

# RHENIUM

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In the past decade, the two most important uses of rhenium have been in high-temperature superalloys and platinum-rhenium catalysts. High-temperature superalloys are used in turbine components in aircraft engines and other aerospace applications. Platinum-rhenium catalysts are used to produce high-octane, lead-free gasoline. Other applications of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, are more diverse; these included thermocouples, heating elements, temperature controls, flashbulbs, vacuum tubes, x-ray tubes and targets, metallic coatings, and electrical contact points. Industry continued research on rhenium recovery from ores and concentrates and the development of new alloys and catalysts.

In the United States, rhenium is a byproduct of molybdenite recovered as a byproduct of porphyry copper ore mined in the copper-molybdenum mines in the Western States. Domestic mine production data for rhenium (table 1) were derived by the U.S. Geological Survey (USGS) from reported molybdenum production at the mines. Domestic demand for rhenium metal and other rhenium products was met principally by imports but also from domestic recovery and stocks.

Compared with that of 2002, 2003 estimated rhenium consumption showed no change; imports of metal for consumption decreased by about 8% and imports of ammonium perrhenate (APR) decreased by about 40% (table 1). Metal powder and APR values were estimated to be about \$1,325 and \$1,200 per kilogram, respectively.

## Consumption

A significant property of rhenium is its ability to alloy with molybdenum and tungsten. Molybdenum alloys containing about 50-weight-percent rhenium have greater ductility and can be fabricated by either warm or cold working. Unlike other molybdenum alloys, this type of alloy is ductile at temperatures above 196° C and can be welded. Alloys of tungsten with 24-weight-percent rhenium have improved ductility and have lower ductile-to-brittle transition temperatures than pure tungsten. Rhenium improves the strength properties of nickel alloys at high temperatures (1,000° C).

Metallurgical uses, such as in superalloys and powder metallurgy, comprised about 70% of rhenium consumption in 2003 and an additional 20%, was in reforming catalysts (Roskill Information Services Ltd., 2004, p. 46). Other uses for these alloys, which collectively represented only about 10% of total consumption, were in crucibles, electrical contacts, electromagnets, electron tubes and targets, heating elements, ionization gauges, mass spectrographs, metallic coatings, temperature controls, thermocouples, semiconductors, and vacuum tubes.

Rhenium is used in petroleum-reforming catalysts for the production of high-octane hydrocarbons, which are used in the formulation of lead-free gasoline. Bimetallic platinum-rhenium

catalysts have replaced many of the monometallic catalysts. Rhenium catalysts tolerate greater amounts of carbon formation in making gasoline and make it possible to operate the production process at lower pressures and higher temperatures. This leads to improved yields (production per unit of catalyst used) and higher octane ratings. Platinum-rhenium catalysts also were used in the production of benzene, toluene, and xylenes, although this use was small compared with that of gasoline production.

Alcoa Howmet Casting, the world's largest investment casting company, was awarded contracts to develop seven components to support Honeywell International's Thermal Power Management System for the Joint Strike Fighter (JSF) aircraft. In addition, Howmet was awarded sole-source contracts with Pratt and Whitney Aircraft for all six of the turbine airfoils in the JSF main engine (Metal Pages, 2003a§<sup>1</sup>).

## Foreign Trade

Imports for consumption of rhenium metal are listed in tables 1 and 2, and those of APR are listed in tables 1 and 3. World supply of rhenium was estimated to be about 32 metric tons (t) (table 4). That represents the quantity of rhenium recovered from concentrates that were processed to recover rhenium values. Rhenium was recovered as a byproduct from porphyry copper-molybdenum or porphyry copper concentrates mined in Armenia, Canada, Chile, Iran, Kazakhstan, Mexico, Peru, Russia, the United States, and Uzbekistan. Rhenium metal and compounds were produced in Chile, France, Germany, Kazakhstan, Netherlands, Russia, the United Kingdom, and the United States.

## World Review

World reserves of rhenium are contained primarily in molybdenite in porphyry copper deposits. U.S. reserves of rhenium are concentrated in Arizona, Montana, New Mexico, and Utah. Chilean reserves are found primarily at four large porphyry copper mines and in lesser deposits in the northern one-half of the country. In Peru, reserves are concentrated primarily in the Toquepala open pit porphyry copper mine and in about 12 other deposits in the rest of the country. Other world reserves are in several porphyry copper deposits and sedimentary copper deposits in Armenia, northwestern China, Iran, Kazakhstan, Russia, and Uzbekistan and in sedimentary copper-cobalt deposits in the Congo (Kinshasa). Identified U.S. resources are estimated to be about 4,500 t, and identified rest-of-the-world resources are estimated to be about 5,500 t.

*Armenia.*—Kronomet of Germany invested \$2.5 million establishing rhenium and molybdenum production at the

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<sup>1</sup>References that include a section mark (§) are found in the Internet References Cited section.

Yerevan Pure Iron Plant (Yerevan) in Armenia (Metal Pages, 2003b§). Khronomet holds 48% of Yerevan stock and private American shareholders own the remaining 52% of the plant. The plant began producing rhenium in April at the rate of 15 kilograms per month (kg/mo), with Khronomet taking all rhenium and molybdenum production. Yerevan plans to increase molybdenum capacity in 2004 to produce molybdenum plates and spirals for lamps to supply the Armenian domestic market.

**Chile.**—Estimates of rhenium production were not readily available as this information was considered proprietary, and the sales of recovered rhenium were mostly done under long-term contracts and were not published. It is generally assumed that about 50% of world rhenium production comes from Chile, and that the world consumption is about 40 to 45 metric tons per year (t/yr) (Taylor, 2002§). The largest producer of molybdenum concentrates in Chile is Corporacion Nacional del Cobre (Codelco). Codelco roasts a portion of their concentrate production, exports a portion of their concentrate directly to various overseas customers, and sends the balance to Molibdenos y Metales S.A. (Molymet) for processing. Only the portion sent to Molymet was processed for rhenium recovery. According to industry sources, Molymet also received concentrates from two other mines in Chile and at least one in Peru.

Molymet's reported molybdenite roasting capacity is about 200 metric tons per day (t/d) (Metal Pages, 2003f§), and they reportedly produce about 21,800 t/yr (48 million pounds per year) of molybdenum. That would equate to roasting about 45,000 t/yr of molybdenite concentrates with a molybdenum content of 48.5%. With the many concentrate sources available to the company, it is reasonable to assume that they operate at full capacity. The reported rhenium concentration in the various South American molybdenum concentrates, ranges from about 300 to 400 parts per million (ppm) (Roskill Information Services Ltd., 2004, p. 6). Assuming an average grade of about 325 ppm rhenium in molybdenite and a recovery of about 90%, rhenium production at Molymet would amount to about 13.2 t/yr operating at full capacity.

Trade sources revealed that since 2000, Molymet received additional rhenium-bearing residues recovered from the stacks of the roasters at its subsidiary plant [Molymex, S.A. de C.V. (Molymex)] in Mexico. Molymex receives molybdenite concentrates from Grupo Mexico's La Caridad Mine and from producers in Chile and Peru. Production estimates for La Caridad were obtained from Grupo Mexico annual reports, and import quantities were obtained from trade statistics for the years 2000 to 2003. The estimated rhenium content of these concentrates was about 325 ppm. In addition, Mexico also imported molybdenite concentrates from Canada and the United States for roasting. Import quantities were obtained from trade statistics for the years 2000 to 2003. The estimated rhenium content of these concentrates was about 250 ppm. Assuming a recovery of 90%, the Molymex rhenium recovery ranged from 2.0 to 2.6 t/yr. The combined recovery from Molymet and Molymex ranged from 13.2 to 15.8 t/yr. This analysis resulted in rhenium production estimates for Chile that are in general agreement with estimates reported in trade publications, about 15 to 20 t/yr. Based on this analysis, the USGS has revised its past estimates of rhenium production from Chile (table 4).

Molymet is building a new plant at its San Bernardo complex, south of Santiago, Chile, to process 40 t/d of molybdenum concentrates. When finished, this plant would increase Molymet's capacity by 20% (Metal Pages, 2003f§). Molymet is also moving its rhenium refinery to the same location and modernizing the recovery facilities.

**Poland.**—The Polish copper company KGHM Polska Miedz S.A. (KGHM), began extracting rhenium from its copper production circuit in March 2003 (Metal Pages, 2003d§). Production was about 20 kg/mo in the form of APR. KGHM planned to increase production to 4,000 kilograms per year (kg/yr) which would make KGHM a significant new source of APR. Working with the Polish Institute of Non-Ferrous Metals, they developed a cost-effective rhenium production process and avoided the need to purchase currently patented technology.

**Russia.**—The Kyshtym Copper-Electrolyte Works (KMEZ) in the Chelyabinsk region of Russia, a major copper producer, announced plans to set up commercial production of rhenium and its salts by yearend (Metal Pages, 2003e§). The company reproduced a trial batch of rhenium in July 2003. Employees owned 52% of KMEZ, East Point Holdings Ltd. of Cyprus owned 28%, and the local Chelindbank held the remaining 20%. In another development, experiments have been performed to extract rhenium from volcanic gas at the Kudryavyl Volcano on Iturup Island by researchers of the Volcanology and Geodynamics Institute, Russian Academy of Sciences (Metal Pages, 2003g§). A pilot plant was deployed in the crater, and researchers recovered 9 grams of pure rhenium. These efforts represent Russia's only plants to develop capacity to recover rhenium.

**Uzbekistan.**—A joint Uzbek-Israeli enterprise for production of molybdenum opened at the Almalyk Mining and Metallurgical Plant (Almalyk) in the Tashkent Region of Uzbekistan (Metal Pages, 2003c§). Previously the semifinished molybdenum byproducts obtained at the copper concentrating plant were sent elsewhere for further processing, resulting in the loss of associated elements. Almalyk specialists developed their own technology for processing molybdenum concentrates to fully recover associated rhenium and osmium.

## Current Research and Technology

Rhenium alloys possess unique attributes that have application in aerospace propulsion systems such as main thruster nozzles on the space shuttle orbiters. These nozzles have to endure extremely high temperatures during launch and extremely cold temperatures during space travel and must endure repeated thermal cycles. Rhenium alloys meet the requirements for use in these environments. Production of these components, however, is both expensive and difficult, as rhenium cannot be worked at room temperature and has the second highest melting point among metals. That makes near-net shape processing techniques, such as chemical vapor deposition (CVD) and powder metallurgy (PM), the production methods of choice. CVD, however, requires many process steps and PM requires machining (Advanced Materials & Processes, 2002).

To overcome these deficiencies, new PM techniques such as powder injection molding (PIM) and cold isostatic processing (CIP) are being developed, which have better net shape capabilities. PIM

is more suited to small, complex shapes, while CIP can be used for larger shapes. Both of these processes yield rhenium components with densities that are greater than 96% of theoretical. Production costs are also expected to be significantly lower than PM and CVD techniques as well. Using CIP techniques, researchers at Rhenium Alloys, Inc. successfully made rhenium-iridium thrusters under a NASA Phase II Small Business Innovative Research program (Kubel, 2001§). These new PM techniques enable manufacture of a wider range of shapes with more complex details that could be incorporated into future propulsion system designs.

## Outlook

The rhenium market was boosted at the Paris Air Show when the United Arab Emirates ordered 20 Airbus A380s, which feature 4 rhenium-containing Rolls Royce Trent 500 engines (Metal Pages, 2003h§). The Trent 500 will contain 2 single-crystal blade sections, one with 3% rhenium and another with 6% rhenium. These applications will take advantage of improved creep resistance of the higher rhenium-content alloy. Furthermore, observers pointed out that when the Canon Muskegon rhenium alloy patent expires, its clients would be able to source rhenium independently and reissue it to others for manufacturing. This could influence other rhenium buyers to enter the market. Finally, trade sources reported good demand from the catalyst sector, with plans announced for development of a new rhenium-containing catalyst.

For the long term (10 to 20 years), recycling of rhenium-bearing catalysts, waste, and scrap was expected to increase. Perhaps the greatest potential for rhenium recovery lies in the molybdenum concentrates that are presently being roasted in facilities that do not recover the rhenium values. A significant portion of the molybdenum concentrate production of Codelco, the largest producer of molybdenum concentrates in Chile, is exported or roasted without rhenium recovery. Capturing this source would significantly increase world rhenium production capacity.

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TABLE 1  
SALIENT U.S. RHENIUM STATISTICS<sup>1</sup>

(Kilograms, gross weight)

	1999	2000	2001	2002	2003
Supply <sup>2</sup>	6,200 <sup>f</sup>	7,100 <sup>f</sup>	5,500 <sup>f</sup>	4,000 <sup>f</sup>	3,900
Consumption <sup>e</sup>	32,500	32,000	32,500	32,500	32,500
Imports:					
Metal	12,800	10,700	20,200	14,300	13,200
Ammonium perrhenate	2,750	7,450	4,560	3,330	1,990

<sup>e</sup>Estimated. <sup>f</sup>Revised.

<sup>1</sup>Data are rounded to no more than three significant digits.

<sup>2</sup>Rhenium contained in molybdenite concentrates, based on calculations by the U.S. Geological Survey.

TABLE 2  
U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY<sup>1</sup>

Country	2002		2003	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Austria	6	\$10	--	--
Chile	14,200	14,500	12,700	\$14,000
China	--	--	3	3
France	--	--	21	31
Germany	127	177	396	322
Japan	--	--	2	2
Netherlands	--	--	33	40
Total	14,300	14,700	13,200	14,400

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau, with adjustments by the U.S. Geological Survey.

TABLE 3  
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY<sup>1</sup>

Country	2002		2003	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Belgium	--	--	371	\$298
China	300	\$235	--	--
Estonia	557	356	183	105
France	306	296	--	--
Germany	239	287	959	821
Kazakhstan	1,840	1,470	329	216
Korea, Republic of	2	7	--	--
Netherlands	--	--	144	122
Russia	92	72	--	--
Total	3,330	2,720	1,990	1,560

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau, with adjustments by the U.S. Geological Survey.

TABLE 4  
RHENIUM: ESTIMATED WORLD PRODUCTION, BY COUNTRY<sup>1,2</sup>

(Kilograms)

Country	1999	2000	2001	2002	2003
Armenia	700	700	750	800	1,000
Canada	1,600	1,600	1,700	1,700	1,700
Chile <sup>3</sup>	15,500 <sup>r</sup>	15,200 <sup>r</sup>	15,800 <sup>r</sup>	15,100 <sup>r</sup>	15,600
Kazakhstan	2,400	2,400	2,500	2,600	2,600
Peru	4,800	4,800	5,000	5,000	5,000
Russia	1,100	1,100	1,200	1,400	1,400
United States <sup>4</sup>	6,200 <sup>r</sup>	7,100 <sup>r</sup>	5,500 <sup>r</sup>	4,000 <sup>r</sup>	3,900
Uzbekistan	NA	NA	NA	NA	NA
Other	3,000	3,000	590	1,000	1,000
Total	35,300 <sup>r</sup>	35,900 <sup>r</sup>	33,000 <sup>r</sup>	31,600 <sup>r</sup>	32,200

<sup>r</sup>Revised. NA Not available.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Table includes data available through June 13, 2004.

<sup>3</sup>Data revised based on new information from Comisión Chilena del Cobre; also includes rhenium content from Mexico processed at Molymet in Chile.

<sup>4</sup>Calculated rhenium contained in MoS<sub>2</sub> concentrates.