

SUBSTITUTION OF BITUMEN BINDER IN HOT ASPHALT PRODUCTION AND USAGE

Document Prepared by Leading Carbon Ltd.

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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. There are currently no approved or pending VCS methodologies within the Manufacturing Industries, Construction or Transportation sectoral scopes. Approved methodologies within the remaining sectoral scopes were reviewed to determine their applicability. No methodologies related to process changes in asphalt production were identified. Two methodologies in the manufacturing sectoral scope were identified as potentially relevant and were reviewed. The methodologies and the results of the review are outlined in Table 1.

Table 1: Summary of Related Methodologies

Methodology	Title	Primary Reduction Mechanism	Comments
AMS-II.D	Energy efficiency and fuel switching measures for industrial facilities	Increase in energy efficiency.	Reviewed because the production of sulphur asphalt requires less energy than conventional production. However, the production of sulphur asphalt requires significant process changes not reflected in this methodology.
ACM0005 v5	Consolidated baseline methodology for increasing the blend in concrete production, CDM October 2009	Avoidance of process CO2 emissions due to feedstock switch.	Reviewed because use of sulphur modifier for asphalt production involves a feedstock switch and substitution of a sulphur product. The production of sulphur asphalt requires significant process changes not reflected in this methodology.

A review of the related methodologies indicated that the process changes required to substitute a sulphur product for bitumen binder would result in significant changes to the existing methodologies, and adaptation would not be feasible. Research into other voluntary and compliance based GHG offset systems did not uncover any existing GHG quantification protocols that relate to the substitution of a solid sulphur product for the asphalt binder used in conventional hot mix asphalt paving mix.

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1 SOURCES

This methodology is based on the *Quantification Protocol for the Substitution of Bitumen Binder in Hot Mix Asphalt Production and Usage v 1.0*, 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; and
- *Tool for the demonstration and assessment of additionality* Version 5.2.1.

In addition, technical and good practice guidance was obtained from Environment Canada's annual GHG reporting, the US EPA's Emission Inventory, the Intergovernmental Panel on Climate Change (IPCC), the Canadian Association of Petroleum Producers (CAPP) and various other reliable sources of information pertaining to the hot mix asphalt 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

This methodology was developed to calculate the greenhouse gas emissions (GHG) reductions achieved by substituting a sulphur product for a proportion of the bitumen binder used in conventional hot asphalt paving. The use of a sulphur product in place of a portion of bitumen binder reduces required quantities of aggregate and bitumen, reduces fuel usage due to lowered mix production temperatures and reduces emissions from the hot mix plant stack and paving.

The sulphur product substituted for asphalt must be Sulphur Extended Asphalt Modifier (SEAM) pellets or a similar solid sulphur product, composed of sulphur and small quantities of plasticizer and H₂S scavenger additives. Other additives such as carbon black could be used to impart particular characteristics to the final product. The product may also contain wax additives, used to further reduce hot mix production and compaction temperatures. Note, however, that reduced hot mix production and compaction temperatures are anticipated for hot mix facilities using SEAM with and without wax additives, and this protocol applies to hot mix facilities using either formulation of SEAM. This methodology is not applicable to project proponents who substitute other products for asphalt binder in paving mix, given the potential differences in the products' component sources, composition and GHG emissions.

The baseline configuration would be the use of conventional hot mix asphalt. The relative amounts of aggregate and bitumen binder vary depends on the type of road paved (e.g. highway or city street). The project activity could be implemented at existing hot mix facilities or new facilities as a best practice technology.

The opportunity for generating GHG emission reductions arises primarily from the avoided production of a proportion of the asphalt binder used in conventional asphalt paving mix and, secondarily, from reduced consumption of fossil fuels due to lower mix production temperatures. GHG emission reductions may also take place due to avoided fugitive emissions of methane associated with the handling and storage of asphalt; such emissions would have been emitted from hot mix facilities where the baseline practice was the use of conventional paving mix.

3 DEFINITIONS

SEAM	Sulphur Extended Asphalt Modifier
Bitumen Handling Emissions	Intentional and unintentional GHG emissions released during bitumen handling and storage from joints, seals, etc. of processing, piping and treatment equipment.
Aggregate	Coarse particulate material including sand, gravel, crushed stone, slag, and recycled concrete, which may be sourced from gravel pits, quarries and other local areas surrounding the hot mix facility.
Binder	Hot mix asphalt binder serves as a waterproof adhesive that binds the aggregate together and includes the sum of the quantities of bitumen and sulphur extender consumed.
Bitumen	A petroleum-based liquid asphalt product, produced from the heavy crude oil refining process. Crude oil at the refinery is first subjected to atmospheric distillation and the short residue is processed in a vacuum tower (i.e. vacuum distillation). Paving grade bitumen is the residue left after distilling off all of the lighter fuels. After refining, bitumen is stored at the refinery at temperatures of approximately 170°C until transportation and delivery to the hot mix facility.
Hot Mix Asphalt	The mixture of binder and aggregate delivered from the hot mix facility to the silo/truck for load-out and delivery to the paving site. The aggregate-to-binder mix ratio depends on optimal pavement performance properties and may vary at each hot mix facility and for each project.

4 APPLICABILITY CONDITIONS

This methodology is applicable to the production of hot mix asphalt using a sulphur extender, where the following conditions are met:

1. The most reasonable and credible baseline scenario is the production of conventional hot mix asphalt, as demonstrated using the methodology outlined in Section 6;
2. A proportion of the bitumen binder used in conventional hot mix asphalt production has been substituted for a solid sulphur product, with or without a wax additive;
3. Industry best practices are followed for appropriate handling, mix production temperatures and disposal of any mix produced at temperatures exceeding the maximum allowable mix temperature, as specified by the sulphur extender manufacturer. This will require strict adherence to the procedures contained in the sulphur extender product's manufacturer documentation for handling and storage of solid sulphur, handling and use of the sulphur extender product, construction specifications, mix design, etc.;
4. Hot mix asphalt production temperatures are monitored at the plant outlet to ensure production within the appropriate temperature range; and
5. The resulting asphalt product meets local legal and technical requirements. In the absence of local technical specifications for asphalt, project proponents must demonstrate that asphalt produced under the project scenario provides the equivalent function to asphalt that would have been produced under the baseline scenario.

5 PROJECT BOUNDARY

The project boundary is the physical, geographic location of the hot mix asphalt production facility. The project boundary includes the storage of aggregate, bitumen and sulphur extender and the production of the hot mix asphalt. A generalized process flow diagram of a typical project is presented in Figure 1.

The temporal project boundary includes the operation of an existing hot mix facility during the incorporation of a sulphur extender project. GHG sources related to the construction and decommissioning of the hot mix 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 hot mix facility.

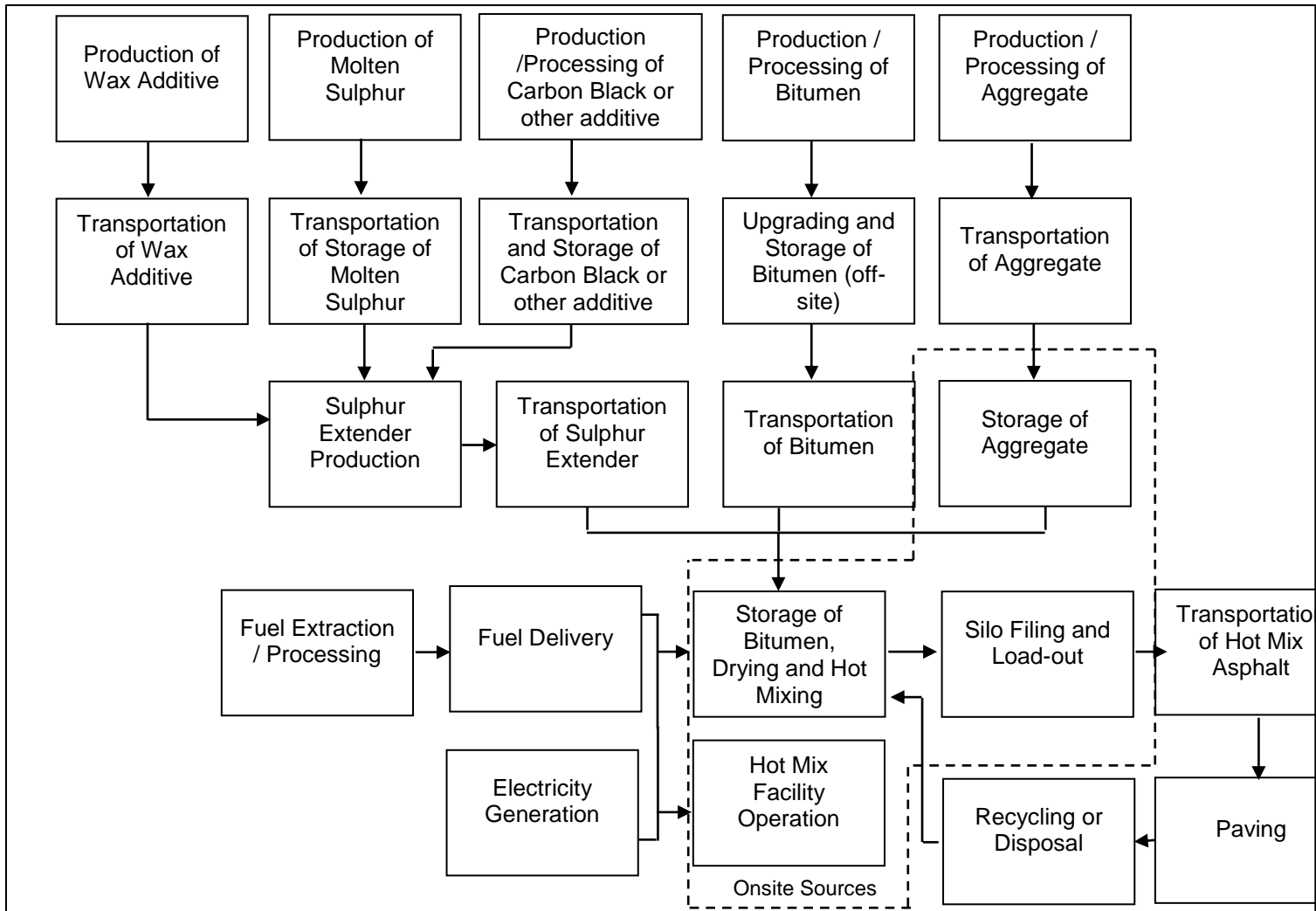


Figure 1: Project Process Flow Diagram

The GHG sources represented in Figure 1 were compared to the sources in the baseline scenario and their relevancy evaluated to determine whether the GHG emissions are included or excluded during quantification of GHG emission reductions. GHG sources included or excluded from the project boundary are presented in

Table 2.

Table 2: GHG Sources

Source		Gas	Included?	Justification/Explanation
Baseline	Production of molten sulphur	CO ₂	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 petroleum refining and would be produced in both the project and baseline scenarios in the same quantity.
		CH ₄	No	
		N ₂ O	No	

Source		Gas	Included?	Justification/Explanation
Production/Processing of Bitumen		CO ₂	Yes	Emissions from the production/processing of bitumen used in asphalt production may be material and can be quantified.
		CH ₄	Yes	
		N ₂ O	Yes	
Production/Processing of Aggregate		CO ₂	Yes	Emissions from the production/processing of aggregate used in asphalt production may be material and can be quantified.
		CH ₄	Yes	
		N ₂ O	Yes	
Transportation and Storage of Molten Sulphur		CO ₂	No	Emissions are based on the quantity of sulphur used in the project scenario; therefore, an equivalent quantity of sulphur would be transported in both the project and baseline scenarios. It is likely that the emissions under this source will be functionally equivalent in the project and baseline, as the distance to sulphur processing facilities will remain the same.
		CH ₄	No	
		N ₂ O	No	
Upgrading and Storage of Bitumen (off-site)		CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
Transportation of Aggregate		CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
Transportation of sulphur product		CO ₂	No	Excluded as the emissions from transportation are likely negligible.
		CH ₄	No	
		N ₂ O	No	
Transportation of Bitumen		CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
Fuel Extraction/Processing		CO ₂	Yes	Included as the emissions may be material and can be quantified.
		CH ₄	Yes	
		N ₂ O	Yes	
Fuel Delivery		CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
Electricity Generation		CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	

Source		Gas	Included?	Justification/Explanation
Project	Storage of Aggregate	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
	Storage of Bitumen, Drying and Hot Mixing	CO ₂	Yes	Included as the emissions may be material and can be quantified. Emissions are dependent on the hot mix temperatures and will therefore vary between the baseline and project scenarios.
		CH ₄	Yes	
		N ₂ O	Yes	
	Hot Mix Facility Operation	CO ₂	No	Excluded as the hot mix facility's operations will not likely be impacted by the project activity and will therefore be functionally equivalent in the project and baseline scenarios.
		CH ₄	No	
		N ₂ O	No	
	Silo Filling and Load-out	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
	Transportation of hot mix asphalt	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
	Paving	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
	Recycling or Disposal	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
		CH ₄	No	
		N ₂ O	No	
Production of wax additive	CO ₂	No	Excluded due to the negligible quantity of wax added to the sulphur extender product and the immaterial quantity of GHG emissions associated with production of this quantity of wax.	
	CH ₄	No		
	N ₂ O	No		
Production of molten sulphur	CO ₂	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 ₄	No		
	N ₂ O	No		
Production/Processing	CO ₂	Maybe	Emissions from the production of	

Source		Gas	Included?	Justification/Explanation
of Carbon Black or other additives	CH ₄	Maybe	additives, each with unique carbon intensity, used in the sulphur extender product may be material and can be quantified.	
	N ₂ O	Maybe		
Production/Processing of Bitumen	CO ₂	Yes	Emissions from the production/processing of bitumen used in asphalt production may be material and can be quantified.	
	CH ₄	Yes		
	N ₂ O	Yes		
Production/Processing of Aggregate	CO ₂	Yes	Emissions from the production/processing of aggregate used in asphalt production may be material and can be quantified.	
	CH ₄	Yes		
	N ₂ O	Yes		
Transportation of wax additive	CO ₂	No	Emissions from the transportation of the small quantity of wax additive used are assumed to be negligible.	
	CH ₄	No		
	N ₂ O	No		
Transportation and Storage of Molten Sulphur	CO ₂	No	Emissions are based on the quantity of sulphur used in the project scenario; therefore, an equivalent quantity of sulphur would be transported in both the project and baseline scenarios. It is likely that the emissions under this source will be functionally equivalent in the project and baseline, as the distance to sulphur processing facilities will remain the same.	
	CH ₄	No		
	N ₂ O	No		
Transportation and Storage of Carbon Black or other additives	CO ₂	No	Excluded as the emissions are negligible given the small quantities of additive consumed.	
	CH ₄	No		
	N ₂ O	No		
Upgrading and Storage of Bitumen (off-site)	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.	
	CH ₄	No		
	N ₂ O	No		
Transportation of Aggregate	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.	
	CH ₄	No		
	N ₂ O	No		
Sulphur Extender Production	CO ₂	No	Excluded for simplification. Given that emissions are based on the quantity of applied sulphur extender, the emissions would be functionally equivalent under the baseline and project scenarios.	
	CH ₄	No		
	N ₂ O	No		
Transportation of	CO ₂	No	Excluded as the emissions from	

Source	Gas	Included?	Justification/Explanation
sulphur extender	CH ₄	No	transportation are likely negligible.
	N ₂ O	No	
Transportation of Bitumen	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	
Fuel Extraction/Processing	CO ₂	Yes	Included as the emissions may be material and can be quantified.
	CH ₄	Yes	
	N ₂ O	Yes	
Fuel Delivery	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	
Electricity Generation	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	
Storage of Aggregate	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	
Storage of Bitumen, Drying and Hot Mixing	CO ₂	Yes	Included as the emissions may be material and can be quantified. Emissions are dependent on the hot mix temperatures and will therefore vary between the baseline and project scenarios.
	CH ₄	Yes	
	N ₂ O	Yes	
Hot Mix Facility Operation	CO ₂	No	Excluded as the hot mix facility's operations will not likely be impacted by the project activity and will therefore be functionally equivalent in the project and baseline scenarios.
	CH ₄	No	
Silo Filling and Load-out	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	
Transportation of hot mix asphalt	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	
Paving	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.
	CH ₄	No	
	N ₂ O	No	

Source		Gas	Included?	Justification/Explanation
	Recycling or Disposal	CO ₂	No	Excluded for simplification. This is conservative as the emissions are likely higher under the baseline scenario.

6 PROCEDURE FOR DETERMINING THE BASELINE SCENARIO

The baseline scenario for projects applying this methodology is the production of conventional hot mix asphalt. 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 road surfaces 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

Emissions under the baseline scenario (in tonnes CO₂E) are determined using the following equation:

$$BE_y = BE_{Fuel} + BE_{Bitumen} + BE_{Aggregate} + BE_{Production} \quad (1)$$

Where:

BE_y = the sum of baseline emissions in a given year, y

BE_{Fuel} = emissions due to the extraction and processing of fuel used in hot mix production

BE_{Bitumen} = emissions due to the production and processing of bitumen

BE_{Aggregate} = emissions due to the production and processing of aggregate

BE_{Production} = emissions due to the storage of bitumen, drying and hot-mixing

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

$$BE_{Fuel} = \sum_{i,x} (Vol\ Fuel\ Mixing_i \times EF\ Fuel_x) \quad (2)$$

Where:

- Vol Fuel Mixing_i = the volume of each type of fuel combusted under the baseline scenario for storage, drying and hot mixing (L, m³ or other). This value is calculated using Equation 8.
- EF Fuel_x = the emissions factor for fuel production and processing for each GHG considered (kg GHG/L, m³ or other).

The emissions due to the production and processing of bitumen are calculated as follows:

$$BE_{Bitumen} = \sum_x \left(\frac{(Mass_{Bitumen\ B} \times Mass_{Paving} \times EF_{Production_{GHGx}})}{\rho} \right) \quad (3)$$

Where:

- Mass_{Bitumen B} = the mass of bitumen consumed (kg/tonne of hot mix produced)
- Mass_{Paving} = the mass of hot mix asphalt produced (tonne)
- EF_{Production_{GHGx}} = the emissions factor for fuel production and processing for each GHG listed (kg/L, m³ or other)
- GHG_x = each GHG to be calculated (CO₂, CH₄ and N₂O in tonnes, or CO₂E)
- ρ = density of bitumen (kg/L)

The emissions due to the production and processing of aggregate are calculated as follows:

$$BE_{Aggregate} = \sum_x (Mass_{Aggregate\ B} \times Mass_{Paving} \times EF_{Aggregate_{GHGx}}) \quad (4)$$

Where:

- Mass_{Aggregate B} = the mass of aggregate consumed (kg/tonne of hot mix produced)
- Mass_{Paving} = the mass of hot mix asphalt produced (tonne)
- EF_{Aggregate_{GHGx}} = the emissions factor for fuel production and processing for each GHG listed (kg/L, m³ or other)
- GHG_x = each GHG to be calculated (CO₂, CH₄ and N₂O in tonnes, or CO₂E)

The emissions due to the storage of bitumen, drying and hot mixing are calculated using the following equations.

$$BE_{Production} = BE_{Hot\ mix\ stack} + BE_{Fuel\ usage} \quad (5)$$

The emissions from the hot mix stack are calculated as follows. For projects where site-specific stack emissions sampling data is available, project proponents may calculate these emissions using the VCS Module *Estimation of Emissions from the Storage, Drying and Hot-Mixing of Bitumen in Hot-Mix Asphalt Production*, v1.0.

$$BE_{Hot\ mix\ stack} = \sum (Mass_{Bitumen\ B} \times Mass_{Paving} \times EF_{Mixer_{CH_4}}) \quad (6)$$

Where:

Mass_{Bitumen B} = the mass of bitumen consumed (kg/tonne of hot mix produced)
 Mass_{Paving} = the mass of hot mix asphalt produced (tonne)
 EF Mixer_{CH4} = the CH₄ emissions factor for the mixing of bitumen in hot mix asphalt production (kg CH₄/kg bitumen)

The emissions due to fuel usage during hot mixing are calculated as follows:

$$BE_{fuel\ usage} = \sum_{i,x} (Mass_{Paving} \times Vol\ Fuel\ Mixing_i \times EF_{Fuel_{i,GHGx}}) \quad (7)$$

Where:

Mass_{Paving} = the mass of hot mix asphalt produced (tonne)
 Vol Fuel Mixing_i = the volume of each type of fuel combusted during hot mixing (L, m³ or other)
 EF Fuel_{i, GHGx} = the emissions factor for fuel combustion for each type of fuel used and GHG listed (kg GHG/L, m³ or other)
 GHG_{i,x} = each GHG to be calculated (CO₂, CH₄ and N₂O in tonnes, or CO₂E)

The volume of each type of fuel combusted during hot mixing can be calculated based on the heating requirements for hot mixing and the theoretical volume of fuel needed to produce this heat, using the following equations:

$$Vol\ Fuel\ Mixing_i = Vol\ Fuel\ Mixing_{i\ Aggregate} + Vol\ Fuel\ Mixing_{i\ Bitumen} \quad (8)$$

$$Vol\ Fuel\ Mixing_{i\ Aggregate} = \frac{Mass_{Aggregate} \times C_{Aggregate} \times (T_{Hot\ mix} - T_{Aggregate})}{HV_{Fuel\ i} \times Eff} + Mass_{Aggregate} \times Vol_{Fuel\ i} \quad (9)$$

$$Vol\ Fuel\ Mixing_{i\ Bitumen} = \frac{Mass_{Bitumen} \times C_{Bitumen} \times (T_{Hot\ mix} - T_{Bitumen})}{HV_{Fuel\ i} \times Eff} \quad (10)$$

Where:

Mass_{Aggregate} = the mass of aggregate consumed (kg/tonne of hot mix produced)
 Mass_{Bitumen} = the mass of bitumen consumed (kg/tonne of hot mix produced)
 C_{Aggregate} = specific heat capacity of aggregate (kJ/kg deg Celsius)
 C_{Bitumen} = specific heat capacity of bitumen (kJ/kg deg Celsius)
 T_{Hotmix} = temperature of hot mix asphalt production (deg Celsius)
 T_{Aggregate} = temperature of aggregate (deg Celsius)
 T_{Bitumen} = temperature of bitumen (deg Celsius)
 HV_{Fuel I} = heating value of fuel consumed (kJ/m³)

Eff = fuel combustion and burner efficiency (%). A default value of 80% combustion efficiency and 80% burner efficiency may be used, for a total efficiency of 64%.

Vol_{Fuel i} = the volume of fuel combusted for aggregate drying (L,m3 or other per kg of aggregate). This value is dependent on the moisture content (%) of the aggregate, and can be estimated based on manufacturer's specifications for fuel consumption

8.2 Project Emissions

Emissions under the project scenario(in tonnes CO₂E) are determined using the following equation:

$$PE_y = PE_{Fuel} + PE_{Add} + PE_{Bitumen} + PE_{Aggregate} + PE_{Production} \quad (11)$$

Where:

PE_y = the sum of project emissions in a given year, y

PE_{Fuel} = emissions due to the extraction and processing of fuel used in hot mix production

PE_{Add} = emissions due to the production and processing of carbon black or other additives used in hot mix production

PE_{Bitumen} = emissions due to the production and processing of bitumen

PE_{Aggregate} = emissions due to the production and processing of aggregate

PE_{Production} = emissions due to the storage of bitumen, drying and hot-mixing.

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

$$PE_{Fuel} = \sum (Vol\ Fuel_i \times EF\ Fuel_{CO_2}); \sum (Vol\ Fuel_i \times EF\ Fuel_{CH_4}); \sum (Vol\ Fuel_i \times EF\ Fuel_{N_2O}) \quad (12)$$

Where:

Vol Fuel_i = the volume of each type of fuel combusted under the project scenario (L, m³ or other)

EF Fuel_x = the emissions factor for fuel production and processing for each GHG listed (kg GHG/L, m³ or other).

The emissions due to the production and processing of additives used under the project scenario must be quantified, the following equation provides guidance (given for carbon black additive):

$$PE_{CB} = \sum \frac{Mass_{SE} \times \%CB \times EF\ Production_{CO_2}}{100}; \sum \frac{Mass_{SE} \times \%CB \times EF\ Production_{CH_4}}{100}; \quad (13)$$

Where:

Mass_{SE} = the mass of sulphur extender consumed (kg)

%CB = the percent of additive (ie. carbon black) in the sulphur extender used (%)

EF Production_{CO₂} = CO₂ emissions factor for additive production (kg CO₂/kg additive)

$EF_{Production_{CH_4}}$ = CH_4 emissions factor for additive production (kg CH_4 /kg additive)

The emissions due to the production and processing of bitumen are calculated as follows:

$$PE_{Bitumen} = \sum_x \left(\frac{(Mass_{Bitumen} \times Mass_{Paving} \times EF_{Production_{GHGx}})}{\rho} \right) \quad (14)$$

Where:

$Mass_{Bitumen}$ = the mass of bitumen consumed (kg/tonne of hot mix produced)
 $Mass_{Paving}$ = the mass of hot mix asphalt produced (tonne)
 $EF_{Production_{GHGx}}$ = the emissions factor for fuel production and processing for each GHG listed (kg/L, m³ or other).
 GHG_x = each GHG to be calculated (CO_2 , CH_4 and N_2O in tonnes, or CO_2E)
 ρ = density of bitumen (kg/L)

The emissions due to the production and processing of aggregate are calculated as follows:

$$PE_{Aggregate} = \sum_x \left((Mass_{Aggregate} \times Mass_{Paving} \times EF_{Aggregate_{GHGx}}) \right) \quad (15)$$

Where:

$Mass_{Aggregate}$ = the mass of aggregate consumed (kg/tonne of hot mix produced)
 $Mass_{Paving}$ = the mass of hot mix asphalt produced (tonne)
 $EF_{Aggregate_{GHGx}}$ = the emissions factor for fuel production and processing for each GHG listed (kg/L, m³ or other).
 GHG_x = each GHG to be calculated (CO_2 , CH_4 and N_2O in tonnes, or CO_2E)

The emissions due to the storage of bitumen, drying and hot mixing are calculated as follows:

$$PE_{Production} = PE_{Hot\ mix\ stack} + PE_{Fuel\ usage} \quad (16)$$

The emissions from the hot mix stack are calculated as follows. For projects where site-specific stack emissions sampling data are available, project proponents may calculate these emissions using the VCS Module *Estimation of Emissions from the Storage, Drying and Hot-Mixing of Bitumen in Hot-Mix Asphalt Production*, v1.0.

$$PE_{Hot\ mix\ stack} = \sum_x \left((Mass_{Bitumen} \times EF_{Mixer_{CH_4}}) \right) \quad (17)$$

Where:

$Mass_{Bitumen}$ = the mass of bitumen consumed (kg)
 $EF_{Mixer_{CH_4}}$ = the CH_4 emissions factor for bitumen used in asphalt production (kg CH_4 /kg bitumen).

The emissions due to fuel usage during hot mixing are calculated as follows:

$$PE_{fuel\ usage} = \sum_{i,x} (Vol\ Fuel_i \times EF_{Fuel_i,GHGx}) \tag{18}$$

Where:

- Vol Fuel_i = the volume of each type of fuel combusted during hot mixing (L, m³ or other)
- EF Fuel_{i, GHGx} = the emissions factor for fuel combustion for each type of fuel used and GHG listed (kg GHG/L, m³ or other).
- GHG_{i,x} = each GHG to be calculated (CO₂, CH₄ and N₂O in tonnes, or CO₂E)

8.3 Leakage

There are no known sources of leakage for this project activity.

8.4 Summary of GHG Emission Reductions

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

$$ER_y = BE_y - PE_y \tag{19}$$

Where:

- ER_y = Net GHG emission 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 to the physical location of the project activity. The project proponent must provide evidence and justification that the values presented in this section 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 determination 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 factors for fuel extraction and
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	processing ($EF_{Fuel\ x}$).
Data unit:	kg (CO ₂ , CH ₄ , N ₂ O) per L, m ³ or other.
Description:	Emission factor describing GHG emissions from production of the fuel combusted under the project and baseline scenarios.
Source of data:	Reference values may be obtained from national and international GHG inventories. The value used should be consistent with the source of the fuel used in the project. 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.
Justification of choice of data or description of measurement methods and procedures applied:	Review of best practice guidance and accepted standards. Reference values are generally available.
Any comment:	

Data Unit / Parameter:	Mass of bitumen consumed under the baseline scenario ($Mass_{Bitumen\ B}$).
Data unit:	kg per tonne of hot mix asphalt produced under the project scenario.
Description:	The bitumen content of conventional hot mix asphalt is used to calculate how much bitumen would have been required for the project, if sulphur extender was not used.
Source of data:	Estimation or measurement
Justification of choice of data or description of measurement methods and procedures applied:	Default values can be estimated based on available data. The bitumen content of conventional hot mix asphalt may be estimated using: <ul style="list-style-type: none"> 1. local or regional paving standards or industry data for the type of road being paved; 2. actual mix composition for the hot mix facility if known.
Any comment:	

Data Unit / Parameter:	Specific heat capacity of bitumen ($C_{Bitumen}$): 2.093
Data unit:	kJ/kg deg C

Description:	Energy required to heat one kilogram of bitumen one degree Celsius
Source of data:	Accepted value
Justification of choice of data or description of measurement methods and procedures applied:	Based on thermodynamic principles and the theoretical heat capacity of bitumen.
Any comment:	Project proponents should determine if the bitumen used for their project is consistent with the definition provided in Section 3.

Data Unit / Parameter:	Specific heat capacity of aggregate ($C_{Aggregate}$): 0.837
Data unit:	kJ/kg deg C
Description:	Energy required to heat one kilogram of aggregate one degree Celsius
Source of data:	Accepted value
Justification of choice of data or description of measurement methods and procedures applied:	Based on thermodynamic principles and the theoretical heat capacity of aggregate.
Any comment:	Project proponents should determine if the aggregate used for their project is consistent with the definition provided in Section 3.

Data Unit / Parameter:	Emission factors for aggregate production ($EF_{Aggregate}$).
Data unit:	kg CO ₂ E per kg of aggregate
Description:	Emission factor for the mining or production of aggregate.
Source of data:	The emission factor should be obtained or calculated from relevant industry data.
Justification of choice of data or description of measurement methods and procedures applied:	The emissions intensity of aggregate production may vary depending on the type and source of the aggregate used. Regional emission factors would provide a reasonable level of accuracy. In the absence of an appropriate emission factor, a zero value may be assumed. This is conservative as aggregate consumption is higher in the baseline scenario.
Any comment:	

Data Unit / Parameter:	Density of bitumen (ρ)
Data unit:	Kg/L
Description:	The density of bitumen (heavy crude oil) used in the project.
Source of data:	Accepted value
Justification of choice of data or description of measurement methods and procedures applied:	Default value obtained from industry standards is 0.98. Densities for different types/compositions of heavy crude oil may be obtained from oil and gas industry in the project region.
Any comment:	Project proponents must ensure that the default value is representative of the type and composition of bitumen used in the project.

Data Unit / Parameter:	Emission factors for bitumen production ($EF_{Production,x}$).
Data unit:	kg GHG per L, m3 or other
Description:	Emission factor for bitumen production for each GHG under consideration (CO_2 , CH_4 , N_2O). Emissions may vary depending on the method of bitumen production.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Emission factors may be available from local authorities or industry associations in the region that the bitumen was produced. In the absence of local data, the reference values provided by CAPP (Appendix A, Table A1) may be used.
Any comment:	Project proponents must ensure that the value is representative of the source of bitumen used in the project.

Data Unit / Parameter:	Mass of aggregate ($Mass_{Aggregate B}$)
Data unit:	kg per tonne of hot mix asphalt produced
Description:	Estimated mass of aggregate that would have been used for the production of conventional hot mix asphalt, based on the mass of hot mix asphalt produced by the project.
Source of data:	Estimation or measurement
Justification of choice of data or description of measurement methods and procedures applied:	Default values may be obtained from local industry records for the type of road being paved, or actual mix composition for the hot mix facility

	may be used if known.
Any comment:	

Data Unit / Parameter:	Emission factor for bitumen use in hot mixing ($EF_{\text{Mixer CH}_4}$).
Data unit:	kg CH ₄ /kg bitumen
Description:	Emission factor for bitumen use in hot mixing. Emissions are dependent on the type of mixer used.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Emission factors are available from equipment manufacturers and governing authorities.
Any comment:	In the absence of manufacturer-specific emission factors, the emission factors listed in Appendix A, Table A2 may be used.

Data Unit / Parameter:	Emission factors for fuel combustion ($EF_{\text{Fuel I,x}}$)
Data unit:	kg (CO ₂ , CH ₄ , N ₂ 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:	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.
Justification of choice of data or description of measurement methods and procedures applied:	Review of best practice guidance and accepted standards. Reference values are generally available.
Any comment:	

Data Unit / Parameter:	Temperature of hot mix asphalt production ($T_{\text{hot mix}}$)
Data unit:	Degree Celsius
Description:	Represents the production temperature of conventional hot-mix asphalt.

Source of data:	Estimation or measurement
Justification of choice of data or description of measurement methods and procedures applied:	Default values may be available from industry common practice or from applicable road construction standards. May also be measured at the hot mix facility prior to the use of sulphur extender.
Any comment:	Default value is 144 degrees C based on asphalt production in Canada. A temperature of 142 degrees C may be more appropriate for softer asphalt or low-volume highways.

Data Unit / Parameter:	Temperature of Aggregate ($T_{\text{Aggregate}}$)
Data unit:	Degree Celsius
Description:	Represents the temperature of aggregate at the time of mixing/addition of binder
Source of data:	Estimation or measurement
Justification of choice of data or description of measurement methods and procedures applied:	Default values may be available from industry common practice. May also be measured at the hot mix facility prior to the use of sulphur extender.
Any comment:	

Data Unit / Parameter:	Temperature of Bitumen (T_{Bitumen})
Data unit:	Degree Celsius
Description:	Represents the temperature of bitumen at the time of mixing/addition to the hot mixer
Source of data:	Estimation or measurement
Justification of choice of data or description of measurement methods and procedures applied:	Default values may be available from industry common practice. May also be measured at the hot mix facility prior to the use of sulphur extender.
Any comment:	

Data Unit / Parameter:	Heating value of fuel ($HV_{\text{Fuel } i}$)
Data unit:	kJ/m^3
Description:	Thermodynamic constant
Source of data:	Accepted value
Justification of choice of data or	Accepted value for the type of fuel used to power

description of measurement methods and procedures applied:	the burner.
Any comment:	For natural gas the default value is 38 095 kJ/m ³ . For other fuel types an appropriate default value may be used.

Data Unit / Parameter:	Fuel combustion and burner efficiency (Eff)
Data unit:	%
Description:	The theoretical or measured efficiency of the hot mixing equipment.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Efficiencies may be available from manufacturers' specifications or as part of the facility's monitoring processes. In the absence of project-specific data, default values may be used. Default values are high and would result in a conservative estimation of emission reductions.
Any comment:	Default values are 80% (combustion) and 80% (burner) for a total efficiency of 64%.

Data Unit / Parameter:	Volume of fuel combusted for aggregate drying (VolFuel _i)
Data unit:	L, m ³ or other per kg of aggregate
Description:	The volume of fuel required to dry aggregate, depending on the equipment used and the moisture content of the aggregate.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Value may be obtained from manufacturer specifications for fuel consumption.
Any comment:	

Data Unit / Parameter:	Moisture content of aggregate
Data unit:	%
Description:	The typical moisture content of the aggregate to be used.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and	Value may be obtained from existing geological studies, sampling data or other sources of data

procedures applied:	proposed by the project proponent.
Any comment:	This value is not used in calculations but is used to determine fuel consumption for aggregate drying based on manufacturer's specifications.

Data Unit / Parameter:	Emission factors for the production of carbon black ($EF_{CB,x}$)
Data unit:	kg (CO ₂ , CH ₄) per kg of carbon black
Description:	Emission factor describing GHG emissions from the production of the carbon black used in the sulphur extender product.
Source of data:	Estimation
Justification of choice of data or description of measurement methods and procedures applied:	Reference values may be obtained from IPCC guidelines. Values are dependent on the production process.
Any comment:	IPCC emission factors are provided in Appendix A, Table A3

9.2 Data and Parameters Monitored

The following data parameters will be monitored during the project.

Data Unit / Parameter:	Mass of hot mix asphalt produced ($Mass_{Paving}$)
Data unit:	tonne
Description:	The mass of hot mix asphalt produced for the project.
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	The project proponent may measure the mass of hot mix asphalt produced in one of three ways: <ol style="list-style-type: none"> 1. Direct metering; 2. Reconciliation of quantity delivered to trucks for load-out; 3. Reconciliation of mass of hot mix asphalt applied or distance paved and thickness of paving within a given time period.
Frequency of monitoring/recording:	Per project with monthly reconciliation if project duration is longer than one month.
QA/QC procedures to be applied:	Cross-checking of metered mass vs. trucking manifests or logs.
Any comment:	

Data Unit / Parameter:	Volume of each type of fuel combusted during the project for storage of bitumen, drying and hot mixing (Vol Fuel _i)
Data unit:	L, m ³ or other
Description:	The volume of fuel used during the project
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: <ol style="list-style-type: none"> 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:	Per project with monthly reconciliation if project duration is longer than one month.
QA/QC procedures to be applied:	Cross-checking of metered volumes vs. theoretical fuel use, analysis of data trends.
Any comment:	Overall hot mix facility fuel usage may be used given that bitumen storage, aggregate drying and hot mixing will likely represent the majority of fuel usage for a facility.

Data Unit / Parameter:	Mass of sulphur extender product consumed (Mass _{SE})
Data unit:	Kg
Description:	The mass of sulphur extender used in the project scenario
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	The project proponent may measure the mass of sulphur extender in one of two ways: <ol style="list-style-type: none"> 1. Direct metering or reconciliation of mass received (preferred); 2. Reconciliation of mass of sulphur extender purchased within a given time period. This provides a reasonable estimate when direct measurement cannot be used.
Frequency of monitoring/recording:	Per project with monthly reconciliation if project duration is longer than one month.
QA/QC procedures to be applied:	Cross-checking of metered volumes vs. supplier/shipping records.
Any comment:	

Data Unit / Parameter:	Percent of carbon black in sulphur extender (% CB)
Data unit:	%
Description:	Default value of 2% obtained from sulphur extender producer.
Source of data:	Default value estimated from sulphur extender production process.
Description of measurement methods and procedures to be applied:	May be determined from sulphur extender producer.
Frequency of monitoring/recording:	Yearly
QA/QC procedures to be applied:	
Any comment:	

Data Unit / Parameter:	Mass of bitumen consumed (Mass _{Bitumen})
Data unit:	kg
Description:	Mass of bitumen used during the project
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	The project proponent may measure the mass of bitumen consumed in one of two ways: <ol style="list-style-type: none"> 1. Direct metering or reconciliation of mass received (preferred); 2. Direct metering of quantity of bitumen purchased from the monthly supplier invoices. This provides a reasonable estimate when the preferred method cannot be used.
Frequency of monitoring/recording:	Per project with monthly reconciliation if project duration is longer than one month.
QA/QC procedures to be applied:	
Any comment:	

Data Unit / Parameter:	Mass of aggregate consumed (Mass _{Aggregate})
Data unit:	kg
Description:	Mass of aggregate used during the project
Source of data:	Measurement
Description of measurement methods and procedures to be applied:	The project proponent may measure the mass of aggregate consumed in several ways: <ol style="list-style-type: none"> 1. Direct metering of reconciliation of mass

	<p>consumed (preferred);</p> <p>2. Reconciliation of mass received;</p> <p>3. Calculation as the difference between the mass of hot mix asphalt produced and the mass of binder consumed; or</p> <p>4. Reconciliation of mass of aggregate purchased within a given time period.</p>
Frequency of monitoring/recording:	Per project with monthly reconciliation if project duration is longer than one month.
QA/QC procedures to be applied:	
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 at least two years after 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 3: Good Practice Guidance

Document Title	Publishing Body/Date	Description
ISO 14064-2:2006: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements	International Standards Organization	ISO 14064-2:2006 specifies principles and requirements and provides guidance at the project level for quantification, monitoring and reporting of activities intended to cause GHG emission reductions or removal enhancements. It includes requirements for planning a GHG project, identifying and selecting GHG sources, sinks and reservoirs relevant to the project and baseline scenario, monitoring, quantifying, documenting and reporting GHG project performance and managing data quality. This document was used to develop the protocol document and full life cycle analysis of the project and baseline scenarios.
National Inventory Report, 1990-2005 - Greenhouse Gas Sources and Sinks in Canada	Environment Canada, 2006	On behalf of the Government of Canada, Environment Canada develops and publishes annually Canada's GHG inventory. The inventory reporting format is based on international reporting methods agreed to by the Parties to the UNFCCC, using the procedures of the Intergovernmental Panel on Climate Change (IPCC). Emission factors for fossil fuel combustion from this document were used to quantify the emissions from hot mixing and aggregate drying in the project and baseline scenarios.
Alberta Offset System Offset Credit Project Guidance Document	Alberta Environment, 2008	This Offset Credit Project Guidance Document is one of a series of guidance documents prepared for the Specified Gas Emitters Regulatory Framework. The purpose of this Guide is to outline the process and requirements for undertaking offset projects in Alberta.
Emission Factor Documentation For AP-42 Section 11.1, Hot Mix Asphalt Production	US EPA, 2005	Discussion of GHG and volatile organic compound (VOC) emissions and emissions of other air contaminations from hot mix asphalt production. Includes development of emission

Document Title	Publishing Body/Date	Description
		<p>factors delineated for various process steps and for batch and drum hot mix facilities.</p> <p>Emission factors from asphalt handling were derived from this document. This document was also used to determine which emission sources at the hot mix asphalt facility would be the most significant.</p>
<p>Emission Inventory Improvement Program: Asphalt Paving, Vol. 3, Chapter 17.</p>	<p>US EPA, 2001</p>	<p>Discussion of GHG and VOC emissions and emissions of other air contaminations from hot mix asphalt production. Includes development of emission factors delineated for various process steps and for batch and drum hot mix facilities.</p> <p>Emission factors from asphalt handling were derived from this document. This document was also used to determine which emission sources and sinks at the hot mix asphalt facility would be the most significant.</p>
<p>Multi-pollutant Emission Reduction Analysis Foundation (MERAFA) for the Hot-mix Asphalt Sector.</p>	<p>Environment Canada and the Canadian Council of Ministers of Environment (CCME), 2002</p>	<p>This report provides background technical information on the Canadian Hot-Mix Asphalt Sector. It includes a profile of the industry, current and projected emissions from the sector, domestic and international emission standards, best available pollution prevention and control techniques and possible emission reduction options.</p> <p>This document was used to outline provincial regulations and measurement requirements and to gain an understanding of common industry practices across Canada.</p>
<p>IPCC Guidelines for National Greenhouse Gas Inventories, Ch. 3, Chemical Industry Emissions.</p>	<p>Intergovernmental Panel on Climate Change (IPCC), 2006</p>	<p>This report provides guidance on estimating GHG emissions that result from the production of various inorganic and organic chemicals for which there are significant contributions to GHG emission levels. Included in this chapter are emission factors for carbon black production.</p> <p>Emission factors for the production of carbon black and an understanding of the production process were obtained from this document.</p>
<p>Performance Properties of Paving Mixtures made with Modified Sulphur Pellets. International Society for Asphalt Pavements (ISAP).</p>	<p>International Society for Asphalt Pavement (ISAP), 2008</p>	<p>Discussion of the history of sulphur extended asphalt (SEA) pavement, the development of SEAM, test results for SEAM performance, and the risks and impacts associated with its use.</p> <p>Description of the development of SEAM and the potential impacts and issues associated with</p>

Document Title	Publishing Body/Date	Description
		its use were retrieved from this document.
Cost and Energy Audit of Sulphur Extended Asphalt Paving Construction.	SUDIC and Alberta Transportation, 1984	<p>This report assesses the actual cost and energy usage associated with sulphur extended asphalt (SEA) pavement construction on a large scale commercial project.</p> <p>This document was used to compare SEAM and SEA and to gain an understanding of the potential energy requirements associated with hot mix asphalt production and paving.</p>
Occupational Hygiene Survey: Sulphur-Extended Asphalt Paving Project.	Alberta Transportation, 1981	<p>This report summarizes the gas emission observed during asphalt and sulphur extended asphalt (SEA) paving projects. Gases of concern were hydrogen sulphide (H₂S) and sulphur oxides.</p> <p>This document was used to compare SEAM and SEA and to gain an understanding of the potential risks associated with hot mix asphalt production and paving.</p>
A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H ₂ S) Emissions by the Upstream Oil and Gas Industry	Canadian Association of Petroleum Producers (CAPP), 2004	<p>A detailed inventory of GHG emissions from the upstream oil and gas sector in Canada with detailed explanations of the methodologies and data sources used. Provides emission factors for the production, processing and combustion of a range of fossil fuel products.</p> <p>Emission factors for the production of bitumen and an understanding of the production process were obtained from this document.</p>
Emission Inventory Guidebook: Processes in Wood, Paper Pulp, Food, Drink and Other Industries, Road Paving with Asphalt	European Environment Agency (EEA), 2006	<p>This report provides a review of the air emissions from various types of asphalt paving mix including hot mix, cutback and liquefied asphalt.</p> <p>This document was used to gain a better understanding of the key emission sources and sinks and potential for variation across different regions and at different sites.</p>
Gravel and Lightly Surfaced Road Resurfacing Projects Quantification Protocol	Alberta Environment, 2008	<p>The Alberta Offset System quantification protocol for gravel and lightly surfaced road resurfacing projects uses an emission factor for aggregate production derived from Statistics Canada, the Aggregates and Quarry Products Association and the Canadian Technical Asphalt Association. References for these documents are provided below:</p> <p>Statistics Canada. (1998). <i>Canadian Minerals</i></p>

Document Title	Publishing Body/Date	Description
		<p><i>Handbook.</i></p> <p>Canadian Technical Asphalt Association. (2005). <i>The Environmental Road of the Future: Analysis of Energy Consumption and Greenhouse Gas Emissions.</i></p> <p>Aggregate and Quarry Products Industry. (2006). <i>A Sustainable Development Report from the Aggregate and Quarry Products Industry.</i></p>
<p>Handling and Storage of Solid Sulphur, Production, Handling and Use of Seam Paving Mixtures, SEAM Construction Specifications, SEAM Mix Design and completion of the Plant Site Checklist for safe plant use.</p>	<p>Shell Sulphur Solutions</p>	<p>These documents outline the requirements for safe handling and use of hot mix asphalt using SEAM as a binder.</p> <p>Documents were referenced and included in the methodology as a requirement for its use, to ensure safe handling and production of hot mix asphalt.</p>

APPENDIX A: Emissions Factors

Bitumen Production

Values for bitumen production were obtained from volume 1 of the technical report: *A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H2S) Emissions* by the Upstream Oil and Gas Industry, dated September 2004, completed by Clearstone Engineering Ltd. on behalf of the Canadian Association of Petroleum Producers (CAPP). These emissions factors are typical for bitumen production in Canada, and may vary according to geographic location and the refinery. Project proponents must ensure that the emission factors used are applicable to their project.

Table A1: Emission Intensity of Bitumen Production

Heavy Crude Thermal Production		
Emissions Factor (CO ₂)	594.2	kg CO ₂ per m ³
Emissions Factor (CH ₄)	3.75	kg CH ₄ per m ³
Emissions Factor (N ₂ O)	0.009	kg N ₂ O per m ³

Hot Mixing

Emission factors for hot mixing were derived from the US EPA’s AP 42 Emission Inventory Supplement to “*Compilation of Air Pollutant Emission Factors. Vol. 1: Stationary Point and Area Sources*” Chapter 11.1 *Hot Mix Asphalt Plants* dated 1994. Emission factors represent the methane content of total organic carbon emissions and were calculated assuming a ‘typical’ content of 5.3% bitumen binger (by weight) in conventional hot mix asphalt.

Table A2: Emission Intensity of Hot Mixing

Plant Type	CH ₄	Units
Natural Gas Batch	0.0001	kg / kg Bitumen
Natural Gas Drum Mix	0.0019	kg / kg Bitumen
No. 2 Fuel Oil Batch Mixer	4.15 E-05	kg / kg Bitumen
No.2 Fuel Oil Drum Mixer	0.0002	kg / kg Bitumen

Carbon Black Production

Values for carbon black production were obtained from IPCC 2006 Guidelines. The majority of the world’s carbon black is produced by the furnace black process. Emission factors for both production methods are equivalent.

Table A2: Emission Intensity of Carbon Black Production

Production Process	CO ₂	CH ₄	Units
Furnace Black	0.66	0.00006	kg/kg carbon black
Thermal	0.66	0.00006	kg/kg carbon black