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National Pollutant Inventory

Emission estimation technique manual

for

Cement manufacturing
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Erratum for cement manufacturing emission estimation technique (EET) manual (Version 2.1 April 2008)

Page	Outline of alteration
28	Correction to emission factor for the combination of Preheater kilns, coal, ESP, sulfur dioxide from 0.012kg/t to 0.12kg/t

Erratum for cement manufacturing emission estimation technique (EET) manual (Version 2.0 November 2006)

Page	Outline of alteration
All	Updated formatting and page layout.
Various	Updated examples
Various	Updated equations
References	Updated references
Appendix A	Updated emission factors

EMISSION ESTIMATION TECHNIQUES FOR CEMENT MANUFACTURING

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CEMENT MANUFACTURING

LIST OF FIGURES, TABLES, EXAMPLES AND EQUATIONS

1. Introduction

The purpose of all emission estimation technique (EET) manuals in this series is to assist Australian manufacturing, industrial, and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in cement manufacturing activities.

The manual covers cement (excepting adhesive or refractory cement) manufacturing activities.

EET MANUAL:	Cement manufacturing	
HANDBOOK:	Cement & lime manufacturing	
ANZSIC CODE:	1993	All classes within the 263 ANZSIC Group
	2006	All classes within the 203 ANZSIC Group

This manual was drafted by the NPI Unit of the Department of the Environment, Water, Heritage and the Arts. It has been developed through a process of national consultation involving state and territory environment agencies and key stakeholders; such as the Australian Cement Industry Federation.

2. Process description

Cement is a fine powder consisting predominantly of calcium silicates, aluminates, aluminoferrites and, to a lesser degree, gypsum and limestone. Around five different raw material groups are used in the manufacture of cement in Australia. These materials are chemically combined through pyroprocessing and subjected to subsequent mechanical processing operations.

2.1 Types of cement produced

Cement manufacturers in Australia produce several types of cement, but Portland cement and blended cement are by far the most common. Portland cement consists primarily of a kiln-fired, fused material known as clinker, which is ground and combined with small amounts of gypsum or a similar material. Portland cement is produced in several grades designed to lend certain properties to concrete. The major ingredients of blended cement are Portland cement, flyash, and slag. Smaller amounts of specialty cements are also produced and include masonry, oilwell, and off-white cements. Off-white cement, which is made from iron-free materials of exceptional purity (usually limestone, china clay or kaolin, and silica), is primarily used to manufacture decorative concrete. Masonry cement, produced by adding limestone and/or other materials to Portland cement, is hydraulic cement used as a component of mortar for masonry construction.

2.2 Portland cement

Portland cement, one of the principal components of blended cement and concrete, is generally made from calcareous materials (e.g. limestone) and argillaceous materials (e.g. clays or shales) together with smaller quantities of iron-bearing materials and sand. To make Portland cement, the raw materials are ground, mixed, heated, and fused in a rotary kiln, cooled, and finally reduced to a fine powder. Figure 1 illustrates the typical cement production process and shows possible emission points throughout the plant.

2.3 Production processes

Cement is manufactured in Australia in four kiln types: wet kilns, grate preheater kilns, preheater kilns, and precalciner kilns. Similar raw materials are used in all kiln types. However, the moisture content and processing techniques differ, as do the kiln designs. Fuels used for firing the kilns include oil, pulverised coal, natural gas, and supplementary waste fuels such as used tyres, spent solvents, and waste fuel oils. In the wet kiln process the raw materials are ground with water which is subsequently evaporated. As a result, this process is more energy-intensive than dry processes. Preheater and precalciner kiln processes use dry grinding technology utilising kiln exhaust gases for drying. All kilns are equipped with grate or planetary type coolers which cool the fused clinker and recuperate energy for firing the kilns or drying raw materials. Over 70% of Australian Portland cement clinker is produced in modern precalciner or preheater kilns. The most common method of cooling the clinker is a reciprocating grate, which is cooled by ambient air. The cooled clinker is transferred to storage. Clinker, together with 4-6% gypsum, is then ground to produce a homogeneous cement powder, which is generally sent to a bulk storage facility and then transported by truck, ship, or rail.

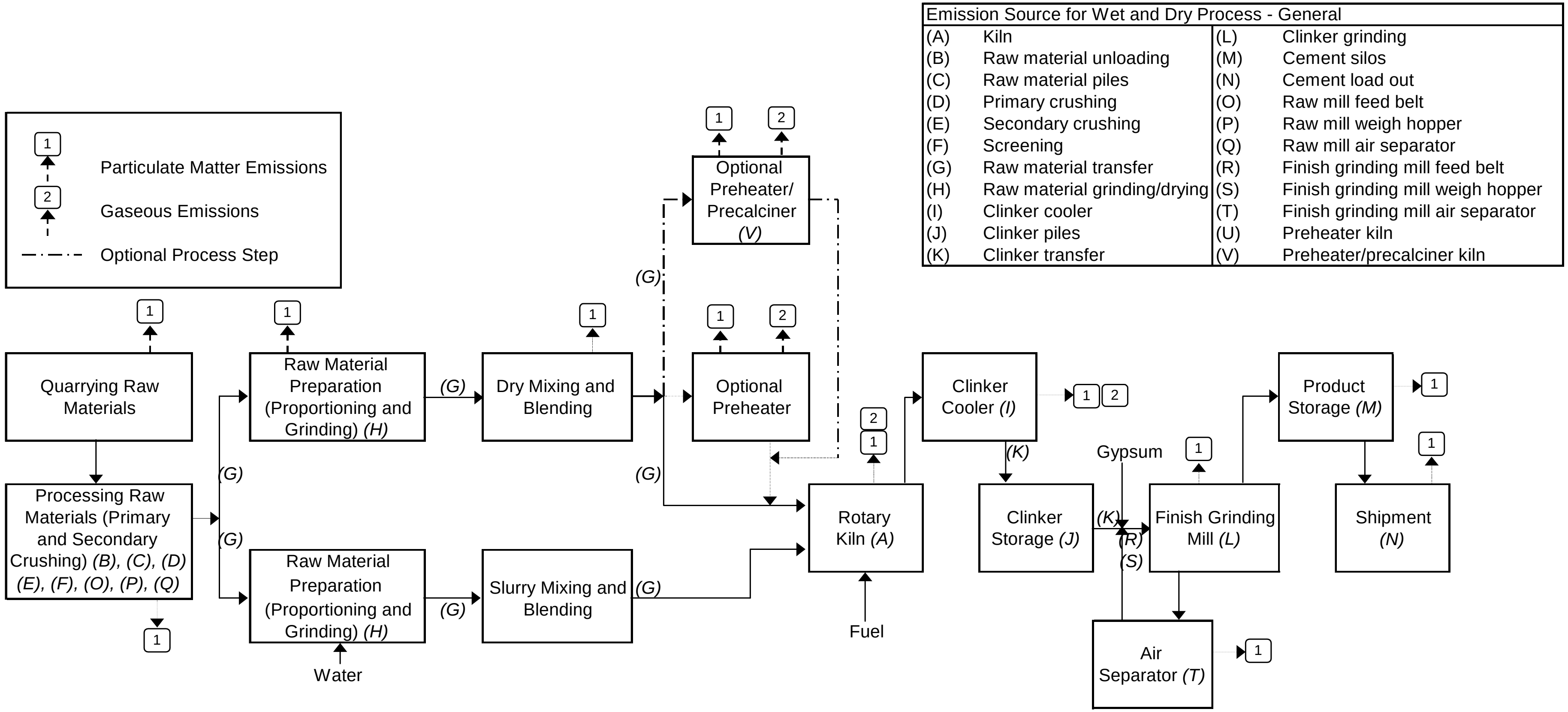

Figure 1 - Process flow diagram
(Adapted from USEPA AP-42 Section 11.6)

3. Emission sources

Emissions from cement manufacturing plants include combustion gases; wastewater; plant maintenance waste; and research and laboratory wastes. Particulate from kiln stacks is the largest emission stream from cement plants. It is commonly collected in baghouses (fabric filters) or precipitators and is returned to the process.

Particulate matter (particles with an equivalent aerodynamic diameter of 10 micrometres or less i.e. $\leq 10\mu m$), oxides of nitrogen, sulfur dioxide, and carbon monoxide are the most likely listed substances emitted during the production of cement. Trace quantities of volatile organic compounds (including benzene and phenol), ammonia, chlorine, some listed metals, and hydrochloric acid may also be emitted.

3.1 Particulate matter (PM_{10})

Sources of PM_{10} emissions at cement plants include:

- quarrying and crushing;
- raw material storage;
- grinding and blending (in the dry process only);
- clinker production;
- finish grinding; and
- packaging and loading.

The largest single source of PM_{10} within cement plants is the pyroprocessing system that includes the kiln and raw material grinding exhaust stacks. Additional sources of PM_{10} are raw material storage piles, conveyors, storage silos, and unloading facilities.

The major constituents of PM_{10} as cement kiln dust are alumina, silica, calcium carbonate, and clay (the primary constituents of cement itself).

3.2 Oxides of nitrogen (NO_x)

NO_x are generated during fuel combustion by oxidation of chemically bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As flame temperature increases the amount of thermally generated NO_x increases. The amount of NO_x generated from fuel increases with the quantity of nitrogen in the fuel. In the cement manufacturing process, NO_x is generated in both the burning zone of the kiln and the burning zone of the precalcining vessel. Fuel use affects the quantity and type of NO_x generated. For example, in the kiln, natural gas combustion with a high flame temperature and low fuel nitrogen may generate a larger quantity of NO_x than does oil or coal, which have higher fuel nitrogen but which burn with lower flame temperatures.

3.3 Sulfur dioxide (SO_2)

SO_2 emissions may be generated both from the sulfur compounds in the raw materials and from the sulfur content of the fuel. The sulfur content of both raw materials and fuels varies, and depends on the facility and the location in Australia. However, the alkaline nature of the cement provides for direct absorption of SO_2 into the product, thereby mitigating the quantity of SO_2 emissions in the exhaust stream. Depending on the process and the source of the sulfur, SO_2 absorption ranges from about 70 to more than 95 per cent.

3.4 Organics

Cement plants may emit a wide range of organic compounds in trace quantities. The range of organic compounds emitted depends on the nature of raw materials and fuels used and the combustion efficiency of the process, and may include polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dioxins and furans.

3.5 Metal compounds

Emissions of metal compounds from cement kilns can be grouped into three general classes: volatile metals, e.g. mercury; semi-volatile metals, including antimony, cadmium, lead, selenium, and zinc; and refractory or non-volatile metals, including chromium, arsenic, nickel, manganese, and copper. Although partitioning of these metal groups is affected by kiln operating procedures, the refractory metals tend to concentrate in the clinker, while volatile metals tend to be emitted through the primary exhaust stack, and semi-volatiles are partitioned between clinker and the primary exhaust.

3.6 Emissions to water

The cement manufacturing process also generates wastewater from the cooling of process equipment. The pollutants contained in cooling waters are principally dissolved solids (potassium and sodium hydroxide, chlorides, and sulfates) and suspended solids. The main control and treatment methods for wastewater involve recycling and reusing wastewater through cooling towers or ponds, settling ponds, containment ponds, and clarifiers. Wastewaters may not always contain NPI-listed substances.

If no wastewater monitoring data exists, emissions to process water can be calculated using a mass balance calculation, or emission factors. The discharge of listed substances to a sewer or tailings dam does not require you to report to the NPI. However, leakage and other emissions (including dust) from a tailings storage facility are reportable. (See also Section Three of the *NPI Guide*.)

3.7 Emissions to land

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids and may contain listed substances. These emission sources can be broadly categorised as:

- surface impoundment of liquids and slurries; and
- unintentional leaks and spills.

4. Emission estimation techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in the *NPI Guide*.

In general, there are five types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility. They include:

- sampling or direct measurement;
- mass balance;
- fuel analysis or other engineering calculations;
- emission factors; and
- approved alternative emission estimation technique.

Select the EET (or mix of EETs) that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of emission estimation techniques that are not outlined in this manual, your data will also be displayed as being of 'acceptable reliability'.

This manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this manual does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

You are able to use an alternative emission estimation technique that is not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.

In general, ongoing direct measurement is the most accurate method for characterising emissions and, where available, such data should be used in preference to other EETs presented in this manual. However, additional direct measurement is not required under the NPI Measure. Direct monitoring may be undertaken as an element of other EETs.

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (e.g. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, i.e. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The **usage**[a] of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for Total Volatile Organic Compounds, TVOCs) reporting threshold is exceeded. If the threshold is exceeded, **emissions** of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

[a] Usage is defined as meaning the handling, manufacture, import, processing, coincidental production or other uses of the substances.

Table 1 lists the variables and symbols used throughout this manual.

Table 1 - List of variables and symbols

Variable	Symbol	Units
Clinker production (activity rate)	A	tonnes/hour
Concentration	C	parts per million volume dry, ppmvd
Emission reduction control factor (i.e. overall control efficiency[a].)	ER_i	% reduction in emissions of pollutant i
Filter catch	C_f	grams (g)
PM_{10} concentration	C_{PM}	grams/m^3
Emission factor for pollutant i	EF_i	kg/t, kg/area, and/or kg/vehicle km travelled.
Total emissions of pollutant i per hour	E_i	kg/hr
Annual emissions of pollutant i	$E_{kpy,i}$	kg/year
Moisture collected	g_{moist}	grams
Moisture in exhaust gas (wet)	$moist_R$	%
Molecular weight	MW	kg/kg-mole
No of wheels for vehicle	NW	
Annual operating hours	OpHrs	hours/year
Volumetric flow rate	Q_w	wet cubic metres per second (m^3/s)
Volumetric flow rate	Q_d	dry cubic metres per second (m^3/s)
Fuel use	Q_f	Typically, kg/hr
Temperature	T	^{o}Celsius, *specify ^{o}C (or if necessary Kelvin, i.e. absolute temperature, K) in each equation*
Wind speed	U	m/sec
Molar volume @ STP (standard temperature and pressure)	V	22.4 m^3/kg-mole @ 0°C and 101.3 kPa
Metered volume at standard temperature and pressure	$V_{m, STP}$	m^3
Vehicle kilometre travelled	VKT	vehicle

Source: Queensland Department of Environment and Heritage, 1998.
[a] Some users may be accustomed to using control efficiency (CE).

4.1 Sampling data or direct measurement

You may wish to undertake direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements. However, the NPI does not require you to undertake additional sampling and measurement.

Stack sampling test reports often provide emissions data in terms of kg/hr or g/m^3 (dry). Annual emissions for NPI reporting can be calculated from this data using Equation 1 or Equation 2 overleaf. Stack tests for NPI reporting should be performed under representative (i.e. normal) operating conditions. You should be aware that some tests undertaken for a state or territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

This section shows how to calculate emissions in kg/hr based on stack sampling data and how to convert this to an annual emissions figure. Calculations involved in determining PM_{10} emissions are used as an example, although the same calculations are applicable for most of the substances listed on the Inventory.

With regards to emission controls for PM_{10}, in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

An example of test results is summarised in Table 2. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of the test run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in m^3/s. The filter weight gain is determined gravimetrically and divided by the volume of gas sampled, as shown in Equation 1 to determine the PM concentration in grams per m^3. Note that this example does not present the condensable PM emissions.

Pollutant concentration is then multiplied by the volumetric flow rate to determine the emission rate in kilograms per hour, as shown in Equation 2 and Example 1.

Equation 1

$$C_{PM} = C_f / V_{m, STP}$$

where:

C_{PM} = concentration of PM or gram loading, g/m^3

C_f = filter catch, g

$V_{m,STP}$ = metered volume of sample at STP, m^3

Equation 2

$$E_{PM} = C_{PM} * Q_d * 3.6 * [273 / (273 + T)]$$

where:

E_{PM} = hourly emissions of PM, kg/hr
C_{PM} = concentration of PM or gram loading, g/m^3
Q_d = stack gas volumetric flow rate, m^3/s, dry
3.6 = 3600 seconds per hour multiplied by 0.001 kilograms per gram
T = temperature of the gas sample, °C

Table 2 - Stack sample test results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (sec)		7 200	7 200	7 200
Moisture collected (g)	g_{MOIST}	395.6	372.6	341.4
Filter catch (g)	C_f	0.0851	0.0449	0.0625
Average sampling rate (m^3/s)		1.67E-04	1.67 E-04	1.67E-04
Standard metered volume (m^3)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (m^3/s), dry	Q_d	8.48	8.43	8.45
Concentration of particulate (g/m^3)	C_{PM}	7.18E-02	3.87E-02	5.37E-02
Note: Scientific notation is used; e.g. 7.38E-02 represents 7.38×10^{-2} or 0.0738 and 7.38E+02 represents $7.38 \times 10^{+2}$ or 738				

Queensland Department of Environment and Heritage 1998

Example 1 - Using stack sampling data

PM emissions calculated using Equation 1 and Equation 2, and the stack sampling data for Test 1 (presented in Table 2 and an exhaust gas temperature of 150°C (423 K)). This is shown below:

C_{PM} = $C_f / V_{m, STP}$
= 0.0851 / 1.185
= $0.072 g/m^3$

E_{PM} = $C_{PM} * Q_d * 3.6 * [273/(273+T)]$
= 0.072 * 8.48 * 3.6 * (273/423K)
= 1.42 kg/hr

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use Equation 3 to calculate the dry particulate emissions in kg/hr.

Equation 3

$$E_{PM} = Q_w * C_{PM} * 3.6 * \left(1 - \frac{moist_R}{100}\right) * \left[\frac{273}{(273+T)}\right]$$

where:

E_{PM}	=	hourly emissions of PM in kilograms per hour, kg/hr
Q_w	=	wet cubic metres of exhaust gas per second, m^3/s
C_{PM}	=	concentration of PM or gram loading, g/m^3
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
$moist_R$	=	moisture content, %
273	=	273 K (0°C)
T	=	stack gas temperature, °C

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM_{10} from total PM emissions, it may be necessary for facility operators to first undertake a size analysis of the stack filter catch. The weight PM_{10} fraction can then be multiplied by the total PM emission rate to produce PM_{10} emissions. Alternatively, assume that 100% of PM emissions are PM_{10}; i.e. assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less ie. ≤10μm.

To calculate moisture content use Equation 4.

Equation 4

Moisture percentage = 100 % * weight of water vapour per specific volume of stack gas/ total weight of the stack gas in that volume.

$$moist_R = \frac{100\% * \frac{g_{moist}}{(1000 * V_{m,STP})}}{\frac{g_{moist}}{(1000 * V_{m,STP})} + \rho_{STP}}$$

where

$moist_R$	=	moisture content, %
g_{moist}	=	moisture collected, g
$V_{m,STP}$	=	metered volume of sample at STP, m^3
ρ_{STP}	=	dry density of stack gas sample, kg/m^3 at STP (if the density is not known a default value of 1.62 kg/m^3 may be used. This assumes a dry gas composition of 50% air, 50% CO_2)

Example 2 - Calculating moisture percentage

A $1.2m^3$ sample (at STP) of gas contains 410g of water. To calculate the moisture percentage use Equation 4.

$$moist_R = \frac{100\% * \frac{g_{moist}}{(1000 * V_{m,STP})}}{\frac{g_{moist}}{(1000 * V_{m,STP})} + \rho_{STP}}$$

$g_{MOIST}/1000 * V_{m,STP}$ = 410 / (1000 * 1.2)
= 0.342
$moist_R$ = 100 * 0.342 / (0.342 + 1.62)
= 17.4%

4.2 Emission factors

An emission factor is a tool that is used to estimate emissions to the environment. In this manual, it relates the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted multiplied by the unit weight, volume, distance, or duration of the activity emitting the substance (e.g. kilograms of sulfur dioxide emitted per tonne of clinker produced.)

When using emission factors, you should be aware of the associated emission factor rating (EFR) code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A	-	Excellent
B	-	Above Average
C	-	Average
D	-	Below Average
E	-	Poor
U	-	Unrated

Emission factors are used to estimate a facility's emissions by the following equation:

Equation 5

$$E_{kpy,i} = [A * OpHrs] * EF_i$$

where:

$E_{kpy,i}$ = emission rate of pollutant i, kg/yr
A = activity rate, t/hr
OpHrs = operating hours, hr/yr
EF_i = uncontrolled emission factor of pollutant i, kg/t

Example 3 - Using emission factors

According to the emission factors listed in Appendix A, 2.7kg of NO_x are emitted for each tonne of clinker produced from a gas-fired precalciner kiln with a fabric filter. It is assumed that the cement plant operates for 1 500 hours per year and that clinker production (activity) averages 250 tonnes per hour during the reporting year. Emissions of NO_x can be estimated from Equation 5.

EF_{NOx} = 2.7 kg/tonne
Activity rate (A) = 250 t/hr
OpHrs = 1 500 hr/yr

$$E_{kpy,NOx} = [A * OpHrs] * EF_i$$
$$= [250 \text{ t/hr} * 1\,500 \text{ hr/yr}] * 2.7 \text{ kg/t}$$
$$= 1\,012\,500 \text{ kg } NO_x\text{/yr}$$

Emission factors developed from measurements for a specific kiln or process may sometimes be used to estimate emissions at other sites. For example, a company may have several units of similar model and size; if emissions were measured from one kiln or belt, an emission factor could be developed and applied to similar units. If you wish to use your own site specific emission factors you should first seek approval from your state or territory environment agency prior to its use for estimating NPI emissions.

Appendix A of this manual contains emission factors for common cement operations within Australia based on kiln type, fuel used and pollution control devices present. To estimate your emissions from the production of clinker you will need to apply Equation 5 to each substance that matches the process configuration of your facility. Emissions against each substance must be reported to the NPI.

4.2.1 PM_{10} emissions from materials handling

Emissions of PM_{10} that occur as a result of materials handling beyond the production of clinker must be considered in the estimating emissions from a facility. If any of the following are relevant to your operation, they should be added to the PM_{10} estimate previously calculated:

a) ***Unenclosed materials handling***:

Where materials handling operations are carried out in an unenclosed area Equation 6 can be used to determine an emission factor of PM_{10}. Wind speed and moisture content of material must be taken into consideration.

Equation 6

Default formula
$$EF_{PM_{10}} = 0.75 * 0.001184 * \left[\frac{(U/2.2)^{1.3}}{(M/2)^{1.4}} \right] * ER_{PM_{10}}$$

where:

EF_{PM10} = emission factor, kg of PM_{10} /tonne of material handled
U = mean wind speed, m/sec
M = mean moisture content of material, %
ER_{PM10} = emission reduction rate, %, Table 3

NB For materials where M= 0 use default of 0.0036 kg/t of material handled.

Table 3 - Emission reduction factors for materials handling and storage

Reduction method	Reduction factors (ER_{PM10})	Control efficiency [a] (CE_{PM10})
Wind breaks	0.7	30%
Water sprays	0.5	50%
Chemical suppression	0.2	80%
Enclosure (2 or 3 walls)	0.1	90%
Covered stockpiles	0.0	100%

Source: The Cement Industry Federation Limited, 1998
[a] Some users may be accustomed to using control efficiencies (CE) in similar calculations.
An ER of 0.2 equates to a CE of 80%.
ER = (1-CE/100)

The emission factor derived above can now be substituted into the general emission factor equation (Equation 5) to determine annual emissions of PM_{10} specific to your unenclosed materials handling.

b) ***Bag filters venting outside:***

Equation 7 can be used to calculate annual emissions of PM_{10} when using outside-venting bag filters.

Equation 7

$$E_{kpy,PM10} = EF_{PM10} * A * OpHrs * 10^{-6}$$

where:

$E_{kpy,PM10}$ = annual emissions of PM_{10}, kg/yr
EF_{PM10} = emission factor for PM_{10}, mg/m^3, in this case $12mg/m^3$
A = activity rate (hourly flow of air exhausted through the bag filter), m^3/hr
OpHrs = operating hours, hr/yr
10^{-6} = conversion factor mg to kg.

(Where $12mg/m^3$ is 80% of the total particulate matter ($15mg/m^3$vented from the bag filter.)

c) Enclosed materials handling:

There is currently no data to assist in determination of emissions of PM_{10} from material handling operations when these activities are performed inside the building.

4.2.2 PM_{10} emissions from materials storage

PM_{10} emissions from active stockpiles due to wind can be calculated using the following equation. Any emissions identified through the following must be added to those already calculated through materials handling and clinker production.

Equation 8

$$E_{PM10} = EF_{PM10} * area * ER_{PM10}$$

where:

E_{PM10} = hourly emissions of PM_{10}, kg/hr
EF_{PM10} = emission factor of PM_{10}, kg/ha/hr
area = area of base of stockpile, ha
ER_{PM10} = emission reduction of PM_{10}, %, (Table 3)

NB: In the absence of available PM_{10} data use the default EF_{PM10} = 0.3 kg/ha/hr.

Example 4 – Stockpile emissions

A stockpile with a half-hectare base is active for the full year. Emissions of PM_{10} are calculated using Equation 8. No information is available on site-specific factors hence the default emission factor is used. Water sprays are used to suppress dust, see Table 3.

Hourly emissions

$$E_{PM10} = EF_{PM10} * Area * ER_{PM10}$$
$$= 0.3 * 0.5 * 0.5$$
$$= 0.075 \text{ kg/hr}$$

Annual emissions

$$E_{kpy,PM10} = E_{PM10} * OpHrs$$
$$= 0.075 * 8760$$
$$= 657 \text{ kg/year}$$

4.2.3 PM_{10} emissions from equipment traffic

For vehicles with a gross mass greater than 5 tonnes operating on unsealed roads use the following equation for PM_{10} emissions (kg/VKT on unsealed roads). Any emissions identified through the following must be added to those already calculated through materials handling, materials storage and clinker production.

NB: VKT = Vehicle Kilometre Travelled.

Equation 9

$$EF_{PM10} = 0.0019 * (NW)^{3.4} * (Silt)^{0.2} * ER_{PM10}$$

where:

EF_{PM10} = emission factor (kg / vehicle kilometre travelled)
NW = number of wheels
Silt = road surface material silt content (g/m^2 as per AS3638)
ER_{PM10} = emission reduction (Table 4)

In the absence of available data use the default EF_{PM10} = 1.5 kg/VKT, which is 75% of total suspended particulate (TSP) matter emitted. Equation 10 can be used to calculate VKT.

Equation 10

$$VKT = D * NU$$

where:

VKT = vehicle kilometre travelled per year, km/yr
D = average distance travelled, km/vehicle/yr
NU = number of vehicles on-site, vehicles

Example 5 illustrates the use of Equation 10 when calculating vehicle kilometre travelled.

Example 5 - Calculating VKT

A reporting facility has two trucks that each travel approximately 13 000 kilometres on-site per year.

Using Equation 10:

VKT = D * NU
= 13 000 km/vehicle/yr * 2 vehicles
= 26 000 km/yr

Table 4 - Emission reduction factors for dust suppression on roads

Reduction method	Reduction factors (ER)	Control efficiency [a] (CE)
Watering (to eliminate visible dust)	0.25	75%
Chemical spraying (rate)	0.20	80%

Source: The Cement Industry Federation Limited, 1998
[a] Some users may be accustomed to using control efficiencies (CE) in similar calculations.
An ER of 0.2 equates to a CE of 80%.
ER = (1-CE/100)

4.2.4 PM10 emissions from fuel preparation & drying

To calculate emissions of PM_{10} from coal drying with dust collectors use Equation 7 .

4.3 Continuous emission monitoring system (CEMS) data

A continuous emission monitoring system (CEMS) provides a continuous record of emissions over time, usually by reporting pollutant concentration. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas or liquid flow rate of that pollutant.

To monitor SO_2, NO_x, TVOCs, and CO emissions using a CEMS, you use a pollutant concentration monitor that measures the concentration in parts per million by volume dry air (ppm_{vd} = volume of pollutant gas/10^6 volumes of dry air). Flow rates should be measured using a volumetric flow rate monitor. Flow rates estimated based on heat input using fuel factors may be inaccurate because these systems typically run with high excess air to remove the moisture out of the kiln. Emission rates (kg/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 5 presents example CEM data output for three periods for a hypothetical kiln. The output includes pollutant concentrations in parts per million dry basis (ppm_{vd}), diluent (O_2 or CO_2) concentrations in percent by volume dry basis (%v, d) and gas flow rates; and may include emission rates in kilograms per hour (kg/hr). This data represents a snapshot of a hypothetical kiln operation. While it is possible to determine total emissions of an individual pollutant over a given time period from this data, assuming the CEM operates properly all year long, an accurate emission estimate can be made by adding the hourly emission estimates if the CEMS data is representative of typical operating conditions.

Although CEMS can report real-time hourly emissions automatically, it may be necessary to estimate annual emissions from hourly concentration data manually. This Section describes how to calculate emissions for the NPI from CEMS concentration data. The selected CEMS data should be representative of operating conditions. When possible, data collected over longer periods should be used.

It is important to note that prior to using CEMS to estimate emissions, you should develop a protocol for collecting and averaging the data in order that the estimate satisfies the local environmental authority's requirement for NPI emissions estimations.

Table 5 - Example CEMS output for an hypothetical kiln firing waste fuel oil

Time	**O_2**	**Concentration (C) (ppm_{vd})**				**Gas flow rate**	**Clinker rate (A)**
	(% by volume)	**SO_2**	**NO_x**	**CO**	**TVOCs**	**(Q_d)**	**(tonnes / hour)**
1	10.3	150.9	142.9	42.9	554.2	8.52	290
2	10.1	144.0	145.7	41.8	582.9	8.48	293
3	11.8	123.0	112.7	128.4	515.1	8.85	270

Hourly emissions can be based on concentration measurements as shown in Equation 11.

Equation 11

$$E_i = (C * MW * Q_d * 3\,600) / [22.4 * (T+273/273) * 10^6]$$

where:

E_i = emissions of pollutant i, kg/hr
C = pollutant concentration, ppm_{vd}
MW = molecular weight of the pollutant, kg/kg-mole
Q_d = stack gas volumetric flow rate, m^3/s, dry
3 600 = conversion factor, s/hr
22.4 = volume occupied by one mole of gas at standard temperature and pressure (0°C and 101.3 kPa), m^3/kg-mole
T = temperature of gas sample, °C

Actual annual emissions can be calculated by multiplying the emission rate in kg/hr by the number of actual operating hours per year (OpHrs) as shown in Equation 12, for each typical time period and summing the results.

Equation 12

$$E_{kpy,i} = \sum (E_i * OpHrs)$$

where:

$E_{kpy,i}$ = annual emissions of pollutant i, kg/yr
E_i = emissions of pollutant i, kg/hr (from Equation 11)
OpHrs = operating hours, hr/yr

Emissions in kilograms of pollutant per tonne of clinker produced can be calculated by dividing the emission rate in kg/hr by the activity rate (clinker production rate (tonnes/hr) during the same period Equation 13) as shown below. It should be noted that the emission factor calculated below assumes that the selected time period (i.e. hourly) is representative of annual operating conditions and longer time periods should be used for NPI reporting where they are available.

Equation 13

$$E_{kpt,i} = E_i / A$$

where:

$E_{kpt,i}$ = emissions of pollutant i per tonne of clinker produced, kg/t
E_i = hourly emissions of pollutant i, kg/hr
A = clinker production, t/hr

Example 6 - Using CEMS data

This example shows how SO_2 emissions can be calculated using Equation 11 based on the CEMS data for Time Period 1 shown in Table 5, and an exhaust gas temperature of 150°C (423 K).

$$E_{SO2,1} = (C * MW * Q * 3\,600) / [(22.4 * (T+273/273) * 10^6]$$
$$= (150.9 * 64 * 8.52 * 3\,600) / [22.4 * (423/273) * 10^6]$$
$$= 296\,217\,907 / 34\,707\,692$$
$$= 8.53 kg/hr$$

For Time Period 2, also at 150°C

$$E_{SO2,2} = 8.11 kg/hr$$

For Time Period 3, also at 150°C

$$E_{SO2,3} = 7.23 kg/hr$$

Say representative operating conditions for the year are:

Period 1 = 1500 hr
Period 2 = 2000 hr
Period 3 = 1800 hr

Total emissions for the year are calculated by adding the results of the three Time Periods using Equation 12:

$$E_{kpy,SO2} = E_{SO2,1} * OpHrs + E_{SO2,2} * OpHrs + E_{SO2,3} * OpHrs$$
$$= (8.53 * 1500) + (8.11 * 2000) + (7.23 * 1800) kg$$
$$= 42021 kg/yr$$

Emissions, in terms of kg/tonne of clinker produced when operating in the same mode as time period 1, can be calculated using Equation 13:

$$E_{kpt,SO2} = E_{SO2} / A$$
$$= 8.53 / 290$$
$$= 2.94 * 10^{-2} kg\ SO_2 \text{ emitted per tonne of clinker produced}$$

When the kiln is operating as in time periods 2 or 3, similar calculations can be undertaken for emissions per tonne.

5. References

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Emission estimation technique manuals are available at the NPI web site (http://www.npi.gov.au).

Appendix A – Emission factors

ESP = Electrostatic precipitator
FF = Fabric filter

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
Precalciner kilns	Coal	ESP	Acetone	0.00019	1.90E-04	U
Precalciner kilns	Coal	ESP	Ammonia (total)	0.00083	8.30E-04	D
Precalciner kilns	Coal	ESP	Arsenic & compounds	0.0000013	1.30E-06	U
Precalciner kilns	Coal	ESP	Benzene	0.004	4.00E-03	C
Precalciner kilns	Coal	ESP	Biphenyl	0.0000031	3.10E-06	U
Precalciner kilns	Coal	ESP	Cadmium & compounds	0.0000042	4.20E-06	U
Precalciner kilns	Coal	ESP	Carbon disulfide	0.000055	5.50E-05	D
Precalciner kilns	Coal	ESP	Carbon monoxide	0.5	5.00E-01	C
Precalciner kilns	Coal	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Precalciner kilns	Coal	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Precalciner kilns	Coal	ESP	Dichloromethane	0.00025	2.50E-04	U
Precalciner kilns	Coal	ESP	Ethylbenzene	0.0000095	9.50E-06	D
Precalciner kilns	Coal	ESP	Fluoride compounds	0.00045	4.50E-04	E
Precalciner kilns	Coal	ESP	Hydrochloric acid	0.002	2.00E-03	D
Precalciner kilns	Coal	ESP	Lead & compounds	0.00036	3.60E-04	E
Precalciner kilns	Coal	ESP	Manganese & compounds	0.000036	3.60E-05	C
Precalciner kilns	Coal	ESP	Mercury & compounds	0.00011	1.10E-04	E
Precalciner kilns	Coal	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Precalciner kilns	Coal	ESP	Oxides of nitrogen	1	1.00E+00	C
Precalciner kilns	Coal	ESP	Particulate matter 10.0 um	0.086	8.60E-02	C
Precalciner	Coal	ESP	Phenol	0.000055	5.50E-05	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Precalciner kilns	Coal	ESP	Selenium & compounds	0.000075	7.50E-05	U
Precalciner kilns	Coal	ESP	Styrene	0.00000075	7.50E-07	U
Precalciner kilns	Coal	ESP	Sulfur dioxide	0.22	2.20E-01	D
Precalciner kilns	Coal	ESP	Toluene	0.00052	5.20E-04	D
Precalciner kilns	Coal	ESP	Total volatile organic compounds	0.013	1.30E-02	D
Precalciner kilns	Coal	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	U
Precalciner kilns	Coal	ESP	Zinc & compounds	0.00013	1.30E-04	C
Precalciner kilns	Coal	FF	Ammonia (total)	0.0038	3.80E-03	E
Precalciner kilns	Coal	FF	Arsenic & compounds	0.000026	2.60E-05	U
Precalciner kilns	Coal	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Precalciner kilns	Coal	FF	Cadmium & compounds	0.0000011	1.10E-06	E
Precalciner kilns	Coal	FF	Carbon monoxide	1.7	1.70E+00	D
Precalciner kilns	Coal	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Precalciner kilns	Coal	FF	Copper & compounds	0.000098	9.80E-05	D
Precalciner kilns	Coal	FF	Formaldehyde	0.00023	2.30E-04	U
Precalciner kilns	Coal	FF	Hydrochloric acid	0.015	1.50E-02	D
Precalciner kilns	Coal	FF	Lead & compounds	0.00021	2.10E-04	D
Precalciner kilns	Coal	FF	Mercury & compounds	0.000024	2.40E-05	C
Precalciner kilns	Coal	FF	Oxides of nitrogen	2.1	2.10E+00	D
Precalciner kilns	Coal	FF	Particulate matter 10.0 um	0.1	1.00E-01	U
Precalciner kilns	Coal	FF	Polychlorinated dioxins and furans	0.00000000097	9.70E-10	U
Precalciner kilns	Coal	FF	Polycyclic aromatic hydrocarbons	0.00000032	3.20E-07	D
Precalciner	Coal	FF	Selenium &	0.000038	3.80E-05	C

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns			compounds			
Precalciner kilns	Coal	FF	Sulfur dioxide	0.5	5.00E-01	U
Precalciner kilns	Coal	FF	Total volatile organic compounds	0.0086	8.60E-03	D
Precalciner kilns	Coal	FF	Zinc & compounds	0.00013	1.30E-04	C
Precalciner kilns	Gas	ESP	Acetone	0.00019	1.90E-04	U
Precalciner kilns	Gas	ESP	Ammonia (total)	0.054	5.40E-02	E
Precalciner kilns	Gas	ESP	Arsenic & compounds	0.0000036	3.60E-06	U
Precalciner kilns	Gas	ESP	Benzene	0.0019	1.90E-03	D
Precalciner kilns	Gas	ESP	Biphenyl	0.0000031	3.10E-06	U
Precalciner kilns	Gas	ESP	Cadmium & compounds	0.00000073	7.30E-07	C
Precalciner kilns	Gas	ESP	Carbon disulfide	0.000079	7.90E-05	C
Precalciner kilns	Gas	ESP	Carbon monoxide	0.17	1.70E-01	C
Precalciner kilns	Gas	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Precalciner kilns	Gas	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Precalciner kilns	Gas	ESP	Dichloromethane	0.00029	2.90E-04	D
Precalciner kilns	Gas	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Precalciner kilns	Gas	ESP	Fluoride compounds	0.00045	4.50E-04	U
Precalciner kilns	Gas	ESP	Hydrochloric acid	0.005	5.00E-03	C
Precalciner kilns	Gas	ESP	Lead & compounds	0.000098	9.80E-05	D
Precalciner kilns	Gas	ESP	Manganese & compounds	0.000096	9.60E-05	C
Precalciner kilns	Gas	ESP	Mercury & compounds	0.0000024	2.40E-06	D
Precalciner kilns	Gas	ESP	Methyl ethyl ketone	0.000048	4.80E-05	D
Precalciner kilns	Gas	ESP	Oxides of nitrogen	1.6	1.60E+00	C
Precalciner	Gas	ESP	Particulate matter 10.0	0.098	9.80E-02	D

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns			um			
Precalciner kilns	Gas	ESP	Phenol	0.000055	5.50E-05	U
Precalciner kilns	Gas	ESP	Selenium & compounds	0.000075	7.50E-05	U
Precalciner kilns	Gas	ESP	Styrene	0.00000075	7.50E-07	U
Precalciner kilns	Gas	ESP	Sulfur dioxide	0.0076	7.60E-03	U
Precalciner kilns	Gas	ESP	Toluene	0.000047	4.70E-05	D
Precalciner kilns	Gas	ESP	Total volatile organic compounds	0.0443	4.43E-02	U
Precalciner kilns	Gas	ESP	Xylenes (individual or mixed isomers)	0.000024	2.40E-05	D
Precalciner kilns	Gas	ESP	Zinc & compounds	0.000045	4.50E-05	D
Precalciner kilns	Gas	FF	Ammonia (total)	0.0051	5.10E-03	U
Precalciner kilns	Gas	FF	Arsenic & compounds	0.000006	6.00E-06	U
Precalciner kilns	Gas	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Precalciner kilns	Gas	FF	Cadmium & compounds	0.0000011	1.10E-06	U
Precalciner kilns	Gas	FF	Carbon monoxide	0.08	8.00E-02	U
Precalciner kilns	Gas	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Precalciner kilns	Gas	FF	Copper & compounds	0.0026	2.60E-03	U
Precalciner kilns	Gas	FF	Formaldehyde	0.00023	2.30E-04	U
Precalciner kilns	Gas	FF	Hydrochloric acid	0.073	7.30E-02	U
Precalciner kilns	Gas	FF	Lead & compounds	0.000038	3.80E-05	U
Precalciner kilns	Gas	FF	Mercury & compounds	0.000012	1.20E-05	U
Precalciner kilns	Gas	FF	Oxides of nitrogen	2.7	2.70E+00	U
Precalciner Kilns	Gas	FF	Particulate matter 10.0 um	0.1	1.00E-01	U
Precalciner kilns	Gas	FF	Polychlorinated dioxins and furans	0.0000000015	1.50E-09	U
Precalciner	Gas	FF	Polycyclic aromatic	0.0011	1.10E-03	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns			hydrocarbons			
Precalciner kilns	Gas	FF	Selenium & compounds	0.0001	1.00E-04	U
Precalciner kilns	Gas	FF	Sulfur dioxide	0.005	5.00E-03	U
Precalciner kilns	Gas	FF	Total volatile organic compounds	0.0443	4.43E-02	U
Precalciner kilns	Gas	FF	Zinc & compounds	0.00017	1.70E-04	U
Precalciner kilns	Other	ESP	Acetone	0.00019	1.90E-04	U
Precalciner kilns	Other	ESP	Ammonia (total)	0.054	5.40E-02	U
Precalciner kilns	Other	ESP	Arsenic & compounds	0.0000065	6.50E-06	U
Precalciner kilns	Other	ESP	Benzene	0.0016	1.60E-03	U
Precalciner kilns	Other	ESP	Biphenyl	0.0000031	3.10E-06	U
Precalciner kilns	Other	ESP	Cadmium & compounds	0.0000042	4.20E-06	U
Precalciner kilns	Other	ESP	Carbon disulfide	0.000055	5.50E-05	U
Precalciner kilns	Other	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Precalciner kilns	Other	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Precalciner kilns	Other	ESP	Dichloromethane	0.00025	2.50E-04	U
Precalciner Kilns	Other	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Precalciner kilns	Other	ESP	Fluoride compounds	0.00045	4.50E-04	U
Precalciner kilns	Other	ESP	Hydrochloric acid	0.025	2.50E-02	U
Precalciner kilns	Other	ESP	Lead & compounds	0.00036	3.60E-04	U
Precalciner kilns	Other	ESP	Manganese & compounds	0.00043	4.30E-04	U
Precalciner kilns	Other	ESP	Mercury & compounds	0.00011	1.10E-04	U
Precalciner kilns	Other	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Precalciner kilns	Other	ESP	Particulate matter 10.0 um	0.1	1.00E-01	U
Precalciner	Other	ESP	Phenol	0.000055	5.50E-05	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Precalciner kilns	Other	ESP	Selenium & compounds	0.000075	7.50E-05	U
Precalciner kilns	Other	ESP	Styrene	0.00000075	7.50E-07	U
Precalciner kilns	Other	ESP	Toluene	0.0001	1.00E-04	U
Precalciner kilns	Other	ESP	Total volatile organic compounds	0.0443	4.43E-02	U
Precalciner kilns	Other	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	U
Precalciner kilns	Other	ESP	Zinc & compounds	0.00027	2.70E-04	U
Precalciner kilns	Other	FF	Ammonia (total)	0.0036	3.60E-03	D
Precalciner kilns	Other	FF	Arsenic & compounds	0.0000091	9.10E-06	U
Precalciner kilns	Other	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Precalciner kilns	Other	FF	Cadmium & compounds	0.000018	1.80E-05	C
Precalciner kilns	Other	FF	Carbon monoxide	0.3	3.00E-01	C
Precalciner kilns	Other	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Precalciner kilns	Other	FF	Copper & compounds	0.0002	2.00E-04	C
Precalciner kilns	Other	FF	Formaldehyde	0.00023	2.30E-04	U
Precalciner kilns	Other	FF	Hydrochloric acid	0.0085	8.50E-03	C
Precalciner kilns	Other	FF	Lead & compounds	0.00025	2.50E-04	C
Precalciner kilns	Other	FF	Mercury & compounds	0.00005	5.00E-05	D
Precalciner Kilns	Other	FF	Oxides of nitrogen	2	2.00E+00	C
Precalciner kilns	Other	FF	Particulate matter 10.0 um	0.1	1.00E-01	U
Precalciner Kilns	Other	FF	Polychlorinated dioxins and furans	0.00000000015	1.50E-10	U
Precalciner kilns	Other	FF	Polycyclic aromatic hydrocarbons	0.00000031	3.10E-07	D
Precalciner kilns	Other	FF	Selenium & compounds	0.000037	3.70E-05	D
Precalciner	Other	FF	Sulfur dioxide	0.0058	5.80E-03	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Precalciner kilns	Other	FF	Total volatile organic compounds	0.0443	4.43E-02	U
Precalciner kilns	Other	FF	Zinc & compounds	0.00017	1.70E-04	U
Preheater kilns	Coal	ESP	Acetone	0.00019	1.90E-04	U
Preheater kilns	Coal	ESP	Ammonia (total)	0.054	5.40E-02	U
Preheater kilns	Coal	ESP	Arsenic & compounds	0.0051	5.10E-03	U
Preheater kilns	Coal	ESP	Benzene	0.00037	3.70E-04	D
Preheater kilns	Coal	ESP	Biphenyl	0.0000031	3.10E-06	U
Preheater kilns	Coal	ESP	Cadmium & compounds	0.0000042	4.20E-06	U
Preheater kilns	Coal	ESP	Carbon disulfide	0.000055	5.50E-05	U
Preheater kilns	Coal	ESP	Carbon monoxide	1	1.00E+00	C
Preheater kilns	Coal	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Preheater kilns	Coal	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Preheater kilns	Coal	ESP	Dichloromethane	0.00025	2.50E-04	E
Preheater Kilns	Coal	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Preheater kilns	Coal	ESP	Fluoride compounds	0.00045	4.50E-04	D
Preheater kilns	Coal	ESP	Hydrochloric acid	0.0048	4.80E-03	C
Preheater kilns	Coal	ESP	Lead & compounds	0.00036	3.60E-04	E
Preheater kilns	Coal	ESP	Manganese & compounds	0.000054	5.40E-05	C
Preheater kilns	Coal	ESP	Mercury & compounds	0.0000033	3.30E-06	D
Preheater kilns	Coal	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Preheater kilns	Coal	ESP	Oxides of nitrogen	3	3.00E+00	C
Preheater kilns	Coal	ESP	Particulate matter 10.0 um	0.095	9.50E-02	D
Preheater	Coal	ESP	Phenol	0.000055	5.50E-05	D

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Preheater kilns	Coal	ESP	Selenium & compounds	0.000075	7.50E-05	U
Preheater kilns	Coal	ESP	Styrene	0.00000075	7.50E-07	U
Preheater kilns	Coal	ESP	Sulfur dioxide	0.12	1.20E-01	E
Preheater kilns	Coal	ESP	Toluene	0.0001	1.00E-04	D
Preheater kilns	Coal	ESP	Total volatile organic compounds	0.065	6.50E-02	C
Preheater kilns	Coal	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	E
Preheater kilns	Coal	ESP	Zinc & compounds	0.00027	2.70E-04	U
Preheater kilns	Coal	FF	Ammonia (total)	0.0051	5.10E-03	U
Preheater kilns	Coal	FF	Arsenic & compounds	0.000006	6.00E-06	U
Preheater kilns	Coal	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Preheater kilns	Coal	FF	Cadmium & compounds	0.0000011	1.10E-06	U
Preheater kilns	Coal	FF	Carbon monoxide	0.8	8.00E-01	U
Preheater kilns	Coal	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Preheater kilns	Coal	FF	Copper & compounds	0.0026	2.60E-03	U
Preheater kilns	Coal	FF	Formaldehyde	0.00023	2.30E-04	U
Preheater kilns	Coal	FF	Hydrochloric acid	0.073	7.30E-02	U
Preheater kilns	Coal	FF	Lead & compounds	0.000038	3.80E-05	U
Preheater kilns	Coal	FF	Mercury & compounds	0.000014	1.40E-05	U
Preheater kilns	Coal	FF	Oxides of nitrogen	3.7	3.70E+00	U
Preheater kilns	Coal	FF	Particulate matter 10.0 um	0.1	1.00E-01	U
Preheater kilns	Coal	FF	Polychlorinated dioxins and furans	0.0000000015	1.50E-09	U
Preheater kilns	Coal	FF	Polycyclic aromatic hydrocarbons	0.0011	1.10E-03	U
Preheater	Coal	FF	Selenium &	0.0001	1.00E-04	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns			compounds			
Preheater kilns	Coal	FF	Sulfur dioxide	0.02	2.00E-02	U
Preheater kilns	Coal	FF	Total volatile organic compounds	0.0675	6.75E-02	U
Preheater kilns	Coal	FF	Zinc & compounds	0.00017	1.70E-04	U
Preheater kilns	Other	ESP	Acetone	0.00019	1.90E-04	U
Preheater kilns	Other	ESP	Ammonia (total)	0.054	5.40E-02	U
Preheater kilns	Other	ESP	Arsenic & compounds	0.0051	5.10E-03	U
Preheater kilns	Other	ESP	Benzene	0.0016	1.60E-03	U
Preheater kilns	Other	ESP	Biphenyl	0.0000031	3.10E-06	U
Preheater kilns	Other	ESP	Cadmium & compounds	0.0000042	4.20E-06	E
Preheater kilns	Other	ESP	Carbon disulfide	0.000055	5.50E-05	U
Preheater kilns	Other	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Preheater kilns	Other	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Preheater kilns	Other	ESP	Dichloromethane	0.00025	2.50E-04	U
Preheater kilns	Other	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Preheater kilns	Other	ESP	Fluoride compounds	0.00045	4.50E-04	U
Preheater kilns	Other	ESP	Hydrochloric acid	0.025	2.50E-02	E
Preheater kilns	Other	ESP	Lead & compounds	0.00036	3.60E-04	U
Preheater kilns	Other	ESP	Manganese & compounds	0.00016	1.60E-04	D
Preheater kilns	Other	ESP	Mercury & compounds	0.000014	1.40E-05	D
Preheater kilns	Other	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Preheater kilns	Other	ESP	Particulate matter 10.0 um	0.1	1.00E-01	U
Preheater kilns	Other	ESP	Phenol	0.000055	5.50E-05	U
Preheater	Other	ESP	Selenium &	0.000075	7.50E-05	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns			compounds			
Preheater kilns	Other	ESP	Styrene	0.00000075	7.50E-07	U
Preheater kilns	Other	ESP	Toluene	0.0001	1.00E-04	U
Preheater kilns	Other	ESP	Total volatile organic compounds	0.074	7.40E-02	D
Preheater kilns	Other	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	U
Preheater kilns	Other	ESP	Zinc & compounds	0.00027	2.70E-04	U
Preheater kilns	Other	FF	Ammonia (total)	0.0051	5.10E-03	U
Preheater kilns	Other	FF	Arsenic & compounds	0.000006	6.00E-06	U
Preheater kilns	Other	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Preheater kilns	Other	FF	Cadmium & compounds	0.0000011	1.10E-06	E
Preheater kilns	Other	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Preheater kilns	Other	FF	Copper & compounds	0.0026	2.60E-03	U
Preheater kilns	Other	FF	Formaldehyde	0.00023	2.30E-04	U
Preheater kilns	Other	FF	Hydrochloric acid	0.073	7.30E-02	E
Preheater kilns	Other	FF	Lead & compounds	0.000038	3.80E-05	U
Preheater kilns	Other	FF	Mercury & compounds	0.000014	1.40E-05	D
Preheater kilns	Other	FF	Particulate matter 10.0 um	0.1	1.00E-01	U
Preheater kilns	Other	FF	Polychlorinated dioxins and furans	0.000000000017	1.70E-11	E
Preheater kilns	Other	FF	Polycyclic aromatic hydrocarbons	0.00000031	3.10E-07	D
Preheater kilns	Other	FF	Selenium & compounds	0.0001	1.00E-04	U
Preheater kilns	Other	FF	Total volatile organic compounds	0.074	7.40E-02	D
Preheater kilns	Other	FF	Zinc & compounds	0.00017	1.70E-04	U
Wet process kilns	Coal	ESP	Acetone	0.00019	1.90E-04	U
Wet process	Coal	ESP	Ammonia (total)	0.054	5.40E-02	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Wet process kilns	Coal	ESP	Arsenic & compounds	0.0000065	6.50E-06	U
Wet process kilns	Coal	ESP	Benzene	0.0016	1.60E-03	U
Wet process kilns	Coal	ESP	Biphenyl	0.0000031	3.10E-06	U
Wet process kilns	Coal	ESP	Cadmium & compounds	0.0000042	4.20E-06	U
Wet process kilns	Coal	ESP	Carbon disulfide	0.000055	5.50E-05	U
Wet process kilns	Coal	ESP	Carbon monoxide	0.4	4.00E-01	E
Wet process kilns	Coal	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Wet process kilns	Coal	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Wet process kilns	Coal	ESP	Dichloromethane	0.00025	2.50E-04	U
Wet process kilns	Coal	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Wet process kilns	Coal	ESP	Fluoride compounds	0.00045	4.50E-04	U
Wet process kilns	Coal	ESP	Hydrochloric acid	0.025	2.50E-02	U
Wet process kilns	Coal	ESP	Lead & compounds	0.00036	3.60E-04	U
Wet process kilns	Coal	ESP	Manganese & compounds	0.00043	4.30E-04	U
Wet process kilns	Coal	ESP	Mercury & compounds	0.00011	1.10E-04	U
Wet process kilns	Coal	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Wet process kilns	Coal	ESP	Oxides of nitrogen	6.9	6.90E+00	E
Wet process kilns	Coal	ESP	Particulate matter 10.0 um	0.3	3.00E-01	U
Wet process kilns	Coal	ESP	Phenol	0.000055	5.50E-05	U
Wet process kilns	Coal	ESP	Selenium & compounds	0.000075	7.50E-05	U
Wet process kilns	Coal	ESP	Styrene	0.00000075	7.50E-07	U
Wet process kilns	Coal	ESP	Sulfur dioxide	0.07	7.00E-02	E
Wet process	Coal	ESP	Toluene	0.0001	1.00E-04	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Wet process kilns	Coal	ESP	Total volatile organic compounds	0.0105	1.05E-02	E
Wet process kilns	Coal	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	U
Wet process kilns	Coal	ESP	Zinc & compounds	0.00027	2.70E-04	U
Wet process kilns	Coal	FF	Ammonia (total)	0.0051	5.10E-03	U
Wet process kilns	Coal	FF	Arsenic & compounds	0.000006	6.00E-06	U
Wet process kilns	Coal	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Wet process kilns	Coal	FF	Cadmium & compounds	0.0000011	1.10E-06	U
Wet process kilns	Coal	FF	Carbon monoxide	0.4	4.00E-01	U
Wet process kilns	Coal	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Wet process kilns	Coal	FF	Copper & compounds	0.0026	2.60E-03	U
Wet process kilns	Coal	FF	Formaldehyde	0.00023	2.30E-04	U
Wet process kilns	Coal	FF	Hydrochloric acid	0.073	7.30E-02	U
Wet process kilns	Coal	FF	Lead & compounds	0.000038	3.80E-05	U
Wet process kilns	Coal	FF	Mercury & compounds	0.000012	1.20E-05	U
Wet process kilns	Coal	FF	Oxides of nitrogen	6.9	6.90E+00	U
Wet process kilns	Coal	FF	Polychlorinated dioxins and furans	0.0000000015	1.50E-09	D
Wet process kilns	Coal	FF	Polycyclic aromatic hydrocarbons	0.0011	1.10E-03	U
Wet process kilns	Coal	FF	Selenium & compounds	0.0001	1.00E-04	U
Wet process kilns	Coal	FF	Sulfur dioxide	0.07	7.00E-02	U
Wet process kilns	Coal	FF	Total volatile organic compounds	0.000065	6.50E-05	E
Wet process kilns	Coal	FF	Zinc & compounds	0.00017	1.70E-04	U
Wet process kilns	Gas	ESP	Acetone	0.00019	1.90E-04	U
Wet process	Gas	ESP	Ammonia (total)	0.054	5.40E-02	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Wet process kilns	Gas	ESP	Arsenic & compounds	0.0000065	6.50E-06	U
Wet process kilns	Gas	ESP	Benzene	0.0016	1.60E-03	U
Wet process kilns	Gas	ESP	Biphenyl	0.0000031	3.10E-06	U
Wet process kilns	Gas	ESP	Cadmium & compounds	0.0000042	4.20E-06	U
Wet process kilns	Gas	ESP	Carbon disulfide	0.000055	5.50E-05	U
Wet process kilns	Gas	ESP	Carbon monoxide	0.3	3.00E-01	E
Wet process kilns	Gas	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Wet process kilns	Gas	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Wet process kilns	Gas	ESP	Dichloromethane	0.00025	2.50E-04	U
Wet process kilns	Gas	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Wet process kilns	Gas	ESP	Fluoride compounds	0.00045	4.50E-04	U
Wet process kilns	Gas	ESP	Hydrochloric acid	0.025	2.50E-02	U
Wet process kilns	Gas	ESP	Lead & compounds	0.00036	3.60E-04	U
Wet process kilns	Gas	ESP	Manganese & compounds	0.00043	4.30E-04	E
Wet process kilns	Gas	ESP	Mercury & compounds	0.00011	1.10E-04	U
Wet process kilns	Gas	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Wet process kilns	Gas	ESP	Oxides of nitrogen	8.2	8.20E+00	E
Wet process kilns	Gas	ESP	Particulate matter 10.0 um	0.13	1.30E-01	D
Wet process kilns	Gas	ESP	Phenol	0.000055	5.50E-05	U
Wet process kilns	Gas	ESP	Selenium & compounds	0.000075	7.50E-05	U
Wet process kilns	Gas	ESP	Styrene	0.00000075	7.50E-07	U
Wet process kilns	Gas	ESP	Sulfur dioxide	0.02	2.00E-02	E
Wet process	Gas	ESP	Toluene	0.0001	1.00E-04	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Wet process kilns	Gas	ESP	Total volatile organic compounds	0.0105	1.05E-02	E
Wet process kilns	Gas	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	U
Wet process kilns	Gas	ESP	Zinc & compounds	0.00027	2.70E-04	U
Wet process kilns	Gas	FF	Ammonia (total)	0.0051	5.10E-03	U
Wet process kilns	Gas	FF	Arsenic & compounds	0.000006	6.00E-06	U
Wet process kilns	Gas	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Wet process kilns	Gas	FF	Cadmium & compounds	0.0000011	1.10E-06	U
Wet process kilns	Gas	FF	Carbon monoxide	0.3	3.00E-01	U
Wet process kilns	Gas	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Wet process kilns	Gas	FF	Copper & compounds	0.0026	2.60E-03	U
Wet process kilns	Gas	FF	Formaldehyde	0.00023	2.30E-04	U
Wet process kilns	Gas	FF	Hydrochloric acid	0.073	7.30E-02	U
Wet process kilns	Gas	FF	Lead & compounds	0.000038	3.80E-05	U
Wet process kilns	Gas	FF	Mercury & compounds	0.000012	1.20E-05	U
Wet process kilns	Gas	FF	Oxides of nitrogen	8.2	8.20E+00	U
Wet process kilns	Gas	FF	Polychlorinated dioxins and furans	0.0000000015	1.50E-09	U
Wet process kilns	Gas	FF	Polycyclic aromatic hydrocarbons	0.0011	1.10E-03	U
Wet process kilns	Gas	FF	Selenium & compounds	0.0001	1.00E-04	U
Wet process kilns	Gas	FF	Sulfur dioxide	0.02	2.00E-02	U
Wet process kilns	Gas	FF	Total volatile organic compounds	0.000065	6.50E-05	E
Wet process kilns	Gas	FF	Zinc & compounds	0.00017	1.70E-04	U
Wet process kilns	Other	ESP	Acetone	0.00019	1.90E-04	U
Wet process	Other	ESP	Ammonia (total)	0.054	5.40E-02	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Wet process kilns	Other	ESP	Arsenic & compounds	0.0000065	6.50E-06	U
Wet process kilns	Other	ESP	Benzene	0.0016	1.60E-03	U
Wet process kilns	Other	ESP	Biphenyl	0.0000031	3.10E-06	U
Wet process kilns	Other	ESP	Cadmium & compounds	0.0000042	4.20E-06	U
Wet process kilns	Other	ESP	Carbon disulfide	0.000055	5.50E-05	U
Wet process kilns	Other	ESP	Chromium (III) & compounds	0.0000039	3.90E-06	U
Wet process kilns	Other	ESP	Di-(2 Ethylhexyl phthalate)	0.000048	4.80E-05	U
Wet process kilns	Other	ESP	Dichloromethane	0.00025	2.50E-04	U
Wet process kilns	Other	ESP	Ethylbenzene	0.0000095	9.50E-06	U
Wet process kilns	Other	ESP	Fluoride compounds	0.00045	4.50E-04	U
Wet process kilns	Other	ESP	Hydrochloric acid	0.025	2.50E-02	U
Wet process kilns	Other	ESP	Lead & compounds	0.00036	3.60E-04	U
Wet process kilns	Other	ESP	Manganese & compounds	0.00043	4.30E-04	E
Wet process kilns	Other	ESP	Mercury & compounds	0.00011	1.10E-04	E
Wet process kilns	Other	ESP	Methyl ethyl ketone	0.000015	1.50E-05	U
Wet process kilns	Other	ESP	Particulate matter 10.0 um	0.3	3.00E-01	U
Wet process kilns	Other	ESP	Phenol	0.000055	5.50E-05	U
Wet process kilns	Other	ESP	Selenium & compounds	0.000075	7.50E-05	U
Wet process kilns	Other	ESP	Styrene	0.00000075	7.50E-07	U
Wet process kilns	Other	ESP	Toluene	0.0001	1.00E-04	U
Wet process kilns	Other	ESP	Total volatile organic compounds	0.0105	1.05E-02	U
Wet process kilns	Other	ESP	Xylenes (individual or mixed isomers)	0.000065	6.50E-05	U
Wet process	Other	ESP	Zinc & compounds	0.00017	1.70E-04	U

Process	Fuel	Control	Substance	Emission factor	Emission factor scientific notation	Rating
kilns						
Wet process kilns	Other	FF	Ammonia (total)	0.0051	5.10E-03	U
Wet process kilns	Other	FF	Arsenic & compounds	0.000006	6.00E-06	U
Wet process kilns	Other	FF	Beryllium & compounds	0.00000033	3.30E-07	U
Wet process kilns	Other	FF	Cadmium & compounds	0.0000011	1.10E-06	U
Wet process kilns	Other	FF	Chromium (III) & compounds	0.00007	7.00E-05	U
Wet process kilns	Other	FF	Copper & compounds	0.0026	2.60E-03	U
Wet process kilns	Other	FF	Formaldehyde	0.00023	2.30E-04	U
Wet process kilns	Other	FF	Hydrochloric acid	0.073	7.30E-02	U
Wet process kilns	Other	FF	Lead & compounds	0.000038	3.80E-05	U
Wet process kilns	Other	FF	Mercury & compounds	0.000012	1.20E-05	U
Wet process kilns	Other	FF	Polychlorinated dioxins and furans	0.0000000015	1.50E-09	E
Wet process kilns	Other	FF	Polycyclic aromatic hydrocarbons	0.0011	1.10E-03	U
Wet process kilns	Other	FF	Selenium & compounds	0.0001	1.00E-04	U
Wet process kilns	Other	FF	Total volatile organic compounds	0.000065	6.50E-05	U
Wet process Kilns	Other	FF	Zinc & compounds	0.00017	1.70E-04	U

Source: Thomas & Bawden (2005).
Note: Emission factors in the above table were determined through measurements conducted at up to eight Australian cement facilities. Where measurement was conducted at three or less facilities, the rating is noted as U, or Unrated.