24 STRONTIUM

24.1 Overview

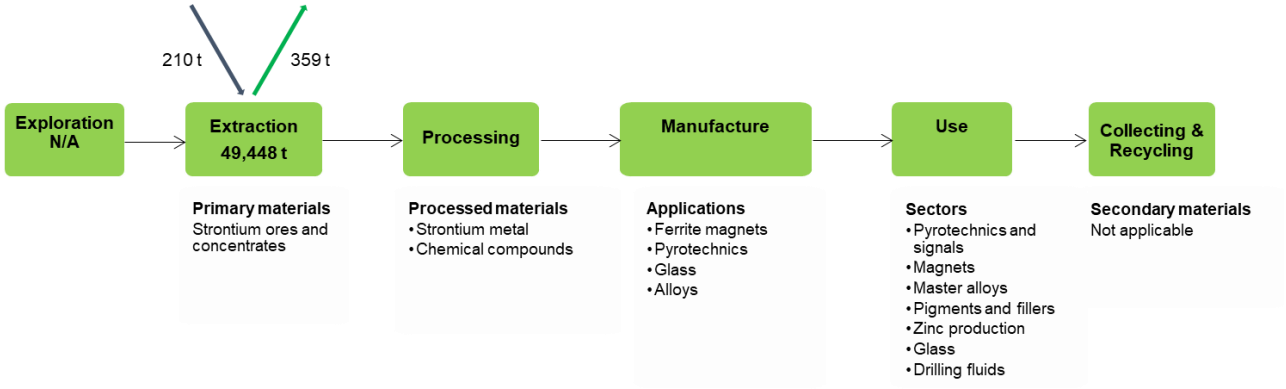

Figure 464: Simplified value chain for Strontium for the EU[264], average 2012-2016

Strontium (chemical symbol Sr) is a metal usually occurring in the earth's crust as celestite (SrSO4) and strontianite (SrCO3), and it is also present in seawater. It is a soft, silver-yellow, alkaline-earth metal, and has a high reactivity with water and air. (Lenntech, 2019; ISE, 2019). The criticality of Strontium for the EU is analysed for the first time.

For the purpose of this assessment the extraction stage of Strontium is analysed using BGS data for production figures of strontium minerals and CN8 code 28369200 "Strontium Carbonate" for trade data. In order to ensure comparability, both production and trade figures are converted to Strontium content. Unfortunately, codes 28051910 "Strontium and Barium" and 261640 "Oxides, Hydroxides, Peroxides, of Strontium or Barium" could not be used because the amounts of barium and strontium could not be separated. Celestate and strontium nitrate trade are not recorded by Eurostat Comext (2019).

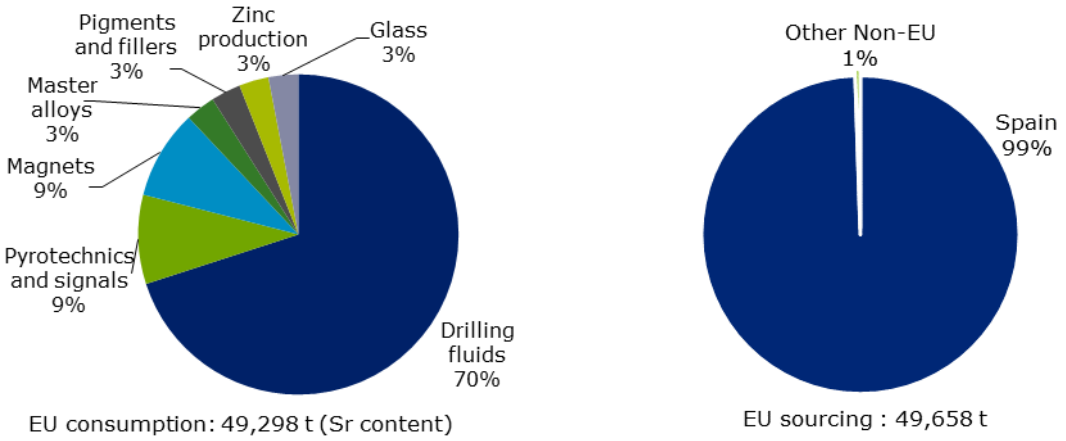

Figure 465: End uses (USGS, 2019) and EU sourcing (BGS, 2019; Eurostat, 2019) of Strontium, 2012-2016 average

[264] JRC elaboration on multiple sources (see next sections)

The average value of strontium carbonate market between 2012 and 2016 was USD 59.2 million. Imports are dominated by Japan (23%) and South Korea (21%) (OEC, 2019).

The apparent consumption of strontium of EU is about 49,300 tonnes per year, averaged over 2012-2016. Main source is Spain supplying almost 100% of EU's strontium demand. Other marginal suppliers are China, Japan, Mexico and Canada.

The EU is a net exporter of strontium, exporting an average of 360 tonnes per year between 2012 and 2016 and importing 210 t. The largest share of strontium is exported to South Korea (36%), followed by India (19%) and Japan (18%) (Eurostat, 2019a).

Strontium compounds are mainly used by ceramics, glass and pyrotechnics industries. For example, strontium carbonate is used to produce permanent ceramic ferrite magnets (applied in small direct current motors, such as windshield wipers), strontium nitrate is used to produce bright red coloured pyrotechnic applications. Strontium metal can be used as an alloy for aluminium to improve strength and ductility for aerospace and automotive applications. Moreover, strontium has a number of medical applications including bone cancer treatment (USGS, 2018).

According to USGS (2019) world resources of strontium are approximately 1 billion tonnes. In the EU Spain has the biggest celestite resources, estimated at 3.6 Mt.

The total world production of strontium is 159,541 tonnes (334,455 tonnes of strontium minerals) per year between 2012 and 2016. Spain was the biggest supplier producing 31% of global supply, followed by Iran (31%), China (19%), Mexico (17%), and Argentina (2%). (BGS, 2019)

The End-of-Life Recycling Input Rate (EoL-RIR) of Strontium is below 1% (UNEP, 2011; SCRREEN workshops, 2019)

Strontium chromate (CrO_4Sr) is labelled a carcinogen, very toxic to aquatic life with long lasting effects and harmful when swallowed by the European Chemicals Agency (ECHA, 2019). Its use requires prior authorisation.

This compound was used as an additive for paints in order to prevent corrosion of aluminium parts for aircraft fuselages and ships (USGS, 2018). It is also on the hazardous substances list in the US, regulated by OSHA.

Strontium ranelate is a prescription drug for osteoporosis patients. However, studies show a possible link between the drug and cardiovascular risks. The European Medicines Agency limited its use to patients that cannot take other osteoporosis medication. (USGS, 2018)

24.2 Market analysis, trade and prices

24.2.1 Global market analysis and outlook

The global market value of strontium carbonate was USD 59.2 million on average in the period 2012-2016, decreasing from USD 64.5 million in 2012 to USD 53.8 million in 2016. In 2017 the market value remained approximately the same as in 2016 (OEC, 2019; USGS, 2019; SCRREEN workshops, 2019).

The main exporter of strontium carbonate is by far Germany with an average market share of 57%. This share is continuously increasing from 49% in 2012 to 63% in 2016. The second largest exporter was Mexico (22%), followed by China (12%) between 2012 and 2016.

The largest importers of strontium carbonate are Japan (23%), South Korea (21%), and the USA (13%) (OEC, 2019).

Strontium will very likely continue to be an important material for ferrite-magnets, ceramics, glass, and pyrotechnics production. As was previously the case, strontium use in oil and gas drilling will continue to be subject to baryte, and oil and gas price trends. Ongoing research in the use of strontium in optical applications or semiconductors might lead to new end uses in the future (USGS, 2019).

Table 192: Qualitative forecast of supply and demand of Strontium

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Strontium	x		+	?	?	+	?	?

24.2.2EU trade

The EU is a net exporter of strontium the average export (360 tonnes per year) being almost 200 tonnes higher than the average import (210 tonnes per year) in the period 2012-2016. However, the amount of exported strontium is decreasing during this time period and in 2015 and 2016 there is a slight surplus of imports.

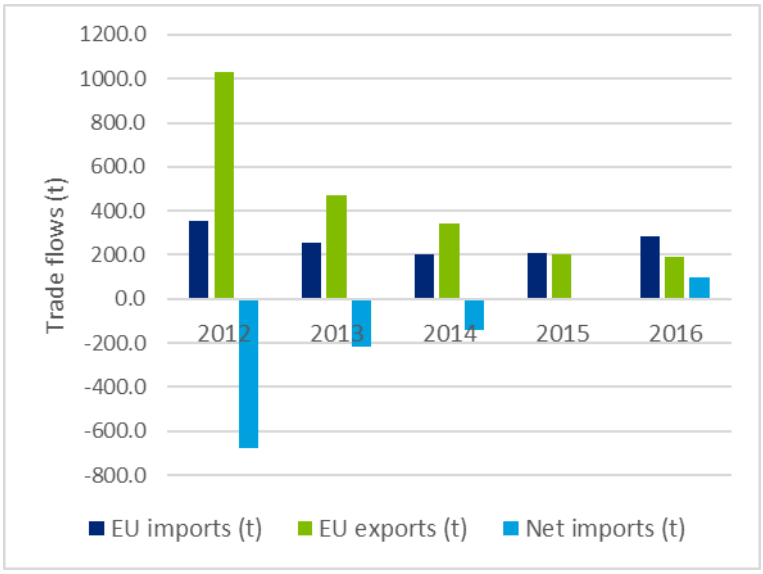

Figure 466: EU trade flows for Strontium (Eurostat, 2019b)

Though with marginal quantities, the main external suppliers for the EU are China (45%), Japan (40%), Mexico (6%) and Canada (3%). There are EU trade agreements in place with Japan, Mexico and Canada (European Commission, 2019). At the moment, there are no exports, quotas or prohibition in place between the EU and its trade partners (Morocco imposes export restrictions on strontium carbonate, but between 2012 and 2016 it was not a trade partner of the EU) (OECD, 2019).

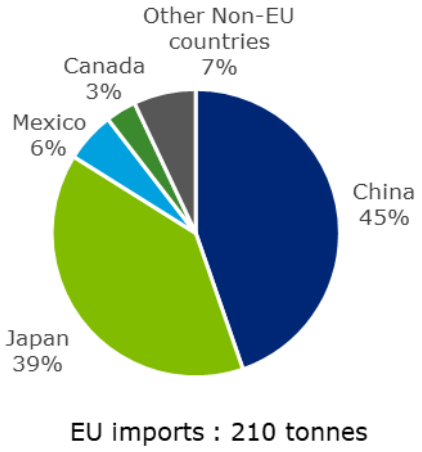

Figure 467: EU imports of Strontium, average 2012-16 (Eurostat, 2019b)

24.2.3Prices and price volatility

Strontium is traded both in form of the mineral celestite, and in form of strontium chemicals and metal. Prices are usually reported in US Dollar per tonne.

USGS records unit values for strontium since 1916, Figure 468 shows price trends until 2015. In previous years prices show a rather high volatility, especially 2004 and 2009 significant price drops were recorded. In 2009 prices decreased by 40% compared to the previous year. After quickly recovering already in 2010 prices decreased again until 2015.

Since 2016 an increase has been registered with celestite prices at USD 78 per tonne in 2016, USD 74 per tonne in 2017 and USD 75 per tonne in 2018.

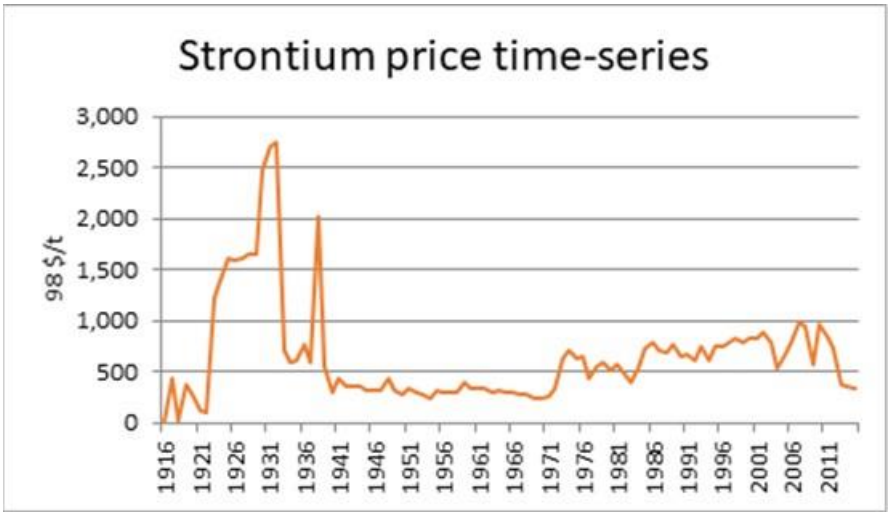

Figure 468: Prices of strontium (USD per tonne, converted to consumer price index 1998) from 1916 to 2015 (USGS, 2019)

24.3 EU demand

The world global production of strontium is about 159,541 tonnes per year averaged over 2012-2016 (Sr content) at a total market value of USD 59.2 million.

24.3.1 EU demand and consumption

The main strontium producer in the EU is Spain and the amount of production is sufficient to supply almost 100% of EU demands. In total 49,650 tonnes of strontium were sourced per year between 2012 and 2016. Other suppliers include China, Japan, Mexico, and Canada. On average the EU consumed 49,300 tonnes per year of strontium in this period.

24.3.2 Uses and end-uses of Strontium in the EU

Figure 469 presents the main uses of all strontium compounds including celestite according to USGS. However, it is questionable if this distribution is valid for EU consumption as well, because there are not as many oil and gas drilling projects as in the USA. Unfortunately, no other sources could be found. If only strontium compounds are considered the distribution looks very different (see Figure 469), and this is more likely to represent European consumption.

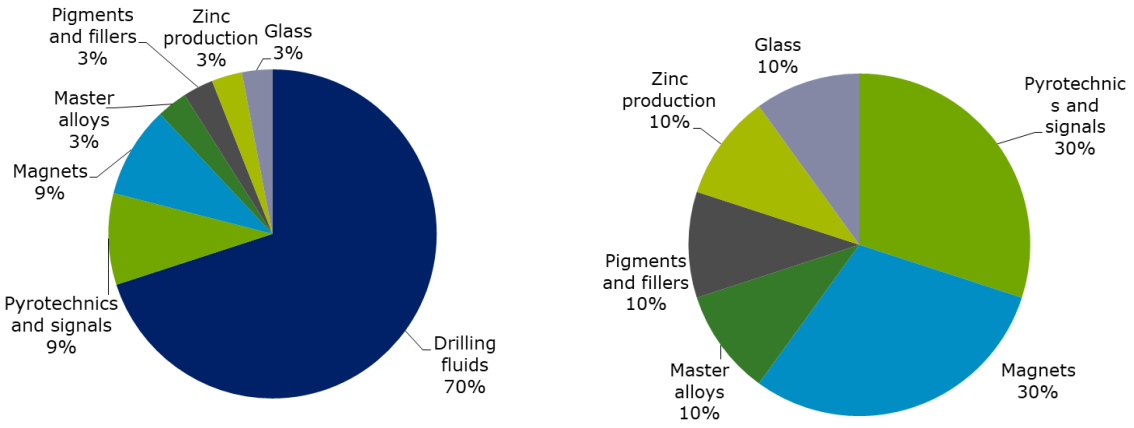

Figure 469: US end uses of Strontium compounds including celestite (left) and Strontium compounds excl. celestite (right). (USGS, 2019; USGS, 2017)

The main end-use of strontium products provided in Figure 469 can be summarised as follows (USGS, 2019):

- Celestite can be used directly in drilling muds for natural gas and crude oil wells, as a substitute for baryte. The amount of strontium used for this application depends on baryte prices.
- A common application of strontium nitrate is as a colouring agent in pyrotechnic applications. It is used to produce bright red colours in fireworks or warning flares for example (alternatively strontium chloride, strontium oxalate, and strontium sulphate can be used). In combination with copper a purple colour can be achieved.
- Permanent ceramic ferrite magnets for small direct current motors, used in automobile windshield wipers, loudspeakers, toys, etc., apply strontium carbonate because it provides effectiveness at high temperatures, low densities, and resistance to corrosion and demagnetisation.
- Previously, the main application of strontium oxide was as glass modifier for cathode-ray-tubes which have almost been completely replaced by flat panel displays. However,

strontium oxide is still used for the production of fiberglass, lab glass and pharmaceutical glass. It enhances optical properties, increases hardness and strength, and intensifies light refraction.

- Strontium oxide and strontium carbonate can be used as nontoxic alternative to barium and lead as frits in ceramic glazes.
- Metallurgy:
  - In aerospace and automotive applications strontium metal is added to aluminium alloys to improve strength and ductility of castings.
  - In Zinc production it can be added to the electrolysis to remove lead impurities.
- Strontium chromate is a corrosion inhibitor previously used in paints, but it is now known that strontium chromate is a carcinogen in humans. Therefore, the European Chemicals Agency limits and monitors its use closely. An alternative is a calcium-strontium-phosphate complex on a silicate core.
- Medical Applications:
  - Strontium ranelate is used in prescription drugs to reduce the occurrence of fractures in osteoporosis patients. However, these drugs are believed to be connected to cardiovascular risks. The European Medicines Agency approved strontium ranelate only for osteoporosis patients that cannot take other medications.
  - The isotope strontium-89 is used for the treatment of bone cancer.
  - Strontium chloride is used in toothpastes to treat temperature- and pressure sensitivity.
- Applications where phosphorescent pigments are needed, for example emergency exits signs, use strontium oxide aluminate as it glows brighter and longer than other pigments.
- Low amounts of strontium are used as a getter in vacuum tubes to remove last traces of air.
- Strontium has many other uses similar to those of calcium and barium, but due to higher costs it is rarely applied. (Lenntech, 2019)
- There is research ongoing for the use of strontium in other high-tech industries which may prove as a future consumer of strontium (semi- and superconductors, memory chips, optical and piezoelectric applications).

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019a).

Table 193: Strontium applications (USGS, 2019), 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019a)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Colouring agent in pyrotechnic applications	C20 – Manufacture of chemicals and chemical products	405.76	C2051 – Manufacture of explosives
Permanent ceramic ferrite magnets for small direct current motors	C28 – Manufacture of machinery and equipment not elsewhere classified	1903,64	C2849 – Manufacture of other machine tools
Production of fiberglass, lab glass	C23 – Manufacture of other non-metallic mineral products	13719,72	C231 – Manufacture of glass and glass products

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
and pharmaceutical glass			
Alloys for aluminium in automotive and aerospace applications	C24 - Manufacture of basic metals	4165,08	C2453 – Casting of light metals
Electrolytic production of zinc to remove lead impurites	C24 - Manufacture of basic metals	237,68	C2443 – Lead, zinc and tin production
Phosphorescent pigments (e.g. exit signs)	C20 – Manufacture of chemicals and chemical products	2262,28	C2012 – Manufacture of dyes and pigments
Drilling fluids	C23 – Manufacture of other non-metallic mineral products	13719,72	

24.3.3 Substitution

In drilling muds the alternative material for strontium carbonate is baryte, which is normally preferred. However, when the price of baryte gets too high, demand shifts to strontium.

Ferrite ceramic magnets can also be produced using barium instead of strontium, accepting a reduced maximum operating temperature (USGS, 2019; SCRREEN workshops, 2019).

24.4 Supply

24.4.1 EU supply chain

Strontium production in the EU provides for 100% of EU demand. Spain is the biggest producer of celestite worldwide, producing an average of 103,660 tonnes per year in the period of 2012-2016. Imports are coming from China (45%), Japan (39%), Mexico (6%) and Canada (3%). The main consumer of EU exports is South Korea (37%), followed by India (19%) and Japan (19%). These numbers result in an import reliance close to zero (Eurostat, 2019a; BGS, 2019).

Thera are only two mines in Granada. The owners are Canteras Industriales, S.A. and Solvay Minerales, S.A. Industriales SL mines yearly a little quantity but obtain the rest of its production from the waste of the celestite mined some years ago. The content of this waste is between 70 and 80% of $SrSO_4$. The company send the production to Solvay plant. Solvay has celestite with a lower content of $SrSO_4$. They process the two mines production to obtain a product with more than 90% of $SrSO_4$. Total production approximately 100,000 tonnes per year. Canteras Industriales sell 3,000-7,000 tonnes to "Química del Estroncio, SL", and a similar quantity to China.

24.4.2Supply from primary materials

24.4.2.1 Geology, resources and reserves of Strontium

Geological occurrence: Strontium is part of the earth's crust with 0.037%. It also occurs in seawater. Due to its reactivity strontium does not occur in its native form, but always in compounds. The minerals that are most important for production due to their strontium content of around 50% are celestite ($SrSO_4$) and strontianite ($SrCO_3$). Celestite deposits were formed by precipitation of strontium sulfate of low solubility from seawater, and strontianite can form hydrothermally or as secondary mineral from celestite. (ISE, 2019)

Global resources and reserves[265]: According to USGS (2019) world resources of strontium exceed 1 billion tonnes. Reserves are estimated at 6.8 Mt.

Active mines can be found in Spain, Iran, China, Mexico and China. However, large celestite deposits have been discovered globally. Barium and Calcium impurities can often lead to a deposit being not economically mineable as their removal is very energy and therefore cost intensive. (USGS, 2018)

EU resources and reserves[266]*:*

About 3.6 million tonnes of celestite are located in Spain. Resource data for some countries in Europe are available at Minerals4EU (2019), as reported in Table 194.

Table 194: Resource data for Europe compiled in the European Minerals Yearbook of Minerals4EU (2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Spain	-	3,600,000	t	Contained $SrSO_4$	Historic Resource Estimates
United Kingdom	-	500,000	t	-	Historic Resource Estimates

[265] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of strontium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template, which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[266] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for strontium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for strontium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for strontium the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Reserves located in Europe are shown in Table 195 (Minerals4EU, 2019).

Table 195: Reserve data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Spain	-	3,743,000	t	-	Proven Reserve
Ukraine (Strontium ore)	Russian Classification	180,670,000	t	-	(RUS) B
Ukraine (Strontium ore)	Russian Classification	678,957,000	t	-	(RUS) C1
Ukraine (Strontium oxide contained)	Russian Classification	191,000	t	-	(RUS) B
Ukraine (Strontium oxide contained)	Russian Classification	674,000	t	-	(RUS) C1

24.4.2.2 World and EU mine production

Only a few countries produce strontium worldwide: Spain and Iran are the largest suppliers (about 31% each), followed by China (19%), Mexico (17%), and Argentina (2%). Between 2012 and 2016 an average of 334,455 tonnes of strontium minerals were produced per year. The Iranian production dropped significantly from 2012 to 2013 to only one quarter of previous amounts (188,790 tonnes in 2012 – 46,240 tonnes in 2013), so did the strontium minerals production in Argentina. While Iran managed to increase amounts again in 2016 to similar levels as before (196,689 t), Argentinian production remained low (1,000 t). Spain, however, increased the production from 2013 to 2014 by almost 40,000 tonnes. In 2016 the amount decreased again to previous levels. (BGS, 2019) The main producer in Spain is Solvay.

In 2017 Iran, Spain and Mexico increased their production leading to a world total of 391,362 tonnes. (BGS, 2019)

A notable increase in production is expected in the coming years due to the growth in demand for strontium ore by China. Although China has proven reserves its celestite has worse characteristics than celestite found in Spain or Mexico. Therefore, China has to rely on imports. (Instituto Geológico y Minero de España, 2017)

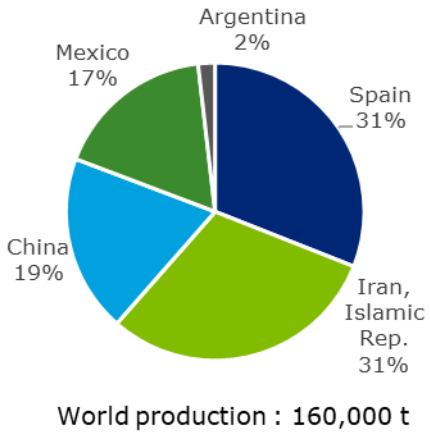

Figure 470: Global mine production of Strontium, 2012-2016 (BGS, 2019).

24.4.3 Supply from secondary materials/recycling

According to UNEP (2011), the End-of-Life Recycling Input Rate of Strontium is below 1%. Therefore, strontium from secondary sources is not considered in this evaluation (EoL-RIR=0).

24.4.4 Processing of strontium

Usually mines produce celestite which is then turned into strontianite. This is done by heating celestite with carbon and thereby reducing to strontium sulphide. There are two possibilities for further processing depending on availability of the necessary reactants. Either carbon dioxide is passed through the strontium sulphide producing strontianite and hydrogen sulphide, or strontium sulphide is reacted with sodium carbonate producing strontianite and sodium sulphide. It is also possible to obtain strontianite in one reaction step, by reacting finely ground celestite with sodium or ammonium carbonate. However, this requires preliminary extensive cleaning, and is therefore rarely conducted.

Strontianite is the raw material for other strontium compounds, and for producing strontium metal.

In order to produce strontium metal strontianite has to be turned into strontium oxide, which is then reduced to elemental strontium in a reaction with aluminium in vacuum. (ISE, 2019)

24.5 Other considerations

24.5.1 Environmental and health and safety issues

As already mentioned before, there are certain compounds of strontium that pose health and environmental risks.

Strontium used to be added to paints in form of strontium chromate to prevent corrosion. (USGS, 2018) As is now known, strontium chromate is a carcinogen in humans, and therefore, its use is subject to authorisation and strict monitoring by the European Chemicals Agency. It is also harmful to aquatic life and can have long lasting effects. (ECHA, 2019)

Strontium is used in strontium ranelate, a prescription drug for osteoporosis patients, to reduce susceptibility to bone fractures. However, this drug is believed to be connected to cardiovascular risks. Therefore, the European Medicines Agency allows it only to be used by patients who cannot take other available osteoporosis pharmaceuticals. (USGS, 2018)

One of strontium's isotopes, Sr-90, that is released into the atmosphere by nuclear fallouts is a beta emitter. Nuclear testing by the USA between 1940 and 1960 and nuclear reactor accidents in Chernobyl (1986) and Fukushima (2011) released high levels of Sr-90, that were eventually absorbed into grasslands, leading to intake by cows and therefore high concentrations in dairy products. Strontium-90 can be absorbed by bone tissue, replacing calcium, eventually destroying bone marrow and leading to cancer. (ISE, 2019)

24.5.2 Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

24.6 Comparison with previous EU assessments

Strontium has not been assessed in previous criticality studies. The results for Economic Importance and Supply Risk of the current study can be seen in Table 196.

Table 196: Economic importance and supply risk results for Strontium in the assessments of 2020

Assessment	2011		2014		2017		2020	
Indicator	not assessed		not assessed		not assessed		EI	SR
Strontium							3,50	2,57

24.7 Data sources

Data for the use of strontium in the EU, as well as price trends in Euro were not available at the time of the assessment.

24.7.1 Data sources used in the factsheet

BGS (2019). World Mineral Production 2013-2017. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

ECHA (2019). Substance information [Online]. Available at: https://echa.europa.eu/de/substance-information/-/substanceinfo/100.029.220?_disssubsinfo_WAR_disssubsinfoportlet_backURL=https%3A%2F%2Fecha.europa.eu%2Fde%2Finformation-on-chemicals%3Fp_p_id%3Ddisssimplesearchhomepage_WAR_disssearchportlet%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_p_col_id%3D_118_INSTANCE_UFgbrDo05Elj__column-1%26p_p_col_count%3D1%26_disssimplesearchhomepage_WAR_disssearchportlet_sessionCriteriaId%3D (Accessed: 03.09.2019)

Eurostat (2019a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 05.09.2019)

Eurostat (2019b). Comext International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/mainxtnet.do (Accessed: 30.08.2019)

Institut für seltene Erden (ISE) (2019). Strontium [Online]. Available at: https://institut-seltene-erden.de/seltene-erden-und-metalle/strategische-metalle-2/strontium/ (Accessed: https://institut-seltene-erden.de/seltene-erden-und-metalle/strategische-metalle-2/strontium/)

Instituto Geológico y Minero de España (2017). Panorama Minero 2017. p. 533. Available at: http://www.igme.es/PanoramaMinero/actual/PANORAMA_MINERO_2017(BU24)(BR).pdf

Lenntech BV (2019). Periodic Table – Strontium [Online]. Available at: https://www.lenntech.com/periodic/elements/sr.htm (Accessed 02.09.2019)

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OEC (2019). Strontium Carbonate Trade [Online]. Available at: https://oec.world/en/profile/hs92/283692/ (Accessed: 13.09.2019)

OEDC (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 03.09.2019)

SCRREEN workshop. (2019). "Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre."

UNEP (2011). Recycling Rates of Metals. Available at: https://www.resourcepanel.org/reports/recycling-rates-metals

USGS (2017). Historical Statistics for Mineral and Material Commodities in the United States. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2018). 2016 Minerals Yearbook – Strontium [Advanced Release]. Available at: https://www.usgs.gov/centers/nmic/strontium-statistics-and-information

USGS (2019). Mineral Commodity Summaries – Strontium. Available at: https://www.usgs.gov/centers/nmic/strontium-statistics-and-information

24.7.2 Data sources used in the criticality assessment

BGS, World mineral statistics data 2019

USGS Mineral Commodity Summaries 2019

Eurostat - Comext database - Code 28369200 "Strontium Carbonate"

T.E. Graedel, 2015, On the materials basis of modern society - supplementary file; Proc Natl Acad Sci USA. 2015 May 19; 112(20): 6295–6300

Study on the review of the list of Critical Raw Materials, 2017

EU Trade Negotiations and agreements - http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

24.8 Acknowledgments

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