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SELENIUM AND TELLURIUM [ADVANCE RELEASE]

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Selenium and Tellurium

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In 2015, domestic production of selenium and tellurium decreased significantly. Only one copper refinery in Texas reported producing primary refined selenium and tellurium. U.S. apparent consumption of selenium and tellurium decreased in 2015 compared with that in 2014. The average U.S. dealers' prices for selenium in 2015 decreased by 18% to $22.09 per pound from $26.78 per pound in 2014, and ended the year at an average of $20.50 per pound. The average In Warehouse Rotterdam price for tellurium in 2015 decreased by 36% to $77 per kilogram from $119 per kilogram in 2014, and ended the year at an 8-year low price of $33.25 per kilogram. These yearend price decreases reflected a decrease in global consumption of selenium and tellurium and an overall decrease in most mineral commodity prices during 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 operated in the United States during 2015. The only U.S. producer of refined selenium and tellurium, ASARCO LLC's (Tucson, AZ) copper refinery in Amarillo, TX, responded to an annual survey of production by the U.S. Geological Survey. To avoid disclosing company proprietary data, production data were withheld. A second copper refinery produced and exported semirefined material containing 90% selenium plus tellurium for toll refining in Asia, and the third refinery generated selenium- and tellurium-containing slimes that were exported for processing. Most of the selenium and tellurium contained in domestic anode slimes came from copper ores in Arizona and Utah. Domestic production of refined selenium and tellurium decreased in 2015 compared with production in 2014.

Consumption

Selenium.—In 2015, world consumption of selenium was estimated to have been slightly less than that in 2014. In 2010, the last year that data were available, global consumption of selenium by application was estimated, in descending order of consumption, as electrolytic manganese and metallurgy, 40%; glass manufacturing, 25%; agriculture, chemicals/pigments, and electronics, 10% each; and other, 5% (Selenium Tellurium Development Association, 2010).

The main metallurgical end use for selenium was for the production of electrolytic manganese in China, where selenium dioxide (SeO_2) was substituted for sulfur dioxide to reduce the power required to operate electrolytic cells. In 2015, electrolytic manganese production in China decreased to 1.01 million metric tons (Mt) from 1.28 Mt in 2014 and 1.48 Mt in 2011. Production capacity also trended downward, decreasing to 1.76 million metric tons per year (Mt/yr) in 2015 from 1.95 Mt/yr in 2014 and 2.4 Mt/yr in 2011. Only 54 producers of manganese were reportedly operating in 2015, down from 78 in 2014 (Chao, 2015b; International Manganese Institute, 2016).

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 was also 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 2015, about 68 gigawatts (GW) of solar cells were produced globally. Conventional crystalline silicon-based cells remained the dominant photovoltaic (PV) technology, accounting for 93% of the market, and thin-film PV cells accounted for 7%. Three major types of thin-film PV cells were in commercial production—amorphous silicon, cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS). In 2015, CdTe solar cell production accounted for 35% of thin-film PV production (National Renewable Energy Laboratory, 2016, p. 68; Fraunhofer-Institut für Solare Energiesysteme ISE, 2016, p. 19).

Tellurium.—World consumption of tellurium was estimated to have decreased in 2015 owing to a continued lack of demand from consumers and investment purchasing in China beginning in August 2014 (Chao, 2015e). Based on a 30% decrease in U.S. imports, U.S. apparent consumption has also decreased (table 1). Industry estimates for tellurium consumption were solar panels, 40%; thermoelectric applications, 35%; metallurgical uses, 10%, and other, 10% (Willing, 2015).

Although thin-film solar cell production was estimated to have remained unchanged in 2015, because of the decreasing cost of conventional silicon-based cells, CdTe solar cell production, and hence use of tellurium in this application, continued to decrease. At the end of 2015, the Federal Government extended subsidies and tax credits aimed at encouraging solar projects in the United States. The subsidies were to expire at the end of 2016, but the budget continuation passed by Congress in December extended the Solar Energy Credit to phase out beginning on January 1, 2019, and decrease incrementally until January 1, 2022, when it would remain at a 10% tax credit. The phase out would apply a 30% credit to any new solar construction that begins before 2019, a 26% credit for any new construction that begins in 2019 or 2020, a 22% credit for new construction that begins in 2021 or 2022, and a 10% credit to any new construction that begins thereafter (U.S. Congress, 2015).

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.

Consumption estimates of tellurium remained stable owing to increasing production capacity in anticipation of new tellurium applications. 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 (Willing, 2015).

Prices

The Platts Metals Week annual average New York dealer price for selenium was $22 per pound in 2015, 18% less than the annual average price in 2014. The price range began the year at $22.50 to $27.00 per pound and ended the year with a range of $17.00 to $19.00 per pound.

The Argus Media group Metal-Pages published Rotterdam 99.99%-pure tellurium price averaged $77 per kilogram in 2015, a 36% decrease from the 2014 price of $119 per kilogram. The monthly average price range in January 2015 was $113 to $122 per kilogram and decreased throughout the year to a range of $28 to $39 per kilogram in December. The sharp decrease throughout the year was attributed to weak demand and the potential release of 170 metric tons (t) of tellurium to the spot market following an audit of the Fanya Metal Exchange (FME) in China (Chao, 2015f)

Foreign Trade

Exports of selenium materials in 2015 decreased by 10% to 468 t from those in 2014. In descending order of quantity, Taiwan, China, the Republic of Korea, Hong Kong, Russia, Indonesia, and Mexico were the destinations for 95% of selenium exports in 2015. Based on unrounded data, the annual average value of exports in 2015 was $17.43 per kilogram ($7.91 per pound), 6% less than the 2014 annual average (table 2). Based on the low value, much of the material reported as selenium was thought to be unrefined metal, residues, and scrap.

In 2015, imports for consumption of selenium, including SeO_2, decreased slightly to 463 t. China, Japan, the Philippines, Germany, Mexico, Norway, the United Kingdom, Belgium, and the Republic of Korea, in descending order of quantity, accounted for 91% of the imports of selenium materials into the United States in 2015. Based on unrounded data, the annual average value of all imported selenium in 2015 was $42.99 per kilogram ($19.50 per pound), 24% less than in 2014 (table 3).

In 2015, imports for consumption of SeO_2 increased by 148% to 19 t from those in 2015. Three countries—China, Germany, and Japan, in decreasing order of quantity—supplied the United States with SeO_2 in 2015, with China accounting for more than 60% of the imports (table 3). Based on unrounded data, the annual average value of imports of SeO_2 was $32.70 per kilogram ($14.83 per pound), about a 52% decrease compared with that of 2014.

In 2015, tellurium exports increased to 41 t, a 46% increase compared with exports in 2014 (table 4). The main destination was Canada, which accounted for 89% of total tellurium exports. Imports for consumption of tellurium decreased by 30% in 2015 compared with imports in 2014 (table 5). The leading suppliers, in descending order of quantity, Canada and China, accounted for 97% 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. Production of selenium was estimated to have slightly decreased to 2,200 t in 2015, principally owing to a 40 t decrease in Germany. Tellurium production was estimated to have increased slightly, principally owing to an estimated production increase in Russia (tables 6, 7). The U.S. Geological Survey estimateed that 2015 world production of tellurium was 114 t, but this does not take into account countries that are known to produce refined tellurium and do not report their output. Market sources estimated that global production of tellurium is between 550 and 650 t (Willing, 2015).

China.—An audit of the FME, ordered by the Kunming government, raised concerns that 170 t of tellurium could be released to the spot market and result in a significant market surplus. The FME's issues were initiated in April, when clients of the FME were unable to withdraw funds from the Ri Jin Bao investment product. The Ri Jin Bao product was based on metals that were to be used in electronics and had promised returns of more than 13% per year. Reportedly, more than 220,000 investors had purchased the Ri Jin Bao product, with a total estimated value of 43 billion yuan ($6.77 billion). In October, the Yunnan Provincial government instructed the municipal government of Kunming to launch an official investigation into the FME. The key points of the investigation were to determine if the FME had made up trading items, concealed facts, created a capital pool and taken control of the funds within, and illegally possessed and used the funds that it had raised. In November, when FME's Web site was shut down, warehouses reportedly still contained 337.8 t of selenium and 170 t of tellurium (Chao, 2015c; Zhao, 2015a–c, 2016).

A new association for gallium, selenium, and tellurium that focused on technological innovation and increasing the value of the three minor metals was formed in June (Chao, 2015a).

Environmental Issues

Researchers determined that the Bowland Shale in northern England had high levels of selenium within the natural gas. The high levels of selenium are of concern, because during the drilling operations, selenium may be released into the local groundwater supplies (Parnell and others, 2016). Selenium in groundwater could cause selenium poisoning, which has initial symptoms of a garlic odor and a metallic taste in the mouth, and following symptoms include gastrointestinal symptoms such as nausea or diarrhea, fatigue, irritability, and joint pain. Selenium as a trace element is nutritionally essential in humans (National Institutes of Health, 2016).

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, or zinc produced from sulfide ores. With selenium and tellurium prices decreasing during 2015 to 9- and 8-year lows, respectively, recovery rates from copper refineries are not expected to increase.

In 2016, the tellurium market is expected to be oversupplied, with estimated production to exceed consumption. Refrigeration companies in China were expected to draw down their existing stocks, and the FME stopped purchasing tellurium for its warehouses. Increased production of CdTe solar cells may be a partial offsetting factor. In 2015, First Solar Inc. sold 3.4 GW of CdTe solar cells, an increase of 17% from their projected sales of 2.9 GW (Chao, 2015d; First Solar Inc., 2016, p. 4, 46; Willing, 2015).

According to Phoenix Infrared Corp. (Lowell, MA)—a producer of optics including zinc-selenide-containing lenses, a critical component for carbon dioxide (CO_2) lasers—selenium consumption in CO_2 lasers is expected to decrease during the next 5 to 10 years owing to increased competition from diode-based fiber lasers, but the amount of hydrogen selenide required for CIGS solar cells is expected to increase (Sparks, 2015).

Tellurium can also be used as an electrode in lithium ion batteries for improved charging performance, but at a much higher cost compared with conventional cobalt electrodes. The tellurium-lithium battery initially has a lower capacity but, after 50 charging cycles, it maintains its capacity with little degradation, outperforming its competitors. This makes tellurium electrode batteries a possibility for high end applications and uses, or in batteries with specialized requirements (Ding and others, 2015).

Canadian specialty metal producer 5N Plus Inc. announced at the Minor Metals Trade Association annual conference that they anticipated that tellurium was going to be oversupplied for the foreseeable future, with consumption around 450 to 550 metric tons per year (t/yr) and production estimated at 550 to 650 t/yr. With all the demand being met, 5N does not see any incentive for companies to recycle tellurium (Willing, 2015).

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TABLE 1
SALIENT SELENIUM AND TELLURIUM STATISTICS[1]

(Kilograms, contained metal, unless otherwise specified)

	2011	2012	2013	2014	2015
Selenium:					
United States:					
Production, primary refined	W	W	W	W	W
Exports	1,350,000	952,000	648,000	521,000	468,000
Imports for consumption, total	601,000	460,000	439,000	475,000 r	463,000
Dealers' price, average, commercial grade,[2] dollars per pound	66.35	54.47	36.17	26.78	22.09
World, refinery production[e]	2,180,000 r	2,220,000 r	2,170,000 r	2,250,000 r	2,200,000
Tellurium, United States:					
Production, primary refined	W	W	W	W	W
Exports	38,600	47,400	42,300	27,900	40,800
Imports for consumption	70,800	36,100	65,300 r	109,000 r	76,000
Price, commercial grade,[3] dollars per kilogram	349.35	149.66	111.95	119.47	77.00

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Data are rounded to no more than three significant digits, except prices.
[2]Source: Platts Metals Week.
[3]The price is the annual average price published by the Argus Media group Metal-Pages for duties unpaid in warehouse (IWH) Rotterdam, 99.99% tellurium.

TABLE 2
U.S. EXPORTS OF SELENIUM[1]

	2014		2015	
Country	Quantity (kilograms, contained Se)	Value	Quantity (kilograms, contained Se)	Value
Australia	--	--	2,010	$31,200
Brazil	8,490	$132,000	3,480	58,500
Canada	4,620	138,000	2,470	69,800
China	23,100	359,000	99,300	1,360,000
Colombia	1,380	21,400	--	--
Denmark	--	--	50	3,880
Dominican Republic	3,890	60,300	640	9,920
Ecuador	110	7,880	--	--
France	33,100	550,000	--	--
Germany	226	3,500	4,710	73,000
Hong Kong	97,900	1,710,000	62,400	872,000
India	184	2,860	--	--
Indonesia	29,200	452,000	22,100	343,000
Japan	32,200	868,000	--	--
Korea, Republic of	190,000	3,910,000	91,900	1,710,000
Latvia	34,000	181,000	--	--
Mexico	7,910	160,000	17,400	298,000
Panama	1,090	16,900	409	12,200
Peru	654	10,100	981	15,200
Philippines	2,720	24,100	2,090	16,200
Russia	--	--	46,300	275,000
South Africa	679	10,500	1,560	24,100
Taiwan	25,200	391,000	103,000	2,880,000
Thailand	177	2,740	--	--
United Kingdom	3,000	69,000	990	9,860
Venezuela	21,100	536,000	6,060	93,900
Total	521,000	9,620,000	468,000	8,160,000

-- Zero.

[1]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 SELENIUM[1]

Class and country	2014 Quantity (kilograms, contained Se)	2014 Value	2015 Quantity (kilograms, contained Se)	2015 Value
Selenium:				
Australia	3,000	$22,100	--	--
Belgium	48,000	2,140,000	31,000	$976,000
Canada	18,400	972,000	15,800	464,000
China	58,600	3,370,000	84,300	3,450,000
Germany	71,500	4,570,000	39,300	1,810,000
Hong Kong	--	--	200	15,900
India	--	--	63	5,040
Israel	1	3,600	--	--
Japan	102,000	5,490,000	60,600	3,660,000
Korea, Republic of	4,170	227,000	24,000	804,000
Mexico	14,500 r	686,000 r	42,800	978,000
Netherlands	5	13,500	7	24,600
New Zealand	--	--	2,020	13,900
Norway	38,400	1,800,000	35,600	232,000
Panama	45,000	2,430,000	21,100	964,000
Peru	120	6,660	--	--
Philippines	33,400	3,010,000	50,600	4,230,000
Russia	1	3,420	--	--
Thailand	6,980	308,000	2,980	131,000
United Kingdom	22,900	1,130,000	33,200	1,520,000
Total	467,000	26,200,000	444,000	19,300,000
Selenium dioxide:[2]				
China	1,900 r	158,000	11,600	387,000
Germany	3,650 r	311,000	4,460	186,000
Japan	2,220 r	59,100	3,150	56,200
Total	7,770 r	528,000	19,200	629,000
Grand total	475,000 r	26,700,000 r	463,000	19,900,000

[r] Revised. -- Zero.
[1] Data are rounded to no more than three significant digits; may not add to totals shown.
[2] Selenium content calculated as 71% of gross weight of material.

Source: U.S. Census Bureau.

TABLE 4

U.S. EXPORTS OF TELLURIUM[1]

	2014		2015	
Country	Quantity (kilograms, contained Te)	Value	Quantity (kilograms, contained Te)	Value
Australia	4	$5,450	--	--
Brazil	--	--	1,200	$114,000
Canada	16,400	690,000	36,200	1,590,000
China	1,280	53,600	6	3,280
Germany	2,090	749,000	1,710	625,000
Hong Kong	5,670	126,000	166	24,900
India	11	2,800	30	4,830
Japan	221	7,710	--	--
Jordan	141	21,200	486	72,700
Korea, Republic of	240	8,870	16	8,450
Mexico	258	24,000	61	2,760
Netherlands	1,190	172,000	420	50,900
Panama	21	3,110	--	--
Singapore	--	--	427	31,900
Switzerland	--	--	--	--
Taiwan	360	54,000	--	--
United Kingdom	--	--	10	2,700
Total	27,900	1,920,000	40,800	2,530,000

-- Zero.

[1]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 TELLURIUM[1]

	2014		2015	
Country	Quantity (kilograms, contained Te)	Value	Quantity (kilograms, contained Te)	Value
Belgium	1,970	$278,000	1,000	$108,000
Canada	81,600 r	2,130,000 r	51,000	2,730,000
China	20,300	3,320,000	22,800	2,940,000
Germany	487	44,600	132	32,800
Japan	605	80,500	28	62,900
Malaysia	(2)	(2)	--	--
Netherlands	--	--	1	2,380
Peru	2,190	221,000	--	--
Philippines	1,390	125,000	1,030	95,700
Ukraine	587	27,100	8	17,600
United Kingdom	25	4,380	--	--
Total	109,000 r	6,230,000 r	76,000	5,990,000

[r]Revised. -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Revised to zero.

Source: U.S. Census Bureau.

TABLE 6

SELENIUM: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Kilograms, contained selenium)

Country[3]	2011	2012	2013	2014	2015
Belgium	200,000	200,000	200,000	200,000	200,000
Canada[4]	35,000	144,000	159,000	159,000	154,000
Chile[5]	75,000	75,000	-- r	-- r	--
Finland	85,663 r, 6	92,769 r, 6	75,000	93,682 r, 6	94,000
Germany[7]	700,000	650,000	700,000	700,000	660,000
India[8]	16,000	16,000	17,000	17,000	17,000
Japan	750,000	755,000	741,300 6	782,451 r, 6	772,768 6
Peru	59,000 r, 6	54,000 r, 6	42,000 r, 6	40,000 r	40,000
Poland	85,000	90,000	90,000	89,800 r	90,000
Russia[6]	140,000	114,620 r	114,160 r	130,810 r	135,000
Serbia	12,947 6	13,200	13,000	13,000	13,000
Sweden	20,000	20,000	20,000	20,000	20,000
United States	W	W	W	W	W
Total	2,180,000 r	2,220,000 r	2,170,000 r	2,250,000 r	2,200,000

[r]Revised. W Withheld to avoid disclosing company proprietary data; not included in total. -- Zero.

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

[2]Insofar as possible, data relate to refinery output only; thus, countries that produced selenium contained in copper ores, copper concentrates, blister copper, and (or) refinery residues but did not recover refined selenium from these materials indigenously were excluded to avoid double counting. Includes data available through June 2, 2016.

[3]In addition to the countries listed, Australia, China, Iran, Kazakhstan, Mexico, the Philippines, and Uzbekistan produced refined selenium, but output was not reported; available information was inadequate for the formulation of reliable estimates of output levels. Australia is known to produce selenium in intermediate metallurgical products and has 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 has facilities for processing selenium scrap.

[4]Excludes selenium intermediates exported for refining.

[5]In 2012, the 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.

[6]Reported figure.

[7]In 2010, RETORTE GmbH substantially increased its production capacity for high-purity selenium, but actual production appeared to decrease in 2012 (in response to decreased demand).

[8]Data are for the fiscal year beginning April 1 of the year stated.

TABLE 7

TELLURIUM: ESTIMATED WORLD REFINERY PRODUCTION, BY COUNTRY[1, 2, 3]

(Kilograms, contained tellurium)

Country[4]	2011	2012	2013	2014	2015
Canada[5]	6,000	11,000	12,000	9,000	9,000
Japan	47,000	43,000	31,000	36,919 [r, 6]	37,356 [6]
Russia	30,000	30,000	31,000	32,500	35,000
Sweden	--	6,791 [6]	24,457 [6]	30,917 [6]	33,000 [6]
United States	W	W	W	W	W

[r]Revised. W Withheld to avoid disclosing company proprietary data. -- Zero.

[1]Estimated data are rounded to no more than three significant digits.

[2]Includes data available through June 6, 2016.

[3]Insofar 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. Data were not totaled because of exclusion of data from major world producers.

[4]In addition to the countries listed, Australia, Belgium, Chile, China, Colombia, Germany, Kazakhstan, Mexico, the Philippines, and Poland were known to produce refined tellurium, but output is not reported; available information was inadequate for the formulation of reliable estimates of the output levels.

[5]Excludes tellurium intermediates exported for refining.

[6]Reported figure.