and extruded. The impure metal is brittle and can only be worked with difficulty.

Tungsten is a most distinctive metal. Its properties include:-

- Hardest of all metals
  - Over 3 times harder than chromium, cobalt, titanium
  - Over 5 times harder than nickel, iron, platinum

- Strongest of all metals
  - Way ahead of the pack

- Highest melting temperature of all metals (2$^{nd}$ highest of all elements)
- Extremely heavy
- Moderate electrical conductivity
- Displays high resistance to corrosion
- Environmentally friendly

Notwithstanding these outstanding qualities, the high cost of fabrication has limited tungsten's commercial use to areas in which its properties are considered essential. These include:

- Metal-Cutting tools
- Light Bulb Filaments
- High Temperature Alloys (aircraft manufacture etc)
- Military Uses (armour plating, and armour piercing projectiles)
- Chemical applications
- Electronic contacts

Most applications for tungsten are relatively mature and therefore growth in consumption will primarily be related to regional economic growth. However, some product growth will occur in the following sectors:

- The US military has recently approved the use of tungsten as a replacement for lead core bullets.
- Expanded super alloy milling capacity has provided new product potential for tungsten and tungsten alloys.
- Rapid expansion of the tooling industry in China and other parts of Asia.

Tungsten prices tend to be quoted in either metric tonne units $WO_3$, which is the equivalent of 1 per cent of a ton. This is therefore the equivalent of 20 pounds of $WO_3$ in the case of short ton units, which contains 15.86 pounds of tungsten content, or of 10

kilograms of $WO_3$ in the case of metric tonne units, which would contain 7.93 kilograms of tungsten content.

# 2.0 WORLD TUNGSTEN RESOURCES

The primary source of all tungsten is either scheelite or wolframite. As the majority of operating production is recorded from dedicated tungsten mines, the content of $WO_3$ in each ore body is the main determining factor in achieving economic levels of production. Even in low-income economies such as China, which enjoys some advantages in terms of labour costs, this rule remains firm, and will influence future supply programs.

## 2.1 Mining and Concentrates

Most tungsten ores contain less than 1.5 per cent $WO_3$ and ore dressing plants are always in close proximity to the mine in order to minimise transport costs.

The ore is initially crushed and at this stage some handpicking or optical sorting usually takes place to upgrade the ore to be processed.

It is then milled to liberate the tungsten mineral crystals. Scheelite ore is normally concentrated by gravimetric methods combined with flotation, while wolframite ore can be concentrated by gravity often in combination with magnetic separation. The concentrate usually contains approximately 65-70 per cent $WO_3$.

## 2.2 Processing

Most tungsten concentrates are then processed chemically to produce ammonium paratungstate (APT). Secondary raw materials like (oxidised) scrap and residues are another important feed for chemical tungsten processing.

## 2.3 Reserves and Production

Current world reserves and primary production of tungsten as assessed by the US Geological Survey are detailed in Table 1.

**Table 1- World Mine Production, Reserves and Reserve Base**

| | Mine Production | | Reserves[1] | Reserve Base[2] |
|---|---|---|---|---|
| | 2003 | 2004 | | |
| **United States** | - | - | 140,000 | 200,000 |
| **Austria** | 1,400 | 1,400 | 10,000 | 15,000 |
| **Bolivia** | 442 | 450 | 53,000 | 100,000 |
| **Canada** | 2,750 | - | 260,000 | 490,000 |
| **China** | 52,000 | 53,000 | 1,800,000 | 4,200,000 |
| **Korea North** | 600 | 600 | NA | 35,000 |
| **Portugal** | 700 | 700 | 25,000 | 25,000 |
| **Russia** | 3,900 | 3,500 | 250,000 | 420,000 |
| **Other Countries** | 290 | 300 | 360.000 | 700,000 |
| **World Total** Rounded | **62,100** | **60,000** | **2,900,000** | **6,200,000** |

**1** - That part of the reserve base, which may be economically extracted or produced at the time of determination.

**2** – The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated.

**Source: USGS January 2005**

**Notes to support this table:**

1. The indicated production figures represent contained metric tonnes of $WO_3$.
2. Each 10 kilograms of $W0_3$ represents 7.93 kilograms of tungsten. Therefore production of primary tungsten units in 2004 was approximately 47,500 tonnes.
3. These regional production figures do not include tungsten units recovered from scrap.
4. Reserve figures in Table 1 encompass a wide range of mineral qualities and do not necessarily comply with the Australian JORC Code for definition of resources and reserves.

The key resource and producing countries are now reviewed in more detail.

### 2.3.1 China

China holds very significant reserves (both proven and probable) of tungsten. According to US Geological Survey Figures published in January 2005 (Table 1), proven reserves total 1,800,000 tonnes (contained $WO_3$) and a further 4,200,000 are classed as probable.

China is by far the world's largest producer of tungsten ore and tungsten primary products. Deposits are spread throughout China with Jiangxi (60 per cent), Hunan (20 per cent) and Yunnan (8 per cent) the largest producing areas.

It has been a major producer of tungsten concentrate for many decades, although its production level decreased from 57 per cent of world production in 1930 to only 19 per cent in 1970. This was then followed by significant up turns and production doubled in the late 1980's from 15,000 tonnes per annum to 30,000 tonnes per annum as China increased its drive to earn foreign currency. This trend continued through the 1990's exceeding 50,000 tonnes per annum by 2003, and a similar quantity in 2004.

However, despite strong domestic and international demand, there is now increasing evidence to suggest that further expansion opportunities in production of tungsten concentrates in China may be limited within current price structures. It is understood that many of the traditional mines have declining grades, which is not only limiting output, but also increasing the cost of production. Other known deposits in China are yet to be confirmed as economic within current price structures.

The net result is that the rapid increase in production is expected to be curtailed and availability of tungsten units to global markets may now start to decline during the next 5-10 years.

### 2.3.2 Russia

The former Soviet Union, the sole area with significant tungsten resources in Eastern Europe, accounts for approximately 12 per cent of world reserves.

The proportion of world average annual output of tungsten from Russia (USSR) was estimated to have increased from 7 per cent in the 1940's to 13 per cent in the 1950's and then stabilised between 19-20 per cent through 1960-1970.

Current concentrate production levels are estimated at 3,500 tonnes per annum.

### 2.3.3 Canada

The US Geological Survey shows Canada as having the largest reserves outside China including two of the world's top ten tungsten deposits in Mactung and Logtun both in the Yukon Territory.

North American Tungsten Corp. Ltd restarted tungsten production from the CanTung Mine in the Northwest Territories in 2002. (The mine had been on care and maintenance since closing in 1986 pending improved marketing conditions) However, in late 2003 the mine was again closed. The operation remains on care and maintenance with the possibility of a restart depending upon improved market conditions.

### 2.3.4 Austria

Austria has a long history of producing tungsten concentrates, however with very limited remaining reserves (both proven and probable), concentrate production levels are limited to approximately 1400 tonnes per annum. There is no expectation of this increasing in the future.

### 2.3.5 Australia

Since the closure of the King Island Scheelite mine in Tasmania in the early 1990's, there has been no production in Australia. The King Island mine was closed due to declining grades, increasing production costs and a rapid decline in market prices.

### 2.3.6 Vietnam

The Tiberon Nui Phao project in Vietnam appears to be the only other non-Chinese Greenfield project on the forward supply horizon, with potential production of between 4 and 6,000 tonnes per annum, with a targeted start-up date of 2008. However, contained $WO_3$ grades in the ore-body appear to be extremely low at 0.2 per cent and, despite credits from other metals such as gold and bismuth, the economics of this project still need to be confirmed.

### 2.3.5 Summary of Global Reserves and Production

In terms of both reserves and production, China is truly the dominant force in the industry and during 2004 was responsible for almost 90 per cent of global production. Russia and Austria are the only two other producing countries of any significance.

However reports from both government and industry sources in China are now consistently indicating that existing concentrate producers are struggling to match increasing demand and APT processors have been forced to curtail production due to concentrate shortages. It is understood that this inability to increase production is primarily due to declining grades in traditional mines and the failure to develop new mines. The government also maintains a strong control over the industry, primarily through the restriction of export licences.

Shortages of concentrates are forecast to become increasingly evident during the next few years, assuming global and Chinese domestic demand continues to increase at current rates. Some industry observers have suggested that if current trends for both Chinese production and consumption are maintained, it remains possible that China will become a net importer of tungsten within the next decade.

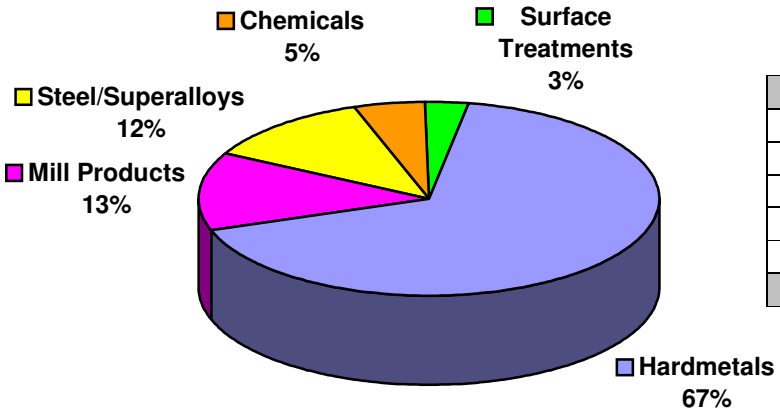
# 3.0 APPLICATIONS OF TUNGSTEN

Applications for tungsten are reasonably diverse, and spread across a number of basic industries including hard metals (essentially tungsten carbide), mill products (tungsten powder, wire), steel/superalloys, chemicals and surface treatments. These are briefly described as follows:

- **Hard Metals**
  - Inserts and tools; rods and drills; wear parts and dies; heavy-duty mining and construction.
- **Mill Products**
  - Welding, sports, medical, aerospace and electronic contacts; lighting; military
- **Steel and Special Alloys**
  - Tool steels; high speed steel; super alloys
- **Chemical**
  - Catalytic; pigments
- **Surface Treatments**
  - Surface treatment – high abrasion resistant surfaces; thermal sprays – extrusion dies, aircraft landing.

During 2004 global consumption of primary tungsten was estimated at approximately 52,000 tonnes and is broken down by industry in Figure 1:

**Figure 1 – 2004 Global Consumption of Primary Tungsten**




| | Tonnes | % |
|---|---|---|
| **Hard Metals** | 35,000 | 67 |
| **Mill Products** | 7,000 | 13 |
| **Steel/Superalloys** | 6,000 | 12 |
| **Chemicals** | 2,500 | 5 |
| **Surface Treatments** | 1,500 | 3 |
| **Total** (rounded) | **52,000** | **100** |

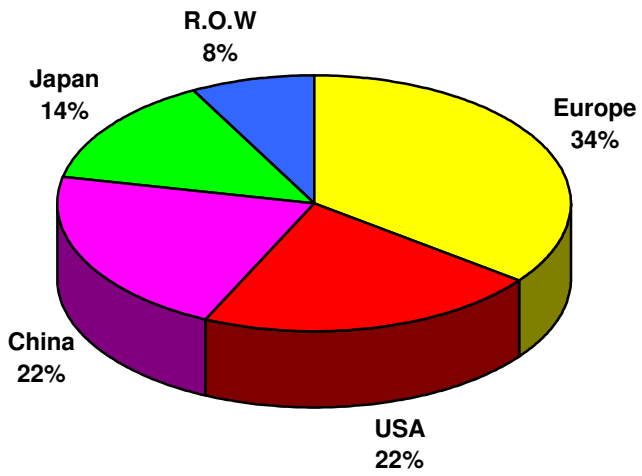
# 4.0 REGIONAL CONSUMPTION

Most tungsten applications are well established and consuming industries are considered mature. Therefore, growth in Europe, USA and Japan is forecast to be consistent with matching economic growth.

In China, economic growth remains projected at an average of around 9 per cent for at least the next five years. Tungsten usage is supported by rapidly expanding steel and construction industries, which are important consumers of tungsten.

The global and regional markets for tungsten products are detailed in Figure 2.:

**Figure 2 - 2004 Global Consumption by Region**




| | Tonnes | % |
|---|---|---|
| **Europe** | 18,360 | 34 |
| **USA** | 11,220 | 22 |
| **China** | 11,220 | 22 |
| **Japan** | 7,140 | 14 |
| **R.O.W** (mainly Asian countries such as Korea and Taiwan) | 4,080 | 8 |
| **Total** | **52,020** | **100** |

## 4.1 Recycling

Recycling is an important factor in the world's tungsten supply. It is estimated that some 30 per cent is recycled, and the tungsten processing industry is able to treat almost every kind of scrap and waste to recover tungsten.

# 5.0 MARKET STRUCTURE AND TRADE

## 5.1 Structure of Trade

On a global basis, tungsten products are traded in a number of forms including ore, concentrate, ferrotungsten, tungsten powders, ammonium paratungstate, tungsten carbide and tungsten oxide.

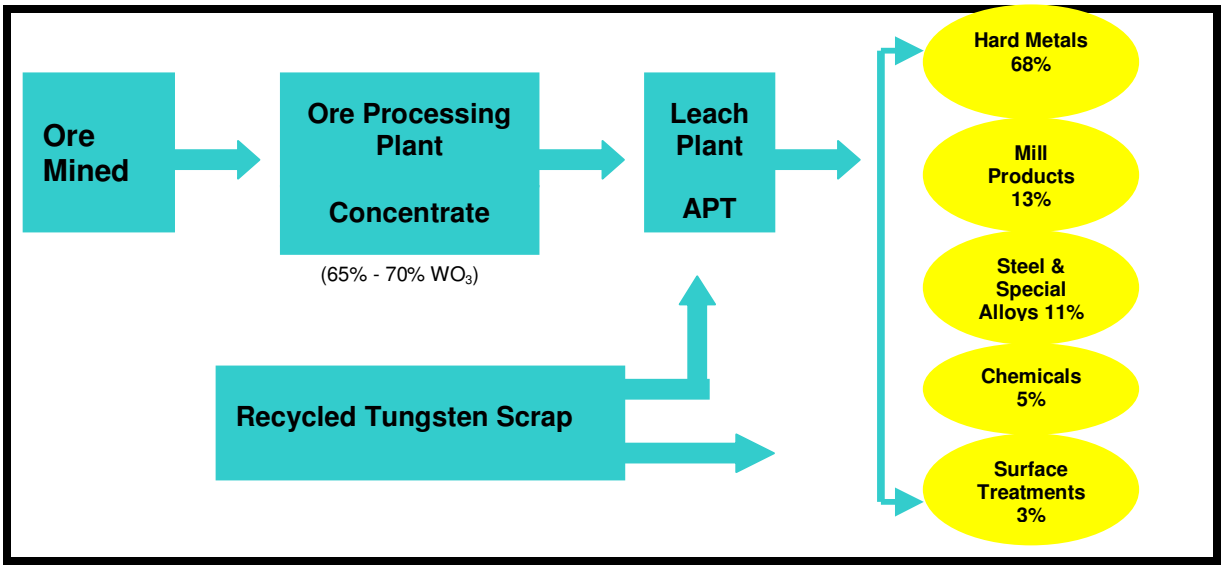
Historically, most producers of hard tools and associated products were centred primarily in North America, and to a lesser extent in Europe and Japan. Processors in these countries source concentrates or APT for further processing and conversion to end products. However, in more recent times, with the advent of China as the major raw material supply source, concentrate is now seldom exported from China, and tungsten is increasingly exported in the form of ferrotungsten, tungsten powders, ammonium paratungstate (APT), tungsten carbide and tungsten oxide.

However, as a direct result of the Chinese moving downstream, and with consistently better quality end products, plus an obvious advantage in sourcing base raw materials, the non-Chinese processors are becoming increasingly disadvantaged, and to the point that they are now urgently seeking alternative sources of competitive raw materials.

Ferrotungsten is mostly sold directly to the global steel industry, and again, this supply program is dominated by the Chinese. With a rapidly expanding domestic steel industry, an increasing percentage is sold domestically.

Figure 3 summarises the current supply chain for tungsten products.

Figure 3 - Supply Chain for Tungsten Products




## 5.2 Supply versus Demand

### 5.2.1 Recent History

In the early 1990's, the global structure of tungsten changed radically. With the cessation of the cold war, the Eastern Bloc countries moved from major importers to exporters. However, even more importantly, production in China increased dramatically as producers chased foreign currency. The net result was that price structures fell significantly and most non-Chinese raw material producers were driven from the industry.

During the 1990's and early 2000's, availability of tungsten in various forms consistently exceeded supply and by mid 2002 prices had fallen to below the cost of production, even for the Chinese producers.

Apart from consistent over-supply during the previous decade, the situation in 2002 was exacerbated by the following factors:

- Further increased and apparently uncontrolled production in China (including illegal mining.
- Confirmed re-start of the CanTung operation in Canada - since closed.
- Economic recession in the USA and Western Europe.

The net result was a further decline of prices with the price of APT falling from approximately US$90 per mtu to below US$55 per mtu by mid 2002. During the same period, the price of tungsten ore (65 per cent $WO_3$) fell from US$70 per mtu to an average of US$40 per mtu.

At this point, the Chinese Government started to recognise the seriousness of the situation, and the whole industry faced the risk of becoming sub-economic. Concurrently, grades in traditional mines were declining and operating costs were increasing rapidly.

Consequently, in late 2002 the following controls were introduced by the Chinese Government.

- Restricted export licences
- Removal of tax rebates for tungsten producers
- Closure of illegal mining operations
- Increased encouragement of downstream processing versus export of ores and base concentrates
- Removal of a 13 per cent export rebate tax.

The impact of these changes has now become evident, and, supported by a rapidly increasing Chinese domestic market, a very tight supply situation of both concentrates and APT now prevails.

### 5.2.2 Forecast Demand Trends

In reviewing forward consumption estimates, it is important to note that during the history of tungsten consumption, and even with the strong price variations over the past decade, global usage has been largely unaffected by price. In turn, it can be argued that the consumption of tungsten in most applications is not price elastic, and even the current strong price increase is unlikely to affect consumption patterns.

Most applications for tungsten can be considered mature, and therefore with the exception of several new minor applications such as tungsten bullets, growth in consumption will be more closely aligned with regional economic growth. On this basis, growth in the large western economies such as North America and Europe is expected to remain at approximately 2-3 per cent per annum. Conversely, in China and other parts of South East Asia, much higher economic growth is also rapidly increasing the demand for tungsten products, particularly for tool cutting, and also as additives to steel production. In the past few years, consumption of tungsten in China has increased by 9 per cent per annum, and this growth rate is expected to continue for the foreseeable future.

### 5.2.3 Forward Supply versus Demand

In summarising the forward supply and demand structure for tungsten over the next decade, it would not yet be appropriate to suggest there will be sustained periods of serious supply shortages. There will however be limited periods (as currently prevails) where market requirements will exceed immediate availability.

Supported by significant reserves in China, and to a lesser extent in Russia, Canada, Australia and possibly Vietnam, new mines are likely to be developed, albeit using lower grade deposits with significantly higher production costs. In turn, for the purposes of this report, we have assumed that the increasing demand as outlined in the following table will be matched by increased supply from new mining operations.

However, in making this assessment, the following points are paramount to the forward supply and demand structure.

- The new plateau of price structures will need to be confirmed for a sustained period to encourage new mining operations both within China and in other countries.

- The Chinese tungsten industry will continue to push downstream with finished products, and subsequently reduced quantities of raw materials will be available for export.
- In turn, western processors will not only continue to be squeezed for raw materials, but will also face increasing competition from end-product manufacturers in China.
- Having clearly recognised this situation for a number of years, major processors and tool manufacturers in North America and Europe will encourage alternative raw material supplies to China.

In summary, the forecast growth in demand for tungsten is likely to be matched with new sources of raw materials from 'Greenfield' operations in China, Russia, Australia and possibly Vietnam, but subject to appropriate economic operational performance.

Table 2 provides the expected supply and demand structure until 2005:

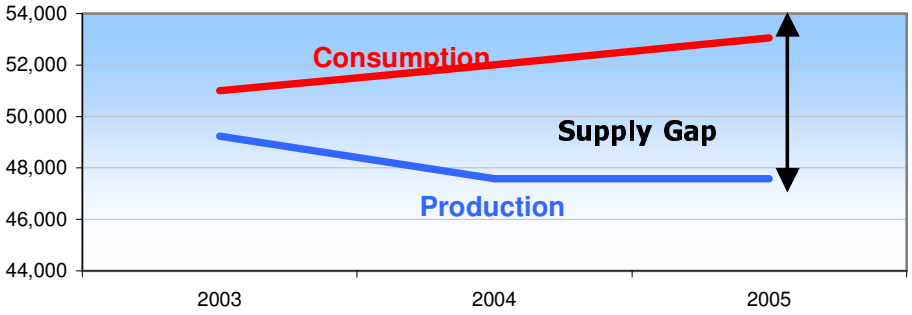
**Table 2 - Supply versus Demand – 2003 – 2005**

(Contained Tungsten)

| | Forecast Growth | 2003 | 2004 | 2005 |
|---|---|---|---|---|
| **Consumption** | | | | |
| **Europe** | 2% | 18,000 | 18,360 | 18,727 |
| **North America** | 2% | 11,000 | 11,220 | 11,444 |
| **China** | 9% | 11,000 | 11,220 | 11,444 |
| **Japan** | 1% | 7,000 | 7,140 | 7,283 |
| **R.O.W.** | 3% | 4,000 | 4,080 | 4,162 |
| **Total** | | **5,1000** | **52,020** | **53,060** |
| **Global Production** | | 49,245 | 47,580 | 47,580 |
| **Supply Gap** | | 1,755 | 4,440 | 5,480 |

In 2003 and 2004, shortfall in production was covered by both consumer and producers stocks; however shortages became evident at the end of 2004. New producers will be required to bridge the supply gap shown in Figure 4.

**Figure 4 - Supply Gap 2003 –2005**




**Source: GBRM**

# 6.0 TUNGSTEN PRICES

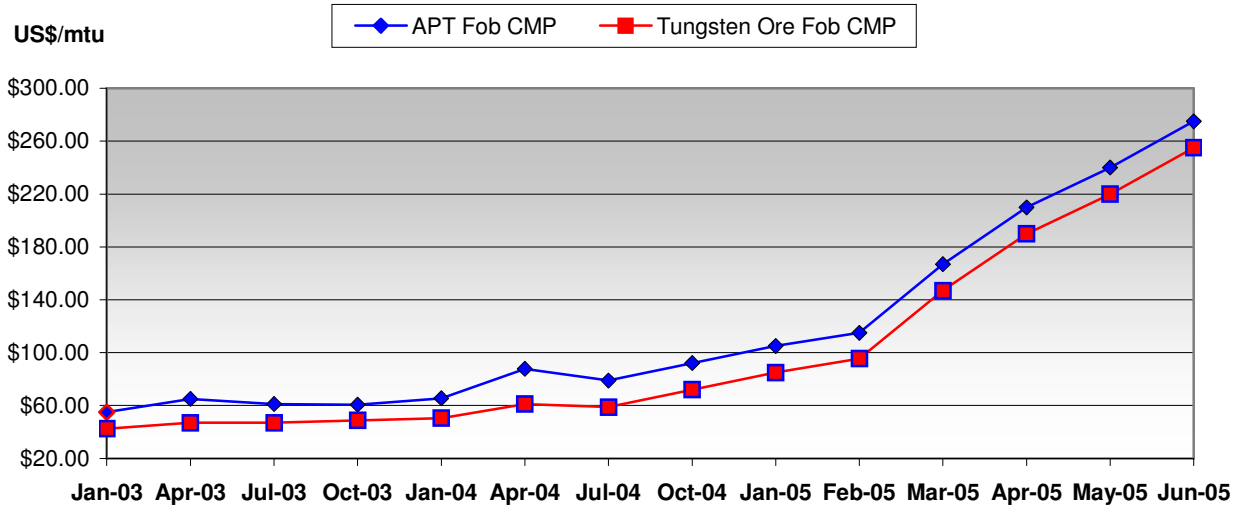
## 6.1 Historical and Current Price Structures

As shown in Figure 5, and for reasons outlined in other sections of this report, during 2002, tungsten prices fell to historically low levels (constant dollar basis), and to a point that was unsustainable even for the lowest cost producers in China.

Following the previously described changes to the management of the industry in China, and particularly through the introduction of strict export licences, since the beginning of 2003, there has been a consistent improvement in the price of all tungsten products, and particularly the key indicators of concentrates and APT.

Commencing in November 2004, and underpinned by real shortages of concentrates, market prices have started to increase even more rapidly. At the time of preparing this report, the market price for concentrate has reached $US255 per mtu ex plant China, and the price of APT had reached US$275 per mtu FOB. This means that since mid 2002, prices have effectively tripled. At least in the short-term, it remains possible they could move even higher, particularly if demand continues to outstrip supply for the balance of 2005.

**Figure 5 – Tungsten Prices – January 2003 – June 2005**




Source: Asian Metal

**Note**: Ore – tungsten concentrate ore 65 per cent $WO_3$
APT - ammonium paratungstate
All prices are quoted in mtu (metric tonne units)

## 6.2 Forward Price Structures

It must be clearly stated that Chinese production and the associated control of the Chinese Government will continue to be the major influence on global tungsten prices for at least the next decade.

However, the Chinese industry has already recognised the need for stable production programs and increased prices, not only to sustain existing operations which are suffering

from declining grades and increasing operating costs, but also to allow investment in future mining operations.

Clearly the reconstruction of the industry in China during 2002 and 2003 has achieved the necessary correction in price structures, and it is unlikely these new price structures will be eroded in the foreseeable future. This gap between concentrates and APT is likely to be maintained at approximately US$20 per mtu.

During the first half of 2005, the industry has witnessed a dramatic increase in prices and at least in the short-term, further increases are possible. However, most industry observers believe the tungsten market is now overvalued and some correction is probable. This correction is likely to come in the second half of 2005, however it remains extremely difficult to accurately forecast a new plateau for the medium and longer terms. Again, this will be strongly influenced by Chinese Government policy and their endeavours to preserve and extend existing mining operations in that country.

Additionally the USA Defense Logistics Agency (DLA) strategic stockpile still contains approximately 26,000 tonnes of concentrate ores and which may eventually be sold back to the market. In recent years, the DLA has been releasing approximately 2500 tonnes per annum, and in line with their policy not to disturb market structures. However it remains possible that the DLA may elect to release additional quantities in the short term and to assist in overcoming current shortages. A significant increase in material released from this stockpile would almost certainly impact on prices in the short-term.

The new price structures should be sufficient to encourage some improvement in mining activities in China, support the restart of mining activities in Canada, and allow the development of new mining operations in Australia and possibly Vietnam.

# 7.0 OPPORTUNITIES FOR NEW SUPPLIERS

As outlined in various sections of this report, the consumption pattern for tungsten is relatively mature. Whilst there are several new potential applications, these are unlikely to significantly change the existing usage structure, and therefore growth in the industry is more related to regional economic growth.

In traditional major markets such as North America and Europe growth in consumption should be consistent with GDP, which at 2-3 per cent is hardly considered spectacular. Conversely, in China, and to a lesser extent in other parts of South East Asia, dramatic growth in construction, automotive manufacture and steel production is rapidly increasing demand. During 2004, Chinese domestic consumption of tungsten increased by more than 10%.

As a direct result of the restructuring of the Chinese tungsten industry, historical over-production has been eliminated. By the end of 2004, real shortages of both concentrates and APT became evident, prices for both concentrates and APT have started to increase rapidly.

Equally importantly, the Chinese Government is actively encouraging downstream processing, and China can now offer both domestic and international markets a full range of tungsten products.

Both these factors are providing increasing pressure on traditional tungsten processors in North America, Europe and Japan. Not only are these companies facing real shortages of raw materials, they are also facing increasing competition from finished products from

China. With the possibility of the existing supply gap becoming wider in the next few years, and with effectively no new concentrate supply programs being confirmed outside China, it is possible that this situation is likely to become even more acute in the immediate and longer term.

Having fully recognised this situation for a number of years, processors and product manufacturers in North America and Europe are now urgently seeking alternative raw material sources. Understandably they are willing to provide long-term purchase agreements to support the development of any new mining operations.

## 7.1 Success Factors

Notwithstanding this position, and particularly due to the increased competition of finished products from China, the western processors have little room to offer price incentives to new concentrate producers. As a result, the success factors for a new entrant to the industry can be summarised as follows:

- A confirmed demonstration that the operation would be competitive with existing operations in China, and that this position could be sustained for at least the life of any agreed sales contract, and ideally on a relatively long-term basis (i.e. not less than 5 years).
- Confirmation of the required quality, with particular attention to the nominated impurity levels, including radioactivity.
- A willingness to enter into long-term supply agreements, and supported by confirmed shipping facilities with established and regular container services.
- Production programs meeting international requirements for both safety and environmental management. Ideally this should include the appropriate ISO qualifications.

Assuming these operating parameters can be achieved, with the recent strong increase in prices for both concentrates and APT, which are expected to be sustained for the foreseeable future, then the opportunity for entry into the tungsten industry as a new concentrate supplier would appear to be excellent, and strongly supported by international tungsten product manufacturers.

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