2017 Minerals Yearbook

RHENIUM [ADVANCE RELEASE]

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Rhenium

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In 2017, U.S. estimated primary rhenium production on a contained-weight basis decreased slightly to 8,200 kilograms (kg), whereas estimated apparent consumption of rhenium increased by 6% from that of 2016 to 42,700 (table 1). Domestic demand for rhenium metal and other rhenium products was met by imports, by production as a byproduct during the recovery of domestic ores and stocks, and by 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 increased availability of superalloy scrap. In addition to being a major source of primary rhenium, the United States also had some of the leading refiners, fabricators, and distributors of rhenium products. World primary production of rhenium on a contained-weight basis in 2017 was estimated to be about 48,800 kg, essentially unchanged from the 49,000 kg in 2016 (table 4). Data in this report are rounded to no more than 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 2017, domestic primary mine production data for rhenium (table 1) were derived by the U.S. Geological Survey 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, p. 15).

Centerra Gold Inc. owned a molybdenum roasting and processing plant in Langeloth, PA. The processing plant had previously been fed by the company's Thompson Creek Mine in Idaho. However, the Thompson Creek Mine was placed on care-and-maintenance status in 2014 and did not produce any molybdenum in 2017. The Langeloth processing plant continued to produce and sell APR and rhenium metal pellets, all recovered as byproducts of processing molybdenum disulfide on a toll basis from various third-party operations (Centerra Gold Inc., 2018, p. 113).

Secondary rhenium is recovered from spent oil refinery catalysts, 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 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 2017, several recyclers continued to reduce their operations owing to lower rhenium metal and APR prices, but industry sources reported that if prices significantly increased again, recycling activity was expected to also increase.

Germany and the United States continued to be the leading secondary rhenium producers. Secondary rhenium production also took place in Canada, Estonia, France, Japan, Poland, and Russia. According to industry sources, approximately 20 to 30 metric tons (t) of rhenium was recycled worldwide in 2017. However, it was expected that this would decrease by approximately 3 to 4 t in 2018, owing to the continued decrease in rhenium prices (Metal Bulletin, 2018).

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 also 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 in 2017, 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.

Global consumption of rhenium was estimated to be approximately 55,000 to 59,000 kg/yr gross weight. 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 that was 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 75% and 83% 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 (Roskill Information Services Ltd., 2015, p. 112). The United States was the world's leading producer of aerospace superalloys and was, therefore, the leading consumer of rhenium. The leading three U.S. consumers were Cannon Muskegon Corp. (Muskegon, MI), General Electric Aviation (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 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 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 to produce 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 allow the production process to operate 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 number 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 2017, the annual average price of APR catalytic-grade rhenium, as reported by Argus Media group—Argus Metals International, was $1,530 per kilogram of contained rhenium, a 39% decrease compared with the $2,510 per kilogram annual average price of 2016. The annual average price of rhenium metal pellets (minimum 99.9% rhenium) was $1,550 per kilogram of contained rhenium in 2017, a 24% decrease from the $2,030 per kilogram annual average price of 2016.

Foreign Trade

Imports of rhenium metal in 2017 were 26,700 kg, a slight increase compared with 25,900 kg of rhenium metal in 2016 (table 2). Chile continued to be the leading supplier of rhenium metal to the United States. In 2017, imports of APR increased to 11,300 kg, 31% more than the 8,570 kg imported in 2016 (tables 1, 3).

World Review

World primary production of rhenium on a contained-weight basis was estimated to be 48,800 kg in 2017 (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 to increase over the next decade.

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, Kazakhstan, Poland, and Uzbekistan also produced rhenium. Japan, the Republic of Korea, Mongolia, and Russia may have also produced rhenium but available information was inadequate to make reliable estimates of output (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 use in catalysts or as a metal powder for use in superalloys. The major producers of rhenium metal and compounds in 2017 continued to be 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.

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 (Chemiemetall GmbH), and a metal facility in China (Luoyang High-tech Molybdenum & Tungsten Material Co. Ltd.) (Roskill Information Services Ltd., 2015, p. 55). In 2017, Molymet reported sales volumes of 20,450 kg of rhenium, a 10% decrease from 2016 (Molibdenos y Metales S.A., 2017, p. 16). Molymet toll roasted byproduct molybdenum concentrates for Corporación Nacional del Cobre de Chile (CODELCO) and 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 (Molibdenos y Metales S.A., 2018, p. 175, 213).

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 was concentrated in Jiangxi and Shaanxi Provinces. Estimates for China were based on 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 and rhenium scrap into catalyst-grade APR (99.9% rhenium) and rhenium pellets (99.9% rhenium) at its facility in Sagard. Secondary rhenium production capacity was estimated to be approximately 2,000 kg/yr (Buss & Buss Spezialmetalle GmbH, undated).

H.C. Starck GmbH & Co. KG (Goslar) continued to recycle rhenium from catalysts and superalloy scrap (H.C. Starck GmbH & Co. KG, 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 also produced APR, rhenium powder, and rhenium pellets. Heraeus operated recycling facilities in Hanau and in Sante Fe Springs, CA (Heraeus Precious Metals GmbH & Co. KG, 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 continued with Cuprum in 2017. 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 Bozshakol mining and concentrating complex in Kazakhstan (Roskill Information Services Ltd., 2015, p. 72–74). The Zhezkazgan smelter reopened in November 2014, on schedule, according to the company. Rhenium production was expected to resume, but exact details have been unavailable since 2014 (Metal Mininginfo, 2015).

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 a capacity to convert APR into 3,500 kg/yr of metallic rhenium. It was also able to supply rhenium metal in powder form according to customer requirements. 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 a, b).

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 continued to explore 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 were no primary rhenium projects in 2017 that were expected to significantly contribute to rhenium availability in the near future. Continued low prices of rhenium caused many rhenium recyclers to stop recycling rhenium to focus on a more profitable market. A substantial increase in rhenium prices would be necessary to result in a turnaround in the rhenium recycling industry (Metal Bulletin, 2018). Compared with the high cost of rhenium recycling, processing engine revert represents a more simple, quick, and cost-effective way to capture and reuse rhenium. The supply of engine revert was expected to continue to have an effect on the stabilization of the rhenium market.

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TABLE 1

SALIENT U.S. RHENIUM STATISTICS[1]

(Kilograms)

	2013	2014	2015	2016	2017
Production, mine, rhenium content[2]	7,110	8,510	7,900	8,440	8,200
Apparent consumption:[e, 3]					
Gross weight	43,200	43,600	49,100	50,300	52,500
Rhenium content	34,700	33,500	39,700	40,300	42,700
Imports:					
Ammonium perrhenate, gross weight	7,020	10,700	9,130	8,570	11,300
Ammonium perrhenate, rhenium content	4,870	7,400	6,340	5,950	7,820
Rhenium metal, rhenium content	22,700	17,600	25,400	25,900	26,700
Total, rhenium content	27,600	25,000	31,800	31,900	34,500
World production, rhenium content	45,600 r	45,100 r	47,900 r	49,000 r	48,800

[e]Estimated. [r]Revised.

[1]Table includes data available through February 20, 2020. Data are rounded to no more than three significant digits.

[2]Estimated mine production of rhenium is calculated by the U.S. Geological Survey and is based on the production of molybdenum concentrates. Secondary rhenium production not included.

[3]Calculated as production plus imports minus exports.

TABLE 2

U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY OR LOCALITY[1]

	2016		2017	
Country or locality	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Austria	--	--	45	$42
Belgium	2,440	$7,120	--	--
Canada	70	80	375	487
Chile	21,600	52,200	21,600	57,200
China	2	4	350	1,850
Germany	1,230	2,800	2,240	3,130
Korea, Republic of	1	5	54	180
Netherlands	280	1,450	--	--
Poland	340	1,850	1,990	7,940
Singapore	--	--	65	215
United Kingdom	--	--	18	58
Total	25,900	65,500	26,700	71,100

-- Zero.

[1]Table includes data available through September 17, 2019. 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 OR LOCALITY[1]

	2016		2017	
Country or locality	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Canada	1,240	$1,340	3,790	$1,410
China	750	768	750	768
Germany	1,570	3,620	1,860	1,180
Japan	--	--	278	254
Kazakhstan	3,260	6,660	1,850	3,150
Korea, Republic of	1,200	1,020	100	85
Netherlands	--	--	144	99
Poland	--	--	920	749
Russia	--	--	101	49
Thailand	--	--	600	437
United Kingdom	140	273	874	1,880
Uzbekistan	411	305	--	--
Total	8,570	14,000	11,300	10,100

-- Zero.

[1]Table includes data available through September 17, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

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

(Kilograms, rhenium content)

Country or locality[3]	2013	2014	2015	2016	2017
Armenia	298	351	350 e	281 r	300 e
Chile[e, 4]	25,000	25,000	26,000	27,000	27,000
China[e]	2,300	2,350	2,500	2,500 r	2,500
Kazakhstan[e]	2,500	300	1,000	1,000	1,000
Poland[5]	7,530	7,710	9,170	9,310 r	9,300 e
United States	7,110	8,510	7,900	8,440	8,200
Uzbekistan	900 e	900 e	1,000 e	466 r	460 e
Total	45,600 r	45,100 r	47,900 r	49,000 r	48,800

[e]Estimated. [r]Revised.

[1]Table includes data available through July 29, 2019. All data are reported unless otherwise noted. Totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Estimated mine production of rhenium based on the production of molybdenum concentrates. Secondary rhenium production not included.

[3]In addition to the countries and (or) localities listed, the Republic of Korea and Russia may have produced rhenium, but available information was inadequate to make reliable estimates of output.

[4]Includes rhenium contained in molybdenum concentrates from Canada, Mexico, Peru, and the United States, processed at Molibdenos y Metales S.A. in Chile.

[5]Based on information from KGHM Ecoren S.A. Calculation based on 69.2% rhenium content of ammonium perrhenate.