



2012 Minerals Yearbook

RHENIUM

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U.S. estimated primary rhenium production decreased by about 8%, while apparent consumption of rhenium increased by about 14% from that of 2011 (table 1). World primary production of rhenium in 2012 was estimated to be about 52,600 kilograms (kg), a 4% increase from that of 2011 (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 Arizona, Montana, New Mexico, and Utah. During roasting of the molybdenite concentrates to produce molybdenum oxide, rhenium is oxidized to 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). In the United States in 2012, only one molybdenum concentrate roasting facility was so equipped—the Freeport McMoRan Copper & Gold Inc. Sierrita facility in Arizona. 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. 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 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.

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.

Of the world's approximately 50- to 55-metric-ton (t) annual consumption of rhenium, 80% was used 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 (a division of United Technologies Corp., Hartford, CT), 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 continued work 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 rhenium prices. GE recycles used, high-pressure turbine blades (HPTBs) made of a rhenium-bearing nickel superalloy, which 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 (General Electric Aviation, 2011).

Rio Tinto plc announced that its molybdenum autoclave process (MAP) plant at Bingham Canyon in Utah was expected to come onstream by the middle of 2014. MAP would allow lower grade molybdenum concentrate to be processed more efficiently than through conventional roasters, allow improved molybdenum recovery and operating flexibility, and enable production of metallurgical and higher chemical grade molybdenum products. MAP would produce chemical grade molybdenic oxide, ammonium dimolybdate, autoclaved molybdenum concentrate, and catalyst grade ammonium perrhenate (Rio Tinto plc, 2013, p. 49). 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 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 2012, the annual average price of APR catalytic-grade rhenium as reported in Metal Bulletin was \$3,990 per kilogram, an 8% decrease compared with the \$4,360 per kilogram annual average price of 2011. The annual average price of rhenium metal pellets (minimum 99.9%) was \$4,040 per kilogram in 2012, a 13% decrease from the \$4,670 per kilogram annual average price of 2011. The rhenium metal pellet price was \$4,630 per kilogram until February, when it continually trended downward for the rest of the year to \$3,420 per kilogram by yearend.

Foreign Trade

Imports of rhenium metal in 2012 were 27,400 kg, a 15% increase compared with 23,800 kg of rhenium metal in 2011. Chile and Poland were the leading suppliers of rhenium metal to the United States. Imports of APR increased to 18,400 kg, a 33% increase compared with 13,800 kg of APR in 2011. 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 primary production of rhenium was estimated to have been about 52,600 kg in 2012 (table 4). This estimate was based on the quantity of rhenium recovered from concentrates that were processed to recover rhenium values. Secondary world production of rhenium in 2012 was estimated to be about 12,000 kg in 2012 (Roskill Information Services Ltd., 2013, p. 15).

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, countries where ore is processed for copper recovery, and the rhenium-bearing residues are recovered at the copper smelters. 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.

Canada.—Molycorp, Inc. reported that its hydrometallurgical rhenium recovery plant in Napanee, Ontario, was focusing on the recycling of rhenium-bearing superalloys. The facility, according to the company, was the first of its kind in North America, and was primarily toll refining rhenium-bearing scrap to produce rhenium as a service to its clients (Molycorp, Inc., undated).

Chile.—According to Molibdenos y Metales S.A. (Molymet) (Santiago), it has the largest rhenium recovery plant in the world, based in Nos, with an estimated capacity of 40 t/yr of rhenium metal and APR. The Nos plant has three concentrate roasters with a total molybdenum treatment capacity of 43,000 t/yr. In addition to its Chilean operations, Molymet has 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., 2013, p. 34). 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. In February 2012, Molymet acquired a 13% interest in Molycorp (Molibdenos y Metales S.A., 2012). 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% rhenium in APR, from approximately 3,000 kg per month of various alloys. The company recycled molybdenum-rhenium alloys, tungsten-rhenium alloys, nickel-based superalloys, and other rhenium-containing scrap metals sourced from European and United States companies. 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), with a rhenium recycling capacity of 11 t/yr, was one of the leading recyclers of rhenium from catalysts. Heraeus operated recycling facilities in Hanau and in Sante Fe, 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).

Kazakhstan.—Zhezkazganredmet (Redmet), Kazakhstan's state-owned rhenium producer, received rhenium-bearing residues from the Zhezkazgan Copper Works mine and smelter complex. Zhezkazgan was controlled by Kazakhmys plc, and its parent Samsung Corp., which received 50% of Redmet's production as payment for the rhenium residues. A disagreement, beginning in 2007, between Kazakhmys 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 Zhezkazgan 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 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 3.5 t of metallic rhenium. It was also able to supply rhenium metal in powder form according to customer requirements. Ecoren increased its crystalline APR production capacity, which was expected to be 6 to 7 t/yr of APR. Ecoren received 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., 2013).

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 expected to increase by an average of 3% per year between 2013 and 2018 to reach 70,400 kg in 2018 (Roskill Information Services Ltd., 2013, p. 101).

Because the life cycle of turbine blades in jet engines is approximately 10 years, significant quantities of second-generation blades (3% rhenium) 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. 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 potential 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%.

However, secondary production of rhenium is more likely to contribute to an increase in supply in coming years than primary production. The entry of Molycorp into recycling of rhenium-bearing scrap is an example of a new opportunity to increase rhenium output. In 2012, Molycorp invested in rhenium recycling with the acquisition of Neo Materials Technologies in Canada and entering into a joint venture with Buss & Buss in Germany (Roskill Information Services Ltd., 2013, p. 25).

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TABLE 1
 SALIENT U.S. RHENIUM STATISTICS¹

(Kilograms, gross weight)

| | 2008 | 2009 | 2010 | 2011 | 2012 |
|-------------------------------------|--------|--------|--------|--------|--------|
| Production ² | 7,910 | 5,580 | 6,100 | 8,610 | 7,910 |
| Apparent consumption ^{c,3} | 51,600 | 37,100 | 39,700 | 42,100 | 48,100 |
| Imports: | | | | | |
| Metal | 35,900 | 21,500 | 23,100 | 23,800 | 27,400 |
| Ammonium perrhenate | 11,200 | 14,300 | 15,100 | 13,800 | 18,400 |

^cEstimated.

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

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

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

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

| Country | 2011 | | 2012 | |
|----------------|--------------------------|-------------------|--------------------------|-------------------|
| | Gross weight (kilograms) | Value (thousands) | Gross weight (kilograms) | Value (thousands) |
| Belgium | -- | -- | 7 | \$55 |
| Canada | -- | -- | 39 | 74 |
| Chile | 22,200 | \$51,400 | 23,900 | 55,200 |
| France | 100 | 335 | -- | -- |
| Germany | 150 | 548 | 397 | 862 |
| Poland | 1,200 | 2,980 | 2,980 | 10,200 |
| United Kingdom | 209 | 556 | 140 | 1,210 |
| Total | 23,800 | 55,800 | 27,400 | 67,500 |

-- 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 | 2011 | | 2012 | |
|--------------------|-----------------------------|----------------------|-----------------------------|----------------------|
| | Gross weight (kilograms) | Value (thousands) | Gross weight (kilograms) | Value (thousands) |
| Canada | 1,610 | \$3,520 | 850 | \$1,450 |
| Germany | -- | -- | 2,300 | 3,910 |
| Kazakhstan | 4,040 | 7,270 | 9,470 | 16,100 |
| Korea, Republic of | 6,000 | 10,800 | 5,200 | 8,840 |
| Netherlands | -- | -- | 182 | 346 |
| United Kingdom | 2,200 | 4,800 | 413 | 858 |
| Total | 13,800 | 26,400 | 18,400 | 31,500 |

-- 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 | 2008 | 2009 | 2010 | 2011 | 2012 |
|------------------------------|----------------------|---------------------|---------------------|---------------------|--------|
| Armenia | 400 | 400 | 400 | 400 ^r | 600 |
| Chile ³ | 27,600 | 25,000 | 25,000 | 24,000 ^r | 27,000 |
| Kazakhstan | 5,500 | 3,000 | 3,000 | 3,000 | 3,000 |
| Korea, Republic of | -- | -- | -- | -- ^r | -- |
| Poland ⁴ | 3,400 ^{r,5} | 2,422 ⁵ | 4,656 ⁵ | 6,000 ⁵ | 6,000 |
| Russia | 1,500 | 1,500 | 1,500 | 1,500 ^r | 1,500 |
| United States ^{5,6} | 7,910 | 5,580 | 6,100 | 8,610 | 7,910 |
| Uzbekistan | 4,800 ^r | 4,800 ^r | 4,800 ^r | 5,400 ^r | 5,400 |
| Other | 2,000 | 1,500 | 1,500 | 1,500 | 1,200 |
| Total | 53,100 ^r | 44,200 ^r | 47,000 ^r | 50,400 ^r | 52,600 |

^rRevised. -- Zero.

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

²Table includes data available through September 12, 2013.

³Data also includes rhenium content from Belgium, Mexico, Peru, and the United States, processed at Molymet in Chile.

⁴Data based on new information from KGHM Ecoren S.A. Calculated based on 69.2% rhenium content of ammonium perrhenate.

⁵Reported figure.

⁶Calculated rhenium contained in molybdenite concentrates. Data rounded to two significant digits.