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 find application 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 porphyry 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 2001, 2002 estimated rhenium consumption showed no change; imports of metal for consumption decreased by about 29% and imports of ammonium perrhenate (APR) decreased by about 27% (table 1). Metal powder and APR values were about $800 per pound and $1,350 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). In 2002, metallurgical uses, such as in superalloys, comprised about 75% of rhenium consumption (Taylor, 2002c§[1]). Other uses for these alloys, which collectively represented only about 5% 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. The balance of consumption was in catalytic uses.

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. In 2002, catalytic uses were estimated to comprise about 20% of the rhenium consumption reported in table 1 (Taylor, 2002c§). 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.

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 31 metric tons (t) (table 4). That represents the quantity of rhenium recovered from concentrates that were processed to recover rhenium values. Rhenium was recovered from some byproduct molybdenite concentrates from porphyry copper deposits in Armenia, Canada, Chile, Iran, Kazakhstan, Mexico, Peru, Russia, the United States, and Uzbekistan. Rhenium metal and compounds were produced in Chile, France, Germany, 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, 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 Congo (Kinshasa). Identified U.S. resources are estimated to be about 5,000 t, and identified rest-of-the-world resources are estimated to be about 6,000 t.

Estimates of rhenium production are not readily available as this information is considered proprietary, and the sales of recovered rhenium are mostly done under long-term contract and are 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,

[1]References that include a section mark (§) are found in the Internet References Cited section.

2002c§). In an attempt to verify the accuracy of this information, the USGS has made the following analysis of Chilean rhenium production. The largest producer of molybdenum concentrates in Chile is Corporacion Nacional del Cobre (Codelco). Codelco roasts a portion of their concentrate production to make technical grade molybdenum oxide, 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 is known to be processed for rhenium recovery. Molymet also receives concentrates from two other mines in Chile and at least one in Peru. Since the amount of Codelco concentrate sent to Molymet will vary with market conditions, as will the supply from the other mines, it is more effective to estimate Chilean rhenium production by examining Molymet.

Molymet's reported molybdenite roasting capacity is about 43,000 t/yr (Molibdenos y Metales S.A., 2002§). With the many concentrate sources available to the company, it is reasonable to assume they operate at full capacity. The reported rhenium concentration in the various South American molybdenum concentrates ranges from about 250 to 400 parts per million (ppm) (Tom Millensifer, Vice President, Powmet, Inc., written commun., August 21, 2003). 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 12.6 t/yr. However, trade sources estimate that Chile produces 15 to 20 t/yr. Further investigation revealed that Molymet receives 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's production of molybdenite concentrates is closely tied to production from the La Caridad Mine. Production estimates for La Caridad were obtained from Grupo Mexico annual reports for the years 1998 to 2002. The estimated rhenium content of these concentrates is about 250 ppm. Assuming a recovery of 90%, the rhenium recovery associated with Molymex ranges from 1.5 to 3.6 t. The combined recovery is as shown below.

ESTIMATED RHENIUM PRODUCTION IN CHILE FROM 1998-2002
(Metric tons)

	1998	1999	2000	2001	2002
Estimated Molymex rhenium contribution[2]	2.7	3.6	3.1	2.5	1.5
Estimated Molymet rhenium contribution	12.6	12.6	12.6	12.6	12.6
Estimated combined rhenium production in Chile	15.3	16.2	15.7	15.1	14.1

This analysis results in rhenium production estimates for Chile that are in general agreement with estimates reported in trade publications. Additional contributions from Molymex, which are associated with rhenium-bearing molybdenum concentrates from porphyry copper mines in the United States that are toll processed by Molymex, have not been included. Based on these data, the USGS has revised its past estimates of rhenium production from Chile (table 4).

The Polish copper company KGHM Polska Miedz S.A. (KGHM) announced in July that it would resume production of rhenium by the end of 2002 (Taylor, 2002a§[2]). Production would be in the form of APR and would be approximately 50 kilograms per month (kg/mo). KGDM noted that during the communist years they recovered approximately 10 to 20 kg/mo. While 500 to 600 kilograms per year of production would not make much impact on the world market, if other copper producers follow this trend, the market could be restructured. In particular, if Codelco in Chile, whose rhenium unit has been mothballed for years, began to recover rhenium from all its molybdenum concentrates, the world rhenium production could be increased by as much as 25%.

[2]Based on rhenium recovery from molybdenum concentrate production from the La Caridad Mine in Mexico.

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 both extreme high-temperatures during launch and extreme 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 can't 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 as well. Using CIP techniques, researchers at Rhenium Alloys, Inc. successfully made rhenium-iridium thrusters under a National Aeronautics and Space Administration 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.

Kazakhstan's National Center for Complex Mineral Processing has developed a new unit to recover rhenium from dust through recycling waste from the local Yuzhmpolimetall Works in Shymkent, Kazakhstan (Metal-Pages, 2002b§). The process reportedly will operate on one-third less electricity than current processes and still recover up to 90% of the available rhenium. This source of rhenium will be added to the existing supply recovered from waste at the Zhezkazgan Copper Works and could potentially make Kazakhstan a world leader in rhenium production.

Outlook

In the next 5 years, demand for rhenium metal was expected to follow the demand for the single-crystal blade used in next generation aircraft turbine engines and in turbine blades in gas-fired, power generation facilities. These applications will take advantage of improved creep resistance the higher rhenium content alloy affords. The first contract for the Joint Strike Fighter (JSF) was let to Lockheed Martin by the U.S. Department of Defense in October 2001 with delivery scheduled to begin after about 6 years (Platts Metals Week, 2002). The JSF will use engines developed by Pratt & Whitney that contain single crystal blades with a rhenium content of 6%, which represents more than a doubling of rhenium content over current practice. While there has been a downturn in the production of new domestic aircraft, there has been a marked increase in the retrofit of existing aircraft to achieve increased fuel efficiency (Taylor, 2002b§). This will add to the demand for rhenium in the immediate future as Russia, in particular, seeks to update their civilian and military fleets (Metal-Pages, 2002a§).

The deregulation of the power industry in the United States has caused the proliferation of smaller, more energy efficient gas-fired power generation plants that augmented or replaced large, centrally located facilities. While the collapse of Enron Corporation did dramatically slow this trend in 2002, the multiyear permitting and construction process for additional facilities is continuing at a more measured pace. A new gas-fired, power generation turbine can have blades containing 3% rhenium that could represent as much as 11 kilograms (25 pounds) of rhenium per turbine (Lipmann Walton & Co., Ltd., 2001). With a typical installation representing three to nine turbines, and with hundreds of installations currently being permitted, the demand for rhenium could increase dramatically. In addition to the above rhenium applications, the petroleum refining catalyst sector is expected to continue consuming about 5 t/yr of rhenium to replace catalysts for the petroleum refining industry (Taylor, 2002c§).

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 is exported or roasted without rhenium recovery. Capturing this capacity would significantly increase world rhenium production.

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TABLE 1
SALIENT U.S. RHENIUM STATISTICS[1]

(Gross weight in kilograms)

	1998	1999	2000	2001	2002
Production[2]	16,700 r	13,200 r	12,400	11,800	10,100
Consumption[e]	28,600	32,500	32,000	32,500	32,500
Imports:	14187	12759	10698	20238	14310
Metal	11,009	2,749	7,445	4,556	3,332
Ammonium perrhenate	11,000	2,750	7,450	4,560	3,330

[e]Estimated. [r]Revised.
[1]Data are rounded to no more than three significant digits.
[2]Rhenium contained in molybdenum concentrates, based on calculations by the U.S. Geological Survey.

TABLE 2
U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY[1]

	2001		2002	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Austria	--	--	6	$10
Chile	16,500	$16,500	14,200	14,500
Estonia	43	30	--	--
France	149	77	--	--
Germany	229	204	127	177
Kazakhstan	685	462	--	--
Mexico	1,970	364	--	--
Romania	412	254	--	--
United Kingdom	291	426	--	--
Total	20,200	18,300	14,300	14,700

-- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.

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

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY[1]

	2001		2002	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
China	--	--	300	$235
Estonia	--	--	557	356
France	206	$197	306	296
Germany	399	338	239	287
Kazakhstan	3,640	2,930	1,840	1,470
Korea, Republic of	--	--	2	7
Russia	--	--	92	72
Sweden	316	144	--	--
Total	4,560	3,610 r	3,330	2,720

rRevised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.

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

TABLE 4
RHENIUM: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Kilograms)

Country	1998	1999	2000	2001	2002
Armenia	1,000	700	700	750	800
Canada	2,200	1,600	1,600	1,700	1,700
Chile[3]	15,300 r	16,200 r	15,700 r	15,100 r	14,100
Kazakhstan	2,400	2,400	2,400	2,500	2,600
Peru	2,300	4,800	4,800	5,000	5,000
Russia	900	1,100	1,100	1,200	1,400
United States[4]	6,900 r	6,600 r	7,500 r	6,200 r	4,400
Uzbekistan	NA	NA	NA	NA	NA
Other	3,200	3,000	3,000	590	1,000
Total	34,200 r	36,400 r	36,800 r	33,000 r	31,000

rRevised. NA Not available.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Table includes data available through June 13, 2003.
[3]Data revised based on new information from Comisión Chilena del Cobre; also includes rhenium content from Mexico processed at Molymet in Chile.
[4]Calculated rhenium contained in MoS_2 concentrates.