



# 2014 Minerals Yearbook

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## RHENIUM [ADVANCE RELEASE]

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# RHENIUM

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In 2014, U.S. estimated primary rhenium production increased by 20% to 8,500 kilograms (kg), while apparent consumption of rhenium slightly increased to 43,000 kg from that of 2013 (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 has increased more quickly than primary production 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 in 2014 was estimated to be about 44,700 kg, a slight increase from the revised 44,300 kg in 2013 (table 4).

## 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  $\text{Re}_2\text{O}_7$  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 ( $\text{NH}_4\text{ReO}_4$ ; APR). 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 responded to the survey representing 100% of production.

Secondary rhenium is recovered from spent oil refinery catalysts, foundry revert (pre-consumer and mill scrap), engine revert (post-consumer 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.

In superalloy 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 metric tons (t) was produced in

2014, a 33% increase from the estimated 4.5 t in 2013 (Roskill Information Services Ltd., 2015, p. 38).

Germany and the United States were the leading secondary rhenium producers. However, secondary rhenium production also took place in Canada, Estonia, Japan, and Russia. In 2014, it was estimated that approximately 10 t of rhenium was recycled using nickel-base superalloy scrap. In 2014, rhenium produced from spent catalysts was estimated at approximately 16 metric tons per year (t/yr) (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 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 kilograms per year (kg/yr). This estimate included primary and secondary rhenium used in the form of metal or APR. It includes 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 leading consumer of

rhenium. The leading three U.S. consumers—Cannon Muskegon Corp. (Muskegon, MI), General Electric Aviation (GE) (a subsidiary of General Electric Co., Fairfield, CT), and Pratt & Whitney (a division of United Technologies Corp., Hartford, CT)—consumed an estimated 45,000 kg of rhenium in 2014 (Minor Metals Trade Association, 2012).

Pratt & Whitney announced that it entered into a long-term agreement with Molibdenos y Metales S.A. (Molymet) (Chile) to buy \$690 million worth of rhenium. Under the agreement, Molymet would continue to supply rhenium for use in all Pratt & Whitney's engine programs, including the next generation PurePower® engine family and the F135 military engine that would power the F-35 Lightning II (Pratt & Whitney, 2014). This high-profile commitment from a large aerospace engine manufacturer highlighted the importance that rhenium will continue to hold in the aerospace industry.

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. 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

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

In 2014, the annual average price of APR catalytic-grade rhenium as reported in Metal Bulletin was \$3,100 per kilogram, a 9% decrease compared with the \$3,400 per kilogram annual average price of 2013. The annual average price of rhenium metal pellets (minimum 99.9%) was \$3,000 per kilogram in 2014, a 5% decrease from the \$3,160 per kilogram annual average price of 2013.

## Foreign Trade

Imports of rhenium metal in 2014 were 17,500 kg, a 23% decrease compared with 22,700 kg of rhenium metal in 2013 (table 2). Chile was the leading supplier of rhenium metal to the United States.

Imports of APR were adjusted by the USGS owing to some imports being misclassified as APR. Rhenium-rich residues, perrhenic acid, and flue dusts have also been included in this category. Adjustments were necessary to show only actual imports of APR. In 2014, imports of APR increased to 10,600 kg, a 51% increase compared with the revised 7,020 kg in 2013 (table 3).

## World Review

World primary production of rhenium was estimated to be 44,700 kg in 2014, not including production from China and Russia (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).

Rhenium was recovered as a byproduct from porphyry copper-molybdenum ores mined primarily in Chile, Mexico, Peru, and the United States. No rhenium was recovered in Mexico and Peru in 2014; however, substantial amounts were contained in unroasted molybdenum concentrates that were exported to Chile, the Netherlands, and the United States. Armenia, Japan, Kazakhstan, the Republic of Korea, 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. The increase in rhenium production in Poland and the major decrease of output in Kazakhstan were the most significant developments in primary rhenium supply in recent years. In addition to the countries listed above, China and Russia were thought to produce rhenium, but output was not reported quantitatively. The major producers of rhenium metal and compounds in 2014 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, northwestern China, Iran, Kazakhstan, Mongolia, Poland, Russia, and Uzbekistan. U.S. reserves were estimated to be about 390,000 kg, and rest-of-the-world reserves were estimated to be about 2,100,000 kg.

**Canada.**—Molycorp, Inc. acquired the hydrometallurgical rhenium recovery plant in Napanee, Ontario, in 2012 when it purchased Neo Material Technologies Ltd. In 2013, Molycorp decided to discontinue operations at Napanee by yearend 2013. In March 2014, Maritime House Ltd., a metal trader based in the United Kingdom, acquired 100% of the plant and renamed it Maritime House Metals Inc. The plant continued to produce catalyst-grade APR, perrhenic acid, and rhenium metal pellets from a range of rhenium-bearing scrap materials. Plant capacity was 2 t/yr of rhenium. The plant was currently being modified to increase capacity as well as to increase the range of rhenium-

bearing scrap that it could recycle economically (Maritime House Ltd., undated).

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 was in the process of constructing its own molybdenum processing plant called Molyb in the port city of Mejillones in northern Chile. It was expected to begin processing rhenium starting in early 2016. The plant was expected to produce 16,000 t/yr of molybdenum trioxide, sulfuric acid, copper, and rhenium. Capacity at Molyb was expected to be 1 t/yr of APR and 6 t/yr of rhenium metal. The rhenium recovered at Molyb was rhenium that would have been recovered at Molymet, and therefore should not be considered as additional rhenium production. In the longer term, Codelco was expected to increase output, and therefore rhenium production could increase (Roskill Information Services Ltd., 2015, p. 61).

**China.**—In China, as in many countries, there were numerous traders that claimed to be able to supply rhenium or APR, and it is difficult to separate those traders from manufacturing companies (Roskill Information Services Ltd., 2015, p. 65). Therefore, it is difficult to formulate reliable estimates of rhenium output levels.

In 2013, Jinduicheng Molybdenum Co. Ltd. (JDC), a subsidiary of Shannxi Youser Group, developed a process to capture rhenium from the molybdenum ores that it mined, concentrated, and roasted. JDC constructed a rhenium recovery plant that was operational by August 2014 (Roskill Information Services Ltd., 2015, p. 65).

**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% rhenium in APR from approximately 3,000 kilograms per month 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. Capacity for secondary rhenium production was estimated to be approximately 2,000 kg/yr (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, California (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. The operations were expected to reopen by 2017. Therefore, during 2014, there was only a small amount of APR produced by Redmet as a result of the lack of feed material from the closed smelter (Metal-Pages, 2014; Roskill Information Services Ltd., 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 t/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 Escondida Mines in Chile owned 15%, 3.6%, and 3%, respectively, by JX Nippon Mining and Metals Corp. (Roskill Information Services Ltd., 2015).

**Poland.**—KGHM Ecoren S.A. (Lubin), a division of Polish copper producer KGHM Polska Miedz 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 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).

The most likely prospects for increased primary production are with Molymet in Chile. When Codelco's Molyb plant becomes operational, some of Molymet's capacity will become available to roast other molybdenum concentrates. 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 increase and have a significant effect on the rhenium market.

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## GENERAL SOURCES OF INFORMATION

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

(Kilograms, gross weight)

	2010	2011	2012	2013	2014
Production <sup>2</sup>	6,100	8,600	7,900	7,100	8,500
Apparent consumption <sup>3</sup>	39,700	42,100	48,100	42,400	43,000
Imports:					
Metal	23,100	23,800	27,400	22,700	17,500
Ammonium perrhenate	15,100	13,800	19,200	7,020 <sup>r</sup>	10,600

<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<sup>1</sup>

Country	2013		2014	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Canada	859	\$1,370	239	\$297
Chile	18,800	47,000	15,700	39,400
China	11	7	6	20
Germany	364	942	913	2,500
Norway	--	--	210	1,280
Poland	2,500	8,890	227	808
United Kingdom	210	1,250	144	751
Total	22,700	59,500	17,500	45,100

-- 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.

TABLE 3  
U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY<sup>1</sup>

Country	2013		2014	
	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Canada	--	--	1,520	\$2,270
Chile	61	\$320 <sup>r</sup>	--	--
Estonia	116 <sup>r</sup>	58	100	\$143
Germany	76	261	295	695
Japan	--	--	1,020	1,100
Kazakhstan	3,990	8,200	4,180	8,540
Korea, Republic of	2,780 <sup>r</sup>	3,970 <sup>r</sup>	3,280	4,890
Poland	--	--	145	184
United Kingdom	--	--	60	123
Total	7,020 <sup>r</sup>	12,800 <sup>r</sup>	10,600	17,900

<sup>r</sup>Revised. -- 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; data adjusted by the U.S. Geological Survey.

TABLE 4  
RHENIUM: ESTIMATED WORLD PRODUCTION, BY COUNTRY<sup>1,2</sup>

(Kilograms)

Country <sup>3</sup>	2010	2011	2012	2013	2014
Armenia	183 <sup>r</sup>	254 <sup>r</sup>	293 <sup>r</sup>	298 <sup>r</sup>	351
Chile <sup>4</sup>	25,000	24,000	27,000	25,000	25,000
Kazakhstan	3,000	3,000	3,000	2,500	300
Poland <sup>5</sup>	4,656 <sup>6</sup>	6,000 <sup>6</sup>	8,075 <sup>6</sup>	7,530 <sup>6</sup>	7,600
United States <sup>6,7</sup>	6,100	8,600	7,900	7,100	8,500
Uzbekistan	1,200 <sup>r</sup>	1,200 <sup>r</sup>	1,200 <sup>r</sup>	900 <sup>r</sup>	900
Other <sup>8</sup>	1,500	1,500	1,200	1,000	2,000
Total	41,600 <sup>r</sup>	44,600 <sup>r</sup>	48,700 <sup>r</sup>	44,300 <sup>r</sup>	44,700

<sup>r</sup>Revised.

<sup>1</sup>World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Includes data available through June 15, 2014.

<sup>3</sup>In addition to the countries listed, China and Russia also produce rhenium but output is not officially reported, and available general information is inadequate for the formulation of reliable estimates of output levels.

<sup>4</sup>Includes rhenium contained in molybdenum concentrates from Belgium, Mexico, Peru, and the United States processed at Molymet in Chile.

<sup>5</sup>Based on information from KGHM Ecoren S.A. Calculations based on 69.2% rhenium content of ammonium perrhenate.

<sup>6</sup>Reported figure.

<sup>7</sup>Calculated rhenium contained in molybdenite concentrates. Data are rounded to two significant digits.

<sup>8</sup>Includes estimates for Japan, the Republic of Korea, and Mongolia.