



2015 Minerals Yearbook

RHENIUM [ADVANCE RELEASE]

RHENIUM

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In 2015, U.S. estimated primary rhenium production on a gross-weight basis decreased by 7% to 11,400 kilograms (kg), whereas estimated apparent consumption of rhenium increased by 14% to 46,000 kg from that of 2014 (table 1). Domestic demand for rhenium metal and other rhenium products was met by imports, as a byproduct during the recovery of domestic ores and stocks, and from the recycling of spent catalysts and superalloy scrap. Secondary rhenium production continued to increase more quickly than primary production, as in recent years, mainly owing to the increasing availability of superalloy scrap. In addition to being a major source of primary rhenium, the United States also has some of the leading refiners, fabricators, and distributors of rhenium products. World primary production of rhenium on a contained-weight basis in 2015 was estimated to be about 49,400 kg, a 5% increase from the revised 47,100 kg in 2014 (table 4). Data in this report are rounded to three significant digits and percentages are calculated from unrounded data.

Production

In the United States, rhenium is produced as a byproduct from molybdenite concentrates that are recovered as a byproduct of porphyry copper-molybdenum ore mined in Arizona, Montana, New Mexico, and Utah. During roasting of the molybdenite concentrates to produce molybdenum oxide, rhenium is oxidized to rhenium heptoxide (Re_2O_7) and passes up the flue stack with the sulfur gases. When the flue dusts and gases are scrubbed, rhenium is dissolved in the resulting sulfuric acid and is eventually precipitated out as ammonium perrhenate (NH_4ReO_4 ; APR). For 2015, domestic primary mine production data for rhenium (table 1) were derived by the U.S. Geological Survey (USGS) from reported molybdenum production at copper-molybdenum mines at four operations. All producers responded to the survey, representing 100% of production.

At the Rio Tinto Kennecott smelter in Garfield, UT [Rio Tinto plc (London, United Kingdom)], the copper concentrate that is produced contains trace amounts of rhenium. When the copper concentrate is smelted, the rhenium volatilizes in the flash smelting process and is recovered as a rhenium-rich acidic liquid. Using continuous ion-exchange technology, approximately 1,000 kilograms per year (kg/yr) of rhenium is recovered (Rio Tinto plc, 2015).

Secondary rhenium is recovered from spent oil refinery catalysts and foundry revert (pre-consumer and mill scrap) and by recycling scrapped end-of-life gas turbine parts (nickel-base superalloy scrap), specifically blades and vanes. Both catalysts and alloys are typically recycled using hydrometallurgical processes; however, pyrometallurgical processes can also be

used. Of these sources, only the recycling of scrap produces additional new rhenium units available to the open market as rhenium metal or APR.

Some of the major companies with the capability to recycle rhenium from spent catalysts and superalloy scrap in the United States were AAA Molybdenum Products Inc. (Broomfield, CO), Colonial Metals Inc. (Elkton, MD), Gemini Industries Inc. (Santa Ana, CA), Heraeus Metal Processing Inc. (Santa Fe Springs, CA), Sabin Metals Corp. (Scottsville, NY), Titan International Inc. (Cinnaminson, NJ), and Umicore Cobalt & Specialty Materials (Wickliffe, OH).

In superalloy scrap recycling, rhenium is completely separated from the other alloys, whereas in the processing of superalloy revert, the rhenium remains part of the alloy throughout the cleaning and remelting process. Processing scrapped engine parts to generate engine revert is a much cheaper and quicker process. The quantity and availability of end-of-life engine parts containing rhenium has increased rapidly since 2004. Estimating engine revert supply is difficult; however, some industry sources have estimated approximately 6,000 kg was produced in 2014, a 33% increase from the estimated 4,500 kg in 2013 (Roskill Information Services Ltd., 2015, p. 38). In 2015, several recyclers reduced their operations owing to lower rhenium metal and APR prices, but industry sources reported that if prices increased again, recycling activity was expected to also increase (Blamey, 2015).

Germany and the United States were the leading secondary rhenium producers. However, secondary rhenium production also took place in Canada, Estonia, France, Japan, Poland, and Russia. In 2014, it was estimated that approximately 10,000 kg of rhenium was recycled worldwide using nickel-base superalloy scrap (Roskill Information Services Ltd., 2015, p. 24, 38). Rhenium recycled from catalysts is generally not included in total rhenium production data, because it almost exclusively remains within the catalyst industry.

Consumption

During the past 30 years, the two most important uses of rhenium have been in high-temperature superalloys and platinum-rhenium catalysts for producing gasoline. 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

¹Deceased.

high-octane, lead-free gasoline. Industry continued to research the potential for increased recycling of rhenium-bearing turbine blades as well as the development of new alloys and catalysts.

Other applications of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, are more diverse and include 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.

Annual global consumption of rhenium was estimated at approximately 55,000 to 59,000 kg/yr. This estimate included primary and secondary rhenium used in the form of metal or APR. The estimate also included the rhenium contained in reconditioned engine revert but not regenerated or recycled rhenium-containing catalysts or rhenium contained in scrap metal generated and then reused by a superalloy foundry or an associated processing plant (Roskill Information Services Ltd., 2015, p. 101–102). It was estimated that between 76% and 81% of this global consumption was used as a 3% or 6% addition to complex nickel-base alloys for the manufacture of single-crystal turbine blades for either aircraft engines or industrial gas turbine engines. The United States was the world's leading producer of aerospace superalloys and was, therefore, the largest consumer of rhenium. The leading three U.S. consumers were Cannon Muskegon Corp. (Muskegon, MI), General Electric Aviation (GE) (Evendale, OH) (a subsidiary of General Electric Co., Fairfield, CT), and Pratt & Whitney (a division of United Technologies Corp., Hartford, CT).

Pratt & Whitney continued to receive rhenium for all of its engine platforms from Molibdenos y Metales S.A. (Molymet) (Chile) after signing a \$690 million agreement in 2014. This high-profile commitment from a large aerospace engine manufacturer highlighted the importance that rhenium holds in the aerospace industry. However, rhenium also represented the third most expensive total material cost per engine, behind only titanium and nickel alloys, even though it represented only a fraction of the total weight in the actual engine (Haflich, 2016).

Rhenium was used in petroleum-reforming catalysts for the production of high-octane hydrocarbons, which were used in the formulation of lead-free gasoline. Bimetallic platinum-rhenium catalysts have replaced many of the monometallic catalysts. Bimetallic platinum-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 minor compared with their use in gasoline production.

Prices

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

In 2015, the annual average price of APR catalytic-grade rhenium as reported in Metal Bulletin was \$2,800 per kilogram,

a 10% decrease compared with the \$3,100 per kilogram annual average price of 2014. The annual average price of rhenium metal pellets (minimum 99.9%) was \$2,700 per kilogram in 2015, a 10% decrease from the \$3,000 per kilogram annual average price of 2014.

Foreign Trade

Imports of rhenium metal in 2015 were 25,400 kg, a 44% increase compared with 17,600 kg of rhenium metal in 2014 (table 2). Chile continued to be the leading supplier of rhenium metal to the United States.

Imports of APR for 2014 were adjusted by the USGS owing to some imports being misclassified. Rhenium-rich residues, perrhenic acid, and flue dusts have also been included in this category. Adjustments were made for 2014 to show only actual imports of APR. In 2015, imports of APR decreased to 9,100 kg, a 15% decrease compared with 10,700 kg in 2014 (table 3).

World Review

World primary production of rhenium was estimated to be 49,400 kg in 2015 (table 4). This estimate was based on the quantity of rhenium recovered from concentrates that were processed to recover rhenium values. World secondary production of rhenium (engine revert and recycling) was estimated to be approximately 16,000 kg in 2014 (Roskill Information Services Ltd., 2015, p. 36). Analysts have reported that the supply of engine revert was expected to continue over the next decade (Mining.com, 2015).

Rhenium was recovered as a byproduct from porphyry copper-molybdenum ores mined primarily in Chile, Mexico, Peru, and the United States. In Mexico and Peru, substantial amounts of rhenium were contained in unroasted molybdenum concentrates that were exported to Chile, the Netherlands, and the United States for processing. Armenia, China, Japan, Kazakhstan, the Republic of Korea, Mongolia, Poland, and Uzbekistan also produced rhenium (table 4). Rhenium was associated with copper minerals in sedimentary ore deposits in Kazakhstan and Poland, countries where ore was processed for copper recovery, and the rhenium-bearing residues were recovered at copper smelters. Rhenium-bearing residues from both sources were processed for recovery either as APR for catalyst uses or as a metal powder for use in superalloys. In addition to the countries listed above, Russia was thought to produce rhenium, but output was not reported quantitatively. The major producers of rhenium metal and compounds in 2015 were Chile, 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. Chile's 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 porphyry copper deposits and sedimentary copper deposits in Armenia, Australia, Canada, China, Iran, Kazakhstan, Mongolia, Poland, Russia, and Uzbekistan. U.S. reserves were estimated to

be about 390,000 kg; rest-of-the-world reserves were estimated to be about 2,100,000 kg.

Canada.—Rhenium was contained in the molybdenum concentrates produced by Teck Resources Ltd. at the Highland Valley Copper Mine in British Columbia and by Taseko Mines Ltd. at the Gibraltar Mine in British Columbia. The molybdenum concentrates were exported for roasting by Climax Molybdenum Co. in the Netherlands and the United States as well as by MolyMet in Chile. However, it was unclear if either Highland Valley or Gibraltar received any byproduct credits (Roskill Information Services Ltd., 2015, p. 51).

Chile.—According to MolyMet, it operated the largest rhenium recovery plant in the world, based in Nos, with an estimated capacity of 40,000 kg/yr of rhenium metal and APR. The Nos plant had three concentrate roasters with a total molybdenum treatment capacity of 43,000,000 kg/yr. In addition to its Chilean operations, MolyMet had molybdenum concentrate roasting facilities in Mexico (Molymex S.A. de C.V.), roasting and ferromolybdenum plants in Belgium (Sadaci N.V.), a powder metallurgy plant in Germany (Chemietall GmbH), and a metal facility in China (Luoyang High-tech Molybdenum & Tungsten Material Co. Ltd.) (Roskill Information Services Ltd., 2015, p. 55). 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.

Codelco, through its subsidiary MOLYB Ltd., continued building its molybdenum concentrate treatment plant, located in Mejillones, Antofagasta Region. The plant was scheduled to begin operations in the second half of 2016 and was expected to produce 16,500,000 kg/yr of molybdenum trioxide and 30,000,000 kg/yr of sulfuric acid. It was also expected to produce rhenium as a byproduct (Corporación Nacional del Cobre de Chile, 2016, p. 107).

China.—In China, as in many countries, there were numerous traders that claimed to be able to supply rhenium or APR. However, it is difficult to separate those traders from manufacturing companies (Roskill Information Services Ltd., 2015, p. 65). Rhenium production and processing is concentrated in Jiangxi and Shaanxi Provinces. Estimates for China were based on new data from China's National Statistical Bureau.

Estonia.—Toma Group (Tallinn) continued to recycle metal alloys containing rhenium at its facility in Tallinn. The facility had a monthly capacity to recycle 130 kg of 69.4% rhenium in APR from approximately 3,000 kg of various alloys. The company recycled molybdenum-rhenium alloys, tungsten-rhenium alloys, nickel-base superalloys, and other rhenium-containing scrap metals sourced from companies in Europe and the United States. Toma continued to research ways of recycling new materials more efficiently (Toma Group, undated).

Germany.—Buss & Buss Spezialmetalle GmbH (Sagard), in a joint venture with MolyCorp, continued to recycle rhenium-containing alloys, rhenium scrap into catalyst grade APR (99.9% rhenium), and rhenium pellets (99.9% rhenium) at its facility

in Sagard. Annual capacity for secondary rhenium production was estimated to be approximately 2,000 kg (Buss & Buss Spezialmetalle GmbH, undated).

Heraeus Precious Metals GmbH & Co. KG (a division of W.C. Heraeus GmbH) was one of the leading recyclers of rhenium from catalysts. Heraeus operated recycling facilities in Hanau and in Sante Fe Springs, CA (Heraeus Precious Metals GmbH & Co. KG, undated).

H.C. Starck GmbH & Co. KG (Goslar) continued to recycle rhenium from catalysts and superalloy scrap (H.C. Starck GmbH & Co. KG, undated).

Japan.—Kohsei Co., Ltd., a Tokyo-based manufacturer of nonferrous metals, announced that its Kitakyushu plant continued to extract rhenium from the turbine blades of scrapped jet engines. The company was expecting to extract approximately 2,000 kg of rhenium from 100,000 kg of scrapped components (Kohsei Co., Ltd., undated).

Kazakhstan.—Zhezkazganredmet (Redmet), Kazakhstan's state-owned rhenium producer, received rhenium-bearing residues from the Zhezkazgan Copper Works mine and smelter complex. The smelter was owned by Kazakhmys plc until October 2014 when the company transferred ownership to Cuprum Holding Group. Kazakhmys then changed its name to KAZ Minerals plc. When the Zhezkazgan smelter was controlled by Kazakhmys, it received 50% of Redmet's production as payment for the rhenium residues. However, it was unclear whether this arrangement would continue with Cuprum. Operations at the Zhezkazgan smelter and refinery were closed in mid-2013 in order to upgrade the facility to process copper-molybdenum ore from the newly developed Bozshakol mining and concentrating complex in Kazakhstan (Roskill Information Services Ltd., 2015, p. 72). The Zhezkazgan smelter reopened in November 2014, strictly on schedule, according to the company. Rhenium production was expected to resume, but exact details were unavailable (Metal Mininginfo, 2015).

Korea, Republic of.—LS-Nikko is a 50–50 joint venture between the Republic of Korea's LS Holdings Co. Ltd. and Japan Korea Joint Smelting Co. Ltd. (JKJS). LS-Nikko had the capacity to produce 4,000 kg/yr of basic-grade APR. The rhenium was recovered from South American copper concentrates treated at LS-Nikko's Onsan smelter in Ulsan Metropolitan City. The main sources of copper concentrates included the Los Pelambres, Collahuasi, and the Escondida Mines in Chile owned 15%, 3.6%, and 3%, respectively, by JX Nippon Mining and Metals Corp. (Roskill Information Services Ltd., 2015, p. 74).

Poland.—KGHM Ecoren S.A. (Lubin), a division of Polish copper producer KGHM Polska Miedź S.A., continued to operate its 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 3,500 kg of metallic rhenium. It was also able to supply rhenium metal in powder form according to customer requirements. KGHM also operated a rhenium recovery circuit at its third copper plant in Legnica, giving it an additional capacity of 500 to 600 kg/yr of rhenium. Ecoren received

waste sulfuric acid from the KGHM plant and then, through hydrometallurgical processes, captured the rhenium to produce the APR and rhenium metal (KGHM Ecoren S.A., undated).

Outlook

Superalloy producers and processors are constantly seeking to improve the performance and properties of their high-pressure turbine blades and vanes. Advances in heat-resistant ceramic coatings and air cooling are particularly important to allow blades to operate in environments where temperatures exceed their melting points. Research also continued into the addition of ruthenium, a more affordable alternative to rhenium, to improve corrosion resistance. Although the benefit of adding rhenium to superalloys is well established, economics cannot be ignored and the high price of rhenium has always been an important consideration (Roskill Information Services Ltd., 2015, p. 113).

There are no primary rhenium projects that are expected to significantly contribute to rhenium availability in the near future, with the possible exception of those in Kazakhstan because they are continuing to increase their rhenium production.

Compared with the high cost of rhenium recycling, processing engine revert represents a simple, quick, and cost-effective way to capture and reuse rhenium. The supply of engine revert is expected to continue to have a significant effect on the stabilization of the rhenium market.

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TABLE 1
SALIENT U.S. RHENIUM STATISTICS¹

(Kilograms, gross weight unless otherwise noted)

	2011	2012	2013	2014	2015
Production ²	12,400	11,400	10,200	12,300	11,400
Production, ³ rhenium content	8,610 ^r	7,910 ^r	7,110 ^r	8,510 ^r	7,900
Apparent consumption ^{e,4}	37,700	58,000 ^r	40,000 ^r	40,500 ^r	46,000
Imports:					
Metal	23,800	27,400	22,700	17,600 ^r	25,400
Ammonium perrenate	13,800	19,200	7,020	10,700 ^r	9,130

^eEstimated. ^rRevised.

¹Data are rounded to no more than three significant digits.

²Based on calculations by the U.S. Geological Survey. Secondary rhenium production not included.

³Based on 80% recovery of estimated rhenium contained in molybdenum disulfide concentrates.

⁴Calculated as production plus imports minus exports and industry stock changes.

TABLE 2
U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY¹

Country	2014		2015	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Belgium	--	--	1,000	\$2,890
Canada	239	\$297	670	973
Chile	15,700	39,400	22,400	55,700
China	6	20	55	318
Germany	1,000 ^r	2,560 ^r	1,020	3,270
Norway	210	1,280	--	--
Poland	227	808	--	--
Switzerland	--	--	40	199
United Kingdom	144	751	68	99
Uzbekistan	--	--	140	112
Total	17,600 ^r	45,100	25,400	63,600

^rRevised. -- Zero.

¹Data 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 COUNTRY¹

Country	2014		2015	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Canada	1,520	\$2,270	1,060	\$1,200
China	60	62	1,500	1,540
Estonia	100	143	542	10
Germany	295	695	393	781
Japan	1,020	1,100	118	144
Kazakhstan	4,180	8,540	4,190	8,960
Korea, Republic of	3,280	4,890	450	430
Netherlands	--	--	125	113
Poland	145	184	--	--
Russia	--	--	179	154
United Kingdom	60	123	--	--
Uzbekistan	--	--	576	620
Total	10,700 ^r	18,000 ^r	9,130	13,900

^rRevised. -- Zero.

¹Data 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 ³	2011	2012	2013	2014	2015
Armenia	254 ⁴	293 ⁴	298 ⁴	351 ⁴	350
Chile ⁵	24,000	27,000	25,000	25,000	26,000
China	2,100	2,200	2,300	2,350	2,400
Kazakhstan	3,000	3,000	2,500	300	1,000
Poland ⁶	6,000 ⁴	8,075 ⁴	7,530 ⁴	7,600 ⁴	8,900
United States ⁷	8,610	7,910	7,110	8,510	7,900
Uzbekistan	1,200	1,200	900	900	1,000
Other ⁸	1,500	1,200	1,000	2,000	1,800
Total	46,700 ^r	50,900 ^r	46,600 ^r	47,000 ^r	49,400

^rRevised.

¹Totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Includes data available through September 26, 2016.

³In addition to the countries listed, Russia also produced rhenium but output was not officially reported, and available general information was inadequate for the formulation of reliable estimates of output levels.

⁴Reported figure.

⁵Includes rhenium contained in molybdenum concentrates from Belgium, Mexico, Peru, and the United States that were processed at Molibdenos y Metales S.A. in Chile.

⁶Based on information from KGHM Ecoren S.A. Calculations based on 69.2% rhenium content of ammonium perrhenate.

⁷Calculated rhenium contained in molybdenite concentrates.

⁸Includes estimates for Japan, the Republic of Korea, and Mongolia.