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SILICON AND FERROSILICON

A. Commodity Summary

Most ferrosilicon is used as an alloying element in the ferrous foundry and steel industries. Aluminum producers and the chemical industry were the main consumers of silicon metal. Ferrosilicon was produced by six companies in seven plants in the United States in 1992, and silicon metal was produced by six companies in eight plants.[1] Exhibit 1 lists these facilities and their locations. There are two standard grades of ferrosilicon, with one grade approximately 50 percent silicon and the other 75 percent silicon by weight.[2] The purity of silicon metal generally ranges from 96 to 99 percent.

EXHIBIT 1

SUMMARY OF FERROSILICON AND SILICON SMELTING AND REFINING FACILITIES (IN 1992)[a]

Facility Name	Location	Products
American Alloys Inc.	New Haven, WA	FeSi and Si
Applied Industrial Minerals Corp.	Bridgeport, AL	FeSi
Dow Corning Corp.	Springfield, OR	Si
Elkem Metals Co.	Alloy, WV	Si
Elkem Metals Co.	Ashtabula, OH	FeSi
Globe Metallurgical Inc.	Beverly, OH	FeSi and Si
Globe Metallurgical Inc.	Selma, AL	Si
Keokuk Ferro-Sil Inc	Keokuk, IA	FeSi
Silicon Metaltech Inc.	Wenatchee, WA	Si
Simetco Inc.	Montgomery, AL	Si
SKW Alloys Inc	Calvert City, KY	FeSi
SKW Alloys Inc	Niagara Falls, NY	FeSi and Si

[a] - Cunningham, L. D., "Silicon." Minerals Yearbook. Volume 1. Metals and Minerals. U.S. Bureau of Mines. 1992. p. 1191.

[1] L.D. Cunningham, "Silicon," from Mineral Commodity Summaries, U.S. Bureau of Mines, January 1995, p. 152.

[2] L.D. Cunningham, "Silicon," from Minerals Yearbook. Volume 1. Metals and Minerals. U.S. Bureau of Mines. 1992. p. 1183.

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B. Generalized Process Description

1. Discussion of Typical Production Processes

In the United States all primary production of ferrosilicon and silicon metal is by the reduction of silica (SiO_2) to silicon (Si) in submerged arc electric furnaces. High purity silicon is made from metallurgical grade silicon, and is, therefore, secondary processing which is outside the scope of this report.

2. Generalized Process Flow Diagram

Exhibits 2 and 3 are typical production flow diagrams illustrating the production of silicon and ferrosilicon. As shown in the exhibits, the feed silica is washed, sized, and crushed. The silica is then mixed with a reducing agent, and either coal, coke, or charcoal. Wood chips are added for porosity. The mixture is fed into the furnace, and when ferrosilicon is being produced, iron or steel scrap is added.[3] The furnace is tapped periodically and the molten ferrosilicon or silicon metal is drawn out and cast into ingots. The ingots are allowed to cool, then are crushed to produce the final product.[4]

High purity silicon used in the electronics industry is made from silicon metal, and is therefore beyond the scope of this report. However, a brief overview of the production process is included for completeness. Naturally occurring quartz is converted to metallurgical grade silicon by heating it with coke in an electric furnace. The low grade silicon is then converted to high grade halide or halosilane which is then reduced with a high purity reagent.[5]

3. Identification/Discussion of Novel (or otherwise distinct) Process(es)

Research is being conducted in Austria on the production of ferrosilicon from lump quartz and charcoal using a plasma reactor. Other input substitutions also are being investigated, including using sand as a replacement for quartz, and taconite tailings instead of iron or steel. In addition, the use of plasma reactors in smelting silicon is being investigated in Austria.[6,7]

4. Beneficiation/Processing Boundaries

EPA established the criteria for determining which wastes arising from the various mineral production sectors come from mineral processing operations and which are from beneficiation activities in the September 1989 final rule (see 54 Fed. Reg. 36592, 36616 codified at 261.4(b)(7)). In essence, beneficiation operations typically serve to separate and concentrate the mineral values from waste material, remove impurities, or prepare the ore for further refinement. Beneficiation activities generally do not change the mineral values themselves other than by reducing (e.g., crushing or grinding), or enlarging (e.g., pelletizing or briquetting) particle size to facilitate processing. A chemical change in the mineral value does not typically occur in beneficiation.

Mineral processing operations, in contrast, generally follow beneficiation and serve to change the concentrated mineral value into a more useful chemical form. This is often done by using heat (e.g., smelting) or chemical reactions (e.g., acid digestion, chlorination) to change the chemical composition of the mineral. In contrast to beneficiation operations, processing activities often destroy the physical and chemical structure of the incoming ore or mineral feedstock such that the materials leaving the operation do not closely resemble those that entered the operation. Typically, beneficiation wastes are earthen in character, whereas mineral processing wastes are derived from melting or chemical changes.

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3 U.S. Environmental Protection Agency, "Silicon and Ferrosilicon," from 1988 Final Draft Summary Report of Mineral Industrial Processing Wastes, 1988, pp. 3-194 - 3-195.

4 L.D. Cunningham, 1992, Op. Cit., p. 1184.

5 "Silicon and Alloys," Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Vol. XX, 1982, p. 836.

6 Goodwill, J. E., "Plasma Melting and Processing - World Developments," 48th Electric Furnace Conference Proceedings, New Orleans, LA, December 11-14th 1990, p. 280.

7 J.E. Goodwill, "Developing Plasma Applications for Metal Production in the USA," Ironmaking and Steelmaking, Vol. XVII, No. 5, 1990, pp. 350-354.

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EPA approached the problem of determining which operations are beneficiation and which (if any) are processing in a step-wise fashion, beginning with relatively straightforward questions and proceeding into more detailed examination of unit operations, as necessary. To locate the beneficiation/processing "line" at a given facility within this mineral commodity sector, EPA reviewed the detailed process flow diagram(s), as well as information on ore type(s), the functional importance of each step in the production sequence, and waste generation points and quantities presented above in Section B.

EPA determined that for this specific mineral commodity sector, the beneficiation/processing line occurs between ore crushing and charging to the furnace because silica is thermally reduced to silicon or ferrosilicon in the furnace. Therefore, because EPA has determined that all operations following the initial "processing" step in the production sequence are also considered processing operations, irrespective of whether they involve only techniques otherwise defined as beneficiation, all solid wastes arising from any such operation(s) after the initial mineral processing operation are considered mineral processing wastes, rather than beneficiation wastes. EPA presents below the mineral processing waste streams generated after the beneficiation/processing line, along with associated information on waste generation rates, characteristics, and management practices for each of these waste streams.

C. Process Waste Streams

1. Extraction and Beneficiation Wastes

The following wastes may result from beneficiation activities: gangue, spent wash water, and tailings. No information on waste characteristics, waste generation, or waste management for these waste streams was available in the sources listed in the bibliography.

2. Mineral Processing Wastes

Dross. The waste to product ratio for dross is approximately 1:99. Dross from the production of silicon metal can be used to produce ferrosilicon. Ferrosilicon dross can be used to produce silicomanganese. Dross can also be sold as an aggregate.[8] Dross is recycled and is not believed to be a solid waste.[9] Existing data and engineering judgement suggest that this material does not exhibit any characteristics of hazardous waste. Therefore, the Agency did not evaluate this material further.

Slag. Existing data and engineering judgement suggest that this material does not exhibit any characteristics of hazardous waste. Therefore, the Agency did not evaluate this material further.

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[8] Personal communication between ICF Incorporated and Joseph Gamboji, U.S. Bureau of Mines, June 28, 1989.

[9] U.S. Environmental Protection Agency, Newly Identified Mineral Processing Waste Characterization Data Set, Volume I, Office of Solid Waste, August 1992, pp. I-4 and I-6.

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EXHIBIT 2

SILICON PRODUCTION

Graphic Not Available.

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EXHIBIT 3

Ferrosilicon Production

Graphic Not Available.

APC Dust/Sludge. The furnaces are generally equipped with fume collection systems and baghouses to reduce air pollution by capturing emissions from the furnace.[10] Originally, the baghouse dust (microsilica) was considered of little or no value. However, microsilica is now used as an additive in a number of different products, including high-strength concrete.[11] Existing data and engineering judgement suggest that this material does not exhibit any characteristics of hazardous waste. Therefore, the Agency did not evaluate this material further.

D. Ancillary Hazardous Wastes

Ancillary hazardous wastes may be generated at on-site laboratories, and may include used chemicals and liquid samples. Other hazardous wastes may include spent solvents, tank cleaning wastes, and polychlorinated biphenyls from electrical transformers and capacitors. Non-hazardous wastes may include tires from trucks and large machinery, sanitary sewage, and waste oil and other lubricants.

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[10] "Silicon and Ferrosilicon," Op. Cit., p. 3-195.

[11] L.D. Cunningham, 1992, Op. Cit., p. 1184.

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