

# 2006 Minerals Yearbook

# RHENIUM

# **R**HENIUM

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In the past decade, the two most important uses of rhenium have been in high-temperature superalloys and platinumrhenium catalysts. Rhenium is used in single-crystal, hightemperature superalloy turbine blades for aircraft engines and other land-based turbine 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 electrical contact points, flashbulbs, heating elements, metallic coatings, temperature controls, thermocouples, vacuum tubes, and x-ray tubes and targets. Industry continued to research the potential for recovery of rhenium from recycled turbine blades and the development of new alloys and catalysts.

In the United States, rhenium is a byproduct of molybdenite concentrates that are 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 coppermolybdenum mines. Domestic demand for rhenium metal and other rhenium products was met principally by imports but also from domestic recovery and stocks. U.S. apparent consumption of rhenium increased by about 30% from that of 2005 (table 1). Metal powder and ammonium perrhenate (APR) values were estimated to be about \$4,330 and \$3,780 per kilogram (kg) of rhenium content, respectively.

#### Consumption

Metallurgical uses, such as in nickel-based superalloys and powder metallurgy, were estimated to represent about 77% of rhenium consumption; rhenium improves the strength properties of nickel alloys at high temperatures (1,000° C). An additional 15% was used in the production of reforming catalysts for the petroleum industry (Roskill Information Services Ltd., 2007). Other uses for rhenium alloys, which collectively represented only about 8% 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 was 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 when making gasoline and make it possible to operate the production process at lower pressures and higher temperatures, which leads to improved yields (production per unit of catalyst used) and higher octane ratings. Platinum-rhenium catalysts also

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were used in the production of benzene, toluene, and xylenes, although this use was small compared with that used in gasoline production.

Record energy prices have accelerated the research and development of natural gas-to-liquid (GTL) technologies, all of which require catalysts (Brumby, 2005). Only 8 GTL plants were in operation in 2006, but as many as 30 additional plants were being considered, some for startup in 2007. Royal Dutch Shell Plc. and Exxon Mobil Corp. each initiated GTL projects in Qatar (Metal-Pages, Ltd., 2006e). Many GTL plants were considering a rhenium-promoted cobalt/aluminum oxide catalyst that would contain up to 1% rhenium content owing to the increased carbon monoxide hydrogenation rate of these catalysts.

Development of a 4th generation nickel-based superalloy was well underway; a patent for the superalloy was granted to United Technologies Corp. on October 3, 2006 (Metal-Pages, Ltd., 2006c). Rhenium content was described as "up to 5 % by weight" versus 6% in the 3rd generation superalloy. Any projected savings in rhenium consumption by using the new superalloy in turbine blade applications could largely be offset by the increased engine size.

#### **Foreign Trade**

Imports of metal increased slightly (table 2), while imports of APR increased sharply, by about 135% (table 3), owing to strong U.S. demand and sales of stockpiled material from Kazakhstan. 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 Review**

World production of rhenium was estimated to have been about 47.2 metric tons (t) in 2006 (table 4). This estimate was based on 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 primarily in Armenia, Canada, Chile, Kazakhstan, Peru, Russia, the United States, and Uzbekistan. The major producers of rhenium metal and compounds were Chile, Germany, the Netherlands, the United Kingdom, and the United States.

World reserves of rhenium are contained primarily in molybdenite in porphyry copper deposits. U.S. reserves of rhenium are concentrated in Arizona, Montana, Nevada, 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. Other world reserves are contained 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 Congo (Kinshasa). The U.S. reserve base was estimated to be about 4,500 t, and rest-of-the-world reserve base was estimated to be about 5,500 t.

Armenia.—In 2006, Yerevan Pure Iron OJSC (Yerevan) saw production of molybdenum metal increase by about 85% to 490 t while production of ferromolybdenum decreased by about 13% to 2,600 t. Yerevan also produced an estimated 150 kg of rhenium in 2006. New equipment to produce molybdenum metal was installed in 2005, as molybdenum metal is a higher value product (Metal-Pages, Ltd., 2007). Yerevan and Armenian Molybdenum Production LLC (AMP) planned to make further equipment investments to produce additional rhenium and also ferrotitanium (Metal-Pages, Ltd., 2006d). The Yerevan plant received molybdenum concentrates from CJSC Zangezur Copper & Molybdenum Plant (Zangezur) in which Yerevan and AMP held a 15% and a 12.5% interest, respectively. The Yerevan plant's entire production was exported to Europe by Germany's Cronimet Holding GmbH. Cronimet owned 51% of the shares in the Yerevan plant and 60% of the shares in the Zangezur plant (Metal-Pages, Ltd., 2006a).

*Chile.*—The leading producer of molybdenum concentrates in Chile was Corporacion Nacional del Cobre (Codelco); most of the company's concentrates were roasted and processed for rhenium recovery by Molibdenos y Metales S.A. (Molymet). According to industry sources, Molymet also received concentrates from two other mines in Chile and at least one in Peru. Since 2000, Molymet received rhenium-bearing residues recovered from the stacks of the roasters at its subsidiary plant, Molymex, S.A. de C.V. (Molymex), in Mexico. Since 2003, Molymet also received rhenium-bearing residues from its subsidiary plant, Sadaci N.V., in Belgium, which toll roasted molybdenum concentrates from a variety of sources. The combined rhenium recovery by Molymet was estimated to be about 19.8 t in 2006.

Molymet planned to boost the molybdenum concentrate processing capacity at its San Bernardo, Chile, plant by 18,000 metric tons per year (t/yr) [40 million pounds per year (Mlb/yr)] and at its Sadaci subsidiary plant in Ghent, Belgium, by 4,500 t/yr (10 Mlb/yr). The expansion at the San Bernardo plant was expected to be completed by mid-2007, and that at the plant in Ghent was expected to be completed in 2009. Molymet also announced plans for a new concentrate roasting plant in northern Chile that would have a capacity of 13,600 t/yr (30 Mlb/yr); production was scheduled to start as early as 2010 (Metal-Pages, Ltd., 2006e).

*Kazakhstan.*—The rhenium production capacity of Zhezkazganredmet (Redmet), Kazakhstan's state-owned rhenium producer, was thought to be about 1,000 kg of APR per month. Historically, Redmet received rhenium-bearing residues from the Dzhezkazgan Copper Works mine and smelter complex, and both companies were under government control. However, after Samsung Corp. and its subsidiary Kazakh Copper acquired controlling interest in Dzhezkazgan, a dispute arose over the value of the rhenium-bearing residues supplied to Redmet. Subsequently, exports of APR from Kazakhstan were halted from the third quarter of 2005 until the fourth quarter of 2006. The dispute was resolved when Redmet agreed to pay for past residues with stockpiled APR and to allot 50% of its APR output to Kazakh Copper for future residues. Kazakh Copper could have an estimated 9,000 kg (20,000 pounds) of stock and the company was waiting for the APR price to rise further before releasing material (Ryan's Notes, 2007). The reduced supply caused the spot price of basic-grade APR to rise to \$4,425 per kg in December.

#### Outlook

Current world demand for rhenium is likely to increase during the coming years. Demand for rhenium in nickel-based single-crystal superalloys is estimated to account for about 77% of current world rhenium consumption. The F-35 Joint Strike Force Fighter project is projected to include production of about 3,000 aircraft and 6,000 engines that would use 3rd generation nickel-based superalloys. The F-22 Raptor is expected to add another 700 aircraft. These 3,700 aircraft will use 6% rhenium superalloys, whereas the previous generation F-16 fighter (about 4,600 aircraft) used 3% rhenium superalloys (Journal of Metals, 2004). In terms of its other military uses, rhenium is used to make parts that control high-temperature exhaust gases from the jet engines of stealth aircraft. Rhenium allows heat to be radiated away from the aircraft quickly before infrared heatseeking missiles can target the engine (Lifton, Jack, 2007).

Rhenium spot prices in Europe appeared to be lower than those in the United States, which lead to increased U.S. imports of APR from European producers in 2006. More than 50% of the U.S. imports of APR in 2006 were from Kazakhstan, however, and those imports will be subject to the 3.1% import duty in 2007 when the Harmonized Tariff Schedule is revised (Metal-Pages, Ltd., 2006f). In addition, the Chinese Government abolished its 13% rebate on exports of rhenium in September 2006 (Metal-Pages, Ltd., 2006b). These changes likely will result in reduced imports of rhenium in the future, which could lead to tightened rhenium supplies and increased prices.

In addition to continued growth in rhenium consumption in single-crystal superalloys for use in gas engine turbine blades, increased rhenium consumption in catalysts is expected. A GTL industry with a 1-million-barrel-per-day capacity would utilize an estimated 25,000 t of catalysts (Brumby, 2005). If only one-half of the planned GTL plants that would use rhenium-promoted catalysts are built within the next decade, rhenium demand could increase by 12.5 t/yr. Additional rhenium demand in a 45-t worldwide industry would severely impact the current supply-demand balance.

Perhaps the greatest potential for increased rhenium production lies in the molybdenum concentrates that are presently being roasted in facilities that are not equipped to recover the rhenium values. For instance, a significant portion of the molybdenum concentrate production of Codelco, the leading producer of molybdenum concentrates in Chile, is exported unroasted or roasted without rhenium recovery. Capturing lost rhenium could increase world rhenium production capacity by an estimated 15 t/yr (Roskill Information Services Ltd., 2007).

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

#### (Kilograms, gross weight)

	2002	2003	2004	2005	2006
Supply <sup>2</sup>	3,400 <sup>r</sup>	3,400 <sup>r</sup>	5,900	7,100	8,100
Apparent consumption <sup>e, 3</sup>	20,000 r	18,000 <sup>r</sup>	25,100 <sup>r</sup>	36,000	46,800
Imports:					
Metal	14,300	13,200	11,800	21,800	22,000
Ammonium perrhenate	3,330 <sup>r</sup>	1,990	10,600 <sup>r</sup>	10,300	24,200

<sup>e</sup>Estimated. <sup>r</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. <sup>3</sup>Calculated as production plus imports minus exports and industry stock changes. TABLE 2

#### U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY $^{\rm l}$

	20	05	2006		
	Gross weight	Value	Gross weight	Value	
Country	(kilograms)	(thousands)	(kilograms)	(thousands)	
Belize	34	\$30			
Chile	19,600	20,600	19,700	\$21,600	
China			28	94	
France	3	3			
Germany	1,340	1,590	1,100	2,950	
Japan			200	927	
Netherlands	173	226	130	281	
United Kingdom	544	720	759	1,970	
Uzbekistan	50	63			
Total	21,800	23,300	22,000	27,800	
7					

-- 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, as adjusted by the U.S. Geological Survey.

# TABLE 3 U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY $^{\rm 1}$

	20	05	2006	06
	Gross weight	Value	Gross weight	Value
Country	(kilograms)	(thousands)	(kilograms)	(thousands)
Belgium	72	\$50	248	\$186
Chile	288	265	364	336
China	714	437	1,140	1,000
Estonia	60	22		
Germany	1,440	1,340	1,610	1,990
Kazakhstan	4,530	2,920	18,000	14,600
Korea, Republic of	2	3		
Netherlands	1,650	1,140	678	556
Poland	432	297	1,310	981
United Kingdom	1,110	572		
Uzbekistan			866	842
Total	10,300	7,040	24,200	20,500
Zara				

-- 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, as adjusted by the U.S. Geological Survey.

#### TABLE 4

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

#### (Kilograms)

Country	2002	2003	2004	2005	2006
Armenia	800	1,000	1,000	1,200	1,200
Canada	1,700	1,700	1,700	1,700	1,700
Chile <sup>3</sup>	15,700	20,100	21,300	20,500	19,800
Kazakhstan	2,600	2,600	5,000	8,000	8,000
Peru	5,000	5,000	5,000	5,000	5,000
Russia	1,400	1,400	1,400	1,400	1,400
United States <sup>4</sup>	3,400	3,400	5,900	7,100	8,100
Uzbekistan	NA	NA	NA	NA	NA
Other	1,000	1,000	1,000	1,000	2,000
Total	31,600	36,200	42,300	45,900	47,200

NA Not available.

<sup>1</sup>Estimated 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, 2007.

<sup>3</sup>Estimated rhenium recovered from roaster residues from Belgium, Chile, and Mexico.

<sup>4</sup>Calculated rhenium contained in molybdenite concentrates.