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RHENIUM

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Rhenium

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U.S. estimated rhenium production increased by about 41%, while apparent consumption of rhenium increased by about 6% from that of 2010 (table 1). World production of rhenium in 2011 was estimated to be about 50,700 kilograms (kg), a 14% increase from that of 2010 (table 4).

Production

In the United States, rhenium is a byproduct of molybdenite concentrates that are recovered as a byproduct of porphyry copper-molybdenum ore mined in the Western States. Rhenium recovery requires roasting in a facility equipped to capture the rhenium compounds in the stack gases. In the United States, only one molybdenum concentrate roasting facility is currently so equipped—the Freeport McMoRan Copper & Gold Inc. Sierrita facility in Arizona. Domestic mine production data for rhenium (table 1) were derived by the U.S. Geological Survey (USGS) from reported molybdenum production at the copper-molybdenum mines. Domestic demand for rhenium metal and other rhenium products was met by imports, from recovery from domestic ores and stocks, and from the recycling of both spent catalysts and superalloy scrap.

Consumption

In the past decade, the two most important uses of rhenium have been in high-temperature superalloys and platinum-rhenium catalysts. Rhenium is used in single-crystal, high-temperature superalloy turbine blades for aircraft engines and land-based turbine applications. Rhenium is used in the turbine blades closest to the combustion zone in gas turbine engines. The use of rhenium-containing blades allows the engine to be designed with closer tolerances and allows operation at higher temperatures, which prolongs engine life and increases engine performance and operating efficiency. Platinum-rhenium catalysts are used to produce high-octane, lead-free gasoline. Industry continued to research the potential for increased recycling of rhenium-bearing turbine blades and the development of new alloys and catalysts.

Other applications of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, are more diverse; these included crucibles, electrical contact points, electromagnets, electron tubes and targets, flashbulbs, heating elements, ionization gauges, mass spectrographs, metallic coatings, semiconductors, temperature controls, thermocouples, vacuum tubes, and x-ray tubes.

Eighty percent of the world's approximately 50 to 55 metric tons (t) annual consumption of rhenium was as a 3% or 6% addition within complex nickel-base alloys for the manufacture of single crystal turbine blades for either aircraft engines or industrial gas turbine engines. Turbine engine producers, such as General Electric Aviation (GE) (a subsidiary of General Electric Co., Fairfield, CT), Pratt & Whitney, and Rolls Royce plc were estimated to consume 45 metric tons per year (t/yr) of rhenium (Minor Metals Trade Association, 2012).

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

GE announced that it had developed two new alloys as part of the company's overall strategy to conserve and recycle rhenium. The first new alloy, N500, a rhenium-free alloy, was expected to be used in stationary parts such as engine nozzles and shrouds. The second new alloy, René N515, used less rhenium (1.5%) while providing the properties of other second-generation alloys that used significantly more rhenium (3%). According to the company, René N515 has been tested extensively and has been introduced into the CFM56 turbine blades in jet engines. Computer modeling enabled the development and introduction of the alloy in 2 years, compared with the traditional developmental time of 4 years (Fink and others, 2010). René N515, however, was described as having an oxidation resistance capability at 1,175 °C, a temperature not expected to be an operating temperature that could power many of the larger jet engines that run at higher temperatures. The only alloys capable of running at these higher temperatures were the current second-generation (3% Re) and third-generation (6% Re) alloys, making GE's new alloys inadequate for larger jet engines (Lipmann Walton & Co. Ltd., 2010).

GE has also been working to lessen its dependence on rhenium by researching a variety of innovative component designs and by using advanced manufacturing processes. Recycling materials from unserviceable engine parts continued to be performed through GE's Reclamation Program that was launched in 2006 in response to the volatile market and rising prices. GE recycles used, high-pressure turbine blades (HPTBs) made of a rhenium-bearing nickel superalloy that are cleaned and melted for reuse in manufacturing new HPTBs. Although the lifespan of engine parts was variable, a turbine blade was expected to last approximately 10 years. According to the company, more than 10% of its rhenium came from recycling, and it expected the percentage to increase in the next few years (General Electric Aviation, 2011).

Rio Tinto plc announced that Kennecott Utah Copper's molybdenum autoclave-process (MAP) facility, first approved in June 2008 and then later put on hold, was expected to begin phase I commissioning in the fourth quarter of 2012, and production at full capacity of 13,600 t/yr of molybdenum was scheduled for the fourth quarter of 2013. The phase 2 expansion to 27,200 t/yr of molybdenum was anticipated to be completed in the first quarter of 2015 (Rio Tinto plc, 2011, p. 78). The MAP was expected to enable lower grade concentrate to be processed more efficiently than in conventional roasters, to allow improved molybdenum recovery, and to enable production of chemical-grade molybdenum products. The new facility would have the capacity to recover approximately 3 to 5 t/yr of rhenium. Unlike the roasting process, the autoclave system would extract rhenium at the crystallization stage and recover it, as in the old roasting process, via ion exchange. The final products would be high-purity ammonium perrhenate (APR) suitable for catalysts and rhenium metal for the aerospace industry (Rio Tinto plc, 2010, p. 40).

Prices

Rhenium has a limited market in terms of the number of participants. A large percentage of rhenium sales, especially for rhenium metal, are made under long-term contracts. The details of the long-term contracts are not made public. The open trade market for both APR and rhenium metal is relatively small.

In 2011, the annual average price of APR catalytic-grade rhenium as reported in Metal Bulletin was $4,360 per kilogram, a 6% decrease compared with the $4,630 per kilogram annual average price of 2010. The annual average price of rhenium metal pellets (minimum 99.9%) was $4,720 per kilogram in 2011, a slight increase from the $4,670 per kilogram annual average price of 2010. The rhenium metal pellet price was $4,690 per kilogram until March, when it trended downward to $4,410 per kilogram. In June, the rhenium metal pellet price increased to $4,850 per kilogram until October, when it decreased to $4,630 per kilogram by yearend.

Foreign Trade

Imports of rhenium metal in 2011 increased to 23,800 kg, a 3% increase compared with 23,100 kg rhenium metal in 2010. Chile and Poland were the leading suppliers of rhenium metal to the United States. Imports of APR decreased to 13,800 kg, a 9% decrease compared with 15,100 kg APR in 2010. Imports for consumption of rhenium metal are shown in tables 1 and 2, and those of APR are shown in tables 1 and 3.

World Review

World production of rhenium was estimated to have been about 50,700 kg in 2011 (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 ores mined primarily in Chile, Mexico, Peru, Republic of Korea, and the United States. In addition to the countries listed, China was thought to produce rhenium, but output was not reported quantitatively. Rhenium is also associated with copper minerals in sedimentary deposits in Armenia, Kazakhstan, Poland, Russia, and Uzbekistan, where ore is processed for copper recovery, and the rhenium-bearing residues are recovered at the copper smelter. Rhenium-bearing residues from both sources are processed for recovery either as APR for catalyst uses, or as a metal powder for superalloys. The major producers of rhenium metal and compounds were Chile, Germany, Poland, 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 deposits and in smaller deposits in the northern 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). U.S. reserves were estimated to be about 390 t, and rest-of-the-world reserves were estimated to be about 2,100 t.

Chile.—Molibdenos y Metales S.A. (Molymet) (Santiago) maintained roasting facilities equipped for rhenium recovery in Belgium, Chile, and Mexico. Molymet toll roasted byproduct molybdenum concentrates for Corporación Nacional del Cobre de Chile (Codelco) and also sourced concentrates from Canada, Mexico, Peru, and the United States. Codelco and Xstrata plc also roasted byproduct molybdenum concentrates in Chile, but those roasters were not equipped for rhenium recovery.

Estonia.—Toma Group (Tallinn) continued to recycle metal alloys containing rhenium at its facility in Tallinn. The facility had a capacity to recycle 130 kg of 69.4% Re in APR, or approximately 3,000 kg per month of raw material per month. The company recycled molybdenum-rhenium alloys, tungsten-rhenium alloys, nickel-based superalloys, and other rhenium containing scrap metals. Toma continued to research ways of recycling new materials more efficiently (Toma Group, undated).

Germany.—Buss & Buss Spezialmetalle GmbH (Sagard) continued to recycle rhenium containing alloys, rhenium scrap into catalyst grade APR (99.9% Re), and rhenium pellets (99.9% Re) at its facility in Sagard. Annual capacity for secondary rhenium production was estimated to approximately 2,000 kg (Buss & Buss Spezialmetalle GmbH, undated).

Kazakhstan.—Zhezkazganredmet (Redmet), Kazakhstan's state-owned rhenium producer, received rhenium-bearing residues from the Dzhezkazgan Copper Works mine and smelter complex in Kazakhstan. Dzhezkazgan was controlled by Kazakh Copper, and its parent Samsung Corp., which received 50% of Redmet's production as payment for the rhenium residues. A disagreement, beginning in 2007, between Kazak Copper and Redmet resulted in rhenium production slipping from 8 t in 2006 to an estimated 3 t in 2009. Rhenium production in 2010 was estimated to be 2 t. The Dzhezkazgan plant continued renovations in 2011, which was expected to further decrease rhenium production in 2011 (Kazakhmys plc, 2010, 2012).

Poland.—KGHM Ecoren S.A. (Lubin), a division of Polish copper producer KGHM Polish Copper S.A., continued to operate their metallic rhenium refinery near the Legnica Copper Smelter. Ecoren reported that British customers, Johnson Matthey plc and Rolls-Royce Group plc, were the major purchasers of its rhenium products. The facility had an annual capacity to convert APR into 3.5 t of metallic rhenium. It was also able to supply rhenium metal in powder form according to customer's requirements. Ecoren also increased its crystalline APR production capacity, which was expected to be 6 to 7 t/yr of APR. Ecoren received the waste sulfuric acid from the KGHM Polish copper plant and then, through hydrometallurgical processes, captured the rhenium to produce the APR and rhenium metal (KGHM Ecoren S.A., 2011).

Uzbekistan.—The Navoi Mining and Metallurgy Combinat (NGMK) continued to process molybdenum concentrates to recover rhenium.

Outlook

The United States is the world's leading producer of aerospace superalloys and is, therefore, the largest consumer of rhenium (Roskill Information Services Ltd., 2010, p. 34). With the leading three consumers—Cannon Muskegon Corp., GE, and Pratt & Whitney—consuming an estimated 45 t/yr of rhenium, more production from new plants, such as Poland's new rhenium facility, are needed. Rhenium consumption was estimated to increase by an average of 5% per year between 2009 and 2015 to reach 71,500 kg in 2015 (Roskill Information Services Ltd., 2010, p. 27).

As the life cycle of turbine blades in jet engines is approximately 10 years, significant quantities of second-generation blades (3% Re) were accumulating. Technology is continuing to be developed to allow recycling of second-generation blades for recovery of rhenium that can be used in the manufacture of new third-generation blades, potentially reducing requirements for virgin rhenium by about 50%. The majority of rhenium is recycled in Germany and the United States, but significant amounts are also being recovered in Estonia and Russia. Secondary rhenium recycling rates are continuing to increase worldwide.

Potential molybdenum producers continued to look at ways to increase the value of future production since the collapse in the molybdenum price during the global economic downturn. For some, producing byproduct rhenium is a strong possibility. One of the great potentials 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 example, Rio Tinto's new MAP facility would allow Rio Tinto to recover approximately 3 to 5 t/yr of rhenium, potentially increasing U.S. rhenium production by more than 50%.

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

(Kilograms, gross weight)

	2007	2008	2009	2010	2011
Production[2]	7,090 r	7,910 r	5,580 r	6,100	8,610
Apparent consumption[e, 3]	48,100	51,600	37,100	39,700 r	42,100
Imports:					
Metal	30,500	35,900	21,500	23,100	23,800
Ammonium perrhenate	15,100	11,200	14,300	15,100 r	13,800

[e]Estimated. [r]Revised.

[1]Data are rounded to no more than three significant digits unless otherwise specified.

[2]Rhenium contained in molybdenite concentrates, based on calculations by the U.S. Geological Survey.

[3]Calculated as production plus imports minus exports and industry stock changes.

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

	2010		2011	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Canada	10	$21	--	--
Chile	21,900	50,200	22,200	$51,400
France	--	--	100	335
Germany	314	520	150	548
Italy	89	584	--	--
Poland	7	24	1,200	2,980
United Kingdom	771	1,430	209	556
Total	23,100	52,800	23,800	55,800

-- Zero.

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

Source: U.S. Census Bureau.

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

Country	2010[r]		2011	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Canada	288	$662	1,610	$3,520
Germany	2,600	6,760	--	--
Kazakhstan	2,890	6,360	4,040	7,270
Korea, Republic of	--	--	6,000	10,800
Netherlands	2,010	4,860	--	--
Poland	4,090	9,930	--	--
Russia	1,030	2,170	--	--
United Kingdom	980	1,910	2,200	4,800
Uzbekistan	1,210	2,540	--	--
Total	15,100	34,500	13,800	26,400

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

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

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

(Kilograms)

Country	2007	2008	2009	2010	2011
Armenia	400	400	400	400	600
Canada	-- r	-- r	-- r	-- r	--
Chile[3]	22,900	27,600	25,000	25,000	27,000
Kazakhstan	7,000 r	5,500	3,000	3,000 r	3,000
Korea, Republic of	--	--	--	--	500
Peru[4]	-- r	-- r	-- r	-- r	--
Poland[5]	2,422 r	3,391 r	2,422 r	4,656	6,000
Russia	1,500	1,500	1,500	1,500	500
United States[6, 7]	7,090 r	7,910 r	5,580 r	6,100	8,610
Uzbekistan	2,000 r	2,000 r	2,000 r	2,500 r	3,000
Other	1,500	2,000	1,500	1,500	1,500
Total	44,800 r	50,300 r	41,400 r	44,700 r	50,700

[r]Revised. -- Zero.
[1]World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.
[2]Table includes data available through June 13, 2012.
[3]Data also includes rhenium content from Belgium, Mexico, Peru and the United States, processed at Molymet in Chile.
[4]No rhenium is recovered in Peru, but unroasted molybdenum concentrates containing rhenium are exported to Molymet in Chile for processing.
[5]Data based on new information from KGHM Ecoren S.A. Calculated based on 69.2% rhenium content of ammonium perrhenate.
[6]Reported figure.
[7]Calculated rhenium contained in molybdenite concentrates.