FINAL TECHNICAL SUPPORT DOCUMENT FOR CERAMICS MANUFACTURING

Office of Air and Radiation
U.S. Environmental Protection Agency

November 2023

CONTENTS

1. Industry Description

The ceramic manufacturing industry comprises a variety of products manufactured from nonmetallic, inorganic materials, many of which are clay-based. The major sectors of ceramic products include bricks and roof tiles, wall and floor tiles, table and ornamental ware (household ceramics), sanitary ware, refractory products, vitrified clay pipes, expanded clay products, inorganic bonded abrasives, and technical ceramics (e.g., aerospace, automotive, electronic, or biomedical applications) (EIPPCB 2007).

Ceramic manufacturing falls under North American Industry Classification System (NAICS) Code 3271 - Clay Product and Refractory Manufacturing. **Table 1** shows the applicable NAICS codes for ceramic manufacturing.

Table 1. NAICS Codes for Ceramic Manufacturing

NAICS4	NAICS	Description
3271		Clay Product and Refractory Manufacturing
	327110	Pottery, Ceramics, and Plumbing Fixture Manufacturing - pottery, ceramics, and plumbing fixtures, and electrical supplies made entirely or partly of clay or other ceramic materials
	327120	Clay Building Material and Refractories Manufacturing - clay refractories, nonclay refractories, ceramic tile, structural clay tile, brick, and other structural clay building materials

2018 US Census data for a primary NAICS code of 3271 (Clay Product and Refractory Manufacturing) demonstrates that production facilities vary from artisan to large-scale, as portrayed in **Table 2**.

Table 2. Corporation Size for Primary NAICS Code 3271 (data from 2018 US Census)

Corporation Size (Number of Employees)	Number of Corporations in NAICS 3271
1 - 9	464
10 - 99	238
100 - 999	78
1,000 - 2,499	16
2,500 - 4,999	4
5,000 +	15
Total Corporations	**815**

2. Total Emissions

Most ceramic products are made from one or more different types of clay (e.g., shales, fire clay, and ball clay). The general process of manufacturing ceramic products, regardless of the product type or scale, is essentially the same. This process consists of raw material processing (grinding, calcining, and drying), forming (wet or dry process), firing (single or multiple stage firing process), and final processing. Greenhouse gas (GHG) emissions are produced during the calcination process in the kiln, dryer, or oven, and from any combustion sources.

Carbon dioxide (CO_2) emissions result from the calcination of carbonates in the raw material (particularly clay, shale, limestone, dolomite, and witherite) and the use of limestone or other additives as a flux (IPCC 2006). Carbonates are heated to high temperatures in a kiln, dryer, or oven, producing oxides and CO_2. Additionally, CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions are produced during combustion in the kiln, dryer, or oven and from other combustion sources on site.

2.1 Process Emissions

The United States Geological Survey (USGS) does not compile statistics such as production for clay as they do for other minerals or chemicals. However, in their 2020 Minerals Commodity Summaries for Clay, they discuss the market for clay materials. For 2019, the USGS reported that 26 million tons of clays were sold or used in the US (USGS 2020). Principal uses for specific clays were estimated to be as follows:

- ball clay—50% floor and wall tile and 15% sanitary ware;
- bentonite—52% pet waste absorbents and 31% drilling mud;
- common clay—34% brick, 29% lightweight aggregate, and 24% cement;
- fire clay—70% heavy clay products (for example, brick and cement) and 30% refractory products and miscellaneous uses;
- fuller's earth—98% pet waste absorbents; and
- kaolin—60% paper coating and filling, 12% paint, and 9% catalysts.

Applying the IPCC defaults of carbonate content for clay (10%) and the loss factor of 1.1, total carbonate use for ceramics production is estimated to be 2.86 million tons (or 2.6 million metric tons) for 2019. Using the IPCC Tier 1 equation and default mix of 85% limestone and 15% dolomite, 2.6 million metric tons of carbonate usage translates to estimated national emissions of 1.16 million metric tons of CO_2 (IPCC 2006).

No ceramics manufacturer currently reports under GHGRP subpart U, Miscellaneous Uses of Carbonate. Subpart U at 40 CFR 98.210(a) indicates "This source category includes any equipment that uses carbonates listed in Table U-1 in manufacturing processes that emit carbon dioxide. Table U-1 includes the following carbonates: limestone, dolomite, ankerite, magnesite, siderite, rhodochrosite, or sodium carbonate. Facilities are considered to emit CO_2 if they consume at least 2,000 tons per year of carbonates heated to a temperature sufficient to allow the calcination reaction to occur." While some ceramics manufacturers may use some carbonates directly, most of the carbonates used are likely those contained in clay rather than from the direct use of pure carbonates, so these ceramics manufacturers are likely not required to report under subpart U. Additionally, some carbonate-based processes are conducted at temperatures well below 1,000°F, which may not heat to a temperature sufficient for calcination to occur.

2.2 Stationary Combustion

The combustion of fuels in stationary combustion sources is a significant source of GHG emissions at ceramic manufacturers. Combustion sources include the kilns or dryers, boilers, and similar devices. Ceramic production facilities that currently report under the GHGRP do so primarily when their GHG emissions from stationary fuel combustion sources exceed the 25,000 mt CO_2e reporting threshold. Of the 815 corporations that produce ceramic products according to the 2018 US Census data, 16 facilities under nine corporations reported under Subpart C of the GHGRP for RY2019; see **Table 3** for Subpart C emissions per corporation from USEPA's FLIGHT for these 16 facilities. Only one corporation reported under a second subpart (subpart S). Only one corporation (two facilities) reported under NAICS 327110 for ceramic sanitary ware production, one reporting corporation (one facility) produced refractories, and the remaining seven corporations (13 facilities) reported under NAICS 327120 for brick and ceramic tile production. 10 of the 16 facilities have submitted annual reports since 2010, three have submitted since 2013, and three have submitted since 2015 or later.

Table 3. Summary of Current NAICS 3271 GHGRP Reporters[a]

Corporation	NAICS	Product	Reported Subparts	2019 Subpart C Emissions for All Facilities (non-biogenic CO_2e MT)
1	327110	Sanitary ware	C	44,566.38
2	327120	Refractories	C,S	198,909.68
3	327120	Ceramic tile	C	232,537.51
4	327120	Brick	C	78,603.26
5	327120	Brick	C	59,568.64
6	327120	Ceramic and porcelain tile	C	41,912.81
7	327120	Ceramic tile	C	38,023.85
8	327120	Brick	C	34,960.89
9	327120	Brick	C	25,610.13
	Total			**754,693.13**

[a] 2019 Subpart C CO_2e calculated using AR5 GWPs (CH_4 GWP of 28 and N_2O GWP of 265).

3. Review of Existing Programs and Methodologies

3.1 Review of Existing Programs

In developing GHG monitoring and reporting options for ceramics manufacturing processes, a number of existing programs and guideline methodologies were reviewed. Specifically, the following resources were examined:

(1) 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Volume 3, Industrial Processes and Product Use, Chapter 2, Mineral Industry Emissions. *Available at:* https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol3.html.

(2) European Union (EU). *Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the Monitoring and Reporting of Greenhouse Gas Emissions Pursuant to Directive 2003/87/EC of the European Parliament and of the Council and Amending Commission Regulation (EU) No. 601/2012.* January 1, 2021. *Available at:* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02018R2066-20210101&from=EN.

(3) CARB (California Air Resource Board). *Unofficial Electronic Version of the Regulation for the Mandatory Reporting of Greenhouse Gas Emissions.* April 2019. https://ww2.arb.ca.gov/mrr-regulation.

(4) Environment and Climate Change Canada (ECCC). Canada's Greenhouse Gas Quantification Requirements. Version 4.0. December 2020. http://publications.gc.ca/collections/collection_2021/eccc/En81-28-2020-eng.pdf.

(5) United States Environmental Protection Agency (USEPA). Greenhouse Gas Reporting Program (GHGRP). Subpart N – Glass Production (40 CFR 98.140) and Subpart U—Miscellaneous Uses of Carbonate (40 CFR 98.210). December 9, 2016.

(6) Australia National Greenhouse and Energy Reporting (Measurement) Amendment (2021 Update) Determination 2021. *Part 3—Mineral products. Source 3C—Use of carbonate for production of mineral product (other than cement, clinker, lime or soda ash)*. June 15, 2021. https://www.legislation.gov.au/Details/F2021L00771

Each of these sources were reviewed to determine the types of emissions to be reported, the facility reporting thresholds, the calculation methodologies, and the monitoring methodologies recommended. The remainder of this section summarizes the key calculation methodologies. The reporting and monitoring options presented in Section 4 and Section 5 are commensurate with the methodologies used in these existing programs and guidelines.

3.2 Calculation Methodologies for Ceramics Manufacturing Processes

From the review of existing programs the following basic calculation methodologies were identified. The calculation methods are presented in terms of their relative accuracy.

Method 1. $\underline{CO_2\ CEMS}$. For each ceramics kiln or dryer with a continuous emission monitoring system (CEMS), measure CO_2 concentration and total exhaust gas flow rate for the combined process and combustion source. Calculate CO_2 mass emissions from these measured values using Equation C-6 and, if necessary, Equation C-7 in 40 CFR 98.33(a)(4). Report the combined process and combustion CO_2 emissions according to the Tier 4 Calculation Methodology specified in 40 CFR 98.33(a)(4).

Method 2. *Mass Balance*. A facility without CEMS can use material input data and a mass balance approach to calculate CO_2 emissions, such as the one used in GHGRP Subpart N – Glass Production in 40 CFR 98.143(b)(2). This method combines the direct measurement of inputs with the emissions calculations based on stoichiometric ratios. This approach requires facilities to determine their calcination fractions (or assume a value of 1.0) and determine the weight fraction of their carbonate inputs, and then apply this information to their carbonate consumption.

$$E_{CO2} = \sum_i \left(MF_i \bullet \left(M_i \bullet \frac{2000}{2205}\right) \bullet EF_i \bullet F_i\right) \qquad \text{(Eq. 1)}$$

Where:

E_{CO2} = Annual process CO_2 emissions (metric tons/year)

MF_i = Annual average decimal mass fraction of carbonate-based mineral *i* in carbonate-based raw material *i*.

M_i = Annual mass of the carbonate-based raw material *i* consumed (tons/year)

2000/2205 = Conversion factor to convert tons to metric tons.

EF_i = emission factor for the carbonate *i*, (metric tons CO_2/ metric ton carbonate, see **Table 4** below)

F_i = Decimal fraction of calcination achieved for carbonate-based raw material *i*, assumed to be equal to 1.0.

i = index of the carbonates used

In subpart N, this equation (Eq. N-1) assumes each carbonate material has only one carbonate mineral. A more general equation considering different clays as different carbonate-based raw materials would be:

$$E_{CO2} = \sum_j \left[\left(M_j \cdot \frac{2000}{2205}\right) \cdot \sum_i (MF_i \cdot EF_i \cdot F_i)\right] \quad \text{(Eq. 1a)}$$

Where "j" is the index for carbonate-based raw material and "i" is the index for carbonate mineral in each carbonate-based raw material.

Method 3. *<u>IPCC Method Tier 3</u>*. The IPCC Tier 3 method is based on an analysis of the direct use of carbonates or the use of materials containing carbonates, including clay. This is a mass balance method based on the mass of the carbonate consumed. This is also the method used in GHGRP Subpart U—Miscellaneous Uses of Carbonate.

$$CO_2 = \sum_i \left(\left(M_i \cdot \frac{2000}{2205}\right) \cdot EF_i \cdot F_i\right) \qquad \text{(Eq. 2)}$$

Where:

CO_2 = Annual CO_2 emissions (metric tons/year)

M_i = Annual mass of the carbonate *i* consumed (tons/year)

2000/2205 = Conversion factor to convert tons to metric tons.

EF_i = emission factor for the carbonate *i* (metric tons CO_2/ metric ton carbonate, see **Table 4** below)

F_i = Decimal fraction of calcination achieved for carbonate-based raw material *i*, assumed to be equal to 1.0.

i = index of the carbonates used

The data on carbonates should reflect pure carbonates and not carbonate rock. If data are only available on carbonate rock, assume a default purity of 95% for carbonate content or 10% for clay content.

Method 4. *IPCC Method Tier 1*. The IPCC Tier 1 method is a mass balance method that assumes limestone and dolomite are the only carbonates used as input, and that 85% of carbonates consumed are limestone and 15% of carbonates consumed are dolomite. The basic equation for estimating emissions under Tier 1 is:

$$CO_2 = \left(M_i \bullet \frac{2000}{2205}\right) \bullet (0.85\ EF_{ls} + 0.15\ EF_d) \qquad \text{(Eq. 3)}$$

Where:

CO_2 = emissions of CO2 from other process uses of carbonates (metric tons/year)

M_i = Annual mass of the carbonate *i* consumed (tons/year)

2000/2205 = Conversion factor to convert tons to metric tons.

EF_{ls} = 0.43971, emission factor for limestone calcination (metric tons CO_2/metric ton carbonate)

EF_d = 0.47732, emission factor for dolomite calcination (metric tons CO_2/metric ton carbonate)

The data on carbonates should reflect pure carbonates and not carbonate rock. If data are only available on carbonate rock, assume a default purity of 95% for carbonate content or 10% for clay content.

The emission factor for each carbonate (EF_i) represents the weighted average of the emission factors for each particular carbonate. CO_2 emission factors for some carbonate-based raw materials are provided in **Table 4**. These factors were pulled from Table N-1 of 40 CFR Part 98 subpart N and from Table 2.1 of the 2006 IPCC Guidelines. The Tier 3 approach requires the full accounting of carbonates (species and amounts) whereas Tier 1 only accounts for limestone and dolomite at fixed composition. Emission factors provided by the carbonate vendor for other minerals not listed in **Table 4** may also be used.

Table 4. CO_2 Emission Factors for Carbonate-Based Raw Materials

Carbonate	Mineral Name(s)	CO_2 Emission Factor [a]
$CaCO_3$	Limestone, Calcite, Aragonite	0.440
$CaMg(CO_3)_2$	Dolomite	0.477
Na_2CO_3	Sodium carbonate, Soda ash	0.415
$MgCO_3$	Magnesite	0.522
$BaCO_3$	Witherite, Barium carbonate	0.223
K_2CO_3	Potassium carbonate	0.318
Li_2CO_3	Lithium carbonate	0.596
$SrCO_3$	Strontium carbonate, Strontianite	0.298
$FeCO_3$	Siderite	0.380

[a] Emission factors in units of metric tons of CO_2 emitted per metric ton of carbonate-based raw material charged to the kiln, dryer, or oven.

4. Options for Reporting Threshold

Different options for reporting thresholds are presented, including no emissions threshold, emissions thresholds of 10,000 mt CO_2e, 25,000 mt CO_2e, and 100,000 mt CO_2e, and a production capacity threshold.

The no emissions threshold includes all ceramics manufacturing facilities included in this Technical Support Document regardless of their emissions or capacity. A large number of small artisan ceramic facilities comprise this industry; 702 corporations (representing 86% of the total 815 corporations) have less than 100 employees corporate-wide and likely low production rates.

Coverage under an emissions threshold would be based on facility emissions. As noted in Section 2, national emissions of CO_2 are estimated at 1.16 million metric tons. Based on the corporate data in **Table 2** of this document, there are approximately 165,000 total corporate employees in the ceramic manufacturing industry. If production is related to number of employees, this suggests emissions are about seven metric tons per employee. Thus, facilities with about 3,570 employees may have ceramics production emissions exceeding the 25,000 metric ton CO_2e threshold. Additionally, ceramics production facilities would likely have combustion emissions, and the combination of combustion and process emissions could put facilities over the emissions threshold.

To assess coverage under these options, we assumed the number of facilities equals the number of corporations for corporations less than 1,000 employees and that there were two facilities per corporation at or above 1,000 employees. We assumed stationary combustion emissions were roughly equal to process emissions for the sake of the emission reporting threshold such that approximately half of the facilities in the 2,500 to 4,999 corporate employees range and all facilities in the greater than 5,000 corporate employees range were assumed to have emissions exceeding the 25,000 metric ton CO_2e threshold.

As production size varies from large corporations to artisanal producers, with a vast majority of facilities likely with low production rates and small GHG emissions, it would be reasonable for this new subpart to have an emissions threshold consistent with 40 CFR 98.2(a)(2). This would avoid reporting burden for small artisanal producers. **Table 5** summarizes the facilities and anticipated emissions that would be covered under the different threshold options. The quantity of emissions covered were estimated to be the same for the 10,000 mt CO_2e and 25,000 mt CO_2e thresholds.

Table 5. Facility and Emissions Coverage based on Reporting Threshold

Option	No. Facilities Covered	% Facilities Covered	Process Emissions Covered (mt CO_2e/yr)	% Process Emissions Covered
All-in (no threshold)	850	100%	1,160,000	100%
10,000 mt CO_2e	34	4.0%	694,106	60%
25,000 mt CO_2e	34	4.0%	694,106	60%
100,000 mt CO_2e	0	0%	0	0%

A production capacity threshold is another option that has been evaluated for subparts included in the GHGRP. This threshold would reduce the reporting burden for facilities that already meet GHGRP reporting thresholds under a different subpart, but may have a small artisan-level ceramics process onsite. An example of a facility that may fall under this type of threshold is a university that reports under subpart D for electricity generation, but has a small ceramics department onsite for students. The production capacity threshold could be similar to subpart U, such that a facility that annually consumed at least 2,000 tons of carbonates or 20,000 tons of clay and heated to a temperature sufficient to allow the calcination reaction to occur would meet the definition of a "ceramics manufacturing facility". Or, since it is possible that some facilities could use very low-carbonate clay, the production capacity threshold could be based on the actual estimated consumption of carbonates (rather than relying on the aforementioned IPCC default that clay contains about 10% carbonates).

5. Options for Monitoring Methods

Two separate monitoring methods were considered for this technical support document: direct measurement and a mass balance emission calculation. These options require annual reporting.

5.1 Direct Measurement (CEMS Method)

Industrial source categories for which the process emissions and/or combustion GHG emissions are contained within a stack or vent can take direct measurement of the GHG concentration in the stack gas and the flow rate of the stack gas using a CEMS. In the case of ceramics manufacturing, process and combustion GHG emissions from kilns and dryers are typically emitted from the same stack.

A CEMS continuously withdraws and analyzes a sample of the stack gas and continuously measures the GHG concentration and flow rate of the total exhaust stack gas. The emissions are calculated from the CO_2 concentration and the flow rate of the stack gas. The CEMS monitoring requirements are outlined in 40 CFR 98.33(a)(4).

5.2 Mass Balance and Combustion Methods

All of the non-CEMS methods require monitoring of mass quantities of carbonate-based raw material (*e.g.,* clay) fed to the process and an emission factor based on the type of carbonate consumed. Additionally, one method requires collection of the average decimal mass fraction of carbonate-based mineral in the clay.

The mass quantities of carbonate-based raw materials consumed by each kiln or dryer can be determined using direct weight measurement of plant instruments or techniques used for accounting purposes, such as calibrated scales, weigh hoppers, or weigh belt feeders. The direct weight measurement can then be compared to records of raw material purchases for the year. The rule could specify a measurement frequency. Typically, the more measurements conducted, the more accurate the average value will be. Similar GHGRP subparts (H, N, and U) require monthly data collection.

A ceramics manufacturing facility can establish the carbon mass fraction either by using information provided by the raw material supplier, by sending samples of each carbonate-based material consumed to an off-site laboratory for a chemical analysis of the carbonate content (weight fraction), by choosing to use the default value of 1.0 for carbonate-based mineral mass fractions, or by using a default value of 0.005 if it is determined that the mass fraction of a carbonate based raw material is below the detection limit of available industry testing standards. Suitable chemical analysis methods include using an x-ray fluorescence standard method, x-ray diffraction standard method, or another method published by an industry consensus standards organization (*e.g.,* ASTM, ASME, API). Examples of suitable methods include, but are not limited to:

(1) ASTM D3682-13 Standard Test Method for Major and Minor Elements in Combustion Residues from Coal Utilization Processes (incorporated by reference, see §98.7),
(2) ASTM D4326-13 Standard Test Method for Major and Minor Elements in Coal and Coke Ash by X-Ray Fluorescence, or
(3) ASTM E1621-21 Standard Guide for Elemental Analysis by Wavelength Dispersive X-Ray Fluorescence Spectrometry. (ASTM, 2023)

The kiln and dryer processes also produce combustion GHG emissions, which are calculated using the equations in 40 CFR 98 subpart C.

6. QA/QC Requirements

Facilities should conduct quality assurance and quality control (QA/QC) 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. Options and considerations for QA/QC would 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. Several examples of QA/QC activities follow:

(1) 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.

(2) All meters or monitors (*e.g.,* fuel flow, gas composition, etc.) that are used to provide data for the GHG emissions calculations should be calibrated prior to the first reporting year, using a suitable method published by a consensus standards organization (e.g., ASTM, ASME, API, AGA, etc.), or as specified by the meter/monitor manufacturer. These meters or monitors shall be recalibrated either annually or at the minimum frequency specified by the manufacturer.

(3) Calibration documentation should be maintained. The estimated accuracy of measurements made with these devices should also be recorded, and the technical basis for the estimates should be provided.

(4) All CO_2 CEMS and flow rate monitors used for direct measurement of GHG emissions should comply with QA procedures for daily calibration drift checks and quarterly or

annual accuracy assessments, such as those provided in Appendix F to Part 60 or similar QA procedures.

7. Options for Estimating Missing Data

A complete record of all measured parameters used in the GHG emissions calculations would be required (e.g., concentrations, flow rates, carbonate raw materials consumed, carbonate content, etc.). Therefore, whenever a quality-assured value of a required parameter is unavailable (e.g., if a CEMS malfunctions during unit operation or if a required sample is not taken), a substitute data value for the missing parameter can be used in the calculations. Options and considerations for missing data would vary depending on the proposed monitoring method. Missing data procedures are applicable for CEMS measurements, mass measurements of raw material, and carbon content measurements.

In general, it is recommended that the average of the data measurements before and after the missing data period be used to calculate the emissions during the missing data period. If, for a particular parameter, no quality-assured data are available prior to the missing data incident, the substitute data value should be the first quality-assured value obtained after the missing data period.

For process sources that use an emission calculation for CO_2 emissions, the emission calculation is derived from carbonate consumption data and carbonate emission factors. For missing data on the amounts of carbonate-based raw materials consumed, use the best available estimate based on all available process data or data used for accounting purposes, such as purchase records. For missing data on the mass fractions of carbonate-based minerals in the carbonate-based raw materials, assume that the mass fraction of each carbonate-based mineral is 1.0.

8. References

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