

# USE OF SULPHUR CONCRETE IN PRECAST APPLICATIONS

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### Relationship to Approved or Pending Methodologies

Approved and Pending methodologies for all sectoral scopes were reviewed to determine if an existing methodology could be reasonably revised to meet the objective of this proposed methodology. Two methodologies related to process changes in concrete production were identified, and are outlined in Table 1.

**Table 1: Summary of Related Methodologies**

Methodology	Title	Primary Reduction Mechanism	Comments
<b>ACM0015 v3</b>	Consolidated baseline and monitoring methodology for project activities using alternative raw materials that do not contain carbonates for clinker production in cement kilns, CDM March 2010	Avoidance of process CO2 emissions due to reduction of carbonate materials in the feedstock.	The use of sulphur concrete requires significant process changes not reflected in this methodology.
<b>ACM0005 v5</b>	Consolidated baseline methodology for increasing the blend in concrete production, CDM October 2009	Avoidance of process CO2 emissions due to feedstock switch.	The use of sulphur concrete requires significant process changes not reflected in this methodology.

A review of the related methodologies indicated that the process changes required to produce sulphur concrete would result in significant changes to the existing methodologies, and adaptation would not be feasible.

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## 1 SOURCES

This methodology is based on the draft *Quantification Protocol for the Use of Sulphur Concrete in Precast Applications v0.4*, issued under the Alberta Specified Gas Emitters Regulation. The methodology references the following CDM Methodological Tools:

- *Combined tool to identify the baseline scenario and determine additionality* Version 3.0.1
- *Tool for the demonstration and assessment of additionality*, Version 5.2.1

Technical data and guidance were obtained from The World Business Council for Sustainable Development report, *Cement Industry Energy and CO<sub>2</sub> Performance "Getting the Numbers Right" (WBCSD, 2009)*. In addition, technical and good practice guidance was obtained from Environment Canada's annual GHG reporting, the US EPA's Emissions Inventory, the Intergovernmental Panel on Climate Change (IPCC) and various other reliable sources of information pertaining to the concrete production industry. The good practice guidance and best science used to develop the quantification methodology are presented in Section 10.

## 2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Concrete is a commonly used material for infrastructure, industrial and construction applications, consisting of aggregate (rock and sand), water and cement. The production of calcium and/or magnesium carbonate-derived cement (often from limestone) releases significant amounts of greenhouse gas (GHG) emissions. This methodology is applicable to processes that involve the substitution of calcium and/or magnesium carbonate-derived ("Portland") cement with an alternative binder such as a modified heated sulphur product during the production of concrete and other concrete-based products such as pre-cast pipe, paving stones, slabs and tanks.

Traditional concrete is formed when limestone- and clay-derived cementitious binders are mixed with water to create chemical bonds with aggregate material, generally sand and rock. The cementitious binder ("clinker") is a key component of cement; however, the production of clinker results in the release of a significant amount of GHG emissions from two main sources: process emissions and combustion emissions. Process emissions occur as a by-product of the calcination process, where a calcium or magnesium carbonate such as limestone is heated with clay to form clinker (primarily calcium oxide) and carbon dioxide. The heat required for the calcination process, normally supplied through the combustion of fossil fuels, results in additional GHG emissions such as releases of carbon dioxide, methane and nitrous oxide.

Portland cement may be partially or completely substituted with other binders such as modified heated sulphur to form a stable, hard concrete product. Sulphur substitutes avoid the process and combustion emissions associated with the manufacture of Portland cement.

In the case of a modified sulphur alternative, the sulphur itself is generated as a by-product of natural gas processing and petroleum refining. Unlike concrete made from Portland cement (which can be cold mixed), concrete made with modified heated sulphur needs to be heated during production.

Despite the need to be hot mixed (with heat likely obtained from the combustion of fossil fuels), concrete and cement products made with modified heated sulphur releases far fewer GHG emissions than concrete made with Portland cement. Modified heated sulphur avoids the process emissions released in the calcination process of clinker production as well as the combustion emissions typically generated to supply heat to the calcination process. The clinker production process typically operates at approximately 1,450 degrees C.

Due to a relatively low melting point for sulphur, the maximum temperature in sulphur concrete product applications is generally 113 degrees C. Sulphur concrete products maintain high strength properties, allowing their use in a wide variety of pre-cast applications such as traffic barriers, drainage tiles, paving stones, and marine defences.

The baseline condition is defined as the production of concrete using traditional cementitious binders derived from limestone and clay that rely on the chemical bonds formed upon contact with water to bind together aggregate material (sand and rock). This binder (“clinker”) is a key component of Portland cement.

The calculation of the emissions related to the production of Portland cement will be based on the mass of sulphur cement used in the project condition. An equivalency factor will be used to provide functional equivalence between the mass of sulphur cement and Portland cement. An emission factor will be applied that represents the mass of carbon dioxide-equivalent GHG emissions per tonne of displaced Portland cement.

### 3 DEFINITIONS

Aggregate	Composition of coarse particulate material such as sand, gravel, crushed stone, slag, and recycled concrete. It may be sourced from gravel pits, quarries and other local sources near to the pre-cast facility. In addition to sand and rock, aggregate may include other materials that can be blended with cement to form a final product such as fly ash and slag.
Binder	An adhesive material that binds with the aggregate to form concrete.
Portland Cement	A finely ground, usually grey coloured mineral powder that, when mixed with water, acts as a glue to bind together aggregate to form concrete.
Sulphur Cement	A product composed of molten elemental sulphur and a proprietary modifier that acts as a glue to bind together aggregate to form sulphur concrete. Sulphur cement requires no water to form sulphur concrete.
Concrete	A composite building material made from the combination of aggregate and a cement binder.
Precast Products	A form of construction where concrete is cast in a reusable mould or form, which is then cured in a controlled environment. Examples of precast products include paving stones, planters, traffic barriers, holding tanks and retaining walls, among many others.

### 4 APPLICABILITY CONDITIONS

This methodology is applicable to the production of sulphur concrete for precast applications, where the following conditions are met:

1. The most reasonable and credible baseline scenario is the production of precast concrete products using Portland cement, as demonstrated using the methodology outlined in Section 6;
2. The handling, storage, mix production temperature and other key factors specified by the manufacturer for the proper and safe use of sulphur cement have been followed by the project proponent. Evidence of adherence to manufacturer specification must be made available during a verification site visit, conducted during precast product production;

3. The resulting sulphur concrete product meets local legal and technical requirements. In the absence of local technical specifications for concrete, project proponents must demonstrate that sulphur concrete produced under the project scenario provides the equivalent function to concrete that would have been produced under the baseline scenario.

## 5 PROJECT BOUNDARY

The project scenario is defined as the production of concrete, substituting all or a portion of the Portland cement content with a sulphur binder product. The project boundary is the physical, geographic location of the precast concrete production facility. Project proponents must account for:

- Direct emissions due to fuel combustion at the precast concrete facility for:
  - heating of aggregate;
  - additional heating of the sulphur additive;
- Direct emissions due to fuel combustion and process emissions outside the precast concrete facility for:
  - Production of the sulphur modifier;
  - Transport of the modifier and modified sulphur product;
- Indirect emissions due to the extraction and processing of fossil fuels used; and
- Indirect emissions due to the degassing of sulphur (if applicable).

A generalized process flow diagram of a typical project is presented in Figure 1.

The temporal project boundary includes the operation of an existing precast concrete facility during the incorporation of a sulphur binder. GHG sources related to the construction and decommissioning of the facility are considered outside the scope of this methodology and have been excluded from quantification. This is reasonable given the minimal emissions associated with the construction and decommissioning phases and the long operational life of the facility.

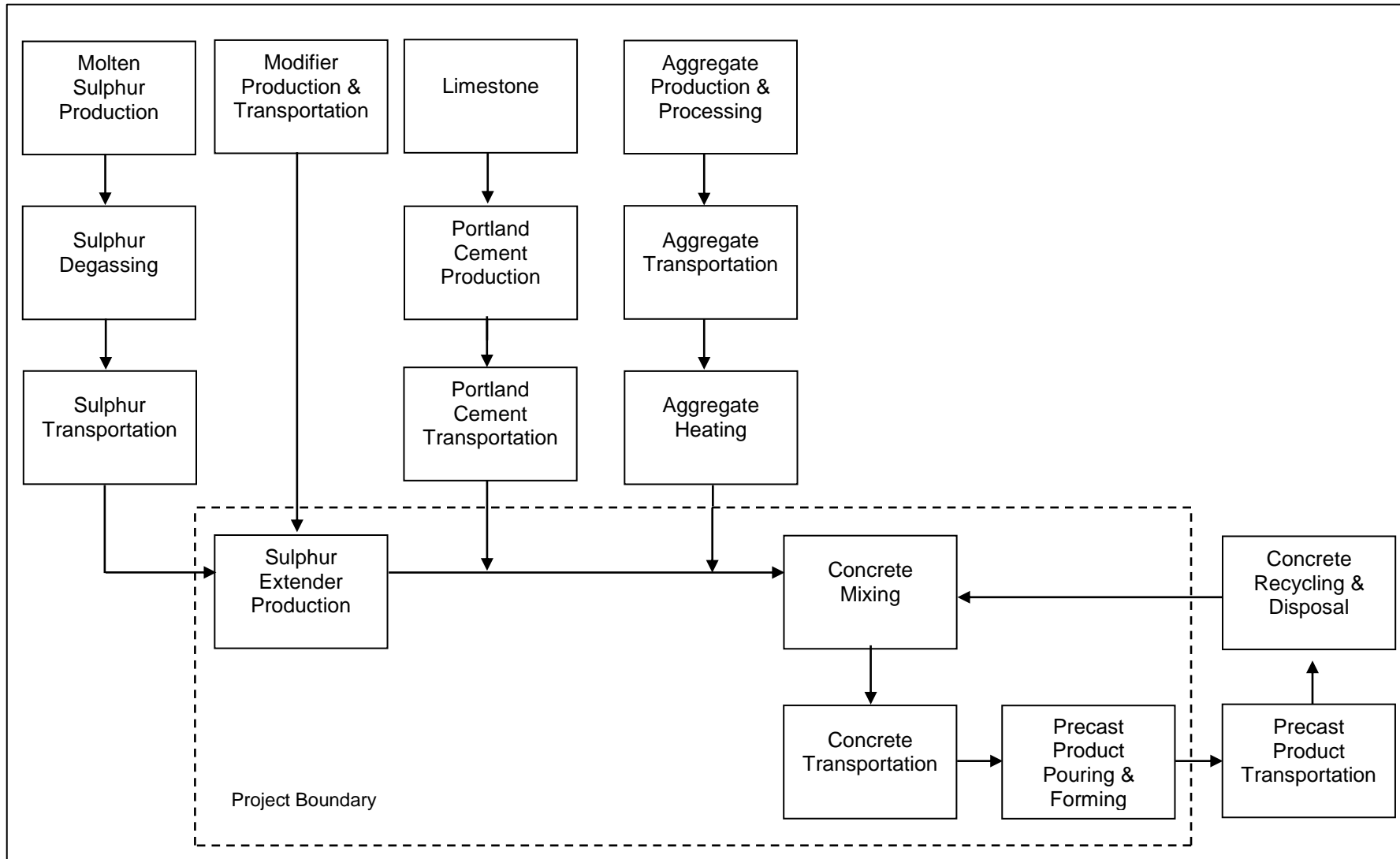


Figure 1: Project Process Flow Diagram

The GHG sources represented in the above process flow diagram were compared to the GHG sources in the baseline scenario and their relevancy evaluated to determine if they should be included or excluded from the quantification methodology. Emission sources included or excluded from the project boundary are presented in Table 1.

Table 1: GHG Sources

Source		Gas	Included?	Justification/Explanation
Baseline	Production of molten sulphur	CO <sub>2</sub>	No	Excluded as the quantity of molten sulphur produced in the project and baseline scenarios are functionally equivalent. Sulphur is a by-product of gas processing and would be produced in both the project and baseline scenarios in the same quantity.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Sulphur degassing	CO <sub>2</sub>	No	If sulphur degassing was occurring in the baseline scenario, it will continue under the project scenario and emissions will be equivalent.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Transportation and Storage of Molten Sulphur	CO <sub>2</sub>	No	If sulphur is used as it is produced rather than storing it, emissions will be lower in the project scenario. Therefore it is conservative to exclude this source.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Limestone Production	CO <sub>2</sub>	No	Less limestone will be produced in the project scenario and therefore emissions will be lower in the project scenario. The emissions from this source are relatively low and difficult to estimate accurately. Exclusion of this source is conservative.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Portland Cement Production	CO <sub>2</sub>	Yes	The quantity of Portland cement used in the project scenario also would have been used in the baseline scenario. The emissions related to the displaced quantity of Portland cement will be quantified.
		CH <sub>4</sub>	Yes	
		N <sub>2</sub> O	Yes	
	Portland Cement Transportation	CO <sub>2</sub>	No	The quantity of Portland cement that is transported in the project scenario would be less than the quantity in the baseline scenario; therefore, it is conservative to exclude these emissions.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Aggregate Production and Processing	CO <sub>2</sub>	No	Excluded as the same quantity of aggregate would be produced and processed in the project and baseline scenarios.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Transportation of Aggregate	CO <sub>2</sub>	No	Excluded as the same quantity of aggregate would be transported in the project and baseline scenarios.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
Water Treatment and	CO <sub>2</sub>	No	Emissions from this source are avoided	

Source		Gas	Included?	Justification/Explanation
Project	Pumping	CH <sub>4</sub>	No	in the project scenario. This emission reduction is not the focus of this methodology. Emissions are excluded as it is conservative to do so.
		N <sub>2</sub> O	No	
	Fuel Extraction/Processing	CO <sub>2</sub>	No	The quantity of fuel consumed in the baseline scenario for the production of Portland cement will be considered in the source: Portland Cement Production.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Fuel Delivery	CO <sub>2</sub>	No	The quantity of fuel consumed in the baseline scenario for the production of Portland cement will be greater than the quantity of fuel consumed in the project scenario for mixing sulphur concrete. Emissions are excluded as it is conservative to do so.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Electricity Generation	CO <sub>2</sub>	No	There will be no incremental electricity consumption in the project scenario over the baseline scenario.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Concrete Mixing	CO <sub>2</sub>	No	The process for concrete mixing is equivalent in the baseline and project scenarios.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Concrete Transportation	CO <sub>2</sub>	No	The same quantity of concrete will be transported in the baseline and project scenarios.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Precast Product Pouring and Forming	CO <sub>2</sub>	No	The process for pouring and forming will not change between the baseline and project scenarios.
		CH <sub>4</sub>	No	
		N <sub>2</sub> O	No	
	Precast Product Transportation	CO <sub>2</sub>	No	There is no difference in the transportation-related emissions between the baseline and project scenarios.
CH <sub>4</sub>		No		
N <sub>2</sub> O		No		
Concrete Recycling or Disposal	CO <sub>2</sub>	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Production of molten sulphur	CO <sub>2</sub>	No	Excluded as the quantity of molten sulphur produced in the project and baseline scenarios are functionally equivalent. Sulphur is a by-product of gas processing and would be produced in both the project and baseline	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		

Source	Gas	Included?	Justification/Explanation
			scenarios in the same quantity
Sulphur degassing	CO <sub>2</sub>	Yes	If sulphur degassing is occurring as a result of the project and the producer would otherwise not be degassing the sulphur, the emissions must be included.
	CH <sub>4</sub>	Yes	
	N <sub>2</sub> O	Yes	
Sulphur Transportation and Storage	CO <sub>2</sub>	Yes	If sulphur was stored in the baseline scenario, transportation emissions in the project scenario are deemed to be additional and must be included.
	CH <sub>4</sub>	Yes	
	N <sub>2</sub> O	Yes	
Modifier Production and Transportation	CO <sub>2</sub>	Yes	Emissions associated with the production and transportation of the sulphur modifier are directly related to the project and must be included.
	CH <sub>4</sub>	Yes	
	N <sub>2</sub> O	Yes	
Limestone Production	CO <sub>2</sub>	No	Less limestone will be produced in the project scenario and therefore emissions will be lower in the project scenario. The emissions from this source are relatively low and difficult to estimate accurately. Exclusion of this source is conservative.
	CH <sub>4</sub>	No	
	N <sub>2</sub> O	No	
Portland Cement Production	CO <sub>2</sub>	No	The quantity of Portland cement used in the project scenario also would have been used in the baseline scenario. The emissions related to the displaced quantity of Portland cement will be quantified.
	CH <sub>4</sub>	No	
	N <sub>2</sub> O	No	
Portland Cement Transportation	CO <sub>2</sub>	No	The quantity of Portland cement that is transported in the project scenario would be less than the quantity in the baseline scenario; therefore, it is conservative to exclude these emissions.
	CH <sub>4</sub>	No	
	N <sub>2</sub> O	No	
Aggregate Production and Processing	CO <sub>2</sub>	No	Excluded as the same quantity of aggregate would be produced and processed in the project and baseline scenarios.
	CH <sub>4</sub>	No	
	N <sub>2</sub> O	No	
Transportation of Aggregate	CO <sub>2</sub>	No	Excluded as the same quantity of aggregate would be transported in the project and baseline scenarios.
	CH <sub>4</sub>	No	
	N <sub>2</sub> O	No	
Fuel Extraction and Processing	CO <sub>2</sub>	Yes	Fuel used for the source: Additional Sulphur Heating is incremental in the project scenario and emissions must be included.
	CH <sub>4</sub>	Yes	
	N <sub>2</sub> O	Yes	

Source		Gas	Included?	Justification/Explanation
Fuel Delivery	CO <sub>2</sub>	No	Excluded as the emissions from transportation are likely negligible.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Electricity Generation and Transmission	CO <sub>2</sub>	No	There will be no incremental electricity consumption in the project scenario over the baseline scenario.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Additional Sulphur Heating	CO <sub>2</sub>	Yes	Any heat derived from sources that emit greenhouse gases is incremental to the baseline scenario and must be included.	
	CH <sub>4</sub>	Yes		
	N <sub>2</sub> O	Yes		
Aggregate Heating	CO <sub>2</sub>	Yes	Any heat derived from sources that emit greenhouse gases is incremental to the baseline scenario and must be included.	
	CH <sub>4</sub>	Yes		
	N <sub>2</sub> O	Yes		
Concrete Mixing	CO <sub>2</sub>	No	The process for concrete mixing is equivalent in the baseline and project scenarios.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Concrete Transportation	CO <sub>2</sub>	No	The same quantity of concrete will be transported in the baseline and project scenarios.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Precast Product Pouring and Forming	CO <sub>2</sub>	No	The process for pouring and forming will not change between the baseline and project scenarios.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Precast Product Transportation	CO <sub>2</sub>	No	There is no difference in the transportation-related emissions between the baseline and project scenarios.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		
Concrete Recycling or Disposal	CO <sub>2</sub>	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.	
	CH <sub>4</sub>	No		
	N <sub>2</sub> O	No		

## 6 PROCEDURE FOR DETERMINING THE BASELINE SCENARIO

The baseline scenario for projects applying this methodology is the production of precast concrete products using Portland cement. Project proponents must demonstrate that this is the most reasonable and credible baseline for their project using the most recent version of the CDM methodological tool “*Combined tool to identify the baseline scenario and determine additionality.*”. Project proponents should use Step 1 of the referenced tool to identify all realistic and credible baseline alternatives. In doing so, relevant local regulations governing the use of different technologies and technical specifications of concrete products should be taken into account.

## 7 PROCEDURE FOR DEMONSTRATING ADDITIONALITY

Additionality will be assessed and demonstrated using the most recent version of the CDM methodological tool “*Combined tool to identify the baseline scenario and determine additionality.*”

## 8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

### 8.1 Baseline Emissions

The production of clinker results in the release of significant process GHG emissions and combustion GHG emissions. Carbon dioxide process emissions occur as a by-product of the calcination process, where a calcium or magnesium carbonate such as limestone is heated with clay to form clinker (primarily calcium oxide) and carbon dioxide. The heat required for the calcination process is typically supplied from the combustion of fossil fuels, resulting in the emission of further carbon dioxide as well as smaller amounts of methane and nitrous oxide.

The calculation of GHG emissions related to the production of Portland cement in the baseline scenario will be based on the mass of sulphur cement used in the project scenario. An equivalency factor will be used to provide functional equivalence between the mass of sulphur cement and Portland cement. Finally, an emission factor will be applied that represents the mass of carbon dioxide-equivalent GHG emissions per tonne of displaced Portland cement.

Emissions under the baseline scenario (in tonnes CO<sub>2</sub> equivalent) are determined using the following equation:

$$BE_y = BE_{Portland} \quad (1)$$

Where:

BE<sub>y</sub> = the sum of baseline emissions in a given year, y

BE<sub>Portland</sub> = emissions due to the production of Portland cement

The emissions due to the production of Portland cement under the baseline scenario are calculated as follows:

$$BE_{Portland} = (Mass_{Precast} \times \%_{PC} - Mass_{Portland\ Cement}) \times EF_{Portland\ Cement\ Production} \quad (2)$$

Where:

Mass <sub>Precast</sub> =	the measured mass of finished precast products (tonnes)
% <sub>PC</sub> =	the manufacturer's specification for the ratio of Portland cement in the finished precast products (unitless value)
Mass <sub>PortlandCement</sub> =	the measured mass of Portland cement used in the finished precast products under the project scenario if not completely replaced by sulphur cement (tonnes)
EF <sub>Portland Cement Production</sub> =	CO <sub>2</sub> equivalent emission factor for the production of Portland Cement (kg CO <sub>2</sub> E per tonne Portland cement)

## 8.2 Project Emissions

Emissions under the project scenario (in tonnes CO<sub>2</sub> equivalent) are determined using the following equation:

$$PE_y = PE_{Degassing} + PE_{Additional\ S\ Heating} + PE_{Agg\ Heating} + PE_{Fuel} + PE_{S\ Trans\&\ Storage} + PE_{Modifier} \quad (3)$$

Where:

PE <sub>y</sub> =	the sum of project emissions in a given year, y
PE <sub>Degassing</sub> =	emissions due to sulphur degassing
PE <sub>Additional S Heating</sub> =	emissions due to the additional heating requirements of sulphur concrete
PE <sub>Agg Heating</sub> =	emissions due to heating the aggregate
PE <sub>Fuel</sub> =	emissions due to the extraction and processing of fuel
PE <sub>S Trans&amp;Storage</sub> =	emissions due to the transportation and storage of sulphur
PE <sub>Modifier</sub> =	emissions due to the production and transportation of the sulphur modifier

The emissions due to sulphur degassing under the project scenario are calculated as follows:

$$PE_{Degassing} = \sum (Vol\ Fuel_i \times EF\ Fuel_{CO_2}) + \left( Vol_{vent\ gas} \times MF_{CO_2} \times \frac{m_{CO_2}}{V_{STP}} \right); \quad (4)$$

$$\sum (Vol\ Fuel_i \times EF\ Fuel_{CH_4}); \sum (Vol\ Fuel_i \times EF\ Fuel_{N_2O})$$

Where:

VolFuel <sub>i</sub> =	the volume of each type of fuel combusted under the project scenario (L, m <sup>3</sup> or other)
EF Fuel <sub>x</sub> =	the emissions factor for fuel production and processing for each GHG listed (kg GHG/L, m <sup>3</sup> or other).
Vol <sub>vent gas</sub> =	volume of degassing vent gas incinerated (m <sup>3</sup> )
MF <sub>CO<sub>2</sub></sub> =	molar fraction of CO <sub>2</sub> in degassing vent gas incinerated (%)
m <sub>CO<sub>2</sub></sub> =	molar mass of CO <sub>2</sub> (kg/mol)
V <sub>STP</sub> =	volume of one kg-mole of an ideal gas at standard temperature and pressure (m <sup>3</sup> )

The emissions for additional heating of sulphur are calculated as follows:

$$PE_{Additional\ Heating} = \sum (Vol\ Fuel_i \times EF\ Fuel_{CO_2}); \sum (Vol\ Fuel_i \times EF\ Fuel_{CH_4}); \sum (Vol\ Fuel_i \times EF\ Fuel_{N_2O}) \quad (5)$$

Where:

VolFuel<sub>i</sub> = the volume of each type of fuel combusted for additional sulphur heating (L, m<sup>3</sup> or other)  
 EF Fuel<sub>x</sub> = the emissions factor for fuel combustion for each GHG listed (kg GHG/L, m<sup>3</sup> or other).

The emissions for heating of aggregate are calculated as follows:

$$PE_{Agg\ Heating} = \sum (Vol\ Fuel_i \times EF\ Fuel_{CO_2}); \sum (Vol\ Fuel_i \times EF\ Fuel_{CH_4}); \sum (Vol\ Fuel_i \times EF\ Fuel_{N_2O}) \quad (6)$$

Where:

VolFuel<sub>i</sub> = the volume of each type of fuel combusted for aggregate heating (L, m<sup>3</sup> or other)  
 EF Fuel<sub>x</sub> = the emissions factor for fuel combustion for each GHG listed (kg GHG/L, m<sup>3</sup> or other).

The emissions due to the extraction and processing of fossil fuels under the project scenario are calculated as follows:

$$PE_{Fuel} = \sum (Vol\ Fuel_i \times EF\ Fuel_{CO_2}); \sum (Vol\ Fuel_i \times EF\ Fuel_{CH_4}); \sum (Vol\ Fuel_i \times EF\ Fuel_{N_2O}) \quad (7)$$

Where:

VolFuel<sub>i</sub> = the volume of each type of fuel combusted under the project scenario (L, m<sup>3</sup> or other)  
 EF Fuel<sub>x</sub> = the emissions factor for fuel production and processing for each GHG listed (kg GHG/L, m<sup>3</sup> or other).

The emissions due to transportation and storage of molten sulphur under the project scenario are calculated as follows:

$$PE_{S\ Trans\&\ Storage} = Mass\ Distance \times EF_{Transport} \quad (8)$$

Where:

Mass Distance = the product of the mass of sulphur and the distance shipped from sulphur manufacturing facility to pre-cast manufacturing facility (tonne.km)  
 EF<sub>Transport</sub> = CO<sub>2</sub> equivalent emissions factor for truck transportation (kg CO<sub>2</sub>E/ tonne.km).

The emissions due to the production and transportation of modifier are calculated as follows:

$$PE_{Modifier} = M_{Modifier} \times EF_{Modifier} + Mass\ Distance_{Modifier} \times EF_{Transport} \tag{9}$$

Where:

- $M_{Modifier}$  = mass of modifier used (tonne)
- $EF_{Modifier}$  = CO<sub>2</sub> equivalent emission factor for modifier production (kg CO<sub>2</sub>E/tonne modifier)
- $Mass\ Distance_{Modifier}$  = the product of the mass of modifier and the distance shipped from modifier manufacturing facility to facility where modifier is added to sulphur (tonne.km)
- $EF_{Transport}$  = CO<sub>2</sub> equivalent emissions factor for truck transportation (kg CO<sub>2</sub>E/ tonne.km).

### 8.3 Leakage

No sources of leakage have been identified for this project activity.

### 8.4 Summary of GHG Emission Reductions

The emission reductions for this project activity are calculated as follows:

$$ER_y = BE_y - PE_y \tag{10}$$

Where:

- $ER_y$  = Net GHG emissions reductions and/or removals in year y
- $BE_y$  =Baseline emissions in year y
- $PE_y$  = Project emissions in year y

## 9 MONITORING

### 9.1 Data and Parameters Available at Validation

The following data will be made available at validation by the project proponent. Default values may vary according the physical location of the project activity. The project proponent must provide evidence and justification that the values presented here are applicable to their project activity, or provide and justify project-specific values as needed.

Should the data parameters listed below not be available at the time of validation, the project proponent must provide a plan for determining and/or monitoring the data during the project. All parameters used must be reviewed on an annual basis to ensure the most current value is used in calculations.

Data Unit / Parameter:	Emission factor for the production of Portland cement ( $EF_{Portland\ Cement\ Production}$ )
Data unit:	kg CO <sub>2</sub> E per tonne of Portland Cement

Description:	Emission factor describing GHG emissions from production of Portland cement.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Reference values may be calculated following the methodology presented in Appendix A, using data published by the World Business Council for Sustainable Development.
Any comment:	Project proponents must provide justification for the selection of kiln type.

Data Unit / Parameter:	Emissions factors for fuel combustion ( $EF_{Fuel, GHG}$ )
Data unit:	kg (CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O) per L, m3 or other of each type of fuel used
Description:	Emission factor describing GHG emissions from combustion of fuel. Used under both the project and baseline scenarios.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Reference values may be obtained from national and international GHG inventories. In the absence of local or regional data, reference values may be obtained from the most recent version of the IPCC guidelines for National Greenhouse Gas Inventories.
Any comment:	Review of best practice guidance and accepted standards. Reference values are generally available.

Data Unit / Parameter:	Molar mass of carbon dioxide: 0.04401
Data unit:	g/mol
Description:	Constant
Source of data:	Accepted value
Justification of choice of data or description of measurement methods and procedures applied:	
Any comment:	

Data Unit / Parameter:	Volume of one kg-mole of an ideal gas at standard temperature and pressure: 23.6449
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Data unit:	m <sup>3</sup>
Description:	Constant
Source of data:	Accepted value
Justification of choice of data or description of measurement methods and procedures applied:	
Any comment:	

Data Unit / Parameter:	Emissions factors for fuel extraction and processing (EF <sub>Fuel I, GHG</sub> )
Data unit:	kg (CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O) per L, m3 or other of each type of fuel used
Description:	Emission factor describing GHG emissions from extraction and processing of fuel combusted.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Reference values may be obtained from national and international GHG inventories. In the absence of local or regional data, reference values may be obtained from the most recent version of the IPCC guidelines for National Greenhouse Gas Inventories.
Any comment:	Review of best practice guidance and accepted standards. Reference values are generally available.

## 9.2 Data and Parameters Monitored

The following data parameters will be monitored during the project.

Data Unit / Parameter:	Mass of precast products produced (Mass <sub>Precast</sub> )
Data unit:	Tonne
Description:	The mass of finished precast concrete products
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct measurement of the mass of the finished product.
Frequency of monitoring/recording:	Each product
QA/QC procedures to be applied:	
Any comment:	Measurement is standard practice.

Data Unit / Parameter:	Ratio of Portland cement in finished product (% <sub>PC</sub> )
Data unit:	Unitless
Description:	The ratio of Portland cement in the finished product
Source of data:	Estimated
Description of measurement methods and procedures to be applied:	Manufacturer's specification for the ratio of Portland cement in the finished product.
Frequency of monitoring/recording:	Per product.
QA/QC procedures to be applied:	
Any comment:	The use of manufacturer's specifications provides a method for establishing functional equivalence between the product used in the baseline scenario and the product used in the project scenario.

Data Unit / Parameter:	Mass of Portland cement used (Mass <sub>Portland</sub> )
Data unit:	Tonnes
Description:	The mass of Portland cement used in the project scenario
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct measurement of the mass of Portland cement used in the project scenario if sulphur cement does not completely replace Portland cement.
Frequency of monitoring/recording:	Per product
QA/QC procedures to be applied:	
Any comment:	

Data Unit / Parameter:	Volume of each type of fuel combusted during the project for sulphur degassing, aggregate heating and additional sulphur heating (VolFuel <sub>i</sub> )
Data unit:	L, m <sup>3</sup> or other
Description:	The volume of fuel used
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	The project proponent may measure the volume of fuel consumed in one of two ways: 1. Direct metering or reconciliation of volumes

	received and in storage (preferred); 2. Reconciliation of volume of fuel purchased within a given time period.
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	Cross-checking of metered volumes vs. theoretical fuel use, analysis of data trends.
Any comment:	

Data Unit / Parameter:	Volume of degassing vent gas incinerated (Vol <sub>vent gas</sub> )
Data unit:	m <sup>3</sup>
Description:	The volume of vent gas incinerated
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct metering of vent gas to the incinerator
Frequency of monitoring/recording:	Continuous metering with monthly reconciliation
QA/QC procedures to be applied:	
Any comment:	

Data Unit / Parameter:	Molar fraction of carbon dioxide in incinerated vent gas (MF <sub>CO2</sub> )
Data unit:	%
Description:	Molar fraction of carbon dioxide in incinerated vent gas
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct metering of vent gas to the incinerator
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	
Any comment:	

Data Unit / Parameter:	Mass distance of sulphur transported to the concrete facility (Mass Distance)
Data unit:	Tonne.km
Description:	Product of the mass of sulphur used and the distance shipped from sulphur manufacturing facility to precast manufacturing facility.

Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct measurement of mass of sulphur received and distance traveled, based on manifests or supplier invoices.
Frequency of monitoring/recording:	Each shipment
QA/QC procedures to be applied:	Retention of trucking manifests, copies of truck logs, or invoices from the supplier.
Any comment:	

Data Unit / Parameter:	Emissions factor for truck transportation ( $EF_{Transport}$ )
Data unit:	kg CO <sub>2</sub> E per tonne.km
Description:	Emissions factor describing transportation emissions.
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Actual measured or local data is to be used. If not available, regional data should be used and, in its absence, IPCC defaults can be used from the most recent version of IPCC Guidelines for National Greenhouse Gas Inventories.
Frequency of monitoring/recording:	Per shipment if actual fuel consumption is used, or annual adjustment of a calculated emissions factor.
QA/QC procedures to be applied:	
Any comment:	

Data Unit / Parameter:	Mass of modifier used in sulphur cement ( $M_{Modifier}$ )
Data unit:	Tonne
Description:	Mass of modifier used in sulphur cement
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct measurement
Frequency of monitoring/recording:	Per shipment of modifier
QA/QC procedures to be applied:	Comparison to historical values and analysis of trends
Any comment:	

Data Unit / Parameter:	Emissions factor for modifier production (EF <sub>Modifier</sub> )
Data unit:	kg CO <sub>2</sub> E/ tonne of modifier
Description:	Emission factor describing emissions due to production of modifier
Source of data:	Estimated
Description of measurement methods and procedures to be applied:	Value provided by the modifier manufacturer based on fuel and electricity consumed.
Frequency of monitoring/recording:	Per shipment of modifier, to be updated annually by manufacturer of modifier
QA/QC procedures to be applied:	Comparison to historical values and analysis of trends
Any comment:	

Data Unit / Parameter:	Mass distance of modifier transported to the concrete facility (Mass Distance)
Data unit:	Tonne.km
Description:	Product of the mass of modifier used and the distance shipped from modifier manufacturing facility to sulphur cement manufacturing facility.
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	Direct measurement of mass of modifier received and distance traveled based on manifests or supplier invoices.
Frequency of monitoring/recording:	Each shipment
QA/QC procedures to be applied:	Retention of trucking manifests, copies of truck logs, or invoices from the supplier.
Any comment:	

Data Unit / Parameter:	Sulphur cement manufacturer's specifications for safe handling, storage and use
Data unit:	Unitless
Description:	The handling, storage, mix production temperature and other key factors specified by the manufacturer for the proper and safe use of must followed by the project proponent.
Source of data:	Each supplier of sulphur cement
Description of measurement methods and procedures to be applied:	Evidence that manufacturer's specifications have been adhered to. Direct measurement of mix

	production temperature, documented handling methods, and similar procedures for each key factor.
Frequency of monitoring/recording:	Each shipment
QA/QC procedures to be applied:	Retention of manufacturer's specifications.
Any comment:	

### 9.3 Description of the Monitoring Plan

The project proponent must develop a monitoring plan detailing the procedures for data capture, measurement and reporting of the data parameters listed in Section 9.2. In general, data quality management must include sufficient data capture such that the mass and energy balances may be easily performed with the need for minimal assumptions and use of contingency procedures. The data should be of sufficient quality to fulfill the quantification requirement and be substantiated by company records for the purpose of verification.

The project proponent shall establish and apply quality management procedures to manage data and information. Written procedures should be established for each measurement task outlining responsibility, timing and record location requirements. The greater the rigour of the management system for the data, the more easily an audit will be conducted for the project.

Record keeping practices shall be established that include:

- Electronic recording of values of logged primary parameters for each measurement interval;
- Printing of monthly back-up hard copies of all logged data;
- Written logs of operations and maintenance of the project system including notation of all shut-downs, start-ups and process adjustments;
- Retention of copies of logs and all logged data for a period of 2 years past the end of the crediting period; and
- Keeping all records available for review by a verification body.

The project proponent must also develop a Quality Assurance/Quality Control (QA/QC) plan to add confidence that all measurements and calculations have been made correctly. QA/QC measures that may be implemented include but are not limited to:

- Protecting monitoring equipment (sealed meters and data loggers);
- Protecting records of monitored data (hard copy and electronic storage);
- Checking data integrity on a regular and periodic basis (manual assessment, comparing redundant metered data and detection of outstanding data/records);
- Comparing current estimates with previous estimates as a 'reality check';
- Provide sufficient training to operators to perform maintenance and calibration of monitoring devices;
- Establish minimum experience and requirements for operators in charge of project and monitoring; and
- Performing recalculations to make sure no mathematical errors have been made.

## 10 REFERENCES AND OTHER INFORMATION

The good practice guidance and best science used to develop the quantification methodology are presented below in Table .

**Table 2: Good Practice Guidance**

Document Title	Publishing Body / Date	Description
General Protocol Guidance		
Canada's National Inventory Report: Greenhouse Gas Sources and Sinks in Canada, 1990-2008	Government of Canada (2010)	On behalf of the Government of Canada, Environment Canada releases a national inventory of greenhouse gases annually in accordance with international UNFCCC reporting standards.
Alberta Offset System Offset Credit Project Guidance Document	Alberta Environment (February 2008)	A draft guidance document outlining how to develop offset projects under the Alberta Offset System.
ISO 14064-2	International Organization for Standardization (2006)	Provides guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.
ISO 14064-3	International Organization for Standardization (2006)	Provides guidance for the validation and verification of greenhouse gas assertions.
Protocols Reviewed		
ACM0015 Version 3: Consolidated baseline and monitoring methodology for project activities using alternative raw materials that do not contain carbonates for clinker production in cement kilns	Clean Development Mechanism – Executive Board (March 2010)	Approved baseline and monitoring methodology for alternative raw materials for clinker production in cement kilns.
Quantification Protocol for the Substitution of Bitumen Binder in Hot Mix Asphalt Production and Usage	Alberta Environment (October 2009)	General guidance on selection of SSR, quantification and monitoring.
ACM0005 Version 5: Consolidated Baseline Methodology for Increasing the Blend in Cement Production	Clean Development Mechanism – Executive Board (October 2009)	Approved baseline and monitoring methodology for reducing the amount of clinker per tonne of blended cement.

Document Title	Publishing Body / Date	Description
Cement Reporting Protocol	California Climate Action Registry	Provides guidance on accounting and reporting GHG emissions for cement companies.
CO2 Accounting and Reporting Standard for the Cement Industry	World Business Council for Sustainable Development, Version 2.0 (June 2005)	Provides a methodology for calculating and reporting CO2 emissions.
DRAFT Quantification Protocol for the Use of Fly Ash in Concrete and Other Cement Based Products	Alberta Environment (October 2008)	Early technical work considering selection of SSRs and quantification for alternatives to cement used to produce concrete and other cement based products.
Other Resources		
Submission to the Prime Ministerial Task Group on Emissions Trading	Cement Australia (March 2007)	Comments on the Issues Paper released by the Prime Minister's Task Group on Emissions Trading
A Sulphur Concrete Retaining Wall	University of Alberta (2002)	An evaluation of the technical feasibility of constructing sizer walls using sulphur concrete.
Corrosion and Chemical Resistant Masonry Materials Handbook, Walter Lee Sheppard	Noyes Publications (1986)	
National Pollution Inventory, Hydrogen Sulfide: Environmental Effects	Australian Government	See <a href="http://www.npi.gov.au/substances/hydrogen-sulfide/environmental.html">http://www.npi.gov.au/substances/hydrogen-sulfide/environmental.html</a> for further information.
A blueprint for a climate friendly cement industry	WWF International	
CO2 emissions from cement production	ICF Incorporated / USEPA	Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
Sulfurcrete Sulfur Concrete Technology	Cominco	
Concrete Technology – Third Edition, M L Gambhir	Tata McGraw-Hill (2004)	
Sulphur concrete – a new construction material	PCI Journal/January-February 1974	

Document Title	Publishing Body / Date	Description
Cement Sector greenhouse gas emissions reduction	The Loreti Group (2009)	
Shell, Life cycle assessment of sulphur concrete	2009 (Confidential; some relevant results of the study have been presented to the Technical Working Group)	Dutch consulting firm INTRON examined a number of pathways to market for sulphur concrete products, and estimated the net GHG and other environmental benefits.
Shell – product information on Shell Thiocrete	See <a href="http://www.shell.com">www.shell.com</a> for further information.	Shell Thiocrete is a modified sulphur binder specifically designed to replace Portland cement in the production of concrete products, such as paving stones and curbs.

**APPENDIX A: Emission Factors for the Production of Portland Cement**

In 2009, The World Business Council for Sustainable Development launched The Cement Sustainability Initiative with a report, *Cement Industry Energy and CO2 Performance “Getting the Numbers Right.”*. The report provides carbon dioxide and energy performance information based on emissions data from individual cement plants. The report aims “to develop representative statistical information on the CO2 and energy performance of clinker and cement production worldwide” (WBCSD, 2009).

The report offers two pieces of essential information needed to derive a regional emission factor for cement production: the emission factor for clinker production (Table A1) and the ratio of clinker in Portland cement (Table A2) on a regional basis.

**Table A1: CO2 Emissions per tonne of clinker per kiln type (Global Average)**

Kiln Type	kg CO <sub>2</sub> /tonne clinker (EF <sub>Clinker</sub> )
Dry with preheater and precalciner	842
Dry with preheater and without precalciner	861
Dry without preheater	955
Semi wet/Semi dry	896
Wet	1043

**Table A2: Ratio of Clinker to Cement on a Regional Basis**

Region	Clinker to Cement Ratio (%)
Africa and Middle East	79
Asia excluding China, India, CIS and Japan	84
China and India	74
CIS	80
Europe	76
Japan, Australia and New Zealand	83
Latin America	74
North America	84
World	78

The emission factor for Portland cement production can be calculated as follows:

$$EF_{Portland} = \frac{Mass_{Clinker}}{Mass_{Cement}} \times EF_{Clinker}$$

Where:

$Mass_{Clinker}/Mass_{Cement}$  = the Clinker to cement ratio provided in Table A2 for the project region  
 $EF_{Clinker}$  = the emission factor per tonne of clinker for the kiln type used in the project region. If the kiln type is not known, the value for a wet kiln must be used as a default.