Attachment 1: Example Calculations
Clinker-Based Methodology

Scenario 1 Assumptions

- **Default Emission Factors**
- **100% CKD Recycled**

California Climate Action Registry (Registry): Cement Reporting Protocol

CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced
EF_{Cli}	=	Clinker emission factor
CKD	=	Quantity CKD discarded
EF_{CKD}	=	CKD emission factor

Where:

Cli	=	1,200,000 ton clinker
EF_{Cli}	=	525 kg CO_2/ ton clinker
CKD	=	0 ton CKD
EF_{CKD}	=	N/A

CO_2 emissions = [(1,200,000 ton clinker) (525 kg CO_2/ton clinker) + 0]

CO_2 emissions = 630,000,000 kg $CO_2 \cdot \frac{1\,\text{ton}}{1{,}016.05\,\text{kg}}$

CO_2 emissions = **620,048 ton CO_2**

IPCC 2006 Guidelines: Cement Production

CO_2 emissions = $M_{Cl} \cdot EF_{Cli} \cdot CF_{CKD}$

Where:

M_{Cl}	=	weight (mass) of clinker produced, ton clinker
EF_{Cli}	=	clinker emission factor, ton CO_2/ton clinker
CF_{CKD}	=	emissions correction factor for CKD, dimensionless

Where:

M_{Cl}	=	1,200,000 ton clinker
EF_{Cli}	=	525 kg CO_2/ ton clinker
CF_{CKD}	=	1.0

CO_2 emissions = (1,200,000 ton clinker) • (525 kg CO_2/ton clinker) • (1.0)

CO_2 emissions = 630,000,000 kg $CO_2 \cdot \frac{1\,\text{ton}}{1{,}016.05\,\text{kg}}$

CO_2 emissions = **620,048 ton CO_2**

Scenario 2 Assumptions

- **Default Emission Factors**
- **2% CKD Correction**

California Climate Action Registry (Registry): Cement Reporting Protocol

CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced
EF_{Cli}	=	Clinker emission factor
CKD	=	Quantity CKD discarded
EF_{CKD}	=	CKD emission factor

Where:

Cli	=	1,200,000 ton clinker
EF_{Cli}	=	525 kg CO_2/ ton clinker
CKD	=	Not Available ∴ CKD CO_2 emissions = 2% clinker emissions
EF_{CKD}	=	N/A

CO_2 emissions = [(1,200,000 ton clinker) (525 kg CO_2/ton clinker) + (clinker CO_2 emissions) (0.02)]

Clinker CO_2 emissions = 630,000,000 kg CO_2 • $\frac{1\text{ ton}}{1{,}016.05\text{ kg}}$ = 620,048 ton CO_2

CO_2 emissions = [620,048 ton CO_2 + (620,048 tons CO_2) (0.02)]

CO_2 emissions = 620,048 ton CO_2 + 12,401 ton CO_2 = **632,449 ton CO_2**

IPCC 2006 Guidelines: Cement Production

CO_2 emissions = M_{Cl} • EF_{Cli} • CF_{CKD}

Where:

M_{Cl}	=	weight (mass) of clinker produced, ton clinker
EF_{Cli}	=	clinker emission factor, ton CO_2/ton clinker
CF_{CKD}	=	emissions correction factor for CKD, dimensionless

Where:

M_{Cl}	=	1,200,000 ton clinker
EF_{Cli}	=	525 kg CO_2/ ton clinker
CF_{CKD}	=	1.02

CO_2 emissions = 1,200,000 ton clinker • 525 kg CO_2/ton clinker • 1.02

CO_2 emissions = 630,000,000 kg CO_2 • $\frac{1\text{ ton}}{1{,}016.05\text{ kg}}$ • 1.02

CO_2 emissions = **632,449 ton CO_2**

Scenario 3 Assumptions

- **Default Emission Factors**
- **CKD Discarded = 252,204 ton**

California Climate Action Registry (Registry): Cement Reporting Protocol

CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced
EF_{Cli}	=	Clinker emission factor
CKD	=	Quantity CKD discarded
EF_{CKD}	=	CKD emission factor

Where:

Cli	=	1,200,000 ton clinker
EF_{Cli}	=	525 kg CO_2/ ton clinker
CKD	=	252,504 ton CKD
EF_{CKD}	=	499 kg CO_2/ ton CKD

CO_2 emissions = [(1,200,000 ton clinker) (525 kg CO_2/ton clinker)
+ (252,504 ton CKD) (499 kg CO_2/ton CKD)]

$$CO_2 \text{ emissions} = [(630{,}000{,}000 \text{ kg } CO_2 \cdot \frac{1 \text{ ton}}{1{,}016.05 \text{ kg}})$$

$$+ (125{,}999{,}496 \text{ kg } CO_2 \cdot \frac{1 \text{ ton}}{1{,}016.05 \text{ kg}})]$$

CO_2 emissions = 620,048 ton CO_2 + 124,009 ton CO_2 = **744,057 ton CO_2**

Cement Kiln Dust Emission Factor (EF_{CKD})

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

Where:

EF_{CKD}	=	Emission factor of partially calcinated CKD (Mass CO_2/mass CKD)
EF_{Cli}	=	Clinker Emission Factor = 525 kg CO_2/ton clinker
d	=	Degree of CKD calcination = 1 (Default Value)

$$EF_{CKD} = \frac{\frac{525 \text{ kg } CO_2\text{/ton clinker}}{1+525 \text{ kg } CO_2\text{/ton clinker}} \text{ x } 1}{1-\frac{525 \text{ kg } CO_2\text{/ton clinker}}{1+525 \text{ kg } CO_2\text{/ton clinker}} \text{ x } 1} = \frac{0.998}{1-0.998} = \frac{0.998}{0.002} = 499 \text{ kg } CO_2\text{/ton CKD}$$

IPCC 2006 Guidelines: Cement Production

CO_2 emissions = $M_{Cl} \bullet EF_{Cli} \bullet CF_{CKD}$

Where:

M_{Cl}	=	weight (mass) of clinker produced, ton clinker
EF_{Cli}	=	clinker emission factor, ton CO_2/ton clinker
CF_{CKD}	=	emissions correction factor for CKD, dimensionless

Where:

M_{Cl}	=	1,200,000 ton
EF_{Cli}	=	525 kg CO_2/ ton clinker
CF_{CKD}	=	1.08

CO_2 emissions = (1,200,000 ton clinker) • (525 kg CO_2/ton clinker) • (1.08)

CO_2 emissions = $[(630{,}000{,}000 \text{ kg } CO_2 \bullet \frac{1 \text{ ton}}{1{,}016.05 \text{ kg}}) \bullet (1.08)]$

CO_2 emissions = **669,652 ton CO_2**

CKD correction factor (CF_{CKD})

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

Where:

CF_{CKD} = emissions correction factor for CKD, dimensionless
M_d = weight of CKD not recycled to the kiln, ton
M_{cl} = weight of clinker produced, ton
C_d = fraction of original carbonate in the CKD, fraction
F_d = fraction calcination of the original carbonate in the CKD, fraction*
EF_c = emission factor for the carbonate, ton CO_2/ton carbonate
EF_{cl} = emission factor for clinker uncorrected for CKD, ton CO_2/ton clinker

$CF_{CKD} = 1 + (252{,}504/ 1{,}200{,}000) \bullet (0.85) \bullet (0.5) \bullet (0.4397/0.5101)$
$CF_{CKD} = 1 + (0.21) \bullet (0.85) \bullet (0.5) \bullet (0.8620)$
$CF_{CKD} = 1.08$

*Note: IPCC 2006 assumes a CKD calcination rate of 50%, where $F_d = 0.5$

SUMMARY:

Default Emission Factor Equations Result in the following CO_2 emissions
Scenario 1: 620,048 ton CO_2
Scenario 2: 632,449 ton CO_2
Scenario 3: 669,652 ton CO_2 (IPCC 2006) and 744,057 ton CO_2 (Registry/CSI)

Scenario 4 Assumptions

- **Plant-Specific Emission Factors**
- **100% CKD Recycled**

The Clinker-Based Methodology: Registry's Cement Protocol

CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced
EF_{Cli}	=	Clinker emission factor
CKD	=	Quantity CKD discarded
EF_{CKD}	=	CKD emission factor

Where:

Cli	=	1,200,000 ton clinker
EF_{Cli}	=	0.52117 ton CO_2/ton clinker (530 kg CO_2/ton clinker)
CKD	=	0 ton CKD
EF_{CKD}	=	0.5211 ton CO_2/ton of CKD (529 kg CO_2/ton CKD)

CO_2 emissions = [(1,200,000 ton clinker) (0.52117 ton CO_2/ ton clinker)
+ (0 ton CKD) (0.5211 ton CO_2/ton CKD)]

CO_2 emissions = **625,404 ton CO_2**

Plant-Specific Clinker Emission Factor (EF_{Cli})

EF_{Cli} = [(CaO content – non-carbonate CaO) • molecular ratio of CO_2/CaO]
+ [(MgO Content – non-carbonate MgO) • molecular ratio of CO_2/MgO]

Where:

CaO Content	=	65%
Molecular Ratio of CO_2/CaO	=	0.785
MgO Content	=	1 %
Molecular Ratio of CO_2/MgO	=	1.092

EF_{Cli} = [0.65 • 0.785] + [0.1 • 1.092] = 0.51025 + 0.01092

$$EF_{Cli} = 0.52117 \text{ ton } CO_2/\text{ton clinker} \cdot \frac{1{,}016.05 \text{ kg}}{1 \text{ ton}} = 530 \text{ kg } CO_2/\text{ton clinker}$$

Plant-Specific Cement Kiln Dust Emission Factor (EF_{CKD})

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

Where:

EF_{CKD}	=	Emission factor of partially calcinated Cement Kiln Dust (mass CO_2/mass CKD)
EF_{Cli}	=	Clinker Emission Factor = 0.52117 ton CO_2/ton clinker
d	=	Degree of CKD calcination = 1 (Default Value)

$$EF_{CKD} = \frac{\frac{0.52117 \text{ ton } CO_2\text{/ton clinker}}{1+0.52117 \text{ ton } CO_2\text{/ton clinker}} \text{ x } 1}{1-\frac{0.52117 \text{ ton } CO_2\text{/ton clinker}}{1+0.52117 \text{ ton } CO_2\text{/ton clinker}} \text{ x } 1} = \frac{0.3426}{1-0.3426} = \frac{0.3426}{0.6574} =$$

$$EF_{CKD} = 0.5211 \text{ ton } CO_2\text{/ton CKD} \bullet \frac{1{,}016.05 \text{ kg}}{1 \text{ ton}} = 529 \text{ kg } CO_2\text{/ton clinker}$$

IPCC 2006 Guidelines: Cement Production

CO_2 emissions = $M_{Cl} \bullet EF_{Cli} \bullet CF_{CKD}$

Where:

M_{Cl}	=	weight (mass) of clinker produced, ton clinker
EF_{Cli}	=	clinker emission factor, ton CO_2/ton clinker
CF_{CKD}	=	emissions correction factor for CKD, dimensionless

Where:

M_{Cl}	=	1,200,000 ton clinker
EF_{Cli}	=	0.52117 ton CO_2/ ton clinker
CF_{CKD}	=	1.0

CO_2 emissions = (1,200,000 ton clinker) • (0.52117 ton CO_2/ton clinker) • (1.0)

CO_2 emissions = **625,404 ton CO_2**

Scenario 5 Assumptions

- **Plant-Specific Emission Factors**
- **2% CKD Correction**

The Clinker-Based Methodology: Registry's Cement Protocol

CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced
EF_{Cli}	=	Clinker emission factor
CKD	=	Quantity CKD discarded
EF_{CKD}	=	CKD emission factor

Where:

Cli	=	1,200,000 ton clinker
EF_{Cli}	=	0.52117 ton CO_2/ton clinker
CKD	=	Not Available ∴ CKD CO_2 emissions = 2% clinker emissions
EF_{CKD}	=	N/A

CO_2 emissions = [(1,200,000 ton clinker) (0.52117 ton CO_2/ton clinker) + (clinker CO_2 emissions) (0.02)]

CO_2 emissions = (625,404 ton CO_2) **+ (**625,404 ton CO_2) • (0.02)

CO_2 Emissions = 625,404 ton CO_2 + 12,508 ton CO_2

CO_2 emissions = **637,912 ton CO_2**

IPCC 2006 Guidelines: Cement Production

CO_2 emissions = M_{Cl} • EF_{Cli} • CF_{CKD}

Where:

M_{Cl}	=	weight (mass) of clinker produced, ton clinker
EF_{Cli}	=	clinker emission factor, ton CO_2/ton clinker
CF_{CKD}	=	emissions correction factor for CKD, dimensionless

Where:

M_{Cl}	=	1,200,000 ton clinker
EF_{Cli}	=	0.52117 ton CO_2/ ton clinker
CF_{CKD}	=	1.02

CO_2 emissions = (1,200,000 ton clinker) • (0.52117 ton CO_2/ton clinker) • (1.02)

CO_2 emissions = **637,912 ton CO_2**

Scenario 6 Assumptions

- **Plant-Specific Emission Factors**
- **CKD Discarded = 252,204 ton**

The Clinker-Based Methodology: Registry's Cement Protocol

CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

Cli	=	Quantity of clinker produced
EF_{Cli}	=	Clinker emission factor
CKD	=	Quantity CKD discarded
EF_{CKD}	=	CKD emission factor

Where:

Cli	=	1,200,000 ton clinker
EF_{Cli}	=	0.52117 ton CO_2/ton clinker
CKD	=	252,504 ton CKD
EF_{CKD}	=	0.5211 ton CO_2/ton CKD

CO_2 emissions = [(1,200,000 ton clinker) (0.52117 ton CO_2/ton clinker)
+ (252,504 ton CKD) (0.5211 ton CO_2/ton CKD)]

CO_2 emissions = 625,404 ton CO_2 + 131,580 ton CO_2

CO_2 emissions = **756,984 ton CO_2**

IPCC 2006 Guidelines: Cement Production

CO_2 emissions = $M_{Cl} \cdot EF_{Cli} \cdot CF_{CKD}$

Where:

M_{Cl}	=	weight (mass) of clinker produced, ton clinker
EF_{Cli}	=	clinker emission factor, ton CO_2/ton clinker
CF_{CKD}	=	emissions correction factor for CKD, dimensionless

Where:

M_{Cl}	=	1,200,000 ton
EF_{Cli}	=	0.52117 ton CO_2/ ton clinker
CF_{CKD}	=	1.08

CO_2 emissions = (1,200,000 ton clinker) • (0.52117 ton CO_2/ton clinker) • (1.08)
CO_2 emissions = **675,436 ton CO_2**

SUMMARY:

Plant-Specific Equations Result in the following CO_2 emissions
Scenario 4: 625,404 ton CO_2
Scenario 5: 637,912 ton CO_2
Scenario 6: 675,436 ton CO_2 (IPCC 2006) and 756,984 ton CO_2 (Registry/CSI)