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2019 Minerals Yearbook

STRONTIUM [ADVANCE RELEASE]

U.S. Department of the Interior
U.S. Geological Survey

September 2024

Strontium

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Strontium minerals were not mined in the United States in 2019, although deposits have been identified and were mined in the past. Domestic apparent consumption of strontium contained in compounds and minerals decreased by 42% in 2019 to 13,500 metric tons (t), mostly as the result of a decrease in celestite imports (table 1). Strontium contained in celestite imports decreased by 53% in 2019 to 7,960 t from 16,900 t in 2018. The quantity of strontium contained in imported strontium compounds decreased by 12% in 2019 to 5,560 t. In 2019, world production of celestite, in gross weight, was an estimated 218,000 t, the same as the revised estimate for 2018 (table 4).

Strontium constitutes about 0.03% of the Earth's continental crust, ranking 17th in abundance among the elements (Wedepohl, 1995, p. 1220). 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 economic.

Legislation and Government Programs

In May 2018, the U.S. Department of the Interior, in coordination with other executive branch agencies, published a list of 35 mineral commodities designated as critical minerals. The list, which included strontium, was developed to serve as an initial focus, pursuant to Executive Order 13817, "A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals" (U.S. Department of the Interior, 2018).

Under section 301(b) of the Trade Act of 1974, as amended, the Office of the United States Trade Representative (USTR) determined that acts, policies, and practices of China related to technology transfer, intellectual property, and innovation were discriminatory or unreasonable and that those actions burdened or restricted United States commerce in 2018 (Office of the U.S. Trade Representative, 2018). Several lists of tariff lines (Lists 1, 2, 3) were compiled, and imports of those materials became subject to an additional import duty for products from China. List 3, which included strontium carbonate; strontium metal; strontium nitrate; and strontium oxide, hydroxide, and peroxide, had a duty rate of 10% imposed in late September 2018. The rate increased to 25% (84 FR 20459) in May 2019 (Office of the U.S. Trade Representative, 2019).

In November 2019, the U.S. International Trade Commission determined that an industry in the United States was injured materially by imports of strontium chromate from Austria and France, under Harmonized Tariff Schedule codes 2841.50.91 and 3212.90.00, which were being sold in the United States at less than fair value. Antidumping duties of 25.90% were assessed on strontium chromate imports from Austria and 32.16% on strontium chromate imports from France (U.S. International Trade Administration, 2019).

Production

Celestite had not been actively mined in the United States since 1959, although deposits in Arizona, California, Ohio, Texas, and Washington were mined in the past. Additional deposits have been identified in Colorado, Kansas, Michigan, New York, Pennsylvania, Tennessee, Virginia, and West Virginia (Culin, 1916; Penick and Haynes, 1983). In the past, domestic production of celestite correlated with the difficulty in obtaining the mineral 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 2019, 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 compounds remained relatively steady for the past few years although trending downward. Consumption of celestite had fluctuated substantially during the prior few years. From 2012 to 2015, more strontium contained in minerals was consumed than strontium contained in chemicals, which had not happened since 1992, when strontium minerals were used to produce strontium chemicals. In 2016, although strontium compound imports decreased, more strontium in chemicals was consumed than in minerals. From 2017 through 2019, strontium minerals were the leading source of strontium consumption in the United States (table 1). Because no strontium carbonate was produced domestically from imported celestite in 2019, 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 processing to be converted into strontium carbonate.

Strontium carbonate was used directly in some applications and also converted into downstream chemicals such as strontium chloride, strontium chromate, strontium hydroxide, and strontium nitrate. Celestite typically had been used as the raw material in strontium carbonate production and consumed directly in small quantities as an alternative to barium sulfate as white filler in industrial products. However, increased celestite imports since 2010 were most likely the result of celestite being used in some drilling muds for natural gas and oil wells. Celestite was used as a substitute for barite in these muds owing to the similar specific gravities of the two minerals (4.10 to 4.20

for the American Petroleum Institute specification for barite and an average of 3.95 for celestite). The possible use of celestite as a substitute for barite or as an additive in drilling muds was more likely when barite prices were high.

Strontium chemicals were mostly consumed by the ceramics, glass, and pyrotechnics industries, with smaller quantities consumed by a multitude of other industries. Strontium carbonate was used to produce permanent ceramic ferrite magnets, which were used extensively in small direct-current motors for automobile windshield wipers, loudspeakers, magnetically attached decorative items, toys, and other electronic equipment. These magnets were produced by several U.S. companies and possessed the chemical and physical properties 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 were used as frits in ceramic glazes as a nontoxic alternative to barium and lead. Strontium oxide was 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, thus 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 consumed strontium in smaller quantities.

Strontium nitrate was 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 also were used in pyrotechnic applications. Strontium pyrotechnic applications included civilian and military flares, fireworks, and tracer ammunition.

In metallurgical applications, strontium metal was added to aluminum alloys to improve the strength and ductility of castings used in aerospace and automotive applications. The addition of even a few hundred parts per million of 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 carbonate was 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.

Historically, strontium chromate was incorporated into paints as a corrosion inhibitor, effectively coating aluminum used in the construction of aircraft fuselages and ships. However, because strontium chromate is classified as a carcinogen in humans because of its hexavalent chromium content, strontium chromate has increasingly been replaced by alternatives in paint. The European Chemicals Agency proposed strict regulations for its use, although achieving comparable corrosion resistance proved difficult using less harmful materials. Research conducted on a mixed-metal calcium-strontium-phosphate complex on a silicate core showed excellent corrosion resistance as a substitute for strontium chromate (Hodges and others, 2010; European Chemical 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 several medical applications including the use of the isotope strontium-89 for the treatment of pain related to certain types of bone cancer (Porter, 1994; Q BioMed Inc., 2017) and the use of strontium chloride in toothpastes to treat temperature and pressure sensitivity.

Strontium exhibits a high dielectric constant, making it an attractive material for use in wireless devices and memory chips (McCoy, 2009; McIntosh, 2009). Strontium titanate was sometimes used as a substrate material for semiconductors and in some optical and piezoelectric applications (Singh and others, 2011). Research also had been conducted on the use of strontium in superconductors and radiation detectors (Carnegie Institution, 2010; Walter, 2010). Strontium may be able to substitute for lead in lead halogen perovskite solar cells and thus possibly represents a more environmentally friendly alternative to the toxic, water-soluble lead currently used (Jacobsson and others, 2015). Strontium niobate when in contact with water under solar irradiation is able to split water into oxygen and hydrogen, which could have significant ramifications for harvesting hydrogen for use in renewable energy (National University of Singapore, 2017). As technologies improve and costs decrease, high-technology industries may use more strontium.

Strontium oxide aluminate was used as a phosphorescent (glow-in-the-dark) pigment in applications such as emergency exit signs, as it glows brighter and longer than those using photoluminescent pigments (Merit Lighting, LLC, 2008). Strontium phosphate was used in the manufacture of fluorescent lights, and the entire range of strontium chemicals was 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 $79 per metric ton (table 3). Imports from Germany and Madagascar were reported in 2019, but the high average unit values (about $1,460 per metric ton and $3,650 per metric ton, respectively) and low quantities indicate that those imports were likely mineral specimens rather than for use as industrial additives or raw materials. The average unit values in 2019 of imported strontium carbonate, strontium metal, and strontium nitrate increased by 14%, 15%, and 13%, respectively, compared with those in 2018, whereas the average unit value of imported strontium oxide, hydroxide, and peroxide decreased by 3%.

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, equaled 18,100 t gross weight (7,960 t of strontium content) in 2019, a 53% decrease compared with those in 2018 (table 1). Celestite imports (gross weight) were only 1,230 t in 2007 but increased to 55,800 t in 2015 before decreasing in 2016 to

10,100 t. Celestite imports (gross weight) decreased in 2019 after increasing in 2018 to 38,400 t, from 25,700 t in 2017. The recent fluctuations in celestite imports may have resulted from increased use of celestite in drilling muds when barite prices were high and oil and natural gas drilling activity was booming. Since 2007, imported celestite most likely was used directly without undergoing chemical transformation.

Imports of strontium compounds (including strontium chemicals and metal) were 9,510 t gross weight (5,560 t of strontium content) in 2019, a decrease of 15% (12% by strontium content) compared with those in 2018 (table 3). Typically, imports of strontium carbonate were relatively steady from year to year, although imports of other strontium compounds were more variable. Imports of strontium compounds into the United States were sourced predominantly from Mexico (51%) and Germany (45%).

Strontium carbonate exports totaled 33 t gross weight (20 t of strontium content) in 2019, a 40% decrease compared with those in 2018. Exports to Canada and the United Kingdom decreased significantly (table 2).

World Review

Large deposits of high-grade celestite have been discovered throughout the world, but active mines were primarily in China, Iran, Mexico, and Spain. These countries accounted for nearly all celestite production, which equaled an estimated 218,000 t in 2019 (table 4). Some celestite was produced in Argentina and some may have been produced in Tajikistan. Many large deposits were not economical to mine owing to high levels of barium and calcium, which are impurities that required cost-prohibitive and energy-intensive methods for separation. Most strontium producers required a minimum of 90% strontium sulfate content to achieve profitability. For ore processing, hand sorting and some washing were all that was necessary at many strontium mines; a few operations used froth flotation, gravity separation, and (or) other methods to beneficiate ore.

Outlook

Improved economic conditions worldwide could spur increased demand for strontium carbonate in more traditional applications, although the global coronavirus disease 2019 (COVID-19) pandemic and measures put in place to mitigate its spread is expected to cause a decline in strontium demand in the United States and in other counties in 2020, especially as the result of a decline in natural gas and petroleum well drilling. Use of strontium by the ceramics, glass, and pyrotechnics industries is expected to continue, with continued demand for strontium for ferrite magnets. In addition, when drilling activity increases, if barite prices are high, celestite use may increase as a partial barite substitute as a drilling mud additive. With developments in advanced applications, consumption of strontium in new end uses may increase.

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TABLE 1
SALIENT STRONTIUM STATISTICS[1]

(Metric tons, strontium content, and dollars per metric ton unless otherwise specified)

	2015	2016	2017	2018	2019
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption:[2]					
Strontium compounds[3]	7,100	6,420	6,660	6,350	5,560
Strontium compounds, gross weight	12,700	11,500	11,800	11,200	9,510
Celestite[4]	24,500	4,420	11,300	16,900	7,960
Celestite, gross weight	55,800	10,100	25,700	38,400	18,100
Exports:[2]					
Strontium carbonate	86	91	36	32	20
Strontium carbonate, gross weight	145	154	60	55	33
Apparent consumption[5]	31,500	10,700 r	17,900	23,200	13,500
Price, average customs value of celestite imports	51	78	74	78	82
World, production of celestite, gross weight	286,000	222,000 r	222,000 r, e	218,000 r, e	218,000 e

eEstimated. rRevised. -- Zero.

[1]Table includes data available through April 16, 2020. Data are rounded to no more than three significant digits.

[2]Source: U.S. Census Bureau.

[3]Strontium compounds, with their respective strontium contents, include strontium metal (100.00%); strontium oxide, hydroxide, and peroxide (70.00%); strontium carbonate (59.35%); and strontium nitrate (41.40%). These factors were used to convert units of strontium compounds to strontium content.

[4]Gross weight converted to strontium content assuming 43.88% strontium content of celestite and an ore grade of 92%.

[5]Production plus imports minus exports.

TABLE 2
U.S. EXPORTS OF STRONTIUM CARBONATE, BY COUNTRY OR LOCALITY[1]

	2018		2019	
Country or locality	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
British Virgin Islands	2,650	$3,130	--	--
Canada	35,400	33,900	13,300	$12,300
Czechia	--	--	10,300	9,830
Korea, Republic of	--	--	200	4,360
United Kingdom	16,700	15,900	9,300	8,840
Total	54,700	52,900	33,100	35,400

-- Zero.

[1]Table includes data available through April 16, 2020. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Free alongside ship value.

Source: U.S. Census Bureau.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY OR LOCALITY[1]

Compound and country or locality	2018 Gross weight (kilograms)	2018 Value[2]	2019 Gross weight (kilograms)	2019 Value[2]
Celestite:				
Germany	21,300	$52,200	22,100	$32,200
Madagascar	9,480	45,800	8,200	30,000
Mexico	38,400,000	2,900,000	18,100,000	1,420,000
Total	38,400,000	3,000,000	18,100,000	1,490,000
Strontium carbonate:				
China	114,000	153,000	14,700	26,200
Germany	4,090,000	3,490,000	4,240,000	3,700,000
Italy	9,400	50,100	10,400	23,300
Mexico	4,200,000	3,520,000	4,580,000	4,760,000
Russia	30	3,600	8,510	209,000
Spain	138,000	140,000	--	--
United Kingdom	56,600	52,800	--	--
Total	8,600,000	7,420,000	8,850,000	8,720,000
Strontium metal:				
China	225,000	2,270,000	19,000	173,000
Japan	2,880	35,100	112	7,000
Madagascar	--	--	5,740	22,300
Mexico	8,730	83,900	428	4,110
United Kingdom	4,640	104,000	8,340	193,000
Total	241,000	2,500,000	33,600	399,000
Strontium nitrate:				
China	503,000	742,000	205,000	345,000
India	3,720	35,700	4,000	38,000
Mexico	1,630,000	2,160,000	269,000	402,000
Norway	1,010	15,200	--	--
Poland	407	5,100	--	--
Russia	5	2,450	--	--
Spain	114,000	137,000	80,000	81,800
Total	2,250,000	3,100,000	559,000	868,000
Strontium oxide, hydroxide, and peroxide:				
France	19,800	29,600	61,200	91,800
Germany	1,550	25,700	1,080	22,000
Japan	--	--	4,800	17,600
Korea, Republic of	72,000	141,000	--	--
Russia	--	--	5	3,250
United Kingdom	--	--	30	2,450
Total	93,300	197,000	67,100	137,000

-- Zero.
[1]Table includes data available through April 16, 2020. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Customs value.

Source: U.S. Census Bureau.

TABLE 4
CELESTITE: WORLD PRODUCTION, BY COUNTRY OR LOCALITY[1]

(Metric tons, gross weight)

Country or locality[2]	2015	2016	2017	2018[e]	2019[e]
Argentina[e]	700	700	700	700	700
China	53,200	65,300 [r]	53,700 [r]	50,000	50,000
Iran	36,760	37,000 [e]	37,000 [e]	37,000	37,000
Mexico	79,022	33,230	40,699	40,000	40,000
Spain	116,765	85,599	90,000 [e]	90,000	90,000
Turkey	--	--	-- [r, e]	-- [r]	--
Total	286,000	222,000 [r]	222,000 [r, e]	218,000 [r]	218,000

[e]Estimated. [r]Revised. -- Zero.

[1]Table includes data available through April 16, 2020. 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.

[2]In addition to the countries and (or) localities listed, Tajikistan may have produced celestite, but available information was inadequate to make reliable estimates of output.