CHAPTER 2

MINERAL INDUSTRY EMISSIONS

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2 MINERAL INDUSTRY EMISSIONS

2.1 INTRODUCTION

This chapter outlines methodologies for estimating process-related carbon dioxide (CO_2) emissions resulting from the use of carbonate raw materials in the production and use of a variety of mineral industry products. There are two broad pathways for release of CO_2 from carbonates: calcination and the acid-induced release of CO_2. The primary process resulting in the release of CO_2 is the calcination of carbonate compounds, during which, through heating, a metallic oxide is formed. A typical calcination reaction, here shown for the mineral calcite or calcium carbonate, would be:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

Acid-induced release of CO_2, for example, via an equation such as:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$$

This occurs in a variety of industries, but is typically the result of small quantities of carbonate being present as an impurity in an acidification process to upgrade a non-carbonate material. For example, in the treatment of phosphate ores with sulphuric acid to produce phosphoric acid, the phosphate concentrate that is to be acidified may contain a small percentage of carbonate minerals. In general, the amount of CO_2 released by acidification of these carbonate impurities will be small.

The focus of this chapter is therefore on the emissions resulting from calcination of carbonate materials. Although the principal process by which calcination-related emissions are released is similar among the source categories in the mineral industry, three source categories are highlighted because of their relatively significant contribution to global emissions. These source categories are Cement Production, Lime Production and Glass Production. In addition to these source categories, this chapter considers emissions resulting from the consumption of carbonates in a variety of other mineral industries including ceramics, soda ash use, and carbonate consumption for non-metallurgical magnesia production.

Limestone and other carbonate materials also are consumed in a variety of other industries not covered in this chapter. Examples include carbonates used as fluxes[1] and slagging[2] agents in metals smelting and refining (e.g., iron and steel production and base metals such as copper), and as inputs to the chemical industry (e.g., fertiliser). The methods outlined in this chapter for estimating emissions from the use of carbonates are applicable to these other industries as well. It is *good practice* to allocate emissions from the use of limestone, dolomite and other carbonates to the industrial source category where they are emitted (e.g., iron and steel production).

As noted throughout Volume 3 on Industrial Processes and Product Use (IPPU), the emission estimation methodologies outlined below consider only process-related emissions and do not consider energy-related emissions. Inventory compilers should ensure that energy-related emissions from these industries are accounted for in the Energy Sector and that there is no double-counting of emissions between the Energy and IPPU Sectors. For example, the calculation of CO_2 emissions from fuel consumed in cement manufacture should consider the combustion of both fossil fuels and waste fuels (tyres, waste oils, paints, etc.) These combustion-related emissions, however, should be included with energy-related emissions and not with IPPU, which should include only the emissions from calcination.

Although methane (CH_4) and nitrous oxide (N_2O) may be emitted from some minerals industry source categories, given current scientific knowledge, these emissions are assumed to be negligible and thus are not addressed in this chapter. CO_2 emissions may result from additional mineral-related activities not identified here; where these are known and can be estimated, they should be included in the inventory.

The source categories in this chapter share a common approach to methodological tiers. Tiers 1 and 2 are based on estimates of the amount of raw materials consumed or products manufactured, along with emission factors that represent the amount of CO_2 emitted per unit of mass. Tier 3 describes direct calculations based on the site-

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[1] Fluxes are raw materials, such as limestone, dolomite, lime and silica sand, which are used to reduce the heat or other energy requirements of thermal processing of minerals (such as smelting of metals). Fluxes also may serve a dual function as a slagging agent.

[2] Slag is a residual silicate melt deliberately formed during the smelting of metallic ores, or in subsequent furnaces (e.g., steel), by the addition of slagging agents (commonly lime, limestone and/or dolomite). Slag contains most of the non-volatile impurities stripped from the ores as well as components derived from any fluxes added to the smelting process.

specific chemistry of raw materials. If site-specific raw materials data are used, it is vital that all sources of carbonate in the raw materials and fuels are accounted for (not just the limestone). The basic emissions calculations for all carbonate-burning industries are similar. They are based on common formula weights and CO_2 ratios, which are presented in Table 2.1 below for convenience.

TABLE 2.1
FORMULAE, FORMULA WEIGHTS, AND CARBON DIOXIDE CONTENTS OF COMMON CARBONATE SPECIES*

Carbonate	Mineral Name(s)	Formula Weight	Emission Factor (tonnes CO_2/tonne carbonate)**
$CaCO_3$	Calcite*** or aragonite	100.0869	0.43971
$MgCO_3$	Magnesite	84.3139	0.52197
$CaMg(CO_3)_2$	Dolomite***	184.4008	0.47732
$FeCO_3$	Siderite	115.8539	0.37987
$Ca(Fe,Mg,Mn)(CO_3)_2$	Ankerite****	185.0225−215.6160	0.40822−0.47572
$MnCO_3$	Rhodochrosite	114.9470	0.38286
Na_2CO_3	Sodium carbonate or soda ash	106.0685	0.41492

Source: CRC Handbook of Chemistry and Physics (2004)

* Final results (i.e., emission estimates) using these data should be rounded to no more than two significant figures.

** The fraction of emitted CO_2 assuming 100 percent calcination; e.g., 1 tonne calcite, if fully calcined, would yield 0.43971 tonnes of CO_2.

*** Calcite is the principal mineral in limestone. Terms like high-magnesium or dolomitic limestones refer to a relatively small substitution of Mg for Ca in the general $CaCO_3$ formula commonly shown for limestone.

**** Formulae weight range shown for ankerite assumes that Fe, Mg, and Mn are present in amounts of at least 1.0 percent.

2.2 CEMENT PRODUCTION

2.2.1 Methodological issues

In cement manufacture, CO_2 is produced during the production of clinker, a nodular intermediate product that is then finely ground, along with a small proportion of calcium sulfate [gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$)], into hydraulic (typically portland) cement. During the production of clinker, limestone, which is mainly calcium carbonate ($CaCO_3$), is heated, or calcined, to produce lime (CaO) and CO_2 as a by-product. The CaO then reacts with silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) in the raw materials to make the clinker minerals (chiefly calcium silicates). The proportion in the raw materials of carbonates other than $CaCO_3$ is generally very small. The other carbonates, if present, exist mainly as impurities in the primary limestone raw material. A small amount of MgO (typically 1-2 percent) in the clinker-making process is desirable as it acts as a flux, but much more than this amount can lead to problems with the cement (van Oss and Padovani, 2002). Cement may be made (ground) entirely from imported clinker, in which case the cement production facility may be considered to have zero process-related CO_2 emissions. As discussed in Section 2.2.1.2, cement kiln dust (CKD) may be generated during the manufacture of clinker. Emission estimates should account for emissions associated with the CKD.

There are no additional emissions associated with the production of masonry cement. Where masonry cement is produced by adding lime to portland cement (or its clinker), the emissions associated with the lime should already be accounted for under lime production. The addition of ground limestone to portland cement or its clinker to produce masonry cement does not lead to additional emissions.

2.2.1.1 CHOICE OF METHOD

The decision tree in Figure 2.1 describes *good practice* in choosing the most appropriate method based on national circumstances. In the Tier 1 method, emissions are based on clinker production estimates inferred from cement production data, correcting for imports and exports of clinker. The estimation of emissions directly from cement production (i.e., applying an emission factor directly to cement production without first estimating clinker production) is not considered to be a *good practice* method because it does not account for clinker imports and exports.

In Tier 2, emissions are estimated directly from clinker production data (rather than clinker production inferred from cement production) and a national or default emission factor. The Tier 3 approach is a calculation based on the weights and compositions of all carbonate inputs from all raw material and fuel sources, the emission factor(s) for the carbonate(s), and the fraction of calcination achieved. The Tier 3 approach relies on plant specific data. If the inventory compiler considers plant-level data to be unreliable or highly uncertain, then it is *good practice* to use Tier 2.

Tier 2 and Tier 3 should also include a correction for CKD. Tier 2 includes a correction addition for emissions associated with CKD not recycled to the kiln. Tier 3 also should account for CKD. Unlike the Tier 2 approach, when using Tier 3, emissions attributed to uncalcined CKD not recycled to the kiln should be subtracted from the total emissions estimate.

Should CO_2 capture technology be installed and used at a plant, it is *good practice* to deduct the CO_2 captured in a higher tier emissions calculation. The default assumption is that there is no CO_2 capture and storage (CCS) taking place. Any methodology taking into account CO_2 capture should consider that CO_2 emissions captured in the process may be both combustion and process-related. In cases where combustion and process emissions are to be reported separately, e.g. for cement production, inventory compilers should ensure that the same quantities of CO_2 are not double counted. In these cases the total amount of CO_2 captured should preferably be reported in the corresponding energy combustion and IPPU source categories in proportion to the amounts of CO_2 generated in these source categories. For additional information on CO_2 capture and storage refer to Volume 3, Section 1.2.2 and for more details on capture and storage to Volume 2, Section 2.3.4.

TIER 1 METHOD: ESTIMATING CLINKER PRODUCTION THROUGH USE OF CEMENT PRODUCTION DATA

As noted above, calculating CO_2 emissions directly from cement production (i.e., using a fixed cement-based emission factor) is not consistent with *good practice*. Instead, in the absence of data on carbonate inputs or national clinker production data, cement production data may be used to estimate clinker production by taking into account the amounts and types of cement produced and their clinker contents and including a correction for clinker imports and exports. Accounting for imports and exports of clinker is an important factor in the estimation of emissions from this source. Emissions from the production of imported clinker should not be included in national emissions estimates as these emissions were produced and accounted for in another country. Similarly, emissions from clinker that is ultimately exported should be factored into national estimates of the country where the clinker is produced. An emission factor for clinker is then applied and the CO_2 emissions are calculated according to Equation 2.1.

EQUATION 2.1
TIER 1: EMISSIONS BASED ON CEMENT PRODUCTION

$$CO_2\ Emissions = \left[\sum_i (M_{ci} \bullet C_{cl\,i}) - Im + Ex \right] \bullet EF_{clc}$$

Where:

CO_2 Emissions = emissions of CO_2 from cement production, tonnes

M_{ci} = weight (mass) of cement produced[3] of type *i*, tonnes

C_{cli} = clinker fraction of cement of type *i*, fraction

Im = imports for consumption of clinker, tonnes

Ex = exports of clinker, tonnes

EF_{clc} = emission factor for clinker in the particular cement, tonnes CO_2/tonne clinker
The default clinker emission factor (EF_{clc}) is corrected for CKD.

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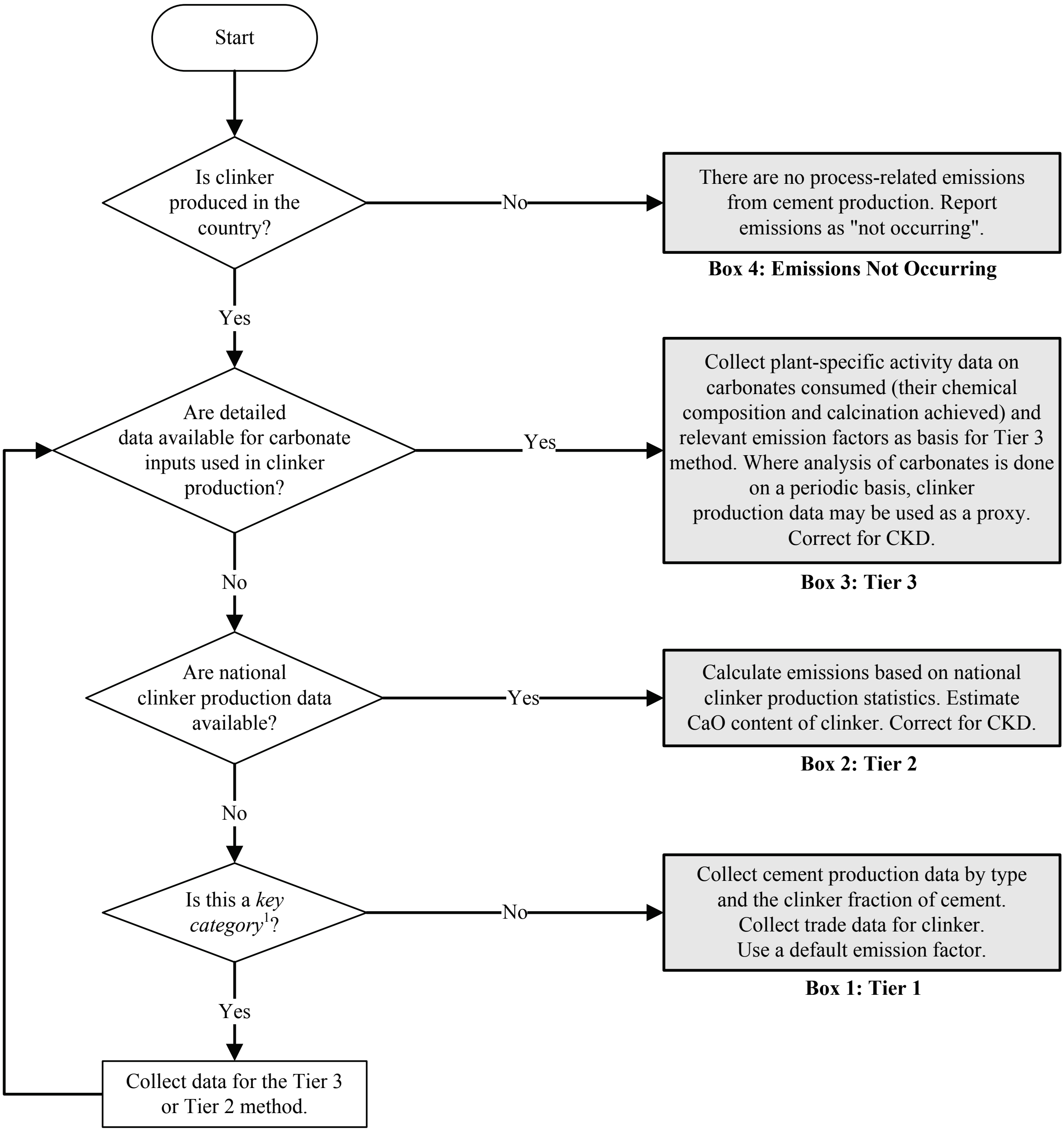
[3] In some statistical compendia production of cement is taken to mean production of cement plus the exports of clinker. If this is the case, it is *good practice* to subtract clinker exports from the M_{ci} factor in Equation 2.1.

Figure 2.1 Decision tree for estimation of CO_2 emissions from cement production



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

TIER 2 METHOD: USE OF CLINKER PRODUCTION DATA

If detailed and complete data (including weights and composition) for carbonate(s) consumed in clinker production are not available (Tier 3), or if a rigorous Tier 3 approach is otherwise deemed impractical, it is *good practice* to use aggregated plant or national clinker production data and data on the CaO content in clinker, expressed as an emission factor in the following Equation 2.2:

EQUATION 2.2
TIER 2: EMISSIONS BASED ON CLINKER PRODUCTION DATA

$$CO_2\ Emissions = M_{cl} \bullet EF_{cl} \bullet CF_{ckd}$$

Where:

CO_2 Emissions = emissions of CO_2 from cement production, tonnes

M_{cl} = weight (mass) of clinker produced, tonnes

EF_{cl} = emission factor for clinker, tonnes CO_2/tonne clinker (See discussion under Section 2.2.1.2, Choice of Emission Factors, for Tiers 1 and 2 below.) This clinker emission factor (EF_{cl}) is not corrected for CKD.

CF_{ckd} = emissions correction factor for CKD, dimensionless (see Equation 2.5)

The Tier 2 approach is based on the following assumptions about the cement industry and clinker production:

1. The majority of hydraulic cement is either portland cement or a similar cement, which requires portland cement clinker;
2. There is a very limited range in the CaO composition of clinker and the MgO content is kept very low;
3. Plants are generally able to control the CaO content of the raw material inputs and of the clinker within close tolerances;
4. Even where the output of clinker is calculated by a plant rather than directly measured, there is generally close agreement between the two determination methods when audits are performed;
5. The CaO content of clinker from a given plant tends not to change significantly over the years;
6. The main source of the CaO for most plants is $CaCO_3$ and, at least at the plant level, any major non-carbonate sources of CaO are readily quantified (see Section 2.2.1.2 below);
7. A 100 percent (or very close to it) calcination factor is achieved for the carbonate inputs for clinker manufacture, including (commonly to a lesser degree) material lost to the system as non-recycled CKD; and
8. Dust collectors at plants capture essentially all of the CKD, although this material is not necessarily recycled to the kiln.

TIER 3 METHOD: USE OF CARBONATE(S) INPUT DATA

Tier 3 is based on the collection of disaggregated data on the types (compositions) and quantities of carbonate(s) consumed to produce clinker, as well as the respective emission factor(s) of the carbonate(s) consumed. Emissions are then calculated using Equation 2.3. The Tier 3 approach includes an adjustment to subtract any uncalcined carbonate within CKD not returned to the kiln. If the CKD is fully calcined, or all of it is returned to the kiln, this CKD correction factor becomes zero. Tier 3 is still considered to be *good practice* in instances where inventory compilers do not have access to data on uncalcined CKD. However, excluding uncalcined CKD may slightly overestimate emissions.

Limestones and shales (raw materials) also may contain a proportion of organic carbon (kerogen), and other raw materials (e.g., fly ash) may contain carbon residues, which would yield additional CO_2 when burned. These emissions typically are not accounted for in the Energy Sector, but, if used extensively, inventory compilers should make an effort to see if they are included in the Energy Sector. Currently, however, too few data exist on the kerogen or carbon contents of non-fuel raw materials for mineral processes to allow a meaningful default value related to the average kerogen content of raw materials to be provided in this chapter. For plant-level raw material-based calculations (Tier 3) where the kerogen content is high (i.e., contributes more than 5 percent of total heat), it is *good practice* to include the kerogen contribution to emissions.

The Tier 3 approach will likely only be practical for individual plants and countries that have access to detailed plant-level data on the carbonate raw materials. Emissions data collected on the plant level should then be aggregated for purposes of reporting national emissions estimates. It is recognized that frequent calculations of emissions based on direct analysis of carbonates could be burdensome for some plants. As long as detailed chemical analyses of the carbonate inputs are carried out with sufficient frequency to establish a good correlation between the carbonates consumed at the plant level and the resulting clinker production, the clinker output may then be used as a proxy for carbonates for emissions calculations in the intervening periods. That is, a plant may derive a rigorously-constrained emission factor for the plant's clinker, based on periodic calibration to the carbonate inputs.

EQUATION 2.3
TIER 3: EMISSIONS BASED ON CARBONATE RAW MATERIAL INPUTS TO THE KILN

$$CO_2\ Emissions = \underbrace{\sum_i (EF_i \bullet M_i \bullet F_i)}_{\text{Emissions from carbonates}} - \underbrace{M_d \bullet C_d \bullet (1-F_d) \bullet EF_d}_{\text{Emissions from uncalcined CKD not recycled to the kiln}} + \underbrace{\sum_k (M_k \bullet X_k \bullet EF_k)}_{\text{Emissions from carbon-bearing non-fuel materials}}$$

Where:

CO_2 Emissions = emissions of CO_2 from cement production, tonnes

EF_i = emission factor for the particular carbonate *i*, tonnes CO_2/tonne carbonate (see Table 2.1)

M_i = weight or mass of carbonate *i* consumed in the kiln, tonnes

F_i = fraction calcination achieved for carbonate *i*, fraction[a]

M_d = weight or mass of CKD not recycled to the kiln (= 'lost' CKD), tonnes

C_d = weight fraction of original carbonate in the CKD not recycled to the kiln, fraction[b]

F_d = fraction calcination achieved for CKD not recycled to kiln, fraction[a]

EF_d = emission factor for the uncalcined carbonate in CKD not recycled to the kiln, tonnes CO_2/tonne carbonate[b]

M_k = weight or mass of organic or other carbon-bearing nonfuel raw material *k*, tonnes[c]

X_k = fraction of total organic or other carbon in specific nonfuel raw material *k*, fraction[c]

EF_k = emission factor for kerogen (or other carbon)-bearing nonfuel raw material *k*, tonnes CO_2/tonne carbonate[c]

Notes on defaults for Equation 2.3:

a: Calcination fraction: In the absence of actual data, it may be assumed that, at the temperatures and residence times achieved in cement (clinker) kilns, the degree of calcination achieved for all material incorporated in the clinker is 100 percent (i.e., $F_i = 1.00$) or very close to it. For CKD, a F_d of <1.00 is more likely but the data may show high variability and relatively low reliability. In the absence of reliable data for CKD, an assumption of $F_d = 1.00$ will result in the correction for CKD to equal zero.

b: Because calcium carbonate is overwhelmingly the dominant carbonate in the raw materials, it may be assumed that it makes up 100 percent of the carbonate remaining in the CKD not recycled to the kiln. It is thus acceptable within *good practice* to set C_d as equal to the calcium carbonate ratio in the raw material feed to the kiln. Likewise, it is acceptable to use the emission factor for calcium carbonate for EF_d.

c: The CO_2 emissions from non-carbonate carbon (e.g., carbon in kerogen, carbon in fly ash) in the non-fuel raw materials can be ignored (set $M_k \bullet X_k \bullet EF_k = 0$) if the heat contribution from kerogen or other carbon is < 5 percent of total heat (from fuels).

2.2.1.2 CHOICE OF EMISSION FACTORS

TIER 1 METHOD

In Tier 1, it is *good practice* to use a default CaO content for clinker of 65 percent; assume that 100 percent of the CaO is from calcium carbonate material; and to incorporate a 2 percent correction factor for CKD (for more discussion on CKD, please refer to the Tier 2 method discussion below.)

For the default CaO composition, 1 tonne of clinker contains 0.65 tonnes CaO from $CaCO_3$. This carbonate is 56.03 percent CaO and 43.97 percent CO_2 by weight (Table 2.1). The amount (X) of $CaCO_3$ needed to yield 0.65 tonnes CaO is: $X = 0.65/0.5603 = 1.1601$ tonnes $CaCO_3$ (unrounded). The amount of CO_2 released by calcining this $CaCO_3 = 1.1601 \bullet 0.4397 = 0.5101$ tonnes CO_2 (unrounded). Assuming a correction addition of 2 percent to account for CKD, the rounded default emission factor (EF_{clc}) for clinker is:

EQUATION 2.4

EMISSION FACTOR FOR CLINKER

$$EF_{clc} = 0.51 \bullet 1.02 \text{ (CKD correction)} = 0.52 \text{ tonnes}CO_2 \text{ / tonne clinker}$$

Under Tier 1, the default EF_{clc} incorporates the correction for CKD. This should not be confused with EF_{cl} under Tier 2, which does not account for the CKD. EF_{cl} should be multiplied by a correction factor, CF_{ckd} (see Equation 2.5) to generate the combined EF for clinker and CKD.

TIER 2 METHOD

Emission factor for clinker (EF_{cl})

In the Tier 2 method, if sufficient country-specific data on CaO content of clinker and inputs of non-carbonate CaO sources are available, it is *good practice* to estimate a country-specific CO_2 emission factor for clinker. As noted above, the derivation of an emission factor for clinker requires that the CaO content of the clinker be known, as well as the fraction of CaO that was derived from a carbonate source (generally $CaCO_3$). The CaO content of clinker is generally within the range of 60 to 67 percent. At a given plant the CaO content will remain stable to within 1 to 2 percent. The basic default emission factor, as recommended under Tier 1, assumes that the clinker is 65 percent CaO and that this is 100 percent derived from $CaCO_3$ and that 100 percent calcination is achieved in the kiln.

The base (i.e., uncorrected for CKD) 0.51 emission factor in Equation 2.4 assumes a 65 percent CaO content in clinker. A similar calculation would yield emission factors for different CaO contents, if these contents are known. For example, for a clinker with 60 percent CaO all derived from $CaCO_3$ the EF_{cl} (not including a correction for CKD) is 0.47, and for 67 percent CaO the EF_{cl} is 0.53.

If it is known that a plant is deriving a significant fraction of CaO from a non-carbonate source (such as steel slag or fly ash), then this component of CaO should first be subtracted. For example, if 4 percent of the CaO in a 65 percent CaO clinker is from slag, then the CaO from carbonate is 61 percent and the calculation for this yields an EF_{cl} of 0.48.

The default emission factor does not include a correction for MgO. For every 1 percent of MgO derived from carbonate the emission factor is an additional 0.011 tonne CO_2/tonne clinker (i.e., $EF_{cl} = 0.510 + 0.011 = 0.52$ tonne CO_2/tonne clinker). Because MgO also may come from a non-carbonate source and because the MgO is deliberately kept low in portland cement, the true MgO from carbonate is likely to be very small. Given the fact that the assumption of a 100 percent carbonate source for the CaO already yields an overestimation of emissions (there is likely to be at least some contribution of CaO from non-carbonate sources) and the fact that some of the MgO is also likely to be from a non-carbonate source, a correction for MgO is not required for a Tier 2 calculation. For uncertainties associated with these assumptions please refer to Table 2.3.

Emissions correction factor for cement kiln dust (CF_{ckd})

Dust may be generated at various points in the kiln line apparatus used to make clinker. The composition of this dust can vary depending on where it is generated but all may be included under the term ‘cement kiln dust’ (CKD). CKD includes particulates derived from the raw materials, and the original carbonate component of the dust may be incompletely calcined. CKD can be efficiently captured by dust control technology and then recycled to the kiln (the preferred practice), or it may be directly returned to the kiln in the combustion air, or (after capture) it may be disposed of. The degree to which CKD can be recycled to the kiln depends on whether or not this causes a quality problem (e.g., excessive alkali content) with the clinker or subsequent finished cement. Any CKD not recycled to the kiln is considered to be ‘lost’ to the process and emissions associated with it will not be accounted for by the clinker. To the degree that the lost CKD represents calcined carbonate raw materials, the emissions from these calcined raw materials represent an addition to the clinker emissions in the Tier 1 and 2 calculations, and a subtraction in the Tier 3 calculation.

As data on the amount of CKD produced may be scarce (except possibly for plant-level reporting), estimating emissions from lost CKD based on a default value can be considered *good practice*. The amount of CO_2 from lost CKD can vary, but ranges typically from about 1.5 percent (additional CO_2 relative to that calculated for clinker) for a modern plant to about 20 percent for a plant losing a lot of highly calcinated CKD (van Oss, 2005). In the absence of data, the default CKD correction factor (CF_{ckd}) is 1.02 (i.e., add 2 percent to the CO_2 calculated for clinker). If no calcined CKD is believed to be lost to the system, the CKD correction factor will be 1.00 (van Oss, 2005). In addition to CKD, the World Business Council for Sustainable Development (WBCSD) separately addresses emissions from bypass dust (which is fully calcined). If the data are available, countries may refer to the WBCSD Protocol to estimate these emissions (WBCSD, 2005).

Where data are available, a correction factor (CF_{ckd} in Equation 2.2) for the ‘lost’ CO_2 emissions can be calculated using Equation 2.5.

The CKD correction factor (CF_{ckd}) for use in Equation 2.2 can be derived as:

EQUATION 2.5
CORRECTION FACTOR FOR CKD NOT RECYCLED TO THE KILN

$$CF_{ckd} = 1 + (M_d / M_{cl}) \bullet C_d \bullet F_d \bullet (EF_c / EF_{cl})$$

Where:

CF_{ckd} = emissions correction factor for CKD, dimensionless

M_d = weight of CKD not recycled to the kiln, tonnes[a]

M_{cl} = weight of clinker produced, tonnes

C_d = fraction of original carbonate in the CKD (i.e., before calcination), fraction[b]

F_d = fraction calcination of the original carbonate in the CKD, fraction[b]

EF_c = emission factor for the carbonate (Table 2.1), tonnes CO_2/tonne carbonate

EF_{cl} = emission factor for clinker uncorrected for CKD (i.e., 0.51 tonnes CO_2/tonne clinker), tonnes CO_2/tonne clinker

Notes:

a: It is assumed that 100 percent of the CKD is first captured. If any CKD vents to the atmosphere, an estimate of this quantity must be made and included in the M_d.

b: It is acceptable to assume that the original carbonate is all $CaCO_3$ and that the proportion of original carbonate in the CKD is essentially the same as that in the raw mix kiln feed.

For example, for M_d/M_{cl} = 0.2, C_d = 0.85, F_d = 0.5, original carbonate all $CaCO_3$ (hence EF_c = 0.4397 tonne CO_2/tonne carbonate), and EF_{cl} = default value of 0.51 tonne CO_2/tonne clinker, the CF_{ckd} = 1.073 (unrounded) - that is, this represents about a 7 percent addition to the CO_2 calculated for the clinker alone.

TIER 3 METHOD

The Tier 3 emission factors are based on the actual CO_2 contents of the carbonates present (see Equation 2.3 and Table 2.1). The Tier 3 approach requires the full accounting of carbonates (species and sources).

2.2.1.3 CHOICE OF ACTIVITY DATA

TIER 1 METHOD

In Tier 1, national-level (or where available, plant-level), data should be collected on the types of cement produced and the clinker fraction of the cement in order to estimate clinker production. Most hydraulic cement produced worldwide is either portland cement, or blended (composite) cements based on portland cement (i.e., portland cement (or clinker) plus pozzolanic or cementitious additives) or masonry-type cements (portland cement plus plasticizing materials such as ground limestone). If cement production cannot be disaggregated by type and it is suspected that significant amounts of blended and/or masonry cements are being produced in addition to portland cement, it is acceptable within *good practice* to assume an overall clinker fraction of 75 percent. If cement production is known to be essentially all portland cement, then it is *good practice* to use a default value of 95 percent clinker. Unfortunately, even if the types of cement produced in the country are known, there can be large variability in the clinker fraction of cement within a given blended or masonry cement type. Table 2.2 provides an illustration of the range of clinker fractions in various cement types. For additional information see DIN (1994) and ASTM (2004a, 2004b). Countries should document clearly any assumptions about the composition of cement and the clinker fraction used to estimate emissions.

Table 2.2
Clinker fraction of blended cement 'Recipes' and overall product mixes (based on U.S. standards ASTM C-150 and C-595; U.S. data may be illustrative for other countries)

Cement Name	Symbol	Recipe	% Clinker	Notes
Portland	'PC'	100% PC	95 - 97 90 - 92	Some U.S. states allow inclusion of 3% GGBFS. Latest standards allow inclusion of ≤ 5% ground limestone.
Masonry	'MC'	2/3 PC	64	varies considerably
Slag-modified portland	I(SM)	slag < 25%	>70 - 93	
Portland BF Slag	IS	slag 25-70%	28 - 70	
Portland pozzolan	IP and P	pozz 15-40%	28 - 79/81	base is PC and/or IS
Pozzolan-modified portland	I(PM)	pozz <15%	28 - 93/95	base is PC and/or IS
Slag cement	S	slag 70+%	<28/29	can use CaO instead of clinker

PERCENT CLINKER IN THE PRODUCT MIX

Percent Additives (Pozzolan + Slag) in the Blended Cement*

Product Mix (PC/blend)**	0%	10%	20%	30%	40%	75%
100/0	95 - 97	0	0	0	0	0
0/100	0	85.5	76	66.5	57	23.8
15/85	14.2	86.9	78.9	70.8	62.7	26.4
25/75	23.8	87.9	80.8	73.6	66.5	41.6
30/70	28.5	88.35	81.7	75.1	68.4	45.2
40/60	38	89.3	83.6	77.9	72.2	52.3
50/50	47.5	90.3	85.5	80.8 ***	76	59.4
60/40	57	91.2	87.4	83.6	79.8	66.5
70/30	66.5	92.2	89.3	86.5	83.6	73.6
75/25	71.1	92.6	90.1	87.8	85.4	77.1
85/15	80.8	93.6	92.2	90.7	89.3	84.3

Notes:

* The inclusion of slag allows for the blend to be portland and/or portland blast furnace slag cement.

Except for 100 percent portland range itself, all other portland assumed to be 95 percent clinker.

** Product Mix refers to range of products of a country, e.g., 75 percent of total production is portland and the rest is blended.

It is assumed that all the hydraulic cement is portland and/or blended, or pure pozzolan. Masonry would approximate a product mix of 60/40 to 70/30 portland/blended, for the 75 percent additive column. Other hydraulic cements (e.g., aluminous) are assumed to be zero.

*** Example: Clinker fraction where a country's cement output is 50 percent portland cement and 50 percent blended cement, and the blended cement contains 70 percent portland cement and 30 percent additives.

Tier 1 also requires a correction for imports and exports of clinker. Data on the quantity of clinker imported and exported from a country are usually available from national customs agencies, the United Nations, national cement associations or trade associations and/or departments of commerce. The typical tariff codes in use for clinker trade are 661.21 (SITC) and 2523.10.00 (HTS). It is important to distinguish trade data for clinker itself from those for the combined category of hydraulic cement and clinker: [codes 661.2 (SITC) and 25.23.0000 (HTS)], and from data on cement imports: [codes 661.22 – 661.29 (SITC) and 2523.21 – 2523.90 (HTS)].

TIER 2 METHOD

The Tier 2 method requires collection of clinker production data. It is suggested that if national surveys currently canvass cement production data, the inventory compiler should investigate the possibility of expanding them to collect clinker production data. It is *good practice* to collect clinker production data directly from national statistics or, preferably, from individual plants. It is also suggested that inventory compilers collect information on the CaO content of the clinker and the fraction of this CaO from carbonate. Where data are available on CaO from non-carbonate sources (e.g., slags and fly ash), this CaO should not be included in the CaO content of clinker used for calculating emissions. If possible, data should be collected to document CKD collection and recycling practices at the plants and likewise on the average or typical composition and calcination fraction of the CKD. Collecting data from individual producers (if complete), rather than using national totals, will reduce the uncertainty of the estimate because these data will account for variations in plant level conditions.

TIER 3 METHOD

The type of activity data required for Tier 3 is likely available only at individual plants. Any reporting entity using Tier 3 should ensure that all carbonate inputs (i.e., types, amounts, all sources) to the kiln are fully investigated as part of the initial implementation of the Tier 3 method, and the full investigation repeated whenever there is any significant change in materials or processes. After a full analysis of the carbonate inputs is completed, and assuming that no significant change in the composition of materials or production process takes place, it is consistent with *good practice* to develop a rigorous plant-specific emission factor based on the carbonate input analysis and apply that emission factor to clinker production (which is typically calculated daily). Subsequently, the clinker production data may then be used as a proxy for the carbonate calculations to estimate emissions. To be consistent with *good practice*, this linkage should be periodically recalibrated.

In general, limestone or similar carbonate rocks will be the dominant (80-90 percent) raw materials used at a typical cement plant, and these data should be collected annually. However it is likely that there could be a carbonate component within clay, shale, sandstone, and other supplementary raw materials, as well as in coal and perhaps some other fuels. If, during the full investigation, it is determined that the amount of carbonates from non-major sources is small (e.g., less than 5 percent of total carbonate) the plant can apply a constant value for the minor source(s) in intervening years before the next full investigation. Recognizing that estimating activity data for these smaller sources may lead to analytical (and other) errors, it may be assumed for emission calculation purposes that the minor source of carbonate is $CaCO_3$, but this assumption should be transparently documented.

Activity data should exclude any carbonates that are not fed into the kiln but are merely introduced into the finish (grinding) mill. For example, a plant may 'dilute' its finished portland cement by blending in a small percentage (1-5 percent) of ground limestone. Carbonates added in the finish mill are not calcined and so do not contribute CO_2.

2.2.1.4 COMPLETENESS

When following a Tier 1 method, inventory compilers should be sure to account for imports and exports of clinker. For countries that are net importers of clinker, failure to deduct the net clinker imports would result in an overestimation of emissions from cement production. For countries that are net exporters of clinker, failure to include the net exports would result in an underestimation of emissions from the cement plants. Potential sources of trade data are discussed in Section 2.2.1.3.

Clinker production data may be available in national statistical databases, or could be collected, even if such data have not been published in national statistics. Cement and/or clinker production data from national statistics may not be complete in some countries where a substantial part of production comes from numerous small kilns, particularly vertical shaft kilns, for which data are difficult to obtain.

Completeness is a particularly important issue to consider where plant specific data are used to estimate national emissions using Tier 3. Under Tier 3, it is important that all clinker-producing plants are considered, and that all carbonates consumed to make clinker are included in the emission calculation. Clinker production plants are well identified in each country, but data on the fraction weight of carbonate(s) consumed may not be readily available. In order for the Tier 3 method to be considered 'complete', all carbonates consumed must be recorded.

In countries where only a subset of clinker plants report data for the Tier 3 method or where there is a transition from Tier 2 to Tier 3, it may not be possible to report emissions using a Tier 3 for all facilities during the transition. Where data on the carbonate inputs are not available for all plants to report using Tier 3, it may be possible to determine the share of production represented by non-reporting plants and use this information to estimate the remaining emissions using Tier 2 in order to ensure completeness during the transition period. A similar approach could be undertaken as a country moves from Tier 1 to Tier 2.

The potential for double counting also should be considered. For example, inventory compilers should review statistics used to estimate emissions from the source category 'Other Process Uses of Carbonates' to ensure that emissions reported in that source category do not result from the use of these carbonates in cement production. Where carbonates are used for cement production, the emission should be reported under Cement Production. Finally, inventory compilers should include only process-related emissions from cement production in this source category. To avoid double-counting, it is *good practice* to account for combustion-related emissions in the Energy volume.

There is one additional issue that, while not included in the current methodology, may become relevant for consideration in the future. Free lime (CaO not part of the formulae of the clinker minerals mentioned above) released during the curing of concrete (i.e., from the hydration of the clinker minerals) can potentially re-absorb atmospheric CO_2 - a process called carbonation. However, the rate of carbonation is very slow (years to centuries) and, as a practical matter, should not be considered for *good practice*. This is an area for future work before inclusion into national inventories.

2.2.1.5 DEVELOPING A CONSISTENT TIME SERIES

These *Guidelines* introduce two changes in the estimation of emissions from cement production. First, under Tier 1, the default emission factor now includes a correction factor for CKD of 2 percent. The correction factor for CKD is now included in Tier 1 because it better reflects the sources of emissions during clinker production It is *good practice* to recalculate previous Tier 1 emissions estimates using the emission factor presented in Section 2.2.1.2.

Also, a new Tier 3 approach based on carbonate inputs to clinker production has been introduced. These data may or may not be available historically. If the inventory compiler chooses to implement Tier 3 (vs. a historical Tier 2 approach) for current and future inventories, they are encouraged to collect these data for historical years to ensure time series consistency. Where these data are not available, the inventory compiler may refer to the 'Overlap approach' (see Volume 1, Section 5.3) to attempt to recalculate previous estimates. The relationship between emissions estimated from the carbonate input approach (Tier 3) and the output-based clinker production approach (Tier 2) should be relatively constant over time for a given plant, but may fail if the number of plants or their technologies or raw materials has changed significantly over time. Once that relationship is established, previous estimates can be recalculated based on this relationship (see Volume 1, Section 5.3). A similar approach could be used where inventory compilers move from a Tier 1 to a Tier 2 approach.

2.2.2 Uncertainty assessment

Uncertainty estimates for cement production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainty related to the emission factor for clinker.

2.2.2.1 EMISSION FACTOR UNCERTAINTIES

For Tier 1, the major uncertainty component is the clinker fraction of the cement(s) produced. If reliable clinker import and export data are not available, then the uncertainty of the clinker production estimate will be higher. Although the default CKD correction factor itself has a very large uncertainty, its effect on the overall emissions calculation is still less than the uncertainty associated with the clinker fraction. Under Tier 2, the major source of uncertainty is associated with determining the CaO content of clinker. If clinker data are available, the uncertainty of the emission factor is equal to the uncertainty of the CaO fraction and the assumption that it was all derived from $CaCO_3$ (Table 2.3). For Tier 3, there is relatively little uncertainty associated with the emission factors of the source carbonates because they are based on stoichiometric ratios. There may be some uncertainty associated with assuming, in Tier 3, that there is 100 percent calcination of carbonates in the CKD.

In general, CKD is the least characterised factor for estimating CO_2 emissions from cement production, regardless of the Tier implemented.

2.2.2.2 ACTIVITY DATA UNCERTAINTIES

Where clinker production data are estimated from cement production, the uncertainty of the activity data can be as high as about 35 percent. For Tier 2, the uncertainty in data on clinker production tonnages, when available, is about 1-2 percent. Collecting data from individual producers (if complete) rather than using national totals will reduce the uncertainty of the estimate because these data will account for variations in conditions at the plant level. This is particularly important for determining possible differences in clinker composition and irregularities in annual production (i.e. using clinker stockpiles instead of production to produce cement at various times). Except for CKD the greatest sources of uncertainty associated with Tier 3 are the uncertainties associated with identification of carbonate species (1-5 percent) and the weight of raw materials.

Although emissions are much smaller than from carbonates, there may be considerable uncertainty associated with estimating emissions from CKD in Tier 2 estimates, and also in Tier 3 if plants do not weigh the CKD that is not recycled to the kiln or if the plants lack CKD scrubbers. Where the weight and composition of CKD are unknown for a plant, the uncertainty will be higher. As an example, an attempt has been made to estimate the approximate uncertainties for different factors in Equations 2.1-2.5 and/or the steps in the manufacture of clinker and cement. The uncertainties are presented in Table 2.3 and are approximate component uncertainties - that is, they are those associated with a particular step or activity in clinker manufacturing. In order to quantify uncertainty for cement (clinker) production, the default uncertainties provided in Table 2.3 should be combined according to the guidance in Volume 1, Section 3.2.3. Where ranges are given for the uncertainty values, the mid-range should be used unless country-specific or plant-specific circumstances suggest that another value should be used.

TABLE 2.3
DEFAULT UNCERTAINTY VALUES FOR CEMENT PRODUCTION

Uncertainty[a]	Comment	Tier
Chemical Analysis/Composition		
2-7%	Assumption of 95% clinker factor in portland cement	1
1-2%	Chemical analysis of clinker to determine CaO	2
3-8%	Assumption of 65% CaO in clinker	2
1-3%	Assumption that 100% CaO is from $CaCO_3$ (uncertainty is higher if ash or slag feeds are used but not accounted for.)	2
1%	Assumption of 100% calcination of carbonate destined to become clinker	2, 3
1-3%	Kerogen (or other non-carbonate carbon) determination	3
1-3%	Overall chemical analysis pertaining to carbonate content (mass) & type	3
1-5%	Assumption that the carbonate species is 100% $CaCO_3$	3
Production Data		
1-2%	Reported (plant-level) cement production data	1
35%	Assumption that country output is 100% portland cement	1
10%	Use of estimated country (or aggregated plant) production data (national statistics).	1, 2
Variable	Use of reported but rounded weight data in cement or clinker (e.g., national-level reporting in large units); uncertainty is one unit in last significant digit shown)	1, 2
1-2%	Weighing or calculation of clinker production, assumes complete reporting	2
1-3%	Uncertainty of plant-level weighing of raw materials	3
CKD		
25-35%	Default assumption that emissions from CKD are 2% of process-related emissions from clinker production. Uncertainty assumes that 33-50% of clinker not recycled. If no recycling takes place or if the calcination percentage significantly exceeds 50%, uncertainty could be 50% or more	
1%	Assumption that original components in CKD are same as raw mix	2, 3
1%	Assumption that all carbonate (calcined or remaining) in CKD is $CaCO_3$	2, 3
10-35%	Estimation of % calcination of CKD	2, 3
20-80%	Assumption of 100% calcination of CKD	2, 3
up to 60%	Assumption of 50% calcination of CKD	2, 3
5%	Weighing of CKD captured by scrubbers	2, 3
1-3%	Weighing of scrubber-captured CKD returned to kiln	2, 3
5-10%	Weighing of scrubber-captured CKD not recycled to kiln (other disposal)	2, 3
10-15%	Estimation of weight of CKD automatically rerouted to kiln	2, 3
20-30%	Estimation of weight of CKD if none is recovered or scrubbed	2, 3
Imports/Exports		
10%	Trade data for clinker (if tariff codes are correctly isolated and cement is not included)	1
50% of import tonnage	Overestimation from failure to deduct for net clinker imports for consumption (this is because, per Equation 2.4, CO_2 is approximately one half the weight of clinker)	1

[a] Estimates are based on expert judgement.

2.2.3 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

2.2.3.1 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

In addition to the general guidance on QA/QC, specific procedures of relevance to this source category are outlined below.

COMPARISON OF EMISSIONS ESTIMATES USING DIFFERENT APPROACHES

Comparisons could be made between emissions estimated using different tiers. For example, if a bottom-up approach is used to collect activity data (i.e., collection of plant-specific data), then inventory compilers should compare the emissions estimates to the estimates calculated using national production data for cement or clinker (top-down approach). In cases where a hybrid Tier 1/2 or Tier 2/3 approach is used during a transition period, it is considered *good practice* also to estimate emissions for all facilities using the lower Tier in order to compare the results of the analysis to the results derived using the hybrid approach. The results of such comparisons should be recorded for internal documentation, including explanations for any discrepancies.

REVIEW OF EMISSION FACTORS

Inventory compilers should compare aggregated national emission factors with the IPCC default factors in order to determine if the national factor is reasonable relative to the IPCC default. Differences between national factors and default factors should be explained and documented, particularly if they are representative of different circumstances.

If the aggregated top-down approach is used, but some limited plant-specific data are available, inventory compilers should compare the site or plant level factors with the aggregated factor used for the national estimate. This will provide an indication of the reasonableness and the representativity of the data.

SITE-SPECIFIC ACTIVITY DATA CHECK

For site-specific data, inventory compilers should review inconsistencies between sites to establish whether they reflect errors, different measurement techniques, or result from real differences in emissions, operational conditions or technology. For cement production, inventory compilers should compare plant data (content of CaO in clinker, content of clinker in cement) with other plants in the country.

Inventory compilers should ensure that emission factors and activity data are developed in accordance with internationally recognised and proven measurement methods. If the measurement practices fail this criterion, then the use of these emissions or activity data should be carefully evaluated, uncertainty estimates reconsidered and qualifications documented. If there is a high standard of measurement and QA/QC in place at most sites, then the uncertainty of the emissions estimates may be revised downwards.

2.2.3.2 REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates. Specific documentation and reporting relevant to this source category follow.

TIER 1 METHOD

In addition to cement production data, the quantity of clinker imports and exports also should be reported. Any information regarding the CaO content of clinker should be documented, including use of default values different from those discussed in section 2.2.1.2.

TIER 2 METHOD

Tier 2 documentation should include a description of how clinker production was estimated by the reporting entity (i.e., directly weighed, weight determined by volume of clinker pile, calculated from raw material inputs, etc.) and at what level the activity data were collected (i.e., plant level or national level). The method (e.g., country specific or IPCC default) for determining the CaO content of clinker should be documented along with any plant-specific information regarding the quantity and type of non-carbonate feeds to the kiln, such as slags or fly ash. All procedures used to quantify and determine the degree of calcination of CKD should be documented. Where the assumption that emissions of CKD are equal to 2 percent of emissions from clinker production is made, this should be transparently reported.

TIER 3 METHOD

When documenting the Tier 3 method it is important to document all the procedures undertaken and methodologies used to identify the weight fraction and identities of all carbonates, including carbonates incorporated in any clay, shales, sandstone or other supplementary raw materials, consumed as raw materials, along with the corresponding emission factors.

Estimating total emissions from carbonate inputs can overestimate emissions if the carbonates are not fully calcined. Any corrections should be documented. This includes documenting the fraction calcination of the raw materials and the quantity and fraction calcination of the CKD.

It is likely that plants will find it impractical to undertake chemical analyses of all raw material inputs on a daily basis for the purpose of CO_2 calculations. Instead, a full investigation will take place at each facility on a number of occasions throughout the year to fully characterise the carbonate inputs. Facilities will likely develop a relationship between carbonate input and clinker production that will be applied to the plant's routine calculation of clinker output for intervening periods. In addition to identifying all procedures used to calculate emissions from the carbonate inputs, all steps necessary to identify the relationship between carbonate input and clinker production should be documented.

All underlying information should be documented and reported, it is not considered *good practice* to report just final emissions estimates.

2.3 LIME PRODUCTION

2.3.1 Methodological issues

Calcium oxide (CaO or quicklime) is formed by heating limestone to decompose the carbonates. This is usually done in shaft or rotary kilns at high temperatures and the process releases CO_2. Depending on the product requirements (e.g., metallurgy, pulp and paper, construction materials, effluent treatment, water softening, pH control, and soil stabilisation), primarily high calcium limestone (calcite) is utilized in accordance with the following reaction:

$$\boxed{CaCO_3 \text{ (high-purity limestone)} + \text{heat} \rightarrow CaO \text{ (quicklime)} + CO_2}$$

Dolomite and dolomitic (high magnesium) limestones may also be processed at high temperature to obtain dolomitic lime (and release CO_2) in accordance with the following reaction: $CaMg(CO_3)_2$ (dolomite) + heat → $CaO{\cdot}MgO$ (dolomitic lime) + $2CO_2$. At some facilities, hydrated (slaked) lime also is produced, using additional hydration operations.

The production of lime involves a series of steps, including the quarrying of raw materials, crushing and sizing, calcining the raw materials to produce lime, and (if required) hydrating the lime to calcium hydroxide.

The consumption of lime as a product may in some cases not result in net emissions of CO_2 to the atmosphere. The use of hydrated lime for water softening, for example, results in CO_2 reacting with lime to re-form calcium carbonate, resulting in no net emissions of CO_2 to the atmosphere. Similarly, precipitated calcium carbonate, which is used in the paper industry as well as for other industrial applications, is a product derived from reacting hydrated high-calcium quicklime with CO_2. During the process of sugar refining, lime is used to remove impurities from the raw cane juice; any excess lime can be removed through carbonation. Any recarbonation in these specific industries may be calculated and reported only where proven and validated methods are used to calculate the amount of CO_2 that reacts with lime to re-form calcium carbonate. Where these conditions are met, this may be reported under Category 2H, Other.

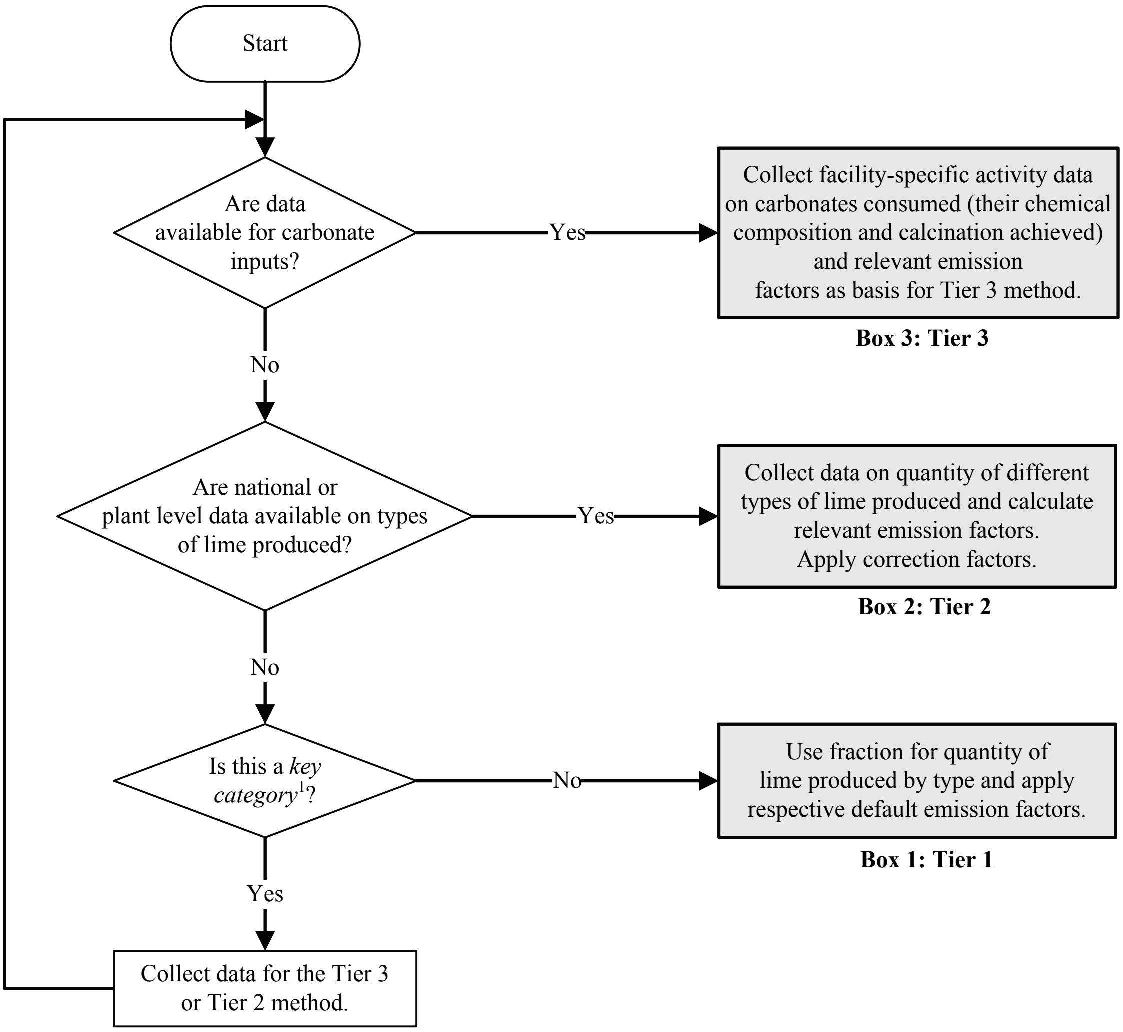
As discussed in Section 2.3.1.3, lime kiln dust (LKD) may be generated during the production of lime. Emission estimates developed using Tier 2 and Tier 3 should account for emissions associated with the LKD.

2.3.1.1 CHOICE OF METHOD

As is the case for emissions from cement production, there are three basic methodologies for estimating emissions from lime production: an output-based approach that uses default values (Tier 1), an output-based approach that estimates emissions from CaO and $CaO{\cdot}MgO$ production and country-specific information for correction factors (Tier 2) and an input-based carbonate approach (Tier 3). Unlike the Tier 3 method which requires a plant-specific assessment, the Tier 1 and Tier 2 methods can be applied either to national, or where possible, plant statistics. The choice of *good practice* method depends on national circumstances, as shown in Figure 2.2.

It is *good practice* to assess the available national statistics for completeness, and for the ratio of limestone to dolomite used in lime production. Some industries produce non-marketed lime reagents for their own processes (e.g., the iron and steel industry for use as a slagging agent). All lime production, whether produced as a marketed or a non-marketed product should be reported under IPCC Subcategory 2A2 Lime Production.

Figure 2.2 Decision tree for estimation of CO_2 emissions from lime production



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

TIER 1 METHOD

The Tier 1 method is based on applying a default emission factor to national level lime production data. While country-specific information on lime production by type (e.g., high calcium lime, dolomitic lime, or hydraulic lime) is not necessary for *good practice* in Tier 1, where data are available to identify the specific types of lime produced in the country, this may be used. It is not necessary for *good practice* to account for LKD in Tier 1.

TIER 2 METHOD

Where national level data are available on the types of lime produced, it is *good practice* to estimate emissions using Equation 2.6. The Tier 2 method requires country-specific information on the proportion of hydrated lime produced. Typical plant-level ratios of lime product to LKD production should be obtained.

EQUATION 2.6
TIER 2: EMISSIONS BASED ON NATIONAL LIME PRODUCTION DATA BY TYPE

$$CO_2\ Emissions = \sum_i (EF_{lime,i} \bullet M_{l,i} \bullet CF_{lkd,i} \bullet C_{h,i})$$

Where:

CO_2 Emissions = emissions of CO_2 from lime production, tonnes

$EF_{lime,i}$ = emission factor for lime of type *i*, tonnes CO_2/tonne lime (see Equation 2.9)

$M_{l,i}$ = lime production of type *i*, tonnes

$CF_{lkd,i}$ = correction factor for LKD for lime of type *i*, dimensionless
This correction can be accounted for in a similar way as for CKD (Equation 2.5, but omitting the factor (Ef_c/EF_{cl}))

$C_{h,i}$ = correction factor for hydrated lime of the type *i* of lime, dimensionless (See discussion under Section 2.3.1.3, Choice of Activity Data.)

i = each of the specific lime types listed in Table 2.4

TIER 3 METHOD

Tier 3 is based on the collection of plant-specific data on the type(s) and quantity(ies) of carbonate(s) consumed to produce lime, as well as the respective emission factor(s) of the carbonate(s) consumed. The Tier 3 method to estimate emissions from lime production is similar to Equation 2.3 for cement production, except there is a correction for LKD, as opposed to CKD and there is no need to correct for emissions from carbon-bearing non-fuel materials. Unlike the case with CKD and cement kilns, LKD is seldom recycled to the lime kiln (but LKD can be used as a feed to a cement kiln). For purposes of estimating emissions in Equation 2.7 it is assumed that no LKD is recycled to the kiln.

EQUATION 2.7
TIER 3: EMISSIONS BASED ON CARBONATE INPUTS

$$CO_2\ Emissions = \sum_i (EF_i \bullet M_i \bullet F_i) - M_d \bullet C_d \bullet (1 - F_d) \bullet EF_d$$

Where:

CO_2 Emissions = emissions of CO_2 from lime production, tonnes

EF_i = emission factor for carbonate *i*, tonnes CO_2/tonne carbonate (see Table 2.1)

M_i = weight or mass of carbonate i consumed, tonnes

F_i = fraction calcination achieved for carbonate *i*, fraction[a]

M_d = weight or mass of LKD, tonnes

C_d = weight fraction of original carbonate in the LKD, fraction[a]. This factor can be accounted for in a similar way as CKD.

F_d = fraction calcination achieved for LKD, fraction[a]

EF_d = emission factor for the uncalcined carbonate in LKD, tonnes CO_2/tonne carbonate[b]

Notes on defaults for Equation 2.7

a: Calcination fractions: In the absence of actual data, it is consistent with *good practice* to assume that the degree of calcination achieved is 100 percent (i.e., F_i = 1.00) or very close to it. For LKD, a F_d of <1.00 is more likely but the data may show high variability and relatively low reliability. In the absence of reliable data for LKD, an assumption of F_d = 1.00 will zero out the subtraction correction for uncalcined carbonate remaining in LKD.

b: Because calcium carbonate is overwhelmingly the dominant carbonate in the raw materials, in the absence of better data it may be assumed that it makes up 100 percent of the carbonate remaining in the LKD. It is thus consistent with *good practice* to set C_d equal to the calcium carbonate ratio in the raw material feed to the kiln. Likewise, in the absence of better data it is consistent with *good practice* to use the emission factor for calcium carbonate for EF_d.

2.3.1.2 CHOICE OF EMISSION FACTORS

TIER 1 METHOD

Tier 1 is an output-based method and applies an emission factor to the total quantity of lime produced. The emission factor is based on the stoichiometric ratios illustrated in Table 2.4, which vary depending on the type of lime produced. The stoichiometric ratio is the amount of CO_2 released by the carbonate precursor to the lime, assuming that the degree of calcination was 100 percent and assuming no LKD. For example, 1 tonne of CaO requires the calcination of 1.785 tonnes of $CaCO_3$ and this releases 0.785 tonne CO_2 if fully calcined.

In the absence of country specific data, it is *good practice* to assume 85 percent production of high calcium lime and 15 percent production of dolomitic lime (Miller, 1999). Based on this, Equation 2.8 illustrates how to calculate the Tier 1 emission factor for lime production.

EQUATION 2.8
TIER 1 DEFAULT EMISSION FACTOR FOR LIME PRODUCTION

$$\begin{aligned} EF_{Lime} &= 0.85 \bullet EF_{high\ calcium\ lime} + 0.15 \bullet EF_{dolomitic\ lime} \\ &= 0.85 \bullet 0.75 + 0.15 \bullet 0.77^{a} \\ &= 0.6375 + 0.1155 \\ &= 0.75 \text{tonnes } CO_2 \text{ / tonne lime produced} \end{aligned}$$

Notes on defaults in Equation 2.8

a: The default EF for dolomitic lime may be 0.86 or 0.77 depending on the technology used for lime production. See Table 2.4.

TABLE 2.4
BASIC PARAMETERS FOR THE CALCULATION OF EMISSION FACTORS FOR LIME PRODUCTION

Lime Type	Stoichiometric Ratio [tonnes CO_2 per tonne CaO or CaO·MgO] (1)	Range of CaO Content [%]	Range of MgO Content[d] [%]	Default Value for CaO or CaO·MgO Content [fraction] (2)	Default Emission Factor [tonnes CO_2 per tonne lime] (1) • (2)
High-calcium lime[a]	0.785	93-98	0.3-2.5	0.95	0.75
Dolomitic lime[b]	0.913	55-57	38-41	0.95 or 0.85[c]	0.86 or 0.77[c]
Hydraulic lime[b]	0.785	65-92[e]	NA	0.75[e]	0.59

Source:

[a] Miller (1999b) based on ASTM (1996) and Schwarzkopf (1995).

[b] Miller (1999a) based on Boynton (1980).

[c] This value depends on technology used for lime production. The higher value is suggested for developed countries, the lower for developing ones.

[d] There is no exact chemical formula for each type of lime because the chemistry of the lime product is determined by the chemistry of the limestone or dolomite used to manufacture the lime.

[e] Total CaO content (including that in silicate phases).

TIER 2 METHOD

Similar to Tier 1, the emission factor for lime production in Tier 2 reflects the stoichiometric ratios between CO_2 and CaO and/or CaO·MgO, and an adjustment to account for the CaO or the CaO·MgO content of the lime. However, unlike Tier 1, Tier 2 requires the use of national level data on lime production by type. It is *good practice* to apply Equation 2.9 to develop the emission factors and to account for the CaO or the CaO·MgO content.

EQUATION 2.9
TIER 2 EMISSION FACTORS FOR LIME PRODUCTION

$$EF_{lime,a} = SR_{CaO} \bullet CaO\ Content$$

$$EF_{lime,b} = SR_{CaO \cdot MgO} \bullet CaO \cdot MgO\ Content$$

$$EF_{lime,c} = SR_{CaO} \bullet CaO\ Content$$

Where:

$EF_{lime\ a}$ = emission factor for quicklime (high-calcium lime), tonnes CO_2/tonne lime

$EF_{lime\ b}$ = emission factor for dolomitic lime, tonnes CO_2/tonne lime

$EF_{lime\ c}$ = emission factor for hydraulic lime, tonnes CO_2/tonne lime

SR_{CaO} = stoichiometric ratio of CO_2 and CaO (see Table 2.4), tonnes CO_2/tonne CaO

$SR_{CaO \cdot MgO}$ = stoichiometric ratio of CO_2 and CaO·MgO (see Table 2.4), tonnes CO_2/tonne CaO·MgO

CaO Content = CaO content (see Table 2.4), tonnes CaO/tonne lime

CaO·MgO Content = CaO·MgO content (see Table 2.4), tonnes CaO·MgO/tonne lime

TIER 3 METHOD

The Tier 3 emission factors are based on the actual carbonates present. (See Equation 2.7 and Table 2.1.) Tier 3 requires the full accounting of carbonates (species and sources) and may include a correction (i.e., subtraction) for uncalcined lime kiln dust.

2.3.1.3 CHOICE OF ACTIVITY DATA

Some industries produce lime and consume it for their operations. This quantity of lime may never be introduced into the market. It is important when collecting activity data for lime production that both marketed and non-marketed lime production are included. In many countries, obtaining statistics on non-marketed lime production may be challenging. It is suggested that inventory compilers identify potential industries where non-marketed lime may be produced (e.g., metallurgy, pulp and paper, sugar refining, precipitated calcium carbonate, water softeners) and inquire whether there is such production. As industries and countries may vary significantly with respect to the quantities of non-marketed lime produced, it is not possible to provide a default value to estimate this activity data.

TIER 1 METHOD

In Tier 1, inventory compilers may use default values for either of the following variables: (1) the types of lime produced and/or (2) the proportion of hydrated lime produced. Table 2.4, provides data on stoichiometric ratios, the ranges of CaO and CaO·MgO contents and the resulting default emission factors, for the main lime types produced. Where there are no disaggregated data for the breakdown of lime types, it is *good practice* to assume that 85 percent is high-calcium lime and 15 percent dolomitic lime (Miller, 1999) and the proportion of hydraulic lime should be assumed zero unless other information is available.

The Tier 1 method for lime production does not incorporate a correction for LKD. The potential exists to exclude some lime sources in the national inventory due to problems with the activity data (see Sections 2.3.1.4 and 2.3.2.2). The Tier 1 method could considerably underestimate emissions if these issues are not carefully considered.

TIER 2 METHOD

In implementing the Tier 2 method, it is important to collect disaggregated data for the three types of lime, as this will improve the emissions estimate. There are three main types of non-hydrated lime:

- High-calcium lime (CaO + impurities);
- Dolomitic lime (CaO·MgO + impurities);
- Hydraulic lime (CaO + hydraulic calcium silicates) that is a substance between lime and cement.

The main reason to distinguish these types is that the first two have different emission factors. It is also important to correct for the proportion of hydrated lime in production. Similar to the Tier 2 method for cement production, data should be collected on all non-carbonate sources of CaO (if applicable).

Significant amounts of LKD may be produced as a by-product during lime production. The quantities generated depend on the type of kiln used and the characteristics of the carbonates used. According to Boynton (1980) an average rotary kiln will yield a dust attrition loss of 9 to 10 percent per tonne of lime produced, or 16 to 18 percent of the raw material input. The chemical composition of the LKD varies depending on the raw material input, but a typical high-calcium lime LKD may contain 75 percent combined calcium oxide and uncalcined calcium carbonate (at roughly a 50:50 ratio), with the remaining impurities consisting of silica, aluminum and iron oxides, and sulphur (depending on the fuel used). Correction for LKD in the Tier 2 and Tier 3 methods is analogous to CKD in cement production in both methodology and default value. If possible, data should be collected on typical ratios of LKD to lime production and on the typical composition of the LKD. In the absence of data, the inventory compiler may assume a correction addition of 2 percent to account for LKD (i.e., multiply emissions by 1.02).

Vertical shaft kilns generate relatively small amounts of LKD, and it is judged that a correction factor for LKD from vertical shaft kilns would be negligible and do not need to be estimated.

TIER 3 METHOD

It is *good practice* to collect plant specific data for the weight fraction of carbonate(s) consumed for lime production and the fraction of calcination achieved. Data should also be collected for the amount (dry weight) and composition of LKD produced. Similar to the Tier 3 method for cement production, emissions from LKD should be subtracted from the Tier 3 estimates.

A couple of key issues should be considered when estimating carbonate consumption data. Data must be available and collected on the plant level, as national level statistics on carbonate consumption for lime production may not be complete. Similar to cement production, although limestone and or dolomite are likely to be the predominant carbonates, it is important to ensure that all carbonate inputs are identified and accounted for.

CORRECTION FOR THE PROPORTION OF HYDRATED LIME

Both high-calcium and dolomitic limes can be slaked and converted to hydrated lime that is $Ca(OH)_2$ or $Ca(OH)_2 \cdot Mg(OH)_2$. It is *good practice* to include a correction for hydrated lime under Tier 2, and where data are available, under Tier 1. If no data are available for Tier 1, it is *good practice* to assume zero production of hydrated lime.

If x is the proportion of hydrated lime and y is the water content in it, it is *good practice* to multiply the production by a correction factor $1 - (x \cdot y)$. Since the vast majority of hydrated lime produced is high-calcium (90 percent), the default values are $x=0.10$ and $y = 0.28$ (default water content), resulting in a correction factor of 0.97. This default correction factor for hydrated lime may be included in Equation 2.6.

2.3.1.4 COMPLETENESS

Complete activity data (i.e., lime production) are needed for *good practice*. Typically, reported production accounts for only a portion of the actual production, because lime production statistics may consider only product that is sold on the market. Use or production of lime as a non-marketed intermediate is not well accounted for or reported. For example, many plants that produce steel, synthetic soda ash, calcium carbide, magnesia and magnesium metal, as well as copper smelters and sugar mills, produce lime but may not report it to national agencies. Omission of these data may lead to an underestimation of lime production for a country by a factor of two or more. Likewise, there may be village-scale or artisanal production of lime for sanitation purposes or for whitewash. All lime production should be reported in this source category, whether produced by lime kilns as a marketed product, or whether produced as a non-marketed intermediate reagent.

Inventory compilers should be cautious to avoid double counting, or omissions, between this source category and emissions from limestone and dolomite consumption. Another potential source of double counting that the inventory compiler should be aware of is associated with hydrated lime. If lime production is corrected for hydrated lime without first establishing whether the lime used to produce hydrated lime is included in total lime production, production of this lime could be double-counted.

Similar to the discussion for cement, when using Tier 3 it is important that all carbonate inputs (e.g., limestone, dolomite, etc.) are accounted for on a plant-specific basis.

Finally, lime-based mortars used in construction gain their strength through the absorption of CO_2, but the rates of the carbonation reaction that occur in practice are very uncertain. As it is believed that this process for the carbonation of mortars can take months to decades, it has not been factored into emission calculations. It is not considered *good practice* to include this factor in emissions calculations at this time. This is an area for future work before inclusion into national inventories.

2.3.1.5 DEVELOPING A CONSISTENT TIME SERIES

It is *good practice* to calculate emissions from lime production using the same method for every year in the time series. These *Guidelines* introduce a new Tier 3 approach based on carbonate input to lime production. These data may or may not be available historically. If the inventory compiler chooses to implement this Tier for current and future inventories they are encouraged to collect this data for historical years to ensure time series consistency. Where these data are not available, the inventory compiler may refer to the 'Overlap approach' (see Volume 1, Section 5.3) to attempt to recalculate previous estimates.

Where data are not available, inventory compilers moving from a Tier 1 to a Tier 2 approach may assume that there has not been a significant shift in the country from use of one carbonate input to another for lime production. This is likely a reasonable assumption, specifically since limestone typically is the predominant carbonate input.

Inventory compilers should disaggregate lime production data into the three mentioned types: high calcium lime, dolomitic lime, and hydraulic lime. Where country specific data are not available for the entire time series for the proportion of lime consumed, or the proportion of hydrated lime, missing years may be estimated by the Interpolation or Trend Extrapolation Approaches as outlined in Volume 1, Section 5.3, or by assuming that the current year is reflective of the proportion of lime produced in earlier years of the time series.

2.3.2 Uncertainty assessment

Uncertainty estimates for lime production result predominantly from uncertainties associated with activity data, and to a lesser extent from uncertainty related to the emission factor. For more information, refer to the uncertainty discussion above for cement production.

TABLE 2.5
DEFAULT UNCERTAINTY VALUES FOR ESTIMATION OF CO_2 EMISSIONS FROM LIME PRODUCTION

Uncertainty	Comment	Tier
4-8%	Uncertainty in assuming an average CaO in lime	1, 2
2%	Emission factor high calcium lime	1, 2
2%	Emission factor dolomitic lime	1, 2
15%	Emission factor hydraulic lime	1, 2
5%	Correction for hydrated lime	1, 2
	Order of magnitude errors possible if non-marketed lime production is not estimated	1, 2, 3
1-2%	Uncertainty of plant-level lime production data. Plants generally do not determine output better than this. Assumes complete reporting.	2
See Table 2.3	Correction for LKD	2, 3
1-3%	Error in assuming 100% carbonate source from limestone (vs. other feeds).	3
1-3%	Uncertainty of plant-level weighing of raw materials	3

Source: Based on expert judgment.

2.3.2.1 EMISSION FACTOR UNCERTAINTIES

As outlined above for cement, there is little uncertainty associated with the emission factor component in the Tier 3 approach. In Tier 2 and Tier 1, the stoichiometric ratio is an exact number and therefore the uncertainty of the emission factor is the uncertainty of lime composition, in particular of the share of hydraulic lime (the uncertainty of the emission factor for hydraulic lime is 15 percent and the uncertainty for other lime types is 2 percent). There is uncertainty associated with determining the CaO content and/or the CaO•MgO content of the lime produced.

2.3.2.2 ACTIVITY DATA UNCERTAINTIES

The uncertainty for the activity data is likely to be much higher than for the emission factors, based on experience in gathering lime data (see Section 2.3.1.4, Completeness, above). Omission of non-marketed lime production may lead to order of magnitude underestimates. The correction for hydrated lime typically leads to additional uncertainty.

As described above for CKD, there is significant uncertainty associated with quantifying the mass of LKD produced and the degree of calcination (and thus emissions) of LKD. It can be assumed that the uncertainty associated with estimating LKD is at least equal to and likely greater than, the uncertainty associated with CKD.

Where ranges are given for the default uncertainties in Table 2.5, the mid-range should be used unless the upper or lower estimates are more reflective of country-specific circumstances.

2.3.3 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

2.3.3.1 QUALITY ASSURANCE/QUALITY CONTROL (QA /QC)

In addition to the cross-cutting guidance on QA/QC, specific procedures of relevance to this source category are outlined below.

COMPARISON OF THE EMISSIONS ESTIMATES USING DIFFERENT APPROACHES

Comparisons could be made between emissions estimated following the Tier 2 approach based on lime production and Tier 3 approach based on carbonate input. Similarly, if the bottom-up approach is used to estimate emissions (i.e., collection of plant specific data), then inventory compilers should compare the emissions estimates to the estimate calculated using national or plant-specific lime production data (top-down approach). In cases where a hybrid Tier 1/2 or Tier 2/3 approach is used during a transition period, it is considered *good practice* also to estimate emissions for all facilities using the lower Tier in order to compare the results of the analysis to the results derived using the hybrid approach. The results of such comparisons should be recorded for internal documentation, including explanations for any discrepancies.

ACTIVITY DATA CHECK

Inventory compilers should confirm the correct definitions of the different types of lime produced in the country. Inventory compilers should also carefully consider industries that may produce non-marketed lime to ensure that these data have been included in the activity data for the inventory.

2.3.3.2 REPORTING AND DOCUMENTATION

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates. Below are general notes that apply to reporting and documentation of emissions and emission reductions from lime production followed by specific information to be reported for the individual tiers.

- If an inventory compiler is reporting on CO_2 recovery from sugar refining, precipitated calcium carbonate or water softening under Category 2H, detailed information should be reported on the methods used for calculating emissions recovered. Both emissions and emission reductions should be reported separately; it is not considered *good practice* to report only net emissions from lime production. In addition, documentation should be provided to illustrate that emission reductions from recarbonation are only reported in the year in which recarbonation occurs (see 2.3.1 above).

- Regardless of the method implemented, inventory compilers should document procedures undertaken to ensure that both marketed and non-marketed lime production are reported (see discussion in Section 2.3.1.4, Completeness).

TIER 1 METHOD

The Tier 1 approach is methodologically the same as Tier 2 except that default values may be used instead of country-specific information to estimate the various parameters. Documentation for Tier 1, therefore, follows Tier 2 below except a clear indication should be made as to where default values are used.

TIER 2 METHOD

Tier 2 documentation should include a discussion of the types of lime produced in the country (including hydrated lime) and how that determination was made (collection of sales data, collection of plant specific consumption data, etc.) The procedures used to identify the CaO and/or CaO·MgO content of lime, as well as non-carbonate feeds to lime kiln also should be reported.

TIER 3 METHOD

Reporting and documentation for Tier 3 for lime production is the same as the Tier 3 method outlined above for cement production, with one minor difference. Instead of collecting information on CKD, data on the quantity and fraction of calcination achieved of LKD should be collected. All underlying information should be documented and reported, it is not considered *good practice* to report just final emissions estimates.

2.4 GLASS PRODUCTION

2.4.1 Methodological issues

Many kinds of glass articles and compositions are used commercially, but the glass industry can be divided into four main categories: containers, flat (window) glass, fibre glass, and specialty glass.

The great bulk of commercial glass is in the first two categories, and is almost entirely soda-lime glass, consisting of silica (SiO_2), soda (Na_2O), and lime (CaO), with small amounts of alumina (Al_2O_3), and other alkalies and alkaline earths, plus some minor ingredients. Insulation grade fibre glass - a major component of the third category - is similar in composition. Individual manufacturers will have proprietary compositions, but these will be minor variations on the basic composition.

This source category also includes emissions from the production of glass wool, a category of mineral wool, where the production process is similar to glass making. The term mineral wool may also be used to refer to natural rock- and slag-based wool. Where the production of rock wool is emissive these emissions should be reported under IPCC Subcategory 2A5. Emissions related to slag production should be reported in the relevant metallurgical source category. The re-melting of slag to make mineral wool does not involve significant process--related emissions and does not need to be reported.

The major glass raw materials which emit CO_2 during the melting process are limestone ($CaCO_3$), dolomite $Ca,Mg(CO_3)_2$ and soda ash (Na_2CO_3). Where these materials are mined as carbonate minerals for their use in the glass industry they represent primary CO_2 production and should be included in emissions estimates. Where carbonate materials are produced through the carbonation of a hydroxide they do not result in net CO_2 emissions and should not be included in the emissions estimate. Minor CO_2-emitting glass raw materials are barium carbonate ($BaCO_3$), bone ash ($3CaO_2P_2O_5 + XCaCO_3$), potassium carbonate (K_2CO_3) and strontium carbonate ($SrCO_3$). Additionally, powdered anthracite coal or some other organic material may be added to create reducing conditions in the molten glass, and will combine with available oxygen in the glass melt to produce CO_2.

The action of these carbonates in the fusion of glass is a complex high-temperature chemical reaction, and is not to be directly compared to the calcination of carbonates to produce quicklime or burnt dolomitic lime. Nevertheless, this fusion (in the region of 1500°C) has the same net effect in terms of CO_2 emissions.

In practice, glass makers do not produce glass only from raw materials, but use a certain amount of recycled scrap glass (cullet). Most operations will use as much cullet as they can obtain, sometimes with restrictions for glass quality requirements. The cullet ratio (the fraction of the furnace charge represented by cullet) will be in the range of 0.4 to 0.6 for container applications, which are the bulk of glass production. Insulation fibre glass makers will generally fall below this level, but will use as much cullet as they can purchase.

Cullet comes from two sources: in-house return of glassware broken in process or other glass spillage or retention, and foreign (i.e., external to the plant) cullet from recycling programs or cullet brokerage services. This second source is important in developed economies, but will be less so in developing countries, where recovery of glassware is not popular.

The retention of dissolved CO_2 in glass is determined to be relatively insignificant and can be ignored for the purposes of GHG emission estimation.

2.4.1.1 CHOICE OF METHOD

TIER 1 METHOD

The Tier 1 method should be used (Equation 2.10) where data are not available on glass manufactured by process or the carbonates used in glass manufacturing. Tier 1 applies a default emission factor and cullet ratio to national-level glass production statistics. The uncertainty associated with this method may be considerably higher than the uncertainty associated with the Tier 2 and Tier 3 methods.

EQUATION 2.10
TIER 1: EMISSIONS BASED ON GLASS PRODUCTION

$$CO_2\ Emissions = M_g \bullet EF \bullet (1 - CR)$$

Where:

CO_2 Emissions = emissions of CO_2 from glass production, tonnes

M_g = mass of glass produced, tonnes

EF = default emission factor for manufacturing of glass, tonnes CO_2/tonne glass

CR = cullet ratio for process (either national average or default), fraction

TIER 2 METHOD

Tier 2 is a refinement of Tier 1. Instead of collecting national statistics on total glass production, emissions are estimated based on the different glass manufacturing processes undertaken in the country. As discussed below, different glass manufacturing processes (e.g., float glass, container glass, fibre glass, etc) typically use different types and ratios of raw materials. The Tier 2 method applies default emission factors to each glass manufacturing process. The emission estimate must, however, be corrected for the fact that a portion of recycled glass (cullet) may also be supplied to the furnace (Equation 2.11).

EQUATION 2.11
TIER 2: EMISSIONS BASED ON GLASS MANUFACTURING PROCESS

$$CO_2\ Emissions = \sum_i [M_{g,i} \bullet EF_i \bullet (1 - CR_i)]$$

Where:

CO_2 Emissions = emissions of CO_2 from glass production, tonnes

$M_{g,i}$ = mass of melted glass of type *i* (e.g., float, container, fibre glass, etc.), tonnes

EF_i = emission factor for manufacturing of glass of type *i*, tonnes CO_2/tonne glass melted

CR_i = cullet ratio for manufacturing of glass of type *i*, fraction

TIER 3 METHOD

The Tier 3 methodology is based on accounting for the carbonate input to the glass melting furnace (Equation 2.12).

EQUATION 2.12
TIER 3: EMISSIONS BASED ON CARBONATE INPUTS

$$CO_2\ Emissions = \sum_i (M_i \bullet EF_i \bullet F_i)$$

Where:

CO_2 Emissions = emissions of CO_2 from glass production, tonnes

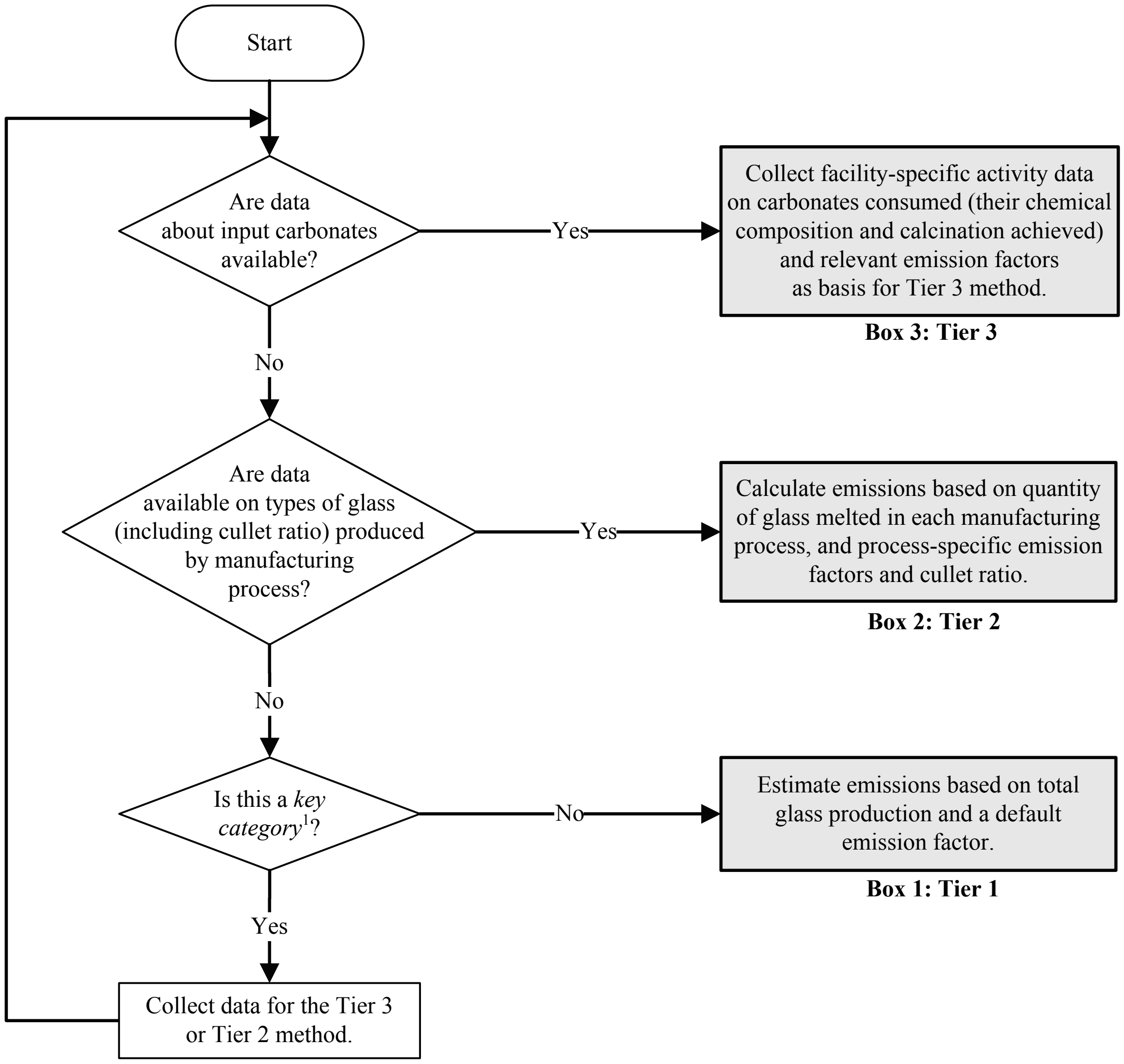
EF_i = emissions factor for the particular carbonate *i*, tonnes CO_2/tonne carbonate (see Table 2.1)

M_i = weight or mass of the carbonate *i* consumed (mined), tonnes

F_i = fraction calcination achieved for the carbonate *i*, fraction

Where the fraction calcination achieved for the particulate carbonate is not known, it can be assumed that the fraction calcination is equal to 1.00.

Figure 2.3 Decision tree for estimation of CO_2 emissions from glass production



Note:

1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

2.4.1.2 CHOICE OF EMISSION FACTORS

TIER 1 METHOD

Tier 1 applies a default emission factor, based on a ‘typical’ raw material mixture, to national glass production data. A ‘typical’ soda-lime batch might consist of sand (56.2 weight percent), feldspar (5.3 percent), dolomite (9.8 percent), limestone (8.6 percent) and soda ash (20.0 percent). Based on this composition, one metric tonne of raw materials yields approximately 0.84 tonnes of glass, losing about 16.7 percent of its weight as volatiles, in this case virtually entirely CO_2.

EQUATION 2.13
TIER 1 DEFAULT EMISSION FACTOR FOR GLASS PRODUCTION

$$EF = 0.167 / 0.84 = 0.20 \text{ tonnes } CO_2 \text{ / tonne glass}$$

TIER 2 METHOD

The Tier 2 method relies on applying default emission factors and cullet ratios to the various types of glass produced in the country (Table 2.6). Where country specific or even plant specific data are available countries are encouraged to use these data to supplement or replace the defaults provided below. Cullet ratios, in particular, can vary significantly both within a country and across countries.

It is *good practice* to use the mid-point values of the ranges provided unless some other value in the range is known to be more representative of country specific circumstances.

TABLE 2.6
DEFAULT EMISSION FACTORS AND CULLET RATIOS FOR DIFFERENT GLASS TYPES

Glass Type	CO_2 Emission Factor (kg CO_2/kg glass)	Cullet Ratio (Typical Range)
Float	0.21	10% - 25%
Container (Flint)	0.21	30% - 60%
Container (Amber/Green)	0.21	30% - 80%
Fiberglass (E-glass)	0.19	0% - 15%
Fiberglass (Insulation)	0.25	10% - 50%
Specialty (TV Panel)	0.18	20% - 75%
Specialty (TV Funnel)	0.13	20% - 70%
Specialty (Tableware)	0.10	20% - 60%
Specialty (Lab/Pharma)	0.03	30% - 75%
Specialty (Lighting)	0.20	40% - 70%

Source: Communication with Victor Aume (2004)

TIER 3 METHOD

The Tier 3 emission factors are based on the actual carbonates consumed in the melting furnace (for the relevant stoichiometric ratios see Table 2.1). The Tier 3 approach requires the full accounting of carbonates (species and sources).

2.4.1.3 CHOICE OF ACTIVITY DATA

TIER 1 METHOD

Activity data for the Tier 1 method includes national statistics for glass production by weight as well a correction for the quantity of cullet used in glass production. Tier 1 assumes a default cullet ratio of 50 percent, therefore national level data on the mass of glass produced can be multiplied by 0.20 • (1 - 0.50) = 0.10 tonnes CO_2/tonne glass in order to estimate national emissions. If country specific information is available for the average annual cullet ratio, countries are encouraged to modify the emission factor accordingly [i.e., EF = 0.20 • (1 - country-specific cullet ratio)].

TIER 2 METHOD

The Tier 2 method requires, at a minimum, the collection of national level data on the quantity of glass melted by manufacturing process. Data for glass often is provided in different units (e.g., tonnes of glass, number of bottles, square meters of glass, etc.) and these should be converted into tonnes. Where possible, data should be collected on a plant-specific basis and aggregated to the national level. Although the Tier 2 method provides default factors for the cullet ratio, if country-specific or plant-specific data are available countries are encouraged to collect these data.

TIER 3 METHOD

For the Tier 3 method plant-level activity data should be collected on the various types of carbonates consumed for glass production.

2.4.1.4 COMPLETENESS

Inventory compilers should consider a number of issues regarding completeness when compiling emission estimates for glass production. First of all, glass is produced from a variety of raw material carbonates. Where emissions are estimated based on carbonate inputs (Tier 3), it is important to ensure that all species and sources of carbonates are included in emission estimates.

Soda ash is a significant input into glass manufacturing in many countries. Inventory compilers are encouraged to ensure that there is no double counting of emissions from soda ash used in glass manufacturing (which should be reported under Category 2A3, Glass Production) and emissions from ‘Other Uses of Soda Ash’, which should be reported separately below. It is important to consider, however, that there may be a number of smaller facilities (e.g., art glass and specialty glass) that are not accounted for in national statistics. Efforts should be made to ensure complete coverage of the industry.

2.4.1.5 DEVELOPING A CONSISTENT TIME SERIES

Glass can be a difficult source for which to acquire activity data because, as noted above, glass production is measured in a variety of units. In order to develop a consistent time series, it is important that the same data sources are used for all years in the Inventory. For additional information for ensuring time series consistency, see Volume 1, Chapter 5.

2.4.2 Uncertainty assessment

2.4.2.1 EMISSION FACTOR UNCERTAINTIES

Similar to cement and lime, where emissions from glass production are estimated based on the carbonate input (Tier 3), the emission factor uncertainty (1-3 percent) is relatively low because the emission factor is based on a stoichiometric ratio. There may be some uncertainty associated with assuming that there is 100 percent calcination of the carbonate input (1 percent).

Because emissions are estimated based on quantity of melted glass in each manufacturing process and default emission factors, the uncertainty of Tier 2 is higher than Tier 3. The emission factors can be expected to have an uncertainty of +/- 10 percent. As illustrated in Table 2.6, the typical range for the cullet ratio varies among different glass types. For the purposes of uncertainty analysis it can be assumed that the ‘typical range’ reflects the 95 percent confidence interval.

Uncertainty associated with use of the Tier 1 emission factor and cullet ratio is significantly higher, and may be on the order of +/- 60 percent.

2.4.2.2 ACTIVITY DATA UNCERTAINTIES

As with cement and lime production, the uncertainty associated with weighing or proportioning raw materials under the Tier 3 approach is approximately 1-3 percent. While it is possible that some carbonate containing raw materials may be brought into the facility but lost as dust (i.e., never calcined) this amount is assumed negligible.

Glass production data are typically measured fairly accurately (+/-5 percent) for Tier 1 and Tier 2. As mentioned above, inventory compilers should be cautious where activity data are not originally available in mass, but rather as a unit (e.g., bottle) or area (e.g., m^2). If activity data have to be converted to mass, this may result in additional uncertainty.

2.4.3 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

2.4.3.1 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

If emissions are estimated using a Tier 3 approach these could be compared with the results using a Tier 2 approach to see if the results are of a similar order of magnitude. Similarly, if emissions were estimated from top down data using the Tier 2 method, these results could be compared with a more rigorous Tier 3 approach at a small number of facilities to see if the Tier 2 defaults used reflect national circumstances. The Tier 2 method relies on estimating emissions based on the different types of glass produced. These estimates could be compared with the results of an audit of the various suppliers of raw materials to the glass industry. For example, national estimates could be compared with estimates of the amount of limestone, soda ash and other carbonates that are sold to the glass industry. Such trade data could be elicited from individual suppliers, or from trade associations.

One of the largest sources of uncertainty in the emissions estimate (Tier 1 and Tier 2) for glass production is the cullet ratio. The amount of recycled glass used can vary across facilities in a country and in the same facility over time. The cullet ratio might be a good candidate for more in-depth investigation.

2.4.3.2 REPORTING AND DOCUMENTATION

TIER 1

For Tier 1, data should be documented and reported to indicate the total quantity of glass produced, and the emission factor applied to estimate emissions (including whether a default or country-specific cullet ratio is used). The process for collecting activity data should be documented (i.e., plant level or national estimates) as should any calculations made to convert glass production to a common unit (e.g., kg).

TIER 2

Tier 2 documentation should include the quantity of glass melted in each manufacturing process outlined in Table 2.6, including any calculation necessary to convert different types of glass into the same units (e.g., convert bottles into kilogram). Emission factors by glass type and cullet ratio should be reported, indicating if defaults are used, and whether data were collected on the plant level or at the national level. It is also useful to report whether cullet was internally generated at the facility or is post-consumer cullet (i.e., purchased cullet). This information may be important for identifying, or verifying, mitigation activities that are based on recycling.

TIER 3

The inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be reproduced. Where the Tier 3 method is implemented, inventory compilers should document the species of carbonates consumed and indicate how they ensure that all carbonate inputs are accounted for (see discussion for Tier 3 in Section 2.2.3.2).

2.5 OTHER PROCESS USES OF CARBONATES

2.5.1 Methodological issues

Limestone ($CaCO_3$), dolomite ($CaMg.(CO_3)_2$) and other carbonates (e.g., $MgCO_3$ and $FeCO_3$) are basic raw materials having commercial applications in a number of industries. In addition to those industries already discussed individually (cement production, lime production and glass production), carbonates also are consumed in metallurgy (e.g., iron and steel), agriculture, construction and environmental pollution control (e.g., flue gas desulphurisation.). As noted in the introduction of this chapter, the calcination of carbonates at high temperatures yields CO_2 (Table 2.1). It should be noted that some uses of carbonates, for example, the use of limestone as an aggregate, do not result in the release of CO_2 and, therefore, do not need to be included in the national GHG inventory (see Table 2.7).

The following discussion provides the general methodologies for estimating CO_2 emissions from the use of carbonates within the mineral industry. These methodologies, however, also are applicable where carbonates are used as fluxes or slagging agents in other source categories. Inventory compilers are suggested, in particular, to consider four broad source categories: (1) ceramics, (2) other uses of soda ash, (3) non-metallurgical magnesia production, and (4) other uses of carbonates.

It is *good practice* to report emissions from the consumption of carbonates in the source category where the carbonates are consumed and the CO_2 emitted. So, where limestone is used for the liming of soils, emissions should be reported in the respective source category of the Agriculture, Forestry and Other Land Use (AFOLU) Sector. Where carbonates are used as fluxes or slagging agents (e.g., in iron and steel, chemicals, or for environmental pollution control etc.) emissions should be reported in the respective source categories where the carbonate is consumed. As discussed in Section 2.3.1.1 above, all marketed and non-marketed production of lime should be reported under Lime Production. The specific source categories discussed below (ceramics, other soda ash use and non-metallurgical magnesia production) should be reported within the minerals category. The Other source category should contain estimates of emissions that do not fit into any of the major categories presented in Table 2.7 below.

CERAMICS

Ceramics include the production of bricks and roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware (household ceramics), sanitary ware, technical ceramics, and inorganic bonded abrasives. Process-related emissions from ceramics result from the calcination of carbonates in the clay, as well as the addition of additives. Similar to the cement and lime production processes, carbonates are heated to high temperatures in a kiln, producing oxides and CO_2. Most ceramic products are made from one or more different types of clay (e.g., shales, fire clay and ball clay). The raw materials are collected and finely crushed in successive grinding operations. The ground particles are then fired in a kiln to produce a powder (which may be liquefied). Additives are subsequently added and the ceramic is formed or moulded and 'machined' to smooth rough edges and achieve the desired characteristics of the ceramic. In the case of traditional ceramics, the ceramics are then dried and glazed prior to firing in the kiln. After firing, some ceramics may undergo additional treatment to achieve the final desired quality.

CO_2 emissions result from the calcination of the raw material (particularly clay, shale, limestone, dolomite and witherite) and the use of limestone as a flux.

OTHER USES OF SODA ASH

Soda ash is used in a variety of applications, including, glass production, soaps and detergents, flue gas desulphurisation, chemicals, pulp and paper and other common consumer products. Soda ash production and consumption (including sodium carbonate, Na_2CO_3) results in the release of CO_2. Emissions from soda ash production are reported in the Chemical Industry, while emissions from use are reported in the respective end use sectors where soda ash is used. Emissions from soda ash used in glass production are already accounted for above. Similarly, where soda ash is used in other source categories such as chemicals, emissions should be reported in that source category.

NON-METALLURGICAL MAGNESIA PRODUCTION

This source category should include emissions from magnesia (MgO) production that are not included elsewhere. For example, where magnesia is produced for use as a fertiliser, *good practice* is to report those emissions under the appropriate section of Chapter 3, Chemical Industry Emissions.

Magnesite ($MgCO_3$) is one of the key inputs into the production of magnesia, and ultimately fused magnesia. There are three major categories of magnesia products: calcined magnesia, deadburned magnesia (periclase) and fused magnesia. Calcined magnesia is used in many agricultural and industrial applications (e.g., feed supplement to cattle, fertilisers, electrical insulations and flue gas desulphurisation). Deadburned magnesia is used predominantly for refractory applications, while fused magnesia is used in refractory and electrical insulating markets.

Magnesia is produced by calcining $MgCO_3$ which results in the release of CO_2 (Table 2.1). Typically, 96-98 percent of the contained CO_2 is released in the production of calcined magnesia, with nearly 100 percent of the CO_2 released during further heating to produce deadburned magnesia. Production of fused magnesia also results in nearly 100 percent release of the CO_2.

OTHER

Emissions may result from a number of other source categories that are not included above. When allocating emissions to this source category, inventory compilers should be careful to not double count emissions already recorded in other source categories.

2.5.1.1 CHOICE OF METHOD

There are two primary methodologies for estimating emissions from the use of carbonate(s) for these source categories. The Tier 1 method assumes that only limestone and dolomite are used as carbonate input in industry, and allows for the use of a default fraction of limestone versus dolomite consumed. Tier 2 is the same as Tier 1 except country specific information on the fraction of limestone versus dolomite consumed must be determined. The Tier 3 method is based on an analysis of all emissive uses of carbonates.

It is possible that Tier 3 could be used for some sub-categories, and a Tier 1 or 2 method used for other categories with limited data availability. Such a hybrid approach is consistent with *good practice.* The selection of method depends on national circumstances.

TIER 1 METHOD

The Tier 1 method is based on Equation 2.14.

EQUATION 2.14
TIER 1: EMISSIONS BASED ON MASS OF CARBONATES CONSUMED

$$CO_2\ Emissions = M_c \bullet (0.85 EF_{ls} + 0.15 EF_d)$$

Where:

CO_2 Emissions = emissions of CO_2 from other process uses of carbonates, tonnes

M_c = mass of carbonate consumed, tonnes

EF_{ls} or EF_d = emission factor for limestone or dolomite calcination, tonnes CO_2/tonne carbonate (see Table 2.1)

It is suggested that inventory compilers ensure that data on carbonates reflect pure carbonates and not carbonate rock. If data are only available on carbonate rock, a default purity of 95 percent can be assumed. For clays a default carbonate content of 10 percent can be assumed[4], if no other information is available.

Soda ash is primarily sodium carbonate, not limestone or dolomite. Therefore, the Tier 1 method for soda ash does not require the default fraction of 85%/15%. Emissions are estimated by multiplying the quantity of soda ash consumed on the national level by the default emission factor for sodium carbonate (see Table 2.1).

TIER 2 METHOD

Under Tier 2, the amount of CO_2 emitted from the use of limestone and dolomite is estimated from a consideration of consumption and the stoichiometry of the chemical processes. Tier 2 uses a similar equation to Tier 1, but Tier 2 requires national data on the quantity of limestone and dolomite consumed in the country (Equation 2.15). It is not *good practice* to use a default for the allocation between these two primary carbonates.

EQUATION 2.15
TIER 2: METHOD FOR OTHER PROCESS USES OF CARBONATES

$$CO_2\ Emissions = (M_{ls} \bullet EF_{ls}) + (M_d \bullet EF_d)$$

Where:

CO_2 Emissions = emissions of CO_2 from other process uses of carbonates, tonnes

M_{ls} or M_d = mass of limestone or dolomite respectively (consumption), tonnes. (Refer to Equation 2.14 above regarding purity.)

EF_{ls} or EF_d = emission factor for limestone or dolomite calcination respectively, tonnes CO_2/tonne carbonate (see Table 2.1)

TIER 3 METHOD

The Tier 3 methodology is similar to the approach outlined for cement above, but there is no need to correct for dust or other raw material inputs (Equation 2.16). As noted above, wherever this approach is used, it is important that all carbonate inputs are considered in the analysis.

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[4] EU-BREF (2005) reports a range of carbonate contents for relevant clays used in the ceramics industry ranging from 0 to over 30 percent.

EQUATION 2.16
TIER 3: CARBONATE INPUT APPROACH FOR OTHER PROCESS USES OF CARBONATES

$$CO_2\ Emissions = \sum_i (M_i \bullet EF_i \bullet F_i)$$

Where:

CO_2 Emissions = emissions of CO_2 from other process uses of carbonates, tonnes

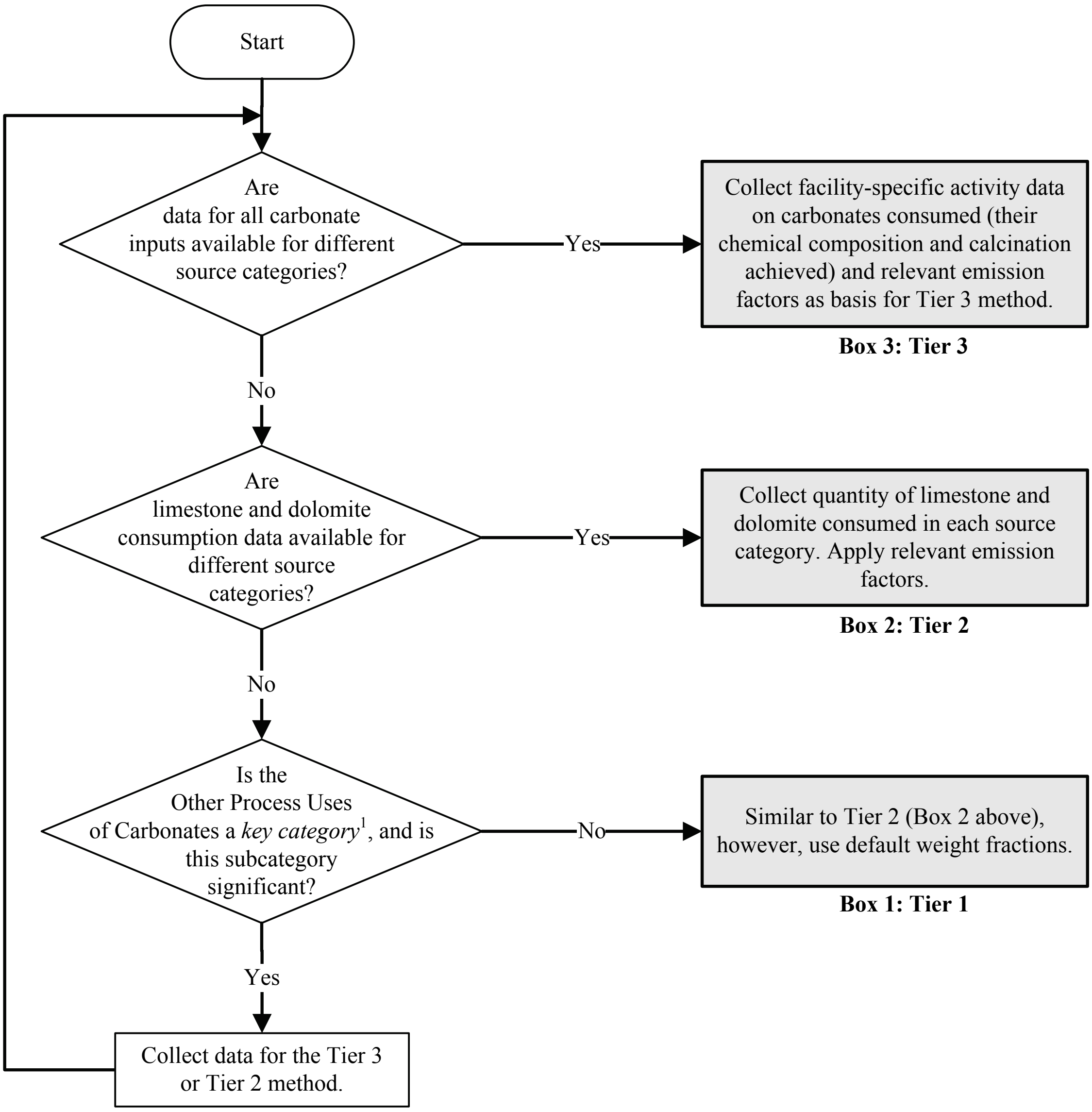
M_i = mass of the carbonate *i* consumed, tonnes (Refer to Equation 2.14 above regarding purity.)

EF_i = emission factor for the carbonate *i*, tonnes CO_2/tonne carbonate (see Table 2.1)

F_i = fraction calcination achieved for the particular carbonate *i*, fraction. Where the fraction calcination achieved for the particular carbonate is not known it can be assumed that the fraction calcination is equal to 1.00.

i = one of the carbonate uses

Figure 2.4 Decision tree for estimation of CO_2 emissions from other process uses of carbonates



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

2.5.1.2 CHOICE OF EMISSION FACTORS

TIER 1 AND TIER 2

The emission factor for the Tier 1 and Tier 2 methodologies is based on the mass of CO_2 released per mass of carbonate consumed (see Table 2.1.) The distinction between Tier 1 and Tier 2 is in the activity data.

TIER 3

The Tier 3 emission factor represents the weighted average of the emission factors of the individual carbonates (see Table 2.1). The Tier 3 approach requires the full accounting of carbonates (species and sources).

2.5.1.3 CHOICE OF ACTIVITY DATA

TIER 1

In the Tier 1 method, the inventory compiler should collect activity data for total carbonate consumption for emissive uses (see Table 2.7 for uses of carbonates that are emissive.) In the absence of better data, it is consistent with *good practice* for inventory compilers to assume that 85 percent of carbonates consumed are limestone and 15 percent of carbonates consumed are dolomite. For soda ash use, the inventory compiler should collect national or plant level data on the total quantity of soda ash used. For clays used in the ceramics industry, the inventory compiler should collect national production data for bricks and roof tiles, vitrified clay pipes, and refractory products and calculate the amount of clay consumed by multiplying production with a default loss factor of 1.1.

TIER 2

It is considered *good practice* to collect activity data to illustrate the total quantity of carbonates consumed in each end use sector. Where specific data are not available to identify the different carbonates consumed in these end use sectors, it is *good practice* to collect national level activity data for limestone and dolomite consumed. Similar to the Tier 1 method, where the fraction of calcination achieved is unknown, it is consistent with *good practice* for the inventory compiler to assume that 100 percent calcination is achieved. Inventory compilers should be cautious not to assume that all limestone and dolomite consumed in the country results in the release of CO_2 emissions. For example, limestone and dolomite are often used as aggregates in a number of processes and this use of crushed stone does not result in emissions (Table 2.7).

TIER 3

The most accurate method is to collect activity data on carbonate consumption by end use. *Good practice* is to collect plant-specific data of the carbonate(s) consumed for that source category and the fraction of calcination of the carbonate achieved. Carbonate consumption is assumed to be equal to the raw material mined (or dredged), plus raw material imported minus material exported. Where the fraction of calcination achieved is unknown, it is consistent with *good practice* for the inventory compiler to assume that 100 percent calcination is achieved. For clay use in the ceramics industry, the inventory compiler should collect clay consumption data for all relevant ceramics products.

2.5.1.4 COMPLETENESS

Completeness is a particular challenge with respect to carbonate-consuming (calcining) industries, because the potential for both underestimation and overestimation exists. As has been noted throughout this chapter, where a method is based on carbonate input, the potential for underestimating the total quantity of carbonates consumed is possible. As such, the Tier 3 method for other process uses of carbonates should only be applied at the plant-level.

The potential also exists for double counting. Inventory compilers should carefully consider how national statistics on limestone, dolomite and other carbonate uses were developed. For example, a data source for the iron and steel industry may contain the total quantity of limestone consumed as a flux, especially to the degree that emissions were part of blast furnace gas or other combustible gas that were included in the fuel combustion emissions from the relevant sector. At a national level, on limestone statistics should be carefully examined to determine whether the data also contains consumption of limestone in the iron and steel industry.

Often national statistics on limestone, dolomite and other carbonate uses contain categories such as ‘other unspecified uses’. Inventory compilers should be cautious that this consumption is not already accounted for in other sources.

The *Guidelines* separately identify two categories (Other Uses of Soda Ash and Non-metallurgical Magnesia Production) that are intermediate products used in a variety of other source categories. Soda ash, in particular, is used in a variety of industries, such as glass production, soaps and detergents. It is suggested that inventory compilers carefully review statistics for those source categories to ensure that no double counting has occurred. For example, where soda ash is used in glass production, emissions should be reported in that category. Where soda ash is used in another industry, emissions should be reported in that industry. Where soda ash is used in another mineral industry or where information is not sufficient to determine where it has been consumed, then emissions should be reported in the Category 2A4b, Other Uses of Soda Ash.

Table 2.7 highlights some questions that inventory compilers may ask themselves to help assure that these emissions are allocated appropriately, and not over-or underestimated.

TABLE 2.7
EMISSIVE AND NON-EMISSIVE USES OF CARBONATES

Where are Carbonates Consumed?	Is source emissive?	If yes, where should emissions be reported?
Agricultural:		
Agricultural limestone	Yes*	AFOLU: 3C2 Liming
Poultry grit and mineral food	No	
Other agricultural uses	No	
Chemical and metallurgical:		
Cement manufacture	Yes	IPPU: 2A1 Cement Production
Lime manufacture	Yes	IPPU: 2A2 Lime Production
Dead burning of dolomite	Yes	IPPU: 2A2 Lime Production, where deadburned; outside of lime industry under Other (2A4d).
Flux stone	Yes	IPPU: 2C Metal Industry, Industry where consumed; unless counted within Energy (for combustible off-gases sold off-site)
Chemical stone	Yes**	Source category where consumed
Glass manufacture	Yes	IPPU: 2A3 Glass Production
Sulphur oxide removal	Yes*	Source category where consumed
Fertilisers	Yes**	IPPU: 2B Chemical Industry
Ceramics and mineral wool:		
Ceramics	Yes	IPPU: Mineral Industry: 2A4a Ceramics
Mineral wools	Yes	IPPU: Mineral Industry: 2A3 Glass Production or 2A4d Other, depending on production process.
Special:		
Mine dusting or acid water treatment	Yes*	Source category where consumed
Asphalt fillers or extenders	No	
Whiting or whiting substitute	No	
Other fillers or extenders	No	
Construction:		
Use as a Fine or Coarse Aggregate	No	

TABLE 2.7 (CONTINUATION)
EMISSIVE AND NON-EMISSIVE USES OF CARBONATES

Production	**Is source emissive?**	**If yes, where should emissions be reported?**
Other miscellaneous uses:		
Refractory stone	No	
Acid neutralization	Yes*	Source category where consumed
Chemicals	No	
Paper manufacture	No	
Abrasives	No	
Sugar refining	Yes	IPPU: Emissions from lime production at sugar mills should be reported under 2A2 Lime Production; all other emissions in 2A4 Other Process Uses of Carbonates. Removals should be reported under 2H2 Food and Beverages Industry.
Others	Yes*, No	Where Yes, IPPU: 2A4 Other Process Uses of Carbonates

* Emissions are by an acidification reaction.

** Emissions could be by calcination and/or acidification.

2.5.1.5 DEVELOPING A CONSISTENT TIME SERIES

Fundamentally, these *Guidelines* treat the consumption of limestone, dolomite and other carbonate uses differently than earlier *IPCC Guidelines* documents. Previous guidance suggested that, except for the case of limestone and dolomite consumed in cement production, lime production and the liming of agricultural soils, all consumption of limestone and dolomite be reported under the source category Limestone and Dolomite Use.

In the *2006 Guidelines*, emissions from other process uses of carbonates should be reported in the source category where they are consumed, and thereby emissions are reported in the sector where they are emitted. This change could require recalculations to ensure time series consistency for the Other Process Uses of Carbonates source category in the Minerals Industry, and also in the other source categories where the carbonates are consumed.

There are a number of ways that inventory compilers may help ensure time series consistency: It is *good practice* for the inventory compiler to consider the following in accordance with Volume 1, Chapter 5.

- If data are available to complete the Tier 3 (or the Tier 2) method for all years, this should be followed.
- If data are only available for certain years, the intervening years may be estimated by interpolation or extrapolation of the trend lines.
- If data on other process uses of carbonates are available at a disaggregated level for only the most recent year, the inventory compiler may elect to apply the proportion of carbonates consumed in each industry for the most recent year, to production trends for the respective industries, similar to the Surrogate Method outlined in Volume 1, Section 5.3. Inventory compilers should be cautious when using this approach however, and consider if there are national circumstances which may have led to the greater use of fluxes or slagging agents for certain industries over the time period.

2.5.2 Uncertainty assessment

2.5.2.1 EMISSION FACTOR UNCERTAINTIES

In theory the uncertainty associated with the emission factor for this source category should be relatively low, as the emission factor is the stoichiometric ratio reflecting the amount of CO_2 released upon calcination of the carbonate. In practice, there are uncertainties due, in part, to variations in the chemical composition of the limestone and other carbonates. For example, in addition to calcium carbonate, limestone may contain smaller amounts of magnesia, silica and sulphur. Assuming that the activity data are collected correctly, and thus the correct emission factor is applied, there is negligible uncertainty associated with the emission factor. There may be some uncertainty associated with assuming a fractional purity of limestone and dolomite in cases where only carbonate rock data are available (+/- 1-5 percent).

2.5.2.2 ACTIVITY DATA UNCERTAINTIES

Activity data uncertainties are greater than the uncertainties associated with emission factors. Assuming that carbonate consumption is allocated to the appropriate consuming sectors/industries, the uncertainty associated with weighing or proportioning the carbonates for any given industry is 1-3 percent. The uncertainty of the overall chemical analysis pertaining to carbonate content and identity also is 1-3 percent. The uncertainty associated with use of the Tier 2 and Tier 1 methods, including the assumption of a default breakdown of limestone versus dolomite of 85%/15%, varies depending on country specific circumstances.

Activity data for limestone and dolomite use may be difficult to collect, as there are a variety of end uses in different industries, some of which are emissive and others not. National statistics may include an end use category of ‘other unspecified uses’ (or an otherwise similar category) and it may be difficult to allocate ‘other unspecified uses’ to the appropriate consuming sector. Where all uses can not be properly identified this will increase uncertainty.

2.5.3 Quality Assurance/Quality Control (QA/QC), Reporting and Documentation

2.5.3.1 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

COMPARISON OF EMISSION ESTIMATES USING DIFFERENT APPROACHES

Emission estimates derived from any Tier can be compared with the other Tiers, even though the Tier 3 approach may be accounting for additional carbonate species not included in the Tier 1 or 2 analyses. Assuming that the same fraction of calcination achieved is used for all Tiers, the emissions estimated using the respective approaches will likely be similar in magnitude, considering that limestone and dolomite likely contribute the greatest percentage of emissions for these sources.

ACTIVITY DATA CHECK

As limestone, dolomite and other carbonates are consumed in a variety of industries there may be a number of different data sources available containing carbonate consumption in the respective industries. For example, data for limestone consumption at various facilities in the iron and steel industry could be compared to see if the quantity of flux used in proportion to facility level production is similar.

Also, plant specific information on use of limestone, dolomite and other carbonates as a flux could be compared with industry association statistics. These industry association statistics could in turn be compared with national level statistics on limestone, dolomite and other carbonate consumption.

It is often useful to examine trends in activity data over time to see if there may be large fluctuations year to year. Inventory compilers should be cautious when drawing conclusions based on trends data, as there may be large year to year fluctuations in these statistics.

2.5.3.2 REPORTING AND DOCUMENTATION

The inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be reproduced. As noted above, the most important consideration that inventory compilers should make when reporting emissions from other process uses of carbonates is that emissions should be reported in the source category where the carbonates are consumed.

TIER 1 AND TIER 2

Information should be reported on the quantity of limestone and dolomite consumed by each industry. Where the breakdown of carbonates consumed in a particular industry is unknown, and a default allocation of 85 percent limestone and 15 percent dolomite is used, this should be documented.

TIER 3

Documentation required for the Tier 3 approach is analogous to the other source categories in this chapter that calculate emissions based on carbonate inputs.

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