

Molybdenum - an extraordinary metal in high demand

By Hans Imgrund and Nicole Kinsman, International Molybdenum Association



Ferromolybdenum (left); Roasting molybdenite concentrate (right). Courtesy of Molymet, Chile

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Molybdenum - an extraordinary

The image shows the US Air Force Memorial at night. Three tall, curved spires made of stainless steel rise against a dark sky. The spires are illuminated from below, creating a bright glow. In the background, the lights of a city are visible. The overall scene is dramatic and highlights the architectural design of the memorial.

The US Air Force Memorial in Arlington, Virginia, USA, was designed by James Ingo Freed. It features three curved spires of welded, 19mm-thick, type 316 stainless steel plate up to 82 metres in height. Photo: Patrick McCafferty.

nary metal in high demand

The recent nickel shortage has attracted a lot of attention. What is less known is that molybdenum too is in ever greater demand, with tightening supplies and soaring prices. A world-wide boom in infrastructure projects, especially those which have critical applications, has fuelled demand for this versatile metal. Stainless Steel World asked Nicole Kinsman and Hans Imgrund of the International Molybdenum Association to explain the background and indicate what the future may hold. Their findings suggest that supplies will remain tight in the short term, but that the long-term supply prospects are looking good.

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Introductory

In the last four years demand for molybdenum soared by 35 per cent. This surge comes mainly from a strong world-wide push to invest in industrial infrastructure: from a factory building boom in China to a rush to develop oilfields, many projects rely on the help of materials containing molybdenum. All this activity has trickled down to

Molybdenum facts

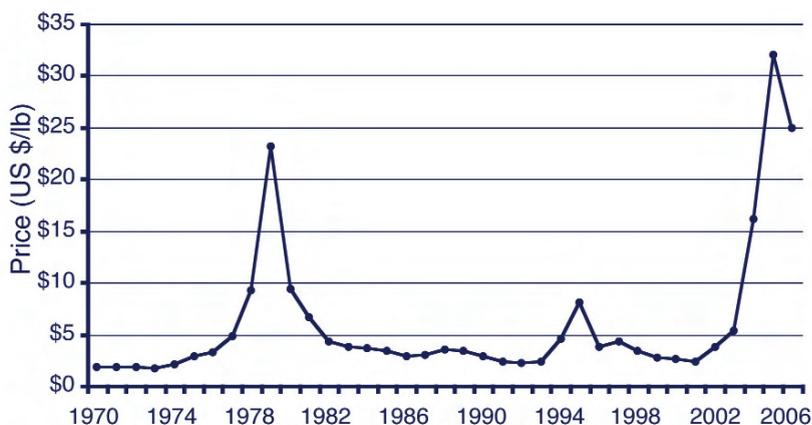
- About 25 per cent of all molybdenum produced is used to make moly-grade stainless steel.
- About 50 per cent is used for other iron-based metals, such as construction steel, tool and high-speed steel and cast iron.
- Molybdenum as an alloying element in steel is almost always used in combination with other elements such as chromium, nickel, vanadium, tungsten or niobium.
- Steel mills add molybdenum either as molybdenum oxide or ferromolybdenum.
- The remaining 25 per cent is purified and used as moly metal, as an alloying element in nickel and other super alloys, as catalysts, lubricants, flame retardants, corrosion inhibitors and pigments.
- Super alloy producers use moly metal pellets as a high-purity alloying addition.

an increase in demand for the metal and the transformation of a market that had been stagnant for nearly 20 years. Molybdenum has diverse appeal: it is used in pipelines, to improve strength to transport oil and gas under high pressure; in processing vessels in the chemical industry, to withstand corrosion in an array of solutions; and even in sculptures, such as the US Air Force Memorial, which is located just across the river from Washington, DC, to keep their finish shiny for a long time. The global interest in going “green” has also had an impact: as more companies reduce plant waste by recycling their waste streams within factory walls, moly-grade stainless steels handle the higher corrosiveness that comes with higher concentration of aggressive substances. Compounds of the element that allow steels to resist high tempera-

tures and stainless steels to resist corrosive environments can also work as an effective lubricant, as a catalyst for the production of oil products or as a pigment to make orange paint.

How molybdenum metal is used

The most important properties of pure molybdenum metal and molybdenum alloys are their high melting point (in the order of 2600°C), high temperature resistance, high wear resistance and good corrosion resistance. These products are often used in applications that require high strength at high temperature, while their coefficient of expansion and thermal conductivity also make them valuable to the electronics industry. Products made of molybdenum metal and molybdenum base alloys include metal powder, wire, sheet, bar and specialised powders.



The price for molybdenum has spiked recently but was at low levels for much of the last 25 years. (Source: Metals Week)

Examples of the metal's uses include parts of industrial furnaces, support wire for tungsten filaments in light bulbs, glass melting equipment, electronic equipment, and metal and plastic forming equipment. One example of a metal-forming product is a piercing plug. It is made of TZM (a molybdenum alloy, dispersion-strengthened with titanium carbide and zirconium oxide) and used for the production of stainless steel tubing. Such piercing plugs are made of TZM because they must have high strength and high wear resistance at the high rolling temperature of stainless steel (see photo.)

Making a better stainless steel

Molybdenum is added to stainless steels to increase corrosion resistance. About 10 per cent of stainless steel production contains molybdenum, of which the content averages about 2 per cent. Traditionally the most important moly-grade stainless steel is the austenitic type 316 (18% Cr, 10% Ni and 2 or 2.5% Mo), which represents about 7 per cent of global stainless steel production. In recent years moly-grade ferritics have grown fast. These include types 444 (18% Cr, 2% Mo), 436 (18% Cr, 1.25% Mo) and 434 (17% Cr and 1% Mo). The combined tonnage of moly-grade ferritics has jumped from 47,000 metric tons in 2002 to 366,000 tons in 2005, according to the International Stainless Steel Forum. Their percentage of total stainless production has grown from 0.3 per cent to 1.7 per cent in just three years. Duplex stainless steels have also been growing strongly to an estimated 200,000 metric tons in 2006.



TZM piercing plug for the production (rolling) of stainless steel tubes (courtesy of Plansee).



This sculpture right next to the ocean shows corrosion staining on type 304 stainless steel due to incorrect grade selection in a demanding environment.

Industrial sectors

The most important uses of moly-grade stainless steel are industrial. The chemical and petrochemical, oil and gas, paper, power, water, food and pharmaceutical industries use processing equipment made of moly-grade austenitic and duplex stainless steels.

Moly-grade stainless steel is also used in architectural applications. The correct selection of stainless steel in these applications is essential to avoid unpleasant surprises, for instance where a moly-free grade was used next to the ocean (see photo). Because the stainless steel selected here is not corrosion-resistant enough for this difficult environment, this sculpture has to be cleaned from superficial corrosion staining every year. The US Air Force Memorial, using a moly-grade type 316 stainless steel

(which contains 2 per cent molybdenum) will most likely not have this problem (see photo).

Making a stronger alloy steel

Molybdenum enhances hardenability, strength and toughness, and elevates the temperature resistance of constructional steels. It is often used in combination with chromium and/or nickel and other alloying elements, with the molybdenum content typically ranging from 0.2 to 1.2 per cent. Moly-grade steel categories include heat-treatable engineering steels, case-hardened steels, high-temperature steels, oil country tubular goods and HSLA (High Strength, Low Alloy) steels. These grades are used in all kinds of engineered products for automotive, shipbuilding, aircraft and aerospace industries; drilling, mining and pro-



These mill cutters are made of high-speed steel with 5 per cent Mo [courtesy of Boehler Edelstahl].

cessing industries; and energy generation industries. Products include vessels, tanks and heat exchangers, gears and shafts, piping and many more.

Making a longer-lasting tool steel

Molybdenum contributes to secondary hardening (in combination with vanadium) in tool steels. It also separates the pearlite and bainite reactions, and therefore allows step quenching. Products made of tool steels include hand tools, knives and saws, forging dies, pressure casting moulds and molding plates. The typical molybdenum content in tool steels is around 0.8 per cent. Molybdenum contributes to secondary hardening and is an important constituent of the primary M6C carbide, which makes high-speed steels more wear-resistant. Principal uses are for cutting tools and saws for steel, cast and non-ferrous materials, twist drills, milling cutters (see photo) and pushing tools. The average molybdenum content in high-speed steels is around 5 per cent.

Molybdenum mining

The main regions of molybdenum mining include South America, North America and China. These regions accounted for 93 per cent of global production in 2006, which was estimated to be 422 million pounds (192,000 metric tons). Roughly 60 per cent of molybdenum is produced as a by-product of another mining operation, most commonly copper production. The ore from copper mines which also produce molybdenum usually contains between 0.5 and 1.5 per cent copper (5 to 15 kg per metric ton of ore) and between 0.01 and 0.05 per cent molybdenum (0.1 to 0.5 kg/t). Major operations mine more than 50 million tons of ore per year, producing over 200,000 tons of copper and between 5,000 and 15,000 tons of moly. For every kilo of copper, between 20 and 40 grams of moly is extracted. For these producers, it is a relatively inexpensive step to extract molybdenum from the ore that is already ground up to take out copper. The revenues from molybdenum are

usually less than 10 per cent of total sales. Therefore, the molybdenum output does not necessarily follow the demand for molybdenum but the demand for copper. The moly output automatically increases when the mine increases its copper production and it falls when the mine decreases its copper production because demand for copper falls.

Mining for moly only (primary production) is much more expensive. A primary mine in the West, with an annual production capacity in the order of 10,000 tons of molybdenum (22 million lbs), takes an investment of several hundred million US dollars to open. Of the 40 per cent molybdenum from primary mines, 25 per cent is produced in China and the CIS and 15 per cent in the West.

Ore grades in primary mines contain between 0.12 and 0.20 per cent moly. Thus, the production of 10,000 tons of Mo requires mining and milling in excess of 5 million tons of ore per year. The cost of this has to be borne by the revenue

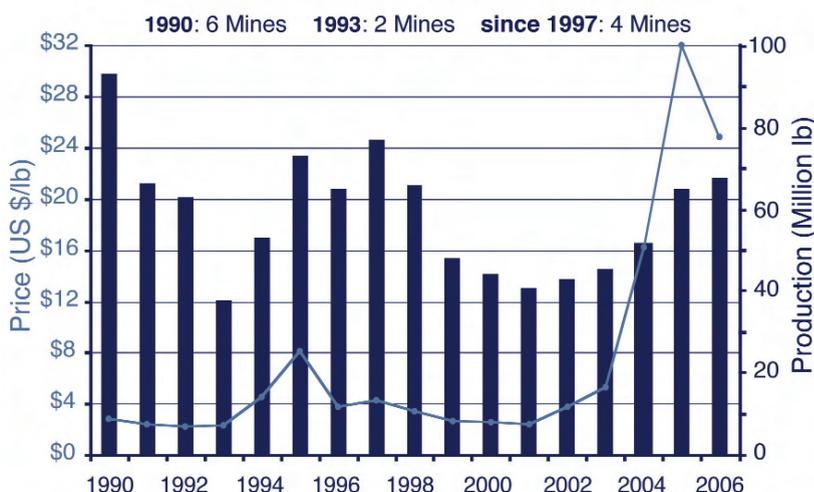
from molybdenum alone. Therefore the production of primary molybdenum is significantly more costly than the production of by-product molybdenum. The primary mines are swing producers, i.e. they increase their production when the market has higher demand for molybdenum and decrease their production when the demand is down.

The changing structure of the industry

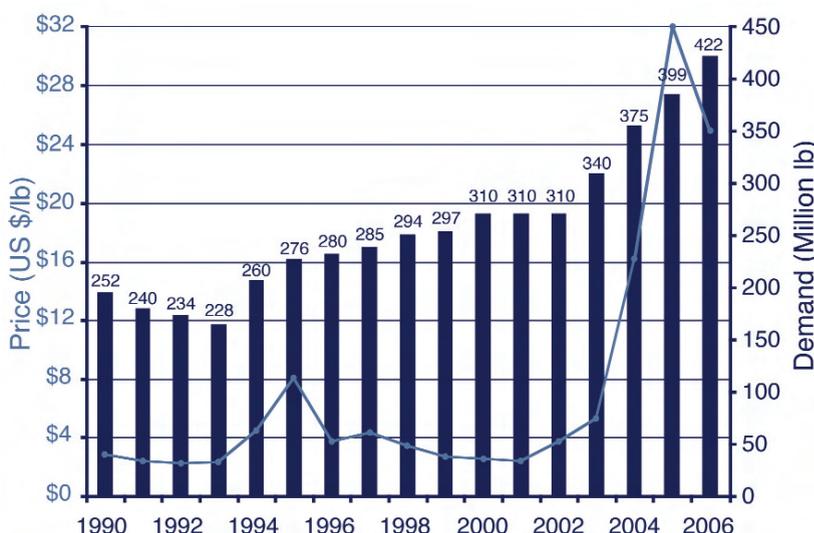
The balance of molybdenum mining has shifted over the years from mainly primary production to mainly by-product production. As copper companies have increased and optimized the recovery of molybdenum, the amount of by-product molybdenum produced has increased significantly in the last 15 years. During that same time, production in China and the availability of Chinese molybdenum for export to the rest of the world have also increased.

Because of these structural changes, the primary mines in North America that have traditionally produced the bulk of molybdenum have decreased their production and have become swing producers: these mines are only able to increase their production, or come back on-stream, when the market demand requires their more costly molybdenum. The by-product mines, on the contrary, produce their lower-cost molybdenum along with copper to fill the demand for copper and do not adjust much to the market conditions for molybdenum.

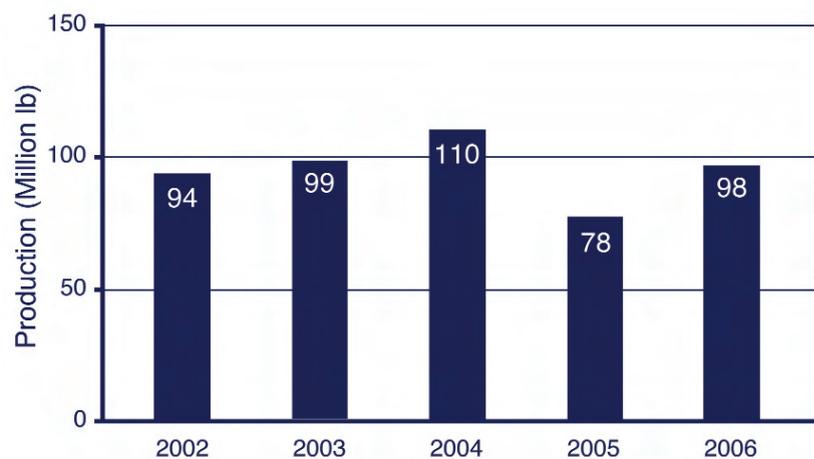
Market conditions became difficult in 2001 and 2002, when the molybdenum price dropped even further after being already low for most of the previous 20 years. The production of the primary mines in North America was reduced to less than 45 million pounds per year, or less than 15 per cent of global production. With this low production level, the swing producers, the primary North American mines, were no longer able to adjust their production sufficiently to absorb changes, particularly strong increases in demand.



Production of Western primary mines has decreased when prices and demand were low for several years. Production from these mines was only about 40 million lb in 2001 and 2002. (Source: IMOA, Metals Week).



Global molybdenum demand has increased strongly in the last four years after being stagnant for several years. (Source: IMOA, Metals Week).



Molybdenum mine production in China has dropped in 2005 as mines were closed due to safety concerns (Source: IMOA)

Company	Mine	Location	Type	Estimated annual capacity (million lb Mo)	Status
Montana/Gruppo Mexico	Butte	USA	Cu by-product	8	Reopened 2004
Quadra Mining Ltd.	Robinson	USA	Cu by-product	1	Started 2006
Taseko Mines	Gibraltar	Canada	Cu by-product	1	Reopened 2005
Anglo American/Falconbridge	Collahausi	Chile	Cu by-product	7	Started 2005
Amerigo (Minera Valle Central)	-	Chile	Cu by-product	1	Started 2005
Golden Phoenix Minerals	Ashdown	USA	Primary	0.5	Started 2006
Roxmark Mines	Nortoba - Tyson	Canada	Primary	1	Started 2006

Table 1: Molybdenum mines recently started or reopened (source: Adams Metals)

Molybdenum demand has increased significantly

As indicated already, the uses for molybdenum-containing products are mostly industrial and include energy generation, oil and gas, chemical processing, transportation, mining, mechanical engineering, building and construction and fabrication. [Demand for molybdenum]

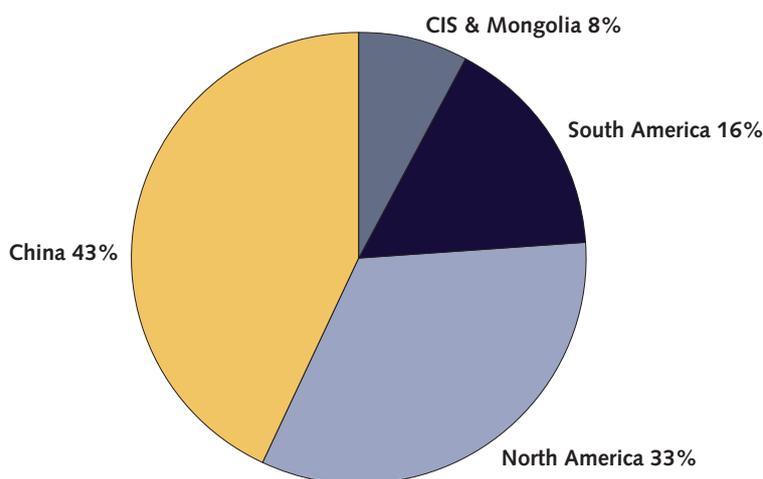
Many of these sectors have seen an up cycle in investment in the last few years. High oil prices have boosted exploration and brought new production facilities online. The new fields often are more difficult to reach and more difficult to tap. Higher temperatures, pressures and concentrations result in a need for better (often molybdenum-alloyed)

materials. Five to ten years ago, for example, refineries did not need to use much stainless steel in their processing. Today, the raw oil to be processed is becoming increasingly aggressive, so stainless steel equipment is becoming more common. The general trend in the chemical and petrochemical industries of increasing process temperatures and pressures to increase plant efficiency also favours the use of moly-grade materials. Similarly, environmentally friendly processing, where effluents are recycled in the plant instead of being released to the environment, increases the need for moly-containing materials that can withstand the higher concentrations of aggressive compounds.

Finally, the rapid expansion of the Chinese economy, creating a need for more industrial processing plants and for investment in new infrastructure, has multiplied the use of moly-grade materials in that part of the world in just a few years. Therefore, molybdenum demand had a compounded annual growth rate of 8 per cent between 2002 and 2006. Such market conditions have not been seen for decades. In fact, between 1990 and 2006 the growth rate was only 3.3 per cent per year. To express this in weight: in the 12 years between 1990 and 2002 the demand for molybdenum increased by 58 million pounds. In the last four years, between 2002 and 2006, the demand increased by 112 mil-

Company	Mine	Location	Type	Planned annual capacity (million lb Mo)	Status	Probable start-up
Freeport / PD	Cerro Verde	Peru	Cu by-product	8	Commissioning	Q2 2007
Roca Mines	Max Moly	Canada	Primary	5	Under Construction	Q3 2007
Alumbrera	Bajo de la Alumbrera	Argentina	Cu by-product	5	Under Construction	Q4 2007
BHP	Pinto Valley	USA	Cu by-product	3	Under Construction	Q4 2007
Mercator	Mineral Park	USA	Cu by-product	10	Under Construction	Q2 2008
Adanac	Ruby Creek	Canada	Primary	10	Feasibility complete; contracting	Q2 2009
Moly Mines Ltd.	Spinfex Ridge	Australia	Cu by-product	20	Completing feasibility	Q3 2009
Grupo Mexico	Canenea	Mexico	Cu by-product	10	Completing feasibility	Q3 2009
Freeport / PD	Climax	USA	Primary	20 to 30	Restarted - conditionally approved	2010
Idaho General	Mount Hope	USA	Primary	30	Completing feasibility	2011
Thompson Cree	Davison	Canada	Primary	8	Starting feasibility study	2012

Table 2. Likely molybdenum mine projects (source: Adams Metals)



Global molybdenum reserves total 19 million tons and are mainly situated in China and North America (source: US Geological Survey 2006).

lion pounds, from 310 million pounds to 422 million pounds. This is over 35 per cent of the total demand in 2002 and 2.5 times as much as the primary mine production in the same year. This situation has created a major strain on the supply of molybdenum.

Molybdenum supply

Mining operations take many years to develop and start. Feasibility studies, environmental impact studies, negotiation with local residents and financing are just part of the process needed to start a new mine or restart a mothballed one. Because of this, metal production cannot be quickly increased when demand increases sharply.

Of course, there is some flexibility to increase production in existing mines, but that flexibility is limited to a few percentage points. The sharp rise in demand after 2002 overwhelmed the swing producers, who had seen their business shrinking continuously during the five preceding years. At the same time, molybdenum production in China was not able to compensate for this limitation. Its production actually decreased in 2005, mainly because the Chinese government had to close some mines due to safety concerns.

The problem was further compounded by limited roasting capacities. Roasting is a necessary step to refine molybdenum. According to estimates by Climax Molybdenum (presented at the 2005 Ryan's Notes

Conference), the Western roasters were running at a capacity utilization rate of 77 per cent in 2003, which moved up to 94 per cent in 2004 and reached 100 per cent in 2005. This combination of circumstances led to the current - and unexpected - tight supply of molybdenum.

High demand leads to mine and roasting expansions

The tight supply situation and the continued high prices of molybdenum over the last four years have prompted many mining companies to develop new molybdenum min-

ing and roasting facilities. Projects have become possible that would not have been profitable at the low molybdenum prices previously seen. New operations that opened in the Americas since 2003 have added an estimated annual capacity of almost 20 million pounds. Production in China also increased by some 20 million pounds in 2006.

Additionally, many new projects are under consideration and in various planning and construction stages. A shortlist can be found in table 2, provided by Terry Adams of Adams Metals Ltd. The lead times for some of these projects are very long. According to Mr Adams there are around 500 other molybdenum projects in discussion with varying probabilities of completion. Roasting capacity should also be growing soon as capacities in the Western world are projected to increase from today's 340 million pounds to 410 million pounds by 2010.

For the long term, known reserves for molybdenum amount to 19 million metric tons, according to the US Geological Survey of 2006. This would be sufficient for 100 years at present demand levels, providing us with a corrosion-free future for many years to come.

About the authors

Dr. Hans Imgrund works as a part-time consultant to IMOA.

A German national, he studied metallurgy at the Clausthal Bergakademie and the Technical University in Berlin. He started his career in the moly business in 1973 as a development engineer of Climax Molybdenum Company.

He worked as Vice President Sales and Marketing for Climax and for Cyprus Mines Corporation from 1981 until his retirement from Climax in 2003.

He was actively involved in the foundation of IMOA and has served on IMOA's Executive Committee since its inception in 1989.



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is the Technical Director of the International Molybdenum Association (IMOA).

A Swiss citizen, she studied mechanical engineering and metallurgy at the Swiss Federal Institute of Technology in Zurich (ETH) and business administration at Carnegie Mellon University in Pittsburgh, USA. In 1995 she started her career as a market development manager at TMR in Pittsburgh, a consulting company focusing on technical consulting in stainless steel. Since 2002 she is Technical Director of IMOA, in charge of the market development programme of the association.

