

BS EN 19694-3:2016



BSI Standards Publication

# Stationary source emissions — Determination of greenhouse gas (GHG) emissions in energy- intensive industries

Part 3: Cement industry

**National foreword**

This British Standard is the UK implementation of EN 19694-3:2016.

The UK participation in its preparation was entrusted to Technical Committee EH/2/1, Stationary source emission.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ISBN 978 0 580 87114 6

ICS 13.040.40

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 July 2016.

**Amendments issued since publication**

Date	Text affected
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EUROPEAN STANDARD

**EN 19694-3**

NORME EUROPÉENNE

EUROPÄISCHE NORM

July 2016

ICS 13.040.40

English Version

## Stationary source emissions - Determination of greenhouse gas (GHG) emissions in energy-intensive industries - Part 3: Cement industry

Émissions de sources fixes - Détermination des  
émissions de gaz à effet de serre (GES) dans les  
industries énérgo-intensives - Partie 3: Industrie du  
ciment

Emissionen aus stationären Quellen - Bestimmung von  
Treibhausgasen (THG) aus energieintensiven  
Industrien - Teil 3: Zementindustrie

This European Standard was approved by CEN on 5 May 2016.

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## European foreword

This document (EN 19694-3:2016) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2017, and conflicting national standards shall be withdrawn at the latest by January 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate M/478 given to CEN by the European Commission and the European Free Trade Association.

EN 19694, *Stationary source emissions — Determination of greenhouse gas (GHG) emissions in energy-intensive industries* is a series of standards that consists of the following parts:

- *Part 1: General aspects*
- *Part 2: Iron and steel industry*
- *Part 3: Cement industry*
- *Part 4: Aluminium industry*
- *Part 5: Lime industry*
- *Part 6: Ferroalloy industry*

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

## Introduction

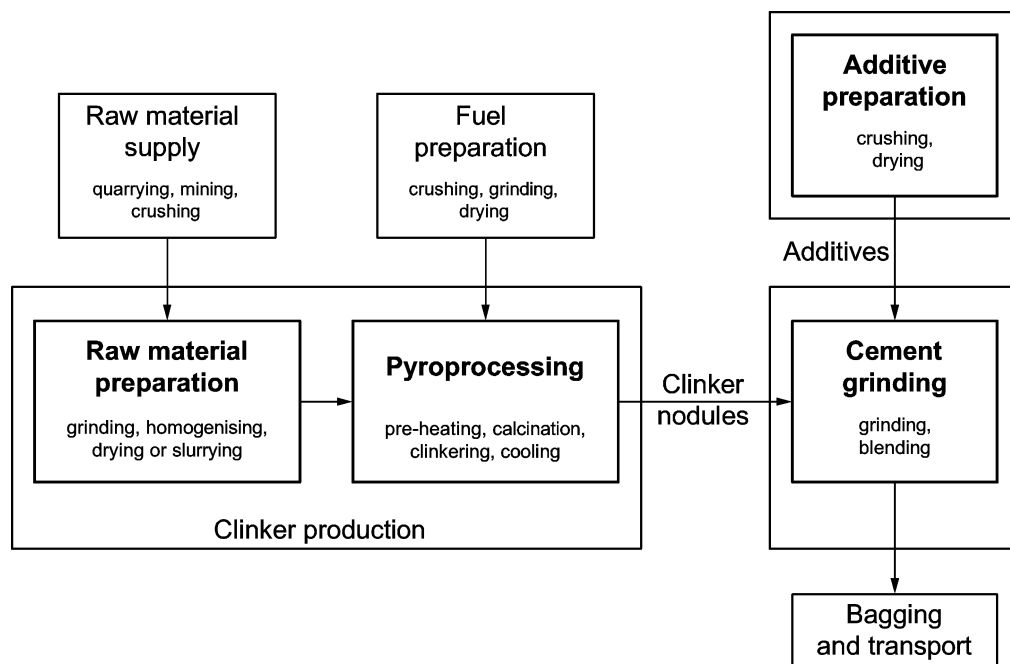
This European Standard for the cement industry has been based on the WBCSD/CSI and WRI: “CO<sub>2</sub> and Energy Accounting and Reporting Standard for the Cement Industry” [1].

### Overview of cement manufacturing process

Cement manufacture includes three main process steps (see Figure 1):

- a) preparing of raw materials and fuels;
- b) producing clinker, an intermediate, through pyro-processing of raw materials;
- c) grinding and blending clinker with other products (“mineral components”) to make cement.

There are two main sources of direct CO<sub>2</sub> emissions in the production process: calcination of raw materials in the pyro-processing stage, and combustion of kiln fuels. These two sources are described in more detail below. Other CO<sub>2</sub> sources include direct GHG emissions from non-kiln fuels (e.g. dryers for cement constituents products, room heating, on-site transports and on-site power generation), and indirect GHG emissions from, e.g. external power production and transports. Non-CO<sub>2</sub> greenhouse gases covered by the Kyoto Protocol<sup>1</sup>, apart from carbon monoxide (CO) methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), are not relevant in the cement context, in the sense that direct GHG emissions of these gases are negligible.



**Figure 1 — Process steps in cement manufacture (source: Ellis 2000, based on Ruth et al. 2000)**

<sup>1</sup> Methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), sulfur hexafluoride (SF<sub>6</sub>), partly halogenated fluorohydrocarbons (HFC) and perfluorated hydrocarbons (PFC)

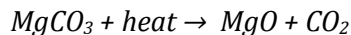
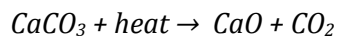
**Table 1 — Overview of input places of materials**

<b>Raw meal</b>	<b>Input place</b>
Raw materials from natural resources	Raw mill
Alternative raw materials	Raw mill
Raw material flows for clinker production	Input place
Raw meal	Kiln feed
Fuel ashes	Burner or precalciner or fuel dryer
Additional raw materials not part of the kiln feed	Kiln inlet
<b>Fuels flows for clinker and cement production</b>	<b>Input place</b>
Fossil fuels	Burner or precalciner or fuel dryer or raw material dryer
Alternative fuels	Burner or precalciner or fuel dryer or raw material dryer
Alternative fossil fuels	Burner or precalciner or fuel dryer or raw material dryer
Mixed fuels	Burner or precalciner or fuel dryer or raw material dryer
Biomass fuels	Burner or precalciner or fuel dryer or raw material dryer
<b>Cement kiln dust</b>	<b>Output place</b>
Dust return	Preheater
Filter dust	Precipitator / filter
By pass dust	Bypass filter
<b>Cement constituents based products</b>	<b>Output place</b>
Clinker	Kiln (cooler)
Cement	Cement mill
Blast furnace slag	Cement mill or grinding station
Fly ash	Cement mill or grinding station
Gypsum	Cement mill or grinding station
Cooler dust	Cooler, is normally added to the clinker flow to the clinker silo
Cement kiln dust	Preheater or precipitator or filter or bypass filter
Limestone	Cement mill or grinding station
Burnt shale	Cement mill or grinding station
Pozzolana	Cement mill or grinding station
Silica fume	Cement mill or grinding station



### CO<sub>2</sub> from calcination of raw materials

In the clinker production process, CO<sub>2</sub> is released due to the chemical decomposition of calcium, magnesium and other carbonates (e.g. from limestone) into lime:



This process is called "calcining" or "calcination". It results in direct CO<sub>2</sub> emissions through the kiln stack. When considering CO<sub>2</sub> emissions due to calcination, two components may be distinguished:

- CO<sub>2</sub> from raw materials actually used for clinker production, these raw materials are fully calcined in the clinker production process;
- CO<sub>2</sub> from raw materials leaving the kiln system as partly calcined cement kiln dust (CKD), or as normally fully calcined bypass dust.

CO<sub>2</sub> from actual clinker production is proportional to the lime content of the clinker,<sup>2</sup> which in turn varies little in time or between different cement plants. As a result, the CO<sub>2</sub> emission factor per tonne of clinker is fairly stable with a default value in this standard of 525 kg CO<sub>2</sub>/t clinker (IPCC default: 510 kg CO<sub>2</sub>/t clinker, CSI default: 525 kg CO<sub>2</sub>/t clinker [19]).

The amount of kiln dust leaving the kiln system varies greatly with kiln types and cement quality standards, ranging from practically zero to over one hundred kilograms per tonne of clinker. The associated emissions are likely to be relevant in some countries or installations.

CO<sub>2</sub> emissions from calcination of raw materials may be calculated by two methods which are in principle equivalent: Either based on the amount and chemical composition of the products (clinker plus dust leaving the kiln system, output methods B1 and B2), or based on the amount and composition of the raw materials entering the kiln (input methods A1 and A2). See 7.2.1, 7.2.2 for details.

### CO<sub>2</sub> from organic carbon in raw materials

The raw materials used for clinker production usually contain a small fraction of organic carbon, which may be expressed as total organic carbon (TOC) content. Organic carbon in the raw meal is converted to CO<sub>2</sub> during pyro-processing. The contribution of this component to the overall CO<sub>2</sub> emissions of a cement plant is typically very small (about 1 % or less). The organic carbon contents of raw materials may, however, vary substantially between locations and between the types of materials used. For example, the resulting emissions may be relevant if a cement company organization (used in this standard) consumes large quantities of certain types of fly ash or shale as raw materials entering the kiln.

### CO<sub>2</sub> from fuels for kiln operation

The cement industry traditionally uses various fossil fuels to operate cement kilns, including coal, petroleum coke, fuel oil, and natural gas. Fuels derived from waste materials have become important substitutes for traditional fossil fuels. These alternative fuels (AF) include fossil fuel-derived fractions such as, e.g. waste oil and plastics, as well as biomass-derived fractions such as waste wood and dewatered sludge from wastewater treatment. Furthermore fuels are increasingly used which contain both fossil and biogenic carbon (mixed fuels), like e.g. (pre-treated) municipal and (pre-treated) industrial wastes (containing plastics, textiles, paper etc.) or waste tyres (containing natural and synthetic rubber).

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<sup>2</sup> A second, but much smaller factor is the CaO and MgO content of the raw materials and additives used.

Both traditional fossil and alternative fuels result in direct CO<sub>2</sub> emissions through the kiln stack. However, biomass and bioliquids are considered “climate change-neutral” in accordance with IPCC definitions. Use of alternative (biomass- or fossil-derived) fuels may, in addition, lead to important emission reductions elsewhere, for instance from waste incineration plants or landfills.

Mineral components (MIC) are natural and artificial materials with latent hydraulic properties. Examples of MIC include natural pozzolana, blast furnace slag, and fly ash. In addition, gypsum is within this standard labelled as MIC. MICs are added to clinker to produce blended cement. In some instances, pure MICs are directly added to the concrete by the ready-mix or construction company. Use of MICs leads to an equivalent reduction of direct CO<sub>2</sub> emissions associated with clinker production, both from calcination and fuel combustion. Artificial MICs are waste materials from other production processes such as, e.g. steel and coal-fired power production. Related GHG emissions are monitored and reported by the corresponding industry sector. Utilization of these MICs for clinker or cement substitution does not entail additional GHG emissions at the production site. Consequently, these indirect GHG emissions shall not be included in the cement production inventory.

The basic mass balance methods used in this standard are compatible with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories issued by the Intergovernmental Panel on Climate Change (IPCC) [4], and with the revised WRI / WBCSD Greenhouse Gas Protocol [9]. Default emission factors suggested in these documents are used, except where more recent, industry-specific data has become available.

The 2006 IPCC Guidelines [4] introduced a Tier 3 method for reporting CO<sub>2</sub> emissions from the cement production based on the raw material inputs (Vol. III, Chapter 2.2.1.1, Formula 2.3). However, a large number of raw material inputs and the need to continuously monitor their chemical composition make this approach impractical in many cement plants. The different raw materials are normally homogenized before and during the grinding process in the raw mill. The WRI / WBCSD therefore recommended alternative methods for input-based reporting of CO<sub>2</sub> emissions from raw material calcination in cement plants. They rely on determining the amount of raw meal consumed in the kiln system. In many cement plants the homogenized mass flow of raw meal is routinely monitored including its chemical analysis for the purpose of process and product quality control. The input methods based on the raw meal consumed are already successfully applied in cement plants in different countries and seem to be more practical than Tier 3 of the 2006 IPCC Guidelines [4]. They were included in the Cement CO<sub>2</sub> and Energy Protocol Version 3 (Simple Input Method A1 and Detailed Input Method A2, 7.2.1).

## 1 Scope

This European Standard specifies a harmonized methodology for calculating GHG emissions from the cement industry, with a view to reporting these emissions for various purposes and by different basis, such as, plant basis, company basis (by country or by region) or even international group basis. It addresses all the following direct and indirect sources of GHG included [1]:

- Direct GHG emissions (scope 1) from sources that are owned or controlled by the organization, such as emissions result from the following sources:
  - process: calcinations of carbonates and combustion of organic carbon contained in raw materials;
  - combustion of kiln fuels (fossil kiln fuels, alternative fossil fuels, mixed fuels with biogenic carbon content, biomass and bioliquids) related to clinker production and/or drying of raw materials and fuels;
  - combustion of non-kiln fuels (fossil fuels, alternative fossil fuels, mixed fuels with biogenic carbon content, biomass and bioliquids) related to equipment and on-site vehicles, room heating/cooling, drying of MIC (e.g. slag or pozzolana);
  - combustion of fuels for on-site power generation;
  - combustion of carbon contained in wastewater.
- Energy indirect GHG emissions (scope 2) from the generation of purchased electricity consumed in the organization's owned or controlled equipment;
- Other indirect GHG emissions (scope 3) from bought clinker. Excluded from this standard are all other scope 3 emissions from the cement industry.

## 2 Normative references

Not applicable.

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

### 3.1

#### **additional raw material**

##### **Adrm**

additional raw materials are not part of the kiln feed and are fed directly to the calciner or the kiln inlet

### 3.2

#### **alternative fossil fuel**

fossil fuel derived from waste materials without biogenic content and not listed by IPCC

### 3.3

#### **alternative raw material**

##### **Arm**

alternative raw materials are raw materials for clinker production derived from artificial resources

### 3.4

#### **bioliquids**

liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass

### 3.5

#### **bypass dust**

discarded dust from the bypass system dedusting unit of suspension preheater, precalciner and grate preheater kilns, normally consisting of kiln feed material which is fully calcined or at least calcined to a high degree

### 3.6

#### **cement**

building material made by grinding clinker together with various mineral components such as gypsum, limestone, blast furnace slag, coal fly ash and natural volcanic material; includes special cements such as the ones based on calcium aluminates

### 3.7

#### **cement (eq.)**

calculated cement production value which is determined from clinker produced on-site in an integrated cement plant applying the plant specific clinker/cement-factor

### 3.8

#### **cement constituent**

main and minor additional constituents of cement plus calcium sulphates and additives in cement

### 3.9

#### **cement kiln dust**

##### **CKD**

any discarded dust from dry and wet kiln system dedusting units, consisting of partly calcined kiln feed material which includes bypass dust or any other dust flows coming from the clinker production

### 3.10

#### **cement constituents based products**

all clinker produced for cement making or direct clinker sale, plus mineral components consumed or processed for sale excluding pre-processed mineral components imported from another cement plant

### 3.11

#### **clinker**

intermediate product in cement manufacturing and the main substance in cement; clinker is the result of calcination of limestone in the kiln and subsequent reactions caused through burning (see EN 197-1)

### 3.12

#### **clinker plant**

plant where clinker is produced without having onsite grinding to cement

### 3.13

#### **concrete addition**

finely divided inorganic material with pozzolanic or latent hydraulic properties or nearly inert, used in concrete in order to improve certain properties or to achieve special properties

### 3.14

#### **fossil direct emissions**

total direct emissions of GHGs within the boundaries excluding GHG emissions from biomass fuels or biogenic carbon content of mixed fuels

### 3.15

#### **dust return**

dust arising during clinker manufacture that is ultimately returned to the raw mill or kiln system; this does not include bypass dust

Note 1 to entry: See Figure 6 for an example of mass flows in the clinker production process.

### 3.16

#### **filter dust leaving the kiln system**

cement kiln dust (CKD) leaving the kiln system excluding by pass dust

### 3.17

#### **fossil fuel**

all fossil fuels listed by IPCC

### 3.18

#### **grinding plant**

plant for cement production where cement constituents are ground without having onsite clinker production

### 3.19

#### **gross emission**

fossil direct GHG emissions excluding GHG emissions from on-site power production

### 3.20

#### **integrated cement plant**

plant where clinker is produced and partly or fully ground to cement

### 3.21

#### **kiln system**

tubular heating apparatus used in the production of clinker, including preheater and/or pre-calciner

### 3.22

#### **kiln feed**

raw materials, often processed as raw meal (including recirculated dust), which are fed to a pre-heater or directly into the kiln system

### 3.23

#### **kiln inlet**

kiln hood, or entrance to the tubular heating apparatus for materials

### 3.24

#### **kiln fuel**

fuel fed to the kiln system plus fuels that are used for drying or processing of raw materials for the production of clinker and the preparation of kiln fuels

### 3.25

#### **mineral components**

cement constituents other than clinker plus concrete additions processed in view of changing their properties

### 3.26

#### **net emission**

gross emissions excluding GHG emissions from alternative fossil fuels and comparable benchmark emissions from external heat or energy transfer

### 3.27

#### **non-kiln fuel**

fuels which are not included in the definition of kiln fuels

### 3.28

#### **petcoke**

petroleum coke, a carbon-based solid fuel derived from oil refineries

### 3.29

#### **raw material**

materials used for raw meal preparation for clinker production

### 3.30

#### **raw material preparation**

processes applied for converting raw materials to raw meal

### 3.31

#### **raw meal**

raw meal consists of the ground raw materials for clinker production

### 3.32

#### **raw meal consumed**

part of the raw meal, which is consumed for clinker production and the formation of calcined bypass dust

### 3.33

#### **recirculated dust**

all dust flows that are reused as kiln feed

Note 1 to entry: See Figure 6 for an example of mass flows in the clinker production process.

### 3.34

#### **total direct GHG emission**

all direct emissions of GHGs within the boundaries including GHG emissions from raw materials processing, fossil fuels, biomass and biogenic carbon content of mixed fuels, and CO<sub>2</sub> from waste water combustion

## 4 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply.

Adrm Additional raw material

AF Alternative fuel

AFR	Alternative fuel and alternative raw material
Arm	Alternative raw material
BPD	Bypass dust
cem eq.	cement (eq.)
cem prod.	cement constituents based product
CKD	Cement kiln dust
cli	clinker
CSI	Cement sustainability initiative of the WBCSD
EF	Emission factor
EU ETS	The CO <sub>2</sub> Emissions Trading Scheme of the European Union
FD	Filter dust
GCV	Gross calorific value (synonym for higher heat value, HHV)
GHG	Greenhouse gas
GWP	Global warming potential
HHV	Higher heat value (synonym for gross calorific value, GCV)
IPCC	Intergovernmental panel on climate change
KF	Kiln feed
KPI	Key performance indicator
LHV	Lower heat value (synonym for net calorific value, NCV)
LOI	Loss on ignition
MIC	Mineral component
$m_N^3$	normal cubic meters (at 1013 hPa and 0 °C)
NCV	Net calorific value (synonym for lower heat value, LHV)
OPC	Ordinary Portland Cement
RM	raw meal
TC	Total carbon (the sum of TOC and TIC)
TIC	Total inorganic carbon
TOC	Total organic carbon
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

## 5 Determination of GHGs based on the mass balance method

### 5.1 General

The volume of GHG emissions may be determined by the mass balance method (see 5.3) or by (continuous) stack emission measurements (see 5.4).

## 5.2 Major GHG in cement

For the mass balance the emissions have been related to carbon assuming that all carbon is converted into CO<sub>2</sub>, with exclusion of all other GHG components assuming that these are negligible.

The measurements should include measurements of CH<sub>4</sub> and N<sub>2</sub>O as these are assumed to be the only important non-CO<sub>2</sub> GHG emissions.

## 5.3 Determination based on mass balance

The GHG emissions of an installation may be determined based on mass balance. Emissions from source streams are calculated from input or production data, obtained by means of measurement systems, and additional parameters from laboratory analyses including calorific factor, carbon content and biomass content. Standard factors may also be used; see Annex B for hints regarding emission factors.

## 5.4 Determination by stack emission measurements

The GHG emissions of an installation may also be determined by measurement. Emissions from an emission source are determined based on continuous measurement of the concentration of the relevant greenhouse gas in the flue gas and of the flue gas flow.

## 5.5 Gross and net emissions

### 5.5.1 General

For the purpose of comparison of GHG emissions of plants/installations from different sectors within the energy-intensive industries it is essential that the boundaries for monitoring and reporting of these emissions are identical on plant level, even when being different in detail for each sector. Within this view the GHG emissions from pure biomass and from the biogenic carbon content of mixed fuels are being recognized as climate change neutral and therefore treated as zero direct GHG emissions.

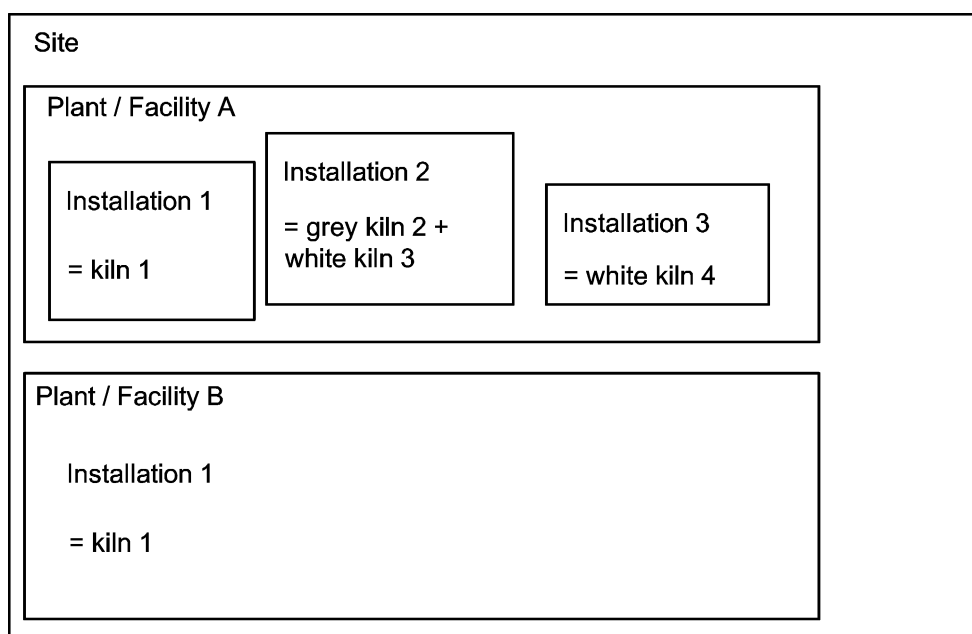


Figure 2 — Site / Facility / Plant / Installation

For a plant this leads to the so called “fossil direct GHG emissions”, to the value of which may be compared with comparable volumes from sites within different sectors. It is an absolute volume of reported GHGs by a plant, site or organization, see Figure 2 and definitions.



But this volume of “fossil direct GHG emissions” cannot be used for comparison of the performances of installations within the cement industry sector. A site that is producing its own electricity (power) will have higher fossil direct GHG emissions than a nearly identical site which gets the electricity from the external grid as emissions of external electricity production are reported as indirect GHG emissions. For comparison reasons the emissions from on-site power productions have to be excluded from the fossil direct GHG emissions leading to the so called “gross emissions”.

This concept of gross emissions enables a comparison of GHG emissions on plant, site or organization level.

**Table 2 — Definitions of direct emissions**

<b>Direct emissions</b>		<b>Minus</b>		<b>Emissions group</b>
Total direct GHG emissions				
Total direct GHG emissions	-	Emissions from pure biomass and from the biogenic carbon content of mixed fuels	=	Fossil direct GHG emissions
Fossil direct GHG emissions	-	Emissions from on-site power production	=	Gross emissions

The concept of gross emissions enables comparison of direct GHG emissions on plant level within the cement industry. This concept does not enable fair comparison of performance of plants and installations for their effect on global climate change – see Tables 2 and 3.

This standard offers the incentive of taking advantage of indirect GHG savings from the use of alternative fuels and raw materials (AFR) by reporting gross (including alternative fossil fuels) and net (excluding alternative fossil fuels) emissions.

Some waste materials may substitute traditional fossil fuels and minerals in cement production. The recovered wastes are called alternative fuels and raw materials (AFR). As a result, direct CO<sub>2</sub> emissions from traditional fuels are reduced but direct CO<sub>2</sub> emissions from wastes (“waste-to-energy conversion”) occur. The direct CO<sub>2</sub> emissions from waste combustion can be higher or lower than the displaced emission, depending on the emission factors of the fuels involved. Moreover, wastes can be of fossil or biomass origin.

In addition to those direct effects, utilization of AFR results in indirect GHG savings at landfills and incineration plants where these wastes may otherwise be disposed. These savings can partly, fully or more than fully offset the direct CO<sub>2</sub> emissions from waste combustion at the cement plant, depending on local conditions (type of waste, reference disposal path), see Figure 3.

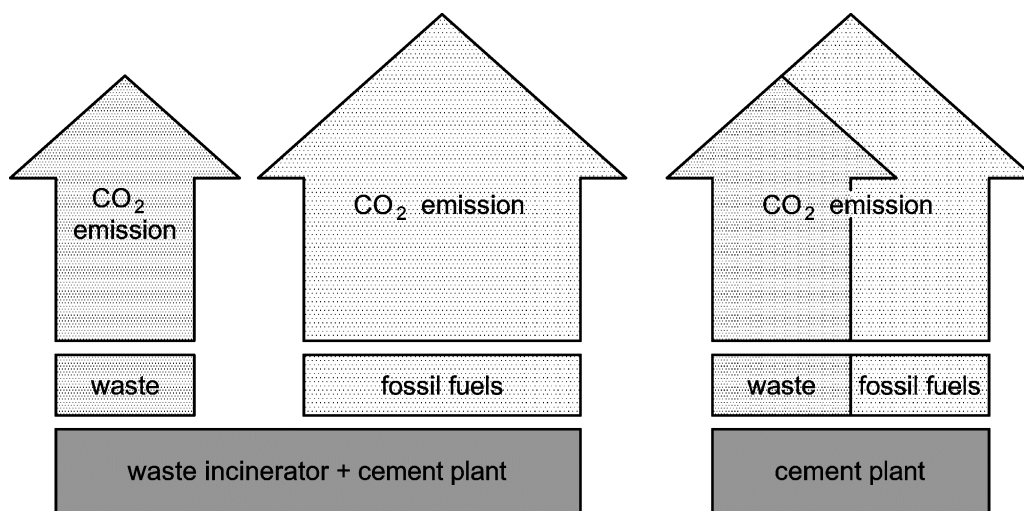
Gross emissions are the total direct GHG emissions (excl. on-site power generation) from a cement plant or organization, including GHG from fossil wastes (but excluding CO<sub>2</sub> from biomass wastes, which is treated as a memo item). Advantages from indirect GHG savings reflect the GHG emission reductions achieved at waste disposal sites as a result of AFR utilization. The actual reductions will usually be difficult to determine with precision; hence the countable savings will to some degree have to be agreed upon by convention, rather than based on “precise” GHG impact assessments.

**Table 3 — Gross and net emissions**

Direct GHG emissions		Minus		Emissions group
Gross emissions	-	Emissions from alternative fossil fuels and non-biogenic content of mixed fuels	—	Net emissions
	-	Comparable benchmark emissions for external heat transfer	—	

Net emissions are the gross emissions minus the advantages for indirect GHG savings. As far as practicable, reported AFR advantages should take into account local circumstances (e.g. national agreements, life cycle analyses of local AFR use, etc.). When reporting to third parties, supporting evidence for the savings should be provided and verified as appropriate. As a default, this standard assumes indirect savings to be equal to the direct GHG emission from fossil AFR use.

This approach is a simplification of the AFR issue. It is however, in the medium-term, the least onerous and most practicable approach, where transparency is achieved through disclosure of gross and net emissions.



**Figure 3 — Indirect saving of GHG emissions by the use of waste as alternative fuel in a cement plant**

## 5.5.2 Gross emissions

### 5.5.2.1 General

**Table 4 — Emission sources included within “Total direct GHG emissions”**

GHG from raw materials + GHG from traditional fossil fuels + GHG from alternative fossil fuels (fossil wastes) + GHG from fossil carbon of mixed (alternative) fuels covering GHG from all kiln fuels and all non-kiln fuels including GHG from on-site power generation + GHG emissions from biomass and biogenic carbon of mixed fuels + GHG from combustion of wastewater
<b>= Total Direct GHG emissions</b>

<b>Memo items</b> <ul style="list-style-type: none"><li>• Indirect GHG (bought electricity &amp; clinker)</li></ul>
---

**Table 5 — Emission sources to be reported within “fossil direct GHG emissions”**

GHG from raw materials + GHG from traditional fossil fuels + GHG from alternative fossil fuels (fossil wastes) + GHG from fossil carbon of mixed fuels covering GHG from all kiln fuels and all non-kiln fuels including GHG from on-site power generation + GHG from combustion of wastewater
<b>= Fossil direct GHG emissions</b>
<b>Memo items</b> <ul style="list-style-type: none"> <li>• GHG from biomass fuels</li> <li>• GHG from biogenic carbon of mixed fuels</li> <li>• Indirect GHG (bought electricity &amp; clinker)</li> </ul>

**Table 6 — Emission sources to be reported within “gross emissions”**

GHG from raw materials + GHG from traditional fossil kiln fuels + GHG from alternative fossil kiln fuels (fossil wastes) + GHG from waste water combustion + GHG from fossil carbon of mixed kiln fuels and non-kiln fuels (excluding on-site power generation)
<b>= Gross emissions</b>
<b>Memo items</b> <ul style="list-style-type: none"> <li>• GHG from biomass fuels</li> <li>• GHG from biogenic carbon of mixed (alternative) fuels</li> <li>• GHG from fossil carbon of mixed fuels used for on-site power generation</li> <li>• Indirect GHG (bought electricity &amp; clinker)</li> </ul>

#### 5.5.2.2 Accounting of CO<sub>2</sub> emissions from the biomass content of fuels

The CO<sub>2</sub> emissions originating from the biogenic carbon content of mixed fuels are not accounted as part of the gross emissions. Biomass CO<sub>2</sub> from these fuels is added up with the CO<sub>2</sub> from pure biomass to give the total biomass CO<sub>2</sub> and reported as memo item. It is subtracted when calculating absolute direct CO<sub>2</sub> emissions.

### 5.5.2.3 Net emissions and indirect GHG savings related to utilization of wastes as alternative fuels

The cement industry recovers large quantities of waste materials for use as fuel and/or raw material. These recovered wastes are also referred to as *alternative fuels and raw materials (AFR)*. By utilizing AFR, cement companies reduce their consumption of traditional fossil fuels while at the same time helping to avoid conventional disposal of the waste materials by landfill or incineration.

Increased utilization of AFR can have an influence on the direct GHG emissions of a cement organization because the emission factors of the AFR can differ from those of the displaced fuels. Moreover, the carbon contained in the AFR can be of fossil and/or biomass origin. As mentioned above, utilization of AFR by the cement industry typically results in GHG emission reductions at landfills and incineration plants where these wastes would otherwise be disposed. The combination of direct GHG emissions impacts, indirect GHG emission reductions, and resource efficiency makes the substitution of AF for traditional fossil fuels an effective way to reduce global GHG emissions (see e.g. IEA 1998, CSI / ECRA 2009 and WBCSD / IEA 2009).

The balance sheet approach described in 5.5.2 ensures completeness, rigor and transparency of reporting.

- Direct GHG emissions resulting from the combustion of fossil AF shall always be included in the organization's gross emissions, in accordance with 7.6.

With the following concept this standard provides a framework for reporting also indirect GHG emission reductions achieved by using alternative fuels.

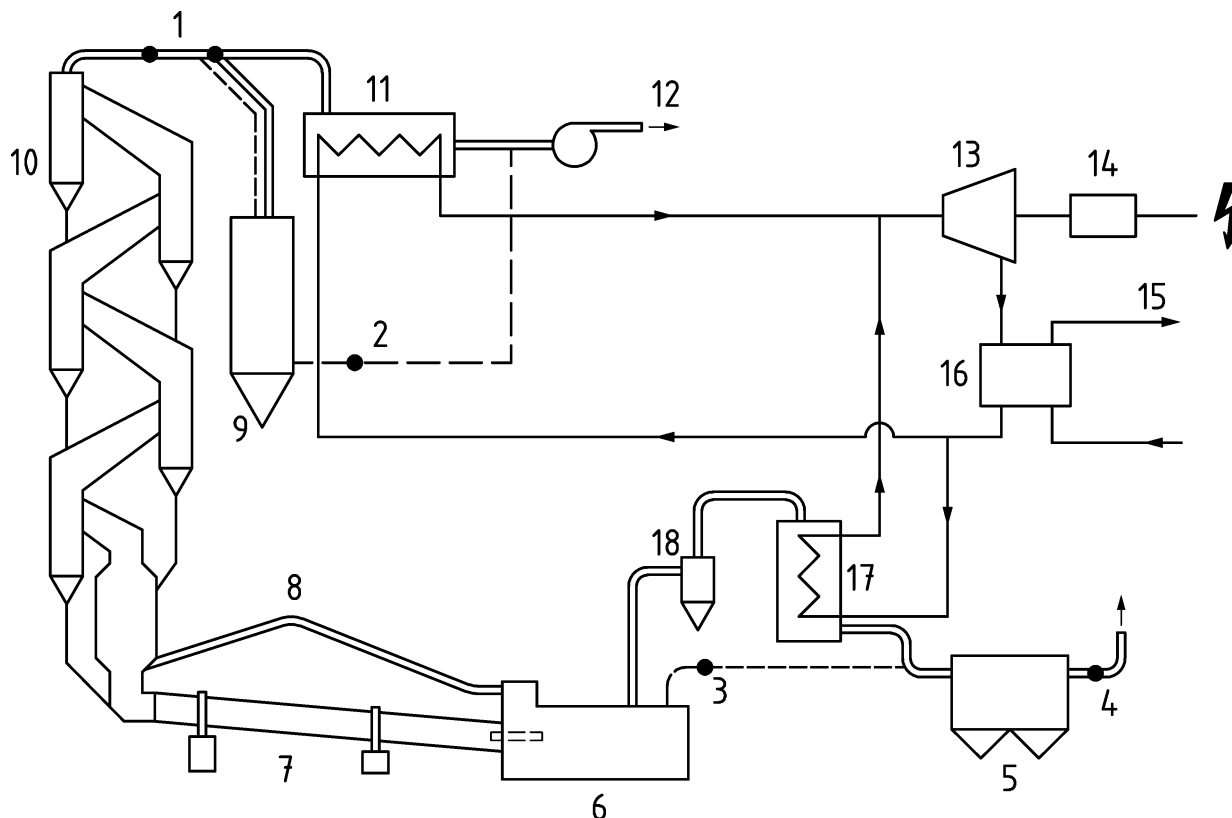
- Indirect GHG emission reductions at landfills and incineration plants are accounted by subtracting from the gross emissions the fossil GHG emissions of alternative fuels.

See 10.2 for the reporting requirements with respect to net emissions.

### 5.5.3 Other indirect GHG emission reductions

#### Utilization of waste heat

Some cement plants export waste heat to external consumers as a substitute for conventional energy sources. In analogy to the indirect effects related to the use of alternative fuels, a cement organization may account for the indirect GHG emission reductions resulting from such waste heat exports.



**Key**

- |                           |                              |
|---------------------------|------------------------------|
| 1 Raw gas from preheater  | 2 Bypass of preheater boiler |
| 3 Bypass of cooler boiler | 4 Cooler exhaust air         |
| 5 Cooler vent filter      | 6 Clinker cooler             |
| 7 Rotary kiln             | 8 Tertiary air duct          |
| 9 Conditioning tower      | 10 Preheater tower           |
| 11 Preheater boiler       | 12 To raw grinding           |
| 13 Turbine                | 14 Generator                 |
| 15 Cooking tower          | 16 Condenser                 |
| 17 Cooler boiler          | 18 De-duster                 |

**Figure 4 — Schematic of application of Waste Heat Recovery (WHR) and electrical power generation in cement manufacture**

Similar advantages may be applied for other forms of waste heat utilization [7]. So this standard offers the possibility of reporting voluntarily waste heat utilization within the plant (e.g. for raw material or slag drying or power generation) in order to allow a fair comparison between plants exporting heat and plants using the heat internally. This requires additional calculation taking into account waste energy utilized only for clinker or cement production and the total energy flow in GJ/a may be reported. The reporting is voluntary.

Further, in the case of electrical power generation from waste heat originating from the kiln system (Figure 4) any additional fuel used in the kiln system is accounted as kiln fuel and consequently emissions are accounted as direct GHG emissions of the kiln system. In order to provide more detailed information, this standard distinguishes between waste heat recovery and separate on-site power generation. In any case, when applying in their voluntary reporting, companies should consider whether their actions indeed contribute to a global reduction in GHG emissions, or merely to a shift of emissions between different entities.

## 6 System boundaries

### 6.1 General

Drawing appropriate boundaries is one of the key tasks in an emissions inventory process.

### 6.2 Operational boundaries

Operational boundaries refer to the types of sources covered by an inventory. A key distinction is between direct and indirect GHG emissions:

- a) **Direct GHG emissions** are emissions from sources that are owned or controlled by the reporting organization. For example, emissions from fuel combustion in a cement kiln are direct emissions of the organization owning (or controlling) the kiln. This includes the direct emissions from additional fuel use such as for raw material or fuel drying or for on-site power generation.
- b) **Indirect GHG emissions** are emissions that result as a consequence of the activities of the reporting company but occur at sources owned or controlled by another organization. For example, emissions from the generation of grid electricity consumed by a cement organization will qualify as indirect.

Clause 7 of this standard provides detailed guidance on the different sources of direct emissions occurring in cement plants. Indirect GHG emissions are addressed in Clause 8.

Companies shall use the operational boundaries outlined in Table 3 for the determination of GHG emissions at the cement plant. Any deviation from these boundaries shall be reported and explained.

**Table 7 — Operational boundaries**

Process Step	Scope	Inclusion in standard	Direct or indirect GHG emissions
Quarrying of raw materials	Scope 1 Scope 3	Scope 1 yes: for quarries owned, controlled or managed by the organization Scope 3 no: for quarries not owned by the organization	Direct Other indirect
Raw materials transport	Scope 1 Scope 3	Scope 1 yes: for lorries owned by the organization Scope 3 no: for lorries not owned by the organization	Direct Other indirect
Raw materials drying	Scope 1	Yes	Direct
Raw materials grinding	Scope 1	Yes	Direct
Fuel preparation in plant	Scope 1	Yes	Direct
Fuel preparation outside plant	Scope 1 Scope 3	Scope 1 yes: for installations owned by the organization Scope 3 no: for installations not owned by the organization	Direct Other indirect
Fuels for kiln	Scope 1	Yes	Direct
Non kiln fuels (raw materials, fuel)	Scope 1	Yes	Direct

Process Step	Scope	Inclusion in standard	Direct or indirect GHG emissions
Mobile transport of fuels	Scope 1 Scope 3	Scope 1 yes: for lorries owned by the organization Scope 3 no: for lorries not owned by the organization	Direct Other indirect
CKD = Bypass and/ or filter dust	Scope 1	Yes	Direct
Calcination	Scope 1	Yes	Direct
Imported Clinker	Scope 3	Yes, needs inclusion for cement process KPIs	Other indirect
Drying of cement constituents	Scope 1	Yes	Direct
Cement grinding	Scope 2	Yes	Energy indirect
Packaging and Dispatch	Scope 2	Yes	Energy indirect
Mobile transport for dispatch	Scope 1 Scope 3	Scope 1 yes: for lorries owned by the organization Scope 3 no: for lorries not owned by the organization	Direct Other indirect
Electricity consumption for whole production process	Scope 2	Yes	Energy indirect
On-site power production	Scope 1	Yes	Direct
Waste Heat Recovery	Scope 1	Yes	Direct
Room heating / cooling	Scope 1	No	Direct
Mobile transport in plant	Scope 1 Scope 3	Scope 1 yes: for mobile equipment owned by the organization Scope 3 no: for mobile equipment not owned by the organization	Direct Other indirect
Stock changes	Scope 1, 2 and 3	Yes, for calculation / KPIs	Direct

## 6.3 Organizational boundaries

### 6.3.1 General

Organizational boundaries define which parts of an organization – for example wholly owned operations, joint ventures and subsidiaries – are covered by an inventory, and how the emissions of these entities are consolidated. This standard provides guidance on organizational boundaries.

### 6.3.2 Which installations should be covered?

GHG emissions result not only from kiln operations, but also from upstream and downstream processes, particularly from quarry operations and (indirectly) cement grinding. These facilities may be located a



considerable distance from each other. In addition, quarries, kilns and grinding stations are sometimes operated by separate legal entities. How should this be accounted for in a legal entity's inventory?

Reporting under this standard shall cover the main direct and indirect GHG emissions associated with cement production as required in Clauses 7, 8 and 10 of this standard. These emissions include also those related to consumption of fuel and electricity in upstream and downstream operations. In particular, cement companies shall include the following types of activities in their reporting to the extent that they control or own the respective installations in accordance with 6.3.2 below:

- a) clinker production, including raw material quarrying and preparation;
- b) preparation or processing of fuels or alternative raw materials (such as fly ash or blast furnace slag) in own installations;
- c) grinding of clinker, additives and concrete additions such as slag, both in integrated cement plants and stand-alone grinding stations;
- d) additional fuel use for own power generation.

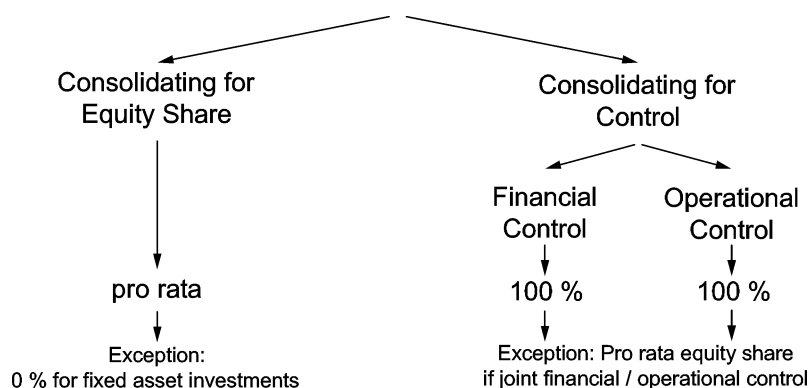
Separate inventories may be established for individual facilities as appropriate, for instance if they are geographically separated or run by distinct operators. The impacts of such a division will cancel out when emissions are consolidated at organization or group level (see also 6.3.3 regarding organization-internal clinker transfers).

### 6.3.3 Operational control and ownership criteria

Three methods have been identified for consolidation of GHG emissions of the cement industry for companies with more than one plant.

- **Equity share:** Under this approach, an organization consolidates its GHG emissions according to the (*pro rata*) equity share it holds in each operation, i.e. according to ownership. As an exception, no emissions are consolidated for so-called fixed asset investments where an organization owns only a small part of the total shares of an operation and exerts neither significant influence nor financial control. Other possible exceptions relate to the *economic substance* of a relationship (see revised WRI / WBCSD Protocol for details).
- **Financial control** is defined as *the ability of an organization to direct the financial and operating policies of an operation with a view to gaining economic benefits from its activities. For example, the financial control usually exists if the organization has the right to the majority benefits of the operation (...), or if it retains the majority risks and rewards of ownership of the operation's assets.* Under this approach, companies consolidate 100 % of the emissions of those operations over which they have financial control. As an exception, consolidation according to equity share is required for joint ventures where partners have joint financial control.
- **Operational control** is defined as an organization's *full authority to introduce and implement its operating policies at an operation.* This criterion is usually fulfilled if an organization is the operator of a facility, i.e. if it holds the operating license. Under this approach, companies consolidate 100 % of the emissions of those operations over which they have operational control. As an exception, consolidation according to equity share is required for joint ventures where partners have joint operational control.

Companies should explicitly state in the report, which methodology they apply.



**Figure 5 — Options for consolidating emissions**

With a view to the characteristics of the cement industry cement companies shall consolidate primarily according to the operational control criterion, and secondly according to the ownership criterion in case operational control is not clearly assigned to a single legal entity.

### 6.3.4 Internal clinker, cement and MIC transfers

Many cement companies transfer large volumes of clinker, cement and mineral components (MICs) like slag or fly ash internally, between different plants and grinding stations. These transferred materials are processed further to other products like low clinker cements and thus have an impact on the clinker/cement factor of the receiving plant. In these cases the risk of double counting occurs. Companies shall ensure their method of calculation and reporting follows the below methods for plant and organizational level.

On plant level internal clinker transfer has to be reported (transfer within the same organization, plus for received and minus for sent clinker). Clinker transferred internally as ingredient of cement has to be reported only if the plant is receiving cement from another plant within the same organization and processes it further to another cement type, which is then reported in that plant. The clinker quantity should be calculated based e.g. on the clinker/cement factor of the transferred cement. Clinker as ingredient of cement bought from other companies (external clinker transfer), which is used for blending, should be reported as “bought clinker”. Total clinker consumed results as:

$$\text{Total clinker consumed} = \text{clinker production} + \text{clinker bought} - \text{clinker sold} - \text{change in clinker stock} + \text{internal clinker transfer} + \text{clinker from cement transfer}$$

On organization level internal clinker transfers are added up for checking purposes. It should be zero on organization level. Clinker from internal cement transfers are reported as a sum of all plants. Total clinker consumed results as:

$$\text{Total clinker consumed (organization level)} = \text{clinker production} + \text{clinker bought} - \text{clinker sold} - \text{change in clinker stock} + \text{internal clinker transfer} - \text{clinker from cement transfer}$$

Generally, the system for internally clinker transfers can also be applied to internal transferred MIC. The amount of exported MIC should always be shown as a positive value, meaning that the plant is selling/exporting. For the reporting it is not relevant whether sold/exported MICs are used in cement or concrete. However, the amount of consumed pre-processed MIC should not be regarded in the amount of cement constituents based products in case it is received from another plant (regardless of belonging to the same or another organization).

On organization level total MIC transfers are summarized as a sum of all plants.

In conclusion, this standard accounts for internal clinker, cement and mineral component transfers. Accounting for internal transfers is required for the analysis of GHG performance indicators at plant level.

## **7 Direct GHG emissions and their determination**

### **7.1 General**

Direct GHG emissions are emissions from sources of the respective plant. In cement plants, direct GHG emissions may result from the following sources:

- a) calcination of carbonates, and combustion of organic carbon contained in raw materials;
- b) combustion of kiln fuels related to clinker production:
  - 1) combustion of traditional fossil kiln fuels;
  - 2) combustion of alternative fossil kiln fuels and mixed fuels with biogenic carbon content;
  - 3) combustion of biomass and bioliquids (including biomass wastes);
- c) combustion of non-kiln fuels:
  - 1) combustion of traditional fossil fuels;
  - 2) combustion of alternative fossil fuels and mixed fuels with biogenic carbon content;
  - 3) combustion of biomass and bioliquids (including biomass wastes);
- d) combustion of fuels for on-site power generation;
- e) combustion of the carbon contained in wastewater.

**Table 8 — CO<sub>2</sub> from raw materials: Methods based on raw material input (A1, A2)**

Emission components	Parameters	Units	Recommended source of parameters
<b>CO<sub>2</sub> from raw materials: Methods based on raw material input (A1, A2)</b>			
Calcination of raw material consumed for clinker production Dust return correction CO <sub>2</sub> released from total carbon in raw meal or loss on ignition (LOI) Calcination of dust	Raw meal consumed Kiln feed CO <sub>2</sub> released from total carbon or LOI Dust leaving kiln system excluding bypass dust CO <sub>2</sub> released from total carbon in dust or LOI	t t mass fraction t mass fraction	Calculated or measured at plant level Calculated or measured at plant level Determined at plant level Measured at plant level Measured at plant level
<b>Furthermore for detailed input method (A2)</b>			
Partial calcination of bypass dust Additional raw materials not included in kiln feed	Bypass dust leaving kiln system Bypass dust CO <sub>2</sub> released from total carbon Additional raw materials Additional raw materials CO <sub>2</sub> released from total carbon	t mass fraction t mass fraction	Measured at plant level Measured at plant level Measured at plant level Measured at plant level

**Table 9 — Parameters and proposed data sources for calculation of direct CO<sub>2</sub> emissions and default CO<sub>2</sub> emission factors of fuels**

<b>Emission components</b>	<b>Parameters</b>	<b>Units</b>	<b>Recommended source of parameters</b>
<b>CO<sub>2</sub> from raw materials: Methods based on clinker output (B1, B2)</b>			
Calcination of raw material consumed for clinker production	Clinker produced Emission factor clinker	t <sup>a</sup> kg CO <sub>2</sub> / t cli <sup>b</sup>	Measured at plant level Default = 525; or as calculated in detailed output method (B2)
Calcination of dust	Dust leaving kiln system Emission factor clinker Dust calcination degree	t kg CO <sub>2</sub> / t cli calcined fraction	Measured at plant level Default = 525; or as calculated in detailed output method (B2) Measured at plant level
Organic carbon in raw materials	Clinker produced Raw meal: clinker ratio TOC <sup>c</sup> content of raw meal	t cli t / t cli mass fraction	Measured at plant level Default = 1,55; may be adjusted to local situation Default = 0,2%; may be adjusted to local situation
<b>Furthermore for detailed output method (B2)</b>			
Calcination of raw material consumed for clinker production	CaO + MgO in clinker	mass fractions	Measured at plant level
Corrections of emission factor clinker	CaO + MgO from non-carbonate sources in raw materials Raw material consumed Ca + Mg silicate sources in raw materials (e.g. as part of clay minerals) Raw material consumed	mass fractions t mass fractions t	Measured at plant level Measured at plant level Measured at plant level (e.g. with QXRD <sup>d</sup> with Rietveld refinement) Measured at plant level
<b>CO<sub>2</sub> from kiln and non-kiln fuel combustion:</b>			
traditional fuels	Fuel consumption Lower heating value Emission factor	t GJ /t fuel t CO <sub>2</sub> /GJ fuel	Measured at plant level Measured at plant level IPCC / CSI /national defaults, or measured at plant level

Emission components	Parameters	Units	Recommended source of parameters
Alternative fossil fuels (fossil AF <sup>e</sup> ) and mixed fuels	Fuel consumption Lower heating value Emission factor Biogenic carbon content	t GJ /t fuel t CO <sub>2</sub> /GJ fuel mass fraction	Measured at plant level Measured at plant level IPCC/CSI / national defaults, or measured at plant level IPCC/CSI / national defaults, or measured at plant level
Biomass and bioliquids (biomass AF)	Fuel consumption Lower heating value Emission factor	t GJ /t fuel t CO <sub>2</sub> /GJ fuel	Measured at plant level Measured at plant level IPCC/CSI / national defaults, or measured at plant level
Wastewater combusted	--	--	Quantification of CO <sub>2</sub> not required
<p>a t = metric tonne b cli = clinker c TOC = Total Organic Carbon d QXRD = Quantitative X-Ray Diffractometry e AF = Alternative Fuels</p>			

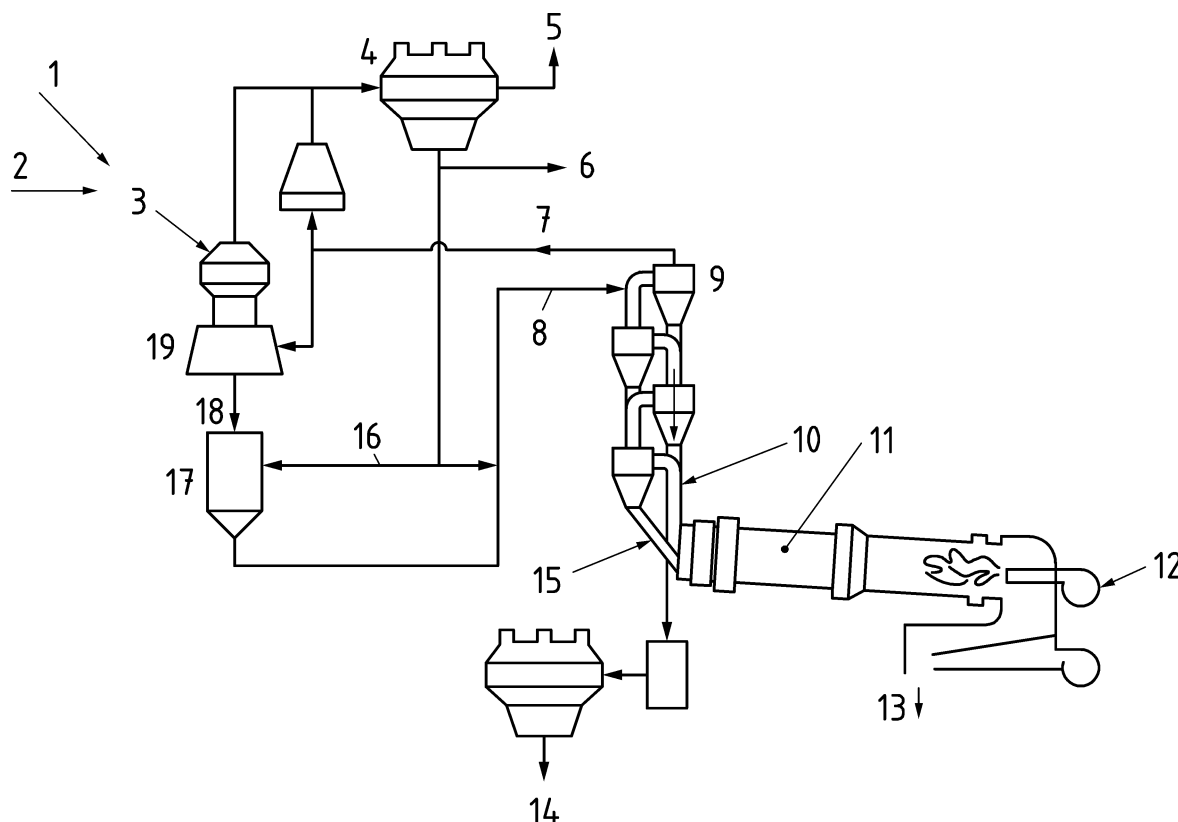
Emission factors, formulas and reporting approaches for these sources are described in the following sections of this clause. Tables 8 and 9 summarize the parameters involved, and the proposed data sources. Generally, companies are encouraged to measure the required parameters at plant level. Where plant- or organization-specific data is not available, the recommended, international default factors should be used. Other default factors (e.g., national) may be preferred to the international defaults if deemed reliable and more appropriate. The following sections provide guidance for choosing between different methods for reporting CO<sub>2</sub> emissions from raw material calcination.

## 7.2 CO<sub>2</sub> from raw material calcinations

### 7.2.1 General

Calcination is the release of CO<sub>2</sub> from carbonates during pyro-processing of the raw meal. Calcination CO<sub>2</sub> is directly linked with clinker production. In addition, calcination of filter dust (FD) and bypass dust (BPD) can be a relevant source of CO<sub>2</sub> where such dust leaves the kiln system for direct sale, addition to cement or other products, or for discarding as a waste.

The following Figure 6 gives an example of relevant mass flows in the clinker production process, as they often occur in plants with a cyclone pre-heater.



**Key**

- |    |  |    |                                |
|----|--|----|--------------------------------|
| 1  | limestone $\text{CaCO}_3$ , $\text{MgCO}_3$                    | 11 | kiln                           |
| 2  | clay, shale, other $\text{CaO}$ , $\text{MgO}$ , $\text{CaSi}$ | 12 | fuel ashes                     |
| 3  | raw material   | 13 | clinker                        |
| 4  | dust filter  | 14 | bypass dust                    |
| 5  | $\text{CO}_2$  | 15 | additional raw material (AdRM) |
| 6  | filter dust leaving the kiln system (FD)                       | 16 | recirculated dust              |
| 7  | dust return  | 17 | silo                           |
| 8  | kiln feed (KF)   | 18 | raw meal (RM)                  |
| 9  | pre-heater   | 19 | raw mill                       |
| 10 | calciner fuel ashes  |    |                                |

**Figure 6 — Example of mass flows in the clinker production process in a plant for the production of clinker with cyclone pre-heater and rotary kiln with filter dust, recirculated dust**

On plant level, calcination  $\text{CO}_2$  may basically be calculated in two ways: based on the volume and carbonate content of the raw meal consumed (input method), or based on the volume and composition of clinker produced (output method) plus dust leaving the kiln system. The clinker-based method is often used in Europe. Both input and output based methods are included in the 2006 IPCC Guidelines [4] for National Greenhouse Gas Inventories (output Tier 1 and 2, input Tier 3<sup>3</sup>). Input and output methods are equivalent. This standard includes both types of methods. Companies may choose to apply the raw meal-based input method or the clinker-based output method. The choice should be made according to the availability of adequate data and measurements of the mass flows. Furthermore, this standard allows for each type applying a simple and a detailed method. The choice between the simple

<sup>3</sup> See IPCC 2006, Vol. III, 2.2.1.1

and the detailed method depends on both the intended use of reporting and the availability of data. The detailed reporting methods shall be preferred, if the data required for the more detailed methods may be made available with sufficient accuracy and within the limits of practicability.

In this standard, mass flows and parameters of the raw meal, kiln feed, CKD (filter and bypass dust) and clinker refer to a dry state (< 1 % humidity). Normally, the residual moisture of these materials is negligible when measurements are performed in the state as the material or fuel is fed to the process.

The CO<sub>2</sub> emissions from the calcination of relatively small amounts of carbonates in fuel ashes added to the kiln system shall be completely accounted for the reporting of fuel CO<sub>2</sub> emissions. Normally, this is assured by determining the CO<sub>2</sub> emission factors for fuels based on the total carbon content (TC) of the fuels, which includes both total organic carbon (TOC) and total inorganic carbon (TIC). Materials with high contents of both TOC and TIC (e.g. municipal sewage sludge) may be regarded as fuel and/or raw material. In any case, the complete CO<sub>2</sub> emissions resulting from their use shall be accounted. Figure 7 summarizes the proposed methodology and the methods for determining the main sources of CO<sub>2</sub> from raw material calcination.

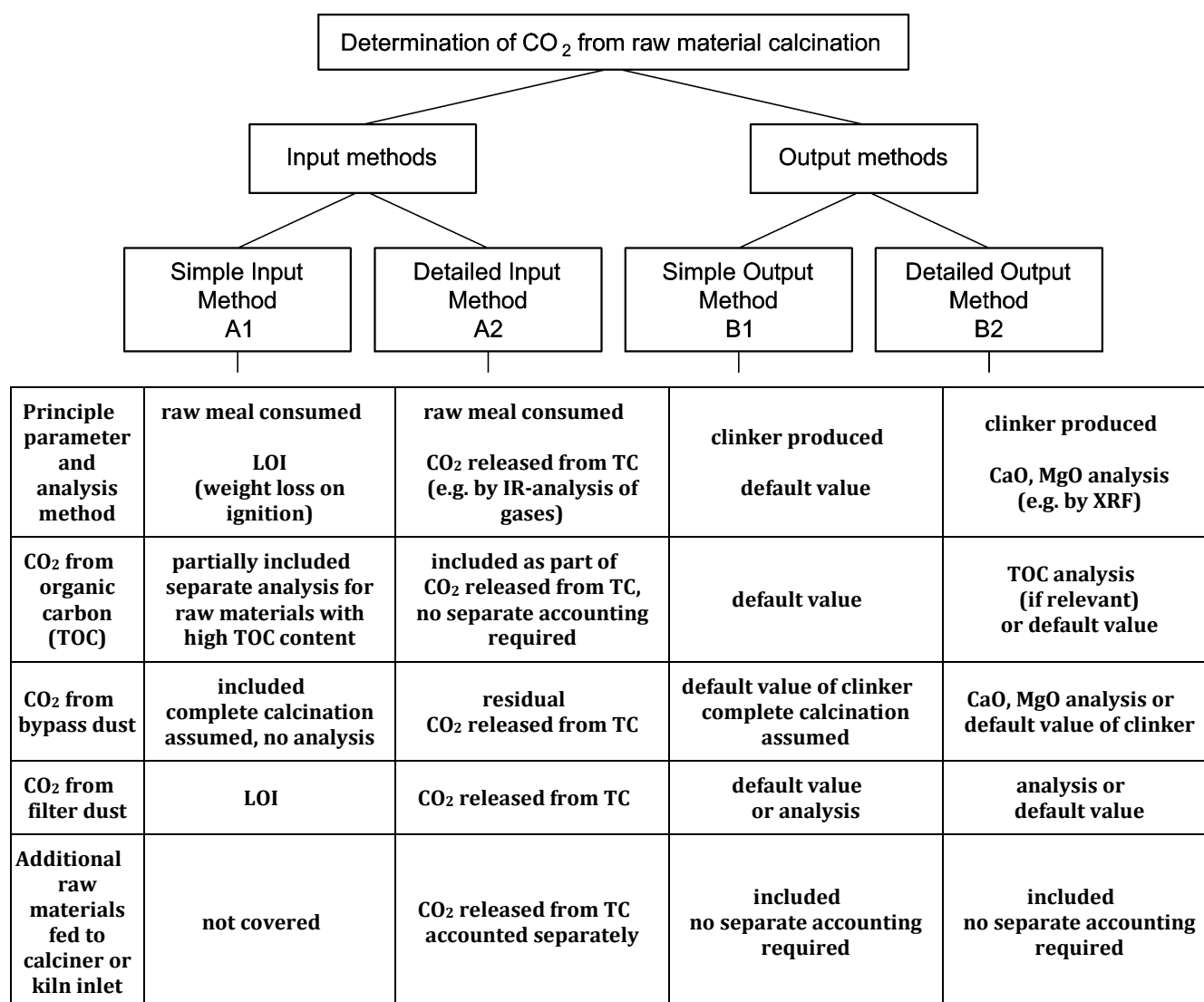


Figure 7 — Overview of methods for the determination of CO<sub>2</sub> emissions from raw material calcination



### 7.2.2 Input methods (A1) and (A2)

The input methods are based on determining the amount of raw meal consumed for clinker production from the kiln feed considering a correction for dust return. Both methods (simple input method A1 and detailed input method A2) account for:

- CO<sub>2</sub> emissions from raw material calcination for clinker production,
- CO<sub>2</sub> emissions from calcination of cement kiln dust (CKD = filter and/or bypass dust) leaving the kiln system,
- CO<sub>2</sub> emissions from the organic carbon content (TOC) of raw materials.

**(1) Raw meal consumed:** The amount of raw meal consumed for the production of clinker in the kiln including calcined bypass dust leaving the kiln system is determined from the amount of **kiln feed** calculated or measured at plant level. The kiln feed weighing is the principle measurement, which determines the final accuracy of reporting according to the input method to the largest extent.

The amount of kiln feed is corrected by subtracting the amount of dust that is returned, e.g. from the pre-heater, and which is either recirculated to the kiln feed or to the raw meal silo or discarded as filter dust leaving the kiln system. The concept of the mass flows is illustrated in Figure 7. The correction of the kiln feed by the rate of dust return prevents double counting of recirculated dust. The input methods thus calculate the amount of raw meal that is consumed for the production of clinker and bypass dust leaving the kiln system, where relevant.

The **fraction of dust return** with reference to the kiln feed shall be determined at plant level. For that purpose different methods may be applied. Two common methods are either direct measuring (weighing) the amount of dust return or determining the fraction of dust return from a kiln mass balance. In such a balance, the mass inputs from the kiln feed and fuel ashes, and the clinker output, the loss on ignition of the raw meal and dust leaving the kiln system (e.g. as bypass dust) are balanced to yield the mass of dust returned to the dust cycle in a certain period.

In any case, the methods applied for determining the fraction of dust return shall provide sufficient accuracy. When measurements from certain periods of kiln operation are used, these shall be representative of the kiln operation during the period, for which the emission report is prepared. Normally, this will require repeated measurements in order to account for potential changes in the fraction of dust return over time and/or changes with different modes of kiln operation.

The **amount of CO<sub>2</sub> emissions** from the calcination of the raw meal consumed is calculated by multiplication with the weight fraction of the **CO<sub>2</sub> released from TC of uncalcined raw meal (RM)** in the detailed input method A2 or in the simple input method A1 its **loss on ignition (LOI)**. The corresponding parameter of the raw meal shall be measured regularly at plant level.

Instead of the raw meal parameter the respective parameter analyzed in samples of the kiln feed may be used, when the difference remains insignificant and a regular analysis of the raw meal cannot be achieved. The difference remains small when the dust returned from the pre-heater system shows a very low degree of calcination (as often observed for kiln systems with dry process and cyclone pre-heaters) or if only very small amounts of dust are recycled from the pre-heater to the kiln feed.

- For this parameter substitution in the simple input method A1, the difference of the kiln feed to the raw meal parameter shall not exceed 1% and the degree of calcination  $d$  in the dust returned from the pre-heater shall not exceed 5 %.
- For the parameter substitution in the detailed input method A2, the difference between both parameters shall be analyzed and it shall be demonstrated that the CO<sub>2</sub> emission reporting is complete and no systematic difference exists between the use of parameters determined from raw meal or kiln feed samples, with regard to the limits of accuracy and practicality.

In addition to inorganic carbonates, the raw materials used for clinker production normally contain a small fraction of **organic carbon**, which is converted to CO<sub>2</sub> during pyro-processing of the raw meal. CO<sub>2</sub> emissions originating from the total organic carbon content (TOC) shall be included in the parameters used for reporting of CO<sub>2</sub> emissions by the input methods:

For the **detailed input method A2**, the **measurement of the CO<sub>2</sub> from total carbon** should determine the complete CO<sub>2</sub> emissions from the raw meal and any additional raw materials. This means it should encompass CO<sub>2</sub> released from the inorganic carbon content (TIC) and the organic carbon content (TOC) of the corresponding materials. Such measurements may be performed, e.g. by total carbon (TC) analysis or by CO<sub>2</sub> IR-analysis of the gases released from the heated and fully oxidized sample.

In the **simple input method A1**, the weight fraction of the **loss on ignition (LOI)** accounts for all CO<sub>2</sub> from the calcination of carbonates. CO<sub>2</sub> emissions from the organic carbon content (TOC) are normally relatively small. They are also accounted by the LOI, but only partially. On the other hand, the mass difference between TOC and the carbon dioxide (CO<sub>2</sub>) emissions from TOC is often more than fully compensated by small amounts of residual humidity in raw meal samples, which is released as water vapour (H<sub>2</sub>O) during heating. This weight loss is also accounted by the LOI. Thus, emission reporting based on the LOI in the simple input method in most cases provides a relatively accurate estimate of the total CO<sub>2</sub> emissions from the calcination and pyro-processing of the raw meal consumed. If raw materials with high organic carbon contents are used, then – instead of the LOI measurements – the CO<sub>2</sub> content including CO<sub>2</sub> emissions from the total organic carbon content (TOC) shall be used as in the detailed input method A2. This could be necessary, for example, if a plant consumes substantial volumes of shale or fly ash high in TOC content as raw materials entering the kiln. In certain cases it may make sense to treat the TOC of such materials separately as a “virtual” fuel component. This means that the material will be distinguished (by calculation) in a raw material component (covering the mineral part/carbonates) and a “fuel part” (based on the TOC content).

**(2) Filter dust leaving the kiln system** refers to all dust that is not recycled to become part of the kiln feed again. For example, it could be sold directly, added to cement or other products, or discarded as a waste. The definition of filter dust leaving the kiln system excludes bypass dust, which is treated separately in the detailed input method A2. The amount of filter dust leaving the kiln system is subtracted as part of the dust return from the measured kiln feed according to the concept of determining the raw meal consumed. Consequently, emissions from the calcination of filter dust leaving the kiln system shall be considered separately. In the dry process filter dust is often uncalcined. However, partially calcined filter dust is often extracted in plants with semi-dry, semi-wet and wet processes. The CO<sub>2</sub> emissions from its calcination need to be accounted. The CO<sub>2</sub> emissions from calcination of raw meal that will form bypass dust are already accounted as calcination CO<sub>2</sub> originating from the raw meal consumed.

CO<sub>2</sub> from filter dust leaving the kiln system shall be calculated based on the relevant volumes of dust and either the carbonate CO<sub>2</sub> content or the LOI of filter dust measured at plant level. From the carbonate CO<sub>2</sub> content or LOI of filter dust and uncalcined raw meal (RM) the CO<sub>2</sub> emission factor  $EF_{FD}$  is calculated according to the following formulae:

$$EF_{FD} = \frac{fCO2_{RM} \times d}{1 - fCO2_{RM} \times d} \quad (1)$$

$$d = 1 - \frac{fCO2_{FD} \times (1 - fCO2_{RM})}{(1 - fCO2_{FD}) \times fCO2_{RM}} \quad (2)$$

where

- $EF_{FD}$  is the emission factor of partially calcined filter dust (t CO<sub>2</sub>/t FD);
- $fCO_{2RM}$  is the weight fraction of carbonate CO<sub>2</sub> in the raw meal (--);
- $d$  is the FD calcination rate (released CO<sub>2</sub> expressed as a fraction of the total carbonate CO<sub>2</sub> in the raw meal);
- $fCO_{2FD}$  is the weight fraction of carbonate CO<sub>2</sub> in the FD (--).

The variables  $fCO_{2RM}$  and  $fCO_{2FD}$  are replaced by  $LOI_{RM}$  and  $LOI_{FD}$  respectively in the simple input method A1, i.e. the weight fractions of the loss on ignition. The calcination rate  $d$  of the FD shall preferably be based on plant-specific data. In the absence of such data, a default value of 0 shall be used for dry process kilns because FD is usually not, or only to a negligible degree, calcined in this process. In other processes (half dry, half wet or wet) calcination rates may be significant. In the absence of data, a default value of 1 shall be used for these kiln types. This value is conservative, i.e. in most cases it will lead to an overstatement of FD-related emissions. Formula (1) for the input method is based on raw meal analysis, while  $EF_{FD}$  according to the output method is based upon the CO<sub>2</sub> emission factor of clinker (see Formula (7)). Both calculation methods should lead to the same result.

In the absence of plant-specific data on dust volumes, the IPCC default for CO<sub>2</sub> from discarded dust (2 % of clinker CO<sub>2</sub>) shall be used. It should be noted, however, that this default is clearly too low in cases where relevant quantities of dust leave the kiln system. Therefore, using plant- or organization -specific data is clearly preferable.

**(3) Partial calcination of bypass dust:** Normally, bypass dust (BPD) extracted from the kiln system is fully calcined. This assumption is made in the simple input method A1. However, in certain types of installations bypass dust is only partially calcined. Depending on the amount of BPD extraction and its degree of calcination, this may be relevant for the accuracy of reporting emissions from raw material calcination. In such cases the detailed input method A2 should be preferred and the amount of BPD leaving the kiln system and the carbonate CO<sub>2</sub> content of the BPD shall be measured at plant level. The amount of residual CO<sub>2</sub> in the mass flow of BPD leaving the kiln system shall then be subtracted from the amount of CO<sub>2</sub> from the calcination of raw meal consumed. This is a correction for the uncalcined fraction of BPD.

**(4) Additional raw materials not included in kiln feed:** Options for considering additional raw materials are provided in the detailed input method A2. In case of raw material additions which are not included in the kiln feed, e.g. directly to the rotary kiln inlet, the simple input method cannot be used. For each type of material, its quantity and CO<sub>2</sub> content including CO<sub>2</sub> emissions from the organic carbon content (TOC) shall be measured at plant level. Only if the same material is additionally reported as fuel with an emission factor based on a relatively high TOC content, then the reporting of CO<sub>2</sub> emissions as additional raw material shall be restricted to its total inorganic carbon content (TIC), compare 7.2.1

Formula for the simple input method A1:

$$CO_2 \text{ Raw Materials} = \text{Kiln Feed} \times (1 - \text{Dust Return Correction}) \times LOI_{RM} + \text{FD leaving kiln system} \times EF_{FD} \quad (3)$$

Formula for the detailed input method A2 as:

$$CO_2 \text{ Raw Materials} = \text{Kiln Feed} \times (1 - \text{Dust Return Correction}) \times fCO_{2RM,TC} + \text{FD leaving kiln system} \times EF_{FD} - \text{BPD leaving kiln system} \times fCO_{2BPD,TC} + \sum_i (ARM_i \times fCO_{2ARM,TC,i}) \quad (4)$$

where (for Formulae (3) and (4)):

$CO_2$ Raw Materials	is the total CO <sub>2</sub> from raw material (t CO <sub>2</sub> /yr);
Kiln Feed	is the amount of kiln feed measured at plant level (t/yr);
Dust Return Correction	is the fraction of returned dust with reference to the kiln feed (--);
$LOI_{RM}$	is the weight fraction of the loss on ignition of raw meal (--);
$fCO_{2, RM, TC}$	is the weight fraction of CO <sub>2</sub> content in the raw meal here including CO <sub>2</sub> emissions from TOC (--);
FD leaving kiln system	is the amount of filter dust leaving the kiln system (t/yr);
$EF_{FD}$	is the CO <sub>2</sub> emission factor of partially calcined filter dust (t CO <sub>2</sub> /t FD);
BPD leaving kiln system	is the amount of bypass dust leaving the kiln system (t/yr);
$fCO_{2, BPD, TC}$	is the weight fraction of CO <sub>2</sub> released from TC in the bypass dust (--);
$ARM_i$	is the amount of additional raw material $i$ (t/yr), which is not part of the kiln feed;
$fCO_{2, ARM, TC, i}$	is the weight fraction of CO <sub>2</sub> released from TC in the additional raw material $i$ (--).

**Adjustments to the concept of the input methods:** In special cases an adjustment of the concept of the input methods might be necessary, in order to reflect certain material flows in a plant and to assure their correct accounting. The adjustments shall be explained and accompanied by an overview of all relevant material flows. Furthermore it shall be demonstrated, that CO<sub>2</sub> emissions from the complete and partial calcination of raw materials and from the organic carbon content of raw materials are completely and more accurately accounted by the adjusted method.

### 7.2.3 Output Methods (B1) and (B2)

To apply the clinker-based output methods, companies shall use their plant-specific data, as follows:

**(1) Clinker:** Calcination CO<sub>2</sub> shall be calculated based on the volume of clinker produced and an emission factor per tonne of clinker. The emission factor shall be determined based on the measured CaO and MgO contents of the clinker, and corrected if relevant quantities of CaO and MgO in the clinker stem from non-carbonate sources. This could be the case, for example, if calcium silicates or fly ashes are used as raw materials entering the kiln.

The determination of the emission factor for clinker shall be clearly documented. The detailed method refers to the CaO and MgO analysis of the clinker and a correction for non-carbonate sources of these oxides.

In the absence of better data, a default of 525 kg CO<sub>2</sub>/t clinker shall be used (**simple output method B1**). This value is comparable to the IPCC default (510 kg CO<sub>2</sub>/t) corrected for typical MgO contents in clinker. See 7.3 for details on the default emission factor.

$$EF_{cli} = fCaO_{cli} \times 0,785 \text{ tCO}_2/\text{t CaO} + fMgO_{cli} \times 1,092 \text{ tCO}_2/\text{t MgO} \quad (5)$$

where

$EF_{cli}$	is the CO <sub>2</sub> emission factor of clinker (kg CO <sub>2</sub> /t clinker);
$fCaO_{cli}$	is the CaO content of clinker (%);
$fMgO_{cli}$	is the MgO content of clinker (%).

Significant contents of non-carbonate CaO and MgO (e.g. from precalcined raw materials) might be subtracted.

**(2) Dust:** CO<sub>2</sub> from bypass dust or filter dust leaving the kiln system shall be calculated based on the relevant volumes of dust and an emission factor. The calculation shall account for the complete volumes of dust leaving the kiln system, irrespective of whether the dust is sold directly, added to cement, or discarded as a waste.

**Bypass dust** is usually fully calcined. Therefore, emissions related to bypass dust shall be calculated using the emission factor for clinker. If there is more information available the emission factor of BPD may be estimated from the calcination rate of BPD according to Formula (7) suggested for FD emissions.

Alternatively, the CO<sub>2</sub> emission factor of bypass dust (EF<sub>BPD</sub>) may be determined from CaO, MgO and remaining carbonate CO<sub>2</sub> analysed in BPD samples. These parameters are directly related to the mass of BPD. This method gives more precise results, especially in the case of components like alkaline chlorides and sulphates being enriched in the BPD compared to the composition of clinker or partially calcined raw meal.

$$EF_{BPD} = CO_{2CaO} + CO_{2MgO} - fCO_{2BPD} = (CO_{2CaO} + CO_{2MgO}) \times d \quad (6)$$

where (for Formula 6):

- $EF_{BPD}$  is the CO<sub>2</sub> emission factor of partially calcined bypass dust (t CO<sub>2</sub>/t BPD);
- $CO_{2CaO}$  is the stoichiometric amount of CO<sub>2</sub> related to the content of calcium oxide in bypass dust (t CO<sub>2</sub>/t BPD);
- $CO_{2MgO}$  is the stoichiometric amount of CO<sub>2</sub> related to the content of magnesium oxide in bypass dust (t CO<sub>2</sub>/t BPD);
- $fCO_{2BPD}$  is the weight fraction of carbonate CO<sub>2</sub> content in the bypass dust (t CO<sub>2</sub>/t BPD);
- $d$  is the BPD calcination rate (released CO<sub>2</sub> expressed as a fraction of the total carbonate CO<sub>2</sub> in fully uncalcined bypass dust).

The calculation of the CO<sub>2</sub> emission factor of BPD (EF<sub>BPD</sub>) according to Formula 6 follows the same method as normally applied for determination of the emission factor of clinker (EF<sub>cli</sub>). However, by using parameters from bypass dust and its specific mass reference, it considers

- a) a reduction of the mass fraction of CaO and MgO in bypass dust (in comparison to calcined raw meal or clinker) due to enrichment of alkaline chlorides and sulphates, and
- b) its partial calcination (degree of calcination  $d$ ):

**Filter dust**, as opposed to bypass dust, is usually not fully calcined. The emission factor for filter dust shall be determined based on the emission factor for clinker and the calcination rate of the filter dust.

$$EF_{FD} = \frac{\frac{EF_{cli}}{1 + EF_{cli}} \times d}{1 - \frac{EF_{cli}}{1 + EF_{cli}} \times d} \quad (7)$$

where

$EF_{FD}$  is the emission factor of partially calcined filter dust (t CO<sub>2</sub>/t FD);

$EF_{Cl}$  is the plant specific emission factor of clinker (t CO<sub>2</sub>/t clinker);

$d$  is the FD calcination rate (released CO<sub>2</sub> expressed as a fraction of the total carbonate CO<sub>2</sub> in the raw meal), see Formula (2).

See B.2 for details about deriving the calculation formula in Formula (7).

The calcination rate  $d$  of the FD shall preferably be based on plant-specific data. In the absence of such data, a default value of 0 shall be used for dry process kilns because FD is usually not or only to a negligible degree calcined in this process. In other processes (half dry, half wet or wet) calcination rates may be significant. In the absence of data, a default value of 1 shall be used for these kiln types. This value is conservative, i.e. it will in most cases lead to an overstatement of FD-related emissions. A2 is based on raw meal analysis, while B.2 is based upon the CO<sub>2</sub> emission factor of clinker. Both mass balance methods should lead to the same result. See 7.3 to 7.6 self-calculating for details on the calcination rate  $d$  and Formulae (1), (2) and (7).

In the absence of plant-specific data on dust volumes, the IPCC default for CO<sub>2</sub> from discarded dust (2 % of clinker CO<sub>2</sub>, see 7.3) shall be used. It should be noted, however, that this default is clearly too low in cases where relevant quantities of dust leave the kiln system. Therefore, using plant- or organization - specific data is clearly preferable.

**(3) CO<sub>2</sub> from organic carbon in raw materials:** In addition to inorganic carbonates, the raw materials used for clinker production usually contain a small fraction of organic carbon which is mostly converted to CO<sub>2</sub> during pyro-processing of the raw meal. The total organic carbon (TOC) contents of raw materials may vary substantially between locations, and between the types of materials used.

Data compiled by the CSI indicate that a typical value for TOC in the raw meal is about 0,1 % to 0,3 % (dry weight). This corresponds to CO<sub>2</sub> emissions of about 10 kg /t clinker, representing about 1 % of the typical combined CO<sub>2</sub> emissions from raw material calcination and kiln fuel combustion.<sup>4)</sup>

CO<sub>2</sub> emissions from organic carbon in raw materials shall be quantified and reported to ensure completeness of the inventory (see Clause 10 on materiality thresholds). However, since their contribution to overall emissions is small, a simple calculation needs to be implemented which multiplies clinker production with the following default values:

- default raw meal to clinker ratio: 1,55
- default TOC content of raw meal: 2 kg /t raw meal (dry weight, corresponding to 0,2 %). This default factor for the TOC content has been checked by collecting and analyzing more than 100 analyses from different raw materials from cement plants all over the world. Based on the analysis of the data the value of the default factor of 0,2 % is confirmed.

Companies are not required to analyse these emissions any further unless they have indications that organic carbon is more relevant. This could be the case, for example, if an organization consumes substantial volumes of shale or fly ash high in TOC content as raw materials entering the kiln. Furthermore, please note that any volumes of dust leaving the kiln system are not automatically reflected in this default calculation.

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<sup>4)</sup> 1,55 t raw meal /t clinker x 2 kg C /t raw meal x 3.664 kg CO<sub>2</sub> /kg C = 11 kg CO<sub>2</sub> /t clinker, under the assumption that all organic carbon is converted to CO<sub>2</sub>. The latter is conservative since a part of the organic carbon will usually be emitted as VOC or CO. The TOC content of 2 kg /t raw meal was determined based on 43 measurements compiled by CSI Member Companies for Europe and Northern Africa and has now been checked by collecting and analysing more than 100 analyses from different raw materials from cement plants all over the world

Companies producing substantial quantities of dust should apply their plant-specific raw meal to clinker ratios if they wish to analyse their TOC-related emissions in more detail. Plant-specific raw meal to clinker ratios should exclude the ash content of the fuels used, to avoid double-counting. For example, if fly ash with a high carbon content is accounted for as a fuel (i.e., by assigning it a heating value and CO<sub>2</sub> emission factor), its ash content should not be included in the raw meal to clinker ratio for the purpose of calculating emissions from TOC in raw meal.

Formula for the output methods B1 and B2:

$$\begin{aligned}
 CO_2 \text{ Raw Materials} &= \text{Clinker} \times EF_{cli} \\
 &+ \text{BPD leaving kiln system} \times EF_{BPD} \\
 &+ \text{FD leaving kiln system} \times EF_{FD} \\
 &+ \text{Raw Meal Consumed} \times fTOC_{RM} \times 3.664
 \end{aligned}
 \tag{8}$$

The raw meal consumed is here calculated by

$$\text{Raw Meal Consumed} = \text{Clinker} \times \text{RM/Cli-ratio}
 \tag{9}$$

where (for Formulae (8) and (9)):

<i>CO<sub>2</sub> Raw Materials</i>	is the total CO <sub>2</sub> from raw material (t CO <sub>2</sub> /yr);
<i>Clinker</i>	is the clinker production measured at plant level (t/yr);
<i>EF<sub>cli</sub></i>	is the CO <sub>2</sub> emission factor of clinker (kg CO <sub>2</sub> /t clinker); simple output method (B1): default value = 0,525 t CO <sub>2</sub> /t clinker; detailed output method (B2): determination according to 7.3;
<i>BPD leaving kiln system</i>	is the amount of bypass dust leaving the kiln system (t/yr);
<i>EF<sub>BPD</sub></i>	is either EF <sub>cli</sub> „ estimated from its calcination rate or determined from analysis (see above);
<i>FD leaving kiln system</i>	is the amount of filter dust leaving the kiln system (t/yr);
<i>EF<sub>FD</sub></i>	is the CO <sub>2</sub> emission factor of partially calcined filter dust determined according to Formula (7) (t CO <sub>2</sub> /t FD);
<i>Raw Meal Consumed</i>	is the amount of raw meal consumed for clinker production and bypass dust (t/yr);
<i>fTOC<sub>RM</sub></i>	is the weight fraction of total organic carbon (TOC) in the raw meal (--); default value = 0,002 = 0,2 %;
<i>RM/Cli-ratio</i>	is the raw meal clinker mass ratio (raw meal consumed per clinker production, -), the addition of fuel ashes and dust leaving the kiln system shall be accounted for its determination; default value = 1,55.

### 7.3 Reporting of CO<sub>2</sub> emissions from raw material calcination based on clinker output: summary of IPCC and CSI recommendations and default emission factor for clinker

IPCC (2006) recommends calculating calcination CO<sub>2</sub> based on the CaO content of the clinker produced (0,785 t CO<sub>2</sub>/t CaO, multiplied with the CaO content in clinker). A default CaO content in clinker of 65 % is recommended, corresponding to 510 kg CO<sub>2</sub>/t clinker.

CO<sub>2</sub> from discarded kiln dust, according to IPCC, should be calculated separately, taking into account its degree of calcination. Where more precise data is not available, IPCC recommends accounting for discarded dust by adding 2 % to clinker CO<sub>2</sub> by default, acknowledging that emissions may range much

higher in some instances. IPCC does not distinguish between bypass dust and filter dust. Furthermore, the IPCC default value neglects CO<sub>2</sub> from decomposition of magnesium carbonates (MgO content in clinker is usually about 2 %).<sup>5</sup>

This standard recommends determining the emission factors for clinker calcination on a plant-specific basis. To this end, an auxiliary worksheet for the detailed output method (B2) has been included in the spreadsheet of the CSI protocol [1], which may account for the specific CaO and MgO content of a plant's clinker as well as non-carbonate sources of CaO and MgO such as calcium silicates, or fly ash added to raw meal. In the absence of plant-specific data, this standard recommends using the simple output method (B1) with a default emission factor of 525 kg CO<sub>2</sub>/t clinker, corresponding to the IPCC default corrected for Mg carbonates.

The CO<sub>2</sub> emission factor for clinker determined from the specific CaO and MgO content does not account for CO<sub>2</sub> emissions resulting from CKD leaving the kiln system and CO<sub>2</sub> emissions, which originate from the **organic carbon content (TOC) of raw materials**. Consequently, these CO<sub>2</sub> emissions are accounted additionally to the CO<sub>2</sub> emissions from calcination of raw material for clinker production (for details see Formula (8) and corresponding descriptions in 7.2.2).

#### 7.4 Determining the FD calcination rate

The FD calcination rate  $d$  shall be calculated according to Formula (10), based on the weight fractions of carbonate CO<sub>2</sub> in the FD and in the raw meal, respectively. The two input parameters  $fCO_{2FD}$  and  $fCO_{2RM}$  shall be measured by chemical analysis. Possible analysis methods include, for example, a loss on ignition test, titration or CO<sub>2</sub> emission analysis by infra-red (IR) detection.

$$d = 1 - \frac{fCO_{2FD} \times (1 - fCO_{2RM})}{(1 - fCO_{2FD}) \times fCO_{2RM}} \quad (10)$$

where

$fCO_{2FD}$  is the weight fraction of carbonate CO<sub>2</sub> in the FD (--);

$fCO_{2RM}$  is the weight fraction of carbonate CO<sub>2</sub> in the raw meal (--).

In the absence of measurement data on the composition of the FD, a default value of 1 shall be used for the calcination rate  $d$ . This value is conservative, i.e. it will in most cases lead to an overstatement of FD-related emissions, because FD is usually not fully calcined.

Alternatively, the maximum degree of calcination  $d$  is calculated from analysis of cement kiln dust samples only as quotient of the maximum CO<sub>2</sub> potentially released during the calcination process (determined from CaO and MgO analyses) and the analysed remaining carbonate CO<sub>2</sub> content of the sample:

$$d = \frac{CO_{2,CaO} + CO_{2,MgO} - CO_{2,sample}}{CO_{2,CaO} + CO_{2,MgO}} \quad (11)$$

where

$CO_{2,CaO}$  is the stoichiometric maximum content of carbonate CO<sub>2</sub> calculated from CaO;

$CO_{2,MgO}$  is the stoichiometric maximum content of carbonate CO<sub>2</sub> calculated from MgO;

<sup>5</sup> Sources: IPCC recommendation: IPCC 2000, pp. 3.9ff; GNR average: Cement Sustainability Initiative. Global Cement Database on CO<sub>2</sub> and Energy Information (<http://www.wbcdcement.org>)



$CO_{2,sample}$  is the carbonate  $CO_2$  content of the sample (carbon dioxide according to EN 196-2 [11]).

## 7.5 Direct determination of the $CO_2$ emission factor of FD from analysis of $CO_2$ content

For the direct determination of the  $CO_2$  emission factor of FD, the combination of Formulae (1) and (10) yields

$$EF_{FD} = \frac{fCO_{2RM} - \frac{fCO_{2FD} \times (1 - fCO_{2RM})}{(1 - fCO_{2FD})}}{(1 - fCO_{2RM}) + \frac{fCO_{2FD} \times (1 - fCO_{2RM})}{(1 - fCO_{2FD})}} \quad (12)$$

Formula (12) is simplified after complementation of the left hand term by multiplication with

$$\frac{\frac{(1 - fCO_{2FD})}{(1 - fCO_{2RM})}}{\frac{(1 - fCO_{2FD})}{(1 - fCO_{2RM})}} = 1 \quad (13)$$

As result the  $CO_2$  emission factor of FD could equally be determined directly by the following formula:

$$EF_{FD} = fCO_{2RM} \times \frac{(1 - fCO_{2FD})}{(1 - fCO_{2RM})} - fCO_{2FD} \quad (14)$$

In Formula (14) the terms in round brackets correct the mass reference of the carbonate  $CO_2$  content  $fCO_{2RM}$  determined in samples of the uncalcined raw meal to the mass reference of FD, which potentially is partially calcined. The  $CO_2$  emission factor of FD,  $EF_{FD}$  is determined from the difference of the carbonate  $CO_2$  content between the potentially partially calcined state and the hypothetical uncalcined state of FD.

## 7.6 Cement specific issues for fuels

### 7.6.1 Traditional fuels

Traditional fuels are fossil fuels including e.g. coal, petcoke, fuel oil and natural gas. The preferred approach is to calculate  $CO_2$  from traditional fuels (but also alternative and non-kiln fuels, see 7.6.2 and 7.8) based on fuel consumption, lower heating values, and the matching  $CO_2$  emission factors.

Fuel consumption and lower heating values (LHV or net calorific value NCV) of fuels are routinely measured at plant level. It is important to note that the applied heating value always has to match the status of the fuel, especially with respect to the correct moisture content during its weighing (e.g. raw coal or dried coal). Normally the lower heating value is determined from a dried sample. Subsequently a moisture correction has to be applied to the result, correcting the mass reference from the dried sample back to the original moisture content of the fuel as it is consumed or weighed.

Furthermore, the correct reference of the  $CO_2$  emission factors (EF) shall be assured. The reference shall be to the heat determined by the lower heating value (LHV). For the conversion of higher heating values (HHV or gross calorific value GCV) to LHV the formula defined in the 2006 IPCC Guidelines (Vol. II, Section 1.4.1.2, Box 1.1) [4] may be applied.

Companies are encouraged to use plant- or country-specific emission factors if reliable data are available. The emission factor of fuels shall be based on the total carbon content. If a fuel contains significant amounts of inorganic carbon (TIC), it may be reported based on its total organic carbon (TOC) content if, in addition,  $CO_2$  emissions from its total inorganic carbon content (TIC) are reported as

CO<sub>2</sub> emissions from raw material calcination. Direct calculation of emissions based on fuel consumption (in tonnes) and fuel carbon content (in percent) is acceptable on the condition that material variations in the composition of the fuel, and especially its water content, are adequately accounted for.

Generally, IPCC recommends accounting for incomplete combustion of fossil fuels. However, usually 99 % to 100 % of the carbon is oxidized<sup>6</sup>. In cement kilns, incomplete oxidation is negligible, due to very high combustion temperatures and long residence time in kilns and no, or minimal, residual carbon found in clinker. Consequently, carbon in all kiln fuels shall be treated as fully oxidized. The CO<sub>2</sub> emission factors of fuels shall always be determined based on the total carbon (TC) content.

### 7.6.2 Alternative fuels

IPC C 1996 and 2006 guidelines for national GHG inventories require the following:

- **CO<sub>2</sub> from biomass and bioliquids** is considered climate-neutral, because emissions may be compensated by re-growth of biomass in the short term. CO<sub>2</sub> from biomass and bioliquids is reported as a "memo item", but excluded from the national emissions totals.
- **CO<sub>2</sub> from fossil fuel-derived wastes** (also called **alternative fossil fuels** or **fossil AF**), in contrast, is not *a priori* climate-neutral. According to IPCC guidelines, GHG emissions from industrial waste-to-energy conversion are reported in the "energy" source category of national inventories, while GHG emissions from conventional waste disposal (landfilling, incineration) are reported in the "waste management" category.
- **CO<sub>2</sub> from mixed fuels with biomass and fossil fractions**: In the case that biomass or bioliquids are combusted jointly with fossil fuels (e.g. pre-treated industrial and/or domestic wastes), a split between the fossil and non-fossil fraction of the fuel should be established and the emission factors applied to the appropriate fractions (IPC C 2006, Vol. II, Section 2.3.3.4).

To ensure consistency with the guidelines of IPCC, there is a need for transparent reporting of the direct CO<sub>2</sub> emissions resulting from AF combustion in cement plants. Therefore, this standard requires reporting as follows:

- Direct CO<sub>2</sub> from combustion of **biomass** (including pure biomass or bioliquids, biomass wastes and the biomass fraction of mixed fuels) shall be reported as a memo item, but excluded from absolute direct GHG emissions. The IPCC default emission factor of 110 kg CO<sub>2</sub>/ GJ for solid biomass shall be used, except where other, reliable emission factors are available.<sup>7</sup> This value lies in the range of different values for solid biomass or bioliquids, which are specified as default emission factors in IPC C 2006 (Vol. II, Section 1.4.2.1).
- Direct CO<sub>2</sub> from combustion of **fossil AF** and the fossil fraction of mixed fuels shall be calculated and included in the direct CO<sub>2</sub> emissions. CO<sub>2</sub> emission factors depend on the type of AF or mixed fuel used and, therefore, shall be specified at plant level where practical. In the absence of plant- or organization -specific data, companies shall use the default emission factors.
- Indirect **GHG savings** achieved through the utilization of AF shall be accounted as **net emissions** in this standard. The definition is further described in 5.5.

Generally, the CO<sub>2</sub> emission factors of all fuels shall represent the complete CO<sub>2</sub> emissions from the use of the fuel based on the total carbon content (TC).

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<sup>6</sup> Compare IPCC 2006, Vol. II, Section 1.4.2.1 and IPCC 1996, Vol. III, p.1.29, Default carbon oxidation factors: 98% for coal, 99% for oil, and 99.5% for natural gas;

<sup>7</sup> See IPCC 1996, Vol. III, p.1.13

Some AF, for example used tyres and impregnated saw dust, contain both fossil and biomass carbon. These fuels shall be treated as mixed fuels and the CO<sub>2</sub> emissions shall be separated in their fossil and biogenic part. This is done by determining the share of the biogenic carbon in the fuel's overall carbon content, according to ISO/EN international standards (e.g. EN 15440) or suitable national standards. For some fuel types this share is difficult and costly to measure, and very variable. Companies are advised to use a conservative approach in determining the biogenic carbon content, meaning that the biogenic carbon content should not be overestimated. A fossil carbon content of 100 % shall be assumed for fuel types in case of a lack of reliable information on their biogenic carbon content until more precise data becomes available.

Fuels, which contribute significantly to the mass of the product clinker with their ash content and which have a significant total inorganic carbon (TIC) content may be reported as fuel with a CO<sub>2</sub> emission factor based on the total organic carbon (TOC) content. In this case and when reporting CO<sub>2</sub> emissions from raw materials based on their input (see 7.2.1), the CO<sub>2</sub> emissions from the TIC content shall be reported additionally. This shall be done by using the detailed input method A2 and the option for reporting additional raw materials (Adrm) which are not part of the kiln feed. If CO<sub>2</sub> emissions from TOC of the material are already reported as fuel, the CO<sub>2</sub> content specified for the additional raw material shall only reflect the remaining TIC content so that CO<sub>2</sub> emissions from the total carbon content (TC) are reported (compare 7.2.1 (4)).

### **7.7 GHG from fuels for kilns**

Kiln fuels in this standard are all fuels fed to the kiln system plus fuels that are used for drying and processing the raw materials or other kiln fuels. Included in this definition are fuels inserted through a main firing system of the kiln as well as fuels added to a calciner or directly to the kiln inlet. In this standard such fuels are regarded as kiln fuels, irrespective of the potential use of waste heat for the production of electrical power. Also fuels used for fuel heating (e.g. for heavy fuel oil used for clinker production) shall be reported under kiln fuels. Fuels used for the drying of mineral components (MIC) used in cement grinding and fuels used for electricity production in an installation that is separate from the kiln system shall be reported as non-kiln fuels.

The specific GHG emissions and the specific fuel energy consumption of clinker production are determined by the use of kiln fuels including the raw material and fuel preparation.

### **7.8 GHG from non-kiln fuels**

Non-kiln fuels include all fuels which are not included in the definition of kiln fuels Clause 3). For instance fuels used

- for plant and quarry vehicles,
- for room heating,
- for thermal process equipment (e.g. dryers), which could be used in the preparation of mineral components (MIC) for cement grinding,
- in a separate installation for on-site production of electrical power.

Cement companies shall ensure the complete reporting of GHG emissions from non-kiln fuels combusted on site. These emissions are accounted for as follows:

- GHG from non-kiln fuels is reported separately, by application type, to provide flexibility in the aggregation of emissions for the following applications:
  - equipment and on-site vehicles;
  - room heating / cooling;

- drying of MIC such as slag or pozzolana;
- on-site power generation in separately fired boilers and diesel/gasoline engine power generation.

Note that fuels consumed for drying of raw materials for the production of clinker and kiln fuels are included in the kiln fuel section.

- GHG from off-site transports by organization -owned fleets is currently excluded from the boundary (see details below).
- Carbon in non-kiln fuels is assumed to be fully oxidized, i.e. carbon storage in soot or ash is not accounted for. The resulting overestimation of emissions will usually be small (approximately 1 %)⁶.

See also Table 7 regarding the process steps which need to be covered to ensure complete reporting according to this standard.

Measured plant-specific lower heating values shall be used, if available. Alternatively IPCC or CSI default values may be applied. If the same type of fuel is used as non-kiln fuel and kiln fuel, then the CO<sub>2</sub> emission factors used for reporting shall correspond. Otherwise, measured plant-specific emission factors shall be used, if available. Alternatively IPCC or CSI defaults values may be applied.

## 7.9 GHG from the combustion of wastewater

Some cement plants inject wastewater in their kilns, for example as a flame coolant for control of nitrogen oxides (NO<sub>x</sub>). The carbon contained in the wastewater is emitted as CO<sub>2</sub>. This standard does not require cement companies to quantify their CO<sub>2</sub> emissions related to wastewater consumption, because these emissions are usually small and, in addition, difficult to quantify:

- most cement plants do not consume wastewater;
- where wastewater is consumed, its carbon content will usually contribute less than 1 % of the plant's overall CO<sub>2</sub> emissions;<sup>8</sup>
- in addition, the carbon contained in the wastewater can be of biomass origin (e.g. sewage), in which case it would have to be counted as a memo item only.

## 7.10 Non-CO<sub>2</sub> GHG emissions from the cement industry

In Annex A of the Kyoto Protocol [4] the United Nations Framework Convention on Climate Change (UNFCCC) defines the following chemical compounds as relevant anthropogenic greenhouse gases (GHG) causing climate change:

- carbon dioxide (CO<sub>2</sub>),
- methane (CH<sub>4</sub>),
- nitrous oxide (N<sub>2</sub>O),
- hydrofluorocarbons (HFCs),

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<sup>8</sup> If a plant uses wastewater, the volume consumed is typically about 10 kg per t of clinker. At a typical carbon content in the wastewater of 5 % by weight, this corresponds to CO<sub>2</sub> emissions of about 2 kg per t of clinker or about 0,2 % of a plant's typical overall CO<sub>2</sub> emissions (values based on data provided by several CSI member companies).

- perfluorocarbons (PFCs), and
- sulphur hexafluoride (SF<sub>6</sub>).

During the clinker and cement production process no HFCs, PFCs or SF<sub>6</sub> are applied. The only possible entry pathways would be minimal quantities of gas remaining in wastes containing foamed plastics. However, such materials are not used as such and are not normally contained in any significant quantity in mixed alternative fuels utilized in the cement industry. Used tyres utilized as alternative fuel in cement plants do not allow for any significant remains of SF<sub>6</sub>.

Non-CO<sub>2</sub> GHG gases, i.e. methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), sulfur hexafluoride (SF<sub>6</sub>), and fluorinated hydrocarbons (PFCs, HFCs) have been measured during the field tests. As a main result of the field tests the conclusion may be drawn that non-CO<sub>2</sub> GHG gases are not significant in the waste gases of cement industry. The main blank values of these measurements are discussed in Annex A.

## **8 Energy indirect and other indirect GHG emissions and their determination**

### **8.1 General**

Energy indirect and other indirect GHG emissions are emissions that are a consequence of the operations of the reporting entity, but occur at sources owned or controlled by another entity. Cement production is associated with indirect GHG emissions from various sources. Key examples include the CO<sub>2</sub> emissions from:

- external production of electricity consumed by cement producers (see 8.2);
- production of clinker bought from other producers and interground with own production;
- production and processing of traditional and alternative fuels by third parties;
- transport of inputs (raw materials, fuels) and outputs (cement, clinker) by third parties.

The definition of the boundaries for the indirect GHG emissions is included in 6.2 under operational boundaries.

Data on energy indirect and other indirect GHG emissions, consisting of several categories, may be useful to assess overall carbon footprint of an industry. To this end, cement companies shall calculate and report GHG both from “external electricity production” and “bought clinker” of energy indirect and other indirect GHG emissions which have a significant impact on GHG emissions.

### **8.2 CO<sub>2</sub> from external electricity production**

CO<sub>2</sub> from external electricity production shall be calculated based on the measured delivery of grid electricity and, preferentially, emission factors obtained from the electricity supplier. Alternatively it is recommended to use governmental data for the national power grid. If both data are not available, an average emission factor for the country may be used. Such factors are based on IEA data which are updated annually (see <http://www.ghgprotocol.org/calculation-tools/cement-sector> for the latest update). Emissions associated with the consumption of electricity during transport and distribution (T&D losses) shall not be included in this calculation. This standard differentiates between the different power sources (purchase, production on-site) and paths of power usage: use for cement production, consumption of power generation auxiliaries (difference between gross and net power production of the power plant) and power sold externally. Power given to other non-cement installations within the same plant shall be treated like power sold externally.

### 8.3 CO<sub>2</sub> from bought clinker

CO<sub>2</sub> from production of bought clinker shall be calculated based on the net clinker transfer (bought clinker minus sold clinker plus internal clinker transfer) of the reporting entity, and the emission factor of the clinker. With respect to clinker transfers within the organization, the real emission factor of the sending plant should be used. If clinker is bought externally, this value is usually not available. In this case a default value shall be used. As a first priority national or regional values shall be applied, if available. As a second priority the global average value may be used.

Please note that the default emission factor of 865 kg CO<sub>2</sub>/t should only be used for calculating the indirect GHG emissions impact associated with net clinker purchases. For a net clinker seller, the clinker purchase balance and hence the resulting emissions will be negative, indicating that the company's clinker sales have indirectly helped to avoid emissions at another cement plant. The same default emission factor should not be used for calculating the gross and net direct GHG emissions of the reporting organization.

The approaches for calculating these two types of indirect GHG emissions are summarized in Clause 8 and Table 10. Besides CO<sub>2</sub> from bought clinker, quantification of other indirect GHG emissions is not required by this standard. This applies, in particular, for indirect GHG emissions related to transports (see Clause 8 for details).

**Table 10 — Parameters and data sources for calculation of energy indirect and other indirect CO<sub>2</sub> emissions as required by this standard**

Emission	Parameters	Units	Source of parameters
CO <sub>2</sub> from external power prod. (energy indirect GHG emission)	Power bought from external grid Emission factor excl. T&D losses	GWh t CO <sub>2</sub> /GWh	Measured at plant level Supplier-specific value or country grid factor
CO <sub>2</sub> from clinker bought (other indirect GHG emission)	Net clinker purchases Emission factor	t cli t CO <sub>2</sub> /t cli	Measured at plant level (bought minus sold clinker + internal clinker transfer) Default factor (from GNR data base [10])

GHG emissions associated with the production of clinker- or cement-substituting mineral components (MIC) shall not be considered as other indirect GHG emission of the cement industry if these emissions are the result of another industrial process. This applies, in particular, to slag produced by the steel industry, and to fly ash produced by power plants.

## 9 Baselines, acquisitions and disinvestments

GHG emissions performance is often measured relative to a past reference year (the “base year”). As a default, the “Kyoto base year” 1990<sup>9</sup> may be used as a reference. In many cases however, the lack of reliable and accurate historical data justifies the use of a more recent base year, especially when compliance or emissions trading is concerned. The choice of base year will also depend on individual country regulations.

<sup>9</sup> Some Annex 1 countries with economies in transition have chosen other years than 1990 as their base year or base period (e.g., Bulgaria and Romania: 1989, Poland: 1988, Hungary: 1985-87). In addition, all Annex 1 countries may choose 1995 as their base year for hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

Acquisitions and divestitures, as well as the opening or closing of plants, will influence an organization's consolidated emissions performance, both in absolute and specific terms. To ensure consistency of baselines (= emissions in and after the base year), companies shall apply the following rules in a consistent way:

- **Adjust the baseline for change by acquisition and divestiture:** Consolidated emissions reported for past years shall always reflect the current amount of shares held in an organization. If an organization is acquired, its past emissions shall be included in the consolidated emissions of the reporting organization. This shall be done either back to the base year, or back to the year the acquired organization came into existence, whichever is later. If an organization is divested, past emissions shall be removed from the consolidated emissions. These adjustments shall be made in accordance with the consolidation rules (see 6.3).
- **No baseline adjustment for “organizational” change:** In case of organic growth of production due to investment in new installations, capacity expansions or improved capacity utilization, the baseline shall not be adjusted. In the same sense the baseline shall not be adjusted for organizational negative growth: Closure of kilns or decrease of production shall not result in a change of the baseline.

## 10 Reporting

### 10.1 General

GHG emissions monitoring and reporting has multiple goals, such as e.g.: internal management of environmental performance, public environmental reporting, reporting for taxation schemes, voluntary or negotiated agreements, and emissions trading. Additional purposes may be, for example, performance benchmarking and product life cycle assessment.

The present standard has been designed as a flexible tool to satisfy these different reporting purposes. The information is structured in such a way that it may be aggregated and disaggregated according to different reporting scopes. Examples include:

- Reporting to national GHG inventories should be compatible with IPCC guidelines. Hence, it should cover all direct GHG emissions, including GHG from fossil wastes. CO<sub>2</sub> from biomass should be reported as a memo item.
- Reporting under CO<sub>2</sub> compliance and taxation schemes will have varying reporting requirements, depending on local conventions. The present standard allows reporting of gross and net emissions and indirect GHG emissions, as appropriate.

The present standard does not define any threshold for excluding “immaterial” emission sources. In practice, the decision whether to include or exclude certain emission sources will also depend on the requirements of the respective reporting framework.

Also the overall uncertainty of a GHG inventory should be reported, see Clause 11 on uncertainty assessment.

### 10.2 Corporate environmental reporting

The objective of voluntary environmental reporting is to provide the reader with a sufficiently accurate picture of the environmental footprint of the reporting organization. This implies that the reporting of cement companies shall cover all relevant emission components:

- gross direct GHG emissions of the reporting entity (calcination, traditional kiln fuels, alternative kiln fuels, non-kiln fuels, with biomass CO<sub>2</sub> as a memo item);

- net emissions (if applicable), calculated from gross emissions minus emissions from the use of alternative fuels;
- main indirect GHG emissions (consumption of grid electricity and bought clinker).

Reporting shall be in absolute (Mt CO<sub>2</sub>/year) as well as specific (kg CO<sub>2</sub>/t cement constituents material) units. Reporting of net emissions alone, omitting gross emissions is not acceptable.

In order to be complete, reporting shall include the CO<sub>2</sub> emissions (including indirect CO<sub>2</sub> emissions from consumption of grid electricity and accounting for own on-site power generation) from the different process steps.

Additional requirements for voluntary reporting include:

- It shall be clearly stated when GHG sources are excluded from the inventory. To this end, this standard requires companies to state the system boundaries of their inventory.
- Companies shall clearly state that they report according to the present standard, and any material deviations from it.

**Table 11 — Recommended inventory boundaries for GHG reporting**  
n. a. = not applicable

Process Step	CO <sub>2</sub> Reporting Mandatory?	Comments
Raw material supply (quarrying, mining, crushing)	Yes – unless n. a.	May require consolidating emissions of two legal entities, if raw material supply is contracted out. See 7.3 for details.
Preparation of raw materials, fuels and additives	Yes – unless n. a.	--
Kiln operation (pyro-processing)	Yes – unless n. a.	--
Cement grinding, blending	Yes – unless n. a.	--
On-site (internal) transports	Yes – unless n. a.	CO <sub>2</sub> from owned vehicles (incl. leased vehicles, excl. owner-drivers) shall be reported. If third-party transports: → n. a.
Off-site transports	No	Reporting not mandatory. If reported, distinguish direct CO <sub>2</sub> (own vehicles, incl. leased vehicles) from indirect CO <sub>2</sub> (third-party vehicles)
On-site power generation	Yes – unless n. a.	Also report CO <sub>2</sub> if operated only occasionally
Room heating / cooling	Yes – unless n. a.	--

### 10.3 Reporting periods

Reporting GHG emissions may be based on calendar years or on financial years, if it helps to reduce reporting costs. From a GHG perspective, there is no problem to report based on financial years, provided that it is done consistently over time, with no gaps or overlaps. Changes in the reporting year should be clearly indicated. National regulations should be taken into account.



## 10.4 Performance indicators

### 10.4.1 General

This standard gives guidelines for providing a flexible basis for GHG emissions monitoring and reporting. The calculation of individual emission components as described above is quite straightforward. The definition of emission totals and specific indicators, in contrast, is highly dependent on the reporting context and purpose, such as: input to national inventories, GHG compliance regimes and emissions trading, industry benchmarking, etc. System boundaries for such reporting depend largely on conventions and practical requirements, rather than on scientific arguments.

With this background, a section on performance indicators is included in the present standard. It contains a number of indicators which are deemed most useful in the light of the current business and policy environment, and associated reporting requirements. Generally, the section on performance indicators is conceived as a flexible vessel where companies may introduce additional parameters according to their needs, for instance different emission (sub-) totals.

A summary of the definitions of the performance indicators (KPIs) is presented in Table 12.

### 10.4.2 Denominator for specific, unit-based emissions

From a sustainable development and business point of view, the reporting of GHG efficiency – the specific or unit based emission – is at least as important as the reporting of absolute emissions. This raises the question how the denominator of the specific emissions should be defined.

Three denominators are appropriate in the cement industry:

- a) clinker,
- b) cement (equivalent),
- c) cement constituents based products.

Each of these three denominators gives a different weighting to the GHG performance involved in different stages of cement manufacturing.

#### a) **Clinker**

In the context of this standard clinker refers to grey and white clinker used for the production of grey and white cement. The production of clinker is the main source of CO<sub>2</sub> in cement production.

#### b) **Cement (equivalent)**

Cement (equivalent) is a cement production value, which is determined from clinker produced on-site applying the plant specific clinker/cement-factor. Hence, it is a virtual cement production under the assumption that all clinker produced in a plant is consumed for cement production in the same plant and applying the real plant specific clinker/cement factor.

c) **Cement constituents based products**

Cement constituents based products consist of all clinker produced by the reporting organization for cement making or direct clinker sale, plus gypsum, limestone, CKD<sup>10</sup> and all cement constituents other than clinker consumed for blending, plus all concrete additions processed at the cement plant in view of changing their properties. Therefore, this denominator is the sum of on-site produced clinker and processed mineral components. Note that the denominator excludes the following:

- 1) bought clinker, used for cement production;
- 2) granulated slag and fly ash from coal fired power plants, which are stored or sold to another organization without any processing for changing their properties (e.g. grinding or thermal treatment);
- 3) cement volumes which are traded without any processing.

The companies shall calculate their specific emissions as follows:

$$\begin{aligned} \text{Specific CO}_2 \text{ per t of cement (eq.)} &= \frac{\text{direct CO}_2 \text{ emission from cement manufacturing}}{\text{own clinker production}} \times \text{clinker/cement (eq.) factor} \\ &= \underbrace{\text{own clinker consumed} + \text{own clinker sold directly}} \end{aligned}$$

**Figure 8 — Calculation of specific emissions**

**Specific GHG per t of cement (equivalent):** The denominator is based on clinker production, assuming that all clinker produced in a plant is consumed for cement production on site. See 10.4.3.2 for definition of clinker/cement (eq.) factor.

$$\begin{aligned} \text{Specific CO}_2 \text{ per ton of cement constituents based product} &= \frac{\text{direct CO}_2 \text{ from cement manufacturing}}{\underbrace{\text{own clinker consumed} + \text{own clinker sold directly}}_{= \text{own clinker production}} + \text{CKD \& cement constituents other than clinker (gypsum, limestone, etc.) consumed for blending} + \text{concrete additions (pure MIC) processed at plant} + \del{\text{clinker bought \& consumed}}} \end{aligned}$$

**Figure 9 — Specific GHG per t of cement constituents based product**

<sup>10</sup> Any dust volumes which leave the kiln system and are ultimately incorporated in cement constituents should be included in the denominator. Examples include CKD added to the cement mill, and direct sales of CKD as a binder. In the standard, such dust volumes should be counted as cement constituents other than clinker used for blending, or counted as concrete additions which are pure mineral components (pure MIC) processed at plant. In contrast, landfilled dust should be excluded from the denominator.

Specific GHG per t of cement constituents based products: The denominator is based on clinker production, hence sold clinker is included and bought clinker is excluded, cement constituents other than clinker and concrete additions are included. See 10.4.3.4 for guidance on clinker stock changes.

### 10.4.3 Denominator for other ratio indicators

#### 10.4.3.1 General

For selected ratio indicators which do not use GHG in the numerator, it is appropriate to include bought clinker, and exclude sold clinker, from the denominator. This applies for:

- specific power consumption per tonne of cement constituents, which should take into account grinding of bought clinker: cement (equivalent);
- the clinker/cement factor, which should describe the ratio between total clinker consumption and total production of cement or concrete additions: cement and concrete additions.

#### 10.4.3.2 Clinker/cement (eq.) factor

As described in 10.4.2 the cement (equivalent) may be calculated from produced clinker divided by the clinker/cement (eq.) factor, which is defined as: Total clinker consumed / (own clinker consumed plus CKD, plus cement constituents other than clinker consumed for blending, plus clinker bought and consumed).

The companies shall calculate their clinker / cement (equivalent) factor as follows:

$$\text{clinker / cement (eq.) factor} = \frac{\text{clinker consumed}}{\text{own clinker consumed} + \cancel{\text{own clinker sold directly}} + \text{CKD \& cement constituents other than clinker (gypsum, limestone, etc.) consumed for blending} + \cancel{\text{concrete additions (pure MIC) processed at plant}} + \text{clinker bought \& consumed}}$$

= own clinker production

**Figure 10 — Calculation of the clinker / cement (equivalent) factor**

The factor is based on clinker consumption. Hence, in the denominator sold clinker is excluded and bought clinker is included. Concrete additions are excluded.

See 10.4.3.4 for guidance on stock changes.

#### 10.4.3.3 Clinker/cement constituents based product factor

The companies shall calculate their clinker / cement constituents based product factor as follows:

$$\text{clinker / cement constituents based product factor} = \frac{\text{clinker consumed}}{\text{own clinker consumed} + \cancel{\text{own clinker sold directly}} + \text{CKD \& cement constituents other than clinker (gypsum, limestone, etc.) consumed for blending} + \text{concrete additions (pure MIC) processed at plant} + \text{clinker bought \& consumed}}$$

= own clinker production

**Figure 11 — Clinker/cement constituents based product factor**

The factor is based on clinker consumption. Hence, in the denominator sold clinker is excluded and bought clinker is included. Furthermore, concrete additions are included.

See Section 10.4.3.4 for guidance on stock changes.

#### 10.4.3.4 Dealing with stock changes and sold and purchased clinker

Direct GHG emissions resulting from clinker production should be reported for the year in which it is emitted. To avoid distortion, specific emissions per tonne of cement constituents based products should therefore be based on the full clinker production of the same year, irrespective of whether the produced clinker is consumed, sold, or stored.

Other ratio indicators such as specific electricity consumption and clinker/cement factors, in contrast, should be based on actual amounts of clinker (plus gypsum and MIC) consumed, irrespective of whether the clinker was produced this year, taken from stock or purchased. When calculating clinker production from clinker consumption or vice-versa, changes in clinker stocks as well as sales and purchases of clinker need to be taken into account (for accounting of material transfers see also 6.3.4).

#### 10.4.3.5 Key Performance Indicators (KPIs)

**Table 12 — List of KPIs**

KPI	Unit	Comment and definition
Fossil direct GHG (including CO <sub>2</sub> from on-site power generation)	[t CO <sub>2</sub> /yr]	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, including CO <sub>2</sub> from on-site power generation
Gross emissions (= fossil direct GHG excluding CO <sub>2</sub> from on-site power generation)	t CO <sub>2</sub> /year	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO <sub>2</sub> from on-site power generation
<ul style="list-style-type: none"> <li>calcination component of gross emissions</li> <li>fuel component of gross emissions</li> </ul>	<p>t CO<sub>2</sub>/year</p> <p>t CO<sub>2</sub>/year</p>	<p>Fossil direct GHG emissions from raw materials</p> <p>Fossil direct t GHG emissions from kiln fuels and non-kiln fuels, excluding CO<sub>2</sub> from on-site</p>
Net emissions (= gross emissions minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels; excluding CO <sub>2</sub> from on-site power generation)	t CO <sub>2</sub> /year	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO <sub>2</sub> from on-site power generation, minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels
CO <sub>2</sub> from biomass sources (including biomass content of mixed fuels)	t CO <sub>2</sub> /year	
Specific gross emissions per tonne of clinker produced	kg CO <sub>2</sub> /t cli	<ul style="list-style-type: none"> <li>Fossil direct GHG emissions, excluding CO<sub>2</sub> from on-site power generation, divided by own clinker production</li> </ul>
<ul style="list-style-type: none"> <li>calcination component</li> </ul>	kg CO <sub>2</sub> /t cli	Fossil direct GHG emissions from

KPI	Unit	Comment and definition
<ul style="list-style-type: none"> <li>fuel component</li> </ul>	kg CO <sub>2</sub> /t cli	<p>raw materials, divided by own clinker production</p> <p>Fossil direct GHG emissions from kiln fuels and non-kiln fuels, excluding CO<sub>2</sub> from on-site power generation, divided by own clinker production</p>
Specific net emissions per tonne of clinker produced	kg CO <sub>2</sub> /t cli	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO <sub>2</sub> from on-site power generation, minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels, divided by own clinker production
<p>Specific gross emissions per tonne of cement constituents based product</p> <ul style="list-style-type: none"> <li>calcination component</li> <li>fuel component</li> </ul>	<p>kg CO<sub>2</sub>/t cem prod</p> <p>kg CO<sub>2</sub>/t cem prod</p> <p>kg CO<sub>2</sub>/t cem prod</p>	<p>Fossil direct GHG emissions, excluding CO<sub>2</sub> from on-site power generation, divided by cement constituents based products</p> <ul style="list-style-type: none"> <li>Fossil direct GHG emissions from raw materials, divided by cement constituents based products</li> <li>Fossil direct GHG emissions from kiln fuels and non-kiln fuels, excluding CO<sub>2</sub> from on-site power generation, divided by cement constituents based products</li> </ul>
Specific net emissions per tonne of cement constituents based product	kg CO <sub>2</sub> /t cem prod	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO <sub>2</sub> from on-site power generation, minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels, divided by own production of cement constituents based products
Improvement rate: Net emissions per tonne of cement constituents based product relative to base year (e.g. 1990)	%	
<p>Specific energy indirect GHG emissions from external power generation:</p> <ul style="list-style-type: none"> <li>per tonne of cement (eq.)</li> <li>per tonne of cement constituents based product</li> </ul>	<p>kg CO<sub>2</sub>/t cem eq</p> <p>kg CO<sub>2</sub>/t cem prod</p>	

KPI	Unit	Comment and definition
Specific other indirect GHG emissions from net clinker imports (+) / exports (-) per tonne of cement constituents based product	kg CO <sub>2</sub> /t cem prod	
Net outbound clinker per net clinker consumption	%	Percentage of direct clinker sales versus clinker consumed to produce cement
Clinker/cement (eq.) factor <sup>a</sup>	%	Calculated based on total clinker consumed and total Portland + Blended cements
Clinker/cement constituents based product factor <sup>b</sup>	%	Total clinker consumed divided by the cement constituents consumed (produced cements) and concrete additions produced (pure MIC processed)
Specific heat consumption of clinker production	MJ/t cli	Total heat consumption of kilns divided by the clinker production
Heat consumption rates of clinker production (kiln fuels):	%	Heat consumption of traditional fossil fuels divided by the total heat consumption of kilns
• traditional fossil fuel rate	%	Heat consumption of alternative fossil fuels divided by the total heat consumption of kilns
• alternative fossil fuel rate	%	Heat consumption of biomass fuels, bioliquids and biomass content of mixed fuels divided by the total heat consumption of kilns
• biomass fuel rate	%	
CO <sub>2</sub> emission factor for kiln fuel mix	t CO <sub>2</sub> /GJ	Total CO <sub>2</sub> from fossil-based kiln fuels divided by total heat consumption of kilns
Total fuel energy rates at plant level (kiln and non-kiln fuels):	%	Total traditional fossil fuel energy used in the whole plant (kiln and non-kiln fuels) divided by total fuel energy
• traditional fossil fuel rate	%	Total alternative fossil fuel energy used in the whole plant (kiln and non-kiln fuels) divided by total fuel energy
• alternative fossil fuel rate	%	

KPI	Unit	Comment and definition
• biomass fuel rate	%	Total biomass fuel energy used in the whole plant (kiln and non-kiln fuels) divided by total fuel energy
Specific total plant power consumption <sup>c</sup>	kWh/t cem & conc add	Total plant power consumption divided by cement constituents consumed (produced cements) and concrete additions (pure MIC processed and sold separately)
Specific power consumption of clinker production	kWh/t cli	Power consumption up to and including clinker production divided by clinker production
Specific power consumption of cement production <sup>c</sup>	kWh/t cem & conc add	Power consumption of cement production incl. power consumption of production of clinker consumed divided by cement constituents consumed (produced cements) and concrete additions (pure MIC processed and sold)
National energy conversion factor for power production of national statistics	MJ <sub>thermal</sub> /kWh	Optional parameter, e.g. from national statistics
Total energy intensity of clinker production (fuel and power)	MJ/t cli	Optional result
<p><sup>a</sup> Clinker/cement (eq.) factor: See 10.4.3.2 for determination.</p> <p><sup>b</sup> Clinker/cement constituents based product factor: See 10.4.3.3 for determination.</p> <p><sup>c</sup> Specific power consumption: In this KPI the power consumption is related to the <u>processing</u> of cement constituents (consumed) and concrete additions (pure MIC processed and sold separately, but exported clinker is excluded. See also Table 12.</p>		

A number of KPIs is recommended according to the experiences from the use of previous reporting schemes: Absolute gross emissions excluding emissions from on-site power generation in t CO<sub>2</sub>/year.

## 11 Uncertainty of GHG inventories

### 11.1 Introduction to uncertainty assessment

#### 11.1.1 Basic considerations

So far as standards for measurement of mass flows and parameters of specific materials, energy consumption or any other emission sources include the analysis of uncertainty, these should be applied.

Applying the described mass balance method to determine GHG emissions of the cement industry in this standard, the procedures for analysing the uncertainty of measured or calculated values should be considered as described in the following sections. They are specified in the general rules of the GUM [3].

The overall uncertainty depends on the uncertainty of the different parameters:

- a) reporting of fuel quantities or production volumes;
- b) analyses of conventional parameters like calorific values;
- c) representativeness of sampling.

Due to their scientific nature, the parameters required for estimating GHG emissions, such as fuel mass flows, lower heating values and emission factors, are not precise point estimates, but involve an uncertainty that may be expressed as an uncertainty range or confidence interval.

The aggregate uncertainty of an emissions estimate for a plant or organization will depend on the individual uncertainties of the underlying parameters.

Quantifying parameter uncertainties is demanding in terms of data and procedures. As a result, statements about the aggregate uncertainty of emissions estimates are inherently uncertain themselves and often involve a subjective component.<sup>11</sup> Nevertheless, there are clear incentives to assess and minimize uncertainty:

- companies may want to rank the sources of uncertainty in their inventory in order to identify priority areas to focus on when improving inventory quality;
- some GHG reporting schemes, for example the monitoring and reporting regulation (MRR) [5] for the EU ETS, set quantitative limits for the uncertainty of key parameters used to estimate emissions from cement plants;
- wherever monetary values are assigned to GHG emissions, uncertainty in emissions estimates may have financial consequences.
- with this background, it is recognized that uncertainty in GHG inventories is a longer-term challenge which deserves attention.

Table 13 identifies the sources of uncertainty which are typically the most relevant in a cement organization, along with measures to minimize them.

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<sup>11</sup> Besides the uncertainty of parameters, there are other error sources that may contribute to the uncertainty of emissions estimates. These include *model uncertainty* – i.e. the question how precisely a mathematical model reflects a specific context – and *scientific uncertainty*, for example related to the global warming potentials [6] used to aggregate different greenhouse gases. In designing this standard, it is aimed to reduce the model uncertainty inherent in cement organization inventories to minimal levels. Addressing scientific uncertainty, on the other hand, is clearly beyond the scope of corporate inventories.



**Table 13 — Typical major sources of uncertainty in cement sector CO<sub>2</sub> inventories, and measures to minimize them**

Parameter	Measures to minimize parameter uncertainty
Clinker production (t/a)	Use alternative estimation methods to cross-check clinker volumes: Based on raw meal consumption and raw meal : clinker ratio Based on cement production and clinker : cement ratio, adjusted for clinker sales and purchases and clinker stock changes Based on direct clinker weighing (where applicable)
Raw meal consumption (t/a)*	Account for double-counting of recirculated dust by weighing devices
Calcination emission factor (kg CO <sub>2</sub> /t clinker)	<ul style="list-style-type: none"> <li>• Calculate plant-specific emission factor based on measured clinker composition (CaO- and MgO-content), rather than using default factor</li> <li>• Account for additions of calcined materials to the kiln via slag, fly ash, etc.</li> </ul>
Calcination emission factor* (kg CO <sub>2</sub> /t raw meal)	<ul style="list-style-type: none"> <li>• Calculate plant-specific emission factor based on measured composition of raw meal (carbonate content)</li> <li>• Account for variations in raw meal carbonate content over time (e.g., additions of calcined materials)</li> </ul>
Fuel consumption (t/a)	Use alternative methods to cross-check fuel consumption: Based on weighing at delivery, or fuel bills; account for stock changes Based on weigh-feeders (where applicable)
Lower heating values of fuels (GJ/t)	Ensure that fuel volumes and lower heating values are based on same moisture content
Emission factors of fuels (kg CO <sub>2</sub> /GJ)	<p>If using fuel mixes (e.g., coal-petcoke mix), disaggregate and apply individual emission factors, or apply weighted emission factor</p> <p>If using specific types of coal, use matching emission factors</p> <p>Measure emission factor of fuel if default factors are deemed non-representative</p> <p>Account for biomass carbon in, e.g., used tyres and impregnated saw dust</p> <p>Use analysis data for biomass content [14] in heterogeneous mixed alternative fuels like pre-treated industrial or domestic wastes, where applicable</p>
* Parameters marked with an asterisk are only relevant if the raw meal based method is used for calculating CO <sub>2</sub> from raw material calcination.	

### 11.1.2 Materiality thresholds

Materiality thresholds are typically applied in the process of independent verification of GHG inventories. For example, a verifier could apply a pre-defined threshold of 5 % to determine whether a single or aggregate error in an inventory leads to a material misstatement. The level of such a threshold will depend on the purpose for which the inventory data are intended to be used.

A materiality threshold should not be interpreted as a permissible quantity of emissions which an organization may leave out of its inventory. For example, exclusion of all sources which contribute less than 1 % to the overall emissions of a cement plant would introduce a systematic bias which is not compatible with the guiding principle that an inventory should be complete. On the other hand, it is important to acknowledge that an organization's resources available for preparing a GHG inventory are

always limited, and that companies should focus on reducing the uncertainty related to their main emission sources.

With this background, the present standard does not define a minimum threshold below which an emission source should be considered “immaterial”. Instead, companies are encouraged to apply simplified methods for quantifying their minor sources of CO<sub>2</sub>. This applies, for example, for CO<sub>2</sub> emissions from organic carbon in raw materials.

In this context, it is useful to reiterate the reasons why the present standard does not require quantification of the following sources of direct GHG emissions:

- GHG emissions from off-site transports of inputs and products are typically small, but also difficult to quantify consistently because these transports are often carried out by third parties see Table 7 in Clause 6;
- GHG emissions from combustion of wastewater (see 7.9), in addition to being small, occur only in relatively few plants, and the carbon may be from biomass sources, see Table 7 in Clause 6;
- CH<sub>4</sub> and N<sub>2</sub>O emissions from kilns are not significant – see 7.10.

## 11.2 Uncertainty of activity data

### 11.2.1 Measuring instruments for the determination of fuel and material quantities

The information on the uncertainty of a measuring instrument may be found in different sources:

- certificates on calibration under national metrological control (where the operational error limits the uncertainty under normal operational conditions),
- the specification from the manufacturer of an instrument and estimate of the additional uncertainty under operation conditions concerning relevant influences, or
- an individual uncertainty assessment under operational conditions (e.g. via regular testing and adjustment of scales),
- deviations of the scale under operation conditions may normally be determined by comparison to a assured reference, e.g. precisely measured weight loss of a pre-loading silo, determination of the material flow by comparison to an assured weighing system, scale testing by use of an appropriate check weight, etc.

See C.1 for example calculations.

### 11.2.2 Aggregated uncertainties in case of mass balances

If the yearly amount of a consumed fuel or of the produced clinker is determined by a mass balance, the aggregated uncertainty for the activity data has to be calculated via error propagation considering the diverse uncertainties of each parameter of the mass balance according to the expanded uncertainty of the involved weighing/measuring method. Also the uncertainty of measuring or estimating stocks in piles, silos, tanks and other stocks in the mass balance has to be considered.

See C.2 for example calculations.

## 11.3 Uncertainties of fuel and material parameters

### 11.3.1 Laboratory analyses for the determination of fuel and material parameters

The uncertainty of analysed parameters of fuels and materials depends mainly on:

- the analysing method,
- the analysing frequency (a decrease of uncertainty is possible by raising the analysing frequency), and
- representative sampling.

Also, the qualification and experience of the persons, who perform the analyses, influences the quality of analysing results.

See C.3 for an example calculation of aggregated uncertainties in case of combined parameters.

### 11.3.2 Uncertainties of total heat consumption and CO<sub>2</sub> emissions of fuels

An uncertainty evaluation according to the formulas included in the CSI Protocol [1] spread sheet resulted in significantly higher relative uncertainties (10 %) for total heat consumption in the complicated setting. This is due to the fact, that the sum of heat is calculated from individual components. The energy of mixed alternative fuels is separated between fossil fraction and biogenic fraction. Thus, the uncertainty of these energy components depends on the relatively high uncertainty of the biogenic fraction of mixed fuels. However, this differentiation is not relevant to the total sum of heat. Consequently, the uncertainty of the total heat consumption of clinker shall not be assessed from the individual components but from the relevant uncertainties of the amounts of fuels and their corresponding heating values.

The uncertainty of CO<sub>2</sub> emissions from fuels in most cases does not depend on the uncertainty of heat values, although the normal way of calculating the emission includes the heat value as in the CSI Protocol and described in the EU Monitoring and Reporting Regulation:

$$\text{activity data} \times \text{lower heat value} \times \text{CO}_2 \text{ emission factor} \times (1 - \text{biogenic carbon content})$$

Normally, the heat specific CO<sub>2</sub> emission factor of fuels is determined from a total carbon analysis and division by the lower heat value. In this case and if consistent analytical results are used, the uncertainty of the product

$$\text{lower heat value} \times \text{CO}_2 \text{ emission factor}$$

depends solely on the uncertainty of the sampling and total carbon (TC) analysis.

For the conversion of TC analytical results to CO<sub>2</sub> emission factors a unique and precise conversion factor shall be used for the CO<sub>2</sub>/C molar ratio, e.g. 3,664.

### 11.4 Uncertainties of continuous stack emission measurements

Reference is made to EN ISO 20988-1 [2]. The overall uncertainty depends on the uncertainty of the different parameters, e.g. measurement of volume flow and concentration measurement. For stack emission measurements (emission data based method, St) uncertainties of 7 % to 10 % were achieved in the field tests for the total CO<sub>2</sub> including CO<sub>2</sub> from biogenic and fossil carbon.

Stack CO<sub>2</sub> emission measurements were subject to the highest relative uncertainty in the verification tests.

The key influence on the uncertainty of the stack emission method is the accuracy of calibration of the continuous measuring instruments for the stack gas velocity and volume flow. It strongly depends on the uncertainty of the applied standard reference method (SRM).

NOTE The uncertainty results to about 5 % under favourable experiment conditions and when the direct CO<sub>2</sub> emissions were regarded, i.e. CO<sub>2</sub> emissions of total carbon without differentiation of fossil and biogenic carbon content. Uncertainty of about 4 % to 6 % of the stack emission measurements in the verification tests was mainly dependent on the uncertainty of the standard reference method (SRM) according to EN ISO 16911-1, which is

used for calibrating and assuring the accuracy of the continuous volume flow measurements in the stack. The indicated uncertainty refers to calibration by 12-fold SRM measurements. SRM uncertainty ranged up to 8 % in case of very low stack gas velocities. A lack of accuracy of the volume flow measurements (activity data) could induce a systematic under- or overestimation of the direct CO<sub>2</sub> emissions of the same magnitude. Systematic differences of +4 % to +6 % were identified in the verification tests and could potentially be caused by a swirl in the stack gas flow and a corresponding systematic effect on the SRM gas velocity measurements.

Additional methods are required for determining the fraction of biogenic CO<sub>2</sub> emissions in case of use of alternative fuels or materials with biogenic carbon content.

### **11.5 Evaluation of the overall uncertainty of a GHG inventory**

In order to determine the overall uncertainty of a GHG inventory, the assessed uncertainties beforehand regarding activity data and parameters have to be aggregated by the error propagation laws.

### **11.6 Application of default values instead of analysing results**

Different situations for different fuels:

- commercial standard fuels, e.g. diesel,
- commercial fuels, e.g. natural gas,
- other fuels, e.g. used tyres or mixed industrial waste.

The cost and effort associated with sampling used tyres and processing them to a quality appropriate for analysis is very high. A representative sampling is nearly impossible and clearly not feasible in the same manner as required for monitoring of other fuels and materials. Sample processing and analytical methods applied are very expensive and subject to a high degree of uncertainty on an individual result, which only may be overcome by a high number of repetitions. At the same time, the composition of tyres is defined by their material and quality requirements. Thus it is highly recommended and perhaps the only practicable solution to apply methods based on standardized average parameters. A focus should be on the correct accounting of the mass of consumed tyres. The content of water and mud in the tyres potentially influence the accuracy of the determined amount of tyres, so it should be ensured if or that no corrections have to be applied.

The results of the field tests prove that methods A2 and B2 proposed by CEN/TC 264/WG 33/SG 3 are well applicable for correctly determining CO<sub>2</sub> emissions in cement plants in complicated plant settings with significant share of alternative raw materials and fuels.

The simple input and output methods A1 and B1 are in general not appropriate for GHG reporting in a complicated plant setting. However, these simple methods may serve as valuable source of information for plausibility checks on the results of the more detailed mass balance methods A2 and B2.

Furthermore, the laboratory experience with the raw meal and clinker matrix is an essential requirement for assuring the accuracy of results. As such materials and corresponding analyses belong to the core competencies of most cement plant laboratories in Europe, less problems with accuracy should be expected from plant laboratory analytical results, as for example verified during all four filed tests.

The laboratory procedures should include inter-laboratory comparisons for the corresponding material matrix, in order to assure accuracy and prevent systematic errors in results used for CO<sub>2</sub> emission reporting.”

The field tests also showed that the simple mass balance methods (A1 and B1) and therefore the application of default values for process emissions should not be used when

- raw materials / raw meal contain a significant content of organic carbon, or

— a significant share of alternative raw materials is used.

## 12 Considerations for applying this standard (verification procedure)

For method A1 to A2 and method B1 and B2 overall uncertainties of 1 % to 5 % are concluded on the basis of the field tests.

New text: The direct GHG emissions of cement plants nearly entirely consist of CO<sub>2</sub>. The input and output mass balance methods account the total carbon content and thus all oxidized carbon (CO<sub>2</sub> and CO). This sum covers more than 99,5 % of the direct GHG emissions. Thus, the contribution of other non-CO<sub>2</sub> GHG emissions is assessed to be very small. The contribution of non-CO<sub>2</sub> GHG is certainly below the achievable overall uncertainty of GHG emissions of cement plants even after accounting their significantly higher greenhouse warming potential.

For the activity data based methods (mass balance input and output methods, A1, A2, B1 and B2) overall uncertainties of 1 % to 5 % are concluded.

NOTE These results integrate the measurement of all relevant mass flows (activity data), lower heating values (LHV), CO<sub>2</sub> emission factors (EF) and biogenic carbon content (BioC).

Overall uncertainties below 2 % were indicated for the mass balance methods by the uncertainty of activity data only.

The detailed input and output methods A2 and B2 are well applicable in complicated plant settings with significant share of alternative raw materials and fuels. The laboratory experience with the raw meal and clinker matrix is an essential requirement for assuring the accuracy of results. The analysis of the most relevant parameters is a core competency of most laboratories in cement plants in Europe.

The application of the input methods (A1, A2) requires frequent controls of the kiln feed scale accuracy and independent quality checks on the kiln feed scale measurement results in order to prevent significant systematic errors (e.g. input vs. output activity data). A correct input mass balance further requires determining the dust return and dust recycling (dust return correction of kiln feed).

Sampling points and methods for heterogeneous and mixed materials shall be selected carefully to ensure well mixed samples. Results should be checked for plausibility, e.g. by assessing the energy and material balances.

The laboratory accuracy may normally be checked efficiently by regular inter-laboratory comparison ('round robin tests') for the relevant material matrices.

Attention should be paid to material and fuel moisture content and its change in material processing and/or in laboratory sample processing. A clear record of the mass reference of activity data and corresponding material parameters are required. Any corrections or transformations of the mass reference shall be applied with special care.

The application of any type of the input or output mass balance method or stack emission method should include independent quality checks for the measurements, e.g. by comparison of two different types of these methods, in order to identify and prevent potential systematic errors. Comparison of the activity data of the input/output mass balance is a common procedure in cement plants, which normally includes the determination and regular control of the raw meal/clinker factor.

Results of any of the methods discussed in this report should always be checked for plausibility based on plant specific and sector-specific indicators. Relevant indicators could be as appropriate to the plant situation e.g.

— comparison of direct CO<sub>2</sub> emissions of any applicable input, output or stack emission measurement methods,

- comparison of raw meal consumed and clinker produced (input vs. output activity data) and the variability of the raw meal clinker factor,
- specific heat consumption,
- specific direct CO<sub>2</sub> emissions of calcination,
- specific direct CO<sub>2</sub> emissions of fuels component (including biogenic CO<sub>2</sub> emissions), etc.

## Annex A (informative)

### Findings from the field tests (analytical interferences)

#### A.1 Laboratory analyses and selection of appropriate methods

In one of the four verification tests external laboratory data showed a systematic error corresponding to -9 % of CO<sub>2</sub> emissions from raw material calcination. This difference was larger than the specified uncertainty. A re-analysis of kiln feed and clinker samples and correction of results was able to decrease this significant systematic error in the most important analytical parameter to -2,5 %. The remaining systematic difference seems due to the selection of different analytical methods for measuring calcium oxide (CaO) and magnesium oxide (MgO): XRF-analysis vs. titration. Both methods were subject to large difference in specified measurement uncertainty (about 1 % vs. >5 %, respectively). Furthermore, close agreement of results from two different laboratories gave confidence in the results of the XRF-analysis, which is commonly applied in most cement plant laboratories for regular product quality control – see Table A.1.

The results of the 2<sup>nd</sup> plant test indicate that analytical results achieved by the titration method for the clinker matrix were not sufficiently precise and robust for emission reporting. It seems utmost important, that sufficient experience with the specific sample matrix, adequate procedures for sample processing and robust analytical methods are applied. Such procedures and methods are often established in cement plant laboratories with key expertise on raw materials, clinker and cement products. External laboratory analysis should be based on similar competence for the methods and sample matrix. For accredited laboratories not only the analytical parameter but also the corresponding material or sample matrix should be encompassed in the scope of accreditation.

**Table A.1— Systematic errors corrected by application of appropriate analytical methods and accuracy**

Clinker	Effect of corrected systematic error on direct CO <sub>2</sub> emissions	Parameter	Relevant method
XRF analysis for CaO, MgO	2 %	Clinker CO <sub>2</sub> EF	Output B2
<b>Raw meal / kiln feed</b>			
XRF analysis for CaO, MgO	1 %	Non-carbonate CaO, MgO, clinker CO <sub>2</sub> EF correction	Output B2
Carbonate CO <sub>2</sub> analysis			
Total carbon (TC) analysis	8 %	Raw meal CO <sub>2</sub> EF	Input A2
Total organic carbon (TOC) analysis	2,4 %	Organic CO <sub>2</sub> emissions	Output B2
Loss on ignition (LOI) analysis	2 %	Raw meal CO <sub>2</sub> EF	Input A1, also for plausibility checks of A2, B2

Analyses of the biogenic carbon content in animal meal and sewage sludge with the selective dissolution method (EN 15440) often lead to erroneous results. This was experienced in the verification tests (field tests) when analytical results of about 85 % biogenic carbon content were found. The assurance of the source of the animal meal clearly confirmed a purely biogenic origin and biogenic carbon content of 100 %. Such confirmation from the material source and well known composition is also suggested as method in the EU monitoring and reporting regulation, Article 39(2) [10].

## A.2 Bypass dust calcination rate and determination of its CO<sub>2</sub> emission factor

The calcination rate of bypass dust cannot normally be calculated based on direct measures of the loss on ignition (LOI). Bypass dust contains higher amounts of salts like chlorides, which are also lost during heating. KCl and NaCl often contribute about 10 % to the total weight loss. Thus, the LOI is no precise measure for estimating the calcination rate  $d$  of bypass dust.

In addition, also inferring the calcination rate  $d$  of bypass dust from the comparison of the carbonate CO<sub>2</sub> content of bypass dust with the originally uncalcined raw meal is complicated. Again this is due to the accumulation of salts and sulphates in the bypass dust, which change the mass reference. A difference of close to 20 % was identified in one of the field tests. In some plants this accumulation can amount to 30 % of the mass of bypass dust. A correction of the mass reference is required for correctly determining the CO<sub>2</sub> emissions of bypass dust based on a measure of its remaining carbonate CO<sub>2</sub> content in comparison to the original carbonate CO<sub>2</sub> content of the raw meal consumed.

The maximum carbonate CO<sub>2</sub> content of raw meal consumed may be obtained from assessing the CaO and MgO content of bypass dust. It is then assumed, that all CaO and MgO originated from CaCO<sub>3</sub> and MgCO<sub>3</sub> carbonates in the raw meal in order to estimate the maximum carbonate CO<sub>2</sub> content. This evaluation automatically yields the correct mass reference for direct comparison to the measured remaining carbonate CO<sub>2</sub> content of bypass dust.

For higher accuracy and if relevant this maximum carbonate CO<sub>2</sub> content may be corrected by a factor for the amounts of CaO and MgO that do not originate from carbonates.

For the assessment two different methods for determining the CO<sub>2</sub> emission factor of filter dust ( $EF_{FD}$  from degree of calcination  $d$ ) and bypass dust ( $EF_{BPD}$  from remaining carbonate CO<sub>2</sub> content) are suggested in 7.2. Considering the theory of both methods, the second method ( $EF_{BPD}$  from remaining carbonate CO<sub>2</sub> content) is recommended for application in case of significant accumulation of certain compounds like salts in bypass dust.

The first method represents a conservative approach, which may normally be applied to dusts from the main filter. For bypass dust (BPD) it will often result in increased CO<sub>2</sub> emission factors. The size of overestimating the emission factor of bypass dust ( $EF_{BPD}$ ) will depend on the accumulation of certain components compared to clinker.

## A.3 Correct reference of parameters regarding moisture

For correct reporting it should be assured that activity data and corresponding parameters are reported with the same mass reference.

This is especially relevant for fuels and their moisture content (see also CSI Guidance Document, p. 17 [1]). Correct reporting may be achieved, e.g. by

- Activity data as tonnes dry material, after correcting process scale data for the moisture content and using the corresponding LHV per dry material.

Alternatively:

- Activity data as tonnes wet material e.g. as measured by a process scale and LHV per wet material with the same moisture content.



In both cases, the moisture content should be sampled and measured correctly. Careful sample handling is required, in order to preserve the original moisture. The determination of the moisture content may only be omitted, when the material consumption is measured as completely dry material, e.g. in case of fly ash or ground and already dried lignite.

Especially an input mass balance for raw materials, raw meal and kiln feed may be calculated much easier and correctly, if mass flow contributions are first all converted to dry mass by subtracting their individual moisture content. In such a dry mass balance also the corresponding material parameters like e.g. loss on ignition (LOI) of the different materials should refer to dry mass.

Some cement plants are used to apply specific process related correction factors to measurement results. E.g. energy correction of lower heating values regarding the energy demand for evaporation of water content of fuels. Such corrections may be practical for controlling the process heat input when exchanging fuels. However, they may cause significant errors in the application of material parameters, if the adjusted reference is not stated clearly and correctly. The application of such types of parameter corrections is therefore not recommended for CO<sub>2</sub> emission reporting.

#### **A.4 Summary of stack emission mass flow results (including non-CO<sub>2</sub> GHG)**

The CO<sub>2</sub> content of the stack gas was analysed according to ISO 12039 [16]. The uncertainty assessment was executed according to the procedure described in EN 15058 [15] (for CO) and resulted in uncertainties in the range of 2,4 % to 3,3 %. Small concentrations of carbon monoxide (CO) were converted by the stoichiometric factor and considered in the direct stack CO<sub>2</sub> emissions. The contribution of CO amounts to less than 0,15 % of the direct emissions.

In all field tests methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions were detected in the kiln stack at the limit of determination (LOD) resulting in an estimated uncertainty of their concentrations and emissions of 50 % or higher. Considering their specific GHG warming potential (GWP) more than 99,5 % of the total CO<sub>2</sub> equivalent emissions consisted of CO<sub>2</sub> and CO.

A total of six spot measurements for fluorinated greenhouse gases performed during two field tests showed that the concentrations of SF<sub>6</sub>, HFCs and PFCs were always below the limit of detection. This result meets the expectation, because there are no known sources for these gases in the cement manufacturing process.

#### **A.5 Relevance of non-CO<sub>2</sub> GHG**

Apart from CO<sub>2</sub>, other GHG emissions can be found in cement industries emissions. Most important are CH<sub>4</sub> (methane) and CO (carbon monoxide), but also some other components have been mentioned.

- a) CO emissions – Carbon monoxide (CO) emissions are completely covered by the mass balance input and output methods (A1, A2, B1, B2), which report emissions based on analysing or inferring the total carbon (TC) content of materials. This is confirmed by the plant tests of the verification exercise. The contribution of CO amounts to less than 0,15 % of the direct GHG emission, which is included in the mass balances.
- b) CH<sub>4</sub> emissions – Methane (CH<sub>4</sub>) emissions in the cement industry can originate from the organic content of raw materials. Thus, their magnitude is likely site and raw material specific. Literature values and results of the plant tests of the verification exercise indicate a maximum contribution to the total greenhouse warming potential of less than 0,01 %.
- c) N<sub>2</sub>O emissions – Literature values of nitrous oxide (N<sub>2</sub>O) emissions indicate values for the contribution to the total emissions expressed as green-house warming potential from 0,02 % to 0,5 %. The value obtained from the measurements in the plant test, is 0,4 %.

- d) Other GHG emissions – During the plant tests of the verification exercise some other non-CO<sub>2</sub> GHG have measured: sulfur hexafluoride (SF<sub>6</sub>), and fluorinated hydrocarbons (PFCs, HFCs). A total of six spot measurements for fluorinated GHG performed during the plant tests showed that the concentrations of SF<sub>6</sub>, HFCs and PFCs were always below the limit of detection. This is confirmed by literature.

From the field tests and literature, it is concluded [18] that non-CO<sub>2</sub> GHG emissions should be assumed to make rather insignificant contribution to the total GHG emissions of cement plants. From the current data and literature the contribution of non-CO<sub>2</sub> GHG emissions to the greenhouse warming potential is assessed to range below 0,5 %. Often the contribution should be expected at less than 0,05 %.

## Annex B (informative)

### Emission factors

#### B.1 Default emission factors

Calculation factors as default values should be in accordance with the requirement of this European Standard and use one of the following values:

- a) Standard factors used by the Member State for its national inventory submission to the Secretariat of the United Nations Framework Convention on Climate Change;
- b) Literature values agreed with the competent authority, including standard factors published by the competent authority, which are representative of more disaggregated sources of fuel streams;
- c) Values specified and guaranteed by the supplier of a material where the operator may demonstrate that the carbon content exhibits a 95 % confidence interval of not more than 1 %.

Values based on analyses carried out in the past, where the operator may demonstrate that those values are representative for future batches of the same material.

#### B.2 Deriving the calculation formula for the emission factor of filter dust

Filter dust (FD) is usually not fully calcined. The CO<sub>2</sub> emission factor for FD may be derived from the mass balance between FD, raw meal and released CO<sub>2</sub>:

$$FD = RawMeal - CO_{2RM} \times d \quad (B.1)$$

where

*FD* is the quantity of filter dust produced (*t*);

*RawMeal* is here the amount of dry raw meal consumed and converted to FD (*t*);

*CO<sub>2RM</sub>* is the total carbonate CO<sub>2</sub> contained in the raw meal (*t*);

*d* is the FD calcination rate (released CO<sub>2</sub> expressed as a fraction of the total carbonate CO<sub>2</sub> in the raw meal).

The CO<sub>2</sub> emission factor for FD is:

$$EF_{FD} = \frac{CO_{2RM} \times d}{FD} = \frac{CO_{2RM} \times d}{RawMeal - CO_{2RM} \times d} \quad (B.2)$$

where

*EF<sub>FD</sub>* is the emission factor for FD (*t* CO<sub>2</sub>/*t* FD).

Since *CO<sub>2RM</sub>* is proportional to the amount of raw meal, Formula (B.2) can be re-written as:

$$EF_{FD} = \frac{fCO_{2RM} \times d}{1 - fCO_{2RM} \times d} \quad (B.3)$$

where

$fCO_{2RM}$  is the weight fraction of carbonate  $CO_2$  in the raw meal (--).

When the raw meal is fully calcined ( $d=1$ ),  $EF_{FD}$  becomes the emission factor for clinker:

$$EF_{Cli} = \frac{fCO_{2RM}}{1 - fCO_{2RM}} \quad (B.4)$$

or re-arranged:

$$fCO_{2RM} = \frac{EF_{Cli}}{1 + EF_{Cli}} \quad (B.5)$$

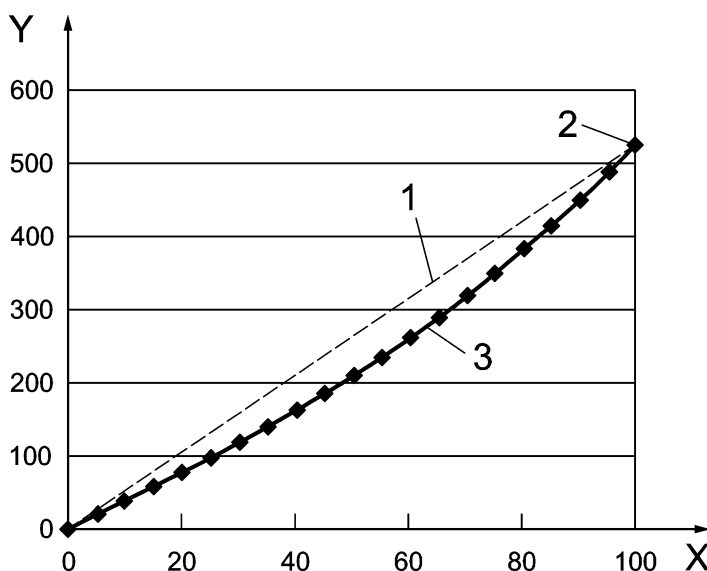
where

$EF_{Cli}$  is the emission factor for clinker (t  $CO_2$ /t cli).

With the help of Formula (B.4), Formula (B.5) can be expressed as:

$$EF_{FD} = \frac{\frac{EF_{Cli}}{1 + EF_{Cli}} \times d}{1 - \frac{EF_{Cli}}{1 + EF_{Cli}} \times d} \quad (B.6)$$

Formula (B.6) allows calculating the emission factor of FD based on (i) the emission factor of clinker, and (ii) the calcination rate of the FD. Figure B.1 illustrates the impact of the calcination rate. The diagonal line indicates that the assumption of a linear dependence between the FD calcination rate and the FD emission factor results in an overestimation of emissions by up to 50 % (at low calcination rates) or up to 55 kg  $CO_2$ /t FD.



Key

X	CKD calcinations rate	1	diagonal for comparison
Y	emission factor for CKD [kg $CO_2$ /t CKD]	2	emission factor clinker = 525 kg $CO_2$ /t cli]
		3	$CO_2$ emission factor CKD

**Figure B.1 — Influence of FD calcination rate on the  $CO_2$  emission factor for FD, using the default clinker emission factor (525 kg  $CO_2$ /t cli) as an example**

## Annex C (informative)

### Uncertainty of activity data

#### C.1 Measuring instruments for the determination of fuel and material quantities

**Table C.1 — Example: Individual uncertainty assessment of a process scale for raw meal**

Date of control with check weight	Observed deviation
12 January 2012	-1,3 %
11 April 2012	+1,9 %
11 July 2012	+3,4 %
10 October 2012	-1,1 %

For the assessment of the scales uncertainty the 95 % confidence interval has to be calculated from the deviations of the scale, which were observed within regular maintenance and controls with check weight.

Standard deviation:

$$s(x_i) = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2} = \sqrt{\frac{(-1,3-0,725)^2 + (1,9-0,725)^2 + (3,4-0,725)^2 + (-1,1-0,725)^2}{(4-1)}} = 2,31 \quad (C.1)$$

where

$x_j$  are the values of observed deviations;

$n$  is the number of deviations;

$\bar{x}$  is the arithmetic mean of observed deviations with

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} = \frac{(-1,3) + 1,9 + 3,4 + (-1,1)}{4} = 0,725 \quad (C.2)$$

Calculation of the 95 % confidence interval according to the t-distribution:

$$\bar{x} \pm t_{\Phi, \alpha} \frac{s(x_i)}{\sqrt{n}} = 0,725 \pm 3,182 \times \frac{2,31}{\sqrt{4}} = 0,725 \pm 3,68 \quad (C.3)$$

With degree of freedom  $\Phi = n-1$  and probability of error  $\alpha = 1 - p$ , where the probability  $p = 0,95$  in case of a 95 % confidence interval and where  $\frac{s(x_i)}{\sqrt{n}}$  = standard uncertainty (su or standard error, se).

Because the confidence interval is calculated from observed relative scale deviations [%], the uncertainty of the scale is here determined as the maximum of the absolute values of upper and lower end of the estimated 95 % confidence interval. This means taking the higher absolute value as expanded uncertainty (maximum permissible error):

maximum of abs (upper end)

$$0,725 + 3,68 = 4,4 \% \text{ and abs(lower end) } = (0,725 - 3,68) \times (-1) = 3,0 \% \rightarrow U_{\text{scale}} = 4,4 \% \quad (\text{C.4})$$

For a significant number of samples the expanded uncertainty U and the 95% confidence interval can be estimated by multiplying the standard uncertainty with a coverage factor  $k = 2$  (instead of  $t_{\phi, \alpha}$ ). In any case the **number of samples n** and the **coverage factor k** should be stated with any estimate of the expanded uncertainty. See, e.g. Table C.2 and GUM [3], Section 3.3.7, Page 7, and Section G.6.6, Page 77. For the example this means:

$$\bar{x} \pm k \frac{s(x_i)}{\sqrt{n}} [\%] = 0,725 \pm 2 \times \frac{2,31}{\sqrt{4}} = 0,725 \pm 2,31 \rightarrow U_{\text{scale}} = 3,0 \% \quad (\text{C.5})$$

**Table C.2 — Determination of the expanded uncertainty of a scale with the corresponding number of observations and applied coverage factor**

Applied measurement instrument	Estimated expanded uncertainty U [%]	k or $t_{\phi, \alpha}$	n
Process scale for kiln feed	3,0	2	4
Process scale for kiln feed	4,4	3,182	4

## C.2 Aggregated uncertainties in case of mass balances

In the following example the complete mass balance is expressed as a sum for the backward calculation of the clinker production from cement sales considering cement and clinker stocks. In this sum for backward calculation stocks according to the initial inventory take a negative sign (not produced during reporting period) and final inventory stocks take a positive sign. A maximum expanded uncertainty of 5 % is assumed for the stock inventory in cement silos as well as for weighing feeders used for cement production.

**Table C.3 — Example: Aggregated uncertainty for the quantity of produced clinker determined by backward projection from cement dispatch**

Sources of uncertainty within the determination of the amount of produced clinker	Amounts [t]	Estimated expanded uncertainties U [%]
<u>Cement sales</u> ( $x_{CS}$ , measured with truck scale under national metrological control):	175 000	1,0
• CEM I 42,5 R	120 000	1,0
• CEM II/A-S 42,5 R		
<u>Cement stocks:</u>	- 15 000	5,0
• CEM I 42,5 R - silo a: initial inventory ( $x_{CSIIa}$ )	2 500	5,0
• CEM I 42,5 R - silo a: final inventory ( $x_{CSFIa}$ )	- 15 000	5,0
• CEM I 42,5 R - silo b: initial inventory ( $x_{CSIIb}$ )	2 500	5,0
• CEM I 42,5 R - silo b: final inventory ( $x_{CSFIb}$ )	- 12 500	5,0
• CEM II/A-S 42,5 R - silo a: initial inventory ( $x_{CSIIa}$ )	4 000	5,0
• CEM II/A-S 42,5 R - silo a: final inventory ( $x_{CSFIa}$ )	- 12 500	5,0
• CEM II/A-S 42,5 R - silo b: initial inventory	1 000	5,0

Sources of uncertainty within the determination of the amount of produced clinker	Amounts [t]	Estimated expanded uncertainties U [%]
$(X_{CSIIb})$ <ul style="list-style-type: none"> <li>CEM II/A-S 42,5 R - silo b: final inventory <math>(X_{CSFib})</math></li> </ul>		
<u>Cement production 1: CEM I 42,5 R</u> $(X_{CEM I 42,5 R})$ , calculated from a mass balance based on cement dispatch measured with truck scale under metrological control and stock changes)	sum to be calculated	aggregated expanded uncertainty to be calculated
<u>Cement production 2: CEM II/A-S 42,5 R</u> $(X_{CEM II/A-S 42,5 R})$ , calculated from a mass balance based on cement dispatch measured with truck scale under metrological control and stock changes)	sum to be calculated	aggregated expanded uncertainty to be calculated
Amount of <u>total cement production</u> $(X_{cemp})$	sum to be calculated	aggregated expanded uncertainty to be calculated
<u>Cement grinding:</u> <ul style="list-style-type: none"> <li>Dosing of gypsum with feed belt</li> <li>Dosing of slag with feed belt</li> <li>Dosing of CKD with feed belt</li> <li>Dosing of additives with feed belt</li> <li>Dosing of anhydrite</li> </ul>	- 7 500 - 22 100 - 6 800 - 100 - 3 500	5,0 5,0 5,0 5,0 5,0
Amount of <u>clinker consumed</u> $(X_{clc})$	sum to be calculated	aggregated expanded uncertainty to be calculated
<u>Clinker stocks:</u> <ul style="list-style-type: none"> <li>Clinker stock at start of the relevant period <math>(X_{stockstart})</math></li> <li>Clinker stock at end of the relevant period <math>(X_{stockend})</math></li> </ul>	- 15 000 5 000	10,0 10,0
Amount of <u>clinker produced</u> $(X_{clip})$	sum to be calculated	aggregated expanded uncertainty to be calculated

Step 1: Calculation of the amount of the production of each sort of cement and the corresponding uncertainty

Production of cement 1:

$$X_{CEM I 42,5 R} [t] = X_{cs} t + (- X_{CSF1a} t) + X_{CSIIa} t + (- X_{CSF1b} t) + X_{CSIIb} t = 150\,000 t \text{ CEM I 42,5 R} \quad (C.6)$$

Production of cement 2:

$$X_{CEM II/A-S 42,5 R} [t] = X_{cs} t + (- X_{CSF1a} t) + X_{CSIIa} t + (- X_{CSF1b} t) + X_{CSII} t = 100\,000 t \text{ CEM II/A-S 42,5 R} \quad (C.7)$$

The following formula for error propagation may be applied to estimate the aggregated relative uncertainty of a sum, if all determinations of the mass balance parameters and their related uncertainties are independent:

$$U_{total} = \frac{\sqrt{\sum_{i=1}^n (U_i \cdot x_i)^2}}{\left| \sum_{t=1}^n x_i \right|} \quad (C.8)$$

where

$x_i$  is the absolute amount of mass flow or material in stocks in the mass balance;

$U_i$  is the relative expanded uncertainty.

Aggregated uncertainty of the production of each sort of cement in case of independent uncertainties of a sum:

$$U_{x_{cempn}} [\%] = \frac{\sqrt{(U_{CS} \times x_{CS})^2 + (U_{CSFIa} \times x_{CSFIa})^2 + (U_{CSIIa} \times x_{CSIIa})^2 + \dots + (U_{CSFIIn} \times x_{CSFIIn})^2 + (U_{CSIIIn} \times x_{CSIIIn})^2}}{|x_{CS} + x_{CSFIa} + x_{CSIIa} + \dots + x_{CSFIIn} + x_{CSIIIn}|} \quad (C.9)$$

$$U_{CEM I 42,5 R} [\%] = \frac{\sqrt{(1,0 \times 175\,000)^2 + (5,0 \times 15\,000)^2 + (5,0 \times 2\,500)^2 + (5,0 \times 15\,000)^2 + (5,0 \times 2\,500)^2}}{|175\,000 + (-15\,000) + 2\,500 + (-15\,000) + 2\,500|} = \frac{205\,400}{150\,000} = 1,37\% \quad (C.10)$$

$$U_{CEM II/A-S 42,5 R} [\%] = \frac{\sqrt{(1,0 \times 120\,000)^2 + (5,0 \times 12\,500)^2 + (5,0 \times 4\,000)^2 + (5,0 \times 12\,500)^2 + (5,0 \times 1\,000)^2}}{|120\,000 + (-12\,500) + 4\,000 + (-12\,500) + 1\,000|} = \frac{150\,500}{100\,000} = 1,51 \quad (C.11)$$

Step 2: Calculation of the uncertainty of total cement production

Total cement production:  $x_{cemp} [t] = x_{cemp1} t + x_{cemp2} t = 150\,000 t + 100\,000 t = 250\,000 t$

Aggregated uncertainty of cement production in case of independent uncertainties of a sum:

$$U_{x_{cemp}} [\%] = \frac{\sqrt{(U_{cemp1} \times x_{cemp1})^2 + (U_{cemp2} \times x_{cemp2})^2 + \dots + (U_{cempn} \times x_{cempn})^2}}{|x_{cemp1} + x_{cemp2} + \dots + x_{cempn}|} = \frac{\sqrt{(1,37 \times 150\,000)^2 + (1,51 \times 100\,000)^2}}{|150\,000 + 100\,000|} \\ = \frac{255\,012}{250\,000} = 1,02\% \quad (C.12)$$

Step 3: Calculation of the uncertainty of cement grinding and of the amount of consumed clinker and the corresponding uncertainty

Clinker consumption:

$$x_{clc} [t] = x_{cemp} t + x_{cemg1} t + x_{cemg2} t + \dots + x_{cemgn} t \quad (C.13) \\ = 250\,000 t + (-7\,500 t) + (-22\,100 t) + (-6\,800 t) + (-100 t) + (-3\,500 t) = 210\,000 t$$

Aggregated uncertainty of clinker consumption in case of independent uncertainties of a sum:



$$U_{x_{cllc}} [\%] = \frac{\sqrt{(U_{x_{cemp}} \times x_{cemp})^2 + (U_{x_{cemg1}} \times x_{cemg1})^2 + (U_{x_{cemg2}} \times x_{cemg2})^2 + \dots + (U_{x_{cemgn}} \times x_{cemgn})^2}}{|x_{cemp} + x_{cemg1} + x_{cemg2} + \dots + x_{cemgn}|}$$

$$= \frac{\sqrt{(1,02 \times 250\,000)^2 + (5,0 \times 7\,500)^2 + (5,0 \times 22\,100)^2 + (5,0 \times 6\,800)^2 + (5,0 \times 100)^2 + (5,0 \times 3\,500)^2}}{|250\,000 + (-7\,500) + (-22\,100) + (-6\,800) + (-100) + (-3\,500)|} = \frac{283\,027}{210\,000} = 1,35 \%$$

(C.14)

Step 4: Calculation of the amount of produced clinker and the corresponding uncertainty

Clinker production:  $x_{clip} [t] = x_{cllc} t + x_{stockend} t + (-x_{stockstart} t) = 210\,000 t + 5\,000 t + (-15\,000 t) = 200\,000 t$

(C.15)

Aggregated uncertainty of clinker production in case of independent uncertainties of a sum:

$$U_{x_{clip}} [\%] = \frac{\sqrt{(U_{x_{cllc}} \times x_{cllc})^2 + (U_{x_{stockend}} \times x_{stockend})^2 + (U_{x_{stockstart}} \times x_{stockstart})^2}}{|x_{clip} + x_{stockend} + x_{stockstart}|}$$

$$= \frac{\sqrt{(1,34 \times 210\,000)^2 + (10,0 \times 5\,000)^2 + (10,0 \times 15\,000)^2}}{|210\,000 + 5\,000 + (-15\,000)|} = \frac{323\,300}{200\,000} = 1,6 \%$$

(C.16)

### C.3 Aggregated uncertainties in case of combined parameters

The determination of the loss on ignition of e.g. limestone bases on the difference of the weight before and after the burning process in a laboratory. For the weighing procedures the same table scale is used under the same conditions (calibration, temperature, etc.), so that the uncertainties of the weighing results are not independent but correlated.

**Table C.4 — Example: The aggregated uncertainty of the loss on ignition (LOI)**

Uncertainty of scale and sample weights	Value
Relative expanded uncertainty of table scale 1 <sup>st</sup> measurement, $U_1$	0,6 %
Relative expanded uncertainty of table scale 2 <sup>nd</sup> measurement, $U_2$	0,6 %
Weight of sample before burning, $x_1$	1 g
Weight of sample after burning, $x_2$	0,645 g

LOI is calculated by subtracting the sample weights before and after burning:  $x_1 - x_2 = 1 \text{ g} - 0,645 \text{ g} = 0,355 \text{ g}$

Therefore, the uncertainty for the loss on ignition is calculated by the formula for correlated relative uncertainties of a sum:

$$U_{total} = \frac{\sqrt{\sum_{i=1}^n (U_i \cdot x_i)}}{\left| \sum_{i=1}^n x_i \right|}$$

(C.17)

where

$x_i$  is the absolute weight of sample;

$U_i$  is the relative expanded uncertainty.

$$U_{total} [\%] = \frac{(U_1 \times x_1) + (U_2 \times x_2)}{|x_1 + x_2|} = \frac{(0,6 \times 1) + (0,6 \times 0,645)}{|1 + (-0,645)|} = \frac{0,987}{0,355} = 2,8 \% \quad (C.18)$$

where

$U_{total}$  is the total relative uncertainty of the determination of the loss on ignition in percent;

$U_{1,2}$  is the relative expanded uncertainty of the mass measurement before and after the burning process in percent;

$x_{1,2}$  is the weight of sample before and after burning.

The uncertainties for high heat values are 1 to 3 %. Considering the moisture and hydrogen content for the determination of the lower heat values, uncertainties in the order of 1 to 4 % were determined in the field tests.

## Annex D (informative)

### Overview on terms in a cement plant

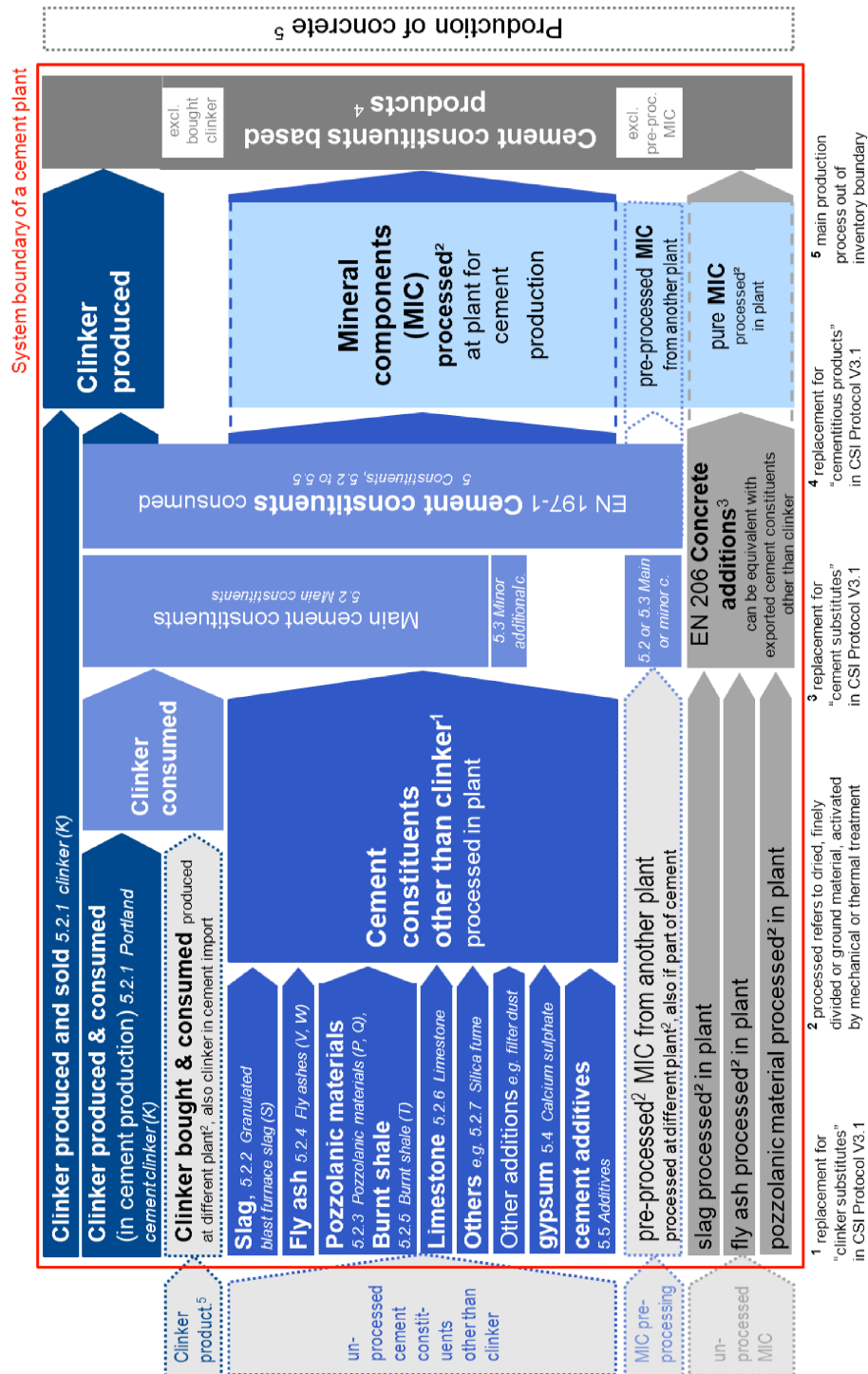


Figure D.1 — Exemplary mass streams and their terms

Exemplary mass streams and their terms

		Cement constituent	Cement constituents based product <i>KPI</i>	Concrete addition	Mineral component	Cement eq.* <i>KPI</i>
<b>Plant A</b>						
Own clinker	→ cement <small>produced consumed</small>	X	X	---	---	X
Own clinker	→ export to B <small>produced not consumed</small>	--	X	---	---	---
Slag	→ cement <small>processed consumed</small>	X	X	---	X	X
Slag	→ export to B <small>processed not consumed</small>	--	X	X	X	---
<b>Plant B</b>						
Clinker import from A	→ cement <small>not produced consumed</small>	X	---	---	---	---
Slag import from A	→ cement <small>not processed consumed</small>	X	---	---	X	X
Slag import from A	→ export <small>not processed not consumed</small>	--	---	---	---	---

\* cement equivalent =  $\frac{\text{clinker}}{\text{cement}} \times \text{own clinker}_{\text{produced}}$

with  $\frac{\text{clinker}}{\text{cement}} = \frac{\text{clinker}_{\text{consumed}}}{\text{cement}_{\text{produced}}} = \frac{\text{own clinker}_{\text{consumed}} + \text{imported clinker}_{\text{consumed}}}{\text{cement}_{\text{consumed}}}$

Figure D.2 — Exemplary mass streams and their terms

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