



2015 Minerals Yearbook

STRONTIUM [ADVANCE RELEASE]

STRONTIUM

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Domestic apparent consumption of strontium decreased slightly in 2015 to 31,500 metric tons (t), mostly as the result of decreased imports of strontium compounds. Imports of the strontium mineral celestite increased slightly, and imports of strontium compounds decreased by 7% (table 1). Apparent consumption of strontium peaked in 1997 and then trended downward until 2011, when consumption began to increase again. The increased imports of strontium minerals since that time likely were the result of increased use of celestite in drilling muds (although this is unconfirmed because the compositions of drilling muds are proprietary) or other unidentified end uses rather than as raw materials for strontium compound production. The last domestic strontium carbonate plant, which used celestite as a raw material, ceased production in 2006. Celestite imports, in gross weight, were less than 1,000 t each year from 2005 through 2007 but increased to 55,800 t in 2015 (table 3). Strontium minerals were not mined in the United States in 2015, although deposits have been identified and were mined in the past. World production of celestite, in gross weight, increased slightly to 354,000 t in 2015 from 350,000 t in 2014 (tables 1, 4).

Strontium constitutes about 0.04% of the Earth's crust, ranking 15th in abundance among the elements (MacMillan and others, 2005). Owing to its high reactivity to air and water, strontium is not found in nature in metallic form. Two strontium-bearing minerals, celestite (strontium sulfate) and strontianite (strontium carbonate), contain strontium in sufficient quantities to make recovery practical. Of the two, celestite occurs much more frequently in sedimentary deposits of sufficient size to make mining attractive.

Legislation and Government Programs

On October 20, 2014, the U.S. Environmental Protection Agency (EPA) announced a preliminary determination to regulate strontium in drinking water. The EPA made an initial determination that ingestion of strontium has adverse health effects, especially on infants, children, and adolescents, because it can replace calcium in bones and affect bone strength. Strontium occurs naturally and has been detected in 99% of public water systems in the United States, 7% of which are at levels of concern (U.S. Environmental Protection Agency, 2014). After evaluating public feedback, the EPA decided, as of January 4, 2016, to delay its decision on regulation of strontium in drinking water until it considered additional data (U.S. Environmental Protection Agency, 2016).

Production

Celestite has not been mined in the United States since 1959, although deposits in Arizona, California, Ohio, Texas, and

Washington were mined in the past. Additionally, deposits have been identified in Colorado, Kansas, Michigan, New York, Pennsylvania, Tennessee, Virginia, and West Virginia (Culin, 1916; Mitchell and Pharr, 1960). Domestic production of celestite correlated with the difficulty obtaining the mineral commodity from former import sources, especially the United Kingdom, during World War I and World War II (Schreck and Foley, 1959).

Although strontium carbonate was not produced in the United States in 2015, it was the principal strontium compound produced globally. Additionally, most other strontium compounds were derived from strontium carbonate. Domestic production of strontium carbonate ceased in 2006 with the closure of the Chemical Products Corp.'s strontium carbonate and strontium nitrate operations in Cartersville, GA. A few companies continued to produce small quantities of downstream strontium chemicals elsewhere in the United States.

Consumption

Consumption patterns for strontium materials have shifted substantially during the past few years, with more strontium in minerals being consumed than strontium in chemicals in 2012–15, which had not happened since 1992. In 2015, consumption of strontium contained in celestite was 24,500 t and consumption of strontium in various chemicals was 7,100 t in the United States (table 1). Because no strontium carbonate was produced domestically from imported celestite in 2015, imported celestite likely was used directly as an additive in drilling muds and underwent no chemical processing. Before 2006, nearly all imported celestite underwent chemical processes to be converted into strontium carbonate.

Strontium chemicals were mostly consumed by the ceramics, glass, and pyrotechnics industries, with smaller quantities consumed by a multitude of other industries. Strontium carbonate is used directly in some applications and also is converted into downstream chemicals such as strontium chloride, strontium hydroxide, or strontium nitrate. Celestite typically has been used as the raw material in strontium carbonate production and was consumed directly in small quantities as an alternative to barium sulfate as white filler in industrial products. Increased imports of celestite since 2010 most likely were the result of celestite being used in some drilling muds used in natural gas and oil wells.

Permanent ceramic ferrite magnets are used extensively in small direct current motors for automobile windshield wipers, loudspeakers, magnetically attached decorative items, toys, and other electronic equipment. Strontium ferrite magnets, produced from strontium carbonate, are produced by several U.S. companies and possess the chemical and physical properties that are ideal for use in these applications, such as effectiveness

at high temperatures, low densities, and resistance to corrosion and demagnetization. Strontium oxide and strontium carbonate are used as frits in ceramic glazes as a nontoxic alternative to barium and lead. Strontium oxide is used as a glass modifier to enhance optical glass properties, increase hardness and strength, and intensify light refraction. Strontium glass is colorless and absorbs ultraviolet and x-ray radiation, an ideal glass for cathode ray tube (CRT) faceplates, although flat panel displays have almost completely replaced CRTs. The fiberglass, lab glass, and pharmaceutical glass industries consume strontium in smaller quantities. Additionally, with future developments in holography, strontium barium niobate could be a significant storage medium for three-dimensional color holograms (Ketchel and others, 1999).

Strontium nitrate is used most commonly as a coloring agent in pyrotechnic applications, to produce a bright red and, in combination with a copper compound, purple. Strontium carbonate, strontium chloride, strontium oxalate, and strontium sulfate can also be used. Strontium pyrotechnic applications include civilian and military flares, fireworks, and tracer ammunition.

In metallurgical applications, strontium metal is added to aluminum alloys to improve the strength and ductility of castings used in aerospace and automotive applications. Addition of even a few hundred parts per million strontium causes the microscopic structure of the alloys to transform from a coarse, plate-like texture to a fine, fibrous network (Timpel and others, 2012). Strontium can be used to remove lead impurities during the electrolytic production of zinc. The addition of strontium carbonate dissolved in sulfuric acid reduces the lead content of the electrolyte and of the zinc deposited on the cathode.

Strontium chromate was incorporated into paints as a corrosion inhibitor, effectively coating aluminum used in the construction of aircraft fuselages and ships. Strontium chromate, however, was classified as a carcinogen in humans because of its hexavalent chromium content, leading many in the paint industry to seek safer alternatives. The European Chemicals Agency proposed strict regulations for its use, although achieving comparable corrosion resistance proved difficult using more environmentally friendly materials. A mixed metal calcium-strontium-phosphate complex on a silicate core provides excellent corrosion resistance (Hodges and others, 2010; European Chemicals Agency, 2012; Koleske and others, 2014, p. 50). Other strontium chemicals were used as catalysts to accelerate the drying of oils, paints, and printing inks (Koleske and others, 2014, p. 55).

Strontium is absorbed and processed in the human body in the same manner as calcium owing to the chemical similarities of the two elements. As a result, strontium has a number of medical applications, including the use of the isotope strontium-89 for the treatment of bone cancer (Porter, 1994), the use of strontium chloride in toothpastes to treat temperature and pressure-related sensitivity, and the recent development of the prescription drug strontium ranelate used to reduce the incidence of fractures in osteoporotic patients by promoting the uptake of calcium into bones. No rigorous clinical studies have been completed that prove whether strontium dietary supplements, such as strontium carbonate and strontium citrate, are effective treatments for

osteoporosis (Johannes, 2013). Further studies, however, have shown that strontium ranelate may present cardiovascular risks that outweigh its benefits (Price, 2014a). Although the European Medicines Agency considered withdrawing the drug from the market, strontium ranelate remained on the market in Europe but only for patients that were unable to take other osteoporosis medication (Price, 2014b).

Strontium exhibits a high dielectric constant, making it an attractive material for use in wireless devices and memory chips. Strontium titanate is sometimes used as a substrate material for semiconductors and in some optical and piezoelectric applications. Research also was conducted on the use of strontium in superconductors and radiation detectors. As the technology improves and costs decrease, high-tech industries may use more strontium (McCoy, 2009; McIntosh, 2009; Physorg, 2010; Walter, 2010; Singh and others, 2011).

Strontium oxide aluminate is used as a phosphorescent (glow-in-the-dark) pigment in applications, such as emergency exit signs, that glow brighter and longer than those using more common photoluminescent pigments (Merit Lighting, LLC, 2008). Strontium phosphate is used in the manufacture of fluorescent lights, and the entire range of strontium chemicals is used in analytical chemistry laboratories.

Prices

Based on data published by the U.S. Census Bureau, the average customs unit value for celestite imported from Mexico was \$51 per metric ton, similar to the unit values since 2012 (table 3). The average unit customs value of imported strontium carbonate was \$0.83 per kilogram, slightly lower than that in 2014. In 2015, the unit value of imported strontium metal increased by 3% to \$7.68 per kilogram from \$7.47 per kilogram. In 2015, the unit value for strontium nitrate was \$1.30 per kilogram, about the same as that in 2014.

Foreign Trade

Strontium exports from and imports into the United States have become unpredictable from year to year. Adequate information to explain the variations is unavailable. Imports of strontium minerals, all of which were celestite from Mexico, were 55,800 t by gross weight (24,200 t by contained weight) in 2015, slightly more than those of 2014. Total strontium chemical imports were 12,700 t by gross weight (5,560 t by contained weight) in 2015, 7% less than those of 2014 (table 3).

Strontium carbonate exports were 145 t by gross weight (63 t by contained weight) in 2015, a decrease of 17% as compared with those in 2014. Export and import data in table 1 represent only the strontium content of the celestite and strontium compounds. Strontium chemical imports into the United States were sourced predominantly from Mexico, 54%; Germany, 39%; and China, 6%.

World Review

Large deposits of high-grade celestite have been discovered throughout the world, but active mines were primarily in China, Mexico, and Spain. These countries accounted for 98% of total celestite production in 2015. Some celestite was also produced in

Argentina, Morocco, and Tajikistan. Many large deposits are not economic to mine owing to high levels of barium and calcium, which are impurities that require energy-intensive and cost-prohibitive methods for separation. Most strontium producers require a minimum of 90% strontium sulfate content to achieve profitability. Hand sorting and some washing are all that are necessary at many strontium mines; a few operations use froth flotation, gravity separation, or other methods to beneficiate ore. Major global producers of strontium chemicals and metal in 2015 were in China, Germany, and Mexico.

Outlook

Improved economic conditions worldwide could spur increased demand for strontium carbonate in more traditional applications. Use of strontium by the ceramics, glass, and pyrotechnics industries is expected to continue, with continued demand for strontium used in ferrite magnets. In addition, if barite prices remain high, strontium could continue to be used as a substitute in drilling fluids. Forthcoming EPA regulations on acceptable levels of strontium in drinking water may affect its domestic use, but the impact of such regulations is uncertain at the present time. With developments in advanced applications, consumption of strontium in new end uses may increase.

References Cited

- Culin, F.L., Jr., 1916, Celestite and strontianite: University of Arizona Bulletin No. 35, Mineral Technology Series No. 13, October 10, 4 p. (Accessed May 9, 2016, at http://repository.azgs.gov/sites/default/files/dlio/files/nid1152/b-35_celestite_strontianite.pdf.)
- European Chemicals Agency, 2012, 4th draft recommendation of priority substances to be included in Annex XIV of the REACH regulation: European Chemicals Agency, June 20, 2 p. (Accessed March 28, 2016, at http://echa.europa.eu/documents/10162/13640/draft_axiv_entries_summarytable_4th_en.pdf.)
- Hodges, S.A., Raurell, D.M., and Llovens, Xavier, 2010, New "eco-friendly" universal corrosion inhibitors: Paint & Coatings Industry, January 1. (Accessed March 28, 2016, at <http://www.pcimag.com/articles/90463-new-eco-friendly-universal-corrosion-inhibitors>.)
- Johannes, Laura, 2013, Can a metal help slow down the effects of osteoporosis?: The Wall Street Journal, June 10. (Accessed August 23, 2016, at <http://www.wsj.com/articles/SB10001424127887324798904578531691422239954>.)
- Ketchel, B.P., Heid, C.A., Wood, G.L., Miller, M.J., Mott, A.G., Anderson, R.J., and Salamo, G.J., 1999, Three-dimensional color holographic display: Applied Optics, v. 38, no. 29, p. 6159–6166. (Accessed May 9, 2016, via <https://www.osapublishing-org.libproxy.unm.edu/ao/abstract.cfm?uri=ao-38-29-6159>.)
- Koleske, J.V., Springate, Robert, and Brezinzki, Darlene, 2014, Additives reference guide: Paint & Coatings Industry, v. 30, no. 6, June 16, p. 38–89.
- MacMillan, J.P., Park, J.W., Gerstenberg, Rolf, Wagner, Heinz, Köhler, Karl, and Wallbrecht, Peter, 2005, Strontium and strontium compounds, in Ullmann's encyclopedia of industrial chemistry (7th ed.): Weinheim, Germany, VCH Verlagsgesellschaft mbH, v. A25, p. 321–327.
- McCoy, Michael, 2009, Precursor powerhouse—Air Liquide finds success in a specialized electronic materials niche: Chemical & Engineering News, August 3, p. 18–19. (Accessed March 28, 2016, at <http://pubs.acs.org/doi/pdf/10.1021/cen-v087n031.p018>.)
- McIntosh, Paul, 2009, Improving mobile wireless performance: Electronic Products, February 19. (Accessed March 28, 2016, at http://www.electronicproducts.com/Analog_Mixed_Signal_ICs/Standard_Linear/Improving_mobile_wireless_performance.aspx.)
- Merit Lighting, LLC, 2008, Photoluminescent exit signs: Pasadena, CA, Merit Lighting, LLC. (Accessed March 28, 2016, at <http://www.meritlighting.com/photoluminescent.html>.)
- Mitchell, R.S., and Pharr, R.F., 1960, Strontium minerals from Wise County, Virginia: Virginia Minerals, v. 6, no. 4, October, p. 1–7.

- Physorg, 2010, Roller coaster superconductivity discovered: Physorg.com, August 18. (Accessed March 28, 2016, at <http://www.physorg.com/news201355600.html>.)
- Porter, A.T., 1994, Use of strontium-89 in metastatic cancer—US and UK experience: Oncology, v. 8, no. 11, October 1, p. 25–29. (Accessed March 28, 2016, at <http://www.cancernetwork.com/oncology-journal/use-strontium-89-metastatic-cancer-us-and-uk-experience>.)
- Price, Caroline, 2014a, Regulators consider withdrawing strontium ranelate over CV safety concerns: Pulse, February 3. (Accessed March 28, 2016, at http://www.pulsetoday.co.uk/clinical/more-clinical-/musculoskeletal/regulators-consider-withdrawing-strontium-ranelate-over-cv-safety-concerns/20005748.article#.VOTb_U0cSUK.)
- Price, Caroline, 2014b, Strontium ranelate gets reprieve from European regulator: Pulse, February 21. (Accessed March 28, 2016, at <http://www.pulsetoday.co.uk/clinical/more-clinical-areas/musculoskeletal/strontium-ranelate-gets-reprieve-from-european-regulator/20005928.fullarticle>.)
- Schreck, A.E., and Foley, J.M., 1959, Strontium, in Metals and minerals (except fuels): U.S. Bureau of Mines Minerals Yearbook 1958, v. 1, p. 1003–1006.
- Singh, Ranjan, Azad, A.K., Jia, Q.X., Taylor, A.J., and Chen, Hou-Tong, 2011, Thermal tunability in terahertz metamaterials fabricated on strontium titanate single-crystal substrates: Optical Letters, v. 36, no. 7, April 1, p. 1230–1232. (Accessed March 28, 2016, at <https://www.osapublishing.org/ol/abstract.cfm?uri=ol-36-7-1230>.)
- Timpel, M., Wanterka, N., Schlesiger, R., Yamamoto, T., Lazarev, N., Isheim, D., Schmitz, G., Matsumura, S., and Banhart, J., 2012, The role of strontium in modifying aluminium-silicon alloys: Acta Materialia, v. 60, no. 9, May, p. 3920–3928. (Accessed April 25, 2016, at https://www.researchgate.net/profile/Melanie_Timpel/publication/257540922_The_role_of_strontium_in_modifying_aluminiumsilicon_alloys/links/54f372880cf24eb8794c2cf6.pdf.)
- U.S. Environmental Protection Agency, 2014, EPA makes preliminary determination to regulate strontium in drinking water: U.S. Environmental Protection Agency, October 20. (Accessed March 29, 2016, at <https://yosemite.epa.gov/opa/admpress.nsf/596e17d7cac720848525781f0043629e/327f339e63facb5a85257d77005f4bf9!OpenDocument>.)
- U.S. Environmental Protection Agency, 2016, Announcement of final regulatory determinations for contaminants on the third drinking water contaminant candidate list: Federal Register, v. 81, no. 1, January 4, p. 13–19. (Accessed June 6, 2016, at <https://www.gpo.gov/fdsys/pkg/FR-2016-01-04/pdf/2015-32760.pdf>.)
- Walter, Katie, 2010, A scintillating radiation detection material: Science and Technology Review, October 18. (Accessed March 28, 2016, at <https://str.llnl.gov/OctNov10/cherepy.html>.)

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

- Evaporites and Brines. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
- Historical Statistics for Mineral and Material Commodities in the United States. Data Series 140.
- Strontium. Ch. in Mineral Commodity Summaries, annual.

Other

- American Ceramic Society Bulletin, monthly.
- Chemical Market Reporter, weekly.
- Engineering and Mining Journal, monthly.
- Industrial Minerals, monthly.
- Mining Annual Review.
- Mining Engineering, monthly.
- Mining Journal, weekly.
- Roskill Information Services Ltd. [last reported on strontium in 1995].
- Strontium—Supply, Demand, and Technology. U.S. Bureau of Mines Information Circular 9213, 1989.
- Strontium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.

TABLE 1
SALIENT STRONTIUM STATISTICS¹

(Metric tons of contained strontium and dollars per metric ton unless otherwise noted)²

	2011	2012	2013	2014	2015
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption: ³					
Strontium compounds	10,000	8,150	7,190	7,600	7,100
Strontium minerals	7,320	8,660	21,900	24,200	24,500
Exports, carbonate ³	18	71	37	104	86
Shipments from Government stockpile excesses	--	--	--	--	--
Apparent consumption ⁴	17,300	16,700	29,000	31,700	31,500
Price, average value of mineral imports at port of exportation	46	50	50	50	51
World, production of celestite, gross weight	379,000 ^r	376,000 ^r	344,000 ^r	350,000 ^r	354,000 ^e

^eEstimated. ^rRevised. -- Zero.

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

²The strontium content of celestite is 43.88%, which was used to convert units of celestite.

³Source: U.S. Census Bureau.

⁴Production plus imports minus exports.

TABLE 2
U.S. EXPORTS OF STRONTIUM CARBONATE, BY COUNTRY¹

Country	2014		2015	
	Gross weight (kilograms)	Value ²	Gross weight (kilograms)	Value ²
Canada	10,600	\$11,700	28,600	\$26,900
China	61,100	58,100	--	--
Hong Kong	63,600	60,400	--	--
Korea, Republic of	7,960	9,500	62,800	59,700
Mexico	181	2,850	37,000	25,200
United Kingdom	31,100	43,600	16,100	35,000
Total	174,000	186,000	145,000	147,000

-- Zero.

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

²Free alongside ship value.

Source: U.S. Census Bureau; data adjusted by the U.S. Geological Survey.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY¹

Compound and country	2014		2015	
	Gross weight (kilograms)	Value ²	Gross weight (kilograms)	Value ²
Celestite, Mexico	55,100,000	\$2,760,000	55,800,000	\$2,850,000
Strontium carbonate:				
China	234,000	368,000	146,000	363,000
France	--	--	300	4,790
Germany	4,790,000	3,900,000	4,900,000	3,980,000
Italy	11,500	124,000	--	--
Japan	--	--	45	2,710
Mexico	5,690,000	4,460,000	4,670,000	3,680,000
Spain	40,000	41,300	--	--
United Kingdom	1,030	128,000	--	--
Total	10,800,000	9,020,000	9,710,000	8,030,000
Strontium metal:				
China	77,500	569,000	116,000	837,000
France	11,000	91,500	7,110	66,800
Germany	--	--	575	8,080
Japan	--	--	500	5,290
Mexico	--	--	17,100	164,000
United Kingdom	--	--	1	2,550
Total	88,500	661,000	141,000	1,080,000
Strontium nitrate:				
China	483,000	666,000	501,000	660,000
France	800	7,520	--	--
Germany	--	--	500	6,020
Hungary	615	13,300	--	--
India	500	4,630	20,900	20,100
Japan	33,500	40,200	16,700	20,700
Mexico	2,160,000	2,790,000	2,160,000	2,810,000
Spain	41,300	48,500	20,000	22,000
Total	2,720,000	3,570,000	2,720,000	3,540,000
Strontium oxide, hydroxide, peroxide:				
France	--	--	25,800	46,100
Japan	225	13,200	77,000	126,000
Total	225	13,200	103,000	172,000

-- Zero.

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

²Customs value.

Source: U.S. Census Bureau.

TABLE 4
CELESTITE: WORLD PRODUCTION, BY COUNTRY^{1,2}

(Metric tons)

Country ³	2011	2012	2013	2014	2015
Argentina	1,056	22,750	5,246 ^r	5,000 ^{r,ε}	5,000 ^e
China ^e	200,000	190,000	180,000	190,000 ^r	180,000
Iran ^e	40,000	20,000	--	--	--
Mexico	40,669	46,192	67,778	64,931 ^r	79,000
Morocco	-- ^r	-- ^r	-- ^r	-- ^r	--
Spain	97,102	96,688 ^r	90,972	90,000 ^e	90,000 ^e
Total	379,000 ^r	376,000 ^r	344,000 ^r	350,000 ^r	354,000 ^e

^εEstimated. ^rRevised. -- Zero.

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

²Includes data available through June 28, 2016.

³In addition to the countries listed, Tajikistan was thought to produce celestite, but available information is inadequate to make reliable estimates of output levels.