CHAPTER 7: CEMENT PLANTS

(Guidance for Regulation Section 95110)

Under California's greenhouse gas reporting regulation, cement plants are required to estimate and report their greenhouse gas (GHG) emissions. This guidance, provided as a "plain language" companion to the regulation including examples, will assist in meeting the GHG reporting requirements. In addition, ARB will provide an on-line GHG reporting tool (available early 2009) that will further guide the reporting process and help to ensure that submitted GHG emissions data are accurate and complete.

This guidance focuses specifically on those portions of the regulation relevant to estimating emissions from cement plants. The key requirements are provided in section 95110 of the regulation, which is available here:
http://www.arb.ca.gov/regact/2007/ghg2007/ghg2007.htm

It is also important to refer to other chapters of this reporting guidance that address those parts of the regulation (e.g., sections 95103 and 95104) that apply to all facilities and sectors, such as the reporting and verification schedules. Also, in some situations, such as when cogeneration occurs onsite or for reporting purchased electricity usage, other portions of the reporting guidance provide the details for estimating emissions from those activities.

7.1 Cement Plant Description

The GHG reporting regulation provides a definition for cement plants that includes industrial structures, installations, plants, or buildings primarily engaged in manufacturing Portland, natural, masonry, pozzolanic, and other hydraulic cement. These plants are typically identified by NAICS (North American Industrial Classification System) code 327310. Aggregate plants, sand and gravel plants, concrete plants, or asphalt plants are not considered cement plants for GHG reporting purposes.

Portland cement is a fine powder, gray or white in color, which consists of a mixture of hydraulic cement materials comprising primarily calcium silicates, aluminates and aluminoferrites. These materials are chemically combined through pyroprocessing and subjected to subsequent mechanical processing operations to form gray and white portland cement.

For a full description of the cement manufacturing process, refer to the U.S. EPA's AP-42, Compilation of Emission Factors, Section 11.6, which is available at this website: http://www.epa.gov/ttn/chief/ap42/ch11/index.html

The purpose of this chapter is to provide guidance on the requirements of section 95110 of the mandatory GHG reporting regulation. As described more specifically in Chapter 1 of this document, this guidance does not add to, substitute for, or amend the regulatory requirements as written in these or other sections of the regulation [Subchapter 10, Article 2, sections 95100 to 95133, title 17, California Code of Regulations].

7.2 Cement Plant Reporting Requirements – Overview

This section explains the information that cement plant operators must include in their GHG emissions data reports. As mentioned previously, this section focuses on key GHG reporting requirements specific to cement plants, but it is also important to be familiar with general requirements such as the reporting schedule, *de minimis* emissions, fuel use measurement accuracy, and recordkeeping requirements.

This document provides guidance for estimating and reporting the following items:

- Fuel consumption, by fuel type for the entire facility
  - and fuel consumption for individual process units or groups of units where separately metered
- GHG combustion emissions, by gas type (i.e., CO_2, N_2O, CH_4) for the entire facility
  - and GHG emissions produced for each fuel type used
- Process emissions from cement manufacturing
- Various process inputs such as lime or magnesium oxide content
- Reporting emissions from electricity generating units or cogeneration units
- Reporting indirect energy usage

7.3 Estimating Fuel Consumption

As with all sectors, cement plants need to report fuel consumption by fuel type for the overall facility for those emission sources subject to reporting. In the case of cement plants, this would mean all fuel consumed by stationary combustion sources at the facility. Emissions from portable or mobile equipment are not included in these estimates. Generally overall facility fuel use information can be readily obtained from fuel purchase invoice data. This data, separated by fuel type and totaled for the entire year, will generally be sufficient for reporting the overall facility fuel usage. Alternatively, it is acceptable to report fuel use from on-site fuel flow meters provided that they meet the requirements of section 95103(a)(9) for accuracy. As mentioned, the consumption of each fuel type must be separately identified and reported.

> *Fuel use* must be reported for individual process units (devices) that are separately metered for fuel use. Reporting of GHG *emissions* at the process unit level is not required.

For fuels that are stored on-site, such as coal, the "stock method" approach may helpful for estimating total facility fuel use. The equation for this calculation is provided in the regulation (section 95115(a)(2)(A)). In simple terms, the method computes the actual amount of fuel consumed during the year, taking into account that some of the purchased fuel may still be on site and unconsumed.

Fuel Consumption in the Report Year =
(Total Fuel Purchases – Total Fuel Sales)
+ (Amount Stored at Beginning of Year – Amount Stored at End of Year)

The regulation also requires reporting of annual fuel consumption for each process unit, or group of units, where fuel use is separately measured (section 95103(a)(2)).

Therefore it is important to keep records of annual fuel use for those devices, processes, or activities that are served by separate fuel meters. These "units" must be individually reported using the ARB's GHG reporting tool.

Examples of individual process units are boilers, dryers, heaters, cogeneration systems, electricity generation, and other stationary combustion sources. For example, if three boilers are fed through a single meter, then the fuel use consumed by the boilers may be reported as a single value. However, when reporting through the on-line tool, space will be provided to describe the sources, in this case, each of the boilers, even if their fuel use is not individually reported. In addition, we welcome reporting of fuel use from the boilers individually if an approach is developed based on boiler size, hours of operation, or other information to subdivide the fuel use to the individual boilers.

Note that it is possible that the combined sum of the fuel use from individually reported process units may not add up to the total facility fuel use. This is possible because not all fuel consumed at the complete facility will necessary be routed through subordinate meters that wholly capture all reported fuel use. Instead, overall facility fuel usage may be reported from the facility revenue meter, with individually metered equipment also reported to enable a more complete understanding of individual facility sources of GHG emissions.

When providing fuel consumption information, all reported fuel values need to be converted to the appropriate units listed below:

- million standard cubic feet for gases,
- gallons for liquids,
- short tons for non-biomass solids, and
- bone dry short tons for biomass-derived solid fuels.

Conversion factors are provided in Table 1 in Appendix A of the regulation for converting between the different units of measure.

7.4 Estimating CO_2, N_2O, and CH_4 Combustion Emissions for Cement Plants

The requirements for computing cement plant CO_2 combustion emissions are specified in sections 95110(b) and (d) of the regulation. The N_2O and CH_4 requirements are provided in section 95110(b).

7.4.1 Reporting CO_2, N_2O and CH_4 Emissions

Before addressing the specific calculation methods, we first present an overview of the end-result emissions data that will be required. When reporting facility emissions, it is necessary to calculate the emissions at two levels of detail. First, for stationary sources, the regulation requires that the GHG emissions be separately computed and reported for the combustion, process, and fugitive emission sources specified in the regulation. Second, the GHG emissions from fuel combustion must be separately identified and reported by fuel type. For example, the CO_2 produced from coal combustion and natural gas combustion is separately tabulated. Finally, the CO_2 emissions from biomass fuel combustion are reported separately from the CO_2 produced by fossil fuel combustion. The examples below illustrate the facility-level reporting.

As an example, assume that a cement kiln at a cement plant produces 65,000 metric tonnes of CO_2 per year from natural gas combustion and 50,000 metric tonnes of CO_2 per year from coal combustion. An additional 10,000 metric tones of CO_2 are produced from non-kiln combustion of natural gas. The overall process-based emissions were estimated as 115,000 tonnes per year. The plant also has a cogeneration facility burning pure wood that produces 10,000 metric tonnes of CO_2 per year. In this case the facility would report the following:

CO_2 Emissions from:	
Natural gas combustion	75,000 tonnes/year
Coal combustion	50,000 tonnes/year
Wood combustion	10,000 tonnes/year
Process emissions	115,000 tonnes/year
Total Facility CO_2 Emissions:	
Fossil fuel combustion	125,000 tonnes/year
Process emissions	115,000 tonnes/year
Biomass Emissions	10,000 tonnes/year

In this simplified example the sum of the fossil fuel CO_2 from the individual combustion sources adds up to the total facility fossil fuel emissions. In a real-world situation this may not always be the case, depending on differences in how overall facility fuel use is accounted for versus how the fuel use at each individual combustion unit is measured. Further, the GHG reporting regulation specifies that the kiln and non-kiln CO_2 emissions must be separately calculated and reported, adding a further level of emissions subdivision that is required (section 95110(a)(3)(D)) beyond the simplification show above.

Note that the kiln and non-kiln CO_2 biomass emissions would also be separately reported. It is important that any CO_2 from biomass combustion be separately identified and reported because these emissions may be considered "carbon-neutral" and could be treated differently in evaluating overall facility emissions.

The approach is the same for the nitrous oxide (N_20) and methane (CH_4). Assume that using appropriate calculation methodologies, the following estimates were computed: 30 tonnes CH_4 emissions from natural gas combustion, 10 tonnes CH_4 from coal combustion, and 120 tonnes CH_4 from wood combustion. Also, it was estimated that the facility produced 7 tonnes N_2O from natural gas combustion, 3 tonnes N_2O from coal combustion, and 40 tonnes N_2O from wood combustion. The following summary data would be reported using the ARB on-line GHG reporting tool.

Combustion Emissions Summary:	
CH_4 (natural gas)	30 tonnes/year
N_2O (natural gas)	7 tonnes/year
CH_4 (coal)	10 tonnes/year
N_2O (coal)	3 tonnes/year
CH_4 (wood)	120 tonnes/year
N_2O (wood)	40 tonnes/year

Total Facility Stationary Combustion Emissions:

CO_2 (fossil fuels)	125,000 tonnes/year (from above)
CH_4 (all fuels)	160 tonnes/year
N_2O (all fuels)	50 tonnes/year
CO_2 (biomass)	10,000 tonnes/year (from above)

*Note: For CH_4 and N_2O emissions, it is not required to separately report the biomass fraction of the emissions. They may be included in the overall CH_4 and N_2O emissions if desired.

Below we walk through the steps involved in calculating GHG emissions for the various GHG emission sources at cement plants.

7.4.2 Calculating CO_2 Combustion Emissions

7.4.2.1 Estimating CO_2 Combustion Emissions Using Continuous Emissions Monitoring (CEMS)

There are two approaches for computing cement plant CO_2 combustion emissions, that may either be used individually or in combination. First, for those processes or systems for which continuous emissions monitoring systems (CEMS) are in place, CEMS data may be used to calculate CO_2 emissions for the activity. The benefit of this approach is that both combustion and process emissions can be measured simultaneously for appropriately instrumented equipment. This approach can greatly simplify the reporting process because process CO_2 emissions do not need to be separately calculated. In addition, the inputs needed to estimate the CO_2 combustion emissions (such as high heat value of carbon content) do not need to be acquired as is required for the other fuel-based methods. Note, however, that fuel consumption for each fuel type must still be reported.

When using CEMS to estimate CO_2 emissions, the requirements of section 95125(g) of the regulation must be met (see Chapter 13 of this document). If these requirements cannot be met, then the fuel-based methods below must be used to estimate CO_2 combustion emissions. To help ensure consistency in reported data, switching back and forth between using CEMS estimates and using fuel-based methods in different years is not allowed. The operator is provided extra time to install a CEMS system, however, as described in section 95103(a)(11) of the regulation.

7.4.2.2 Estimating CO_2 Combustion Emissions Using Fuel-Based Methods

If CEMS are not used, or if certain devices or equipment are not routed through the CEMS system, then the CO_2 emissions from these sources need to be estimated based on fuel analysis. The requirements that apply to cement plant operators for calculating CO_2 from fuel combustion are provided in section 95110(d) of the regulation.

These requirements vary by fuel type. For natural gas, either the measured high heating value (HHV) or the carbon content of the fuel is used to estimate CO_2 emissions. Coal or petroleum coke CO_2 emissions are calculated by measuring the carbon content of the fuel. For tires and other waste-derived fuels, heat content, carbon content, or source testing may be used to estimate the CO_2 emissions. For each fuel, section 95110(d) refers to the appropriate sections of the regulation which describe the sampling requirements, calculation methods, and other requirements for computing CO_2 emissions from the fuel combustion. Table 7.4.2.2, below, summarizes the cement plant testing and sampling requirements for each fuel.

Table 7.4.2.2. Cement Plant CO_2 Emission Estimation – Fuel Testing and Sampling Requirements

Fuel Type	***Regulation Section***	***Testing and Sampling Requirements***
Natural Gas and Associated Gas (refinery fuel gas or flexigas)	95125(c) or 95125(d)	Monthly high heat value if HHV between 975 and 1100 (95125(c)); monthly carbon content testing if HHV < 975 or >1100; except, carbon testing three times per day for refinery fuel gas, and daily for flexigas (95125(d))
Coal or Petroleum Coke	95125(d)	Compute carbon content monthly, based on analysis of combined weekly samples
Other Fossil Fuels	95125(c) or 95125(d)	For specified "other" fuels, measure HHV on receipt of new delivery or monthly; or monthly carbon testing
Refinery Fuel Gas	95125(e)	Daily carbon content except weekly for small refiners; for HHV either hourly if on-line instrumentation used, or, daily, to coincide with carbon measurement
Landfill Gas or Biogas	95125(c) or 95125(d)	Monthly HHV measurement or monthly carbon content
Biomass Solids	95125(a), 95125(c), 95125(d), 95125(h)(3)	Use of default emission factors, or monthly HHV from weekly subsamples, or monthly carbon content from weekly subsamples, or approved source testing
Waste Derived Fuels	95125(c), 95125(d), 95125(h)(3)	Monthly HHV with biomass fraction analysis; or monthly carbon content, with weekly subsamples for solids and biomass fraction analysis; or source testing with biomass derived fraction
Co-Firing of Fuels	As specified above for individual fuel types; determine biomass fraction if applicable, 95125(h)(2)	Use appropriate methods shown for individual fuel types; evaluate biomass derived fraction as required
Start-Up Fuels	95125(a) or as specified above for fuel types	Use default emission factors in Appendix A of the regulation, or other methods specified above for fuels

Because the fuel sampling requirements require monthly, weekly, or even daily (for refinery fuel gas) sampling, it is important to become familiar with the specific requirements for those fuel types used at the plant. In this way the appropriate sampling protocols and data management systems can be put in place at the facility to collect the heat, carbon, or other data required for the emissions calculations. Section 95125 of the regulation and the associated guidance (see Chapter 13) provide the requirements for each method.

If the cement plant operator also runs stationary combustion equipment for purposes of electricity generation or cogeneration, then the emissions calculations methods required of the power generation and cogeneration sectors must be used for those sources. Chapters 8 and 9 of this document address electricity generation and cogeneration.

7.4.3 Calculating CH_4 and N_2O Combustion Emissions

Cement plants must calculate and report their N_2O (nitrous oxide) and CH_4 (methane) emissions from stationary combustion using the methods specified in section 95125(b) of the regulation, as described in Chapter 13. The following options are available when calculating N_2O and CH_4 emissions for the plant:

- Default Emission Factors: Table 6 in Appendix A of the regulation provides N_2O and CH_4 emission factors for the most common types of fuels used in stationary combustion. Method 95125(b) in the regulation provides the equation for applying these emission factors and calculating emissions. Either the default heat content can be used, if provided in Appendix A of the regulation, or a measured value can be applied (see section 95125(c)) for heat content measurement methods). If the heat content is measured for any combusted fuel, it is also reported (section 95110(a)(3)(C)).
- Optionally, source testing may be performed to develop facility-specific emission factors for N_2O or CH_4. Section 95125(b)(4) describes the mechanism for developing facility-specific source test data to determine the N_2O or CH_4 emissions from fuel combustion.

Chapter 12 of this guidance provides an example for computing methane and nitrous oxide emissions from combustion. As with CO_2 emissions, the facility N_2O and CH_4 emissions are required to be reported as a total value for the entire facility, as well as subdivided by each fuel type combusted (per section 95103(a)(2)).

7.5 Estimating Process CO_2 Emissions from Cement Manufacturing

7.5.1 Collecting Input Data for Computing Process Emissions

Process CO_2 emissions from a cement plant are primarily produced through the chemical reactions of feedstocks during pyroprocessing to produce cement clinker. If CEMS (continuous emissions monitoring systems) are used for the kiln, then it is not necessary to independently compute and report the CO_2 process emissions. Process emissions would be reported in combination with kiln combustion emissions. Fuel use for each fuel type must still be reported, though.

If CEMS are not used, then the process emissions are calculated using the Clinker-Based Methodology provided in section 95110(c) of the regulation. To perform the calculations it is necessary to collect the input data shown in the following table.[1] The table also includes the input needed to compute the process emissions from the carbon in raw materials which could be converted to CO_2 during processing.

Table 7.5.1 Input Data for Cement Plant Process CO_2 Emissions

Input Name	***Units***
Clinker produced	metric tonnes/yr
CaO content of clinker	% annual average
MgO content of clinker	% annual average
Non-carbonate CaO	metric tonnes/yr
Non–carbonate MgO	metric tonnes/yr
Amount of discarded CKD not recycled to the kiln	metric tonnes/yr
Organic content of raw materials	% annual average

Note that the units in the table above are provided in terms of tonnes per year or annual average percentages. For computing the CO_2 process emissions, the regulation does not specify the sampling frequency for CaO or MgO content. Unless the feedstock is fairly consistent over the course of a year, it may be more accurate to use monthly samples to derive month-specific clinker emission factors. These factors would then be multiplied by the monthly clinker production to calculate monthly emissions, which can be summed to an annual value. For reporting, the annual average emission factor would be reported. Regardless of whether a single annual CaO and MgO value is used, or if some more frequent sampling is employed, it is important to ensure that the pertinent data are available and well documented to assist in the later verification of the emissions data.

7.5.2 Process CO_2 Emissions Calculation Equation

The equation below is used to compute the process emissions from cement manufacturing. This approach calculates the CO_2 emissions based on the amount of clinker produced as well as the amount of cement kiln dust (CKD) not recycled to the kiln. The equation includes two emission factor terms, EF_{Cli} and EF_{CKD}, each of which is computed using additional equations in the regulation and discussed below. The equation includes two parts. The first part multiplies the amount of clinker produced (Cli) by the computed clinker emission factor (CO_2/tonnes clinker, EF_{Cli}) to calculate clinker production CO_2 emissions. In the second part, the amount of cement kiln dust (CKD) that is not recycled back into the kiln is multiplied by a computed CKD emission factor (CO_2/tonnes CKD, EF_{CKD}). The CKD emission factor uses the clinker emission factor computed for the plant and adjusts for the plant-specific calcination rate.

To calculate overall process CO_2 emissions for the plant, emissions from clinker production and the residual discarded CKD are summed, as shown in the equation below.

[1] Portions of the process emissions guidance and general structure provided from the Cement Reporting Protocol. California Climate Action Registry (CCAR), December 2005. http://www.climateregistry.org/tools/protocols/industry-specific-protocols.html

Equation 1. Clinker-Based CO_2 Emissions Equation

CO_2 Emissions (metric tonnes) = [(Cli) * (EF_{Cli})] + [(CKD) * (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced, metric tonnes
EF_{Cli}	=	Clinker emission factor, metric tonnes CO2/metric tonne clinker computed as specified in section 95110(c)(1)(A) of the regulation
CKD	=	Quantity CKD discarded, metric tonnes
EF_{CKD}	=	CKD emission factor, computed as specified in section 95110(c)(1)(B) of the regulation

7.5.2.1 Step 1: Compute Clinker Emission Factor

With the data shown in Table 7.5.1, calculate the annual Clinker Emission Factor for the cement plant using the equation below. As shown in the equation, the average annual calcium oxide (CaO) and magnesium oxide (MgO) contents of the clinker are required.

Equation 2. Clinker CO_2 Emission Factor Equation

EF_{Cli} = [(CaO content – non-carbonate CaO) * Molecular ratio of CO_2/CaO]
+ [(MgO Content – non-carbonate MgO) * Molecular Ratio of CO_2/MgO]

Where:

CaO Content (by weight)	=	CaO content of Clinker (%)
Molecular Ratio of CO_2/CaO	=	0.785
MgO Content (by weight)	=	MgO content of Clinker (%)
Molecular Ratio of CO_2/MgO	=	1.092
Non-carbonate CaO (by weight)	=	Non-carbonate CaO fraction of Clinker (%)
Non-carbonate MgO (by weight)	=	Non-carbonate MgO fraction of Clinker (%)

In addition, the portions of the CaO and MgO in the clinker that were derived from non-carbonate sources are subtracted from the overall clinker CaO and MgO values. This adjustment is based on the assumption that the additional non-carbonate feedstocks used to produce CaO and MgO do not release CO_2 during processing (unlike the calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) feedstocks). It is recommended that operators conduct lab analysis to verify that the "loss on ignition" of the imported non-carbonate materials to determine the actual amount of carbonate, carbon, and hydrocarbons released, and adjust the equations accordingly.[2] Non-carbonate inputs include materials such as steel, slag, calcium silicates, or fly ash.

The example below shows the computation of the clinker emission factor (EF_{Cli}) for a hypothetical facility. Of course, this type of calculation is best performed in a spreadsheet or other electronic data system so input values can be updated as needed, and all inputs, data sources, and calculations, can be clearly documented.

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[2] CCAR Cement Protocol, December 2005.

Example 1. Estimate CO_2 Emissions from Clinker Production (does not include CKD)

Based on the clinker emission factor equation above (equation 2), the data below are needed and are collected for the facility. Gathering and preparing these values over the course of a year for a complex facility is not trivial, so allow sufficient time and resources. It is important to assure that the data used are representative of overall plant operations throughout the year being reported. Also, the data sources (weighing devices, chemical analyses, fuel meters, etc.) must be appropriately calibrated, quality assured, and documented.

Input Data:

Input Name	***Value***	***Units***
Clinker produced	500	metric tonnes/yr
CaO content of clinker	60	% by mass
MgO content of clinker	5	% by mass
Non-carbonate source of CaO	75	Kg/tonne clinker
Non-carbonate source of MgO	0	Kg/tonne clinker

<u>Step a</u>: Convert percentages to mass ratios

60% CaO content of clinker = 0.60 tonnes CaO/tonne clinker
5% MgO content of clinker = 0.05 tonnes MgO/tonne clinker

<u>Step b</u>: Compute the corrected CaO and MgO content of the feedstock

0.60 tonne CaO/tonne clinker – (0.075 tonne non-carbonate CaO/tonne clinker)
= 0.52 tonne CaO/tonne clinker

0.05 tonne MgO/tonne clinker – (0.0 tonne non-carbonate MgO/tonne clinker)
= 0.05 tonne MgO/tonne clinker

<u>Step c</u>: Compute CO_2 formation potential for CaO and MgO content in clinker

0.52 tonne CaO/tonne clinker * 0.785 tonne CO_2/tonne CaO
= 0.41 tonne CO_2/tonne clinker
0.050 tonne MgO/tonne clinker * 1.092 tonne CO_2/tonne MgO
= 0.055 tonne CO_2/tonne clinker

(Note: 0.785 = molecular weight CO_2/molecular weight CaO = 44/56
and 1.09 = molecular weight CO_2/molecular weight MgO = 44/40)

<u>Step d</u>: Compute the Clinker emission factor

EF_{Cli} = 0.41 tonne CO_2/tonne clinker + 0.055 tonne CO_2/tonne clinker
= 0.47 tonne CO_2/tonne clinker

<u>Step e</u>: Compute emissions from clinker

$Emissions_{Cli}$ = EF_{Cli} * Clinker produced
= 0.47 tonne CO_2/tonne clinker * 500 tonnes clinker/year
= 235 tonnes CO_2/year

<u>Step f:</u> Review calculations

Check inputs, unit conversions, and calculations. Include the annual clinker production emissions value in a summary spreadsheet which will be used to compute the overall cement plant process emissions.

7.5.2.2 Step 2: Compute CKD Emission Factor

Following calculation of the clinker emission factor, the next step is to compute a cement kiln dust (CKD) emission factor. The emission factors for the clinker and the CKD are different because it is likely that the CKD will include some fraction of uncalcinated calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). The uncalcinated materials will not have been released CO_2 during processing, so the CO_2 emissions per tonne of CKD material are less than the emissions for clinker because the carbonates are still bound in the CKD.

> NOTE: Computation and use of the CKD emission factor are not required in cases where the cement kiln dust is recycled back to the kiln. This step may be deleted and the equation adjusted accordingly.

This CKD emission factor computation is for CKD produced at the plant, and not recycled back into kiln, over the course of a year. For CKD reintroduced back into the kiln, it is assumed that the carbonates ultimately convert to oxides, and the emissions are accounted for in the clinker emission factor. The CKD factor is derived using the clinker emission factor (computed above) and the degree of CKD calcination, which is calculated in the next step and is represented by “d” in the equation below.

Equation 3. CKD CO_2 Emission Factor Equation

$$EF_{CKD} = \frac{\frac{EF_{Cli}}{1+EF_{Cli}} * d}{1 - \frac{EF_{Cli}}{1+EF_{Cli}} * d}$$

Where:

EF_{CKD}	=	CKD Emission Factor
EF_{Cli}	=	Clinker Emission Factor
d	=	CKD Calcination Rate (see equation below)

The CKD calcination rate equation below is used as an input to the CKD emission factor equation above. This equation represents the fraction of the carbonate CO_2 which has been released, or converted, in the CKD.

Equation 4. CKD Calcination Rate Equation

$$d = 1 - \frac{fCO_{2CKD} * (1 - fCO_{2RM})}{(1 - fCO_{2CKD}) * fCO_{2RM}}$$

Where:

fCO_{2CKD} = weight fraction of carbonate CO_2 in the CKD

fCO_{2RM} = weight fraction of carbonate CO_2 in the raw material

Using the results of the CKD Calcination Rate Equation as input to the CKD Emission Factor, compute the CKD emission factor.

Example 2. Estimate CO_2 Emissions from Cement Kiln Dust

Based on the cement kiln dust (CKD) emission factor equation above (equations 3 and 4), the data below are needed and are collected for the facility. Gathering and preparing these values over the course of a year for a complex facility is not trivial, so allow sufficient time and resources. It is important to assure that the data used are representative of overall plant operations throughout the year being reported. Also, the data sources (weighing devices, chemical analyses, fuel meters, etc.) must be appropriately calibrated, quality assured, and well documented.

Input Data:

Input Name	***Value***	***Units***
Clinker Emission Factor (EF_{Cli})	0.47	Tonne CO_2/tonne clinker
Weight fraction of carbonate CO_2 in the CKD, fCO_{2CKD}	60	% by mass (assumed same as clinker)
Weight fraction of carbonate CO_2 in raw material, fCO_{2RM}	85	% by mass
Clinker produced	500	metric tonnes/yr
Amount of discarded CKD not recycled to the kiln	5.0	Metric tonnes/year (assumed 1% clinker production)

<u>Step a</u>: Compute the CKD calcination rate

The CKD calcination rate in equation 4 is required to compute the CKD emission factor. For this example, it is assumed that the weight fraction of carbonate CO_2 in the CKD is 60%, the same as the CaO weight content for the clinker, shown previously. The weight fraction of carbonate CO_2 in the raw material is estimated (or calculated) to be 85%

Applying Equation 4, we get,

$d = 1 – [(0.60 * (1-0.85))/((1-0.60)*0.85))] = 1 – (0.09/0.34) = 1 – 0.26 = 0.73$

<u>Step b</u>. Compute the CKD emission factor

Applying Equation 3,
$EF_{CKD} = [(0.47 / (1 + 0.47)) * 0.73] / [(1 - (0.47 / (1 + 0.47)) * 0.73]$

$EF_{CKD} = 0.23/0.77 = 0.30$ tonnes CO_2/tonne CKD

7.5.2.3 Step 3: Compute Clinker-Based Process Emissions for the Cement Plant

Finally, returning to the original equation shown in 7.5.2, the cement plant CO_2 emissions can now be calculated. The inputs are the total annual clinker produced (Cli), the annual CKD produced (CKD), the cement plant clinker emission factor (EF_{Cli}) and the CKD emission factor (EF_{CKD}) emission factor. As shown in the example below, these parameters are input into Equation 1 to compute the annual CO_2 clinker-based process emissions for the plant.

Example 3. Calculating Process Emissions for a Cement Plant

With the preliminary computations complete, it is a simple matter to compute the facility CO_2 process emissions using Equation 1.

$$CO_2 \text{ Emissions (metric tonnes)} = [(Cli) * (EF_{Cli})] + [(CKD) * (EF_{CKD})]$$

Input Data:

Input Name	***Value***	***Units***
Cli, Clinker produced	500	metric tonnes/yr
EF_{Cli}	0.47	tonne CO_2/tonne clinker
CKD, Cement kiln dust remaining	5.0	metric tonnes/yr
EF_{CKD}	0.30	tonne CO_2/tonne CKD

CO_2 Emissions = [500 metric tonnes clinker/year * 0.47 tonne CO_2/tonne clinker]
+ [5.0 metric tonnes CKD/year * 0.30 tonnes CO_2/tonne CKD]

= 235 tonnes CO_2 + 1.5 tonnes CO2
= 236.5 tonnes CO_2/year

7.5.2.4 Step 4. Compute CO_2 from Organics in Raw Materials

Some feedstocks used in cement plants will include small amounts of organic materials. Some of these materials will convert to CO_2 during pyroprocessing in the kiln. To account for these additional CO_2 emissions, an approximation is made for the amount of CO_2 released. This is based on an assumption of that 0.2 percent of the raw material (by weight) is carbon (total organic carbon, or TOC)[3].

Equation 5. CO_2 Emissions from Organics in Raw Materials Equation

$$CO_2 \text{ emissions} = (TOC_{R.M.}) * (R.M.) * (3.664)$$

Where:
$TOC_{R.M}$ = 0.2% = Organic carbon content of raw material (%)
R.M. = The amount of raw material consumed (metric tonnes/yr)
3.664 = The CO_2 to carbon molar ratio

7.6 Fugitive Methane Emissions – Coal Storage

If there is coal storage onsite at the cement plant, the fugitive methane emissions produced from the methane off-gassed by the stored coal needs to be estimated and reported. The reporting requirements are provided in section 95125(j) of the regulation and they are described in Chapter 13 of this guidance document. To

[3] *The Cement CO_2 Protocol: CO_2 accounting and Reporting Standard for the Cement industry*, Version 2.0, June 2005, The Cement Sustainability Initiative. World Business Council for Sustainable Development.

perform this calculation the amount of coal purchased will be needed, as well as the source (geographically) of the coal. This information, with emission factors in regulation Appendix A, Table 10, is used to compute the fugitive methane emissions.

7.7 Indirect Energy Usage

The regulation also requires cement plant operators to report their indirect energy use. Indirect energy is energy purchased from another source, such as electricity or heat. Only the energy use needs to be reported, not the associated emissions. Electrical energy is reported as kilowatt-hours (kWh) and thermal energy is reported as British thermal units (Btu). The guidance to sections 95125(k) and (l) of the regulation, found in Chapter 13, provides additional information about how to report facility energy use. Generally, only power bills will be needed to calculate electricity usage. Similar records can be used to estimate thermal energy purchases.

7.8 Electricity Generating Units and Cogeneration – Secondary Sector

In additional to the primary Cement Plant reporting, it may also be necessary to report "secondary sector" emissions. If electricity generation or cogeneration occurs at the facility (within the same contiguous boundary and under the operational control of the cement plant), emissions from these secondary sector activities must be included in the emissions data report. If the electricity generating or cogeneration facility has a nameplate generating capacity of 1 MW or more, and its CO_2 emissions from electricity generating activities trigger the separate reporting threshold of 2,500 metric tonnes, the reported emissions for the secondary sector must comply with the requirements of regulation sections 95111 and 95112, as applicable. Regulation section 95111 includes the electricity generating facility reporting requirements and is described in Chapter 8 of this document, while section 95112 provides the cogeneration system requirements and is discussed in Chapter 9. Refer to those sections of the regulation and the associated guidance chapters for more information.

> ***Do you have electricity generation or a cogeneration system on site?***
>
> If your system is at least 1 MW and emitted at least 2.500 MT CO_2 from electricity generation, refer to the methods provided for the electricity generation and cogeneration sectors to calculate GHG emissions from these sources. See Chapters 8 and 9.

If the electricity generating activities are not large enough to trigger these additional reporting requirements, include these emissions in the facility GHG report as additional stationary sources, with emissions calculated specific to fuel type like the facility's other sources.

The regulation also includes definitions for "cogeneration facility," "cogeneration system," "generating facility," "generating unit," and "electricity generating facility," which may be helpful in evaluating whether these types of activities or units are at the facility.

7.9 Efficiency Metrics for Cement Plants

Cement plants are required to compute efficiency metrics for the plant as specified in section 95110(e) of the regulation. The efficiency metrics relate the plant's CO_2

emissions to a production variable, in this case the amount of clinker produced, or the amount of clinker and other materials. They also provide a normalized basis for understanding cement plant emissions and allow for comparisons of emissions rates among plants relative to their production.

For ARB reporting, the total stationary combustion and process CO_2 emissions for the plant are divided by the amount of clinker or product used. For the ARB cement efficiency metric, do not include CO_2 emissions from mobile combustion sources or purchased electricity, steam, or heat in the CO_2 emissions total.

> For the ARB cement efficiency metric, do not include CO_2 emissions from mobile combustion sources or purchased electricity, steam, or heat in the CO_2 emissions total.

To assist with the specifics of efficiency metric reporting, additional detail has been added to the reporting step-by-step guide for Cement Plants. This includes a listing of the specific fields to be reported, descriptions of the fields, and how to enter the data into the tool. In preparing your report, it is important to reference the updated Cement Plant step-by-step reporting guide, which is here: http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-tool.htm. Specifically for efficiency metrics, refer to Section 7.4 in the guide and the section titled, Additional Resources for Efficiency Metrics Reporting and Supplemental Benchmarking Data, provided at the end of the step-by-step guide.

7.9.1 Efficiency Metric for Clinker

The equation for computing the efficiency metric for clinker is shown below.

$$\frac{CO_2 \text{ emissions (tonnes)}}{\text{Metric tonne clinker}} = \frac{\text{Direct } CO_2 \text{ emissions from cement manufacturing (tonnes)}}{\text{(Own clinker consumed or added to stock)} + \text{(own clinker sold directly)}}$$

As the equation shows, the denominator includes the clinker manufactured and consumed by the plant, any clinker in storage at the plant (added to stock), and any clinker sold by the plant. Basically, this is the clinker production for the year. The numerator is the sum of the plant's annual combustion and process CO_2 emissions, computed using the previously described methods. The CO_2 emissions and the clinker are both input into the equation as metric tonnes, produced annually. The purpose of the equation is to relate the annual cement plant CO_2 emissions to the amount of clinker produced by the cement plant during the 12 month calendar year reporting period.

7.9.2 Efficiency Metric for Cementitious Product

The equation for computing the efficiency metric for cementitious product is below.

$$\frac{CO_2 \text{ Emissions (tonnes)}}{\text{Cementitious Product}} = \frac{\text{Direct } CO_2 \text{ emissions from cement manufacturing}}{\begin{array}{c}\text{Own clinker}\\ \text{consumed or}\\ \text{added to stock}\end{array} + \begin{array}{c}\text{own clinker}\\ \text{sold directly}\end{array} + \begin{array}{c}\text{gypsum, limestone,}\\ \text{CKD \& clinker}\\ \text{substitutes consumed}\\ \text{for blending}\end{array} + \begin{array}{c}\text{cement}\\ \text{substitutes}\end{array}}$$

This efficiency metric is more comprehensive than the clinker metric because in addition to the clinker produced, it also includes additional materials used by the cement plant such as cement substitutes and gypsum. This approach accounts for the use of clinker and cement substitutes as a CO_2 emission reduction strategy and intergrinding mineral components with clinker to make blended cements (i.e., clinker substitution) or as a binder (i.e., cement substitution).[4] The annual CO_2 emissions and the clinker and other inputs are all input as metric tonnes. Again, the purpose of the equation is to relate the annual CO_2 emissions to the amount of specified materials used during the reporting year.

Note that for this equation the denominator does not necessarily equal the total cement sales. It excludes: purchased clinker, used for cement production; granulated slag that is sold to and ground by another company; and, cement volumes that are traded without any processing.

7.10 Summary of Data to Be Reported

The ARB online reporting tool will guide cement plant operators through the full reporting process and will provide different options and pathways based on the facility type to help simplify the process. Nevertheless, a significant amount of data will need to be tabulated. Some of it will already be on hand through normal business practices, such as amounts of different fuels used and the quantity of clinker produced. But some of the data, such as fuel heat content or source test emission factors for GHGs, may need to be collected for the first time.

The table below summarizes each of the data elements required to be reported by cement plants. Note that in some cases, not all items will always be reported. For example, if CEMS are used to estimate CO_2 emissions, then the carbon or heat content would not be reported. Or, if there is a cogeneration plant under the control of the cement plant, there are additional reporting requirements, not shown here, that must be met. Also recognize that some of the required fields include multiple items. For example, each fuel type and the amount used must be separately reported, as well as the individual GHG emissions produced from each fuel.

Also note that as with all sectors, reporting of mobile sources of emissions is optional. The reporting tool will also allow the operator to voluntarily provide information on other sources not required to be reported. Sources voluntarily reported are subject to verifier review. The sources will be tagged in the reporting tool as voluntarily reported and separately displayed in emissions reports.

[4] Cement Reporting Protocol. California Climate Action Registry, December 2005. http://www.climateregistry.org/tools/protocols/industry-specific-protocols.html
Also, portions of text in the section are adapted from the CCAR protocol or used directly.

Table 7.10 Summary of Cement Plant Data Reporting Requirements*

Field Name	*Units*	*Notes*
Facility Level Totals		
Total CO_2 Emissions	metric tonnes	Includes combustion & process
Total N_2O Emissions	metric tonnes	
Total CH_4 emissions	metric tonnes	
Stationary Combustion Emissions		
Fuel Type	name	Report for each fuel
Fuel consumed annually	scf, gal, tons	Report for each fuel
Emissions by Fuel Type	metric tonnes	CO_2, CH_4, and N_20 by fuel type
Annual Average Carbon Content (if measured)	facility specific	By fuel type for fuels measured
Annual Average Heat Content (if measured)	facility specific	By fuel type for fuels measured
Facility specific emission factors (if applicable)	kg CO_2, CH_4, N_2O /fuel unit	By fuel type when used. One or multiple GHGs may be included
CEMS if applicable	metric tonnes	
Total Stationary Combustion Emissions	metric tonnes	Sum of CO_2, CH_4, and N_2O combustion emissions (no process emissions)
Direct Process Emissions		
Clinker Based Methodology for CO_2 Emissions		
Clinker Emission Factor	kg CO_2/metric tonnes clinker	
Quantity of Clinker Produced	metric tonnes	
CaO Content of Clinker	%	
MgO Content of Clinker	%	
Non-Carbonate CaO	%	
Non-Carbonate MgO	%	
CKD Emission Factor	kg CO_2/metric tonnes CKD	Applies to cement plants that discard CKD.
Plant-specific CKD Calcination Rate	unitless	
Quantity of CKD Discarded	metric tonnes	
CO_2 Emissions from Clinker Production	metric tonnes	
TOC Content in Organic Materials		
Amount of Raw Material Consumed	metric tons	
Organic Carbon Content of Raw Material	%	
CO_2 Emissions from TOC in Raw Materials	metric tons	
Total Direct Process Emissions	metric tons	

Field Name	***Units***	***Notes***
Fugitive Emissions		
Coal Type	name	
Total Tons of Coal Purchased	tons	
Emission Factor	scf CH_4/metric ton	multiple types
Total Fugitive Emissions of CH4	metric tons	
Efficiency Metrics		
Amount of own clinker consumed	metric tons	
Amount of clinker added to stock	metric tons	
Amount of clinker sold directly	metric tons	
Type of clinker substitutes consumed for blending	name	
Amount of clinker substitutes consumed for blending	metric tons	multiple types
Type of cement substitute consumed for blending	name	
Amount of cement substitute consumed for blending	metric tons	multiple types
Efficiency Metric (clinker)	CO_2 tonnes/tonne	
Efficiency Metric (clinker + substitutes)	CO_2 tonnes/tonne	
Indirect Energy Use		
Annual Electricity Purchases	kWh	
Electricity Provider	name	
Annual Energy Purchase (steam)	BTUs	
Energy Provider	name	
Electricity Generation		
Use electricity generation reporting requirements		See regulation and guidance for requirements
Cogeneration		
Use cogeneration reporting requirements		See regulation and guidance for requirements.

* Note: This table is provided for guidance only. If any conflict is found between this table and the regulation, the regulation always takes precedence.