

Category		Title
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Coordinator

Jeroen Kuenen

Contributing authors (including to earlier versions of this chapter)

Jan Berdowski, Pieter van der Most, R. Wessels Boer, Otto Rentz, Dagmar Oertel, Jozef M. Pacyna, Martin Pierce, Carlo Trozzi, Tinus Pulles and Wilfred Appelman

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1 Overview

Cement manufacture is a major mineral commodity industry. During the manufacturing process natural raw materials are finely ground and then transformed into cement clinker in a kiln system at high temperatures. The clinkers are cooled and ground together with additions into a fine powder known as cement. Cement is a hydraulic binder, i.e. it hardens when mixed with water. Cement is used to bind sand and gravel together in concrete.

In 2006, 266 million tonnes of cement were produced in the EU-27 by 356 installations (European Commission, 2007). Large cement plants produce some 4 000 tonnes of cement per day.

Releases from the cement kiln system come from the physical and chemical reactions of the raw materials and the fuels. The main constituents of the exit gases are nitrogen and excess oxygen from the combustion air, and carbon dioxide and water from the raw materials and the combustion process.

The exit gases also contain small quantities of dust, sulphur dioxide, nitrogen oxides, carbon monoxide, chlorides, fluorides, ammonia, and still smaller quantities of organic compounds and heavy metals.

The cement industry, like other industrial activities, is strictly regulated via national and international legislation regarding environmental protection. Emission levels of pollutants are, therefore, to a large extent determined by the abatement technologies applied in order to comply with regulations.

In most countries, cement clinker production plants would probably be classified as ‘key category’ plants (see the general guidance chapter on methodological choice in Part A of the Guidebook for further information) as regards emissions of certain pollutants, and ‘non-key category’ plants with respect to other pollutants.

The combustion process in the cement kiln system is an integrated part of the production process, where the fuel-ash becomes part of the cement clinkers and the energy input is consumed to create the hydraulic clinker components. It is therefore not possible to distinguish the process and combustion emissions from one another. Because most of the pollutants will to a large extent originate from the fuels, all the emissions from the pyroprocessing will be addressed under source category 1.A.2.f Manufacturing Industries and Construction (Combustion) — Other. In this chapter, a tier 2 technology-specific emission factor table will be dedicated to emissions from combustion in the cement production process.

2 Description of sources

2.1 Process description

The production of cement involves broadly four stages:

- extraction and pre-processing of raw materials;
- pyroprocessing to produce clinker;
- blending and grinding of clinker to cement;
- storage, packing and delivery of cement.

2.1.1 Extraction and pre-processing of raw materials

The raw materials for cement production are a mixture of minerals containing calcium oxide, silicon oxide, aluminium oxide and ferrous oxide. The main raw materials, including limestone, chalk, marl and shale or clay, are extracted from quarries. In most cases, the quarry is close to the plant. After primary crushing, the raw materials are transported to the cement plant for storage and further preparation. Other raw materials, such as bauxite, iron ore, blast furnace slag, sand or recycled material, are brought in from elsewhere.

Some 1.57 tonnes of raw materials are required to produce one tonne of cement clinker.

The raw materials, in controlled proportions, are ground and mixed together to form a homogeneous blend with tight specifications regarding fineness and chemical composition.

2.1.2 Pyroprocessing to produce clinker

This part of the production process is the most important in terms of energy input, emission potential, product quality and cost.

The production of clinker takes place in a kiln system in which the minerals of the raw mix are transformed at high temperatures into new minerals with hydraulic properties. The fine particles of the raw mix move from the cool end to the hot end of the kiln system and the combustion gases move the other way from the hot end to the cold end. This results in an efficient transfer of heat and energy to the raw mix and an efficient removal of pollutants and ash from the combustion process. During the passage of the kiln system the raw mix is dried, pre-heated, calcined and sintered to clinker, which is rapidly cooled with air and stored.

The basic chemistry of the cement manufacturing process begins with decomposition of calcium carbonate at about 900 °C to leave calcium oxide (CaO) and liberated gaseous carbon dioxide (CO₂); this process is known as calcination. This is followed by the clinkering process in which the calcium oxide reacts at a high temperature (typically 1 400–1 500 °C) with silica, alumina, and ferrous oxide to form the silicates, aluminates and ferrites of calcium that constitute the clinker. The clinker is then rapidly cooled.

The cement industry is highly energy intensive. The theoretical thermal energy demand for the chemical/mineralogical reactions of clinker production (not including drying and preheating) is about 1 700 MJ/tonne clinker. The actual thermal energy demand for different kiln systems and sizes is approximately 3 500–5 000 MJ/tonne clinker (European Commission, 2007).

Various fuels can be used to provide the heat and energy required for the process. The main fossil fuels used in Europe are coal and petroleum coke. Costs normally preclude the use of gas or oil. However, the high temperatures and long residence time in the kiln system imply considerable potential for the destruction of organic substances. This makes the use of different types of waste and biomass possible, and the use of such less expensive options has increased during the past 15 years.

The main ash constituents of fuels are silica, alumina and metal compounds. These combine with the raw materials to become part of the clinker.

2.1.3 Blending and grinding of cement clinker

Portland cement is produced by inter-grinding cement clinker and sulphates such as gypsum and anhydrite. Sulphates are required to achieve the desired setting properties of the cement. In

blended cements (composite cements) there are other constituents, such as granulated blast furnace slag, natural or artificial pozzolanas, limestone, or inert fillers. These will be inter-ground with the clinker or may need to be dried and ground separately.

2.1.4 Storage, packing and delivery of cement

Cement is stored in silos. Different cements are stored separately. Cement is transferred from the silos either directly into bulk road, rail or ship tankers, or to a bagging station.

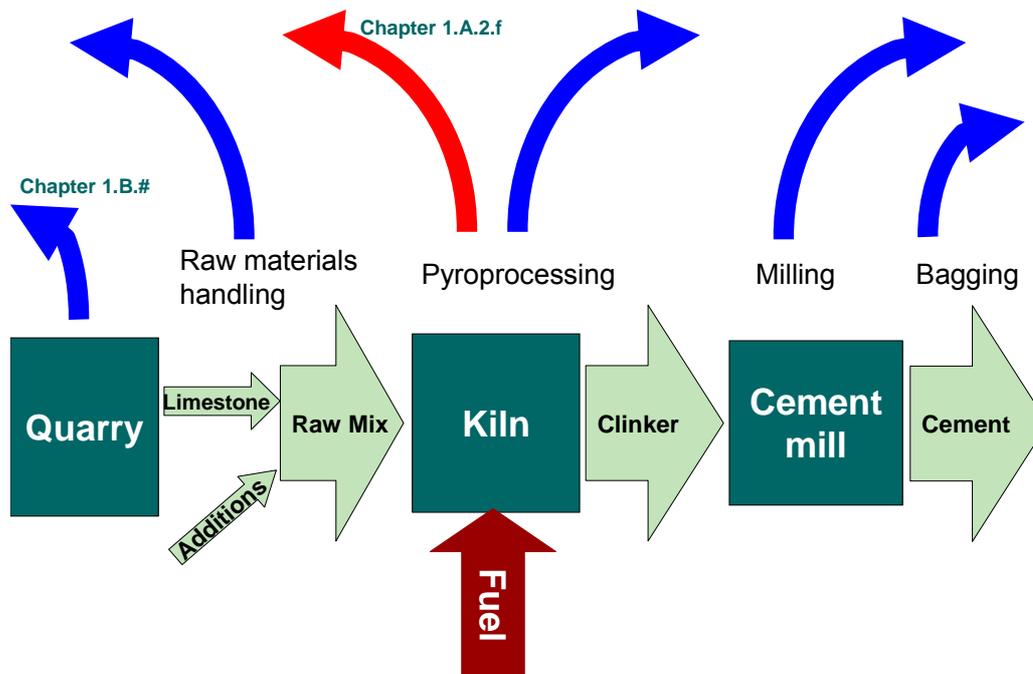


Figure 2.1 Production of cement. Combustion emissions are indicated in red, process emissions are indicated in blue. Emissions from quarrying are addressed in chapter 1.B.1.a and those of combustion in chapter 1.A.2.f

2.2 Techniques

There are four main process routes for the manufacture of cement —dry, semi-dry, wet and semi-wet processes.

- In the dry process the raw materials are ground and dried to raw meal in the form of a flowable powder. The dry raw meal is fed to the preheater or precalciner kiln, or more rarely to a long dry kiln.
- In the semi-dry process, dry raw meal is pelletized with water and fed into a grate preheater in front of the kiln or into a long kiln equipped with crosses.
- In the wet process, the raw materials (often with high moisture content) are ground in water to form a pumpable slurry. The slurry is either fed directly into the kiln or first to a slurry dryer.
- In the semi-wet process, the slurry is first dewatered in filter presses. The filter cake is either extruded into pellets and fed to a grate preheater or fed directly to a filter cake dryer for raw meal production.

The choice of process is, to a large extent, determined by the state of the raw materials (dry or wet). Wet processes consume more energy and are thus more expensive.

The hot clinker nodules must be rapidly cooled in order to preserve their hydraulic properties. Clinker coolers are therefore part of the kiln system and placed directly after the hot end of the kiln. The clinkers are cooled by ambient air which is then used in the kiln as combustion air. Part of the hot air may also be used for drying solid fuels and raw materials or vented to the atmosphere.

Grinding of raw materials, fuels and cement are most often carried in large ball mills but roller mills, roller presses and impact mills are also used.

2.3 Emissions

The main emissions from the production of cement are emissions to air from the kiln system. Releases come from the physical and chemical reactions of the raw materials and the fuels. The main constituents of the exit gases are nitrogen and excess oxygen from the combustion air and carbon dioxide and water from the raw materials and the combustion process which is an integrated part of the process. The exit gas also contains small quantities of air pollutant. The following pollutants have been listed in the Best Available Techniques Reference (BREF) document on the issue (European Commission, 2007):

- oxides of nitrogen (NO_x);
- sulphur dioxide (SO₂) and other sulphur compounds;
- dust;
- volatile organic compounds (VOC);
- polychlorinated dibenzodioxins and dibenzofurans (PCDDs and PCDFs);
- metals and their compounds;
- hydrogen fluoride (HF);
- hydrogen chloride (HCl);
- carbon monoxide (CO);
- ammonia (NH₃).

The present chapter only considers emissions of particulate matter from cement plants, which mainly originate from pre- and after-treatment. Emissions from the kiln are a combination of combustion and process emissions but the emissions of the main pollutants — NO_x, sulphur oxides (SO_x), CO, non-methane volatile organic compounds (NMVOC), and NH₃ — as well as heavy metals and persistent organic pollutants (POPs) are assumed to originate mainly from the combustion of the fuel. These emissions are therefore treated in chapter 1.A.2.f, which addresses combustion in cement production. This does not mean that these pollutants are not emitted in the process but since it is not possible to split the process and combustion emissions from cement production, it has been decided to treat these pollutants in the combustion chapter.

In all kiln systems, the solid material is mixed with hot combustion gases. This mixing affects the emission of pollutants, since it acts as a built-in dry scrubber in which the pollutants are absorbed by or condensed on the fine raw material flowing counter.

NO_x are formed in the combustion process either by oxidation of the nitrogen in the combustion air (thermal NO_x), or by oxidation of the nitrogen compounds in the fuel (fuel NO_x). Thermal NO_x form at temperatures above 1200°C. Due to the very high temperatures in the cement kiln thermal NO_x dominate. Nitrogen monoxide accounts for about 95 % and nitrogen dioxide for about 5 %.

SO₂ emissions from cement plants are primarily determined by the content of volatile sulphur in the raw materials. This sulphur is emitted as SO₂ from the low temperature end of the kiln system. Sulphur present as sulphates in the raw materials is only partly decomposed at high temperatures and almost completely discharged from the kiln system with the clinker. Sulphur introduced into the kiln with the fuels is oxidised to SO₂ and will not lead to significant SO₂ emissions as SO₂ formed at the hot end of the kiln system reacts with the reactive, fine raw materials in the sintering zone, the precalciner and the hot part of the preheater.

Dust (including particulate matter) emissions have traditionally been one of the main environmental concerns in relation to cement manufacture. Today, however dust emissions are reduced and controlled by very efficient filters. The main sources of dust are the stacks of the kiln system. In addition some channelled dust emissions occur in connection with the various grinding processes (raw materials, fuels, cement), and diffuse dust emission may arise from storage and handling of raw materials, fuels, clinker and cement, as well as from vehicle traffic used at the manufacturing site.

Chlorides and fluorides may enter into the kiln system with the raw materials and/or the fuels. The greater part is captured by the fine raw material particles and is discharged from the kiln system with the clinker. Small quantities leave the kiln system adsorbed on dust particles.

Emissions of VOC, CO and NH₃ can occur in the primary steps of the kiln process (preheater, precalciner), when impurities (such as organic matter) that are present in the raw materials are volatilised as the raw mix is heated.

PCDDs and PCDFs can result from a combination of formation mechanisms, depending on kiln and process design, combustion conditions, raw materials and the type and operation of emission control equipment. In Europe, cement production is rarely a significant source of PCCD or PCDF emissions, even when wastes and hazardous wastes are used as fuel, due to the high temperatures of combustion in the kiln.

Metals introduced into the kiln through the raw materials or the fuel will be present in either the releases or in the clinker. The vast majority of heavy metals are retained in the clinker. Extremely volatile metals such as mercury and thallium are not incorporated into the clinker to the same degree as other metals. At the high temperatures many heavy metals evaporate and then condense on the clinker, on partly reacted raw materials or dust particles.

2.4 Controls

The cement industry, like other industrial activities, is strictly regulated via national and international legislation regarding environmental protection. Emission levels of pollutants are, therefore, to a large extent determined by the abatement technologies applied (e.g. dust filtration) in order to comply with regulations.

The various emission reduction technologies used in the cement industry have been described in detail in the BREF document (European Commission, 2007).

3 Methods

3.1 Choice of method

Figure 3.1 presents the procedure for estimating process emissions from the cement industry. The basic procedure is as follows:

- If the detailed information is available such that higher tiered methods can be employed: use it.
- A Tier 1 method may only be used if cement production is not a key category. This method is based on default emission factors and national production quantities.
- If the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is easier to obtain the necessary input data for this approach than to collect facility level data needed for a Tier 3 estimate. The Tier 2 method is based on technology-specific national emission factors and quality specific national production statistics.
- The alternative of applying a Tier 3 method, using detailed process modelling is not explicitly included in this decision tree. However, detailed modelling will always be done at facility level and results of such modelling could be seen as ‘facility data’ in the decision tree.

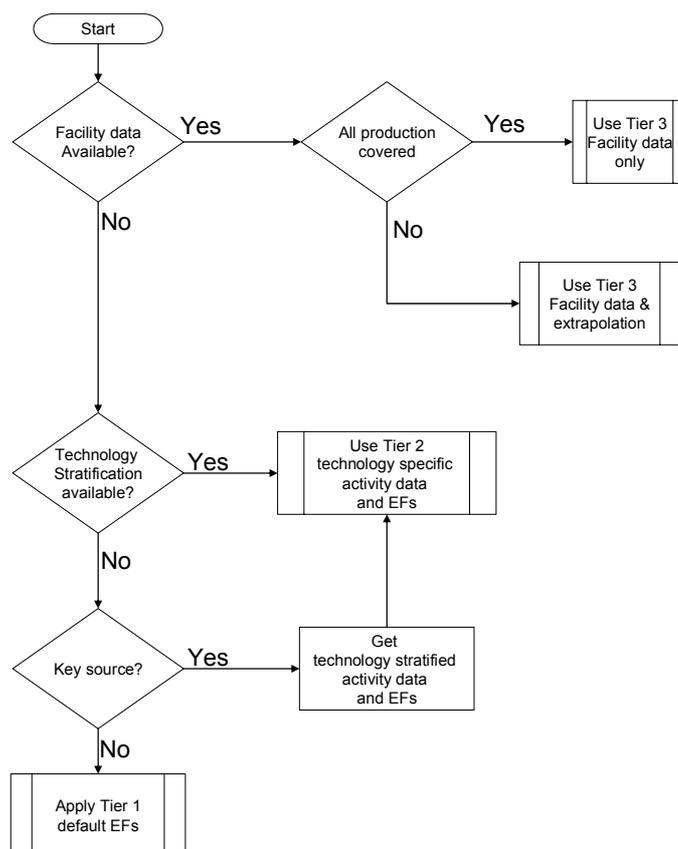


Figure 3.1 Decision tree for source category 2.A.1 Cement production

Cement clinker production plants may not be considered to be a key category as regards certain pollutants, whereas they may be considered to be a key category for other pollutants. Also some countries require emissions of certain pollutants from individual facilities to be reported to national registers. So, all three tiers would probably have to be used in most countries to estimate the emissions of the various pollutants from the cement industry.

Cement production includes emissions from combustion of fuels as well as processing the raw meal. All emissions originating from combustion are treated in the chapter 1.A.2.f. However, this does not necessarily mean that those emissions originate only from combustion of fuels. For instance, emitted heavy metals and sulphur dioxide may also originate from the raw meal.

Since we expect the majority of these emissions to originate from the fuel rather than from the raw meal, all emissions except for particulate matter are addressed in chapter 1.A.2.f.

3.2 Tier 1 default approach

3.2.1 Algorithm

The Tier 1 approach for process emissions from cement uses the general equation

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \quad (1)$$

where:

- $E_{pollutant}$ is the emission of a pollutant (kg)
- $AR_{production}$ is the annual production of cement (in Mg)
- $EF_{pollutant}$ is the emission factor of the relevant pollutant (in kg pollutant / Mg cement produced)

This equation is applied at the national level, using annual national total cement production data. Information on the production of cement, suitable for estimating emissions using the simpler estimation methodology (Tiers 1 and 2), is widely available from United Nations statistical yearbooks or national statistics.

The Tier 1 emission factors assume an ‘averaged’ or typical technology and abatement implementation in the country and integrate all different sub-processes in the cement production between feeding the raw material into the process and the final shipment off the facilities.

In cases where specific abatement options are to be taken into account a Tier 1 method is not applicable and a Tier 2 or Tier 3 approach must be used.

3.2.2 Default emission factors

The Tier 1 approach needs emission factors for all relevant pollutants that integrate all sub-processes within the industry from inputting raw materials to the final shipment of the products off site.

The default emission factors for cement production are provided in Table 3.1. The emission factors are rounded figures calculated as the average of the ranges of emissions shown in Table 1.24 of the revised BREF document (European Commission, 2007). The BREF ranges are interpreted as the 95 % confidence interval, while the geometric mean of this range is chosen as

the value for the emission factor in the table below. This ‘average of the ranges’ is used as these may well represent the situation in an industry where there are no national emission limit values and no reported plant-specific emissions for certain pollutants (in which case Tiers 1 or 2 have to be used).

The mass figures presented in the emission factor table are based on an average 2 000 m³/ton clinker and 1 million tonnes of clinker per year. The IPPC BREF document (European Commission, 2001) reports a specific heat demand for clinker production of approximately 3 500 to 5 000 MJ/tonne clinker, depending on fuel type and kiln operation (wet or dry). The emissions due to the combustion of these fuels are covered in chapter 1.A.2.f.

Table 3.1 Tier 1 emission factors for source category 2.A.1 Cement production

Tier 1 default emission factors					
NFR Source Category	2.A.1	Name		Cement production	
Fuel	NA				
Not applicable	NH ₃ , Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, PCP, SCCP				
Not estimated	NO _x , CO, NMVOC, SO _x , Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, Total 4 PAHs, HCB				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
TSP	220	g/Mg cement produced	110	440	European Commission (2007)
PM ₁₀	200	g/Mg cement produced	100	400	European Commission (2007)
PM _{2.5}	110	g/Mg cement produced	55	220	European Commission (2007)

Emission factors in the table above are provided for particulate fractions only and include the additional emissions resulting from the handling and processing of the product and raw materials. Particulate matter (PM) emissions from the combustion processes are included in chapter 1.A.2.f. For Tier 1 the emissions of NO_x, CO, NMVOC, SO_x, heavy metals and POPs can be assumed to be mainly due to the combustion of the solid and waste fuels and will be included in the emission factors in chapter 1.A.2.f. To avoid double counting, it is good practice to estimate these emissions in chapter 1.A.2.f. In the Tier 1 approach they will, as far as they originate from the chemical composition of the raw meal, be reported as ‘not estimated’ (NE).

3.2.3 Activity data

Information on the production of cement, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), should be a basic nationally available statistic. It is good practice to collect these data from the national statistical agency, but it is also widely available from United Nations statistical yearbooks or from CEMBUREAU (www.cembureau.eu).

Since emission factors are expressed per mass of clinker produced, activity statistics must be recalculated from cement to clinker production statistics. Most cement produced is Portland cement, which has an average clinker content of 90–97 % (IPCC, 2006).

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 ‘Choice of activity statistics’ (IPCC, 2006). The IPCC 2006 Guidelines require collection of production data for different types of cement and on the clinker content of these cement types. For the emissions of CO₂, this is probably more important than for the emissions of air pollutants. Nevertheless, if these data are available for the reporting of greenhouse gases, it is good practice to also use this

data for the estimation of air pollutant emissions. The IPCC 2006 Guidelines provide default clinker fractions for different types of cement in table 2.2 in Chapter 2 of Volume 3.

3.3 Tier 2 technology-specific approach

3.3.1 Algorithm

The Tier 2 approach is similar to the Tier 1 approach. To apply the Tier 2 approach, both the activity data and the emission factors need to be stratified according to the different techniques that may occur in the country. These techniques may include:

- different end products with different clinker contents;
- wet or dry milling processes;
- dust capture;
- any other emission abatement technologies implemented in the country.

The approach followed to apply a Tier 2 approach is as follows. First, stratify the cement production in the country to model the different product and process types occurring in the national cement industry into the inventory by:

- defining production using each of the separate product and/or process types (together called ‘technologies’ in the formulae below) separately; and
- applying technology-specific emission factors for each process type:

$$E_{\text{pollutant}} = \sum_{\text{technologies}} AR_{\text{production,technology}} \times EF_{\text{technology,pollutant}} \quad (2)$$

where:

$AR_{\text{production,technology}}$ = the production rate within the source category, using this specific technology

$EF_{\text{technology,pollutant}}$ = the emission factor for this technology and this pollutant

A country where only one technology is implemented is a special case where the algorithm in equation (2) reduces to:

$$E_{\text{pollutant}} = AR_{\text{production}} \times EF_{\text{technology,pollutant}} \quad (3)$$

where:

$E_{\text{pollutant}}$ = the emission of the specified pollutant

$AR_{\text{production}}$ = the activity rate for the cement production

$EF_{\text{pollutant}}$ = the emission factor for this pollutant

The emission factors in this approach still will include all sub-processes within the industry between the feeding of raw materials until the produced cement is shipped to the customers.

3.3.2 Technology-specific emission factors

Applying a Tier 2 approach for the process emissions from cement production, technology-specific emission factors are needed. These are provided in the present subsection. A BREF document for this industry is available at <http://eippcb.jrc.es/pages/FActivities.htm>. In subsection 4.3.1 of the present document emission factors derived from the emissions associated with the use of Best Available Techniques (BAT) are provided for comparison.

The present subsection provides a series of technology specific process emission factors for cement production, both the wet and dry kiln process. These factors are applicable to Eastern Europe, Caucasus and Central Asia (EECCA) countries.

3.3.2.1 Wet kiln process

Table 3.2 gives the emission factors for the wet kiln process for EECCA countries. No other data are available.

Table 3.2 Tier 2 emission factors for source category 2.A.1 Cement production, wet process kiln

Tier 2 emission factors					
	Code	Name			
NFR Source Category	2.A.1	Cement production			
Fuel	NA				
SNAP (if applicable)	040612	Cement (decarbonizing)			
Technologies/Practices	Wet kiln process				
Region or regional conditions	EECCA countries				
Abatement technologies	ESP2, 98.9% efficiency				
Not applicable	NH3, Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, PCP, SCCP				
Not estimated	NOx, CO, NMVOC, SOx, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, Total 4 PAHs, HCB				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
TSP	0.6	kg/Mg cement produced	0.4	0.9	Kakareka (2008)
PM10	0.51	kg/Mg cement produced	0.34	0.77	Kakareka (2008)
PM2.5	0.18	kg/Mg cement produced	0.12	0.27	Kakareka (2008)

3.3.2.2 Dry kiln process

In the dry kiln process the raw meal is fed into the kiln dry. The main reason for this is energy efficiency. Typically the dry process uses 30–40 % less energy compared to the wet process. The feeding of dry material into the kiln will, however, typically result in higher emissions of dust as compared to the wet kiln process.

The Tier 2 emission factors for the dry kiln process in Table 3.3 are again for EECCA countries, no other data are available.

Table 3.3 Tier 2 emission factors for source category 2.A.1 Cement production, dry process kiln

Tier 2 emission factors					
	Code	Name			
NFR Source Category	2.A.1	Cement production			
Fuel	NA				
SNAP (if applicable)	040612	Cement (decarbonizing)			
Technologies/Practices	Dry kiln process				
Region or regional conditions	EECCA countries				
Abatement technologies	ESP2, 99.5% efficiency				
Not applicable	NH ₃ , Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, PCP, SCCP				
Not estimated	NO _x , CO, NMVOC, SO _x , Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, Total 4 PAHs, HCB				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
TSP	2.5	kg/Mg cement produced	1.7	3.8	Kakareka (2008)
PM10	1.3	kg/Mg cement produced	0.8	1.9	Kakareka (2008)
PM2.5	0.94	kg/Mg cement produced	0.6	1.4	Kakareka (2008)

3.3.3 Abatement

A number of add on technologies exist that are aimed at reducing the emissions of specific pollutants. The resulting emission can be calculated by replacing the technology-specific emission factor with an abated emission factor as given in the formula:

$$EF_{technology,abated} = (1 - \eta_{abatement}) \times EF_{technology,unabated} \quad (4)$$

The present subsection sets out default abatement efficiencies for abatement options, applicable in the cement industry.

3.3.3.1 Dust capture

The abatement efficiencies given in Table 3.4 below are based on the Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP) (Visschedijk *et al.*, 2004) and calculated with respect to an older plant, with only an electrostatic precipitator (ESP) in the main stack and limited control of fugitive sources.

Table 3.4 Abatement efficiencies ($\eta_{abatement}$) for source category 2.A.1 Cement production

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.A.1	Cement production			
Fuel	NA				
SNAP (if applicable)	040612	Cement (decarbonizing)			
Abatement technology	Pollutant	Efficiency	95% confidence interval		Reference
		Default Value	Lower	Upper	
ESP on main stack and smaller fabric filters for moderate control of fugitive sources	particle > 10 μ m	93%	62%	100%	Visschedijk et al. (2004)
	10 μ m > particle > 2.5 μ m	34%	23%	51%	Visschedijk et al. (2004)
	2.5 μ m > particle	40%	27%	60%	Visschedijk et al. (2004)
Additional fabric filters on the oven stack; effective control of fugitive sources	particle > 10 μ m	98%	66%	100%	Visschedijk et al. (2004)
	10 μ m > particle > 2.5 μ m	80%	53%	100%	Visschedijk et al. (2004)
	2.5 μ m > particle	73%	49%	100%	Visschedijk et al. (2004)

3.3.4 Activity data

Information on the production of cement, suitable for estimating emissions using the simpler estimation methodology (Tiers 1 and 2), is widely available from United Nations statistical yearbooks or national statistics, or from CEMBUREAU (www.cembureau.eu).

For a Tier 2 approach these data need to be stratified according to the technologies and abatement applied. Typical sources for these data might be industrial branch organisations within the country or specific questionnaires submitted to individual cement works.

Since emission factors are expressed per mass of clinker produced, activity statistics must be recalculated from cement to clinker production statistics. Most cement produced is Portland cement, which has an average clinker content of 90–97 % (IPCC, 2006).

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 ‘Choice of activity statistics’ (IPCC, 2006).

3.4 Tier 3 emission modelling and use of facility data

3.4.1 Algorithm

There are two different methods to apply emission estimation methods that go beyond the technology specific approach described above:

- detailed modelling of the cement production process;
- facility-level emission reports.

3.4.1.1 Detailed process modelling

A Tier 3 emission estimate, using process details will make separate estimates for the consecutive steps in the cement production process:

- handling raw materials;
- pyroelectric processing;
- final steps to produce the products as they leave the facility (‘bagging’).

3.4.1.2 Facility-level data

Where facility-level emissions data of sufficient quality (see the guidance chapter on inventory management and data collection in Part A of the Guidebook) are available, it is good practice to use these data. There are two possibilities:

- facility reports cover all cement production in the country;
- facility-level emission reports are not available for all cement plants in the country.

If facility level data cover all cement production in the country, it is good practice to compare the implied emission factors (reported emissions divided by the national cement production) with the default emission factor values or technology-specific emission factors. If the implied emission factors are outside the 95 % confidence intervals for the values given below, it is good practice to explain the reasons for this in the inventory report

If the total annual cement production in the country is not included in the total of the facility reports, it is good practice to estimate the missing part of the national total emissions from the source category, using extrapolation by applying:

$$E_{Total, pollutant} = \sum_{Facilities} E_{Facility, pollutant} + \left(National\ Production - \sum_{Facilities} Production_{Facility} \right) \times EF \quad (5)$$

Depending on the specific national circumstances and the coverage of the facility-level reports as compared to the total national cement production, it is good practice to choose the emission factor (EF) in this equation from the following possibilities, in decreasing order of preference:

- technology-specific emission factors, based on knowledge of the types of technologies implemented at the facilities where facility-level emission reports are not available;
- the implied emission factor derived from the available emission reports:

$$EF = \frac{\sum_{Facilities} E_{Facility, pollutant}}{\sum_{Facilities} Production_{Facility}} \quad (6)$$

- the default Tier 1 emission factor. This option should only be chosen if the facility-level emission reports cover more than 90 % of the total national production.

3.4.2 Tier 3 emission modelling and use of facility data

Cement kilns are major industrial facilities and emissions data for individual plants might be available through a pollutant release and transfer registry (PRTR) or another emission reporting scheme. When the quality of such data is assured by a well developed QA/QC system and the emission reports have been verified by an independent auditing scheme, it is good practice to use such data. If extrapolation is needed to cover all cement production in the country either the implied emission factors for the facilities that did report, or the emission factors as provided above could be used (see subsection 3.3.2 above).

Emission levels of pollutants from cement plants are to a large extent determined by the abatement technologies applied in order to comply with regulations. National emission factors may therefore be calculated from national emission limit values, providing a reasonable estimate for the country's specific emission factor.

National emission limit values (ELVs) exist for several pollutants in most countries. Normally, such ELVs apply to all cement plants, independent of the technology used and the type of final products. As the emissions from cement production originate almost entirely from the kiln system during clinker production, the ELVs may be related to the exit gases from the kiln system.

Emission factors related to clinker production may be calculated as follows:

$$EF_{pollutant, clinker} = ELV_{pollutant} \times EG_{clinker} \quad (7)$$

where :

$EF_{pollutant, clinker}$ = clinker-related emission factor of pollutant (mg pollutant/tonne clinker)

$ELV_{pollutant}$ = national emission limit value of pollutant (mg/Nm³ exit gas)

$EG_{clinker}$ = volume of exit gas (Nm³/tonne clinker)

Emission factors related to various types of cement may be calculated as follows:

$$EF_{\text{pollutant, cement, type}} = ELV_{\text{pollutant, clinker}} \times CF \quad (8)$$

where:

$EF_{\text{pollutant, cement type}}$ = emission factor specific for cement type (mg pollutant/tonne cement)

$EF_{\text{pollutant clinker}}$ = clinker related emission factor of pollutant (mg pollutant/tonne clinker)

CF = clinker factor (tonnes clinker/tonne cement)

If cement production cannot be disaggregated by cement type and it is expected that significant amounts of blended cement are being produced in addition to ordinary cement, it is acceptable to assume an overall clinker factor of 0.75. If cement production is known to be essentially all ordinary cement, an overall clinker factor of 0.95 may be used, as suggested in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

If national emission limit values are not available for certain pollutants and national emission factors for the various cement types can not be found by other means, the default emission factors presented in Table 3.1 may be used as the clinker related emission factor ($EF_{\text{pollutant, clinker}}$).

3.4.3 Activity data

Since PRTR generally do not report activity data, such data in relation to the reported facility-level emissions are sometimes difficult to find. A possible source of facility-level activity might be the registries of emission trading systems.

For projection purposes, plant-specific emission factors would be required. These could be calculated from recent reported plant emissions divided by recent information on total cement production.

Should annual emissions not be available for certain plants calculations may be performed based on ELVs included in their operating permit. Calculations may be carried out in a similar way as described in subsection 3.3.2 above.

In many countries national statistics offices collect production data at the facility level but these are in many cases confidential. However in several countries, national statistics offices are part of the national emission inventory systems and the extrapolation, if needed, could be performed at the statistics office, ensuring that confidentiality of production data is maintained.

4 Data quality

Cement production is a process in which the hot flue gases from a combustion process are directly injected into the reactor where the chemistry and physics take place. This means that splitting the emissions between combustion and non-combustion is not always simple. If such a split is indeed difficult to obtain, emissions could be reported under the present source category (2.A.1) or under source category 1.A.2.f.

4.1 Completeness

In cases where attempts are made to indeed split the emissions from cement manufacturing between combustion emissions and non-emission combustions, care must be taken to include all emissions.

It is good practice to check whether the emissions reported as 'included elsewhere' (IE) under source category 2.A.1 are indeed included in the emissions reported under combustion under source category 1.A.2.f.

4.2 Avoiding double counting with other sectors

In cases where it is possible to split these emissions, it is good practice to do so. However, care must be taken that the emissions are not double counted.

It is good practice to check that the emissions reported under source category 2.A.1 are not included in the emissions reported under source category 1.A.2.f.

4.3 Verification

Figures based on Tiers 1 and 2 may be checked against data available in pollutant release and transfer registers e.g. E-PRTR.

National emission figures based on the Tier 3 method could be checked against default emission factors described in Table 3.1 and against data reported under E-PRTR.

4.3.1 Best Available Technique emission factors

The revised BREF document for the cement and lime industry (European Commission, 2007) describes the techniques and associated emission levels when using Best Available Techniques. The BAT associated emission levels are listed in Table 4.1. More information is available in the BREF document.

Table 4.1 BAT associated emission factors for source category 2.A.1 Cement production

	Code	Name		
NFR Source Category	2.A.1	Cement production		
Fuel	NA	not applicable		
Pollutant	Value	Unit	95% confidence interval	
			Lower	Upper
NOx	300	mg/Nm ³	200	500
SOx	300	mg/Nm ³	200	400
TSP	25	mg/Nm ³	20	30

The factors in Table 4.1 are expressed related to the gas flow. These can be recalculated in terms of mass per mass of cement produced or energy used. To compare the emission factors, knowledge about the gas flow per tonne of cement produced is required. The following average conversion factors may be used:

- 2000 m³/tonne clinker;
- 90 % default clinker content of cement.

For specific information on these conversion factors, please refer to the BREF document for the cement and lime industry (European Commission, 2007).

4.4 Developing a consistent time series and recalculation

No specific issues for Tier 1 and 2.

For Tier 3 using facility-level data, it might occur that a different selection of facility level data is included in different years. This can lead to time series inconsistencies. Moreover, PRTR data generally are available for specific years only. Splicing such recent reported data under EPRTR/EPER with historical data could be used to get consistent time series. Splicing could be used for both the activity data and the country-specific emission factors.

Unexpected discontinuities in time series can occur when specific cement works come into operation or are closed in specific years. If this happens, it is good practice to document such explanations clearly in the inventory archives.

4.5 Uncertainty assessment

It is rather difficult to assess current uncertainties of emission estimates for pollutants emitted during the cement production. The uncertainties of sulphur dioxide emission estimates can be assessed in a similar way as the uncertainties of the estimates for the fossil fuel combustion (see chapter 1.A.2.f).

It has been concluded that up to 50 % of uncertainties may be assigned to the emission estimates of most of the trace elements emitted from major point sources in Europe (Pacyna, 1994). Similar uncertainty can be assigned for emission estimates of these compounds from cement production.

4.5.1 Emission factor uncertainties

No specific issues.

4.5.2 Activity data uncertainties

No specific issues.

4.6 Inventory quality assurance/quality control (QA/QC)

Emissions from cement production as discussed in the present chapter only include the emissions due to causes other than combustion of fuels. Emissions from fuel combustion are to be reported under source category 1.A.2.f in the combustion sector. It is good practice to check whether the cement production data used in the present chapter are consistent with the associated fuel use as reported in the combustion sector. As indicated above (in subsection 2.1) the energy required to produce clinker is 3.5–5 GJ/tonne. However, because of heat loss during production, actual values can be much higher.

4.7 Gridding

It is good practice to consider cement production plants as point sources if plant-specific data are available. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

4.8 Reporting and documentation

No specific issues.

5 Glossary

ESP	Electrostatic precipitator: dust emissions abatement equipment
FF	Fabric filters: dust emissions abatement equipment
combustion process with contact	<p>A process in which the hot flue gases from a combustion process are directly injected into the reactor where the chemistry and physics take place converting the raw materials into the product. Examples are:</p> <ul style="list-style-type: none"> • primary iron and steel • cement • lime

6 References

European Commission, 2001. *Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries, December 2001.*

European Commission, 2007. *Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries.* Draft September 2007. Available at <http://eippcb.jrc.es>. [Accessed 5 August 2009]

IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds), National Greenhouse Gas Inventories Programme. IGES, Japan.

Kakareka, 2008. *Personal communication.* Institute for problems of use of natural resources and ecology, Belarusian National Academy of Sciences, Minsk.

Visschedijk, A.J.H., Pacyna, J., Pulles, T., Zandveld, P. and Denier van der Gon, H., 2004. 'Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP)'. In: Dilara, P. et al (eds), *Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004.* EUR 21302 EN, JRC, pp. 163–174.

7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on combustion and industry. Please refer to the TFEIP website (www.tfeip-secretariat.org) for the contact details of the current expert panel leaders.