Technical Support Document for the Silicon Carbide Production Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases

Office of Air and Radiation

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1. Industry Description

Silicon carbide is primarily an industrial abrasive manufactured from silica sand or quartz and petroleum coke (USGS 2006). Applications of silicon carbide include semiconductors, body armor, and the manufacture of Moissanite, a diamond substitute. The silicon carbide sector discussed in this Technical Support Document is limited to the production of "abrasive-grade" silicon carbide. Approximately 35,000 metric tons of "abrasive-grade" silicon carbide valued at 24.3 million dollars was produced by a single facility in Illinois in 2006. Similarly, 35,000 metric tons of "metallurgical-grade" silicon carbide was produced in 2006 at the same facility (USGS 2006). A small manufacturer in Kentucky is known to produce non-abrasive grade silicon carbide for "heat-resistant products" though the quantity produced is unknown (USGS 2006).

Table 1. U.S. Producers of Silicon Carbide

Company	2006 Silicon Carbide Production (metric tons)	2006 Silicon Carbide Production (million $)
Exolon Corp.	35,000	24.3

Source: USGS Minerals Yearbook 2006 (http://minerals.usgs.gov/minerals/pubs/commodity/abrasives/myb1-2006-abras.pdf)

Silicon carbide is produced through the following reaction:

$$SiO_2 + 3C \rightarrow SiC + 2CO\ (+\ O_2 \rightarrow 2CO_2)$$

2. Total Emissions

Silicon carbide process emissions (U.S EPA 2008) totaled 100,226 mtCO_2e in 2006. Of the total, process-related CO_2 emissions accounted for 91% (91,700 mtCO_2e) and CH_4 emissions accounted for 9% (8,526 mtCO_2e). On-site stationary combustion emissions from silicon carbide production amounted to 9,045 mtCO_2e (less than one percent of the total emissions).

2.1 Process Emissions

As shown above, carbon dioxide (CO_2) and methane (CH_4) are emitted during the production of silicon carbide. Petroleum coke is utilized as the carbon source during silicon carbide production. Approximately 35% of the carbon is retained within the silicon carbide, and the remaining carbon is converted to CO_2 and CH_4. The presence of hydrogen-containing volatile compounds in the petroleum coke may cause formation and emission to the atmosphere of CH_4 (IPCC 2006). .

2.2 Stationary Combustion

Combustion emissions of GHGs from the production of silicon carbide are limited to the fuel inputs used for equipment necessary to the manufacturing process. The existing silicon carbide plant uses natural gas as the fuel for the product dryer and uses electric furnaces.

3. Review of Existing Programs and Methodologies

Emissions monitoring from the silicon carbide sector are addressed in both the *U.S. Inventory* (U.S. EPA 2008) and *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The *U.S. Inventory* relies upon standard emission factors from the IPCC to report CO_2 emissions for the silicon carbide sector whereas the IPCC itself offers three tiers including a reporting method that utilizes facility-specific petroleum coke consumption data (Tier 3). No additional protocols were identified from emission trading schemes, voluntary programs or industry trade groups.

4. Options for Reporting Threshold

4.1 Emissions Thresholds

Four emissions threshold levels were considered for the silicon carbide manufacturing sector based on actual emissions. These thresholds, 100,000, 25,000, 10,000, and 1,000 mtCO_2e per year, were analyzed. All threshold levels were found to incorporate all silicon carbide manufacturing facilities included in this Technical Support Document. Table 2 provides the threshold analysis for the silicon carbide sector. The threshold analysis estimated total emissions for the silicon carbide sector at 109,271 tons CO_2. This total was the additive sum of process emissions (100,226 mtCO_2e) and combustion emissions (9,045 mtCO_2e). The single facility with known production that has been identified would surpass the 100,000 tons CO_2 reporting threshold.

Table 2. Emissions Threshold Analysis for Silicon Carbide Production

Threshold Level (Metric Tons)	Process Emissions (Metric Tons CO2e/yr)	CO2 Emissions (Metric Tons/yr)	Total National Emissions (Metric Tons CO2e)	Number of Entities	Emissions Covered		Entities Covered	
					Tons CO_2e/yr	Percent	Number	Percent
100,000	100,226	9,045	109,271	1	109,271	100%	1	100%
25,000	100,226	9,045	109,271	1	109,271	100%	1	100%
10,000	100,226	9,045	109,271	1	109,271	100%	1	100%
1,000	100,226	9,045	109,271	1	109,271	100%	1	100%

Process emissions were calculated using default emission factors for both CO_2 and CH_4 per metric ton of silicon carbide produced. The amount of silicon carbide produced is limited, in this analysis, to "abrasive-grade" silicon carbide. The factors, 2.62 metric tons of CO_2 per metric ton of raw material used and 11.6 kg of CH_4 per metric ton of carbide produced, were published by the IPCC and are equivalent to a Tier 1 estimation method (IPCC 2006). Calculations of process emissions followed the equation:

$$E_{CO2} = [(EF_{CO2} * AD) + (EF_{CH4} * AD*21)]$$

Where:

E_{CO2}	= Emissions of CO_2 and CH_4, ($mtCO_2e$)
EF_{CO2}	= Emissions factor for CO_2
EF_{CH4}	= Emissions factor for CH_4
AD	= Silicon carbide production, (metric tons)
21	= Global warming potential for CH_4, (mt CO_2/mt CH_4)

Combustion emissions were estimated through data collected from a Title V permit that listed the number, type, and fuel consumption rate of stationary emission sources at the known silicon carbide production facility. Assuming that each emission unit within the facility operated continuously (24-hours a day, 365 days a year) at 90% capacity, emissions were estimated for a solution heater that ran on natural gas and consumed 2.5 MMBtu/hr, and a rotary dryer that ran on natural gas and consumed 19.1 MMBtu/hr (Illinois EPA 2004).

4.2 Capacity Thresholds

Four capacity threshold levels were considered for the silicon carbide manufacturing sector based on facility capacity. These thresholds, 35,000, 25,000, 10,000, and 1,000 metric tons silicon carbide produced per year, were analyzed.

Table 3 provides the capacity threshold analysis for the silicon carbide sector. Four reporting threshold levels were considered for the silicon carbide production sector. These thresholds were 35,000, 25,000, 10,000, and 1,000 metric tons of silicon carbide produced per year. The single facility with known production that has been identified would surpass the 35,000 metric tons reporting threshold.

Table 3. Capacity threshold Analysis for Silicon Carbide Production

Capacity Threshold (metric tons silicon carbide produced per year)	Process Emissions (Metric Tons CO2e/yr)	Number of Entities	Emissions Covered		Entities Covered	
			Metric Tons CO_2e/yr	Percent	Number	Percent
35,000	111,362	1	111,362	100%	1	100%
25,000	111,362	1	111,362	100%	1	100%
10,000	111,362	1	111,362	100%	1	100%
1,000	111,362	1	111,362	100%	1	100%

4.3 No Emissions Threshold

The no emissions threshold includes all silicon carbide manufacturing facilities included in this Technical Support Document regardless of their emissions or capacity.

The option of regulating all silicon carbide manufacturing facilities regardless of their emissions profile is similar to the emissions threshold option when only the known facility is considered because at each threshold level the known facility would be regulated. When the possibility of new facilities is considered, the no emissions threshold option becomes more inclusive since it is likely that an emissions threshold option would not include smaller facilities at certain emission thresholds.

5. Options for Monitoring Methods

Three separate monitoring methods were considered for this technical support document: a simplified emission calculation (Option 1), a hybrid method (Option 2), and direct measurement (Option 3). All of these options require annual reporting.

5.1 Option 1: Simplified Emission Calculation

Option 1 follows the IPCC's Tier 1 protocol. The Tier 1 monitoring method requires raw material input or output to be known in addition to a standard emission factor. Table 4 gives the standard emission factors for Tier 1. According to the 2006 IPCC Guidelines, the default CO_2 emission factors are relatively uncertain because industrial-scale carbide production processes differ from the stoichiometry of theoretical chemical reactions (IPCC 2006). The guidelines recommend assuming general uncertainty of ±10% for the CO_2 and CH_4 emission factors.

The equation for calculating emissions is:

$$CO_2 \text{ Emissions} = AD * EF$$

Where:

CO_2 Emissions = process emissions of CO_2

AD = Petroleum coke input or silicon carbide output

EF = Standard emission factor.

Table 4. Standard emission factors

Carbide Type	CO_2 Emission Factor (ton/ton product)	CH_4 Emission Factor (ton/ton product)
Silicon Carbide	2.62	0.0116

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

5.2 Option 2: Input-Based Method

Option 2 follows the IPCC's Tier 3 protocol. The Tier 3 monitoring method requires raw material input data to be known and for plant-specific carbon content factors to be determined. The equation for calculating emissions is:

$$CO_2 \text{ Emissions} = AD * EF_{CO2}$$

Where:

CO_2 Emissions = Emissions of CO_2

AD = Petroleum coke activity data

EF_{CO2} = Emissions factor

The emissions factor is calculated using the formula:

$$EF_{CO2} = 0.65 * CCF * COF * (44/12)$$

Where:

EF_{CO2}	= Emissions factor
0.65	= Adjustment factor for amount of carbon in silicon carbide product (assuming 35 percent of carbon input is in the carbide product)
CCF	= Carbon content factor (assumed 90-95 percent if plant data is not available)
COF	= Carbon oxidation factor (assumed to be 1 if plant data is not available)
44/12	= Ratio of molecular weights, CO_2 to carbon.

Use the above equations with the default CH_4 emissions factor to estimate CH_4 emissions.

5.3 Option 3: Direct Measurement

For industrial source categories for which the process emissions and/or combustion GHG emissions are contained within a stack or vent, direct measurement constitutes either measurements of the GHG concentration in the stack gas and the flow rate of the stack gas using a CEMS, or periodic measurement of the GHG concentration in the stack gas and the flow rate of the stack gas using periodic stack testing. In the case of silicon carbide, process and combustion GHG emissions are not emitted from the same stack. Process emissions from the product furnaces are emitted from four separate stacks and combustion emissions from the product dryer are emitted from a fifth stack.

Elements of a CEMS include a platform and sample probe within the stack to withdraw a sample of the stack gas, an analyzer to measure the concentration of the GHG (e.g., CO_2) in the stack gas, and a flow meter within the stack to measure the flow rate of the stack gas. The emissions are calculated from the concentration of GHGs in the stack gas and the flow rate of the stack gas. A CEMS continuously withdraws and analyzes a sample of the stack gas and continuously measures the GHG concentration and flow rate of the stack gas.

For direct measurement using stack testing, sampling equipment would be periodically brought to the site and installed temporarily in the stack to withdraw a sample of the stack gas and measure the flow rate of the stack gas. Similar to CEMS, for stack testing the emissions are calculated from the concentration of GHGs in the stack gas and the flow rate of the stack gas. The difference between stack testing and continuous monitoring is that the CEMS data provide a continuous measurement of the emissions, while a stack test provides a periodic measurement of the emissions. A method using periodic, short-term stack testing would be appropriate for those facilities where process inputs (e.g., carbonaceous reducing agents such as petroleum coke) and process operating parameters remain relatively consistent over time. In cases where there is the potential for significant variations in the process input characteristics or operating conditions, continuous measurements would be needed to accurately record changes in the actual GHG emissions from the sources resulting from any process variations.

6. Procedures for Estimating Missing Data

Options and considerations for missing data vary will vary depending on the proposed monitoring method. Each option would require a complete record of all measured parameters as well as parameters determined from company records that are used in the GHG emissions calculations (e.g., carbon contents, monthly fuel consumption, etc.).

6.1 Procedures for Option 1: Simplified Emissions Calculation

For process sources that use a simplified emission calculation no missing data procedures would apply because the emission calculation is derived from default emission factors and activity data. Businesses closely track activity data such as purchase and use of production inputs, therefore therefore, 100 percent data availability would be expected.

6.2 Procedures for Option 2: Input-Based Method

For process sources that use a site-specific emission factor no missing data procedures would apply because the site-specific emission factor is derived from an initial carbon content analysis from the petroleum coke supplier (carbon content analysis test) and used in each calculation. The same factor would be multiplied by the production rate or process input rate, which are readily available. Therefore, 100 percent data availability would be required.

6.3 Procedures for Option 3: Direct Measurement (Annual Reporting)

6.3.1 Continuous Emission Monitoring Data (CEMS)

For options involving direct measurement of CO_2 emissions using CEMS, Part 75 establishes procedures for the management of missing data. Specifically, the procedures for managing missing CO_2 concentration data are specified in §75.35. In general, missing data from the operation of the CEMS may be replaced with substitute data to determine the CO_2 emissions during the period for which CEMS data are missing. Section 75.35(a) requires the owner or operator of a unit with a CO_2 CEMS to substitute for missing CO_2 pollutant concentration data using the procedures specified in paragraphs (b) and (d) of §75.35; paragraph (b) covers operation of the system during the first 720 quality-assured operation hours for the CEMS, and paragraph (d) covers operation of the system after the first 720 quality-assured operating hours are completed.

During the first 720 quality-assured monitor operating hours following initial certification at a particular unit or stack location, the owner or operator would be required to substitute CO_2 pollutant concentration data according to the procedures in §75.31(b). That is, if prior quality-assured data exist, the owner or operator would be required to substitute for each hour of missing data, the average of the data recorded by a certified monitor for the operating hour immediately preceding and immediately following the hour for which data are missing. If there are no prior quality-assured data, the owner or operator would have to substitute the maximum potential CO_2 concentration for the missing data.

Following the first 720 quality-assured monitor operating hours, the owner or operator would have to follow the same missing data procedures for SO_2 specified in §75.33(b). The specific methods used to estimate missing data would depend on the monitor data availability and the duration of the missing data period.

6.3.2 Stack Testing Data

For options involving direct measurement of CO_2 flow rates or direct measurement of CO_2 emissions using stack testing, “missing data” is not generally anticipated. Stack testing conducted for the purposes of compliance determination is subject to quality assurance guidelines and data quality objectives established by the U.S. EPA, including the Clean Air Act National Stack Testing Guidance published in 2005 (EPA 2005). The 2005 EPA Guidance Document indicates that stack tests should be conducted in accordance with a pre-approved site-specific test plan to ensure that a complete and representative test is conducted. Results of stack tests that do not meet pre-established quality assurance guidelines and data quality objectives would generally not be acceptable for use in emissions reporting, and any such stack test would need to be re-conducted to obtain acceptable data.

The U.S. EPA regulations for performance testing under 40 CFR § 63.7(c)(2)(i) state that before conducting a required performance test, the owner/operator is required to develop a site-specific test plan and, if required, submit the test plan for approval. The test plan is required to include “a test program summary, the test schedule, data quality objectives, and both an internal and external quality assurance (QA) program” to be applied to the stack test. Data quality objectives are defined under 40 CFR § 63.7(c)(2)(i) as “the pre-test expectations of precision, accuracy, and completeness of data.” Under 40 CFR § 63.7(c)(2)(ii), the internal QA program is required to include, “at a minimum, the activities planned by routine operators and analysts to provide an assessment of test data precision; an example of internal QA is the sampling and analysis of replicate samples.” Under 40 CFR § 63.7(c)(2)(iii) the external QA program is required to include, “at a minimum, application of plans for a test method performance audit (PA) during the performance test.” In addition, according to the 2005 Guidance Document, a site-specific test plan should generally include chain of custody documentation from sample collection through laboratory analysis including transport, and should recognize special sample transport, handling, and analysis instructions necessary for each set of field samples (EPA 2005).

The U.S. EPA anticipates that test plans for stack tests that are expected to be used to obtain data for the purposes of emissions reporting would be made available to EPA prior to the stack test and that the results of the stack test would be reviewed against the test plan prior to the data being deemed acceptable for the purposes of emissions reporting.

7. QA/QC Requirements

Facilities should conduct quality assurance and quality control of the production and consumption data, supplier information (e.g., carbon contents), and emission estimates reported. Facilities are encouraged to prepare an in-depth quality assurance and quality control plan which would include checks on production data, the carbon content information received from the supplier and from the lab analysis, and calculations performed to estimate GHG emissions. Several examples of QA/QC procedures are listed below.

7.1 Stationary Emissions

Facilities should follow the guidelines given by the Stationary Combustion Source Section of this TSD.

7.2 Process Emissions

Options and considerations for QA/QC will vary depending on the proposed monitoring method. Each option would require unique QA/QC measures appropriate to the particular methodology employed to ensure proper emission monitoring and reporting.

7.2.1 Continuous Emission Monitoring System (CEMS)

For units using CEMS to measure CO_2 emissions, the equipment should be tested for accuracy and calibrated as necessary by a certified third party vendor. These procedures should be consistent in stringency and data reporting and documentation adequacy with the QA/QC procedures for CEMS described in Part 75 of the Acid Rain Program.

7.2.2 Stack Test Data

U.S. EPA regulations for performance testing under 40 CFR § 63.7(c)(2)(i) state that before conducting a required performance test, the owner/operator is required to develop a site-specific test plan and, if required, submit the test plan for approval. The test plan is required to include "a test program summary, the test schedule, data quality objectives, and both an internal and external quality assurance (QA) program" to be applied to the stack test. Data quality objectives are defined under 40 CFR § 63.7(c)(2)(i) as "the pre-test expectations of precision, accuracy, and completeness of data." Under 40 CFR § 63.7(c)(2)(ii), the internal QA program is required to include, "at a minimum, the activities planned by routine operators and analysts to provide an assessment of test data precision; an example of internal QA is the sampling and analysis of replicate samples." Under 40 CFR § 63.7(c)(2)(iii) the external QA program is required to include, "at a minimum, application of plans for a test method performance audit (PA) during the performance test." In addition, according to the 2005 Guidance Document, a site-specific test plan should generally include chain of custody documentation from sample collection through laboratory analysis including transport, and should recognize special sample transport, handling, and analysis instructions necessary for each set of field samples (US EPA 2005).

7.3 Data Management

Data management procedures should be included in the QA/QC Plan. Elements of the data management procedures plan are as follows:

- For measurements of carbonate content, assess representativeness of the carbonate content measurement by comparing values received from supplier and/or laboratory analysis with IPCC default values.
- Check for temporal consistency in production data, carbonate content data, and emission estimate. If outliers exist, they should be explained by changes in the facility's operations or other factors. A monitoring error is probable if differences between annual data cannot be explained by:
    - Changes in activity levels,
    - Changes concerning fuels or input material,
    - Changes concerning the emitting process (e.g. energy efficiency improvements) (European Commission 2007).

- Determine the "reasonableness" of the emission estimate by comparing it to previous year's estimates and relative to national emission estimate for the industry:
    - Comparison of data on fuel or input material consumed by specific sources with fuel or input material purchasing data and data on stock changes,
    - Comparison of fuel or input material consumption data with fuel or input material purchasing data and data on stock changes,
    - Comparison of emission factors that have been calculated or obtained from the fuel or input material supplier, to national or international reference emission factors of comparable fuels or input materials
    - Comparison of emission factors based on fuel analyses to national or international reference emission factors of comparable fuels, or input materials,
    - Comparison of measured and calculated emissions (European Commission 2007).

- Maintain data documentation, including comprehensive documentation of data received through personal communication:
    - Check that changes in data or methodology are documented

8. Types of Emission Information to be Reported

Silicon carbide facilities should report both process (CO_2) and combustion related (CO_2, CH_4, and N_2O) greenhouse gas emissions. The data to be reported may vary depending on monitoring options selected. However, all nitric acid production facilities should report the number of nitric acid production lines, annual nitric acid production (on a 100% acid basis), annual nitric acid production capacity (on a 100% acid basis), electricity usage (kilowatt-hours), emission factor(s) used, type of nitric acid production process(es) used, abatement technology used (if applicable), abatement utilization factor (percent of time that abatement system is operating), abatement technology efficiency, and annual operating hours. For reporting options for stationary combustion refer to EPA-HQ-OAR-2008-0508-004.

8.1 Other Information to be Reported

The facility should report its annual CO_2 and CH_4 emissions from silicon carbide production process (in metric tons); annual production of silicon carbide (in metric tons); annual capacity of silicon carbide production (in metric tons); annual operating hours; annual consumption of petroleum coke (in metric tons); carbon content of petroleum coke consumed for each calendar quarter; facility-specific emission factors; and annual electricity usage, KWhr/yr for each silicon carbide manufacturing facility.

8.2 Additional Data to be Retained Onsite

Facilities should be required to retain data concerning monitoring of GHG emissions onsite for a period of at least five years from the reporting year. For CEMS these data would include CEMS monitoring system data including continuous-monitored GHG concentrations and stack gas flow rates, calibration and quality assurance records. For stack testing these data would include stack test reports and associated sampling and chemical analytical data for the stack test. Process data including petroleum coke consumption and feed rates and petroleum coke carbon contents should also be retained on site for a period of at least five years from the reporting year. EPA could use such data to conduct trend analyses and potentially to develop process or activity-specific emission factors for the process.

9. References

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