Comparison of silicon decarbonization methods to reduce process emissions and energy consumption

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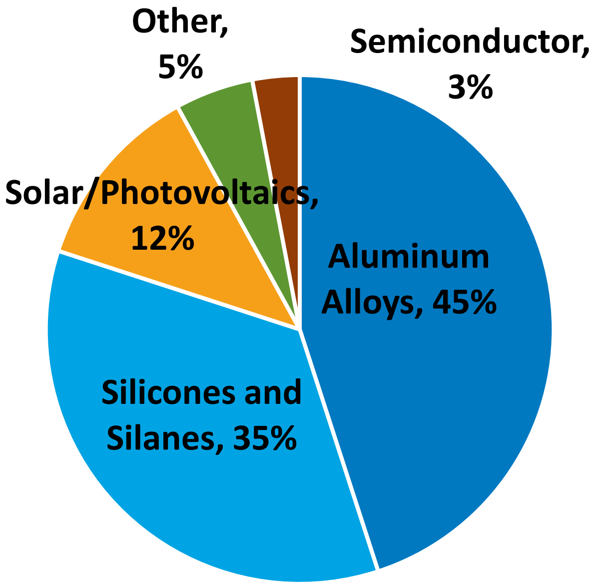
Photo by Dennis Schroeder, NREL 55200

Metallurgical grade silicon (MGS)

- Silicon is the second most abundant element in the Earth's crust
- Its semimetal properties give it a wide range of applications
- Silicon demand is expected to grow in the coming years

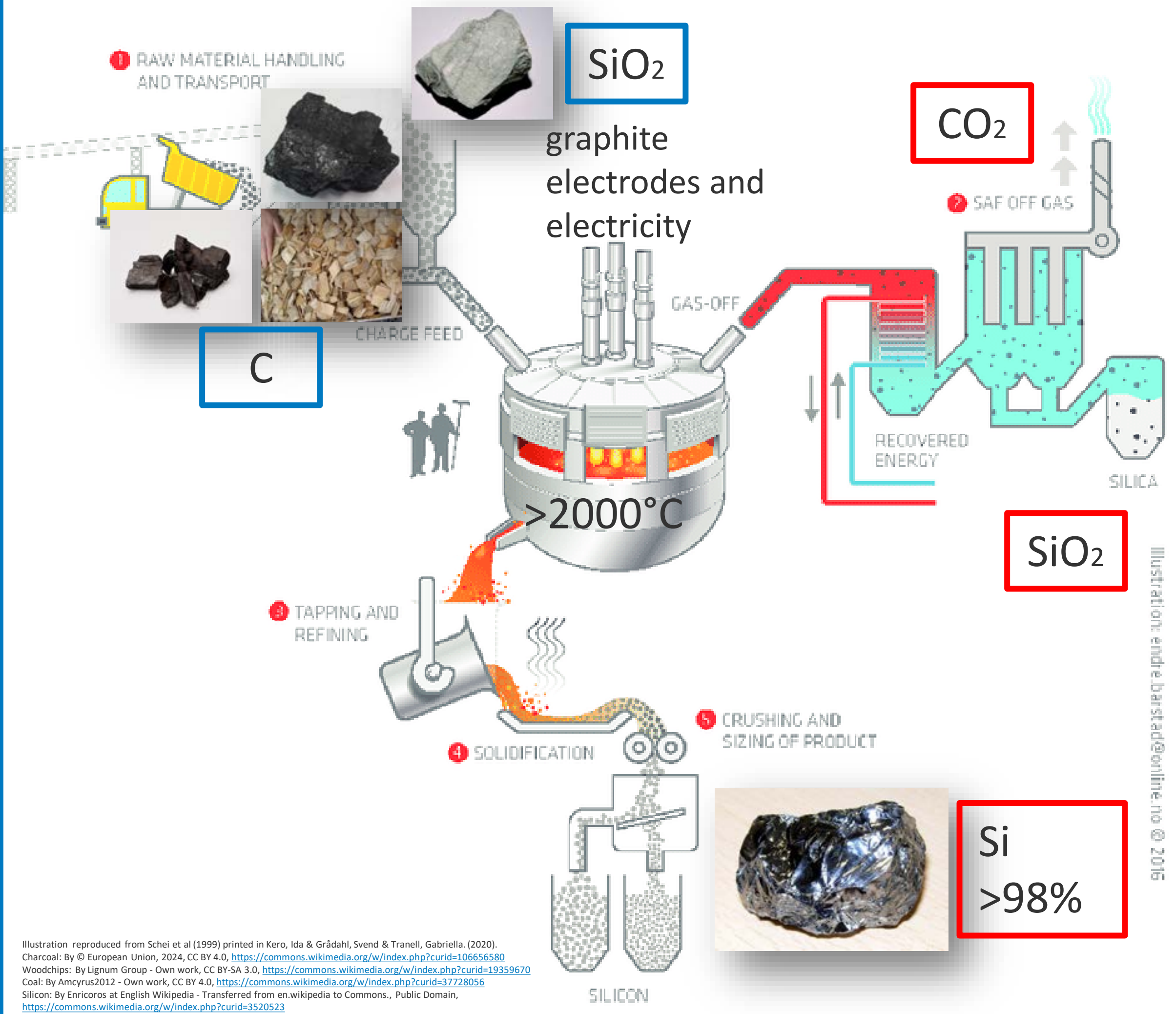


Silicon use by application, according to the CRU Market Data, 2017, adapted from Chalamala B., Manufacturing of Silicon Materials for Microelectronics and Solar PV. 2018: Sandia National Laboratories. p. https://www.osti.gov/servlets/purl/1497235.

Metallurgical silicon production

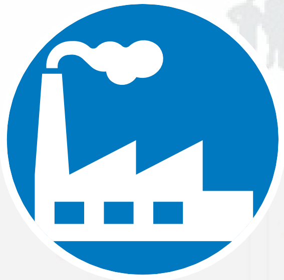
- Power consumption = 11-13 kWh/kgSi
- Total CO_2 emissions= 10-12 tCO_2e/tSi
- Process emissions = 4.7-5 tCO_2e/tSi

How do we decarbonize a process that relies on carbon as a main reactant?



Silicon decarbonization pathways

Biocarbon



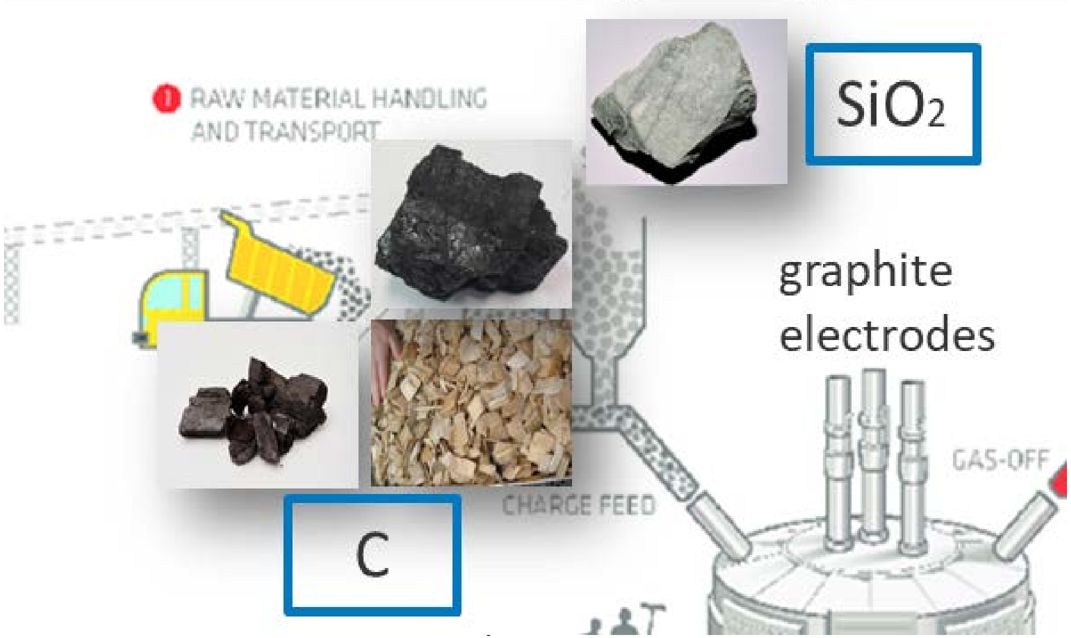
Carbon Capture

Aluminothermic Reduction

Use of Hydrogen

Electrochemical Reduction

Biocarbon substitution



- The traditional raw material mix can be changed to 100% bio-based carbon materials *without sacrificing yield*
- Can reduce emissions by ~90%
- Biocarbon must have certain properties
- Is this a long-term solution in line with biomass availability?

Carbon capture (CC)

- Can we make CC viable?
- Concentration of CO_2 in the off gas too small
- Gas recirculation as a possible solution

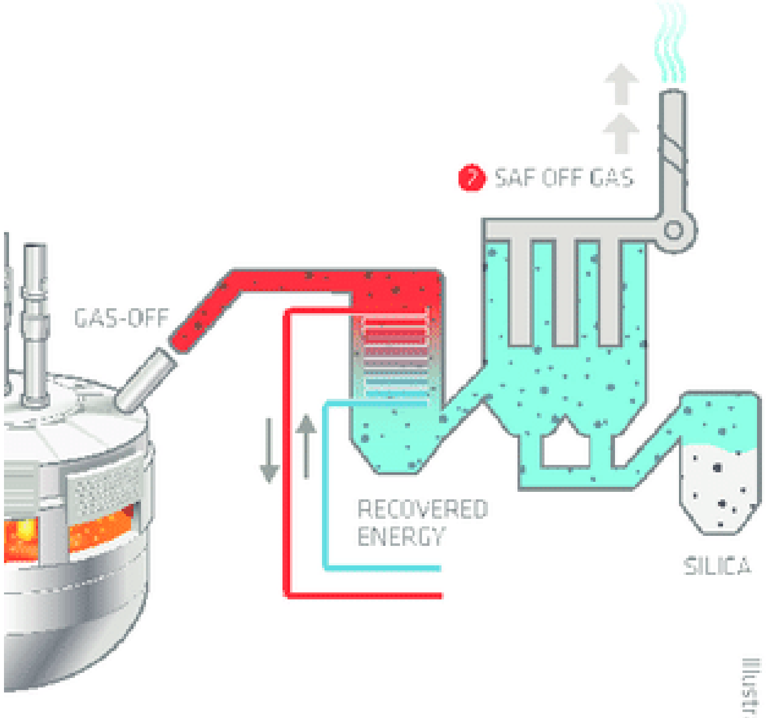


Illustration reproduced from Schei et al (1999) printed in Kero, Ida & Grådahl, Svend & Tranell, Gabriella. (2020).

Aluminothermic reduction

1650 °C

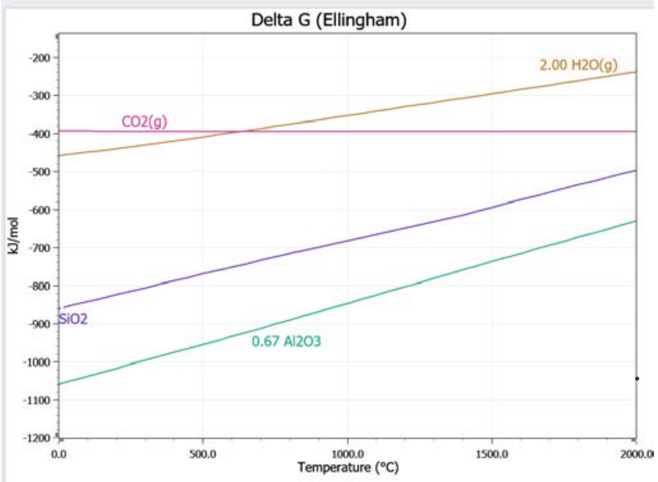
Al-dross + SiO_2-CaO slag = Si-Al alloy + Al_2O_3 slag

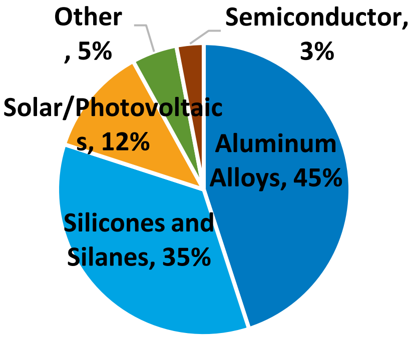
Mix of aluminum and various oxides, byproduct of aluminum smelting

Purity determined by raw materials

Recyclable slag

- Thermodynamically favorable
- Uses byproducts to increase circularity, *but will have embedded emissions*
- Is the aluminum in the dross more valuable than the silicon alloy product?





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Hydrogen in silicon production

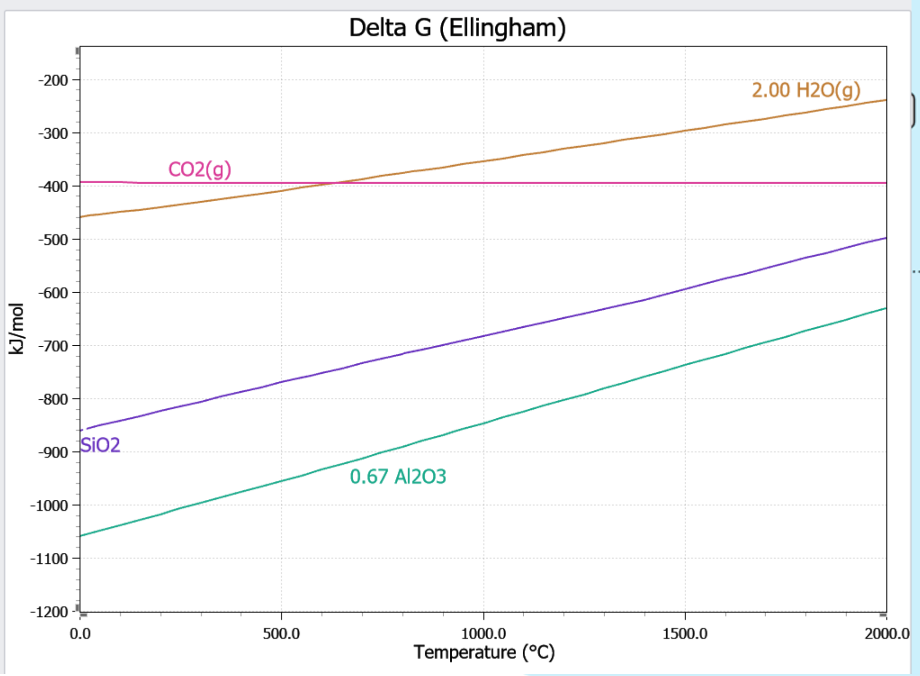
Combined with natural gas to mimic Si producing reaction in furnace

$SiO_2 + H_2 = S$

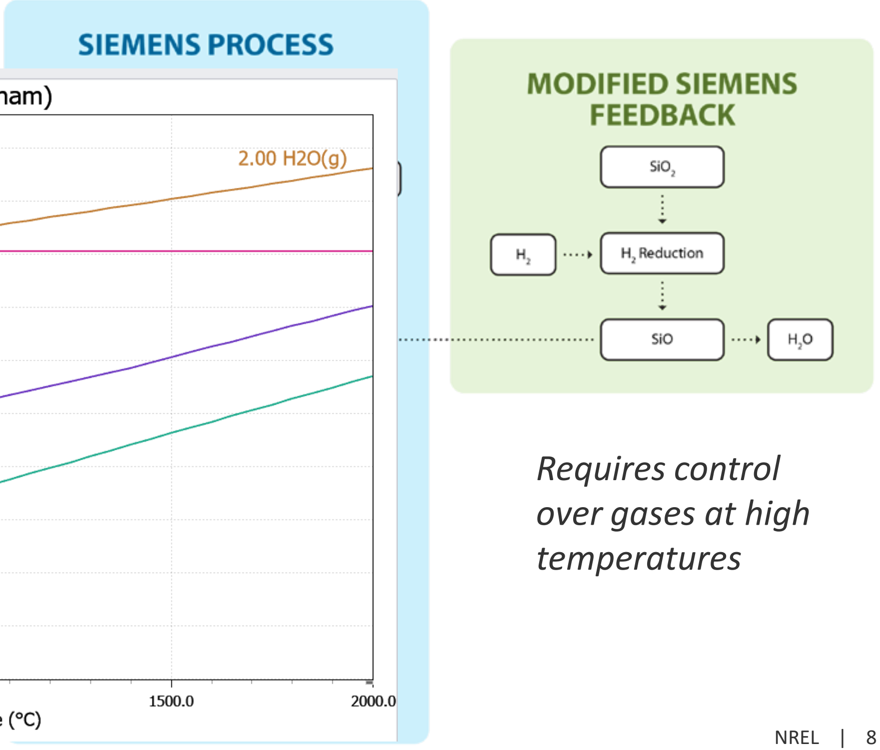
$2CH_{4(g)} + \mathbf{SiO_{(g)}} = \mathbf{S}$

$\mathbf{SiO_{(g)}} + \mathbf{SiC} =$

Not emissi



Modified Siemens feedstock



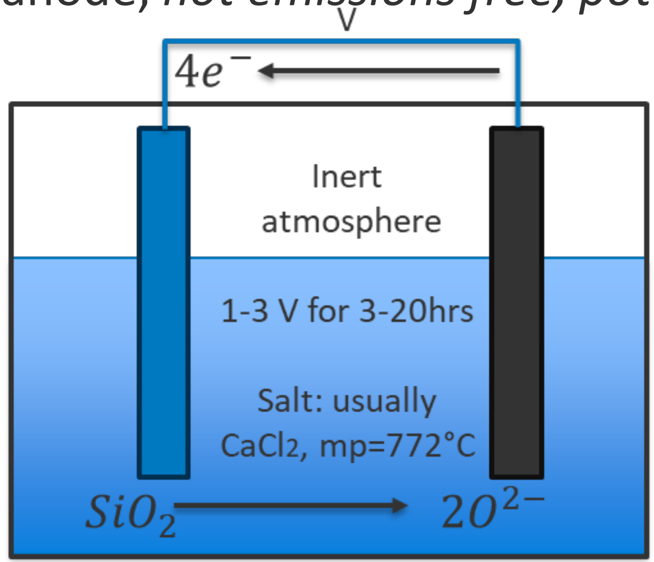
Graphic by Dominique Barnes, NREL

Requires control over gases at high temperatures

Molten salt electrochemistry

- Well-established method for producing other metals
- Operates at temperatures much lower than other methods (750-900°C v. 1600-2000°C), sacrifices kinetics
- Potential for high purity silicon product
- Uses a graphite anode, *not emissions free, potentially high power consumption*

Cathode:
Steel, Si wafers, Ni, etc. and a source of SiO_2



Anode:
Usually graphite

$$SiO_2 + 4e^- = Si + 2O^{2-}$$

$$2O^{2-} + 2C = 2CO + 4e^-$$

Summary of silicon decarbonization pathways

Biocarbon

Pro: lowers process emissions ~90%, little change to existing process

Con: requires specific biomass supply

Carbon Capture

Pro: removes CO_2 emissions from air, no change to existing process

Con: viability and fossil carbon consumption

Aluminothermic Reduction

Pro: carbon free process using Al-byproduct

Con: purity and viability, embedded emissions

Use of Hydrogen

Pro: potentially carbon free

Con: theoretical, unstable gases and high temperatures

Electrochemical Reduction

Pro: lowers process heat and emissions

Con: benchtop scale, requires graphite

Thank you

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