DEDICATED TO MAKING A DIFFERENCE

Cement Sustainability Initiative (CSI)

CO_2 and Energy Accounting and Reporting Standard for the Cement Industry

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The Cement CO_2 and Energy Protocol

wbcsd

Version 3.0






Appendices

1 Introduction

1.1 Preface for the Revised Protocol Version 3

Under the umbrella of the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD), a number of leading cement companies are collaborating on monitoring and reporting of greenhouse gas emissions. One of these issues is the industry's emissions of carbon dioxide (CO_2), the main greenhouse gas (GHG) contributing to man-made global warming.

In 2001, the CSI companies agreed on a methodology for calculating and reporting CO_2 emissions: the Cement CO_2 Protocol. While accounting for the specific needs of the cement industry, the protocol was closely aligned with the overarching Greenhouse Gas Protocol developed under a joint initiative of the WBCSD and the World Resources Institute (WRI).

The revised Version 2 of the Cement CO_2 Protocol was published in June 2005. It incorporates changes based on extensive practical application of the protocol by many cement companies worldwide. In addition, the revised protocol has again been aligned with the revised edition of the WRI / WBCSD Greenhouse Gas Protocol[1], which was published in April 2004.

This revised Version 3 of the Cement CO_2 and Energy Protocol is published in May 2011 and is intended to be applied for reporting of data[2] starting in the year 2011. It takes account of the further extended experiences with the application of the Protocol Version 2 and its evaluation for several years by many cement companies worldwide and in the CSI Getting the Numbers Right project (GNR). As reporting of energy (fuels, power) data is most important for the calculation of CO_2 emissions, the name of the protocol has been amended to Cement CO_2 and Energy Protocol.

Principle objectives for the revision of the Protocol were:

> Introducing additional key performance indicators (KPIs), e.g. KPIs based on cement in addition to those based on cementitious materials.

> Accounting the CO_2 emissions originating from the biomass content of mixed biomass and fossil fuels as climate neutral.

> Introducing more extensive methods for reporting CO_2 from on-site electrical power generation.

> Introducing simple and detailed methods for reporting of the calcination CO_2 emissions based on the kiln input.

> Enhancing the options for reporting of different fuel types and materials including non-kiln fuels.

> Historic data shall remain unchanged, meaning that they shall not be re-calculated based on the partly changed formula in Version 3.

> Solving problems with double counting of material transfers in aggregated data, e.g. on company or national level.

> Improved user friendliness and inclusion of a validation tool for first-step quality control.

The main changes between Version 2 and Version 3 of the Protocol are summarized in Appendices 6 and 7.

1.2 General Objectives

The Cement CO_2 and Energy Protocol is intended as a tool for cement companies worldwide. It provides a harmonized methodology for calculating CO_2 emissions, with a view to reporting these emissions for various purposes. It addresses all direct and the main indirect sources of CO_2 emissions related to the cement manufacturing process and on-site power generation in absolute as well as specific or unit-based terms.[3] The protocol comprises three main elements:

1. This guidance document,

2. An Excel spreadsheet. The spreadsheet is designed as a practical tool to help cement companies to prepare their CO_2 inventories. An overview of the spreadsheet structure is provided in Appendix 1, and

3. An Internet Manual for more detailed explanations and FAQs on the spreadsheet and guidance, available at www.Cement-CO2-Protocol.org.

The guidance document and the spreadsheet are collectively referred to as ”the Protocol”.

The purpose of this guidance document is to explain the rationale and structure of the spreadsheet, and to provide calculation and reporting instructions. In order to make the protocol comprehensible to stakeholders from outside the cement sector, some background information on the cement production process has been included in Appendix 2. In addition to that, a detailed manual for the application and explanation of the spreadsheet has been prepared and is available via Internet (www.Cement-CO2-Protocol.org).

Section 12 contains a Glossary of acronyms and abbreviations. Please note that in this protocol, metric tonnes are used, where 1 tonne (t) = 1000 kilograms (kg). For other abbreviations of units and numeric prefixes, see Appendix 5.

1.3 Relation to other CO_2 Protocols

The basic calculation methods used in this protocol are compatible with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[4] issued by the Intergovernmental Panel on Climate Change (IPCC), and with the revised WRI / WBCSD Greenhouse Gas Protocol[1]. Default emission factors suggested in these documents are used, except where more recent, industry-specific data has become available.

The 2006 IPCC Guidelines introduced a Tier 3 method for reporting CO_2 emissions from the cement production based on the raw material inputs (Vol. III, Chapter 2.2.1.1, Equation 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 CSI Task Force therefore recommended alternative methods for input-based reporting of CO_2 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. They were included in the Cement CO_2 and Energy Protocol Version 3 (Simple Input Method A1 and Detailed Input Method A2, Section 3.3).

For many parameters, Version 3 offers the possibility of reporting on at least two different levels of detail. For example, for internal company use or for companies starting the CO_2 reporting with the protocol, it is possible to use more simple methods and default values. More detailed methods are offered for companies reporting in specific schemes like the European Greenhouse Gas Emissions Trading Scheme (EU ETS) or companies with long-term experience with CO_2 reporting.

Various changes from Version 2 to Version 3 of the protocol were motivated by experiences from parallel reporting in other schemes. On the one hand, for example. taking into account biomass CO_2 from mixed (alternative) fuels has been derived from similar methodologies used in the EU ETS. On the other hand, the inclusion of a detailed method for considering CO_2 emissions from on-site power generation is a consequence of the increased membership of CSI, covering many companies with plants in Asia (e.g. China, India), where these technologies are used extensively.

Therefore, Version 3 allows cement companies to report their CO_2 emissions to national governments in accordance with IPCC requirements and, in addition, it can be applied as a flexible tool that facilitates reporting under various schemes, such as:

> The European Greenhouse Gas Emissions Trading Scheme (EU ETS);[5]

> “Act on promotion of global warming countermeasures”[6] and "Act on the Rational Use of Energy"[7] of the Japanese Government.

Furthermore, a new CO_2 reporting protocol for the cement industry is currently being developed in China. Generally, it should be noted that reporting requirements under specific voluntary or mandatory schemes can sometimes deviate from this Cement CO_2 and Energy Protocol. Consequently, companies reporting their CO_2 emissions should always state which protocol they have followed.

1.4 Defining Organizational and Operational Boundaries

Drawing appropriate boundaries is one of the key tasks in an emissions inventory process. In line with WRI / WBCSD Greenhouse Gas Protocol (2004)[1] and the international standard ISO 14064-1[8] this protocol distinguishes organizational and operational boundaries.

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. Chapter 7 of this protocol provides guidance on organizational boundaries. In particular, cement companies shall include the following types of activities in their voluntary reporting under this protocol, to the extent that they control or own the respective installations:

> Clinker production, including raw material quarrying and preparation;

> Grinding of clinker, additives and cement substitutes such as slag, both in integrated cement plants and stand-alone grinding stations;

> Additional fuel use for on-site power generation; and

> Preparation or processing of fuels or fly ash in own installations.

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

> **Direct emissions** are emissions from sources that are owned or controlled by the reporting company. For example, emissions from fuel combustion in a cement kiln are direct emissions of the company owning (or controlling) the kiln. This includes the direct emissions from additional fuel use for on-site power generation.

> **Indirect emissions** are emissions that result as a consequence of the activities of the reporting company but occur at sources owned or controlled by another company. For example, emissions from the generation of grid electricity consumed by a cement company will qualify as indirect.

Chapter 3 of this protocol provides detailed guidance on the different sources of direct emissions occurring in cement plants. Indirect emissions are addressed in Chapter 4.

In the context of operational boundaries, it is useful to recall the concept of scopes as defined in the revised WRI / WBCSD Protocol[1].

- **Scope 1** emissions are direct emissions occurring from sources that are owned or controlled by the company. For example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc. (...). Direct CO_2 emissions from the combustion of biomass shall not be included in scope 1 but reported separately, e.g. as Memo-Item.

- **Scope 2** emissions are indirect emissions from the generation of purchased electricity consumed in the company's owned or controlled equipment. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated.

- **Scope 3** is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services. Additional examples are listed in ISO 14064-1 [8], Annex B.

The revised WRI / WBCSD Protocol requires that companies shall separately account for and report on scopes 1 and 2. Verification shall also cover scope 1 and 2 emissions. The Cement CO_2 and Energy Protocol is consistent with this reporting requirement, except for some minor deviations which are summarized in Section 9.4.

2 Principles for the CO_2 and Energy Protocol

GHG accounting and reporting shall be based on the following principles:

> **Relevance:** Ensure that the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making needs of users – both internal and external to the company.

> **Completeness:** Account for and report on all GHG emission sources and activities within the chosen inventory boundary. Disclose and justify any specific exclusions.

> **Consistency:** Use consistent methodologies to allow for meaningful comparison of emissions over time. Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series.

> **Transparency:** Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.

> **Accuracy:** Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information.

This protocol was designed with a view to the above principles, which are consistent with the revised WRI / WBCSD Protocol[1]. In addition, the protocol aims to meet the following principles:

1. Avoid double-counting at plant, company, group, national, and international levels;

2. Allow to distinguish between different drivers of emissions (technological improvement, internal and external growth);

3. Allow to report emissions in absolute as well as specific (unit-based) terms;

4. Reflect the full range of direct and indirect CO_2 abatements achieved;

5. Provide a flexible tool suiting the needs of different monitoring and reporting purposes, such as: internal management of environmental performance, public corporate environmental reporting, reporting under CO_2 taxation schemes, reporting under CO_2 compliance schemes (voluntary or negotiated agreements, emissions trading systems), industry benchmarking, and product life-cycle analysis.

2.1 Calculation versus measurement

In principle, the GHG emissions of an installation can be determined by calculation or measurement. Version 3 of the Cement CO_2 and Energy Protocol relies – as did Version 2 – on calculation methods.

Using calculation-based methodologies emissions from source streams are determined based on input or production data obtained by means of measurement systems and additional parameters from laboratory analyses (calorific factor, carbon content, biomass content etc.) and/or standard factors.

Measurement-based methodologies for the determination of emissions from an emission source are based on continuous measurement of the concentration of the relevant greenhouse gas in the flue gas and of the flue gas flow.

The overall uncertainty depends on the accuracy of the determination methods of the different parameters. Industry has long-term experiences with accurate reporting of fuel quantities or production volumes. Also the analyses of conventional parameters like calorific values can be carried out with a very high accuracy. An important influencing factor on the uncertainty of the determination of CO_2 emissions by calculations is representativeness of sampling. The accuracy of concentration measurement techniques has been proven over long time to be high. Again, representativeness of sampling is key. The limiting factor of applying the measurement methodology is

- the low accuracy of volume flow measurement
- the impossibility of assessment of abatement measures and
- limited experience with the comparison of measured versus calculated data

which makes it – for the time being – more recommendable to use the calculation methodologies.

3 Direct Greenhouse Gas Emissions from Cement Manufacturing

3.1 Overview

Direct emissions are emissions from sources that are owned or controlled by the reporting entity. In cement plants, direct CO_2 emissions result from the following sources:

1. Calcination of carbonates, and combustion of organic carbon contained in raw materials;

2. Combustion of kiln fuels related to clinker production (see Section 3.7):
   a. Combustion of conventional fossil kiln fuels;
   b. Combustion of alternative fossil kiln fuels (also called fossil AF or fossil wastes) and mixed fuels with biogenic carbon content;
   c. Combustion of biomass fuels and biofuels (including biomass wastes);

3. Combustion of non kiln fuels (see Section 3.8):
   a. Combustion of conventional fossil fuels
   b. Combustion of alternative fossil fuels (also called fossil AF or fossil wastes) and mixed fuels with biogenic carbon content;
   c. Combustion of biomass fuels and biofuels (including biomass wastes);

4. Combustion of fuels for on-site power generation;

5. Combustion of the carbon contained in wastewater.

Table 1: Parameters and proposed data sources for calculation of direct CO_2 emissions.
See protocol spreadsheet for default CO_2 emission factors of fuels

Emission components	Parameters	Units	Proposed source of parameters
CO_2 from raw materials: Methods based on raw material input (A1, A2)			
> Calcination of raw material consumed for clinker production	Raw meal consumed Kiln feed Dust return correction CO_2 content in raw meal or loss on ignition (LOI)	t t mass fraction mass fraction	Calculated Measured at plant level Determined at plant level Measured at plant level
> Calcination of dust	Dust leaving kiln system excluding bypass dust CO_2 content in dust or loss on ignition (LOI)	t mass fraction	Measured at plant level Measured at plant level
Furthermore for detailed input method (A2) > Partial calcination of bypass dust	Bypass dust leaving kiln system and Bypass dust CO_2 content	t mass fraction	Measured at plant level Measured at plant level
> Additional raw materials not included in kiln feed	Additional raw materials Additional raw materials CO_2 content	t mass fraction	Measured at plant level Measured at plant level
CO_2 from raw materials: Methods based on clinker output (B1, B2)			
> Calcination of raw material consumed for clinker production	Clinker produced Emission factor clinker	t kg CO_2/ t cli	Measured at plant level Default = 525; or as calculated in detailed output method (B2)
> Calcination of dust > Organic carbon in raw materials	Dust leaving kiln system Emission factor clinker Dust calcination degree Clinker produced Raw meal : clinker ratio TOC content of raw meal	t kg CO_2/ t cli calcined fraction t cli t / t cli mass fraction	Measured at plant level Default = 525; or as calculated in detailed output method (B2) Measured at plant level Measured at plant level Default = 1.55; can be adjusted Default = 0.2%; can be adjusted
Furthermore for detailed output method (B2)			
> Calcination of raw material consumed for clinker production	CaO + MgO in clinker	mass fractions	Measured at plant level

t = metric tonne, AF = Alternative fuels, cli = clinker, TOC = Total organic carbon, QXRD = Quantitative X-Ray Diffractometry

Emission components	Parameters	Units	Proposed source of parameters
> Corrections of emission factor clinker	CaO + MgO from non-carbonate sources in raw materials Ca + Mg silicate sources in raw materials (e.g. as part of clay minerals)	mass fractions t mass fractions t	Measured at plant level Measured at plant level Measured at plant level (e.g. with QXRD with Rietveld refinement) Measured at plant level
CO_2 from kiln and non-kiln fuel combustion:			
> Conventional fuels	Fuel consumption Lower heating value Emission factor	t GJ /t fuel t CO_2 /GJ fuel	Measured at plant level Measured at plant level IPCC / CSI defaults, or measured
> Alternative fossil fuels (fossil AF) and mixed fuels	Fuel consumption Lower heating value Emission factor Biogenic carbon content	t GJ /t fuel t CO_2 /GJ fuel mass fraction	Measured at plant level Measured at plant level CSI defaults, or measured CSI defaults, or measured at plant level
> Biomass fuels (biomass AF)	Fuel consumption Lower heating value Emission factor	t GJ /t fuel t CO_2 /GJ fuel	Measured at plant level Measured at plant level IPCC / CSI defaults, or measured
> Wastewater combusted	–	–	Quantification of CO_2 not required

t = metric tonne, AF = Alternative fuels, cli = clinker, TOC = Total organic carbon, QXRD = Quantitative X-Ray Diffractometry

Emission factors, formulas and reporting approaches for these sources are described in the following sections of this chapter. *Table 1* summarizes the parameters involved, and the proposed data sources. Detailed information on the input parameters of the spreadsheet is provided in a manual, which is available in the internet (www.Cement-CO2-Protocol.org). Generally, companies are encouraged to measure the required parameters at plant level. Where plant- or company-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_2 emissions from raw material calcination.

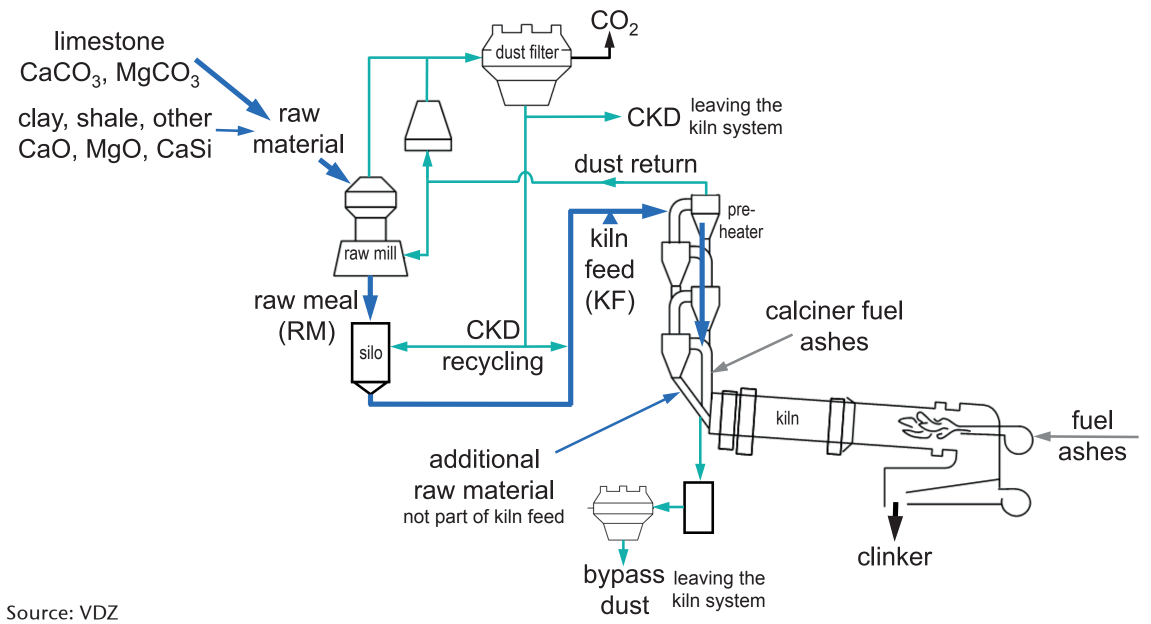
3.2 CO_2 from Raw Material Calcination

Calcination is the release of CO_2 from carbonates during pyro-processing of the raw meal. Calcination CO_2 is directly linked with clinker production. In addition, calcination of cement kiln dust (CKD) and bypass dust can be a relevant source of CO_2 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 gives an example of relevant mass flows in the clinker production process, as they often occur in plants with a cyclone pre-heater.

On plant level, calcination CO_2 can 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

Figure 1: Example of mass flows in the clinker production process in a plant for the production of clinker with cyclone pre-heater and rotary kiln.



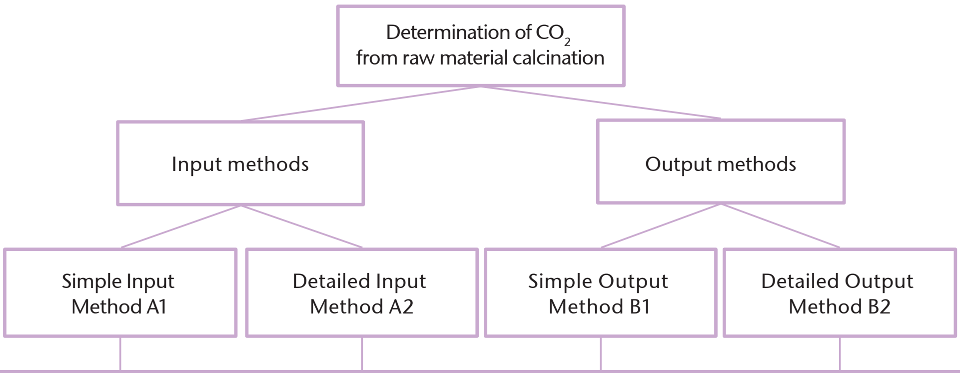
Source: VDZ

clinker-based method is often used in Europe. Both input and output based methods are included in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[4] (Output Tier 1 and 2, Input Tier 3[9]) and the Guidelines for Monitoring and Reporting of Greenhouse Gas Emissions (MRG)[5] in the European Emission Trading System (EU ETS, Input Method A, Output Method B).

Input and output methods are, in theory, equivalent. The WBCSD/CSI decided to include both types of methods in the Protocol Version 3 spreadsheet. 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, the spreadsheet allows for each type applying a simple and a detailed method. The choice between the simple 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 can be made available with sufficient accuracy and within the limits of practicability. The simple methods are also intended for companies that just started CO_2 reporting. After a few years such companies should start using the detailed methods – in order to apply detailed methods in all plants where possible – after gaining experience with CO_2 reporting, appropriate measurements and the quality control of measurements by using one of the simple methods. In any case, possible sources of error such as direct additions of carbonate-containing materials to the kiln, internal recycling of dust, as well as incomplete calcination of dust leaving the kiln system shall be accounted for. In the spreadsheet mass flows and parameters of the raw meal, kiln feed, CKD, 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 process of the kiln system.

The CO_2 emissions from the calcination of relatively small amounts of carbonates in fuel ashes added to the kiln system shall be completely accounted by the reporting of fuel CO_2 emissions. Normally, this is assured by determining the CO_2 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) can be regarded as fuel and/or raw material. In any case, the complete CO_2 emissions resulting from their use shall be accounted.

Figure 2: Overview of methods for the determination of CO_2 emissions from raw material calcination



Principle parameter and analysis method	raw meal consumed LOI (weight loss on ignition)	raw meal consumed CO_2 content (e.g. by IR-analysis of gases)	clinker produced default value	clinker produced CaO, MgO analysis (e.g. by XRF)
CO_2 from organic carbon (TOC)	partially included separate analysis for raw materials with high TOC content	included as part of CO_2 content no separate accounting required	default value	TOC analysis (if relevant) or default value
CO_2 from bypass dust	included complete calcination assumed, no analysis	residual CO_2 content	default value of clinker complete calcination assumed	CaO, MgO analysis or default value of clinker
CO_2 from CKD	LOI	CO_2 content	default value or analysis	analysis or default value
Additional raw materials fed to calciner or kiln inlet	not covered	CO_2 content accounted separately	included no separate accounting required	included no separate accounting required

3.3 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_2 emissions from raw material calcination for clinker production,

> CO_2 emissions from calcination of bypass dust and cement kiln dust (CKD) leaving the kiln system,

> CO_2 emissions from the organic carbon content (TOC) of raw materials.

The necessary calculations are performed in auxiliary sheets in the spreadsheet, which are separate from the plant sheet. The results from one of the auxiliary sheets 'CalcA1' or 'CalcA2' serve as input into the plant sheet.

(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** 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 in the auxiliary sheets CalcA1 or CalcA2 by subtracting the amount of dust, that is returned, e.g. from the pre-heater, and which is either recycled to the kiln feed, raw meal silo or discarded as cement kiln dust (CKD) leaving the kiln system. The concept of the mass flows is illustrated in *Figure 1*. The correction of the kiln feed by the rate of dust return prevents double counting of recycled dust. According to this concept, also the amount of CKD leaving the kiln system is accounted as part of the dust return and therefore subtracted from the amount of kiln feed. As principle term the input methods thus calculate the amount of raw meal that is consumed for the production of clinker including 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 can 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 output of 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. An example for this method is presented in the manual that describes the use of the spreadsheet in the internet (www.Cement-CO2-Protocol.org).

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 must 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_2 emissions** from the calcination of the raw meal consumed is calculated by multiplication with the weight fraction of the **CO_2 content 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 can 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_2 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 mostly converted to CO_2 during pyro-processing of the raw meal. CO_2 emissions originating from the total organic carbon content (TOC) shall be included in the parameters used for reporting of CO_2 emissions by the input methods:

For the **detailed input method A2**, the **measurement of the CO_2 content** should determine the complete CO_2 emissions from the raw meal and any additional raw materials. This means it should encompass CO_2 released from the inorganic carbon content (TIC) and the organic carbon content (TOC) of the corresponding materials. Such measurements can be performed, e.g. by total carbon (TC) analysis or by CO_2 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_2 from the calcination of carbonates. CO_2 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_2) emissions from TOC is often more than fully compensated by small amounts of residual humidity in raw meal samples, which is released as water vapor (H_2O) 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_2 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_2 content including CO_2 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 can 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) Cement kiln dust (CKD) 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. In this Cement CO_2 and Energy Protocol the definition of CKD leaving the kiln system excludes bypass dust, which is treated separately. The amount of CKD 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 (see above). Consequently, CO_2 emissions from the calcination of CKD leaving the kiln system must be considered separately. In the dry process CKD is often uncalcined. However, partially calcined CKD often is extracted in plants with semi-dry, semi-wet and wet processes. The CO_2 emissions from its calcination need to be accounted. The CO_2 emissions from calcination of raw meal that will form bypass dust are already accounted as calcination CO_2 originating from the raw meal consumed.

CO_2 from cement kiln dust (CKD) leaving the kiln system shall be calculated based on the relevant volumes of dust and either the CO_2 content or the LOI of CKD measured at plant level. From the CO_2 content or LOI of CKD and uncalcined raw meal (RM) the CO_2 emission factor EF_{CKD} is calculated in the auxiliary sheets for the input methods A1 and A2 according to the following equations:

Equation 1: $$EF_{CKD} = \frac{fCO2_{RM} \times d}{1 - fCO2_{RM} \times d}$$

Equation 2: $$d = 1 - \frac{fCO2_{CKD} \times (1 - fCO2_{RM})}{(1 - fCO2_{CKD}) \times fCO2_{RM}}$$

where EF_{CKD} = emission factor of partially calcined cement kiln dust (t CO_2/t CKD)
$fCO2_{RM}$ = weight fraction of carbonate CO_2 in the raw meal (--)
d = CKD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in the raw meal)
$fCO2_{CKD}$ = weight fraction of carbonate CO_2 in the CKD (--)

The variables $fCO2_{RM}$ and $fCO2_{CKD}$ are replaced by LOI_{RM} and LOI_{CKD} respectively in the simple input method A1, i.e. the weight fractions of the loss on ignition. The calcination rate d of the CKD 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 CKD is usually not, or only to a negligible degree, calcined in this process. In other processes (half dry, half wet or wet) calcination rates can 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 CKD-related emissions. *Equation 1* is based on raw meal analysis, while *Equation 5* is based upon the CO_2 emission factor of clinker. Both calculation methods should lead to the same result. See Appendix 3 for details on the *Equations 1, 2* and *5*.

In the absence of plant-specific data on dust volumes, the IPCC default for CO_2 from discarded dust (2% of clinker CO_2, see Appendix 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 company-specific data is clearly preferable.

(3) Partial calcination of bypass dust: Normally, bypass dust 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 bypass dust extraction and its degree of calcination, this can 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 bypass dust leaving the kiln system and the CO_2 content of the bypass dust shall be measured at plant level. The amount of residual CO_2 in the mass flow of bypass dust leaving the kiln system shall then be subtracted from the amount of CO_2 from the calcination of raw meal consumed. This is a correction for the uncalcined fraction of bypass dust.

(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_2 content including CO_2 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_2 emissions as additional raw material shall be restricted to its total inorganic carbon content (TIC, compare Section 3.6).

Equation for the simple input method A1 as implemented in auxiliary sheet CalcA1:

Equation 3: CO_2 *Raw Materials* =
Kiln Feed × (*1 – Dust Return Correction*) × LOI_{RM}
+ *CKD leaving kiln system* × EF_{CKD}

Equation for the detailed input method A2 as implemented in auxiliary sheet CalcA2:

Equation 4: CO_2 *Raw Materials* = *Kiln Feed* ×
(*1 – Dust Return Correction*) × $fCO2_{RM}$
+ *CKD leaving kiln system* × EF_{CKD}
– *BypassD leaving kiln system* × $fCO2_{BypassD}$
+ $\sum_i (ARM_i \times fCO2_{ARM,i})$

where for *Equation 3* and *4*: CO_2 *Raw Materials* = total CO_2 from raw material (t CO_2/yr), plant sheet line 39 Kiln Feed = amount of kiln feed measured at plant level (t/yr)
Dust Return Correction = fraction of returned dust with reference to the Kiln Feed (--)

LOI_{RM} = weight fraction of the loss on ignition of raw meal (--)

$fCO2_{RM}$ = weight fraction of CO_2 content in the raw meal here including CO_2 emissions from TOC (--)

CKD leaving kiln system = amount of cement kiln dust leaving the kiln system (t/yr)

EF_{CKD} = CO_2 emission factor of partially calcined cement kiln dust (t CO_2/t CKD)

BypassD leaving kiln system = amount of bypass dust leaving the kiln system (t/yr)

$fCO2_{RM}$ = weight fraction of CO_2 content in the bypass dust (--)

ARMi = amount of additional raw material *i* (t/yr), which is not part of the *Kiln Feed*

$fCO2_{ARM,i}$ = weight fraction of CO_2 content 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. In that case, the corresponding adjustments shall be made in a customized auxiliary sheet, not in the plant sheet. The adjustments shall be explained and accompanied by an overview of all relevant material flows. Furthermore it shall be demonstrated, that CO_2 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.

3.4 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_2 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 ash are used as raw materials entering the kiln.

The determination of the emission factor for clinker shall be clearly documented. To this end, an auxiliary worksheet has been included in the spreadsheet (**Detailed output method B2, auxiliary sheet CalcB2**). 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_2/t clinker shall be used (**Simple output method B1**). This value is comparable to the IPCC default (510 kg CO_2/t) corrected for typical MgO contents in clinker. See Appendix 3 for details on the default emission factor. The calculation for the simple output method B1 can be performed entirely in the plant sheet and **no separate auxiliary sheet** is required.

(2) Dust: CO_2 from bypass dust or cement kiln dust (CKD) 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.

CKD, as opposed to bypass dust, is usually not fully calcined. The emission factor for CKD shall be determined based on the emission factor for clinker and the calcination rate of the CKD, in accordance with *Equation 5*. This equation has been incorporated in the spreadsheet.

Equation 5: $$EF_{CKD} = \frac{\frac{EF_{Cli}}{1+EF_{Cli}} \times d}{1 - \frac{EF_{Cli}}{1+EF_{Cli}} \times d}$$

where EF_{CKD} = emission factor of partially calcined cement kiln dust (t CO_2/t CKD)
EF_{Cli} = plant specific emission factor of clinker (t CO_2/t clinker)
d = CKD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in the raw meal)

The calcination rate *d* of the CKD 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 CKD is usually not or only to a negligible degree calcined in this process. In other processes (half dry, half wet or wet) calcination rates can 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 CKD-related emissions. *Equation 1* is based on raw meal analysis, while *Equation 5* is based upon the CO_2 emission factor of clinker. Both calculation methods should lead to the same result. See Appendix 3 for details on the calcination rate *d* and *Equations 1, 2* and *5*.

In the absence of plant-specific data on dust volumes, the IPCC default for CO_2 from discarded dust (2% of clinker CO_2, see Appendix 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 company-specific data is clearly preferable.

(3) CO_2 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_2 during pyro-processing of the raw meal. The total organic carbon (TOC) contents of raw materials can vary substantially between locations, and between the types of materials used.

Data compiled by the CSI Task Force indicate that a typical value for TOC in the raw meal is about 0.1 – 0.3% (dry weight). This corresponds to CO_2 emissions of about 10 kg /t clinker, representing about 1% of the typical combined CO_2 emissions from raw material calcination and kiln fuel combustion.[10]

CO_2 emissions from organic carbon in raw materials shall be quantified and reported to ensure completeness of the inventory (cf. Section 8.3 on materiality thresholds). However, since their contribution to overall emissions is small, a simplified self-calculating mechanism has been implemented in the spreadsheet 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 by the CSI Task Force "Climate Protection" the value of the default factor of 0.2% is confirmed.
Companies are not required to analyze these emissions any further unless they have indications that organic carbon is more relevant in their context. This could be the case, for example, if a company 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.

Companies producing substantial quantities of dust should enter their plant-specific raw meal to clinker ratios if they wish to analyze 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_2 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.

Equation for the output methods B1 and B2 as implemented in plant sheet:
Equation 6: CO_2 Raw Materials = Clinker × EF_{cli} / 1000 + BypassD leaving kiln system × EF_{cli} / 1000 + CKD leaving kiln system × EF_{CKD} + Raw Meal Consumed × $fTOC_{RM}$ × 3,664

The *Raw Meal Consumed* is here calculated by *Equation 7*: *Raw Meal Consumed* = *Clinker* × *RM/Cli-ratio*
where for *Equation 6* and *7*:

CO_2 Raw Materials = total CO_2 from raw material (t CO_2/yr), plant sheet line 39

Clinker = clinker production measured at plant level (t/yr)

EF_{cli} = CO_2 emission factor of clinker (kg CO_2/t clinker); simple output method (B1): default value = 525 kg CO_2/t clinker; detailed output method (B2): determined in auxiliary sheet CalcB2

BypassD leaving kiln system = amount of bypass dust leaving the kiln system (t/yr)

CKD leaving kiln system = amount of cement kiln dust leaving the kiln system (t/yr)

EF_{CKD} = CO_2 emission factor of partially calcined cement kiln dust determined according to *Equation 5* (t CO_2/t CKD)

Raw Meal Consumed = amount of raw meal consumed for clinker production and bypass dust (t/yr)

$fTOC_{RM}$ = weight fraction of total organic carbon (TOC) in the raw meal (--); default value = 0.2%

RM/Cli-ratio = raw meal clinker mass ratio (raw meal consumed per clinker production, --), the addition of fuel ashes and dust leaving the kiln system must be accounted for its determination; default value = 1.55

3.5 CO_2 from Conventional Fuels

Conventional fuels are fossil fuels including e.g. coal, petcoke, fuel oil and natural gas. The preferred approach is to calculate CO_2 from conventional fuels (but also alternative and non-kiln fuels, see Sections 3.6 and 3.8) 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) must 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 equation defined in the 2006 IPCC Guidelines[4] (Vol. II, Section 1.4.1.2, Box 1.1) can be applied.

Default emission factors per GJ lower heating value are listed in the protocol spreadsheet. The defaults for coal, fuel oil and natural gas are from IPCC (1996). Small differences exist to the default emission factors stated in 2006 IPCC Guidelines (Vol. II, Section 1.4.2.1, Table 1.4; Section 2.3.2.1, Table 2.3). Historic data based on IPCC 1996 default values shall not be recalculated. From 2011 reporting IPCC 2006 default values shall be used. Both are offered in the spreadsheet. The default value for petcoke is based on analyses compiled by the CSI Task Force (see Appendix 4 for details).

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 can 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_2 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[11]. 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_2 emission factors of fuels shall always be determined based on the total carbon (TC) content.

3.6 CO_2 from Alternative Fuels, Mixed Fuels and Biomass Fuels

The cement industry increasingly uses a variety of alternative fuels (AF) which are typically derived from wastes and therefore, without this use, would have to be disposed of in some other way, usually by landfilling or incineration. AF serve as a substitute for conventional fossil fuels. They include fossil fuel-based fractions, such as, waste oil and plastics, and biomass fractions, such as waste wood and sewage sludge.

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

> **CO_2 from biomass fuels** is considered climate-neutral, because emissions can be compensated by re-growth of biomass in the short term. CO_2 from biomass fuels is reported as a ”memo item“, but excluded from the national emissions totals. The fact that biomass is only really climate-neutral if sustainably harvested, is taken into account in the “Land use change and forestry“ sections of the national inventories, where CO_2 emissions due to forest depletion are reported.

> **CO_2 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_2 from mixed fuels with biomass and fossil fractions:** In the case that biofuels 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 (IPCC 2006, Vol. II, Section 2.3.3.4).

To ensure consistency with the guidelines of IPCC as well as WRI / WBCSD, there is thus a need for transparent reporting of the direct CO_2 emissions resulting from AF combustion in cement plants. Therefore, this protocol requires reporting as follows:

> Direct CO_2 from combustion of **biomass** (including biomass fuels, biomass wastes and the biomass fraction of mixed fuels) shall be

reported as a memo item, but excluded from emissions totals. The IPCC default emission factor of 110 kg CO_2/ GJ for solid biomass shall be used, except where other, reliable emission factors are available.[12] This value lies in the range of different values for solid biofuels, which are specified as default emission factors in IPCC 2006 (Vol. II, Section 1.4.2.1).

> Direct CO_2 from combustion of **fossil** AF and the fossil fraction of mixed fuels shall be calculated and included in the direct CO_2 emissions **(gross emissions** and **gross emission including CO_2 from on-site power generation,** i.e. **total direct CO_2 emissions).** CO_2 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 company-specific data, companies shall use the default emission factors provided in the spreadsheet, which are based on measurements and estimates compiled by the CSI Task Force.

> Indirect **GHG savings** achieved through the utilization of AF shall be accounted as **net emissions** in the Protocol. Note that therefore the definition of net emissions in Protocol Version 3 is changed compared to the Protocol Version 2. The definition is further described in Chapter 5. It corresponds to its original definition in Protocol Version 1.

> Other indirect **GHG savings** or a **balance with acquired emission rights** shall be accounted separately. An option that was included In Protocol Version 2 for this purpose has been deleted in the Protocol Version 3.

Generally, the CO_2 emission factors of all fuels shall represent the complete CO_2 emissions from the use of the fuel based on the total carbon content (TC).

Some AF, for example used tires and impregnated saw dust, contain both fossil and biomass carbon. These fuels shall be treated as mixed fuels and the CO_2 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 international standards (e.g. EN 15440). 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 can be reported as fuel with a CO_2 emission factor based on the total organic carbon (TOC) content. In this case and when reporting CO_2 emissions from raw materials based on their input (Section 3.3), the CO_2 emissions from the TIC content must be reported additionally[9]. This shall be done by using the detailed input method A2 and the option for reporting additional raw materials (ARM) which are not part of the kiln feed. If CO_2 emissions from TOC of the material are already reported as fuel, the CO_2 content specified for the additional raw material shall only reflect the remaining TIC content so that CO_2 emissions from the total carbon content (TC) are reported (compare Section 3.3 (4)).

3.7 CO_2 from Kiln Fuels

Kiln fuels in this protocol 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 protocol 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 CO_2 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. Note that in Protocol Version 2 the fuels used for drying of raw material and for mineral components were reported together under non-kiln fuels. For a fair comparison of plants using separate fuels on one hand and waste heat on the other hand for drying of raw materials and fuels, these fuels have now been allocated to kiln fuels in Protocol Version 3. This leads to a certain break in the timeline of the performance indicators (KPIs, Section 6 and Appendix 9) when switching from Version 2 to Version 3. For most plants the impact should be of low significance.

3.8 CO_2 from Non-Kiln Fuels

Overview

Non-kiln fuels include all fuels which are not included in the definition of kiln fuels (Section 3.7). 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 CO_2 emissions from non-kiln fuels combusted on site. These emissions are accounted for in the spreadsheet as follows:

- CO_2 from non-kiln fuels is reported separately, by application type, to provide flexibility in the aggregation of emissions. The spreadsheet distinguishes 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

  Note that fuels consumed for drying of raw materials for the production of clinker and kiln fuels are included in the kiln fuel section.
- CO_2 from off-site transports by company-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%)[11]. Companies wishing to account for incomplete oxidation of carbon in non-kiln fuels shall do so in accordance with the WRI / WBCSD tool for stationary fuel combustion[1].

See also *Table 8* in Section 9.2 regarding the process steps which need to be covered to ensure complete reporting according to this protocol.

Measured plant-specific lower heating values shall be used, if available. Alternatively IPCC or CSI default values can be applied. If the same type of fuel is used as non-kiln fuel and kiln fuel, then the CO_2 emission factors used for reporting shall correspond. Otherwise, measured plant-specific emission factors shall be used, if available. Alternatively IPCC or CSI defaults values can be applied.

CO_2 from Transports

Like any other manufacturing process, cement production requires transports for the provision of raw materials and fuels as well as for the distribution of products (clinker, cement, concrete). In some cases, clinker is transferred to another site for grinding. Transport modes include conveyer belts, rail, water, and road. If transports are carried out by independent third parties, the associated emissions qualify as *indirect*. See Chapter 4 for details on indirect emissions.

Figure 3 provides a breakdown of transport types related to cement production. This protocol requires that companies account for energy consumption and associated emissions of on-site transports carried out with own vehicles (including leased vehicles). Examples include the fuel consumption of quarry vehicles and the electricity consumption of conveyor belts. Note that emissions related to consumed electricity qualify as *indirect*, except if the electricity is produced by the company itself (on-site power production).

In contrast, this protocol does not require companies to quantify emissions related to the following types of transport:

- On-site transports carried out by third parties (i.e. vehicles not owned or controlled by the reporting entity);

- All off-site transports, (e.g. of fuels, intermediates and finished products), irrespective of whether the transports are carried out by third parties or by company-owned fleets.

Please note, however, that the complete exclusion of off-site transports can represent a deviation from the requirement of WRI / WBCSD to report the emissions from all owned and controlled sources[1]. Companies aiming to comply with this WRI / WBCSD requirement have to report the emissions of their owned and controlled fleets, both for on- and off-site transports.

3.9 CO_2 from Wastewater

Some cement plants inject wastewater in their kilns, for example as a flame coolant for control of nitrogen oxides (NO_x). The carbon contained in the wastewater is emitted as CO_2. This protocol does not require cement companies to quantify their CO_2 emissions related to wastewater consumption, because these emissions are usually small and, in addition, difficult to quantify:

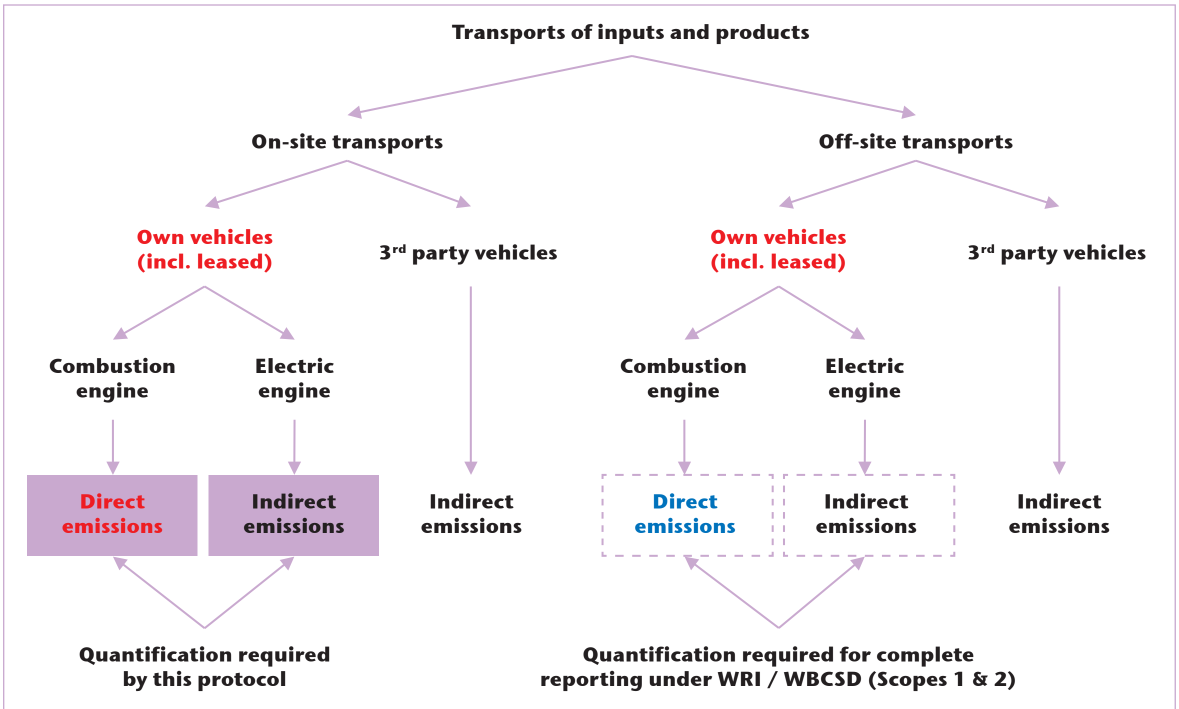
- Most cement plants do not consume wastewater;
- Where wastewater is consumed, its carbon content will usually contribute less than 1% of the plant's overall CO_2 emissions;[13]
- In addition, the carbon contained in the wastewater can be of biomass origin (e.g., sewage), in which case it would have to be counted as a memo item only.

However, companies should be prepared to show that their consumption of waste water has no material impact on their overall CO_2 emissions.

3.10 Non-CO_2 Greenhouse Gases

Emissions of methane (CH_4) from cement kilns are very small due to the high combustion temperatures in the kilns. CH_4 emissions are typically about 0.01% of kiln CO_2 emissions on a CO_2-equivalent basis.[14] Likewise, data compiled by the CSI Task Force indicate that emissions of nitrous oxide (N_2O) from cement kilns are typically small, but these data are currently too limited in scope to allow for generalized conclusions.[15] The other GHG covered by the Kyoto Protocol (PFC, HFC, SF_6) are found not to be relevant in the cement context.

Figure 3: Breakdown of transports by type, and coverage of this protocol



This protocol does not require cement companies to quantify their non-CO_2 GHG emissions from kilns. Besides the relative insignificance of these gases in the context of cement production, the main underlying reason is that most voluntary and mandatory reporting schemes are currently restricted to CO_2 for the reporting of the cement sector.

Relevant emissions of CH_4 and N_2O may, however, result from the stationary combustion of non-kiln fuels (e.g., dryers, on-site power generation). If required, these emissions should be reported using the WRI / WBCSD calculation tool for stationary fuel combustion[1] (see www.ghgprotocol.org).

4 Indirect Greenhouse Gas Emissions

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 greenhouse gas emissions from various sources. Key examples include the CO_2 emissions from:

- External production of electricity consumed by cement producers;
- Production of clinker bought from other producers and interground with own production;
- Production and processing of conventional and alternative fuels by third parties;
- Transport of inputs (raw materials, fuels) and outputs (cement, clinker) by third parties.

Data on indirect emissions can be useful to assess overall carbon footprint of an industry. To this end, cement companies shall calculate and report two of the above four categories of indirect emissions:

- **CO_2 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 www.ghgprotocol.org/standard/tools.htm for the latest update). In accordance with requirements of the revised WRI / WBCSD Protocol (Chapter 4 and Appendix A), emissions associated with the consumption of electricity during transport and distribution (T&D losses) shall not be included in this calculation. Version 3 offers much more detailed possibility to report emissions and credits from power use, on-site power production both by waste heat recovery (WHR) and separate on-site power generation (OPG) as well as from power purchase and sales. Therefore a section called "power balance" has been included which 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.
- **CO_2 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 company, 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 from the GNR website shall be used (see www.wbcsdcement.org, look for Getting the Numbers Right, GNR). These values are updated regularly by the CSI. As a first priority national or regional values shall be applied, if available. As a second priority the global average value can be used.

In Version 3 of the protocol (in contrast to Version 2) double counting of clinker transfers (as well as of cement and MIC transfers) are considered automatically (see Section 7.4 for more detailed information on company-internal transfers). Please note that the default emission factor of 865 kg CO2/t should only be used for calculating the indirect 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 emissions of the reporting company.

The approaches for calculating these two types of indirect emissions are summarized in *Table 2*. Quantification of other indirect emissions is not required by this protocol. This applies, in particular, for indirect emissions related to transports (see Section 3.8 for details).

Table 2: Parameters and data sources for calculation of indirect CO_2 emissions as required by this protocol

Emission	Parameters	Units	Source of parameters
CO_2 from external power prod. (indirect emission)	Power bought from external grid Emission factor excl. T&D losses	GWh t CO_2 /GWh	Measured at plant level Supplier-specific value or country grid factor
CO_2 from clinker bought (indirect emission)	Net clinker purchases Emission factor	t cli t CO_2 /t cli	Measured at plant level (bought minus sold clinker + internal clinker transfer) Default factor (from GNR data base)

CO_2 emissions associated with the production of clinker- or cement-substituting mineral components (MIC) shall not be considered an indirect 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.

5 Gross and Net CO_2 Emissions

5.1 Overview

Version 1 of the Cement CO_2 Protocol established in 2001 offered the possibility of taking advantage of reporting credits for 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.

In Version 2 the definition of gross and net emissions was changed: An option for reporting the result of an 'Emissions balance' by subtracting 'Emission offsets' or 'Emissions rights' as 'Net emissions' was included. However, experience from the CSI companies show that this concept was rarely used. In consequence, the original definition of 'Net emissions' according to the Protocol Version 1, was re-established.

Waste can substitute conventional fossil fuels and minerals in cement production. The recovered wastes become alternative fuels and raw materials (AFR). As a result, direct CO_2 emissions from conventional fuels are reduced but direct CO_2 emissions from wastes ("waste-to-energy conversion") occur. The direct CO_2 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_2 emissions from waste combustion at the cement plant, depending on local conditions (type of waste, reference disposal path), see *Figure 4*.

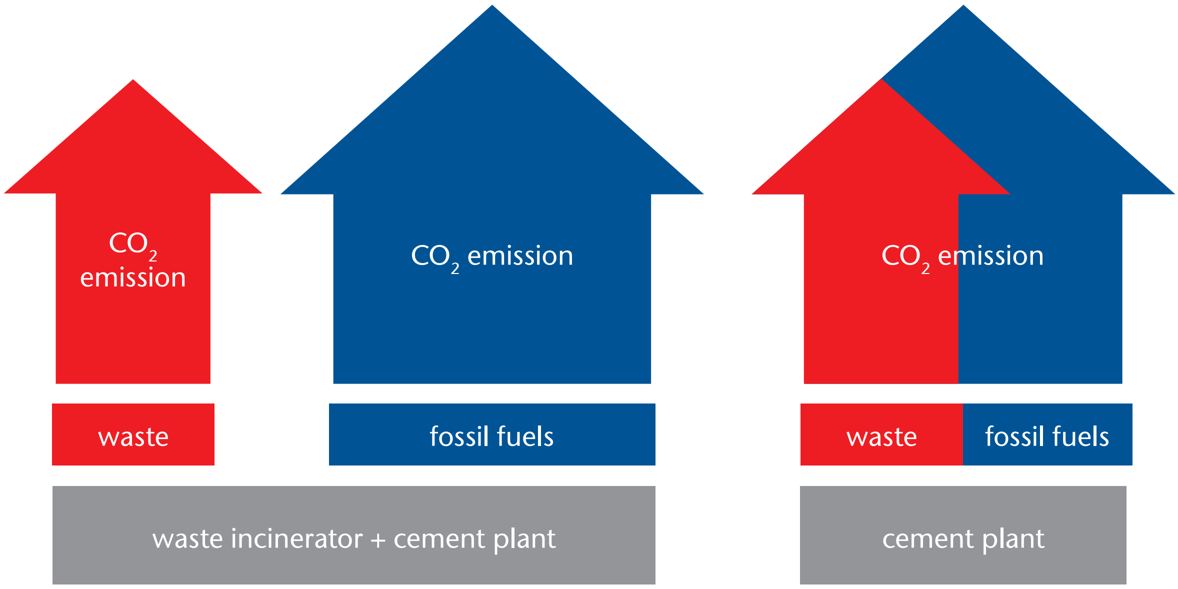
Therefore, the protocol defines the following indicators:

Gross Emissions are the total direct CO_2 emissions from a cement plant or company, including CO_2 from fossil wastes (but excluding CO_2 from biomass wastes, which is treated as a memo item). Credits 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 creditable savings will to some degree have to be agreed upon by convention, rather than based on "precise" GHG impact assessments.

Net Emissions are the gross emissions minus the credits for indirect GHG savings. As far as practicable, reported AFR credits 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 credits should be provided and verified as appropriate. As a default, the protocol assumes credits for indirect savings to be equal to the direct CO_2 emission from fossil AFR use.
The protocol recognizes that 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. International convention on a more precise treatment of AFR has yet to be reached.

A key objective of this protocol is to ensure that cement companies can report the complete direct and fossil CO_2 emission from activities within the organizational boundaries of the company. As an increasing number of cement plants worldwide (especially in Asia) produce electric power on-site, the definition of gross and net emissions shall also reflect this fact. On one hand, and as a basic principle, absolute emissions have to be reported including all sources, i.e. including emissions from power generation. On the other hand, a fair comparison of cement plants with and without on-site power generation is only possible if emissions from (separate) power generation are excluded. Hence, as principle parameter direct emissions are determined as 'Absolute gross CO_2 emissions including CO_2 from on-site power generation'. Additionally, the definition of 'Absolute Gross CO_2' as parameter for the derivation of the specific performance indicators was adjusted to exclude CO_2 emissions from on-site power generation. Consequently, specific indications are reported for cement production only.

Figure 4: Indirect saving of CO_2 emissions by the use of waste as alternative fuel in a cement plant



The following sections describe the framework of the definition of the absolute gross and net CO_2 emission values.

5.2 Gross CO_2 Emissions

Absolute gross CO_2 emissions including CO_2 from on-site power generation are the total fossil and direct CO_2 emissions from a cement plant or company in a given period. Gross emissions include CO_2 from alternative fossil fuels, but exclude CO_2 from biomass fuels and the biomass content of mixed fuels, since these emissions are regarded as climate-neutral. The CO_2 emissions from biomass and indirect CO_2 emissions are normally treated as a memo item in emission reports.

Table 3: Emission sources to be reported within "gross emissions including CO_2 from on-site power generation"

Emissions
CO_2 from raw materials
+ CO_2 from conventional fossil fuels
+ CO_2 from alternative fossil fuels (fossil wastes)
+ CO_2 from fossil carbon of mixed (alternative) fuels covering CO_2 from all kiln fuels and all non-kiln fuels including CO_2 from on-site power generation
= **Total direct emissions**

Memo items
CO_2 from biomass fuels CO_2 from biogenic carbon of mixed (alternative) fuels
Indirect CO_2 (bought electricity & clinker)

Absolute gross CO_2 emissions are the fossil and direct CO_2 emissions (excluding on-site electrical power production) from a cement plant or company in a given period. Gross emissions include CO_2 from alternative fossil fuels, exclude CO_2 from biomass fuels and the biomass content of mixed fuels, since these emissions are regarded as climate-neutral. Gross emissions further exclude CO_2 emissions from on-site power generation, in installations which are separate from the kiln system and use fuel energy other than waste heat from the kiln system, since the electrical power in many cement plants is imported from the grid and related to *indirect* emission. The CO_2 emissions from biomass and indirect CO_2 emissions are normally treated as a memo item in emission reports.

Table 4: Emission sources to be reported within "gross emissions"

Emissions
CO_2 from raw materials
+ CO_2 from conventional fossil kiln fuels
+ CO_2 from alternative fossil kiln fuels (fossil wastes)
+ CO_2 from fossil carbon of mixed (alternative) kiln fuels and non-kiln fuels (excluding on-site power generation)
+ CO_2 from non-kiln fuels excluding CO_2 from on-site power generation
= **Gross CO_2 Emissions**
= **Direct emissions (excluding CO_2 form on-site power generation)**

Memo items
CO_2 from biomass fuels
CO_2 from biogenic carbon of mixed (alternative) fuels
Indirect CO_2 (bought electricity & clinker

Note that the direct CO_2 emissions from on-site power generation are not included in the indirect CO_2 emissions reported as memo item according to Protocol Version 3.

Accounting of CO_2 emissions from the biomass content of fuels

In the Cement CO_2 Protocol Version 2 it was only possible to report pure fossil fuels or pure biomass fuels. It did not allow taking into account fuels containing both biomass and fossil carbon, as, for example, mixed industrial wastes or waste tires. As of Protocol Version 3, the CO_2 emissions originating from the biogenic carbon content of mixed fuels are not accounted as part of the gross emissions. Therefore, additional sections have been included in the Protocol Version 3 spreadsheet, so that the biomass content of mixed fuels can be reported. Biomass CO_2 from these fuels is added up with the CO_2 from pure biomass fuels to total biomass CO_2 and reported as memo item. It is subtracted when calculating gross CO_2 emissions. A default value for biomass content of such fuels has only been included for waste tires (27%). The evaluation of other waste fuels by the Task Force "Climate Protection" has shown that the variation of their biogenic carbon content was so big that no representative default values could be assumed.

5.3 Net CO_2 Emissions and Indirect Emission Reductions 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 (AF)* in this protocol. By utilizing AF, cement companies reduce their consumption of conventional fossil fuels while at the same time helping to avoid conventional disposal of the waste materials by landfilling or incineration.

Increased utilization of AF can have an influence on the direct CO_2 emissions of a cement company because the emission factors of the AF can differ from those of the displaced fuels. Moreover, the carbon contained in the AF can be of fossil and/or biomass origin. As mentioned above, utilization of AF 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 emissions impacts, indirect emission reductions, and resource efficiency makes the substitution of AF for conventional fossil fuels an effective way to reduce global GHG emissions (see e.g. IEA1998, CSI / ECRA 2009 and WBCSD / IEA 2009).

The requirements regarding the reporting of CO_2 emissions from fossil fuel-based AF (also called "fossil AF" or "alternative fossil fuels") vary widely between different schemes. The balance sheet approach described in Section 5.1 ensures completeness, rigor and transparency of reporting under different schemes.

- Direct CO_2 emissions resulting from the combustion of fossil AF must always be included in the company's gross emissions, in accordance with Section 3.6.

With the following concept this Protocol provides a framework for reporting also indirect emission reductions achieved by using alternative fuels:

- Indirect GHG emission reductions at landfills and incineration plants are accounted by subtracting the fossil CO_2 emissions from alternative fuels.

- The resulting net emissions, being the gross emissions minus the emission from alternative fossil fuels, reflect the emissions according to the rules of the reporting scheme under consideration.

The Cement CO_2 and Energy Protocol Version 3 defines an indicator for a company's net CO_2 emissions, as follows:

Net emissions are the gross emissions minus the CO_2 emissions from alternative fossil fuels.

Net CO_2 Emissions = Gross CO_2 Emissions – fossil CO_2 emissions from AF

Net emissions as defined here are an indicator for a company's net carbon footprint. They reflect a company's direct emissions as well as emission reductions achieved indirectly by preventing the need for incineration or land filling of waste materials. As mentioned in Section 5.1 in this method the discount for CO_2 from fossil alternative fuels is a proxy because real (but unknown) overall balance can result in a higher or lower reduction. See Section 9.2 for the reporting requirements with respect to net emissions.

Some global cement companies have voluntarily committed to their own group-wide CO_2 reduction targets, including the convention that the use of AF is considered a means to reduce global emissions (i.e., CO_2 from both fossil and biomass AF is considered effectively climate-neutral). These companies can assess a credit equivalent based on their CO_2 emissions from fossil AF by comparison of net and gross CO_2 emissions. Since those companies will report both gross and net emissions, full transparency of information is guaranteed.

Regarding the last example, the WBCSD/CSI emphasizes that companies shall apply a "default" credit for fossil AF only for their voluntary corporate environmental reporting. Whenever reporting under a regulated scheme, companies shall respect the provisions of that scheme in relation to AF. Detailed instructions for voluntary environmental reporting are provided in Chapter 9.

5.4 Other Indirect Emission Reductions

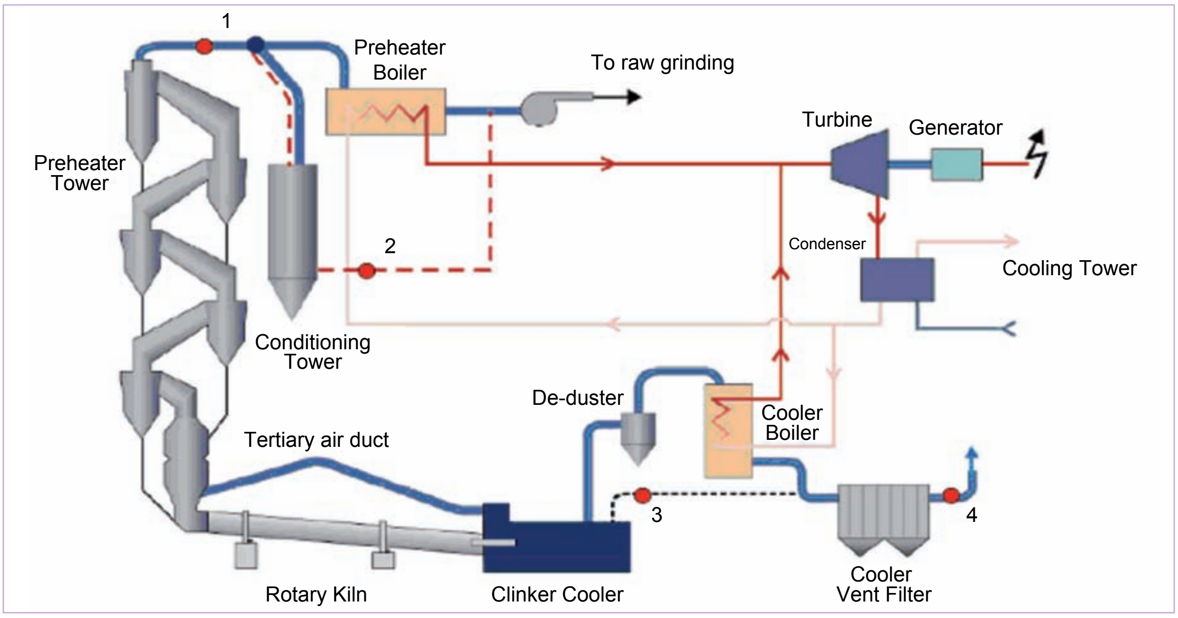
Utilization of Waste Energy

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 company may account for the indirect GHG emission reductions resulting from such waste heat exports by separate determination and accounting outside the protocol, provided that the rules of the relevant reporting schemes allow such crediting. The credit for waste heat export shall neither influence the company's net CO_2 emissions, nor its gross CO_2 emissions which according to the definition in this protocol reflect the direct CO_2 emissions (including and excluding on-site power generation) which are associated with the production of the heat.

Similar credits may be applied for other forms of waste energy utilization. So Version 3 offers the possibility of reporting voluntarily waste heat utilization within the plant (e.g. for raw material or slag drying) in order to allow a fair comparison between plants exporting heat and plants using the heat internally. The calculation has to be done separately from the protocol spreadsheet and the total energy flow in GJ/a can be inserted. The reporting is voluntary.

However, in the case of electrical power generation from waste heat originating from the kiln system (*Figure 5*) any additional fuel used in the kiln system is accounted as kiln fuel and consequently emissions are accounted as direct CO_2 emissions

Figure 5: Schematic of application of Waste Heat Recovery (WHR) and electrical power generation in cement manufacture. 1 gas from preheater, 2 bypass of preheater boiler, 3 bypass of cooler boiler, 4 cooler air.



of the kiln system in this Protocol Version 3. In order to provide more detailed information, Version 3 distinguishes between waste heat recovery and separate on-site power generation. In any case, when applying such credits 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. For example, if a cement company produces power on-site based on fossil fuels (as opposed to waste heat), global emissions will essentially be the same as in the case where the same amount of power is supplied by an external generator, unless there is a significant difference in generation technology; hence the appropriateness of a credit for the power generation by the cement company may be considered questionable in this case.

Recarbonation of Cement as a CO_2 Sink

When poured concrete is curing, it reabsorbs some CO_2 from the atmosphere. Re-absorption is however small compared to the emissions from cement production[16]. More CO_2 is absorbed throughout the lifetime of the concrete product, but very slowly. A recent study (ECRA 2008) has summarized the available published research results with respect to concrete recarbonation:

The quantification of the CO_2 uptake is subject to the diversity of concrete applications and to parameters affecting the chemical reaction of carbonation. Despite differences in single results, the following general statements can be made:

- Carbonation of concrete occurs unavoidably, but is no risk for concrete buildings, which were built under consideration of the appropriate technical rules.
- The CO_2 uptake by carbonation during a service life of 50 to 70 years is limited due to the comparatively small exposed surfaces of concrete construction units and due to the carbonation rate depending on diffusion processes. Nevertheless, it can reach an order of magnitude of about 60 up to 100 kg CO_2 per tonne of cement which is roughly 10 % of the initial CO_2 emission from cement production.
- For after-service life (the time period after demolition), a larger binding potential is calculated due to the huge increase of the concrete surface by crushing. High demolition and recycling rates affect the balance positively. At least, a further 10 to 15 % of the initial CO_2 emission from cement production can be taken up by carbonation.
- As a result, a capacity in the magnitude of 20 to 25 % of the initial CO_2 emission from cement production will be rebound by

carbonation of concrete during its life cycle.

- Additional amounts of CO_2 can be bound if an intermediate storage period will be imposed between the processing of the demolished concrete and the emplacement. Active carbonation of finely crushed concrete could use the carbonation capacity to a higher extent, but there is a lack of experiences in practice so far.

Due to the present lack of accurate and quantifiable data, recarbonisation of cement and concrete is currently not part of this protocol. This may change in the future.

Carbon Capture and Storage

Carbon Capture and Storage (CCS) means the separation of carbon dioxide from the flue gas stream of an installation, the purification and liquefaction of the CO_2, transport to a sequestration site and finally underground long-term storage. Other technologies are considered aiming at the transformation of the captured CO_2 in a useful product in order to avoid risks which are linked to the separation of such huge quantities of compressed and liquefied gases. The main focus of policy currently lies on the power sector as this is operating by far the biggest CO_2 sources. Nevertheless, CCS is discussed more and more also for big industrial sources like steel or cement plants.

Different types of technologies are discussed for CO_2 capture, like so-called pre-combustion (e.g. gasification and carbon separation from fossil fuels), post-combustion (absorption or adsorption techniques) or oxyfuel technologies. All these technologies require huge amounts of energy (e.g. for desorption of absorbents or oxygen generation by air separation) leading to a significant energy penalty. For the clinker burning process current research results show e.g. a doubling of the power consumption for oxyfuel technology and a doubling of both power and fuel energy consumption for the amine scrubbing (CSI/ECRA 2009, ECRA 2009).

Therefore, depending on the technology the application of CCS would lead to higher fuel energy consumption (and thus direct CO_2 formation) as well as higher power consumption (leading to additional direct or indirect CO_2 formation). In order to achieve an overall CO_2 reduction the CO_2 formed additionally ("CO_2 penalty") has to be captured as well. Therefore a distinction has to be made between "CO_2 captured" (which covers all CO_2 treated in a capture installation) and "CO_2 abated" (which is the CO_2 reduced in relation to the process without CO_2 capture).

Until today, no harmonized accounting rules have been defined worldwide (e.g. the EU ETS does not foresee any additional emission rights for CO_2 capture installations). The idea is that they have to pay off by the reduced CO_2 emissions in the basic process (e.g. the power plant), which otherwise has to buy the allowances. By this, the EU ETS refers automatically to the "CO_2 abated" and the benefit of the CO_2 abatement is allocated to the company operating the basic process.

Version 3 of the Cement CO_2 and Energy Protocol does not foresee the possibility of reporting credits from CCS, as these technologies are quite far from industrial application today. In case of implementation of a capture process (e.g. as pilot or demonstration project) these credits should be reported (separately) according to the respective accounting scheme and only if the CO_2 is really stored safely and long-term.

This position might change if and when CCS becomes viable in the cement industry.

6 Performance Indicators

6.1 Introduction

The CO_2 and Energy Protocol aims to provide a flexible basis for CO_2 emissions monitoring and reporting. The calculation of individual emission components as described above is quite straightforward. The definition of emission totals and ratio indicators, in contrast, is highly dependent on the reporting context and purpose, such as: input to national inventories, CO_2 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** has been added to the protocol spreadsheet. 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 can introduce additional parameters according to their needs, for instance different emission (sub-) totals.

A number of KPIs have been added in Version 3 compared to Version 2. Different motivations have been the reason to include these indicators. Some of them are helpful in internal company reporting and have been calculated separately before by many companies. Others are based on requirements set by legally binding schemes (like EU ETS) or conventions (like the GNR scheme). A summary of the definitions of the performance indicators (KPIs) in Version 3 is presented in Appendix 7 together with a comparison to Protocol Version 2.

6.2 Denominator for Specific, Unit-Based Emissions

From a sustainable development and business point of view, the reporting of CO_2 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:
1. Clinker
2. Cement (equivalent)
3. Cementitious products

Each of these three denominators gives a different weighting to the CO_2 performance involved in different stages of cement manufacturing.

> **Clinker**
In the context of this protocol 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_2 in cement production.

> **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.

- **Cementitious products:**
  Cementitious products consist of all clinker produced by the reporting company for cement making or direct clinker sale, plus gypsum, limestone, CKD[17] and all clinker substitutes consumed for blending, plus all cement substitutes. For this denominator, the terms "cementitious products" or "binders" are used, as it is a sum of clinker and mineral components. The denominator excludes clinker bought from third parties for the production of cement, since this clinker is already included in the inventory of the third party[18]. Note that the denominator excludes the following:

- Bought clinker, used for cement production;

- Granulated slag and fly ash from coal fired power plants, which are stored or sold to another company without any processing for changing their properties (e.g. grinding or thermal treatment);

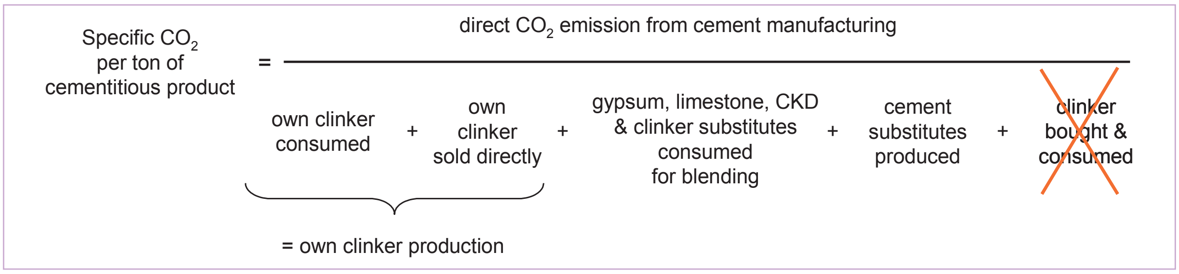
- Cement volumes which are traded without any processing.

The WBCSD/CSI decided that companies shall calculate their specific emissions as follows (see also *Figure 6* and *7*):

Equation 8: Definition of specific (= unit-based) CO_2 emission. The denominator is based on clinker production, assuming that all clinker produced in a plant is consumed for cement production on site. See Section 6.3 for definition of clinker/cement (eq.)-factor

$$\text{Specific } CO_2 \text{ per t of cement (eq.)} = \frac{\text{direct } CO_2 \text{ emission from cement manufacturing}}{\underbrace{\text{own clinker production}}_{= \text{ own clinker consumed } + \text{ own clinker sold directly}}} \times \text{clinker/cement (eq.) factor}$$

Figure 6: Definition of specific (= unit-based) CO_2 emission. The denominator is based on clinker production, hence sold clinker is included and bought clinker is excluded, cementitious products are included. See Section 6.4 for guidance on clinker stock changes.



6.3 Denominator for Other Ratio Indicators

For selected ratio indicators which do not use CO_2 in the numerator, it is appropriate to include bought clinker, and exclude sold clinker, from the denominator. This applies for:

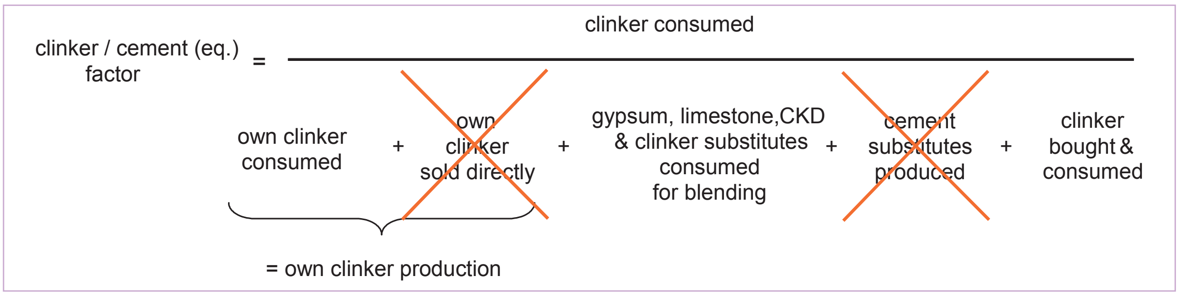
- Specific power consumption per tonne of cementitious product, which should take into account grinding of bought clinker;

- The clinker/cement factor, which should describe the ratio between total clinker consumption and total production of cement or cementitious product. Both factors have been implemented in the protocol spreadsheet.

Clinker/cement (eq.) factor

As described in Section 6.2 the cement (equivalent) can be calculated from produced clinker divided by the clinker/cement (eq.) factor, which is defined as: Total clinker consumed / (own clinker consumed plus gypsum, limestone, CKD, plus clinker substitute consumed for blending, plus clinker bought and consumed. The proposed clinker/cement (eq.) factor is shown in *Figure 7*.

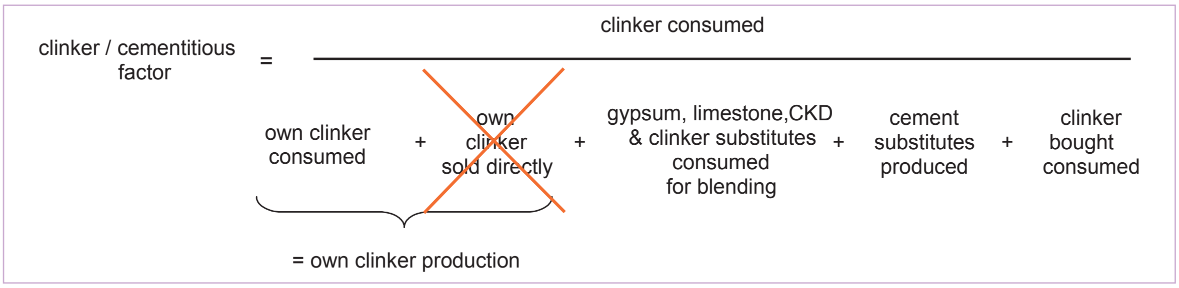
Figure 7: Definition of clinker/cement (eq.) factor. The factor is based on clinker consumption. Hence, in the denominator sold clinker is excluded and bought clinker is included. Cement substitutes are excluded. See Section 6.4 for guidance on stock changes.



Clinker/cementitious factor

The proposed clinker/cementitious factor is shown in *Figure 8*.

Figure 8: Definition of clinker/cementitious factor. The factor is based on clinker consumption. Hence, in the denominator sold clinker is excluded and bought clinker is included. Furthermore, cement substitutes are included. See Section 6.4 for guidance on stock changes.



6.4 Dealing with Stock Changes and Sold and Purchased Clinker

Direct CO_2 resulting from clinker production should be reported for the year in which it is emitted. To avoid distortion, specific emissions per tonne of cementitious product 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 Section 7.4).

6.5 New General Performance Indicators (KPIs)

A number of new KPIs have been added according to the experiences from the use of Version 2. These are:

- CO_2 emission factor for kiln fuel mix in t CO_2/GJ
- Total Conventional Fossil Fuel Rate at Plant Level in %
- Total Alternative Fossil Fuel Rate at Plant Level in %
- Total Biomass Fuel Rate at Plant Level in %
- Specific power consumption of clinker production in kWh/ t clinker

A summary of their definition is presented in Appendix 7.

7 Organizational Boundaries

7.1 Which Installations Should Be Covered?

CO_2 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?

When reporting under externally imposed schemes such as the EU ETS, the boundaries with respect to installations will be guided by the rules of the respective scheme.

Voluntary reporting under this protocol, in contrast, shall cover the main direct and indirect CO_2 emissions associated with cement production as required in Chapters 3, and 4 of this document, and as foreseen in the protocol spreadsheet. 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 voluntary reporting under this protocol, to the extent that they control or own the respective installations in accordance with Section 7.2 below:

- Clinker production, including raw material quarrying and preparation;
- Grinding of clinker, additives and cement substitutes such as slag, both in integrated cement plants and stand-alone grinding stations;
- Additional fuel use for own power generation
- Preparation or processing of fuels or fly ash in own installations.

Separate inventories may be established for individual facilities as appropriate, for instance if they are geographically separated or run by distinct operators.[19] The impacts of such a division will cancel out when emissions are consolidated at company or group level (see also Section 7.4 regarding company-internal clinker transfers). Section 9.2 provides more guidance on voluntary environmental reporting.

7.2 Operational Control and Ownership Criteria

The revised WRI / WBCSD Protocol distinguishes two basic approaches according to which companies can consolidate the emissions of their operations: the *equity share* approach and the *control* approach. The latter is again divided based on whether *financial control* or *operational control* is used as a criterion.

These three approaches are briefly summarized below, and illustrated in *Figure 9*. Text in italics denotes quotations from the revised WRI / WBCSD Protocol. For details on each approach as well as illustrative examples, please refer to Chapter 3 of the WRI / WBCSD document[1].

- **Equity share:** Under this approach, a company 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 a company 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 a company 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 company 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.*

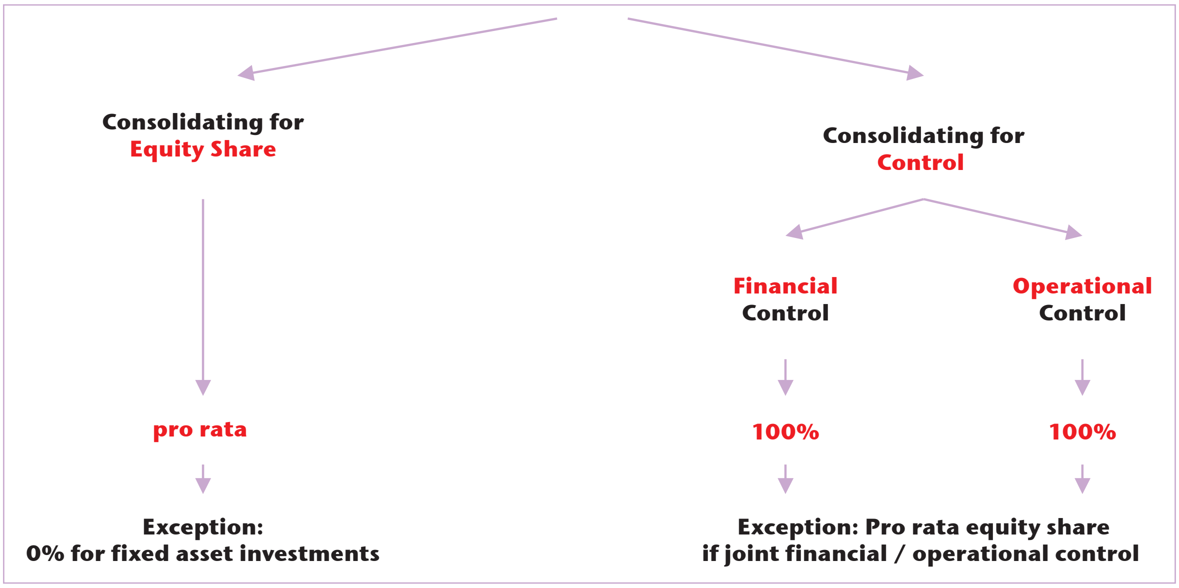
  Under this approach, companies consolidate 100% of the emissions of those operations over which they have financial control. As an exception, consolidation according to equity share is required for joint ventures where partners have joint financial control.

- **Operational control** is defined as a company's *full authority to introduce and implement its operating policies at an operation.* This criterion is usually fulfilled if a company 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.[20]

In defining control for GHG accounting purposes, companies are advised to follow their existing rules and practices for financial reporting. Companies should explicitly state which methodology they apply. Likewise, the revised WRI / WBCSD Protocol recommends to account for any special contracts in joint operations that specify how the ownership of emissions, or the responsibility for managing emissions and associated risk, is distributed between the parties.

The revised WRI / WBCSD Protocol makes no recommendation as to whether voluntary public GHG emissions reporting should be based on the equity share or any of the two control approaches. Instead, it encourages companies to apply the equity share *and* a control approach *separately*, and states that companies need to decide on the approaches best suited to their business activities and GHG accounting and reporting requirements.

Figure 9: Options for consolidating emissions as recommended by WRI / WBCSD



With a view to the characteristics of the cement industry, the WBCSD/CSI decided that 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. This approach is summarized in *Table 5*. See the revised WRI / WBCSD Protocol for more detailed guidance and illustrative examples for these consolidation rules.

Table 5: Key for consolidating corporate GHG emissions of cement companies, as adopted by the WBCSD/CSI.

Criterion for Consolidation	% GHG to consolidate by reporting entity
First criterion: Operational control	
The reporting entity has operational control	100%
Another legal entity has operational control	0 %
Operational control is not clearly assigned to a single shareholder ("Joint operational control")	Relative to share ownership (see below)
Second criterion: Equity share ownership	
0% – 100% ownership	pro rata ownership

Companies are expected to follow this guidance where appropriate, and should clearly state in their reporting that this is the case, i.e. 'data is reported in accordance with CSI guidelines'. Where company consolidation practice differs from CSI guidelines, companies are expected to clearly state the procedure used so that any differences are clear to interested stakeholders.

7.3 Consolidating Emissions and Emission Rights

The optional methods for consolidating emissions and emission rights in the Cement CO_2 Protocol Version 2 were excluded from the Protocol Version 3. Nevertheless, such calculations can be performed separately by companies if needed. If companies wish to consolidate their emission rights, they should proceed in the same way as they consolidate their emissions. When consolidating emission rights, it is important to ensure that emission rights for each plant are calculated according to the same rules across the whole area of consolidation.

7.4 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. Using Version 2 of the protocol the companies had to adapt their reporting on plant and company level accordingly. Some guidance but no harmonized methodology was given or used. Therefore, in Version 3 the plant sheet as well as the company sheet have been adapted according to the following method of reporting (please see also CSI Internet Manual for more detailed advice):

On plant level internal clinker transfer has to be reported (transfer within the same company, 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 company 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:

Total clinker consumed = clinker production + clinker bought – clinker sold – change in clinker stock + internal clinker transfer + clinker from cement transfer

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

Total clinker consumed (company level) = clinker production + clinker bought – clinker sold – change in clinker stock + internal clinker transfer - clinker from cement transfer.

Concerning internal MIC transfers the names of various lines have been changed compared to Version 2 for clarification. On plant level internally transferred MICs as ingredient of cement should be reported only if the plant is receiving cement from another plant in the same company. Total internal MIC transfers are summarized in a separate line. It should only be filled, if the plant is selling MIC to another plant in the same company. The amount should always be entered as a negative value, meaning that the plant is selling/exporting. This data is not used for any calculation on plant level. For the reporting it is not relevant whether sold/exported MICs are used in cement or concrete.

On company level some lines have been renamed as on the plant level (only for clarification). Total MIC transfers are summarized as a sum of all plants (it will be negative). Line 19 summarizes total pure MIC products used as cement substitute, which are calculated and reported separately.

In conclusion, Version 3 of the protocol accounts for internal clinker, cement and MIC transfers. Accounting for internal transfers is required for the analysis of CO_2 performance indicators at plant level.

7.5 Baselines, Acquisitions and Divestitures

CO_2 emissions performance is often measured relative to a past reference year (the “base year”). As a default, the “Kyoto base year” 1990[21] can 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.

Acquisitions and divestitures, as well as the opening or closing of plants, will influence a company’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 a company. If a company is acquired, its past emissions shall be included in the consolidated emissions of the reporting company. This shall be done either back to the base year, or back to the year the acquired company came into existence, whichever is later. If a company is divested, past emissions shall be removed from the consolidated emissions. These adjustments shall be made in accordance with the consolidation rules (see Section 7.2).

- **No baseline adjustment for “organic” 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 organic negative growth: Closure of kilns or decrease of production shall not result in a change of the baseline.

For illustrative examples regarding choice of base year and baseline adjustment, see the revised WRI / WBCSD Protocol.

8 Managing Inventory Quality

8.1 Summary of Recommendations of Revised WRI / WBCSD Protocol

The revised WRI / WBCSD Protocol provides extensive guidance on the management of inventory quality. This Section 8.1 summarizes some key points. See the WRI / WBCSD document for details.

Implementing an Inventory Program
The design, updating and refinement of a company's GHG inventory are a lasting task that should be addressed in the context of a comprehensive and systematic *inventory program*. Such a program will target the four basic components of a company's inventory:

> **Methods:** These are the technical and scientific approaches underlying a company's inventory. This protocol provides harmonized and robust methods for preparing a cement company's inventory. Companies are, however, encouraged to verify that these methods suit their specific requirements. In addition, companies should ensure that any methods which they devise and apply on their own accurately reflect the characteristics of their emissions sources.

> **Data:** This is the basic information on activity levels, emission factors, processes, and operations. A corporate inventory program will establish reliable collection procedures for high quality data and ensure the maintenance and improvement of these procedures over time.

> **Processes and systems:** These are the institutional, managerial and technical procedures for preparing GHG inventories. They include the team and the processes charged with producing and updating a high-quality inventory. Where appropriate, these processes may be integrated with other corporate data management processes.

> **Documentation:** This is the record of methods, data, processes, systems, assumptions, and estimates used to prepare an inventory. Since estimating GHG emissions is inherently technical, high quality, transparent documentation is particularly important to credibility.

Implementing an Inventory Quality Management System
An *inventory quality management system* serves to ensure and improve the quality of the four basic components of a company's inventory – methods, data, processes and systems, and documentation. The revised WRI / WBCSD Protocol recommends that companies should take the following seven steps in implementing quality management:

1. **Establish an inventory quality team:** This team should be responsible for implementing a quality management system, and continually improving inventory quality. The team will coordinate interactions between relevant business units, facilities, and external entities such as government agencies or verifiers.

2. **Develop a quality management plan:** This plan describes the steps a company is taking to implement its quality management system. It should be incorporated in the inventory program from the beginning, although further rigor and coverage of certain procedures may be phased in over time. The plan should include procedures for all organizational levels and inventory development processes – from

initial data collection to final reporting. For efficiency and comprehensiveness, companies should integrate (and extend as appropriate) existing quality management systems to cover GHG management, such as any ISO procedures. The bulk of the plan should focus on the practical measures described in steps three and four below.

3. **Perform generic quality checks:** These apply to data and processes across the entire inventory, focusing on data handling, documentation, and emission calculations. A set of generic quality checking measures is provided in *Table 6* below.

4. **Perform source-specific quality checks:** This includes more rigorous investigations into the boundaries, assumptions and calculations for specific source categories, such as the emissions associated with individual fuels used in a cement plant. It also includes a qualitative and/or quantitative assessment of the uncertainty of emissions estimates by source category (see details on uncertainty in Section 8.2 below).

5. **Review final inventory estimates and reports:** After the inventory is completed, an internal technical review should focus on its engineering, scientific and other technical aspects. Subsequently, an internal managerial review should focus on securing official corporate approval for the inventory. A third type of review involves an external verifier. For details on independent verification, see the revised WRI / WBCSD Protocol[1] and the Requirements for Assurance of CSI CO_2 data in Appendix 8.

6. **Institutionalize formal feedback loops.** The results of the reviews in step 5, as well as the results of every other component of a company's quality management system, should be fed back via formal feedback procedures to the quality management team identified in step 1, and to the persons responsible for preparing the inventory.

7. **Establish reporting, documentation, and archiving procedures:** The quality management system should contain record keeping procedures that specify what information will be documented for internal purposes, how that information should be archived, and what information is to be reported for external stakeholders.

Table 6: Examples of generic quality checking measures.

Data Gathering, Input and Handling Activities
> Check a sample of input data for transcription errors
> Identify spreadsheet modifications that could provide additional controls or checks on quality
> Ensure that adequate version control procedures for electronic files have been implemented
Data Documentation
> Confirm that bibliographical data references are included in spreadsheets for all primary data
> Check that copies of cited references have been archived
> Check that assumptions and criteria for selection of boundaries, base years, methods, activity data, emission factors and other parameters are documented
> Check that changes in data or methods are documented
Emission Calculations
> Check whether units, parameters, and conversion factors are appropriately labeled
> Check that conversion factors are correct
> Check the data processing steps (e.g. equations) in the spreadsheets
> Check that spreadsheet input data and calculated data are clearly differentiated
> Check a representative sample of calculations, by hand or electronically
> Check some calculations with abbreviated calculations (i.e. back of the envelope calculations)
> Check the aggregation of data across source categories, business units, etc.
> Check consistency of times series inputs and calculation results

Source: Based on WRI / WBCSD 2004, p.51

8.2 Dealing with Uncertainty

Due to their scientific nature, the parameters required to estimate GHG emissions, such as fuel volumes, lower heating values and emission factors, are not precise point estimates, but involve an uncertainty that can be expressed as an uncertainty range or confidence interval. For example, the best estimate emission factor for petcoke, according to the results of chemical analyses of 361 samples compiled by the CSI Task Force, is 92.8 kg CO_2/GJ with a 95% confidence interval of ± 0.2 kg CO_2/GJ. This means that the true emission factor for the analyzed petcoke samples falls with 95% probability within the uncertainty range of 92.8 ± 0.2 kg CO_2/GJ.

The aggregate uncertainty of an emissions estimate for a plant or company will depend on the individual uncertainties of the underlying parameters. WRI / WBCSD have developed a tool and guidance to help assess these uncertainties (see www.ghgprotocol.org for details).

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.[22] 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 guidelines 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 can have financial consequences.

With this background, the WBCSD/CSI recognizes that uncertainty in GHG inventories is a longer-term challenge which deserves attention. *Table 7* identifies the sources of uncertainty which are typically the most relevant in a cement company, along with measures to minimize them.

Table 7: Typical major sources of uncertainty in cement sector CO_2 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 recycled dust by weighing devices
Calcination emission factor (kg CO_2/t clinker)	> Calculate plant-specific emission factor based on measured clinker composition (CaO- and MgO-content), rather than using default factor > Account for additions of calcined materials to the kiln via slag, fly ash, etc.
Calcination emission factor* (kg CO_2/t raw meal)	> Calculate plant-specific emission factor based on measured composition of raw meal (carbonate content) > Account for variations in raw meal carbonate content over time (e.g., additions of calcined materials)
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

Parameter	Measures to Minimize Parameter Uncertainty
Emission factors of fuels (kg CO_2/GJ)	> If using fuel mixes (e.g., coal-petcoke mix), disaggregate and apply individual emission factors, or apply weighted emission factor > If using specific types of coal, use matching emission factors (see protocol spreadsheet, Comments column of Worksheet "Fuel emission factors" > Measure emission factor of fuel if default factors are deemed non-representative > Account for biomass carbon in, e.g., used tires and impregnated saw dust > Use analysis data for biomass content in heterogeneous mixed alternative fuels like pre-treated industrial or domestic wastes, where applicable

* Parameters marked with an asterisk are only relevant if the raw meal based method is used for calculating CO_2 from raw material calcination.

8.3 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. Chapter 10 of the revised WRI / WBCSD Protocol provides details on the concept of materiality in verification.

A materiality threshold should not be interpreted as a permissible quantity of emissions which a company can 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 a company'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, this protocol 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_2. This applies, for example, for CO_2 emissions from organic carbon in raw materials (see Section 3.2, 3.3 and 3.4).

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

> CO_2 emissions from off-site transports of inputs and products (Section 3.8) are typically small, but also difficult to quantify consistently because these transports are often carried out by third parties.

> CO_2 emissions from combustion of wastewater (Section 3.9), in addition to being small, occur only in relatively few plants, and the carbon can be from biomass sources;

> CH_4 and N_2O emissions from kilns (Section 3.10) are very small.

The exclusion of these latter emission sources is, therefore, based on several reasons and not just on a quantified materiality threshold.

8.4 Inclusion of a Validation Tool

Within the reporting for the CSI Getting the Numbers Right (GNR) project a validation tool is used for a plausibility check of the reported data after they have been uploaded to the website of the service provider. In order to simplify this process the validation tool has been implemented in the spreadsheet of the Protocol Version 3 itself. This allows the user to perform a first check of the inserted data and calculations for plausibility before delivering (uploading) them to the GNR project for evaluation. A detailed description of the use of the validation tool is given in the internet manual at www.Cement-CO2-Protocol.org.

9 Recommendations for Reporting

9.1 Introduction

CO_2 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 can be, for example, performance benchmarking and product life cycle assessment.

The protocol has been designed as a flexible tool to satisfy these different reporting purposes, while always meeting the criteria described in Chapter 2. The information is structured in such a way that it can 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 CO_2 emissions, including CO_2 from fossil wastes. CO_2 from biomass fuels should be reported as a memo item.

> Reporting under CO_2 compliance and taxation schemes will have varying reporting requirements, depending on local conventions. The protocol allows reporting of gross and net emissions and indirect emissions, as appropriate.

This protocol does not define any threshold for excluding "immaterial" emission sources. The underlying reasons are explained in Section 8.3. In practice, the decision whether to include or exclude certain emission sources will also depend on the requirements of the respective reporting framework. With respect to voluntary environmental reporting, this protocol suggests specific boundaries in the next section.

9.2 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 company. This implies that the reporting of cement companies shall cover all relevant emission components:

> Gross direct CO_2 emissions of the reporting entity (calcination, conventional kiln fuels, alternative kiln fuels, non-kiln fuels, with biomass CO_2 as a memo item);

> Net emissions (if applicable), calculated from gross emissions minus emissions from the use of alternative fuels;

> Main indirect emissions (consumption of grid electricity and bought clinker).

Reporting shall be in absolute (Mt CO_2/year) as well as specific (kg CO_2/t cementitious material) units. Reporting of net emissions alone, omitting gross emissions is not acceptable.

> In order to be complete, reporting shall include the CO_2 emissions (including indirect CO_2 emissions from consumption of grid electricity and accounting for own on-site power generation) from the different process steps as shown in *Table 8*.

Additional requirements for voluntary reporting include:

> It shall be clearly stated when CO_2 sources are excluded from the inventory. To this end, the

protocol spreadsheet requires companies to state the boundaries of their inventory.

- Companies shall clearly state that they report according to this Cement CO_2 and Energy Protocol Version 3, and any material deviations from it.

9.3 Reporting Periods

Reporting GHG emissions based on financial years, rather than calendar years, can help 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.

9.4 Scopes of Revised WRI / WBCSD GHG Protocol

The revised WRI / WBCSD Protocol classifies emissions under different scopes. *Table 9* shows how the emissions sources discussed in this protocol relate to the classification of WRI / WBCSD.

The revised WRI / WBCSD Protocol requires companies to separately account for and report on scopes 1 and 2. The Cement CO_2 and Energy Protocol provides a basis for complete reporting as required by WRI / WBCSD, with the exception of CO_2 from company-owned off-site transport fleets, CO_2 from combustion of wastewater, and CH_4 and N_2O emissions. As explained in Section 8.3, these latter emission sources are excluded as a default for various reasons, but can be included if required.

Table 8: Recommended inventory boundaries for voluntary CO_2 reporting

Process Step	**CO_2 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 Section 7.1 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_2 from owned vehicles (incl. leased vehicles, excl. owner-drivers) must be reported. If third-party transports: ®n.a.
Off-site transports	No	Reporting not mandatory. If reported, distinguish direct CO_2 (own vehicles, incl. leased vehicles) from indirect CO_2 (third-party vehicles)
On-site power generation	Yes – unless n.a.	Also report CO_2 if operated only occasionally
Room heating / cooling	Yes – unless n.a.	--

n.a. = not applicable

Table 9: Reporting scopes of WRI / WBCSD, and corresponding sections of this protocol

WRI / WBCSD classification	Corresponding sections of this protocol
Scope 1: Direct GHG emissions (only if sources are owned or controlled)	
> Process emissions	Section 3.2: CO_2 from raw material calcination Section 3.2: CO_2 from organic carbon in raw materials
> Stationary combustion sources	Sections 3.5, 3.6 and Section 3.7: CO_2 from kiln fuels Section 3.8: CO_2 from non-kiln fuels Section 3.9: CO_2 from wastewater
> Mobile combustion sources	Section 3.8: CO_2 from non-kiln fuels
> Non-CO_2 greenhouse gases	Section 3.10: Non-CO_2 greenhouse gases
Scope 2: Indirect GHG emissions from purchased electricity	Section 4: Indirect emissions from grid electricity
Scope 3: Other indirect emissions	Section 4: Indirect emissions from bought clinker

10 Further Information

Appendix 1 describes the protocol spreadsheet. The spreadsheet itself contains

- a "Comments" sheet which provides a short explanation for every line of the main worksheet.
- a "Frequently asked questions (FAQ)" section to provide support for questions to the different sections of the spreadsheet.

For further questions, information or comments on this protocol, please refer to the Internet Manual: www.Cement-CO2-Protocol.org

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12 Glossary, Acronyms and Abbreviations

Quotations from the glossary of the revised WRI / WBCSD Protocol (2004) are marked with an asterisk*. Quotations from the glossary of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories are marked with double asterisk**. See the WRI / WBCSD Protocol and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for an extended glossary.

Absolute emission

Absolute GHG emissions are expressed as a mass stream, for example in tonnes of CO_2 per year (t CO_2/yr).

AF

Alternative fuels

AFR

Alternative fuels and raw materials. This definition includes alternative raw materials, which contain a significant amount of organic matter.

Allowance*

A GHG allowance is a commodity giving its holder the right to emit a certain quantity of GHG. GHG allowances are typically allocated by a regulator to the emitters covered by a cap and trade system.

Alternative fuels

Fuel materials or products used as a source of thermal energy and not classified as traditional fuel. In the cement industry wastes such as plastics, solvents, waste oil, end-of-life tires, etc. and different types of mixed or pure biomass fuels are used.

Annex I

Annex I to the UNFCCC lists the developed country Parties which have special responsibilities in meeting the objective of the Convention. They include the OECD countries (excl. Mexico and Korea), the countries of Eastern Europe, Russia, and the European Union. Under the Kyoto Protocol, Annex I Parties have accepted quantified emissions limitation or reduction commitments for the period 2008–12.

ARM

Additional raw materials, e.g. added directly to the calciner or kiln inlet, that are not part of the kiln feed, which is normally a homogenized mass flow fed to a pre-heater system.

Baseline

Reference emission level. The term is used with different meanings in different contexts. It can denote:

- the historical emission level of an entity in a reference year,
- the projected future emission level of an entity if no extra mitigation measures are taken (business-as-usual scenario),
- the hypothetical emission level against which the climate benefits of GHG reduction projects are calculated.

Biogenic carbon**

Carbon derived from biogenic (plant or animal) sources excluding fossil carbon. Note that peat is treated as a fossil carbon in these guidelines as it takes so long to replace harvested peat.

Biomass**

Organic matter consisting of, or recently derived from living organisms (especially regarded as fuel) excluding peat; includes products, by-products and waste derived from such material.

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.

Cap and trade*

A system that sets an overall emissions limit, allocates emissions allowances to participants, and allows them to trade allowances and emission credits with each other.

Cement

A 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. It acts as the binding agent when mixed with sand, gravel or crushed stone and water to make concrete. While cement qualities are defined by national standards, there is no worldwide, harmonized definition or standard for cement. In the WBCSD – CSI Protocol and the "Getting the Numbers Right" database, "cement" includes all hydraulic binders that are delivered to the final customer, i.e., including all types of Portland cements, composite cements and blended cements, but excluding direct sales of pure clinker". See Section 6.3

Cement (eq.)
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.

Cementitious products
All clinker produced by the reporting company for cement making or direct clinker sale, plus gypsum, limestone, CKD and all clinker substitutes consumed for blending, plus all cement substitutes. For this denominator, the terms "cementitious products" or "binders" are used, as it is a sum of clinker and mineral components. The denominator excludes clinker bought from third parties for the production of cement, since this clinker is already included in the inventory of the third party.

cem eq.
Cement (eq.)

cem prod
Cementitious products

Climate-neutral
Burning of climate-neutral fuels does not increase the GHG stock in the atmosphere over a relevant time span. CO_2 emission from renewable biomass contained in alternative fuels is climate-neutral because they are compensated by an equivalent absorption by plants.

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.

CKD
Cement kiln dust, relevant for complete CO_2 reporting is especially the partly calcined CKD leaving the kiln system, i.e. discarded dust from long dry and wet kiln system dedusting units, consisting of partly calcined kiln feed material (see also 'dust return'). Extraction and discarding of CKD and bypass dust serve to control excessive circulating elements input (alkali, sulphur, chlorine), particularly in cases of low-alkaline clinker production. The term "CKD" is sometimes used to denote all dust from cement kilns, i.e. also from bypass systems.

cli
Clinker

Credit*
GHG offsets can be converted into GHG credits when used to meet an externally imposed target. A GHG credit is a convertible and transferable instrument usually bestowed by a GHG program.

CSI
Cement Sustainability Initiative: The CSI is a global effort by 24 major cement producers with operations in more than 100 countries who believe there is a strong business case for the pursuit of sustainable development. Collectively these companies account for about one third of the world's cement production and range in size from very large multinationals to smaller local producers. http://www.wbcsdcement.org

Direct emissions
Direct GHG emissions are emissions from sources that are owned or controlled by the reporting entity. Examples include the emissions from cement kilns, company-owned vehicles, quarrying equipment, etc.

Dust return
Part of the kiln feed which is not consumed for clinker production or to form bypass dust but which is returned to a dust cycle. The cycle often involves the raw mill and a dust filter system. Relatively small amounts of cement kiln dust (CKD) leaving the kiln system originate from this dust cycle and dust return.

EF
Emission factor, here normally CO_2 emission factor per mass for materials or per heat for fuels.

EU ETS
The CO_2 emissions trading scheme of the European Union which started in 2005. The EU ETS covers CO_2 emissions from most significant industrial sources. From 2013, also other GHG will be included. For further information see http://ec.europa.eu/clima/policies/ets/index_en.htm

Fossil carbon**
Carbon derived from fossil fuel or other fossil source.

GCV
Gross calorific value (=higher heat value, HHV)

GHG
The greenhouse gases listed in Annex A of the Kyoto Protocol include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6).

GNR
"Getting the Numbers Right" Project and CSI's global cement database covering over 800 plants around the world belonging to CSI member companies.

Gross CO_2 emissions
Total direct CO_2 emissions (excluding on-site electricity production) originating from fossil carbon, i.e. excluding CO_2 emissions from biomass which are considered climate-neutral. As of Protocol Version 3 the CO_2 emissions originating from the biogenic carbon content of mixed fuels are not accounted.

GWP**
Global Warming Potentials are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme CO_2 over a period of time (e.g., 100 years).

HHV
Higher heat value (= gross calorific value, GCV), often in GJ per ton of fuel The higher heat value includes the latent heat contained in water vapor, which is released when condensing water vapor so that all water is in liquid state. Compare 2006 IPCC Guideline[4], Vol. II, Section 1.4.1.2.

Indirect emissions
Indirect GHG emissions are emissions that are a consequence of the operations of the reporting company, but occur at sources owned or controlled by another company. Examples include emissions related to purchased electricity, employee travel and product transport in vehicles not owned or controlled by the reporting company, and emissions occurring during the use of products produced by the reporting company.

Inventory
A quantified list of an organization's GHG emissions and sources.

IPCC
The Intergovernmental Panel on Climate Change is an international body of scientists. Its role is to assess the scientific, technical and socio-economic information relevant to the understanding of the risk of human-induced climate change (www.ipcc.ch).

KF
Kiln feed

Kiln (**)
A tubular heating apparatus used in the production of clinker (2006 IPCC Guidelines 'manufacture of cement'). The calcination reaction may take place in the kiln itself, or, where so-equipped, it may partly or completely take place in a preheater and/or precalciner apparatus ahead of the kiln.

Kiln feed
Raw materials, often processed as raw meal, which are fed to a pre-heater or directly into the kiln system. The kiln feed often contains a certain quantity of recycled dust, which was returned from the pre-heater or kiln system (see also 'dust return').

Kiln fuel
Fuels 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 (See Section 3.7).

KPI
Key Performance Indicator is an industry used term for a type of Measure of Performance. KPIs are commonly used by organizations to evaluate its success or the success of a particular activity in which it is engaged.

LHV
Lower heat value (= net calorific value, NCV), often in GJ per ton of fuel. The lower heat value excludes the latent heat contained in water vapor. Compare 2006 IPCC Guideline[4], Vol. II, Section 1.4.1.2.

LOI
Loss on Ignition is a test used in inorganic analytical chemistry, particularly in the analysis of minerals. It consists of strongly heating ("igniting") a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change.

MIC
Mineral components are natural or artificial mineral materials with hydraulic properties, used as a clinker or cement substitutes (e.g. blast furnace slag, fly ash, pozzolana).

Mixed fuels
Term used in this Guidance Document for referring to fuels that are a mix of biomass and fossil fuel, i.e. fuel with a certain biogenic carbon content.

Net CO_2 emissions
Gross CO_2 emissions minus CO_2 emissions from alternative fossil fuels. This definition corresponds to the original Protocol Version 1. Note that the option for subtracting bought emission rights for reporting net emissions according to the alternative definition in Protocol Version 2 was rarely used.

Non-kiln fuel
Fuels used by the company, which are not included in the definition of kiln fuels. For instance fuels used for plant and quarry vehicles, room heating, thermal process equipment (e.g. dryers) for the preparation of mineral components for cement grinding or in an installation separate from the kiln for on-site production of electrical power (See Section 3.8).

Nm³
Normal cubic meters (at 1013 hPa and 0 °C)

NCV
Net calorific value (=lower heat value, LHV), often in GJ per ton of fuel. The net calorific value excludes the latent heat contained in water vapor.

Offset*
GHG offsets are discrete GHG emission reductions used to compensate for (i.e., offset) GHG emissions elsewhere, for example to meet a voluntary or mandatory GHG target or cap. Offsets are calculated relative to a baseline that represents a hypothetical scenario for what emissions would have been in the absence of the mitigation project that generates the offsets. To avoid double-counting, the reduction giving rise to the offset must occur at sources or sinks not included in the target or cap for which it is used.

OPC
Ordinary Portland cement. In the CSI Cement CO_2 and Energy Protocol OPC refers to a common type of cement with high clinker content, consisting of over 90% ground clinker and about 5% gypsum. Note that differences exist between names and definitions of cement types in national standards. OPC is often referred to as:
'Portland cement' or 'CEM I' according to the European standard EN 197-1:2007,
'Portland cement' or 'P·I' or 'P·II' according to the Chinese standard GB175-2007,
'Portland cement Types I to V according to the US standard ASTM C 150 and
'Portland' or 'PC' as described in the 2006 IPCC Guideline for National Greenhouse Gas Inventories.
Whereas according to the Chinese standard GB175-2007 the name
'Ordinary Portland cement' with the notation 'P·O', and the notation
'P·C' for 'Composite Portland cements' can refer to cement types with significantly lower content of clinker.

Petcoke
Petroleum coke, a carbon-based solid derived from oil refineries.

Pozzolana
A material that, when combined with calcium hydroxide, exhibits cementitious properties.
Process emissions** Emissions from industrial processes involving chemical transformations other than combustion.

Protocol
The methodology for calculating, monitoring and reporting GHG emissions.

Raw material preparation
Processes applied for converting raw materials to raw meal (e.g. grinding, homogenization, drying).

Raw meal
Raw meal consists of the grinded raw materials. The raw material processing can involve drying or the addition of water. Its composition is controlled and normally very stable, because the clinker burning process requires a defined chemical composition of the kiln feed.

Raw material
Materials used for raw meal preparation, e.g. limestone, iron ore, sand etc., before they are treated thermally, e.g. for drying.

Raw meal consumed
The part of the raw meal, which is consumed for clinker production and the formation of calcined bypass dust. Compared to the kiln feed, the quantity of raw meal consumed excludes the part of recycled dust (see 'dust return').

RM
Raw meal

Specific emissions
Specific emissions are emissions expressed on a per unit output basis, for instance in kg of CO_2 per tonne of cement.

TC
Total carbon, the sum of TOC and TIC

TIC
Total inorganic carbon: carbon, mostly bound in the mineral matter of materials (e.g. carbonates in fuel ashes).

TOC
Total organic carbon

Traditional fuels
Fossil fuels defined by the International Panel on Climate Change (IPCC) guidelines, including mainly: coal, petcoke, lignite, shale, petroleum products and natural gas.

UNFCCC
United Nations Framework Convention on Climate Change; Parties to the UNFCCC are those nations which have signed the Convention.

WBCSD
World Business Council for Sustainable Development: The WBCSD is a CEO-led, global association of some 200 companies dealing exclusively with business and sustainable development. The Council provides a platform for companies to explore sustainable development, share knowledge, experiences and best practices, and to advocate business positions on these issues in a variety of forums, working with governments, non-governmental and intergovernmental organizations. Members are drawn from more than 30 countries and 20 major industrial sectors. The Council also benefits from a global network of some 60 national and regional business councils and regional partners. http://www.wbcsd.org

WRI
World Resources Institute: The WRI is an environmental think tank founded in 1982 based in Washington, D.C. in the United States. WRI is an independent, non-partisan and non-profit organization with a staff of more than 100 scientists, economists, policy experts, business analysts, statistical analysts, mapmakers, and communicators developing and promoting policies with the intention of protecting the Earth and improving people's lives.

A1 Cement CO_2 and Energy Protocol Spreadsheet

The protocol spreadsheet is a Microsoft Excel document. It contains the following worksheets:

1. Read Me:
This sheet explains the meaning of the different colors used in the worksheets and provides additional instructions for the user. An extended section with frequently asked questions and the respective answers has been added in Version 3.

2. Comments:
This sheet gives a short explanation of every line of the Plants Worksheet.

More detailed explanations will be provided in an internet manual (www.Cement-CO2-Protocol.org) and on the CSI website (www.wbcsdcement.org).

3. Plants:
One worksheet for each plant of a company.

4. CalcA1:
Simple Input Method (A1) auxiliary worksheet for determining CO_2 emissions from raw material calcination (can be created for plants with kiln operation).

5. CalcA2:
Detailed Input Method (A2) auxiliary worksheet for determining CO_2 emissions from raw material calcination (can be created for plants with kiln operation).

6. CalcB2:
Detailed Output Method (B2) auxiliary worksheet for determining the corrected CO_2 emission factor of clinker (can be created for plants with kiln operation).

7. Company:
Consolidation to company level of the information of every plant.

8. Validation:
Validation Tool for first hand quality control of input data.

9. Control Plant:
Detailed validation tool report on plant level.

10. Fuel CO_2 factors:
Default CO_2 emission factors for fuels used in cement plants.

A2 Greenhouse Gas Sources and Abatement Options in Cement Production

Overview of Cement Manufacturing Process
Cement manufacture includes three main process steps (see *Figure A2-1*):

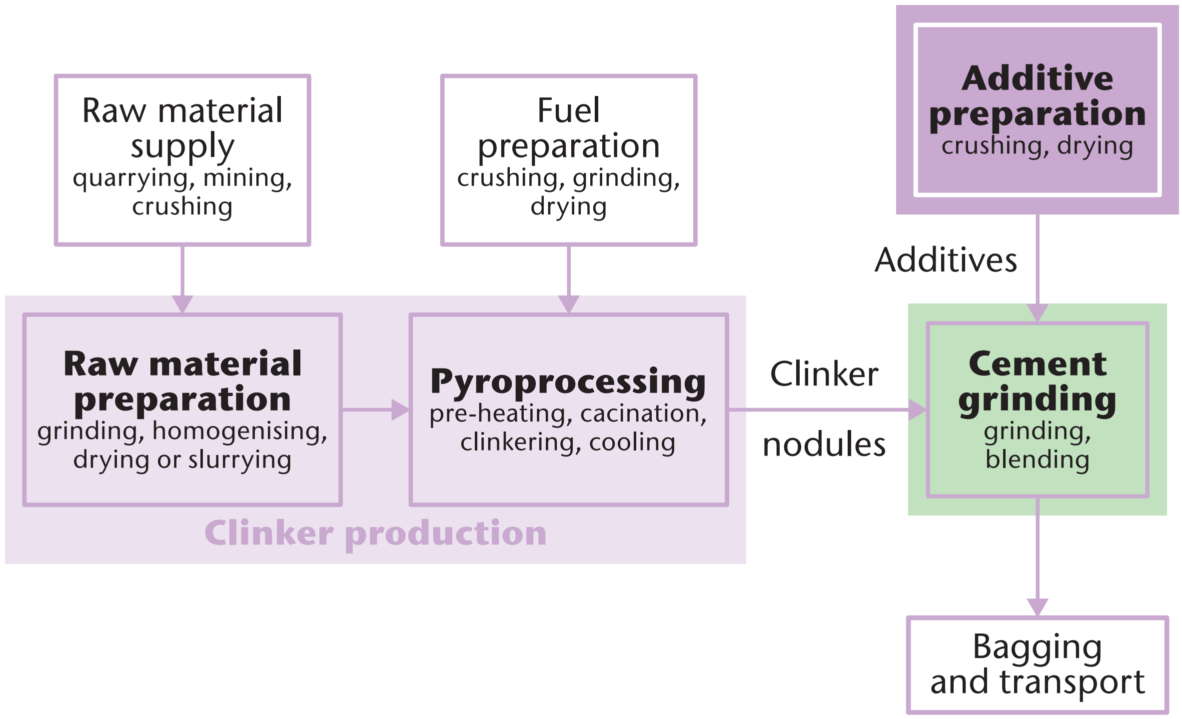
1. preparing of raw materials;

2. producing clinker, an intermediate, through pyro-processing of raw materials;

3. grinding and blending clinker with other products ("mineral components") to make cement.

There are two main sources of direct CO_2 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_2 sources include direct emissions from non-kiln fuels (e.g. dryers, room heating, on-site transports), and indirect emissions from e.g. external power production and transports. Non-CO_2 greenhouse gases covered by the Kyoto Protocol[23] are not relevant in the cement context, in the sense that direct emissions of these gases are negligible.

Figure A2-1: Process steps in cement manufacture.



Source: Ellis 2000, based on Ruth et al. 2000

CO_2 from Calcination of Raw Materials

In the clinker burning process, CO_2 is released due to the chemical decomposition of calcium carbonates (e.g. from limestone) into lime:

$$CaCO_3 + heat^{®}\ CaO + CO_2$$

This process is called "calcining" or "calcination". It results in direct CO_2 emissions through the kiln stack. When considering CO_2 emissions due to calcination, two components can be distinguished:

- CO_2 from raw materials actually used for clinker production, these raw materials are fully calcined in the clinker production process;
- CO_2 from raw materials leaving the kiln system as partly calcined cement kiln dust (CKD), or as normally fully calcined bypass dust.

CO_2 from actual clinker production is proportional to the lime content of the clinker,[24] which in turn varies little in time or between different cement plants. As a result, the CO_2 emission factor per tonne of clinker is fairly stable (IPCC default: 510 kg CO_2/t clinker, CSI default: 525 kg CO_2/t clinker).

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_2 emissions from calcination of raw materials can be calculated based in two ways 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 Section 3.2, 3.3, 3.4 and Appendix 3 for details.

CO_2 from Organic Carbon in Raw Materials

The raw materials used for clinker production usually contain a small fraction of organic carbon, which can be expressed as total organic carbon (TOC) content. Organic carbon in the raw meal is converted to CO_2 during pyro-processing. The contribution of this component to the overall CO_2 emissions of a cement plant is typically very small (about 1% or less). The organic carbon contents of raw materials can, however, vary substantially between locations and between the types of materials used. For example, the resulting emissions can be relevant if a company consumes large quantities of certain types of fly ash or shale as raw materials entering the kiln.

CO_2 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. In recent years, fuels derived from waste materials have become important substitutes. 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, like, e.g. pre-treated industrial wastes (containing plastics, textiles, paper etc.) or waste tires (containing natural and synthetic rubber).

Both conventional and alternative fuels result in direct CO_2 emissions through the kiln stack. However, biomass fuels are considered "climate-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.

CO_2 Abatement Options

CO_2 emissions in the cement industry can be tackled by different measures. The main categories of CO_2 abatement potentials include:

- use of mineral components to substitute clinker;
- fuel switching: for instance, use of natural gas or (biomass containing) AF instead of coal;
- use of (partly) decarbonated raw materials;
- energy efficiency: technical and operational measures to reduce fuel and power consumption per unit clinker or cement produced; and
- reduction of dust leaving the kiln system (cement kiln dust, bypass dust), where this occurs in relevant quantities.

Mineral components (MIC) are natural and artificial materials with latent hydraulic properties. Examples of MIC include natural pozzolana, blast furnace slag, and fly ash. 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. MIC use leads to an equivalent reduction of direct CO_2 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. As a consequence, these indirect emissions must not be included in the cement production inventory.

A3 Details on Calcination CO_2

Reporting of CO_2 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_2 based on the CaO content of the clinker produced (0.785 t CO_2/t CaO, multiplied with the CaO content in clinker). A default CaO content in clinker of 65% is recommended, corresponding to 510 kg CO_2/t clinker.

CO_2 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_2 by default, acknowledging that emissions can range much higher in some instances. IPCC does not distinguish between bypass dust and cement kiln dust (CKD). Furthermore, the IPCC default value neglects CO_2 from decomposition of magnesium carbonates (MgO content in clinker is usually about 2%).[25]

CSI 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 protocol spreadsheet, which allows to 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, CSI recommends using the simple output method (B1) with a default emission factor of 525 kg CO_2/t clinker, corresponding to the IPCC default corrected for Mg carbonates.

The CSI is currently discussing whether regional or national factors could be reported based on the GNR data collection. In the future, these values could potentially be used as default values as well. The CO_2 emission factor for clinker determined from the specific CaO and MgO content does not account for CO_2 emissions resulting from CKD leaving the kiln system and CO_2 emissions, which originate from the organic carbon content (TOC) of raw materials. Consequently, these CO_2 emissions are accounted additionally to the CO_2 emissions from calcination of raw material for clinker production. This addition is implemented for the output methods (B1 and B2) in the plant sheet (see Section 3.4).

CO_2 from Cement Kiln Dust: Deriving the Calculation Formula
Cement kiln dust (CKD) is usually not fully calcined. The CO_2 emission factor for CKD can be derived from the mass balance between CKD, raw meal and released CO_2:

Equation 1:

$$CKD = RawMeal - CO2_{RM} \times d$$

where
CKD = quantity of cement kiln dust produced (t)

RawMeal = here amount of dry raw meal consumed and converted to CKD (t)

$CO2_{RM}$ = total carbonate CO_2 contained in the raw meal (t)

d = CKD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in the raw meal)

The CO_2 emission factor for CKD is:

Equation 2:

$$EF_{CKD} = \frac{CO2_{RM} \times d}{CKD} = \frac{CO2_{RM} \times d}{RawMeal - CO2_{RM} \times d}$$

where
EF_{CKD} = emission factor for CKD (t CO_2/t CKD)

Since $CO2_{RM}$ is proportional to the amount of raw meal, *Equation 2* can be re-written as:

Equation 3:

$$EF_{CKD} = \frac{fCO2_{RM} \times d}{1 - fCO2_{RM} \times d}$$

where
$fCO2_{RM}$ = weight fraction of carbonate CO_2 in the raw meal (–).

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

Equation 4:

$$EF_{Cli} = \frac{fCO2_{RM}}{1 - fCO2_{RM}},$$

or re-arranged:

Equation 5:

$$fCO2_{RM} = \frac{EF_{Cli}}{1 + EF_{Cli}}$$

where

EF_{Cli} = emission factor for clinker (t CO2/t cli)

With the help of *Equation 5*, *Equation 3* can be expressed as:

Equation 6:

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

Equation 6 has been entered into the spreadsheet. It allows calculating the emission factor of CKD based on (i) the emission factor of clinker, and (ii) the calcination rate of the CKD. *Figure A3-1* illustrates the impact of the calcination rate. The diagonal line indicates that the assumption of a linear dependence between the CKD calcination rate and the CKD emission factor results in an overestimation of emissions by up to 50% (at low calcination rates) or up to 55 kg CO_2/t CKD.

Determining the CKD Calcination Rate

The CKD calcination rate d shall be calculated according to *Equation 7*, based on the weight fractions of carbonate CO_2 in the CKD and in the raw meal, respectively. The two input parameters $fCO2_{CKD}$ and $fCO2_{RM}$ shall be measured by chemical analysis. Possible analysis methods include, for example, a loss on ignition test, titration or CO_2 emission analysis by infra-red (IR) detection.

Equation 7:

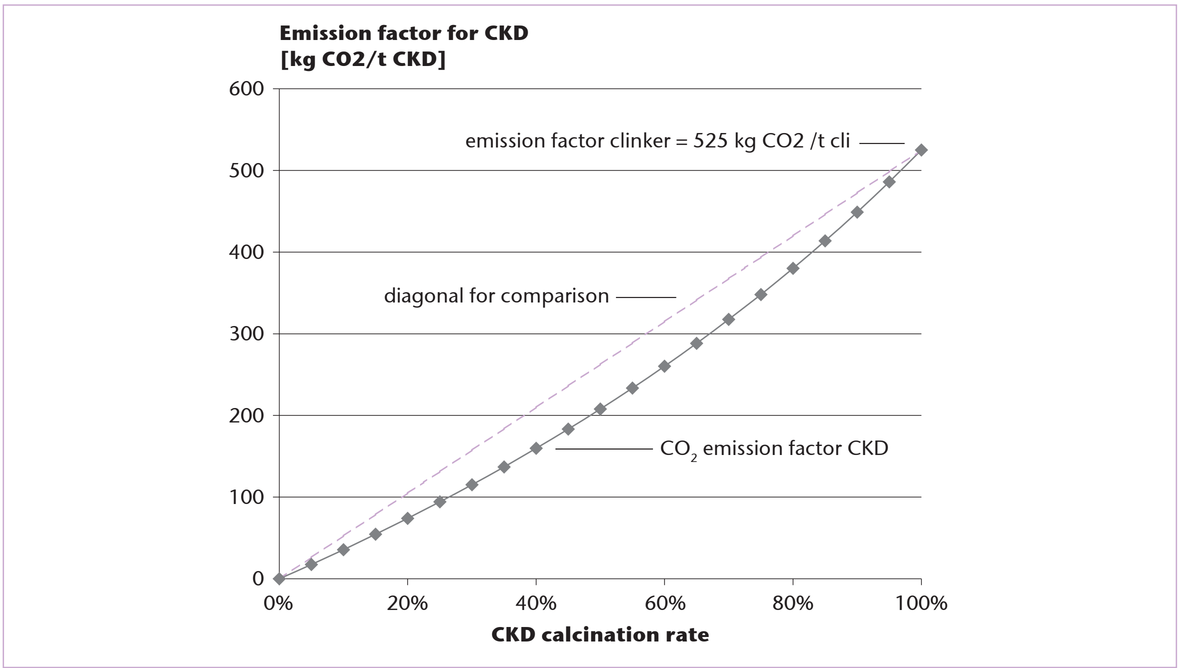
$$d = 1 - \frac{fCO2_{CKD} \times (1 - fCO2_{RM})}{(1 - fCO2_{CKD}) \times fCO2_{RM}}$$

where

$fCO2_{CKD}$ = weight fraction of carbonate CO_2 in the CKD (--)

$fCO2_{RM}$ = weight fraction of carbonate CO_2 in the raw meal (–)

Figure A3-1: Influence of CKD calcination rate on the CO_2 emission factor for CKD, using the default clinker emission factor (525 kg CO_2/t cli) as an example.



In the absence of measurement data on the composition of the CKD, 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 CKD-related emissions, because CKD is usually not fully calcined.

Direct determination of the CO_2 emission factor of CKD from analysis of CO_2 content

For the direct determination of the CO_2 emission factor of CKD, the combination of *the Equations 3* and *7* yields

Equation 8:

$$EF_{CKD} = \frac{fCO2_{RM} - \dfrac{fCO2_{CKD} \times (1 - fCO2_{RM})}{(1 - fCO2_{CKD})}}{(1 - fCO2_{RM}) + \dfrac{fCO2_{CKD} \times (1 - fCO2_{RM})}{(1 - fCO2_{CKD})}}$$

Equation 8 can be simplified after complementation of the left hand term by multiplication with

Equation 9:

$$\frac{\dfrac{(1 - fCO2_{CKD})}{(1 - fCO2_{RM})}}{\dfrac{(1 - fCO2_{CKD})}{(1 - fCO2_{RM})}} = 1$$

As result the CO_2 emission factor of CKD could equally be determined directly by the following equation:

Equation 10:

$$EF_{CKD} = fCO2_{RM} \times \frac{(1 - fCO2_{CKD})}{(1 - fCO2_{RM})} - fCO2_{CKD}$$

In *Equation 10* the terms in round brackets correct the mass reference of the CO_2 content $fCO2_{RM}$ determined in samples of the uncalcined raw meal to the mass reference of CKD, which potentially is partially calcined. The CO_2 emission factor of CKD EF_{CKD} is determined from the difference of the CO_2 content between the potentially partially calcined state and the hypothetical uncalcined state of CKD.

A4 Background Material on Fuel Emission Factors

This appendix summarizes background information on fuel emission factors collected by the CSI Task Force.

Petcoke

The CSI Task Force compiled data on the emission factor of high-sulphur petcoke used by its member companies in 2003. The results are:

Average value:	92.8 kg CO_2/GJ
Standard deviation:	2.08 kg/GJ
No. of samples:	361

Table A4-1: Regional coverage of petcoke samples (No. of samples)

Latin America	Canada / U.S.	Europe	Asia	Africa	Total
40	1	291	20	9	361

The samples were mostly taken in 1999–2003. They cover different world regions, with a focus on Europe (see *Table A4-1*). The resulting average of 92.8 kg CO_2/GJ replaces the former default value of 100 kg CO_2/GJ in the original version of the Cement CO_2 Protocol, which was based on preliminary estimations. It is also different from the default CO_2 emission factor of 97.5 kg CO_2/GJ, which is suggested in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[4].

Alternative Fuels

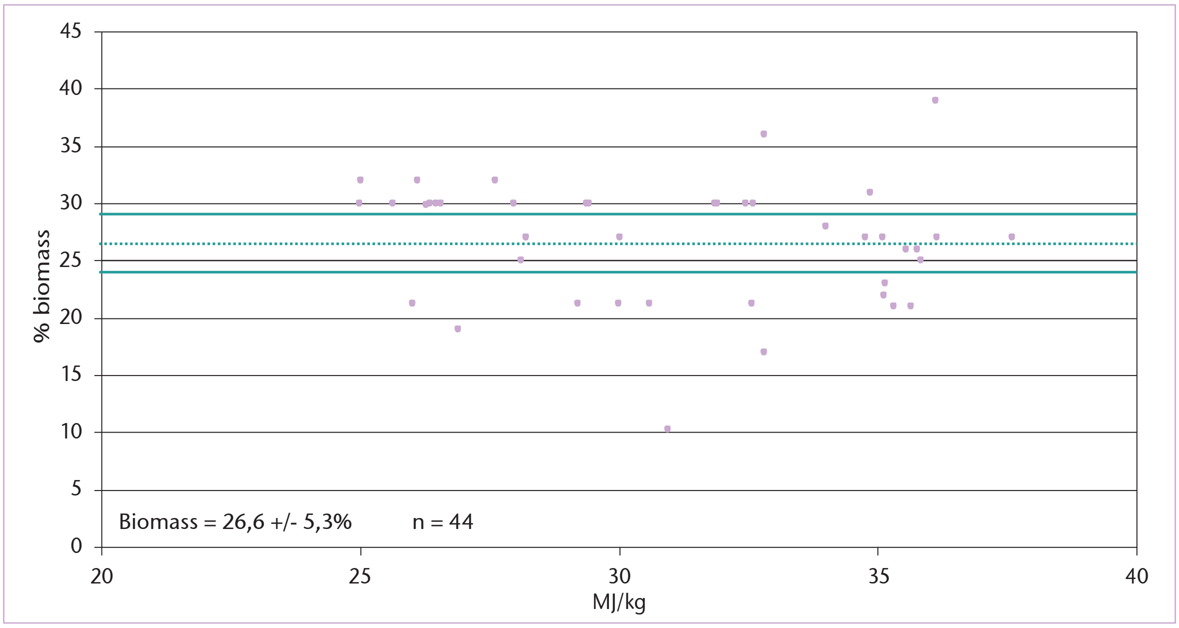
The CSI Task Force compiled data on the emission factors of some alternative fuels from its member companies in 2003-04. The results are shown in *Table A4-2*:

Table A4-2: Analysis data on alternative fuels compiled by the CSI Task Force. CO_2 emission factors were rounded to two digits in the spreadsheet

Fuel	No of Samples	CO_2 Emission Factor Average (kg /GJ)	Standard Deviation (kg /GJ)
Fossil-based alternative fuels:			
Waste oil	90	74.2	5.6
Solvents	116	73.8	14.9
Biomass fuels:			
Animal meal	116	89.2	6.5

In 2008/2009 the Taskforce collected data about the biomass content of different alternative fuels in order to investigate the possibility of introducing adequate default values into the spreadsheet. As a result, only for waste tires (including shredded tires) a sufficiently consistent data base could be found (see *Figure A4-1*) and a default value of 27% biomass has been included. This value coincides with default values set in different European countries like Austria or Germany for the reporting within the European Emissions Trading Scheme.

Figure A4-1: Analysis data on the biomass content related to the calorific value of waste tires (including shredded tires) compiled by the CSI Task Force



A5 Numeric Prefixes, Units and Conversion Factors

Prefixes and multiplication factors			
Multiplication Factor	**Abbreviation**	**Prefix**	**Symbol**
1 000 000 000 000 000	10^{15}	peta	P
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto	h
10	10^{1}	deca	da
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	m

Abbreviations for chemical compounds		Units and abbreviations	
CH_4	Methane	cubic metre	m^3
N_2O	Nitrous Oxide	hectare	ha
CO_2	Carbon Dioxide	gram	g
CO	Carbon Monoxide	tonne	t
NO_x	Nitrogen Oxides	joule	J
NMVOC	Non-Methane Volatile Organic Compound	degree Celsius	°C
NH_3	Ammonia	calorie	cal
CFCs	Chlorofluorocarbons	year	yr
HFCs	Hydrofluorocarbons	capita	cap
PFCs	Perfluorocarbons	gallon	gal
SO_2	Sulphur Dioxide	dry matter	dm
SF_6	Sulphur Hexafluoride		
CCl_4	Carbon Tetrachloride		
C_2F_6	Hexafluoroethane		

Source: IPCC 1996, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories and IPCC 2006, IPCC Guidelines for National Greenhouse Gas Inventories.

Conversion Factors

To convert from	To	Multiply by
grams (g)	metric tons (t)	1×10^{-6}
kilograms (kg)	metric tons (t)	1×10^{-3}
megagrams	metric tons (t)	1
gigagrams	metric tons (t)	1×10^{3}
pounds (lb)	metric tons (t)	4.5359×10^{-4}
tons (long)	metric tons (t)	1.016
tons (short)	metric tons (t)	0.9072
barrels (petroleum, US)	cubic metres (m^3)	0.15898
cubic feet (ft^3)	cubic metres (m^3)	0.028317
litres	cubic metres (m^3)	1×10^{-3}
cubic yards	cubic meters (m^3)	0.76455
gallons (liquid, US)	cubic meters (m^3)	3.7854×10^{-3}
imperial gallon	cubic meters (m^3)	4.54626×10^{-3}
joule	gigajoules (GJ)	1×10^{-9}
kilojoule	gigajoules (GJ)	1×10^{-6}
megajoule	gigajoules (GJ)	1×10^{-3}
terajoule (TJ)	gigajoules (GJ)	1×10^{-3}
Btu	gigajoules (GJ)	1.05506×10^{-6}
calories, kg (mean)	gigajoules (GJ)	4.187×10^{-6}
tonne oil equivalent (toe)	gigajoules (GJ)	41.86
kWh	gigajoules (GJ)	3.6×10^{-3}
Btu / ft^3	GJ / m^3	3.72589×10^{-5}
Btu / lb	GJ / metric tons	2.326×10^{-3}
lb / ft^3	metric tons / m^3	1.60185×10^{-2}
psi	bar	0.0689476
kgf / cm^3 (tech atm)	bar	0.980665
atm	bar	1.01325
mile (statue)	kilometer	1.6093
ton CH_4	ton CO_2 equivalent	21
ton N_20	ton CO_2 equivalent	310
ton carbon	ton CO_2 equivalent	3.664

Sources: International Energy Annual, 1998; http://www.eia.doe.gov/emeu/iea/convheat.html
BP Group Reporting Guidelines, 2000

Source: WRI / WBCSD GHG Protocol, Guideline for Stationary Fuel Combustion www.ghgprotocol.org

A6 Main Changes in the Cement CO_2 and Energy Protocol from Version 2 to Version 3

The revision of the Cement CO_2 and Energy Protocol was performed based on extended experiences with the application of the Protocol Version 2 and its evaluation for several years by many cement companies worldwide. Main changes for the Protocol Version 3 were made regarding the following issues:

- Additional key performance indicators (KPIs), including KPIs based on equivalent cement production (see Appendix A7)
- Change of the definition of kiln fuels
- Accounting of climate-neutral CO_2 emissions from the biomass content of mixed fuels
- Reporting of CO_2 emissions from raw material calcination with the choice between simple and detailed methods and either based on kiln input or output
- More extensive (optional) reporting of CO_2 from power generation on-site ("power balance")
- Adding of harmonized rules to avoid double counting of internal clinker, cement and MIC transfers and consolidation of plant level to company level accordingly
- Change of the definition of net and gross emissions (like in Version 1)

Some minor and/or formal changes have been made as well:

- Inclusion of additional general information on the installation into the spread sheet
- Inclusion of a validation tool
- Deletion of the section on emission rights
- Increase of flexibility of reporting for different types of fuels, e.g. the use of alternative fuels for onsite power generation or bio-diesel for trucks in the quarry
- Update of the default emission factor for bought clinker
- Updated guidance for emission factors for power from national grid
- Option for reporting of "waste heat used internally" e.g. for on-site power generation

Key Performance Indicators

An objective for the revision of the Protocol was, to keep as many of the KPIs from Version 2 unchanged in Version 3 so that there should be no or as few as possible breaks in the timeline of the KPIs. This could be fulfilled in most cases.

After new members joined the CSI, especially from Asia, and more installations with on-site power generation start using the protocol the concept of a power balance was included. At the same time an adjustment of the definition of gross CO_2 emissions was therefore necessary.

The original KPI, which reports the total direct CO_2 emissions and its definition remained unchanged. However, its name was amended to "Absolute gross CO_2 including CO_2 from on-site power generation".

A second new KPI was defined in order to achieve comparability of principle KPIs for the production of clinker and cement. This KPI is now named "Absolute gross CO_2". It reports the direct emissions from raw materials, kiln fuels and non-kiln fuels excluding CO_2 from on-site power generation. The definition of its fuel component was adjusted accordingly. Furthermore, all specific KPIs are defined based on the adjusted definition of "Absolute gross CO_2".

In plants without on-site power generation, the two KPIs will deliver the same result, i.e. the total direct CO_2 emissions (Scope 1). However, the KPIs in Version 3 using "Absolute gross CO_2" (excluding CO_2 from on-site power generation) allow for better comparability of specific CO_2 emissions between plants with and without on-site power generation. Without on-site power generation, the corresponding CO_2 emissions occur out of the boundaries of the specific plant as indirect emissions (Scope 2) from purchased electrical power.

A second minor adjustment was made for clarification, which does not influence the KPI except for the following issue. The fuels used for raw material and fuel drying have been allocated to kiln fuels. This adjustment only influences some of the general KPIs on the kiln heat consumption. For most plants the impact on the corresponding KPIs should be of low significance. The KPIs, which report on total heat consumption and direct CO_2 emissions from kiln fuels and non-kiln fuels, are not affected.

In particular, the revision of the guideline to the Cement CO_2 and Energy Protocol Version 3 involved the main changes listed in *Table A6-1*. The table includes information where in the Protocol a more detailed description of the respective addition or modification can be found.

Table A6-1: Changes in Version 3 compared to Version 2

Change / Item	Guidance Chapter	Spreadsheet
Introduction of Protocol Version 3	1.1	
Update of reference documents	1.1, 1.2, 1.3, 1.4	
Amendment of the description of organizational and operational boundaries and scopes for emission reporting: Inclusion of emissions from on-site electrical power generation	1.4	
Reporting of CO_2 from power generation on-site (on site electricity production)	4, 5.2	
Accounting of climate-neutral CO_2 emissions from the biomass content of mixed fuels	3.5, 5.2	Lines 50, 83, 96, 200a-200h
Re-definition of net CO_2 emissions corresponding to Protocol Version 1. The option for the balance of emissions and emission rights within the protocol is discontinued in Version 3	5.3	Lines 71-77
Adjustment of the definition of Gross CO_2 emissions to direct CO_2 excluding CO_2 from on-site power generation	5.1, 5.2, 5.3, Appendix 6	Line 59c
Deletion of the section on emission rights	5	Lines 64a-65a
Reference to Internet Manual web address	10	
Update of reference documents,	11	
Glossary revised and amended	12	
Definition of net and gross emissions	12	Lines, 59, 59c, 71
Introduction of new methods for reporting of CO_2 emissions from raw material calcination with the choice between a) simple and detailed methods and b) either based on kiln input or output including detailed description and equations	3.1, 3.2, 3.3, 3.4,	Lines 7n, 34d-39
New or amended auxiliary sheets as extension of the calcination sheet in the Protocol Version 2	Appendix 1	Sheets CalcA1, CalcA2, CalcB2
Amended description of methods for accounting CO_2 from calcination of raw materials and equations	Appendix 3	

Change / Item	Guidance Chapter	Spreadsheet
Added equations for the direct determination of the CO_2 emission factor of CKD from analysis of CO_2 content	Appendix 3	
Updated default emission factors for some alternative fuels	Appendix 4	Sheet Fuel CO_2 Factors
Description of main changes from Protocol Version 3	Appendix 6 and 7	
Inclusion of additional general information on the installation into the spread sheet	Appendix 6	Lines 6a, 6b, 7aa
Revised allocation of the fuels used for raw material and fuel drying together to kiln fuels instead of non-kiln fuels	3.7, 3.8, Appendix 6	Lines 25, 25a, 40-43, 94-96a, 124-126a, 154-156a,
Overview of performance indicators (KPIs) in the Cement CO_2 and Energy Protocol Version 3 and comparison with Protocol Version 2	Appendix 7	--
New key performance indicators (KPIs), including KPI based on equivalent cement production and new structuring of KPI section	Appendix 7	Lines 59c, 60a, 60b, 63- 63b, 75, 82c, 83a, 92a, 96a-96d, 98-98c
Increase of flexibility of reporting for different types of fuels, e.g. the use of alternative fuels for onsite power generation or biodiesel for trucks in the quarry	3.5, 3.6, 3.7, 3.8	Lines 124-126a, 154-156a, 192a, 192b, 199a, 200a-200h, 301ba, 301d, 302c, 303k-303j, 304i-304h, 311ba-311d, 313k-313j, 314i, 314g, 312c
Default emission factor for bought clinker	4	Line 49b
Avoiding double counting of internal clinker, cement and MIC transfers	7.4	Plant sheet: Lines 9, 10b, 10c, 11, 17a, 19, 19a, 19b, 19c
Consolidation of plant level to company level		Company Sheet
Updated guidance for emission factors for power from national grid	4	
Option for reporting of “waste heat used internally” e.g. for on-site power generation	5.4	
Inclusion of the validation tool	8.4	Sheets Validation, ControlPlant

A7 Performance Indicators (KPIs) in the Cement CO_2 and Energy Protocol Version 3

PERFORMANCE INDICATORS in Protocol Version 3 (line number, name, unit, comment and definition)					**Comparison of Protocol Version 3 to Version 2**	
New and adjusted performance indicators (KPIs) are marked by bold numbers and names. See comparison of Protocol Version 3 and Version 2 on the right hand side for more details.				Line numbers are listed without the prefix 'line' in the equations that define the KPIs and where necessary unit conversions are specified in square brackets, e.g. [1000 kg/t]		
Absolute Direct CO_2 Emissions					**new order of KPIs on absolute CO_2**	
59	Absolute gross CO_2 including CO_2 from on-site power generation	[t CO_2/yr]	Total direct emissions from raw materials, kiln fuels and non-kiln fuels, including CO_2 from on-site power generation	= 39 + 43 + 46	adjusted name of KPI	= 39 + 43 + 46
Gross CO_2 Emissions (=direct fossil CO_2 excluding CO_2 from onsite power generation)					**adjusted definition of gross CO_2 excluding CO_2 from on-site power generation**	
59c	Absolute gross CO_2	[t CO_2/yr]	Total direct emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation	= 59 – 45c	new adjusted KPI definition	
59a	– calcination component	[t CO_2/yr]	Direct emissions from raw materials	= 39		
59b	– fuel component	[t CO_2/yr]	Direct emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation	= 43 + 44 + 45a + 45b = 43 + 46 – 45c	adjusted according to 59c	= 43 + 46

Net CO_2 Emissions (= gross CO_2 minus alternative fossil fuels CO_2; excluding CO_2 from onsite power generation)					**changed concept for net CO_2**	
71	**Absolute net CO_2**	[t CO_2/yr]	Total direct emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, minus alternative fossil fuels	= 59c – 41	changed definition and according to 59c	= 59 – 65a
Biomass CO_2 Emissions (Memo Item)					**changed to absolute value**	
83a	**Absolute CO_2 from biomass sources (including biomass content of mixed fuels)**	[t CO_2/yr]		= 50	new adjusted KPI absolute value and biomass content of mixed fuels included	KPI 83 = 50 / 21a
Specific Gross and Net CO_2 Emissions per Clinker Produced					**new order and new KPIs on specific CO_2**	
60	Specific gross CO_2 per tonne of clinker produced	[kg CO_2/t cli]	Total direct emissions, excluding CO_2 from on-site power generation, divided by own clinker production	= 59c / 8 * [1000 kg/t]	according to 59c	= 59 / 8
60a	**– calcination component**	[kg CO_2/t cli]	Direct emissions from raw materials, divided by own clinker production	= 59a / 8 * [1000 kg/t]	new KPI	
60b	**– fuel component**	[kg CO_2/t cli]	Direct emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by own clinker production	= 59b / 8 * [1000 kg/t]	new KPI	

73	Specific net CO_2 per tonne of clinker produced	[kg CO_2/t cli]	Net emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by own clinker production	= 71 / 8 * [1000 kg/t]	according to 71	
Specific Gross and Net CO_2 Emissions per Cement (equivalent)					**new order and new KPIs on specific CO_2**	
63	**Specific gross CO_2 per tonne of cement (eq.)**	[kg CO_2/t cem eq.]	Total direct emissions, excluding CO_2 from on-site power generation, divided by total cement (equivalent)	= 59c / 21b * [1000 kg/t]	new KPI	
63a	**– calcination component**	[kg CO_2/t cem eq.]	Direct emissions from raw materials, divided by total cement (equivalent)	= 59a / 21b * [1000 kg/t]	new KPI	
63b	**– fuel component**	[kg CO_2/t cem eq.]	Direct emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by total cement (equivalent)	= 59b / 21b * [1000 kg/t]	new KPI	
75	**Specific net CO_2 per tonne of cement (eq.)**	[kg CO_2/t cem eq.]	Net emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by own production of cement (equivalent)	= 71 / 21b * [1000 kg/t]	new KPI	

Specific Gross and Net CO_2 Emissions per Cementitious Produced					new order of KPIs on specific CO_2	
62	Specific gross CO_2 per tonne of cementitious product	[kg CO_2/t cem prod]	Total direct emissions, excluding CO_2 from on-site power generation, divided by own production of cementitious products (excluding bought clinker in cement)	= 59c / 21a * [1000 kg/t]	according to 59c	= 59 / 21a
62a	– calcination component	[kg CO_2/t cem prod]	Direct emissions from raw material calcination, divided by own production of cementitious products	= 59a / 21a * [1000 kg/t]	unchanged	
62b	– fuel component	[kg CO_2/t cem prod]	Direct emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by own production of cementitious products	= 59b / 21a * [1000 kg/t]	according to 59b	
74	Specific gross CO_2 per tonne of cementitious product	[kg CO_2/t cem prod]	Net emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by own production of cementitious products	= 71 / 21a * [1000 kg/t]	according to 71	
77	Improvement rate - net CO_2 per tonne of cementitious product	[% relative to base yr]	Reduction of specific net emissions relative to base year (default 1990),	= (74 year n - 74 year 1990) / 74 year 1990 * [100%]	according to 74	

Specific Indirect CO_2 Emission					**new KPI added**	
82c	**Specific indirect CO_2 from external power generation per tonne of cement (eq.)**	[kg CO_2/t cem eq.]		= 49a / 21b * [1000 kg/t]	new KPI	
82a	Specific indirect CO_2 from external power generation per tonne of cementitious product	[kg CO_2/t cem prod]		= 49a / 21a * [1000 kg/t]	unchanged	
82b	Specific indirect CO_2 from net clinker imports (+) / exports (-) per tonne of cementitious product	[kg CO_2/t cem prod]		= 49c / 21a * [1000 kg/t]	unchanged	
General Performance Indicators					**new KPIs added, adjusted definition of kiln fuels**	
91	Net outbound clinker per net clinker consumption	[%]	Percentage of direct clinker sales versus clinker consumed to produce cement	= (10 - 9 - 10b - 10c) / 11	unchanged	
92a	**Clinker/cement (eq.) factor*[1]**	[%]	Calculated based on total clinker consumed and total Portland + Blended cements	= 11 / 20	new KPI	
92	Clinker/cementitious factor*[2]	[%]	Clinker/cementitious factor (excluding clinker sold, including clinker bought) = Total clinker consumed divided by the total of cements produced	= 11 / 21	KPI name adjusted	
93	**Specific heat consumption of clinker production**	[MJ/t cli]	Total heat consumption of kilns divided by the clinker production	= 25 * [10^6 MJ/TJ] / 8	adjusted definition of kiln fuels	

94	**Conventional fossil fuel rate (kiln fuels)**	[%]	Consumption of conventional fossil fuels divided by the total heat consumption of kilns	= 26 / 25	adjusted definition of kiln fuels	
95	**Alternative fossil fuel rate (kiln fuels)**	[%]	Consumption of alternative fossil fuels divided by the total heat consumption of kilns	= 27 / 25	adjusted definition of kiln fuels	
96	**Biomass fuel rate (kiln fuels)**	[%]	Consumption of biomass fuels and biomass content of mixed fuels divided by the total heat consumption of kilns	= 28 / 25	adjusted definition of kiln fuels, biomass content of mixed fuels included	
96a	**CO_2 emission factor for kiln fuel mix**	[kg CO_2/GJ]	Total CO_2 from fossil-based kiln fuels divided by total heat consumption of kilns;	= 43 / 25a	new KPI	
96b	**Total Conventional Fossil Fuel Rate at Plant Level**	[%]	Total conventional fossil fuel energy used in the whole plant divided by total fuel energy use in %	= (26 + 321 + (321c * (1 - 200g)) + 322 + 323k + 324aa) / (25 + 321 + 321c + 322 + 323k + 323g + 323i + 324aa + 324f + 324h)	new KPI	
96c	**Total Alternative Fossil Fuel Rate at Plant Level**	[%]	Total alternative fossil fuel energy used in the whole plant divided by total fuel energy use in %	= (27 + 323g + 324f) / (25 + 321 + 321c + 322 + 323k + 323g + 323i + 324aa + 324f + 324h)	new KPI	
96d	**Total Biomass Fuel Rate at Plant Level**	[%]	Total biomass fuel energy used in the whole plant divided by total fuel energy use in %	= (28 + (321c * 200g) + 323i + 324h) / (25 + 321 + 321c + 322 + 323k + 323g + 323i + 324aa + 324f + 324h))	new KPI	

General Performance Indicators					new KPIs added	
97	Specific total power consumption*3	[kWh/t cem prod]	Total plant power consumption divided by total cements and substitutes produced	= 33 * [1000 kWh/ MWh] / 21	unchanged	
98	**Specific power consumption of clinker production**	[kWh/t clinker]	Power consumption up to and including clinker production divided by clinker production	= 33e * [1000 kWh/ MWh] / 8	new KPI	
98c	**Specific power consumption of cement production*3**	[kWh/t cem prod]	Power consumption of cement production incl. power consumption of production of clinker consumed divided by cement and substitute production	= (98 * 92) + (33 - 33e) * 1000 / 21	new KPI	
98a	**National energy conversion factor**	[MJ/KWh]	Optional parameter	input	new KPI	
98b	**Total energy intensity of clinker production (fuel and power)**	[MJ/t cli]	Optional result	= 98 * 98a + 93	new KPI	

*1 Clinker/cement (eq.) factor: The clinker/cement (eq.) factor is defined as: Total clinker consumed / (own clinker consumed plus gypsum, limestone, CKD plus clinker substitute consumed for blending plus clinker bought and consumed). Definition of clinker/cement (eq.) factor as in Protocol Guidance Document Version 3, Section 6.3. The factor is based on clinker consumption. Hence, in the denominator sold clinker is excluded and bought clinker is included. Cement substitutes are excluded. See also the equation for its calculation in the 5th column.

*2 Clinker/cementitious factor: Definition of clinker / cementitious factor as in Protocol Guidance Document Version 3, Section 6.3. The factor is based on clinker consumption. Hence, in the denominator sold clinker is excluded and bought clinker is included. Furthermore, cement substitutes are included. See also the equation for its calculation in the 5th column.

*3 Specific power consumption: In this KPI the power consumption is related to the processing of cementitous products. Hence, it is referenced to cements and substitutes produced. In the denominator sold clinker is excluded and bought clinker is included. See also the reference to line 21 in the equation for its calculation in the 5th column. Note: The reference is different from the definition, which is used to report specific CO_2 emissions per ton of cementitous product in the Protocol Guidance Document Version 3, Section 6.2.

A8 Requirements for Assurance of CSI CO_2 Data

In order to establish a standard assurance method and increase transparency, reliability and accuracy of reporting of CO_2 and other Climate Change KPIs to stakeholders, these KPIs must be independently assured in accordance with the following requirements:

Item	Requirement
Assurance Level	Assurance must be, at least, a Limited Assurance done at company level.
Assurer Reputation	The assurer must be a recognized, independent third party assurance practitioner.
Scope of Assured Data	Assurance must include all agreed CSI CO_2 and Energy Protocol KPIs.
Frequency of Assurance	Assurance must be carried out at least once every two years at company level, assuring data from both years.
Coverage of Sites	Assurers must decide the number and location of sites to be visited in order to check the accuracy and quality from representative source data.
Sampling Plan	Plants assured under other schemes (e.g. EU ETS, CDM) must be counted as samples for CSI CO_2 assurance, in order to avoid double verification.
Assurance Standard	Assurance must be conducted following guidelines from the CSI CO_2 and Energy Protocol and from ISAE 3000, ISO 14064-3 or a similar standard.
Materiality Threshold	Data can only be considered material if any difference/inconsistency found in one or more of CO_2 Inventory KPIs is less than 5%.
Assurance Statement	The assurer must provide to the CSI Member an assurance statement summarizing the conclusions about the CO_2 Inventory KPIs and explicitly mentioning the use of the CSI CO_2 and Energy Protocol Guidelines and the number of sites visited and corresponding % of CO_2 emissions covered.
Deadline	Data must be verified and reported: > Old plants/ new plants/ acquisitions – two years at most > New CSI members – four years at most

Endnotes

1 WRI / WBCSD 2004, World Business Council for Sustainable Development & World Resources Institute. The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard. Revised Edition. http://www.ghgprotocol.org

2 This protocol and related activities shall be compliant with all applicable legal requirements, including competition laws and regulations, whether related to information exchange or to other competition law requirements, guidelines, or practices.

3 Absolute emissions are expressed in tonnes of CO_2. Specific emissions are expressed in kilograms of CO_2 per unit product.

4 IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp

5 See the Monitoring and Reporting Guidelines (MRG) of the EU ETS (EC 2007), http://ec.europa.eu/clima/policies/ets/monitoring_monitoring_en.htm

6 See "Act on promotion of global warming countermeasures", http://www.env.go.jp/earth/ghg-santeikohyo/manual/chpt2.pdf

7 "Act on the Rational Use of Energy", http://www.enecho.meti.go.jp/topics/080801/kinyuyouryou.pdf

8 ISO 14064-1: 2006-03. *Greenhouse gases. Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*. International Organization for Standardization, Switzerland.

9 See IPCC 2006, Vol. III, 2.2.1.1

10 1.55 t raw meal /t clinker x 2 kg C /t raw meal x 3.664 kg CO_2 /kg C = 11 kg CO_2 /t clinker, under the assumption that all organic carbon is converted to CO_2. 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

11 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;

12 See IPCC 1996, Vol. III, p.1.13

13 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_2 emissions of about 2 kg per t of clinker or about 0.2% of a plant's typical overall CO_2 emissions (values based on data provided by several CSI member companies).

14 IPCC (1996, Table I-17) provides a default emission factor of approx. 1 g CH_4 /GJ for cement kilns, which corresponds to about 0.01% of the total CO_2-equivalent emissions per GJ fuel use. Assumptions: Direct CO_2 from cement plants is 56 – 100 kg CO_2 /GJ from fuel combustion, plus 130 – 170 kg CO_2 /GJ from raw materials calcination, totaling 186 – 270 kg CO_2 /GJ. In comparison, 1 g CH_4 /GJ corresponds to 21 g CO_2e/GJ on a 100 year time horizon. The IPCC default is confirmed by a small set of company data compiled by the CSI Task Force.

15 IPCC defaults for N_2O emissions from cement kilns are currently not available. A limited set of data compiled by the CSI Task Force indicates that N_2O concentrations in kiln flue gas are usually below 10 mg /Nm^3. Limited experience shows that this also remains value if SNCR technology is used for NO_x abatement. This corresponds to about 7 kg CO_2e /t clinker, or about 0.8% of the typical CO_2 emissions associated with clinker production.

16 See IPCC 1996, Vol. III, p.2.5

17 Any dust volumes which leave the kiln system and are ultimately incorporated in cementitious products should be included in the denominator. Examples include CKD added to the cement mill, and direct sales of CKD as a binder. In the protocol spreadsheet, such dust volumes shall be counted under mineral components used for blending, or under mineral components used as cement substitutes. In contrast, landfilled dust should be excluded from the denominator.

18 This denominator has been considered in the earlier versions of the protocol as the most appropriate basis for monitoring emissions performance and calculating national cement industry benchmarks.

19 This may be required, for instance, if installations are defined according to the European Union's IPPC directive.

20 The case of joint operational control is not explicitly addressed in the revised WRI / WBCSD Protocol, but is inferred here by analogy from the joint financial control case.

21 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 can choose 1995 as their base year for hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

22 Besides the uncertainty of parameters, there are other error sources that can 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 used to aggregate different greenhouse gases. In designing the protocol spreadsheet, the CSI Task Force aimed to reduce the model uncertainty inherent in cement company inventories to minimal levels. Addressing scientific uncertainty, on the other hand, is clearly beyond the scope of corporate inventories. See Chapter 7 of the revised WRI / WBCSD Protocol for details.

23 Methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), and fluorinated hydrocarbons (PFCs, HFCs)

24 A second, but much smaller factor is the CaO- and MgO content of the raw materials and additives used.

25 Sources: PCC recommendation: IPCC 2000, pp. 3.9ff; GNR average: Cement Sustainability Initiative. Global Cement Database on CO_2 and Energy Information (http://www.wbcsdcement.org)

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The WBCSD is a CEO-led, global coalition of some 200 companies advocating for progress on sustainable development. Its mission is to be a catalyst for innovation and sustainable growth in a world where resources are increasingly limited. The Council provides a platform for companies to share experiences and best practices on sustainable development issues and advocate for their implementation, working with governments, non-governmental and intergovernmental organizations. The membership has annual revenues of USD 7 trillion, spans more than 35 countries and represents 20 major industrial sectors. The Council also benefits from a network of 60 national and regional business councils and partner organizations, a majority of which are based in developing countries.

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