



2016 Minerals Yearbook

SELENIUM AND TELLURIUM [ADVANCE RELEASE]

SELENIUM AND TELLURIUM

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In 2016, selenium and tellurium were not refined in the United States. Three copper refineries produced either semirefined selenium and tellurium or selenium- and tellurium-containing copper anode slimes, and all production was exported for further processing. U.S. imports and exports of selenium and tellurium decreased in 2016 compared with those in 2015. The average Platts Metals Week New York dealer price for selenium in 2016 increased by 7% to \$23.69 per pound from \$22.09 per pound in 2015, and the average In Warehouse Rotterdam price for tellurium, as reported by Argus Media group – Argus Metals International, decreased by 60% in 2016 to \$31.44 per kilogram from \$78.12 per kilogram in 2015.

Except for two mines in China that began mining tellurium as a principal product in 2010, selenium and tellurium were recovered as byproducts of nonferrous metal mining, principally from the anode slimes produced during the electrolytic refining of copper. Selenium and tellurium were also recovered as byproducts of gold, lead, nickel, platinum-group metals, and zinc.

Production

Three primary electrolytic copper refineries produced selenium- and tellurium-containing intermediate products in the United States in 2016. ASARCO LLC's (Tucson, AZ) copper refinery in Amarillo, TX, produced semirefined selenium and tellurium, which were exported to Mexico for further processing. Freeport-McMoRan Inc.'s (Phoenix, AZ) copper refinery at El Paso, TX, produced and exported semirefined material containing tellurium to Asia. Rio Tinto Kennecott's [a subsidiary of Rio Tinto plc (United Kingdom)] refinery at Garfield, UT, generated selenium- and tellurium-containing slimes. Most of the selenium and tellurium contained in domestic anode slimes came from copper ores mined in Arizona and Utah. Domestic production of selenium and tellurium decreased in 2016, with production of refined selenium coming to a halt and production of tellurium decreasing by 3%.

Consumption

Selenium.—In 2016, domestic and global consumption data for selenium were unavailable. In 2010, the last year that data were available, global consumption of selenium by application was estimated as, in descending order of consumption, electrolytic manganese and metallurgy; glass manufacturing; agriculture, chemicals and (or) pigments, and electronics; and other (Selenium Tellurium Development Association, 2010).

The main metallurgical end use for selenium in 2016 was for the production of electrolytic manganese in China, where selenium dioxide (SeO₂) was substituted for sulfur dioxide to reduce the power required to operate electrolytic cells. In 2016, global manganese production increased by 8% to 1.27 million metric tons (Mt), of which China remained the main producer

(Metal-Pages, 2017b). In other metallurgical applications, selenium was used with bismuth to substitute for lead as a free-machining agent in brass plumbing fixtures. Metallurgical-grade selenium also was used as an additive to cast iron, copper, lead, and steel alloys.

In the glass industry, selenium was used to decolorize the green tint caused by iron impurities in container glass and other soda-lime silica glass. It was also used in art and other glass to produce a ruby red color and in architectural plate glass to reduce solar heat transmission through the glass.

Selenium is a micronutrient essential to human and animal health, and in areas with selenium-poor soils, selenium has been added to fertilizer and applied to acreage used to grow animal feed to increase selenium in the diet of animals and, in turn, the diet of humans. This practice was more common outside the United States, especially in countries with selenium-poor soils.

Cadmium sulfoselenide compounds were used as pigments in ceramics, glazes, paints, and plastics. Selenium pigments have good heat stability, react well to moisture, and are resistant to ultraviolet or chemical exposure. These pigments produce a wide range of red, orange, and maroon colors but, because of the relatively high cost and the toxicity of cadmium-based pigments, their use was limited to applications where cost was not the prevailing factor and human contact was limited, such as art pieces.

In 2016, three major types of thin-film photovoltaic (PV) cells were in commercial production—amorphous silicon, cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS). However, thin-film solar cells accounted for only about 4% of all solar cells produced annually; the majority of PV solar cell production continued to be dominated by the conventional crystalline silicon technology (Fraunhofer-Institut für Solare Energiesysteme ISE, 2016, p. 19). Global PV cell and module production in 2016 was estimated by industry sources to be between 78 and 82 gigawatts (GW). China produced about 50 GW of solar cells and modules in 2016, with plans to reach an installed annual production capacity of 110 GW by 2020, revised downward from 150 GW (Xinhua, 2016; Jäeger-Waldau, 2017).

Tellurium.—Industry estimates for global tellurium consumption by application were solar panels, 40%; thermoelectric applications, 35%; and metallurgical uses and other, 10% each. First Solar, Inc. (Tempe, AZ), one of the world's leading producers of CdTe solar panels, suspended operations at its CdTe factory in Toledo, OH, in November to restructure its business. The company announced that it would discontinue production of its more expensive Series 5 solar cells and convert the existing production facility to produce larger and less expensive Series 6 solar cells through 2017 and 2018 (Willing, 2015; First Solar Inc., 2016; Metal-Pages, 2016f).

Other uses for tellurium include thermal imaging and thermoelectric cooling. In thermal-imaging devices for infrared

sensors and heat-seeking missiles, mercury-cadmium-telluride was built up on a base of cadmium-zinc-telluride and was used to convert the raw image into a crisp screen picture in a cryo-cooled environment. Semiconducting bismuth telluride was used in thermoelectric cooling devices. These devices consist of a series of semiconducting material couples that, when connected to a direct current, cause one side of the thermoelement to cool and the other side to heat. Thermoelectric coolers were used in electronics and military applications, such as the cooling of infrared detectors, integrated circuits, laser diodes, and medical instrumentation, as well as in high-end automobiles to cool cup holders and seats. In China, these devices were used in refrigerators, water dispensers, and other home appliances.

In metallurgy, tellurium was used in steel as a free-machining additive, in copper to improve machinability without reducing conductivity, in lead to improve resistance to vibration and fatigue, in cast iron to help control the depth of chill, and in malleable iron as a carbide stabilizer.

Tellurium was used as a vulcanizing agent and as an accelerator in the processing of rubber and in catalysts for synthetic fiber production. Other applications included the use of tellurium as a pigment to produce blue and brown colors in ceramics and glass.

Prices

The Platts Metals Week annual average New York dealer price for selenium was \$23.69 per pound in 2016, 7% more than the annual average price in 2015. The price was stable at about \$20 per pound until midyear, when it rose to a monthly average of \$34 per pound. The price then fell to \$14 per pound in November and decreased to a low of \$8.50 per pound in December.

The Rotterdam 99.99%-pure tellurium price published by Argus Media group – Argus Metals International averaged \$31.44 per kilogram in 2016, a 60% decrease from the 2015 price of \$78.12 per kilogram. The monthly average price range began the year at \$20 to \$39 per kilogram in January and increased throughout the year to a range of \$23 to \$39 per kilogram in December.

Foreign Trade

Selenium.—Exports of selenium materials in 2016 decreased by 68% to 150 metric tons (t) from those in 2015. In descending order of quantity, Indonesia, China, Japan, Hong Kong, and Russia were the destinations for 91% of selenium exports in 2016. Exports to Taiwan had the largest decrease, declining from 103,000 kilograms in 2015 to no exports in 2016, followed by the Republic of Korea (decrease of 87,100 t) and China (decrease of 76,800 t). Partially offsetting these decreases were increased exports to Indonesia (increase of 29,800 t) and Japan (increase of 22,500 t). Based on unrounded data, the annual average value of exports in 2016 was \$11.84 per kilogram (\$5.37 per pound), 32% less than the 2015 annual average (table 2). Because of the low value, much of the material reported as selenium was thought to be unrefined metal, residues, and scrap.

In 2016, imports for consumption of selenium, including the selenium content of SeO₂, decreased by 5% from 463 t to

441 t. China, the Philippines, Mexico, Germany, Belgium, the Republic of Korea, Japan, Norway, the United Kingdom, and Canada, in descending order of quantity, accounted for 99% of the imports of selenium materials into the United States in 2016. Based on unrounded data, the annual average value of all imported selenium in 2016 was \$29.51 per kilogram (\$13.38 per pound), 31% less than in 2015 (table 3).

In 2016, imports for consumption of SeO₂ increased by 54% to 30 t from those in 2015. Three countries—the Republic of Korea, China, and Germany, in decreasing order of quantity—supplied the United States with the 96% of the SeO₂ imports in 2016, with the Republic of Korea accounting for 58% of the imports (table 3). Based on unrounded data, the annual average value of imports of SeO₂ was \$18.10 per kilogram (\$8.21 per pound), about a 45% decrease compared with that of 2015.

Tellurium.—In 2016, tellurium exports were 4 t, a 90% decrease compared with exports in 2015 (table 4). The main destinations were Canada, the Philippines, and the Republic of Korea, which combined accounted for 83% of total tellurium exports. Imports for consumption of tellurium decreased by 4% in 2016 compared with imports in 2015 (table 5). The leading suppliers, in descending order of quantity, Canada and China, accounted for 94% of the total imports of tellurium metal into the United States.

World Review

Global selenium and tellurium output cannot be determined easily because not all companies or countries report production and trade in scrap and semirefined products may be included with refined metal trade data. World production of selenium, excluding U.S. production, was estimated to have increased slightly to 2,250 t in 2016, principally owing to an estimated 40-t increase in Germany. World production of tellurium, excluding U.S. production, was estimated to have increased by 11%, principally owing to estimated production increases in Canada and Sweden (tables 6, 7). The U.S. Geological Survey estimated that 2016 world production of tellurium was 133 t, but this does not take into account countries that were known to produce refined tellurium and did not report their output. Market sources reported that global production of tellurium in 2016 was 516 t (Metal-Pages, 2017a).

China.—China produced an estimated 920 t of selenium in 2016, a 13% increase from the 2015 estimate of 810 t. China's estimated production of tellurium was 279 t, a slight decrease from the 2015 estimate of 280 t.

In April 2016, the Government of China announced plans to increase its PV capacity during the next 5 years, adding 15 to 20 GW of solar power generation capacity annually, reaching a total capacity of 75 to 120 GW. These new solar plants could drive up the consumption of minor metals, including cadmium, indium, gallium, selenium, and tellurium. Industry sources estimated that 1 GW of CIGS solar cells required about 30 t of indium and 15 to 20 t of gallium (Metal-Pages, 2016b).

China Triumph International Engineering Group Co., Ltd. started a new project to build a 1.5-gigawatt-per-year (GW/yr) CIGS solar cell production plant in Bengbu, Anhui Province. No timeframe was given for the completion date. Triumph produced

silicon solar cells through its subsidiary Jietion Solar China Co., Ltd. at a rate of 1 GW/yr (Metal-Pages, 2016d).

The price of SeO₂ in China reached a low of CNY54 to CNY57 per kilogram (\$7.94 to \$8.68 per kilogram) in late May. Daye Nonferrous Metals Group Holdings Co., Ltd. reportedly attempted to raise the SeO₂ price by halting its sales of SeO₂ in August. Daye had a production capacity of 10 to 20 metric tons per month of SeO₂. The SeO₂ price rose significantly at the end of the year owing to an unexpected increase in demand from manganese producers in China. The SeO₂ price in China ended the year at CNY220 to CNY250 per kilogram (\$32.34 to \$36.75 per kilogram). Rising zinc prices increased the price of selenium because zinc concentrates were a source of selenium. (Metal-Pages, 2016c, e).

China's leading copper producer, Jiangxi Copper Co. Ltd., continued its normal output of SeO₂ and tellurium metal despite annual maintenance performed in May. The company's production of SeO₂ and tellurium in May was 25 t and 2 t, respectively, unchanged from April (Metal-Pages, 2016g).

India.—India planned to expand its solar capacity to 100 GW/yr by 2022 from 5 GW/yr in 2015. As a result of the ongoing expansion of the country's solar capacity, India's selenium consumption was estimated to have increased in 2016. Imports of selenium metal into India nearly doubled in 2016 to 565 t from 296 t in 2015 (Xu, 2016; Global Trade Information Services, Inc., 2017).

Sweden.—Byproduct tellurium production at New Boliden AB's Kankberg gold mine increased by 17% in 2016 to 38,700 kg from 33,000 kg in 2015. Boliden reopened the Kankberg Mine in 2012, and the mine's life was expected to extend through 2020 (New Boliden AB, 2011; Metal-Pages, 2016a, 2017a, c).

Outlook

The supply of selenium and tellurium is directly affected by the production of the principal product from which it is derived—copper—and to a lesser extent, by the production of gold, lead, nickel, platinum-group metals, and zinc produced from sulfide ores. Selenium and tellurium prices were slowly recovering throughout 2016 from their 9- and 8-year lows, respectively, reached in 2015, but recovery rates from copper slimes are not expected to increase at the 2016 prices.

In 2017, the tellurium market is expected to be oversupplied, with estimated production to exceed consumption. Production from Boliden is expected to continue at current or higher levels, and consumption of tellurium at First Solar is expected to decrease while the company upgrades its Dayton, OH, production facility (Metal-Pages, 2016f).

At the 2017 Minor Metals Trade Association Conference in Dublin, Ireland, the China Nonferrous Metals Industry Association predicted that demand for selenium will fluctuate with the electrolytic manganese industry. Although other selenium-consuming industries, like solar and agricultural products, are growing, their overall demand remains relatively small. In China, production of selenium products is not enough to supply domestic demand, and imports will continue.

China's consumption of tellurium has decreased since 2012 and is expected to decline further through 2018 owing to decreasing demand for tellurium-based solar cells and increased manufacturing efficiency in the alloy and thermoelectric sectors (Metal-Pages, 2017a).

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TABLE 1
SALIENT SELENIUM AND TELLURIUM STATISTICS¹

(Kilograms, contained metal, unless otherwise specified)

	2012	2013	2014	2015	2016
Selenium:					
United States:					
Production, primary refined	W	W	W	W	W
Exports	952,000	648,000	521,000	468,000	150,000
Imports for consumption	460,000	439,000	475,000	463,000	441,000
Dealers' price, average, commercial grade, ² dollars per pound	54.47	36.08 ^r	26.78	22.09	23.69
World, refinery production, excluding U.S. production	2,260,000 ^r	2,170,000	2,250,000	2,190,000 ^r	2,250,000 ^p
Tellurium:					
United States:					
Production, primary refined	W	W	W	W	W
Exports	47,400	42,300	27,900	40,800	4,150
Imports for consumption	36,100	65,300	109,000	76,000	72,700
Price, commercial grade, ³ dollars per kilogram	149.96 ^r	112.05 ^r	119.37 ^r	78.12 ^r	31.44
World, refinery production, excluding U.S. production	93,700 ^r	104,000 ^r	115,000 ^r	119,000 ^r	133,000

^pPreliminary. ^rRevised. W Withheld to avoid disclosing company proprietary data.

¹Table includes data available through August 2, 2017. Data are rounded to no more than three significant digits, except prices.

²Source: Platts Metals Week.

³The price is the annual average price published by the Argus Media group – Argus Metals International for duties unpaid in warehouse (IWH) Rotterdam, 99.99% tellurium.

TABLE 2
U.S. EXPORTS OF SELENIUM¹

Country or locality	2015		2016	
	Quantity (kilograms, contained Se)	Value	Quantity (kilograms, contained Se)	Value
Australia	2,010	\$31,200	958	\$14,800
Belgium	--	--	396	6,140
Brazil	3,480	58,500	220	3,160
Canada	2,470	69,800	1,090	32,700
China	99,300	1,360,000	22,500	150,000
Colombia	--	--	375	9,680
Denmark	50	3,880	--	--
Dominican Republic	640	9,920	--	--
Germany	4,710	73,000	390	6,050
Hong Kong	62,400	872,000	19,500	113,000
India	--	--	178	2,750
Indonesia	22,100	343,000	51,900	805,000
Japan	--	--	22,500	348,000
Korea, Republic of	91,900	1,710,000	4,760	73,800
Mexico	17,400	298,000	5,710	113,000
Panama	409	12,200	--	--
Peru	981	15,200	--	--
Philippines	2,090	16,200	--	--
Russia	46,300	275,000	19,300	91,500
Saudi Arabia	--	--	75	3,190
South Africa	1,560	24,100	--	--
Taiwan	103,000	2,880,000	--	--
United Kingdom	990	9,860	--	--
Venezuela	6,060	93,900	--	--
Total	468,000	8,160,000	150,000	1,770,000

-- Zero.

¹Table includes data available through August 2, 2017. 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 SELENIUM¹

Class and country or locality	2015		2016	
	Quantity (kilograms, contained Se)	Value	Quantity (kilograms, contained Se)	Value
Selenium:				
Belgium	31,000	\$976,000	27,400	\$431,000
Canada	15,800	464,000	14,600	235,000
China	84,300	3,450,000	88,200	1,420,000
Germany	39,300	1,810,000	57,300	1,320,000
Hong Kong	200	15,900	--	--
India	63	5,040	--	--
Japan	60,600	3,660,000	19,000	1,110,000
Korea, Republic of	24,000	804,000	13,000	167,000
Mexico	42,800	978,000	64,800	788,000
Netherlands	7	24,600	6	17,000
New Zealand	2,020	13,900	2,540	19,100
Norway	35,600	232,000	17,800	128,000
Panama	21,100	964,000	--	--
Philippines	50,600	4,230,000	88,100	6,510,000
Russia	--	--	1,000	21,500
Serbia	--	--	960	14,400
Thailand	2,980	131,000	--	--
United Kingdom	33,200	1,520,000	16,700	286,000
Total	444,000	19,300,000	411,000	12,500,000
Selenium dioxide:²				
Belgium	--	--	950	23,000
China	11,600	387,000	6,550	147,000
Germany	4,460	186,000	4,690	131,000
Japan	3,150	56,200	272	10,200
Korea, Republic of	--	--	17,200	226,000
Total	19,200	629,000	29,600	537,000
Grand total	463,000	19,900,000	441,000	13,000,000

-- Zero.

¹Table includes data available through August 2, 2017. Data are rounded to no more than three significant digits; may not add to totals shown.

²Selenium content calculated as 71% of gross weight of material.

Source: U.S. Census Bureau.

TABLE 4
U.S. EXPORTS OF TELLURIUM¹

Country or locality	2015		2016	
	Quantity (kilograms, contained Te)	Value	Quantity (kilograms, contained Te)	Value
Brazil	1,200	\$114,000	--	--
Canada	36,200	1,590,000	1,390	\$252,000
China	6	3,280	21	8,680
Germany	1,710	625,000	4	2,800
Hong Kong	166	24,900	--	--
India	30	4,830	--	--
Japan	--	--	323	17,500
Jordan	486	72,700	352	52,800
Korea, Republic of	16	8,450	1,020	222,000
Mexico	61	2,760	--	--
Netherlands	420	50,900	--	--
Philippines	--	--	1,030	94,400
Singapore	427	31,900	15	4,000
Switzerland	--	--	1	4,900
United Kingdom	10	2,700	--	--
Total	40,800	2,530,000	4,150	660,000

-- Zero.

¹Table includes data available through August 2, 2017. Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF TELLURIUM¹

Country or locality	2015		2016	
	Quantity (kilograms, contained Te)	Value	Quantity (kilograms, contained Te)	Value
Belgium	1,000	\$108,000	1,500	\$84,400
Canada	51,000	2,730,000	37,700	2,180,000
China	22,800	2,940,000	30,900	2,340,000
Germany	132	32,800	242	55,100
Japan	28	62,900	237	25,300
Netherlands	1	2,380	--	--
Philippines	1,030	95,700	2,160	188,000
Ukraine	8	17,600	3	8,430
Total	76,000	5,990,000	72,700	4,880,000

-- Zero.

¹Table includes data available through August 2, 2017. Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 6
SELENIUM: WORLD REFINERY PRODUCTION, BY COUNTRY OR LOCALITY¹

(Kilograms of contained selenium)

Country or locality ²	2012	2013	2014	2015	2016 ^P
Belgium ^c	200,000	200,000	200,000	200,000	200,000
Canada ^{c,3}	145,000 ^r	138,000 ^r	142,000 ^r	156,000 ^r	176,000
Chile ^{c,4}	75,000	--	--	--	--
Finland	92,769	72,459 ^r	93,682	94,000 ^e	96,000 ^e
Germany ^c	650,000	675,000 ^r	675,000 ^r	660,000	700,000
India ^{c,5}	16,000	17,000	17,000	17,000	17,000
Japan	755,000 ^e	741,300	782,451	772,768	752,000
Peru	54,000	42,000	40,000 ^e	40,000 ^e	45,000
Poland ^c	90,200 ^r	80,200 ^r	80,000 ^r	80,000 ^r	87,000
Russia	114,620	114,160	130,810	135,000	145,000 ^e
Serbia ^c	13,200	13,000	13,000	13,000	14,500
Sweden ^c	20,000	20,000	20,000	20,000	20,000
Turkey	31,000 ^r	59,000 ^r	53,000 ^r	-- ^r	--
United States	W	W	W	W	W
Total	2,260,000 ^r	2,170,000	2,250,000	2,190,000 ^r	2,250,000

^cEstimated. ^PPreliminary. ^rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.

¹Includes data available through May 8, 2017. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²In addition to the countries and (or) localities listed, Australia, China, Iran, Kazakhstan, Mexico, the Philippines, and Uzbekistan may have produced refined selenium, but available information was inadequate to make reliable estimates of output. Australia was known to produce selenium in intermediate metallurgical products and had facilities to produce elemental selenium. In addition to having facilities for processing imported anode slimes for the recovery of selenium and precious metals, the United States had facilities for processing selenium scrap.

³Excludes selenium intermediates exported for refining.

⁴The noble metals plant at Ventanas temporarily stopped production for limited periods of time during the fourth quarter of 2012, and planned to continue to limit production during the first quarter of 2013.

⁵Data are for the fiscal year beginning April 1 of the year stated.

TABLE 7
TELLURIUM: WORLD REFINERY PRODUCTION, BY COUNTRY OR LOCALITY^{1,2}

(Kilograms of contained tellurium)

Country or locality ³	2012	2013	2014	2015	2016 ^P
Bulgaria ^c	2,470 ^r	5,010 ^r	4,930 ^r	4,050 ^r	4,000
Canada ^{c,4}	11,000	12,000	9,500 ^r	10,000 ^r	18,000
Japan	43,000 ^e	31,000 ^e	36,919	37,356	38,000 ^e
Russia ^c	30,400 ^r	31,000 ^r	32,500 ^r	35,000	35,000
Sweden	6,791	24,457	30,917	33,000	38,000
United States	W	W	W	W	W
Total	93,700 ^r	104,000 ^r	115,000 ^r	119,000 ^r	133,000

^cEstimated. ^PPreliminary. ^rRevised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

¹Includes data available through May 8, 2017. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Insofar as possible, data relate to refinery output only; thus, countries that produced tellurium contained in copper ores, copper concentrates, blister copper, or refinery residues but did not recover refined tellurium are excluded to avoid double counting.

³In addition to the countries and (or) localities listed, Australia, Belgium, Chile, China, Colombia, Germany, Kazakhstan, Mexico, the Philippines, and Poland were known to produce refined tellurium, but output was not reported; available information was inadequate to make reliable estimates of output.

⁴Excludes tellurium intermediates exported for refining.