Criticality assessment
-
Silicon metal

14

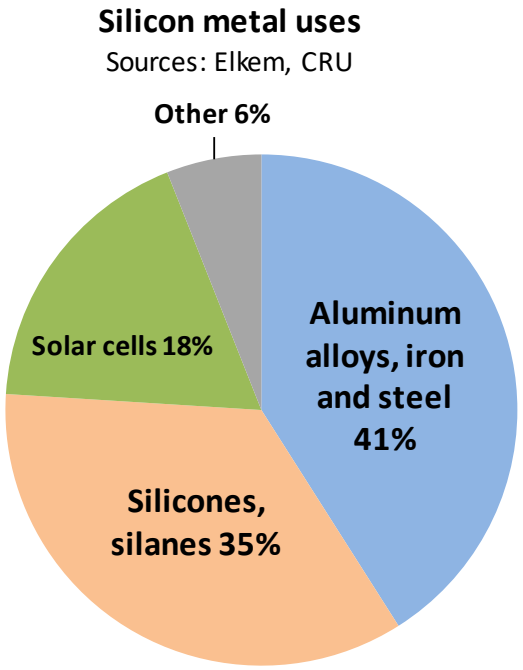
Si

Silicon

Géosciences pour une Terre durable
brgm

comes
Comité pour les métaux stratégiques

- **Main uses of silicon metal in the world in 2018:**



2018 world consumption: 2.9 Mt

- **Trends in global consumption :**
  - **Increasing consumption** due to silicones, solar cells, and aluminum alloys. Growth is estimated at **4.5 %** over the next 5 years[2].
  - Li-on batteries containing Si are being developed very actively. These batteries could achieve higher capacities.

[1] Elkem 2019
[2] CRU 2019

14
Si
Silicon

Data

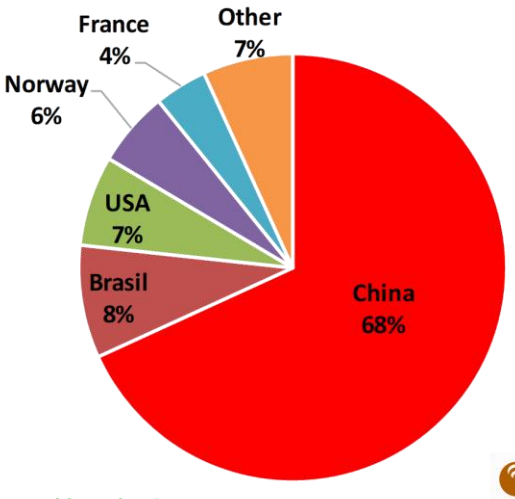
- **Is the substance a byproduct? No**
  - Silicon metal is obtained after the carboreduction of high-purity silica (quartzite, quartz pebbles, sandstone, flint). Contrary to popular belief, natural sand is not used as an input to produce silicon metal for technical reasons (e.g. circulation issues of SiO and CO gases in electric arc furnaces)

- **World mine production* 2018 (silicon metal only) :**
  - Production : **3.8 Mt Si** (on the basis of 2.8 tonnes of quartz to produce 1 tonne of silicon metal, with 46 % of quartz being Si)
  - Distribution : **not precisely known**. Silicon metal being mainly produced close to quartz quarries, please refer to countries where silicon metal is produced

- **World metal production 2018 :**
  - Primary production[2] : **3.0 Mt Si**
  - HHI (Herfindahl-Hirschman Index) = **0.48** highly concentrated market (see beside)
  - HHI 10-year variation: **+ 9 %** (HHI of 0.44 in 2008)
  - Secondary production: **very small**[4]

Geographical distribution of primary silicon metal production

Sources : CRU, Argus Media



Estimated 2018 world production: 3.0 Mt

*Siliceous rock extraction falls under the quarries regulations in France

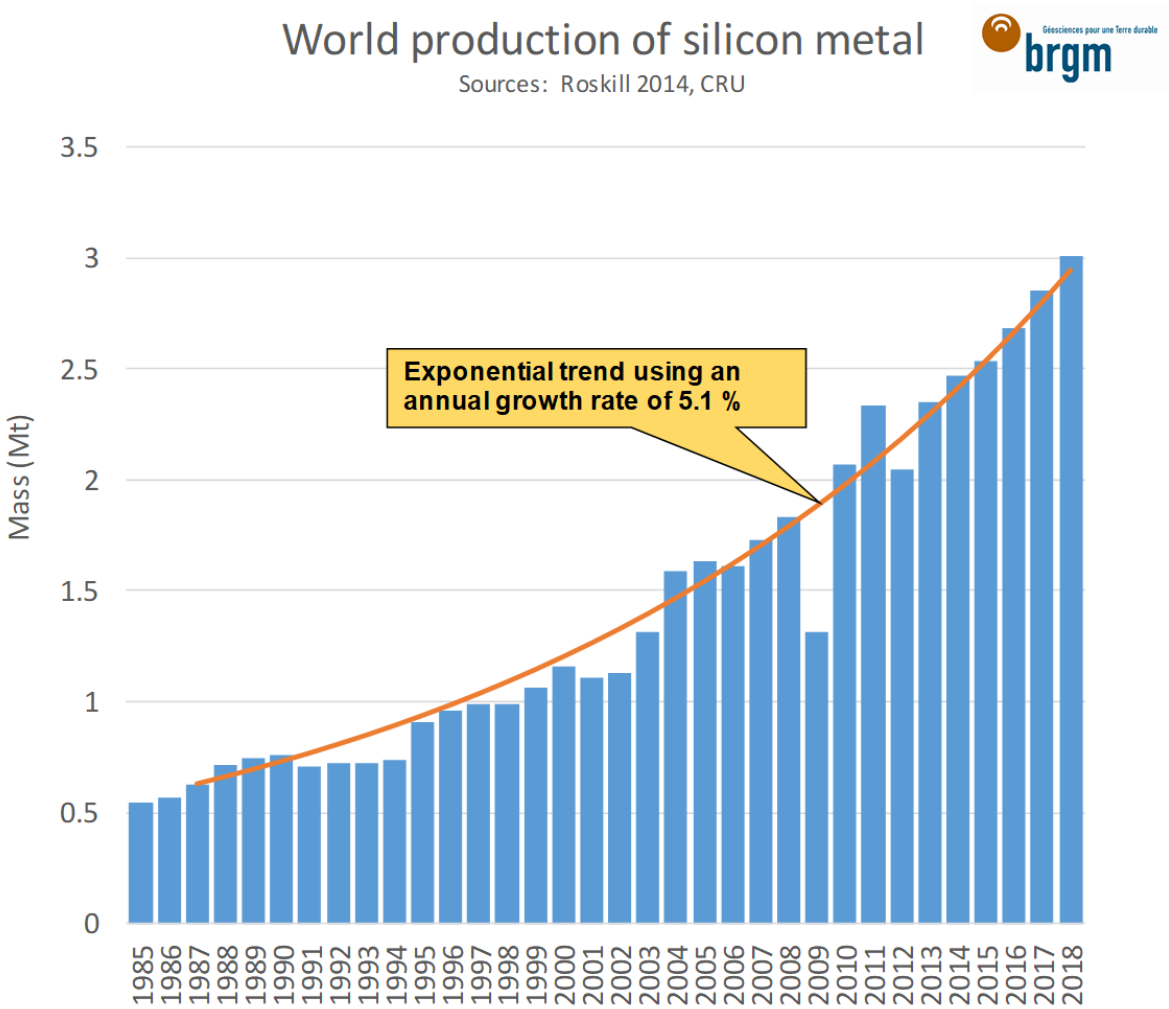
[2] CRU 2018

[3] Argus Media 2019

[4] Latunussa, Cynthia E.L., Fulvio Ardente, Gian Andrea Blengini, and Lucia Mancini. 'Life Cycle Assessment of an Innovative Recycling Process for Crystalline Silicon Photovoltaic Panels'. Solar Energy Materials and Solar Cells 156 (November 2016): 101–11. https://doi.org/10.1016/j.solmat.2016.03.020.

14
Si
Silicon

- **Average annual growth rate (AAGR)[2,4] :**
  - AAGR of metal production over 30 years (1987-2017) : **+ 5.1 %**
  - AAGR of metal production over 10 years (2007-2017) : **+ 5.1 %**



[2] CRU 2018
[5] Roskill 2014

14
Si
Silicon

Data

1 – Uses and consumption

2 – World production and resources

3 – Substitutability

4 – Recycling

5 – Price

6 – Restrictions to international trade, regulations

7 – French production and resources

8 – The French industry

9 – Imports, exports, and consumption in France

Criticality matrix

More information

Disclaimer

brgm

comes
Comité pour les métaux stratégiques

- **Known reserves and evolution:**
  - **Not estimated accurately**. Quartz (SiO_2) resources are very large*. However, for technical and economical reasons, silicon metal is produced only from very high-purity quartz (> 98 % SiO_2)

- **Geographical distribution of reserves:**
  - **Not known**

- **Trends in the production of silicon metal:**
  - **Increasing production** due to robust demand in the sectors of silicones, aluminum and semi-conductors (solar and electronics). Other uses such as Si-anode Li-ion batteries could develop in the near future. It is remarkable that the ferrosilicon market has been decreasing since 2011 due to a decreasing demand. This was likely caused by the use of lower grades of FeSi in steels, although global steel demand increased. Short-term stress on raw materials is limited due to easily convertible FeSi capacities to Si capacities, and large overcapacities (especially in China).
  - The main obstacles to an increase in Si metal production are a high dependency of intense and continuous power supply (11-14 kWh/kg Si), increasing raw materials' cost, and significant environmental impacts of fossil fuel use (coal, lignite, coke)

*Silicon is the most abundant element in the Earth's crust (28 %) after oxygen (49 %). SiO_2 makes up 67 % of the Earth's crust

14
Si
Silicon

- **Substitutions :**
  - Silicon metal is **not substitutable** as a substance in most of its uses. However, more expensive technical alternatives may exist in alloys, chemistry, solar and electronic applications (e.g. CdTe and CIGS photovoltaic thin films, Ge wafers, etc.). Note some alternatives may show a significant toxicity (e.g. cadmium in CdTe photovoltaic cells)

14
Si
Silicon

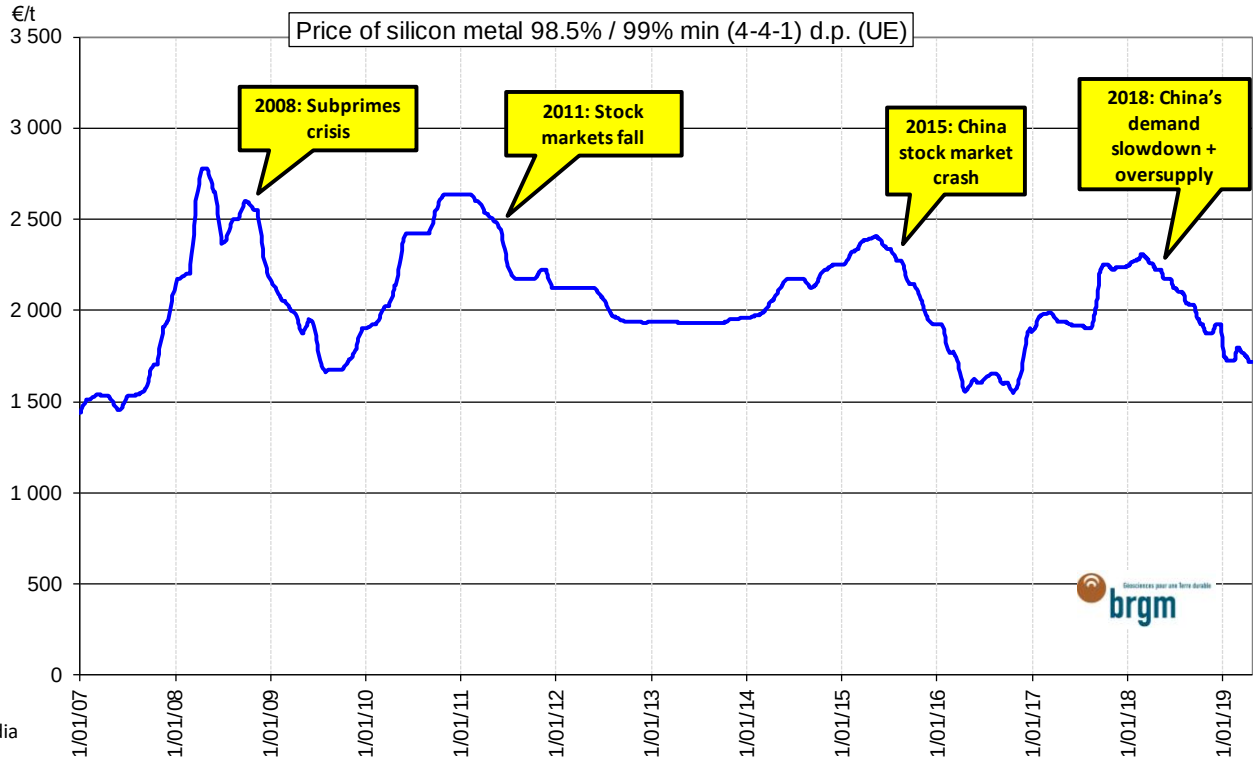
- **Recycling rates :**
  - End-of-life recycling rate is **near zero**[4,5,6]. Some silicon may be recycled during the recycling of silicon-containing alloys, but without elemental separation (not functional recycling)
  - New silicon metal scraps and Si-kerf (cutting slurry) may be recycled during production
  - Recycling of photovoltaic panels and electronic products is theoretically possible. However, the small quantities available in products, as well as the difficulty to separate Si parts from the other components makes it hardly profitable. Some companies (e.g. RoSi Solar) develop solutions to recycle high-purity silicon, or polysilicon, in the form of scraps or sludge

[4] Latunussa, Cynthia E.L., Fulvio Ardente, Gian Andrea Blengini, and Lucia Mancini. 'Life Cycle Assessment of an Innovative Recycling Process for Crystalline Silicon Photovoltaic Panels'. Solar Energy Materials and Solar Cells 156 (November 2016): 101–11. https://doi.org/10.1016/j.solmat.2016.03.020
[5] Roskill 2014
[6] Critical Raw Materials Alliance, https://criticalrawmaterials.org/silicon-metal/

14
Si
Silicon

- **Price determination**
  - High-purity quartz (> 98 %) prices at **50-100 $/t**
  - Silicon metal price is determined between producers and consumers, directly or through traders. Argus Media publishes Chinese, European, and US American stock market prices

- **Price variation[7] :**
  - 2018 average price (silicon metal 98.5%-99% min (4-4-1) d.p. (UE)): **€ 2 107 / t**
  - 1-year variation of average price (2017-2018): **+ 2 %**
  - Estimate of global market value (average price × production): **6.3 G€**



[7] Argus Media

14
Si
Silicon

Data

brgm

comes
Comité pour les métaux stratégiques

- **Restrictions to international trade[8,9] :**
  - **Europe: antidumping import tax** from China (from 16.3 % to 16.8 %) on silicon metal of purity < 99.99 %
  - **Etats-Unis: import tax** from China (139 %) on silicon metal of purity < 99.99 %. Customs regulations are very dynamic in this country. For instance, strong taxes (up to 135 %) on imports from Brasil, Norway, Australia and Kazakhstan were declared by the Trump administration in March 2018, before being cancelled in April 2018.
  - **Canada: import tax** from China (235 %) on silicon metal of purity < 99.99 %
  - Some taxes are set on photovoltaic components containing cristalline silicon coming from asian countries. In the US : taxes up to 30 % on China. In Europe : taxes ranging between 27 % and 65 % on China, Malaysia, and Taiwan.
  - Other taxes could be set during the year, depending on the commercial relations between China and the US

- **REACH regulation[10] :**
  - Silicon metal is not rated as a dangerous substance by the European Chemicals Agency (ECHA)

[8] European Union regulations, https://eur-lex.europa.eu/
[9] US Customs Border Protection, https://aceservices.cbp.dhs.gov/adcvdweb/
[10] ECHA 2019

14
Si
Silicon

brgm
Géosciences pour une Terre durable

comes
Comité pour les métaux stratégiques

- **Mine* production in France:**
  - Mine production in 2018[11]: 230 kt of quartz, or **106 kt Si**, dedicated to the French silicon metal production (estimated on the basis of 2.8 tonnes of quartz per tonne of silicon metal, 55 % of quartz extracted in France, and a 46 % Si content in quartz)
  - Share of world mine production in 2018: **about 3 %** (according to global production estimate)
  - Historical production: **not known**
  - Evaluated resources in Metropolitan France[11,12,13]: on the basis of 2018 production, quarriers estimate several decades of resources

- **Metal production in France:**
  - Metal production in 2018[11]: **150 kt** Si
  - Share of world metal production in 2018: about **5 %**

*Siliceous rock extraction falls under the quarries law in France

[11] FerroPem, 2019

[12] S. Colin, Les différentes sources d'approvisionnement de la filière française du silicium métal : états des lieux et perspectives, BRGM/RP-66749-FR, 2017

[13] P. Marteau, Mémento sur le silice industrielle, BRGM/RP-66167-FR, 2016

14
Si
Silicon

brgm
Géosciences pour une Terre durable

comes
Comité pour les métaux stratégiques

- **French companies involved in the silicon metal supply chain (non-exhaustive list):**
  - Mines and quarries[12,13] : **Imerys, CM Quartz, Decremps, Fulchiron, Sibelco**
  - Metallurgy: **FerroPem**, French subsidiary of group **Ferroglobe**
  - Intermediate products: No company in silicon metal refining (polysilicon production)
  - Recycling: **RoSi Solar**

- **French downstream industries depending on silicon metal (non-exhaustive list):**
  - Aluminum: **Trimet**, **Liberty House**
  - Silicones: **Elkem**
  - Solar modules: **Photowatt**, **Voltec**
  - Electronics: **Soitec**, **STmicroelectronics**, **Sil'Tronix**

[12] S. Colin, Les différentes sources d'approvisionnement de la filière française du silicium métal : états des lieux et perspectives, BRGM/RP-66749-FR, 2017
[13] P. Marteau, Mémento sur le silice industrielle, BRGM/RP-66167-FR, 2016

14
Si
Silicon

- **External trade[11,14] :**
  - **125 kt Si** exported in 2018 by FerroPem

French trade statistics on raw and intermediate silicon products
Raw data, CIF-FOB except military equipment. Source : http://lekiosque.finances.gouv.fr

	2017			2018			2017-2018 variation		Main partners in 2018
	Monetary	Physical	unit.val.	Monetary	Physical	unit.val.	Monetary	Physical	(% mass)
Silicon, mass content >= 99,99% of silicon (28046100)									
Exports	883 k€	94 t	9.4 €/kg	439 k€	53 t	8.3 €/kg	-50.3%	-43.6%	Hong-Kong 58%, Ukraine 29%, Singapore 2%
Imports	1 948 k€	293 t	6.6 €/kg	3 198 k€	584 t	5.5 €/kg	+64.2%	+99.3%	United Kingdom 51%, Germany 35%, Netherlands 9%
Balance	-1 065 k€	-199 k€		-2 759 k€	-531 k€		-159.1%	-166.8%	
Silicon, mass content < 99,99% de silicium (28046900)									
Exports	C	C		C	C				See code 28990003 below
Imports	49 681 k€	28 890 t	1.7 €/kg	51 550 k€	26 002 t	2.0 €/kg	+3.8%	-10.0%	Norway 58%, Netherlands 24%, undetermined 5%
Balance									
Group of confidential products. Other non-metallic mineral products not elsewhere classified (28990003), unknown silicon content									
Exports	63 279 k€	51 159 t	1.2 €/kg	70 037 k€	55 569 t	1.3 €/kg	+10.7%	+8.6%	Germany 23%, Spain13%, Italy 10%
Imports	0 k€	0 t	0.0 €/kg	0 k€	0 t	0.0 €/kg	0.0%	0.0%	
Balance	63 279 k€	51 159 k€		70 037 k€	55 569 k€		+10.7%	+8.6%	

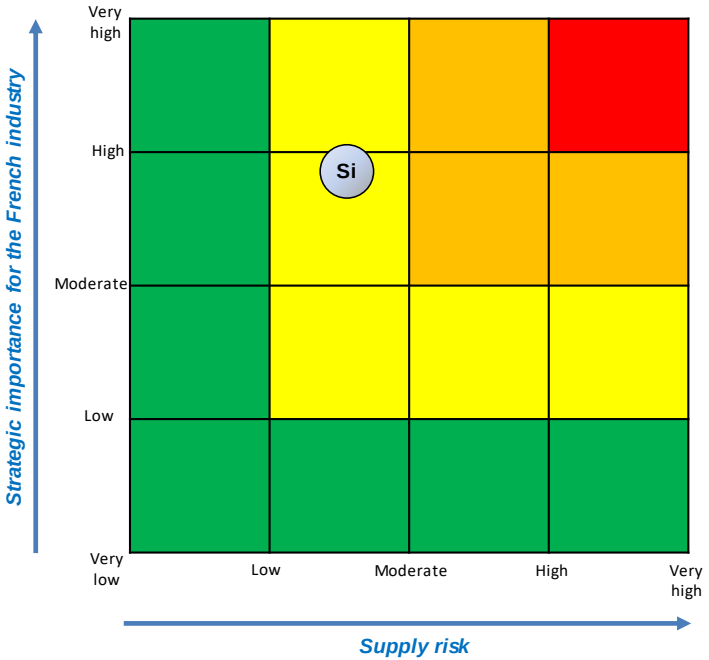
C : Confidential. Exports of code 28046900 are added to exports of code 28990003 in the combined nomenclature

- **Apparent consumption in 2018[11,14]**
  - production + importations – exportations = **53 kt**
- **Recycling :**
  - Collectable material: **not estimated**, but likely to be in increasing amounts with solar cells and semiconductors. PV Cycle is an eco-friendly organization to collect end-of-life solar panels
  - Collected material: **very small amount**. In 2018, Véolia built the first European solar panel recycling facility in France. However, silicon is not efficiently recycled yet

[11] FerroPem 2019
[14] www. lekiosque.finances.gouv.fr

14
Si
Silicon

Silicon metal criticality



Economic importance

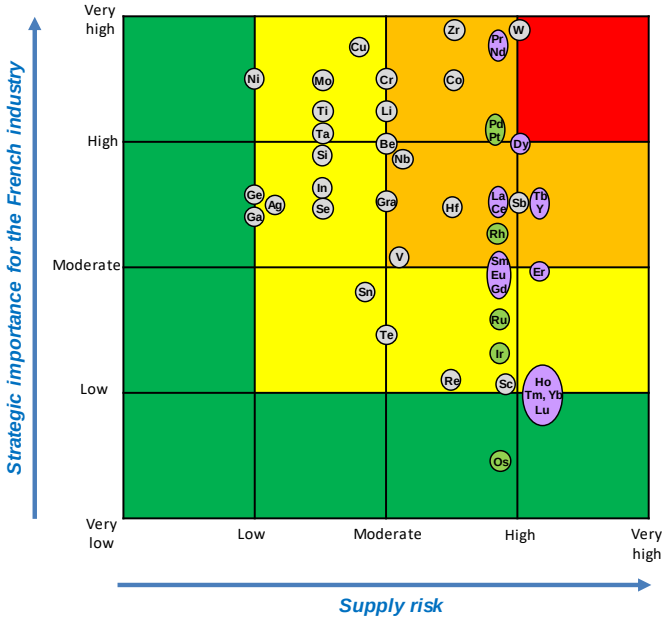
- Silicon metal is essential to several industrial sectors (aluminum, silicones, solar, electronics, and others)

Supply risks

- France has large resources of high-purity quartz
- Global leader, group Ferroglobe, is the unique producer of silicon metal in France (subsidiary FerroPem)
- Solar-grade and electronic-grade silicon metals are not produced in France

General criticality matrix

CRITICALITY POSITION OF THE SUBSTANCES THAT WERE PREVIOUSLY ASSESSED BY BRGM
Last update: mid 2019



High criticality zone. Protection measures should be taken by the State. Criticality indicators should be continuously monitored

High criticality zone. Active monitoring recommended (market watch, alerts, countermeasure scenarios)

Moderate criticality zone. Business intelligence recommended (reports and data updates recommended)

Low criticality zone. Regular monitoring recommended

Platinum group

Rare-earth elements

Gra — Natural graphite

14
Si
Silicon

brgm
Géosciences pour une Terre durable

comes
Comité pour les métaux stratégiques

References:

- 1 Elkem 2019
- 2 CRU 2018
- 3 Argus Media 2019
- 4 Latunussa, Cynthia E.L., Fulvio Ardente, Gian Andrea Blengini, and Lucia Mancini. 'Life Cycle Assessment of an Innovative Recycling Process for Crystalline Silicon Photovoltaic Panels'. Solar Energy Materials and Solar Cells 156 (November 2016): 101–11
- 5 Roskill 2014
- 6 Critical Raw Materials Alliance, https://criticalrawmaterials.org/silicon-metal/
- 7 Argus Media
- 8 European Union regulations, https://eur-lex.europa.eu/
- 9 US Customs Border Protection, https://aceservices.cbp.dhs.gov/adcvdweb/
- 10 ECHA 2019
- 11 FerroPem 2019
- 12 S. Colin, Les différentes sources d'approvisionnement de la filière française du silicium métal : états des lieux et perspectives, BRGM/RP-66749-FR, 2017
- 13 P. Marteau, Mémento sur le silice industrielle, BRGM/RP-66167-FR, 2016
- 14 Le kiosque de Bercy, www.lekiosque.finance.gouv.fr

See also:

- L'élémentarium, Société Chimique de France: www.lelementarium.fr

Main analyst:

- Antoine Boubault, BRGM

For any questions:

- Please contact BRGM, the French geological survey, on the mineral-info's platform at: http://www.mineralinfo.fr/contact

14
Si
Silicon

brgm
Géosciences pour une Terre durable

comes
Comité pour les métaux stratégiques

Disclaimer

BRGM collects data from the best available sources, some of them being publicly accessible, some requiring a dedicated subscription. Although BRGM brought reasonable care and due diligence to prepare this criticality assessment, we do not accept liability for the accuracy of the data and analyses. In case of important business issues, we recommend you to ask us for a bespoke assessment that will better match your needs. In all cases, BRGM and COMES will never be responsible for the direct and indirect damages resulting from the use of the data contained in the present document