SCRREEN2

This project has received funding from the European

Union's Horizon 2020 research and innovation programme

under grant agreement No 958211.

Start date: 2020-11-01 Duration: 36 Months

FACTSHEETS UPDATES BASED ON THE EU FACTSHEETS 2020

STRONTIUM

Author(S):

TABLE OF CONTENT

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STRONTIUM

OVERVIEW

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).

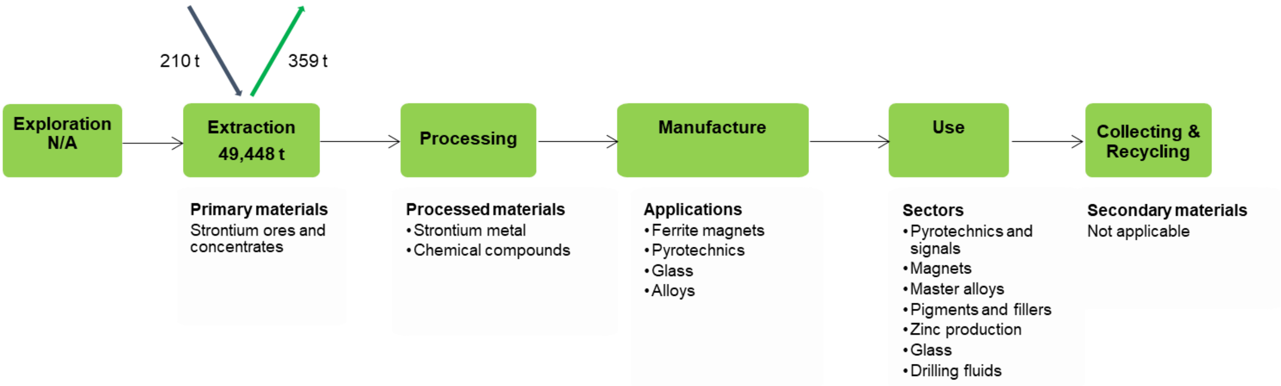

Figure 1. Simplified value chain for strontium in the EU[1]

Table 1. Strontium supply and demand in metric tonnes, Sr content, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
156,417	Iran 37% Spain 34% China 16% Mexico 11%	53,577	34%	Spain 99.7% Mexico 0.3%	0%

Prices: Strontium is traded both in the form of the mineral celestite and in the form of strontium chemicals and metal. In previous years (2000-2015), celestite prices were frequently below the € 51 per tonnes average. Since 2016, the price experienced a significant improvement in performance with prices reaching an all-time high in 2019 at 82 USD per ton.

Primary supply: Only a few countries produce strontium worldwide. Iran, Spain, China and Mexico are the main producers. Their world production shares in 2021 were about: 37%, 34%, 16% and 11%. Iran is a major producer since 2017. Spanish strontium production has been significantly increased between 2019 (from

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

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90.000 tonnes) and 2021 (150.000 tonnes). The main producer in Spain is Solvay. A notable increase in production is taking place during the last 3 years due to the growth in demand for strontium ore by China.

Secondary supply: The recycling rate of strontium is very limited (<1%) (UNEP, 2011) due to low recyclability of Sr-containing end-products. Residues resulting from the manufacture of strontium ferrite are recycled/re-generated through a combination of nanostructuration, homogenization and thermal treatment (Bollero et al. 2017). In the contrast, researchers have shown that Sr recovery by containing end-of-life cathode ray tube is challenging due to the difficulty of lead separation and decontamination (Qi et al. 2019).

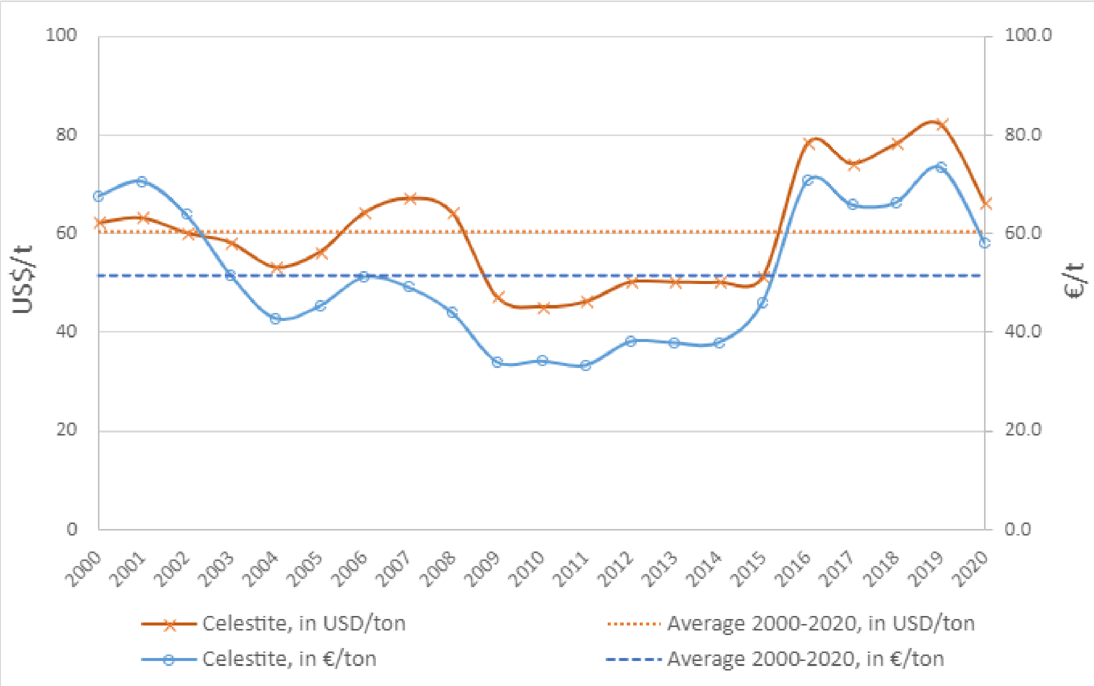

Figure 2. Annual average price of celestite ($SrSO_4$) between 2000 and 2020 (USGS, 2021)[2].

[2] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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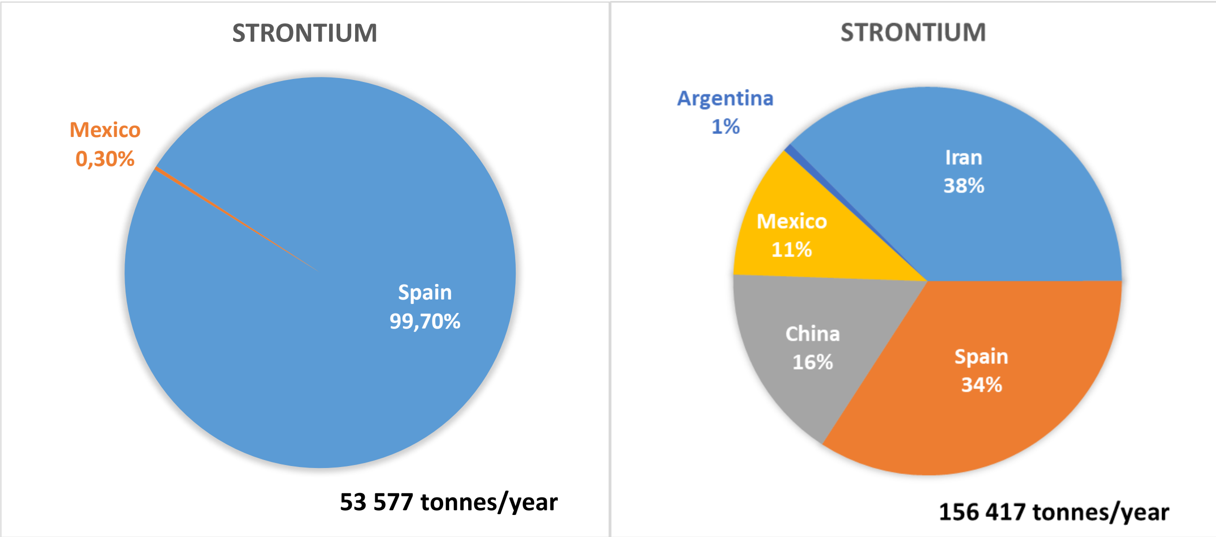

Figure 3. EU sourcing of strontium carbonate (Eurostat 2022) and global primary production of strontium concentrate (BGS 2022), both in Sr content.

Uses: The main end-uses of strontium products can be summarised as follows: Industrially, strontium and especially its compounds are used in many ways, including in the electrical and electronics industry (as a component of phosphors, batteries, electrical capacitors and optical devices), the glass industry, the metalworking industry, pyrotechnics and in medicine. In addition, it is used in archaeology and geology as a probe material (USGS, 2019; UPB 2022).

Substitution: In drilling muds, the alternative material for strontium carbonate is barite, which is normally preferred, but celestite may substitute for some barite, especially when barite prices are high. (USGS, 2022). Ferrite ceramic magnets can also be produced using barium instead of strontium, accepting a reduced maximum operating temperature (USGS, 2022; SCRREEN workshops, 2019). Substituting for strontium in pyrotechnics is hindered by difficulty in obtaining the desired brilliance and visibility imparted by strontium and its compounds. (USGS, 2022).

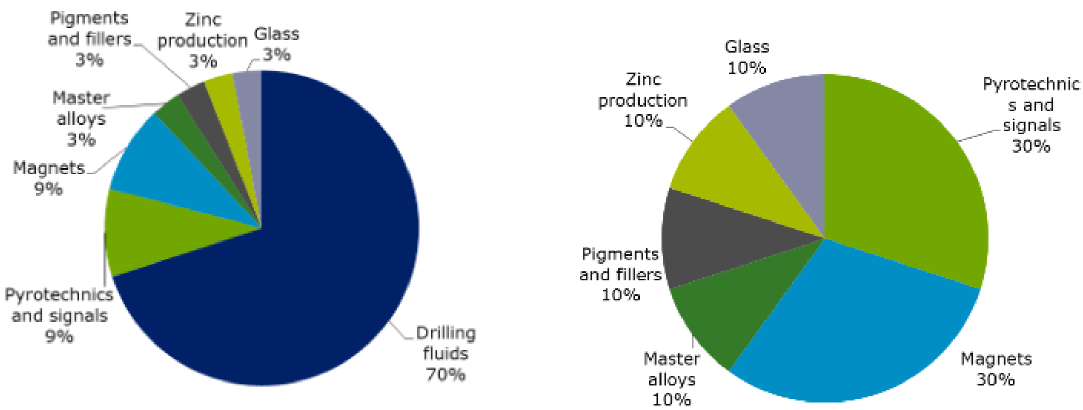

Figure 4: EU uses of Strontium compounds including celestite (left) and Strontium compounds excl. celestite (right). (USGS, 2019; USGS, 2017).

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Table 2. Uses and possible substitutes

Application	Share	Substitutes	Cost	Performance
Magnets	40%	Barium	Very high costs (more than 2 times)	Similar
Drilling fluids	0%	Baryte	Very high costs (more than 2 times)	Similar

Other issues: Strontium in its elemental form occurs naturally in many compartments of the environment, including rocks, soil, water, and air. It is always present in the air as dust, and it is characterized by high water solubility. The presence of this substance in the air is increased by human activities, such as coal and oil combustion, while its presence in waters is a consequence of rock weathering. When strontium concentration in water exceeds regular concentrations, this is usually caused by human activities. (CLP, 2008) lists strontium chromate as very toxic to aquatic life with long-lasting effects (hazard codes H400 and H410. In 2018, the Government of Canada issued a Guideline Technical Document for Public Consultation dealing with Strontium in drinking water. The purpose of the consultation is to solicit comments on the proposed guideline, on the approach used for its development and on the potential economic costs of implementing it, as well as to determine the availability of additional exposure data. A maximum acceptable concentration (MAC) of 7.0 mg/L is proposed for strontium in drinking water, based on bone effects in rats and using currently available scientific studies and approaches (Canada, 2018).

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 3. Strontium supply and demand in metric tonnes, Sr content, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
156,417	Iran 37% Spain 34% China 16% Mexico 11%	53,577	34%	Spain 99.7% Mexico 0.3%	0%

Iran and Spain are the two most significant strontium producers worldwide followed by China, Mexico and Argentina. Strontium carbonate is the most traded strontium compound and from which other strontium compounds can be derived as well (USGS, 2021). The global strontium carbonate market is fragmented by the presence of major players who acquire smaller companies and further develop innovative strontium carbonate products to strengthen their position in the competitive market. Some of the top key players in the strontium carbonate market include Solvay (Belgium), Quimica Del Estroncio S.A. (Spain), Basstech International (USA), and Joyieng Chemical Limited (China) (Market Watch, 2022).

EU TRADE

Table 4. Relevant Eurostat CN trade codes for Strontium

Processing/refining	
CN trade code	**Title**
28332950	Strontium sulphate
28369200	Strontium carbonate
28051910	Strontium and Barium
261640	Oxides, hydroxides, peroxides, of Strontium and Barium

For EU trade, the data is only available for strontium carbonate in either EU stat or UN Comtrade database. The 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.

The EU is a net exporter of strontium carbonate (CN 28369200) with an total export of 24,345 tonnes from 2000 to 2021. On average the export has been increased continuously from the 2000 quantity of 40 tonnes to 3005 tonnes in 2021. The average EU import of strontium carbonate was 2365 tonnes/year between 2000 and 2021 and it is almost constant from 2012 to 2021 at an average yearly import of 450 tonnes.

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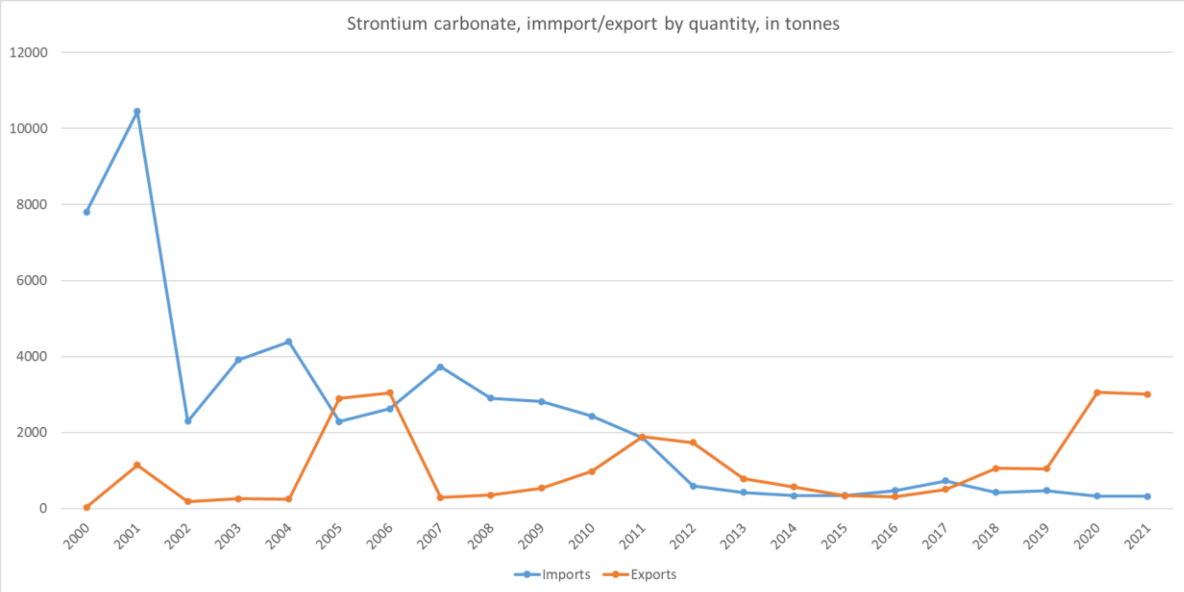

Figure 5. EU trade flows of Strontium Carbonate (CN 28369200) from 2000 to 2021 (based on Eurostat, 2022)

The main import partners of EU are China (37%), Mexico (29%), Russia (22%) between 2000 and 2021. China used to be the main supplier until 2016 but Mexico has overtaken others as the main import partner in last five years. There are EU trade agreements in place with Japan, Mexico, and Canada (European Commission, 2019). 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 or between 2016-2020, it was not a trade partner of the EU) (OECD, 2019).

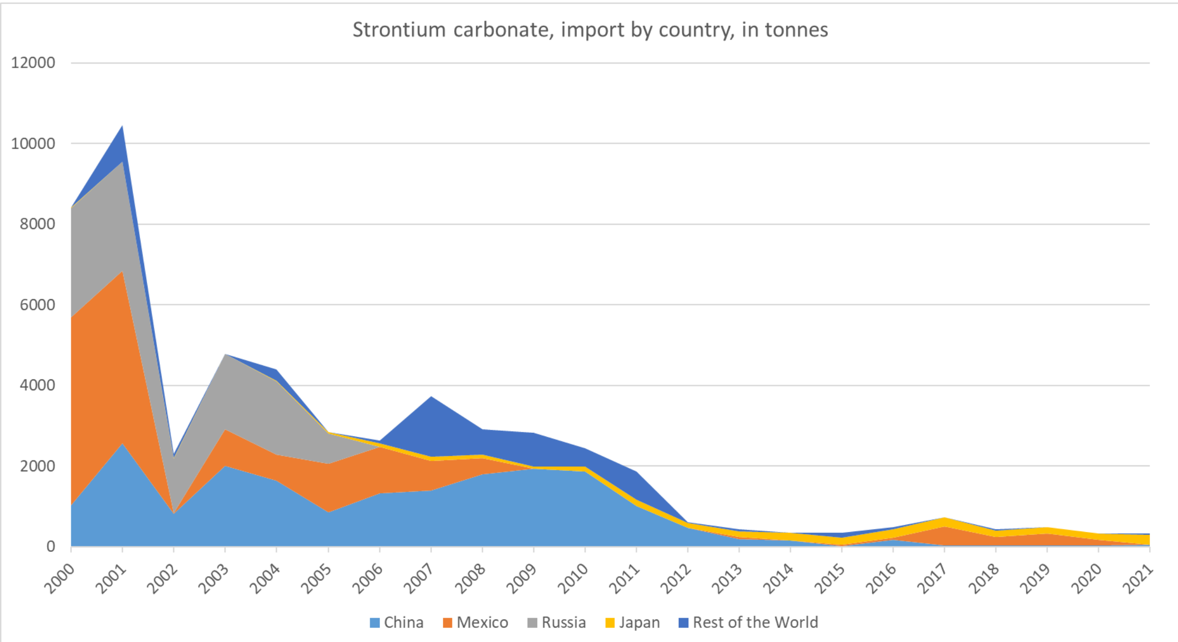

Figure 6. EU imports of Strontium Carbonate by country between 2000 and 2021 (Eurostat, 2022)

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PRICE AND PRICE VOLATILITY

Strontium is traded both in the form of the mineral celestite and in the form of strontium chemicals and metal. In previous years (2000-2015), celestite prices were frequently below the 51 €/ton, on average. Since 2016 prices experienced a significant increase, reaching an all-time high in 2019 at 73 €/ton. However, the price declined to 58 $/ton by 2020. This decline can be attributed to a decrease in apparent consumption by 63% in 2020 compared with that in 2019 because of the economic slump caused by the global COVID-19 pandemic (USGS, 2022).

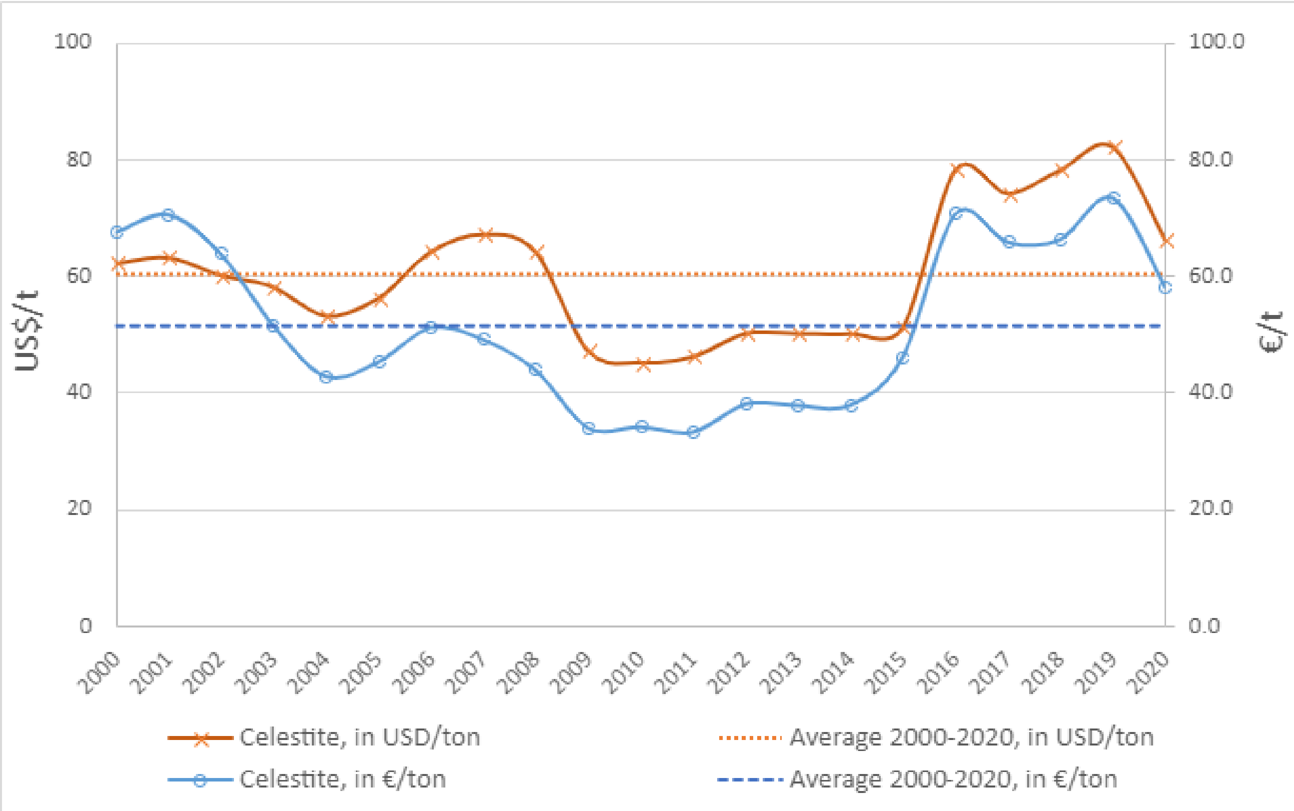

Figure 7. Annual average price of celestite between 2000 and 2020, in US$/kg and €/kg (USGS, 2021). Dash lines indicates average price for 2000-2020.

OUTLOOK

Strontium market size was over USD 400 million in 2017 and is projected to expand at over 6% CAGR between 2018 and 2025 (Global Market Insights, 2018). It is expected that the global strontium market will experience considerable growth at a fast rate. This is due to increased demand from several end-user industries (BlueQuark Research & Consulting, 2021). 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). Asia-Pacific region is anticipated to be the most significant market for strontium compounds due to its growing

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population which boosts the demand in the medical, dental and construction sectors. There is also a conscientious effort to invest in research and innovation which will aid in this region's dominance (BlueQuark Research & Consulting, 2021).

DEMAND

GLOBAL AND 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. On average the apparent EU consumption of strontium was 48,395 tonnes per year between 2016 and 2020.

Strontium processing stage apparent EU consumption is presented by HS code CN 28369200 Carbonates; strontium carbonate. Import and export data is extracted from UNComtrade (2021). Production data is extracted from BGS (2021) for strontium minerals (celestite, 43.88% strontium content).

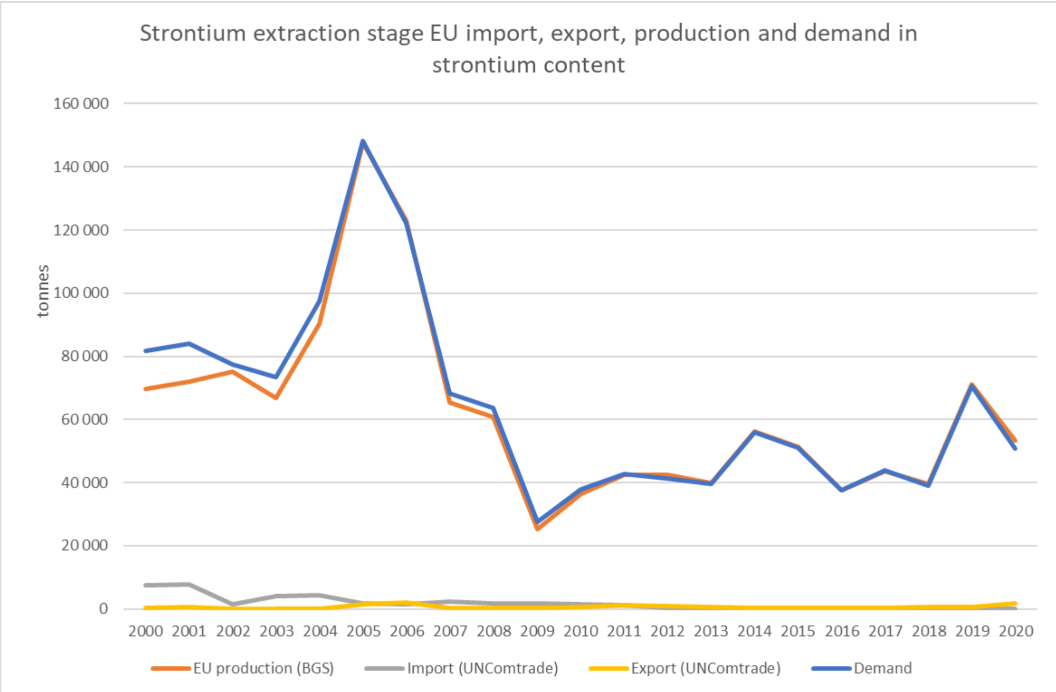

Figure 8. Strontium (CN 28369200 strontium carbonate) processing stage apparent EU consumption. Production data from BGS (2021) for strontium minerals is available for 2000-2020. Consumption is calculated in strontium content (EU production+import-export). Demand spike in 2005 and lowered demand afterwards is estimated to be caused by introduction of flat-screen TV technology that does not demand strontium carbonate (USGS, 2006).

Based on UNComtrade (2021) and BGS (2021) average import reliance of strontium at extraction stage is -0.87% for 2016-2020.

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GLOBAL AND EU USES AND END-USES

Figure 9 presents the main uses of strontium in the EU.

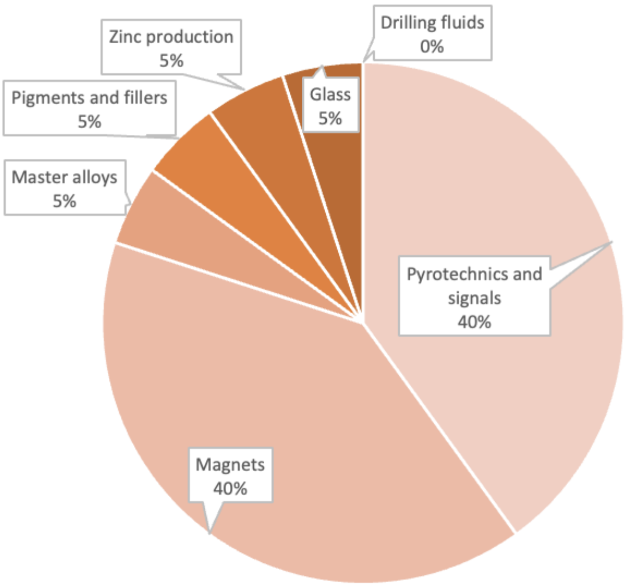

Figure 9. EU uses of Strontium compounds (USGS, 2022, validated by SCRREEN experts, 2022).

Table 5. Strontium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector for 2019 (*2014 data only) (Eurostat, 2022)

Applications	2-digit NACE sector	Value-added of sector (millions €)	Examples of 4-digit NACE sector
Colouring agent in pyrotechnic applications	C20 - Manufacture of chemicals and chemical products	117,150	C2051 – Manufacture of explosives
Permanent ceramic ferrite magnets for small direct current motors	C28 - Manufacture of machinery and equipment n.e.c.	200,138*	C2849 - Manufacture of other machine tools
Production of fiberglass, lab glass and pharmaceutical glass	C23 - Manufacture of other non-metallic mineral products	72,396	C231 - Manufacture of glass and glass products
Alloys for aluminium in automotive and aerospace applications	C24 - Manufacture of other non-metallic mineral products	63,700	C2453 – Casting of light metals
Electrolytic production of zinc to remove lead impurities	C24 - Manufacture of other non-metallic mineral products	63,700	C2443 - Lead, zinc and tin production
Phosphorescent pigments (e.g. exit signs)	C20 - C20 - Manufacture of chemicals and chemical products	117,150	C2012 – Manufacture of dyes and pigments
Drilling fluids	C23 - Manufacture of other non-metallic mineral products	72,396	

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The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (Table 5).

The main end-use of strontium products can be summarised as follows: Industrially, strontium and especially its compounds are used in many ways, including in the electrical and electronics industry (as a component of phosphors, batteries, electrical capacitors, and optical devices), the glass industry, the metalworking industry, pyrotechnics and in medicine. In addition, it is used in archaeology and geology as a probe material (USGS, 2019; UPB 2022).

PYROTECHNIC APPLICATIONS

A common application of strontium nitrate ($Sr(NO_3)_2$) 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. Strontium nitrate also plays an important role in technical pyrotechnics (Tropag, 2022).

PERMANENT CERAMIC FERRITE MAGNETS

Permanent ceramic ferrite magnets for small direct current motors, used in automobile windshield wipers, loudspeakers, toys, etc., contain strontium carbonate ($SrCO_3$) because it provides effectiveness at high temperatures, low densities, and resistance to corrosion and demagnetisation. Permanent magnets made of hard ferrite consist of iron oxide and additionally strontium or barium. For the magnetic properties, it is irrelevant whether barium or strontium is used. However, the most used is the latter because of lower costs and higher availability (ML, 2022).

PRODUCTION OF FIBREGLASS

In the past, the main application of strontium oxide (SrO) was as glass modifier for cathode-ray-tubes which have almost been completely replaced by flat panel displays. However, strontium oxide is still used to produce fiberglass. For example, Haag (2015) researched the fabrication of glass fibres and characterised their behaviour upon irradiation with 243 nm and 307 nm light, which is required for the excitation of trapped strontium ions into Rydberg states[3]. SrO is also used for lab glass and pharmaceutical glass, since it enhances optical properties, increases hardness and strength, and intensifies light refraction.

AEROSPACE AND AUTOMOTIVE APPLICATIONS

In aerospace and automotive applications strontium metal is added to aluminium alloys to improve strength and ductility of castings.

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[3] The Rydberg states of an atom or molecule are electronically excited states with energies that follow the Rydberg formula as they converge on an ionic state with an ionization energy.

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In Zinc production, Sr is added in the electrolysis process to remove lead (Pb) impurities and improve final product quality.

MEDICAL APPLICATIONS:

Various forms of strontium are used as medicine.

- Strontium ranelate, a strontium(II) salt of ranelic acid, 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.
- Strontium isotope ^{89}Sr is used for the treatment of bone cancer.
- Strontium chloride ($SrCl_2$) is used in toothpastes to treat temperature- and pressure sensitivity.

Scientists are testing strontium ranelate to see if it can be taken orally to treat thinning bones (osteoporosis). The aim is to reduce the risk of vertebral and hip fractures. This active ingredient serves the following purposes: promoting the proliferation of bone-building cells, inhibiting the growth of bone-degrading cells, promoting the formation of collagen (Onmeda, 2022). Strontium isotope ^{89}Sr is given intravenously for treating prostate cancer and advanced bone cancer (Orthopaedie-innsbruck, 2022). Strontium chloride ($SrCl_2$) hexahydrate is added to toothpaste to relieve pain in teeth sensitive to low temperature and high pressure.

DRILLING MUDS

Celestite, or celestine, is a mineral consisting of strontium sulphate ($SrSO_4$) that can be used directly in drilling muds for natural gas and crude oil wells, as a substitute for baryte.

PHOSPHORESCENT PIGMENTS

Applications where phosphorescent pigments are needed, for example emergency exits signs, use strontium oxide aluminate as it glows brighter and longer than other pigments.

Afterglow or phosphorescent materials obtain their luminous properties by incorporating a phosphorescent pigment, usually strontium aluminate ($SrO{\cdot}Al_2O_3$) doped with rare earths. This ceramic-like material is produced in a sintering process at high temperatures. The manufacturing process produces sintered blocks that are then crushed and ground in a complex process. Finally, the raw pigment is sieved to the desired fineness and particle sizes. The larger the particles, the better the luminosity. However, strontium aluminate is very hard and thus correspondingly abrasive in processing. With a Mohs hardness of 9, it is almost as hard as diamond. Therefore, depending on the substrate material and further processing, it may be necessary to use finer grades (KM, 2009).

RESEARCH ONGOING

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).

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SUBSTITUTION

When drilling muds, the alternative material for strontium carbonate ($SrCO_3$) is barite, which is normally preferred, but celestite may substitute for some barite, especially when barite prices are high. (USGS, 2022)

Ferrite ceramic magnets can also be produced using barium instead of strontium, accepting a reduced maximum operating temperature (USGS, 2022; SCRREEN workshops, 2019).

Substituting for strontium in pyrotechnics is hindered by difficulty in obtaining the desired brilliance and visibility imparted by strontium and its compounds. (USGS, 2022).

PYROTECHNICS

Substituting for strontium in pyrotechnics is hindered by difficulty in obtaining the desired brilliance and visibility imparted by strontium and its compounds (USGS, 2022). Regarding more environmentally friendly pyrotechnics, strontium can be replaced by lithium. Lithium and its salt compounds colour the flames red. So far, it has been used less in fireworks (Artelt, 2021).

FERRITE CERAMIC MAGNETS

Barium can substitute strontium in ferrite ceramic magnets; however, the resulting barium composite will have a reduced maximum operating temperature when compared with that of strontium composites (USGS, 2022).

Permanent magnets made of hard ferrite consist of iron oxide and additionally either strontium (Sr) or barium (Ba, a heavy metal). For the magnetic properties, it is irrelevant whether barium or strontium is used; mostly it is the latter, if only because of the lower costs and better availability (ML, 2022).

Table 6. Uses and possible substitutes.

Application	Share*	Substitutes	Cost	Performance
Magnets	40%	Barium	Very high costs (more than 2 times)	Similar
Drilling fluids	0%	Baryte	Very high costs (more than 2 times)	Similar
EU uses of Strontium compounds (USGS, 2022, validated by SCRREEN experts, 2022).				

SUPPLY

EU SUPPLY CHAIN

Strontium production in the EU covers by 100% the respective demand. The average primary production in EU, in terms of celestite and other minerals, during the period 2015-2019 was around 100.000 tonnes (Eurostat, 2020). Spain is the main producer of celestite In Europe. Imports are coming from China (45%),

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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.

SUPPLY FROM PRIMARY MATERIALS

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

According to USGS (2022) 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

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 7.

Table 7. 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

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The strontium reserves located in Europe are shown in Table 8 (Minerals4EU, 2019).

The existence of strontianite ($SrCO_3$) occurrences have been reported in two localities in Finland. In Siilinjärvi carbonatite, LREE-bearing strontianite co-exists with apatite, monazite-(Ce), pyrochlore-group minerals and REE-bearing Ti–Nb-phases. Apatite is currently mined at Siilinjärvi as a phosphate resource. SrO is contained at notable concentration in dolomite (0.5 wt.%), baryte (1-1.4 wt.%) and apatite (0.8 wt.%) phases (Ani, 2013). Sokli phoscorite– magmatic carbonatite complex contains late-stage dykes of dolomite carbonatite cutting the earlier intrusions and the fenites, and contain apatite and monazite together with Sr–Ba-LREE-bearing carbonates including strontianite (Goodenough et al. 2016). However, in both two localities, the total amount and the average concentration of strontium in the carbonatites has not been estimated. Furthermore, is uncertain whether strontium is possible to be recovered as a by-product.

Table 8. 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

WORLD AND EU MINE PRODUCTION

Only a few countries produce strontium worldwide. The global primary production of strontium concentrate (mainly celestite) since 2000 can be seen in Figure 1 (USGS, since 2000). Spain, Iran, China and Mexico consist the main producers. Their world production shares in 2021 were about: 42%, 25%, 22%, 10%. Iran consist a major producers since 2017. Spanish strontium production has been significantly increased between 2019 (from 90.000 tonnes) and 2021 (150.000 tonnes). The main producer in Spain is Solvay. A notable increase in production is taking place during the last 3 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).

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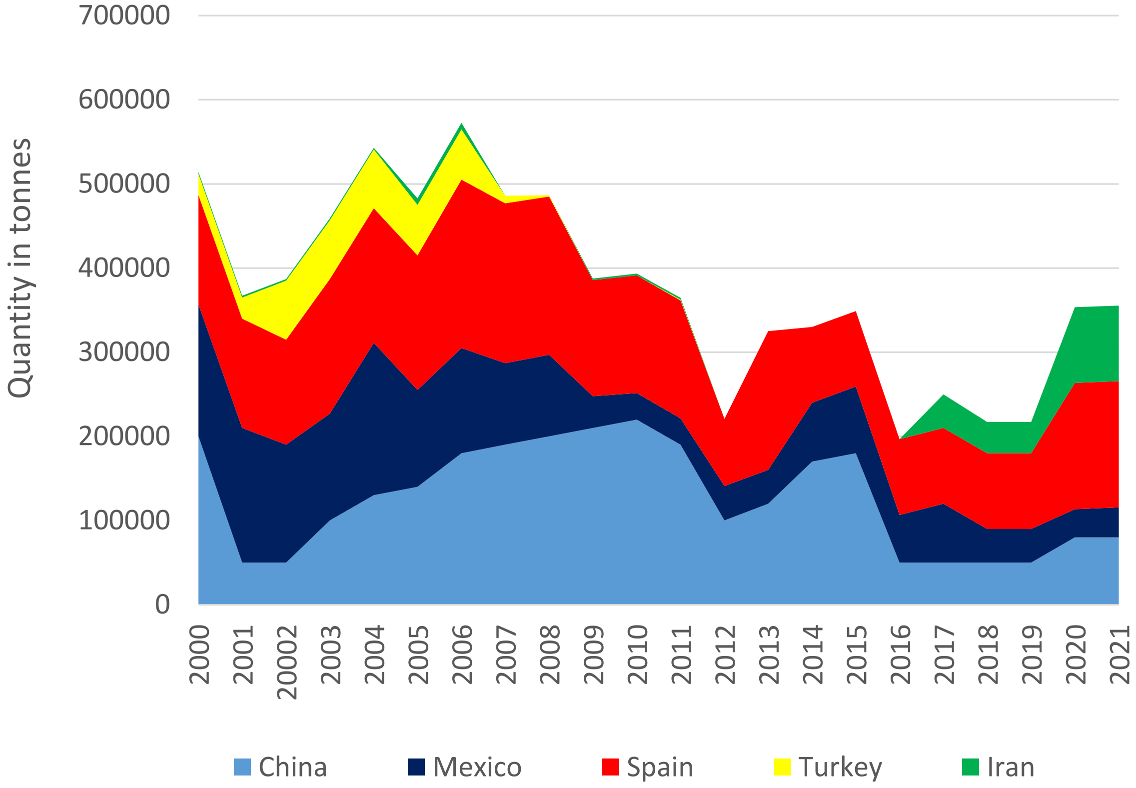

Figure 10. Global primary production of strontium concentrate (mainly celestite) since 2000 (USGS, since 2022).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

The recycling rate of strontium is considered to be very limited (<1%) (UNEP, 2011) due to the low recyclability of the Sr-containing end-products. Recent scientific research at laboratory scale is focused on the recycling of: (a) Sr-bearing sludge from nuclear plants and (b) residues from the strontium ferrite magnets industry. In first case, the production of high-purity strontianite and hematite nanoparticles as by-product was achieved through a treatment with nitric acid followed by the precipitation of iron oxide using glycol (Bian et al. 2020). In the second case, residues resulting from the manufacture of strontium ferrite are recycled/re-generated through a combination of nanostructuration, homogenization and thermal treatment (Bollero et al. 2017). In the contrast, researches have shown that Sr recovery by containing end-of-life cathode ray tube is challenging due to the difficulty of lead separation and decontamination (Qi et al. 2019).

PROCESSING OF STRONTIUM

Celestite ($SrSO_4$) and strontianite ($SrCO_3$) are the two naturally occurring strontium minerals but only celestite is an exploitable source of strontium processed for the production of strontium carbonate, from which other strontium chemicals (strontium nitrate, chloride, hydroxide, etc.) are obtained. $SrCO_3$ is industrially produced from celestite concentrates by using two methodologies: (a) the black ash and (b) the double decomposition

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(direct conversion) processes. Following the black ash process, $SrSO_4$ is reduced with coke at temperatures over 950 °C to produce water soluble SrS. The strontium sulphide is leached with hot water and strontium is precipitated using sodium carbonate and/or carbon dioxide as $SrCO_3$ from the solution (Figure 2). Following the double decomposition or direct conversion method, finely powdered celestite reacts with hot aqueous sodium carbonate solution (>90 °C) to obtain directly $SrCO_3$ and sodium sulphate by-product according to the following reaction:

$$SrSO_4 (s) + Na_2CO_3(aq) \rightarrow SrCO_3(s) + Na_2SO_4(aq)$$

Black ash method produces a high-purity $SrCO_3$ product, however it is more energy intensive in comparison to the double decomposition process (Obut et al. 2006).

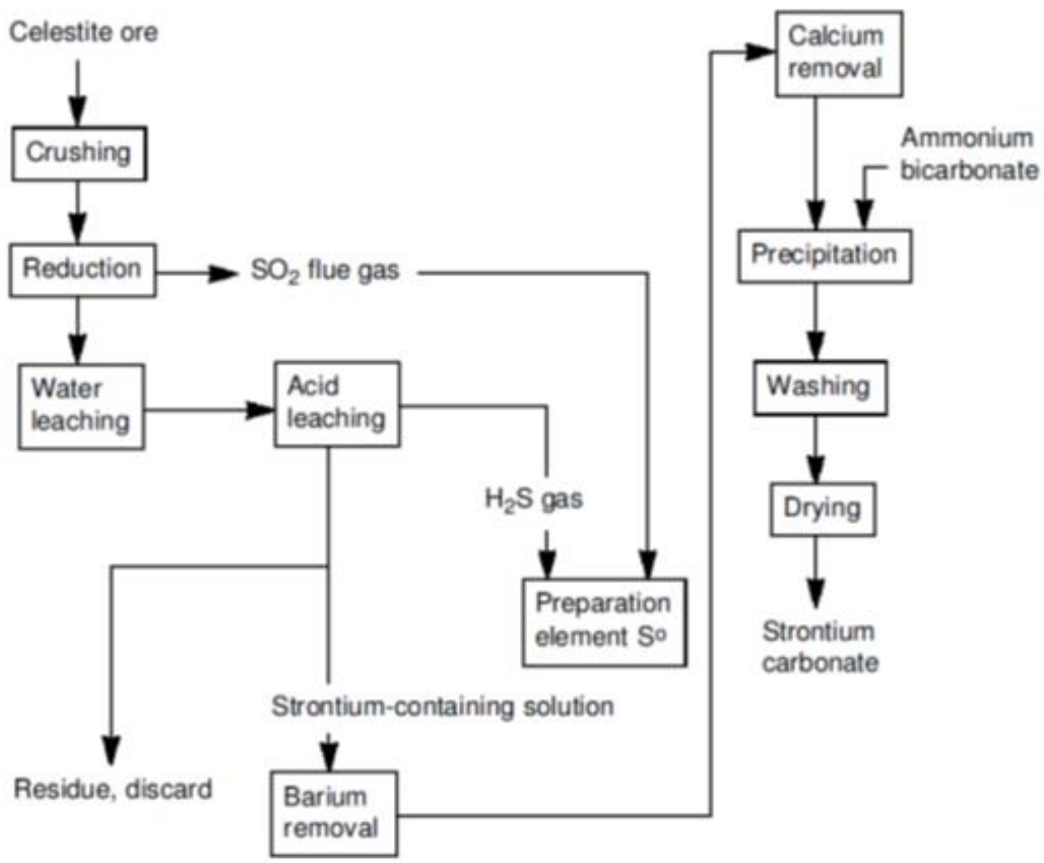

Figure 11. Simplified flowsheet of celestite processing to produce strontium carbonate through the initial carbothermal reduction (black ash method) of the celestite concentrate (Chen and Zhu, 2000).

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).

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OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Elemental strontium (Sr) is considered safe for humans, especially at low concentrations. Food and drinking water are a source of strontium intake but it does not pose a significant risk to human health. The only strontium compound that is considered a danger to human health, even in small quantities, is strontium chromate ($SrCrO_4$) which is known to cause lung cancer, though the risks of exposure have been greatly reduced by safety procedures in companies. The ingestion of the radioactive isotope of strontium ^{90}Sr via contaminated water and food is a major exposure pathway for the population and can in turn result in health issues such as bone disorders and bone cancer (Höllriegl, V. et al., 2011).

Strontium chromate is on the List of substances subject to authorization (List of Substances of Very High Concern, SVHCs) and on ANNEX XIV of (REACH, 2006) given that it is presumed to be carcinogenic to humans (class 1B). Moreover, (CLP, 2008) catalogues strontium chromate as a substance that may cause cancer (hazard code H350) and is harmful if swallowed (H302).

The radioactive isotope ^{90}Sr together with all radionuclides that emit β-radiation carcinogenic to humans is listed in Group 1 of carcinogenic substances (IARC 2012).

ENVIRONMENTAL ISSUES

(CLP, 2008) lists strontium chromate as very toxic to aquatic life with long-lasting effects (hazard codes H400 and H410.

Soil concentrations may also be increased by human activities, such as the disposal of coal ash and incinerator ash, and industrial wastes. Part of the strontium present in soils dissolves in water and it is likely to move deeper and enter the groundwater (Burger, A. et al., 2019).

The strontium isotope ^{90}Sr has a half-life of 29 years. It is not likely to occur naturally in the environment, but it is a result of human activities, such as nuclear bomb testing and radioactive storage leaking. The only way to decrease concentrations of this isotope is through radioactive decay to stable zirconium. Particles of radioactive strontium in the environment will eventually end up in soils or water bottoms, where they mix with other strontium particles (US ATSDR, 2004).

NORMATIVE REQUIREMENTS

In 2018, the Government of Canada issued a Guideline Technical Document for Public Consultation dealing with Strontium in drinking water. The purpose of the consultation is to solicit comments on the proposed guideline, on the approach used for its development and on the potential economic costs of implementing it, as well as to determine the availability of additional exposure data. A maximum acceptable concentration (MAC) of 7.0 mg/L is proposed for strontium in drinking water, based on bone effects in rats and using currently available scientific studies and approaches (Canada, 2018).

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In (EPA 2022) the international, national, and state regulations and guidelines regarding stable strontium in air, water, and other media are summarized. For a full reference consult (EPA 2022).

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF STRONTIUM FOR EXPORTING COUNTRIES

The value of strontium exports did not exceed 0.1 % of the total shares in any of the exporting country in (COMTRADE, 2022)

SOCIAL AND ETHICAL ASPECTS

No data was found

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

No recent information available

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