



SHELL SEAM
TECHNICAL PROTOCOL PLAN
SEPTEMBER, 2008

Table of Contents

| | |
|---|-------------------------------------|
| PART A: IDENTIFICATION OF THE PROTOCOL DEVELOPER | ERROR! BOOKMARK NOT DEFINED. |
| A.1 Title of the Base Protocol | Error! Bookmark not defined. |
| A.2 Lead Protocol Developer | Error! Bookmark not defined. |
| A.3 Initiating Group..... | Error! Bookmark not defined. |
| | |
| PART B: DESCRIPTION OF THE TECHNICAL PROTOCOL PLAN | 1 |
| B.1 Description of the Project Type and How Real Reductions will be Achieved..... | 1 |
| B.2 Description of Background Information / Best Practice Guidance Used | 2 |
| B.3 Regulatory, Legal Requirements and/or Government Incentive/Grant Programs.. | 7 |
| B.4 Barriers and Risks to Implementation..... | 8 |
| B.5 Review of Technology | 9 |
| B.6 Review of Existing Projects..... | 12 |
| B.7 Summary of Quantification Approaches | 13 |
| B.8 Other Impacts..... | 13 |
| B.9 Assessment of Baseline Scenarios | 14 |
| B.10 Selection of Baseline Scenario..... | 15 |
| B.11 Definition of the Project Condition..... | 18 |
| B.12 Functional Equivalence..... | 18 |
| B.13 Flexibility Mechanisms..... | 18 |

PART B: Description of the Technical Protocol Plan

B.1 Description of the Project Type and How Real Reductions will be Achieved

Project Description and Scope

This protocol is applicable to projects that involve the substitution of a proportion of the bitumen binder used in conventional hot asphalt paving for a sulphur product. This protocol is intended to be applied to hot mix facilities in the hot mix asphalt industry. This activity reduces required quantities of aggregate and bitumen, reduces fuel usage due to reduced mix production temperatures and reduces emissions from the hot mix plant stack and paving.

The sulphur product being substituted for asphalt must be either sulphur extended asphalt modifier (SEAM) pellets or a similar solid sulphur product composed of carbon black, sulphur, and small quantities of plasticizer and H₂S scavenger additives. 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 protocol is not applicable to project proponents substituting other products for asphalt binder in paving mix, given the potential differences in sourcing of components, composition and GHG emissions.

The baseline configuration would be the use of conventional hot mix asphalt, whose composition of aggregate versus bitumen binder will vary depending on the type of road paved (i.e. highway versus city street). In Alberta conventional hot mix asphalt is produced at a temperature ranging from 130 to a maximum of 155 degrees Celsius, typically around 145 degrees Celsius¹. The project activity could be implemented at existing hot mix facilities or implemented at new facilities as a best practice technology.

The opportunity for generating carbon offsets with the protocol arises primarily from the avoided production of a proportion of the asphalt binder used in conventional asphalt paving mix and reduced consumption of fossil fuels due to lower mix production temperatures. There is also the opportunity for greenhouse gas (GHG) emission reductions from avoided fugitive emissions of methane associated with the handling and storage of asphalt that would have been emitted from hot mix facilities where the baseline practice was the use of conventional paving mix.

As there is an opportunity for generating emission reductions from substitution of bitumen binder for SEAM in hot mix asphalt, such projects will positively impact Canada's National GHG Inventory under Energy Sector emissions for Fossil Fuel Production and Stationary Combustion in Manufacturing Industries.

¹ Values obtained from correspondence with Alberta Transportation

To demonstrate that a project meets the requirements under this protocol, the project developer must provide evidence that:

1. Industry best practices for appropriate handling, mix production temperatures and disposal of any mix produced at temperatures exceeding 155°C are followed. This will require strict adherence to the procedures contained in the following documentation: *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; and
2. Hot mix production temperatures are monitored at the plant outlet to ensure production within the appropriate temperature range.

Alberta Offset System Eligibility Criteria

The Substitution of Bitumen Binder in Hot Asphalt Paving Mix protocol has been developed in accordance with the key principles and eligibility criteria of the Alberta Offset system. In order for a GHG emission reduction activity to create eligible offsets in the Alberta Offset System, a number of eligibility criteria must be met under the Specified Gas Emitters Regulation (SGER), as specified in the Offset Credit Project Guidance Document (2008). Table 2.1 contains a systematic review of how the protocol meets these requirements.

Table 2.1 Eligibility Criteria

| Principle | Analysis |
|-----------------------------------|--|
| Start Date | The proposed protocol is applicable to projects that initiate or increase the use of SEAM in hot mix asphalt <u>after</u> January 1, 2002. The project activities could be implemented at existing mixing facilities that were using conventional hot mix asphalt or at new facilities. |
| Crediting Period | Projects applying this protocol will have a credit duration period of 8 years, consistent with Alberta Offset system guidelines. |
| Real | <p>The use of SEAM as a partial substitute for the bitumen binder in hot mix asphalt decreases the overall requirements for bitumen and aggregate, material that require fossil-fuel derived energy to produce. It also reduces fuel consumption through lower mix temperatures. Therefore, the displacement of a functionally equivalent quantity of bitumen with SEAM constitutes a real GHG reduction based on the avoidance of the GHG emissions associated with the production of bitumen and aggregate and reduced fuel consumption for hot mixing.</p> <p>The baseline condition in this protocol represents the paving mix composition and fuel consumption prior to the project. The baseline condition represents business as usual, as it is modeled from the original or typical composition of paving mix prior to the substitution of SEAM for a proportion of the asphalt binder typically used. This represents what was actually used prior to the project activity / what is typically used in Alberta. As such GHG reductions achieved by the project are measured relative to the emissions that would have been generated had the project not occurred. This is in line with the requirements outlined in Alberta Offset System guidance documents.</p> |
| Demonstrable, Quantifiable | GHG reductions from the use of SEAM can be quantified following scientifically acceptable methods based on actual measurement and monitoring. The quantification approaches discussed in this document and the proposed protocol are derived from consensus-based good practice guidance documents developed internationally (refer to section B.2) that give a high degree of certainty with regard to the sources and |

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| | <p>sinks of GHG emissions associated with hot mix asphalt production.</p> <p>The quantification methodologies outlined in the proposed protocol provide a high a level of accuracy and reliability through the use of emission factors from best practice guidance and measurement of fuel usage and emissions in the project condition following industry best practices. Emissions are determined based on the quantity of hot mix asphalt produced in the project condition.</p> <p>The quantification approach is transparent and consistent with industry best practices with data being collected as part of annual monitoring and reporting requirements. Data should be of sufficient quality to be verifiable by a third party. In particular, the emission factors and sampling methodology may be used to verify that appropriate modeling of fuel consumption and emissions was conducted.</p> |
| Not Required by Law | <p>Under current Alberta legislation, there are no requirements regulating energy efficiency or fuel consumption of the hot mix facilities considered in this protocol. Existing regulations may require project sites to maintain sulphur, PM and benzene emissions within provincial regulations but make no mention of greenhouse gas emissions. Therefore, the project activity is surplus to regulation.</p> <p>Note that facilities regulated as Large Final Emitters under Alberta's Specified Gas Emitters Regulation would not be eligible for offset generation.</p> |
| Ownership | <p>For consistency with other Alberta Offset System protocols the proposed protocol does not explicitly assign ownership, but instead states the minimum data collection requirements in order to adequately quantify the net GHG benefit of the project activity. It is therefore up to each project proponent to provide proof of ownership of all offsets claimed at the time of third party verification or upon request by Alberta Environment (e.g. through contracts with other participants in the fly ash distribution chain).</p> |
| Counted Once | <p>The GHG benefits associated with this activity could be claimed by the hot mix facility, producer of SEAM or other participants in the supply chain. As such, the project proponent would be responsible for clearly establishing ownership to ensure that double counting of GHG emission reductions does not occur.</p> |
| Occurred in Alberta | <p>Only projects located in Alberta are eligible for offsets. The proposed protocol applies to projects located in Alberta that use SEAM in the production of hot mix asphalt. As such, hot mix facilities and / or roads located outside of the province would not be eligible.</p> |

B.2 Description of Background Information / Best Practice Guidance Used

The opportunity for generating carbon offsets from this project activity arises mainly from the direct and indirect reductions in GHG emissions due to reduced fuel usage for drying and hot mixing and reduced bitumen extraction and processing.

Good practice guidance and best available science 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 were used to develop this document. Table 2.2 contains a detailed listing of the good practice guidance and best science used to develop the quantification approach.

TABLE 2.2 Good Practice Guidance

| 1. Document Title | 2. Publishing Body / Date | 3. 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 | <p>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 greenhouse gas (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.</p> <p>This document was used to develop the protocol document and full life cycle analysis of the project and baseline conditions.</p> |
| National Inventory Report, 1990-2005 - Greenhouse Gas Sources and Sinks in Canada | Environment Canada, 2006 | <p>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).</p> <p>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 conditions.</p> |
| Alberta Offset System Offset Credit Project Guidance Document | Alberta Environment, 2008 | <p>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.</p> <p>This document was referenced throughout protocol development, to ensure rules were followed and the protocols is consistent with all Alberta Offset System requirements.</p> |
| Emission Factor Documentation For AP-42 Section 11.1, Hot Mix Asphalt Production | US EPA, 2005 | <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> |

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| Emission Inventory Improvement Program: Asphalt Paving, Vol. 3, Chapter 17. | US EPA, 2001 | <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> |
| Multi-pollutant Emission Reduction Analysis Foundation (MERAFA) for the Hot-mix Asphalt Sector. | Environment Canada and the Canadian Council of Ministers of Environment (CCME), 2002 | <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> |
| IPCC Guidelines for National Greenhouse Gas Inventories, Ch. 3, Chemical Industry Emissions. | Intergovernmental Panel on Climate Change (IPCC), 2006 | <p>This report provides guidance on estimating greenhouse gas emissions that result from the production of various inorganic and organic chemicals for which there are significant contributions to greenhouse gas 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> |
| Performance Properties of Paving Mixtures made with Modified Sulphur Pellets. International Society for Asphalt Pavements (ISAP). | International Society for Asphalt Pavement (ISAP), 2008 | <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 its use were retrieved from this document.</p> |
| 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 | Alberta Transportation, 1981 | This report summarizes the gas emission observed during asphalt and sulphur extended asphalt (SEA) |

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| Asphalt Paving Project. | | <p>paving projects.</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). Canadian Minerals Handbook.</p> <p>Canadian Technical Asphalt Association. (2005). The Environmental Road of the Future: Analysis of Energy Consumption and Greenhouse Gas Emissions.</p> <p>Aggregate and Quarry Products Industry. (2006). A Sustainable Development Report from the Aggregate and Quarry Products Industry.</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. | Shell Sulphur Solutions | <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 protocol as a requirement for its use, to ensure safe handling and production of hot mix asphalt.</p> |

B.3 Regulatory, Legal Requirements and/or Government Incentive/Grant Programs

Regulatory / Legal Requirements

In Canada, the majority of hot mix asphalt paving mix (and subsequently the largest quantity of emissions) is produced in the provinces of Alberta, British Columbia, Ontario and Quebec. The exception is Manitoba where despite lower levels of production, emissions are significant due to uncontrolled dryer / burner emissions. In Alberta, BC, Ontario and Quebec approximately 50% of hot mix plants have scrubbers or filters to control emissions, and the distribution of fuel usage by number of facilities ranges from 50% to 65% using gas and 35% to 50% burning oil².

While there are no Canada-wide regulations specifically applicable to hot mix facilities, facilities must comply with the requirements of the Canadian Environmental Protection Act (CEPA 1999), National Pollutant Release Inventory (NPRI), National Ambient Air Quality Objectives (NAAQO's), Environment Canada's Management of Toxic Substances program, and the Canadian Council of Ministers of the Environment's Canada-wide Standards (CWSs) for Particulate Matter (PM) and Ozone.

In Alberta, hot mix asphalt production is regulated by the Environmental Protection and Enhancement Act Substance Release Regulation AR 124/94. This regulation provides a Code of Practice for asphalt paving plants and specifies minimum environmental requirements, pollution control technology, record keeping and reporting, and limits for PM and opacity. PM emissions must be less than 0.2 grams per kilogram of stack exhaust gas, and opacity must be less than 40% averaged over six months. The regulation also states that there must be no offensive odors and fugitive emissions must not cause an adverse effect³.

Hot mix facilities with emissions of greater than 100,000 tonnes CO_{2E} per year are regulated as Large Final Emitters (LFEs) under Alberta's Specified Gas Emitters Regulation (SGER). Facilities classified as LFEs are not eligible for offset generation, but may earn performance credits to use towards their compliance obligations by reducing greenhouse gas emissions at their site. There are no other specific regulations for GHG or VOC emissions for the hot mix asphalt industry in Alberta.

Alberta has requested that mixing be conducted at a lower SEAM to bitumen ratio than that most commonly applied. As such, the ratio will be in the range of 25% SEAM and 75% bitumen to 35% SEAM and 65 % bitumen instead of 40% SEAM and 60% bitumen. Note that the use of a lower SEAM to bitumen ratio will decrease the quantity of emission reductions achieved by the project activity due to the higher bitumen content of

² Environment Canada and the Canadian Council of Ministers of Environment (CCME). (2002). Multi-pollutant Emission Reduction Analysis Foundation (MERAF) for the Hot-mix Asphalt Sector.

³ Alberta Environmental Protection, *Code of Practice for Asphalt Paving Plants*, Substance Release Regulation (A.R. 124/93) under the Environmental Protection and Enhancement Act

the mix. The province has also requested that asphalt used be one grade softer, which may impact on VOC emissions.

In British Columbia, the Waste Management Act (BC Reg. 217/97) specifies emissions limits, requirements for emissions testing, siting, particulate control, fugitive dust management, equipment operation and maintenance, and noise limits. In terms of emissions, maximum limits for PM, organics, opacity and carbon monoxide from hot mix asphalt plants are specified. New and existing plant limits are 60 mg per m³ versus 120 mg per m³ for organics and 200 mg per m³ versus 120 mg per m³ for CO. Opacity must not exceed 20%. These limits are the most stringent among Canadian jurisdictions⁴.

In the US, the EPA's Clean Air Act Standards of Performance for Hot-Mix Asphalt Facilities limit particulate emissions and opacity. Standards are implemented by state agencies as required. Each state and different jurisdictions within each state may have additional and / or more stringent emission requirements. In California, annual reporting of emissions to the Air Resources Board (ARB) is required for facilities exceeding an emission threshold, and in 2007 the state approved a regulation requiring the adoption of mandatory reporting of GHG emissions from major sources. Hot mix facilities are also required to meet emission limits for opacity, PM, odour and SO₂. Limits vary between counties.

Note that a given SEAM to bitumen mix ratio may also be selected to comply with provincial or state requirements. For example, in Alberta the province has requested that the product be used at a 25 to 35% SEAM content.

Emissions from the dryer and hot mixer may vary depending on the level of stringency of air emission regulations in different jurisdictions. For example, transportation emissions in California may be lower due to regulations on tail-pipe emissions from transportation. Emissions could also be lower in jurisdictions with more stringent regulations on hot mix asphalt plants, such as those that require dryers / mixers to have filters. Further, the fuel required to dry the aggregate will vary depending on its moisture content in any given region, and the quantity of fuel required to maintain asphalt at desired temperatures prior to mixing may be higher in windy and / or colder regions.

Government Incentive / Grant Programs

No applicable regional or federal grant / incentive programs have been identified.

B.4 Barriers and Risks to Implementation

Various technical, data and market-based issues may affect the implementation and quantification of emission reductions from this project type. In particular, data shortcomings may include a lack of hot mix facility baseline fuel usage data for each

⁴ British Columbia, *Asphalt Plant Regulation*, B.C. Reg. 217/97 under the Waste Management Act, deposited June 27, 1997

given mix formulation, and characterization of GHG emissions from aggregate drying and hot mixing.

In terms of fuel usage, to prevent data availability from acting as a barrier to offset generation, the protocol will provide a baseline quantification based on the heat required to heat each component to required mix production temperatures. Similarly, two options will be included for calculating hot mix stack emissions. The first option would be to measure stack emissions in the project condition and using conventional hot mix asphalt. Depending on whether a given facility samples emissions from the hot mixing process, this may or may not be feasible. If site-specific data for hot mixing is not available, proponents will quantify these emissions using emission factors from the US EPA.

To date it is unknown if a feasible sampling methodology for determining life-cycle methane emissions from paving has been developed or whether separation of methane and non-methane VOC emissions from paving is feasible. As such, to ensure that the data requirements of the quantification protocol are reasonable, this emission source and sink (SS) will be excluded from quantification. This is conservative, as sampling conducted to date indicates that methane emissions are lower in the project condition⁵. A flexibility mechanism allowing project proponents to include paving emissions should additional data become available, will be included.

To address broad applicability concerns and minimize any risks associated with the use of SEAM paving mix, the protocol will specify that industry best practices for appropriate handling, mix production temperatures and disposal of any mix produced at temperatures exceeding 155°C must be followed by the project developer. These risks will be addressed through the requirement that project developers strictly adhere to the procedures outlined in the following documentation developed by Shell: *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.

B.5 Review of Technology

As discussed, this technical seed document applies to the substitution of a proportion of the bitumen binder used in conventional paving mix with a solid sulphur binder called SEAM. The original sulphur-extended asphalt (SEA) process was developed in the 1970s and its use continued into the early 1980s until the rise in sulphur prices made it too expensive for use in road paving mixtures. The use of molten sulphur resulted in odour and vapour emissions during paving application, that while in compliance with regulations at the time, would not likely have met current regulations⁶.

In the late 1970's a sulphur pastillising process was developed to convert molten sulphur to a solid form. This process was first used for SEA paving in the late 1990's and at this time, solid sulphur pellets began to be used in hot mix paving, thereby eliminating the

⁵ Third party sampling data available from Shell Sulphur Solutions

⁶ Strickland et al. (2008). Performance Properties of Paving Mixtures made with Extended Sulphur Pellets. ISAP.

fumes and odours associated with the use of hot molten sulphur⁷. This solid sulphur product is referred to as sulphur-extended asphalt modifier (SEAM) and it is used as an additive or binder in paving mix.

SEAM is especially appropriate for use in areas of heavy duty or high traffic use, for thick or long life pavement designs, for upgrading the quality of paving mixes made with lower quality aggregates or poor quality bitumen, and to prevent pavement cracking in cold climates⁸. It is composed of sulphur, a dispersing agent to reduce gas formation, an H₂S scavenger, and a plasticizer to improve pavement durability. It may also be modified to include a wax additive used to lower mix production and compaction temperatures. This modified product will be referred to as SEAM plus.

The updated SEAM process uses solid pellets, which are added directly to the mixer. SEAM pellets are made from elemental sulphur that is produced as a byproduct of fuel production and sulphur recovery operations at natural gas plants, sour natural gas wells, crude oil petroleum refineries, and oil sand operations. Sulphur production is the result of desulphurization of the oil industry in response to increasing stringent air regulations and is produced involuntarily. To produce SEAM, sulphur is degassed and blended with various additives including carbon black and potentially wax. The process involves combining molten elemental sulphur and additives in a mixer, then forming pellets using either a pastillizing plant or a wet-process pelletizing plant.

SEAM pellets may be added at a ratio ranging from 25% SEAM plus 75% bitumen weight ratio to 40% SEAM plus 60% bitumen. The recommended mix ratio is 40% SEAM to 60% bitumen. Note that use of the same volume of binder for both conventional and SEAM paving mix, with result in an increase in the binder content (by weight) for SEAM paving mix because the density of SEAM is almost two times greater than that of bitumen. Subsequently, the quantity of aggregate required will be slightly lower.

Mix is then heated to a target temperature of 140°C (+/- 5°C). Note that use of SEAM plus may lower mix temperatures by an additional 10°C. As discussed, adding sulphur as a solid pellet avoids the issues associated with handling, storage and use of molten sulphur. Given that it is designed to produce paving mixtures at lower temperatures, it also minimizes the emissions associated with mix production.

During mixing bitumen chemically combines with some of the sulphur added, serving to lower its viscosity and increase its ductility. The portion of sulphur that does not dissolve crystallizes as it cools, and acts as a structuring or strengthening agent in the paving mix⁹. Because SEAM decreases the viscosity of the paving mix, lower temperatures can be used than for conventional asphalt will still achieving uniform mixing. This is beneficial

⁷ ibid

⁸ ibid

⁹ ibid

as study has indicated that higher temperatures result in higher particulate matter (PM), PAH, and VOC emissions¹⁰.

The chemical combination of sulphur and bitumen during mixing requires close control of the temperature during mixing and paving to ensure that H₂S and SO₂ emissions are controlled and maintained within regulations and exposure limits. Manufacturing and handling protocols have been developed that include control of the temperature at 140°C, and any mix produced above a temperature of 155°C should be disposed of in a segregated and controlled manner due to the potential for gas to be released during paving and compaction. Note that the target mix temperature can be easily maintained as the type of binder used for paving mixtures made with modified sulphur pellets is usually composed of a high temperature performance grade asphalt¹¹. In addition, SEAM reduces the viscosity of bitumen, thereby allowing for optimal mixing at a lower temperature¹².

Prior to development of the SEAM technology, the US Federal Highway Administration Transportation Research Board conducted a study on the long-term performance of a large number of SEA roads¹³. This study confirmed that sulphur can be used effectively to build durable, long-lasting highways. In addition, the performance-related properties of SEAM paving mix have been studied in significant depth since its development and no negative performance-related effects have been observed. Rather, SEAM paving mix results in improved structural properties and enhanced rut resistance, fatigue resistance, and cracking resistance¹⁴. Therefore, while SEAM is a newer product and does not have the long track record of SEA, it can be expected to provide more durable roads based on the improvements observed to date and the technical properties it imparts to the paving mix.

In terms of emissions and energy usage, an in-depth study of the SEA process was sponsored by Alberta Transportation and conducted by the Sulphur Development Institute of Canada (SUDIC) in 1984 for a large-scale commercial SEA paving project¹⁵. The study concluded that 10.6% total energy savings were realized from the SEA paving project versus conventional paving. In addition, Alberta Transport conducted an Occupational Hygiene Survey¹⁶ for a SEA Paving Project in 1981. The study identified mishandling of molten sulphur as the greatest hazard and raised no undue concerns regarding SEA use, provided that appropriate precautions were taken by workers (i.e. using eye goggles and disposable dust respirators). Note that for both of these studies, the

¹⁰ Kirro et al. (1996). Emissions of Volatile and Semi-Volatile Organic Compounds and Particulate Matter from Hot Asphalts. University of Southern California.

¹¹ Strickland et al. (2008). Performance Properties of Paving Mixtures made with Extended Sulphur Pellets. ISAP.

¹² *ibid*

¹³ *ibid*

¹⁴ *ibid*

¹⁵ SUDIC & Alberta Transportation. (1984). Cost and Energy: Audit Sulphur Extended Asphalt Pavement Construction.

¹⁶ Alberta Transportation. (1981). Occupational Hygiene Survey: Sulphur-Extended Asphalt Paving Project.

mixing process involved pre-blending molten sulphur with hot asphalt cement prior to adding heated aggregate to the mixer.

No similar field study has been conducted for SEAM pellets. However, the results of the Alberta Transportation study can be applied to SEAM by discounting any impacts associated with the handling of molten sulphur and accounting for any impacts associated with the production and addition of SEAM pellets to the hot asphalt mix. Given that the handling of molten sulphur was identified as the largest hazard in the Alberta Transportation study, the hazards associated with SEAM versus SEA use are significantly reduced.

The emissions associated with SEAM paving mix production and application have been assessed through sampling programs conducted in Calgary and Edmonton, Alberta. Sampling indicates that total hydrocarbon emissions from the hot mix stack and VOC emissions during paving are lower for SEAM versus conventional paving mix and that all emissions are within provincial regulations. Results of these field studies will be discussed in further detail in Section B.6.

B.6 Review of Existing Projects

Case studies have been conducted at several facilities located in Alberta and British Columbia to characterize the performance and emissions associated with SEAM versus conventional asphalt paving mix.

Sampling conducted over a period of three days by an independent third party at a hot mix facility in Calgary in 2004 found that total hydrocarbon emissions for SEAM mix were lower than those for conventional mix¹⁷. Note that emissions from this analysis were expressed as methane. In this study, SEAM paving mix was then applied at a busy intersection in Calgary and subjected to three years of pavement wearing. Re-inspection three years following application indicated no problems and the pavement was reported to have performed as expected¹⁸.

Sampling conducted over a period of two days in Edmonton in 2002 during paving with SEAM measured VOC emissions at levels of approximately half those associated with conventional mix¹⁹. Sampling data was reviewed by the Alberta Research Council (ARC) and the difference in emissions was attributed to the lower processing temperatures required for SEAM mix. Further study may be conducted by Shell to provide a more in-depth analysis of the life-cycle VOC emissions associated with paving.

In 2006 a paving recycling demo was conducted in New Westminster. In this project SEAM paving at a 40% SEAM to 60% bitumen ratio was applied to an high traffic intersection where frequent pavement replacement and deformation was required.

¹⁷ Maxxam Analytics Inc. (2004). Source Emission Survey for Shell Canada Ltd and LaFarge Construction.

¹⁸ Shell Sulphur Solutions. (2008). Calgary SEAM Wearing Course Demonstration Pavement – Construction and Performance After Three Years.

¹⁹ Standard General Inc. (2002). Volatile Organic Constituent Measurements at the Asphalt Paver – Asphalt vs. SEAM Paving.

Pavement was then recovered after being left to age in-situ for two months. At the hot mix facility three days of stack emission sampling was conducted for paving mixed at a ratio of 20% recycled SEAM to 80% new pavement versus 20% conventional to 80% new paving mix. Stack emissions for both types of paving mix were within regulations, however results for PM, organics, and other contaminants from recycled SEAM versus conventional paving mix were inconclusive²⁰.

B.7 Summary of Quantification Approaches

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.

B.8 Other Impacts

According to recent studies and field testing conducted at hot mix plants in Calgary, Edmonton, and New Westminster, no additional undo air emissions, risks or environmental impacts are anticipated from the substitution of SEAM for a proportion of the asphalt binder used in conventional asphalt.

Recent field testing conducted over a period of three days by an independent third party at a hot mix facility in Calgary indicated slightly higher particulate matter (PM) and SO₂ emissions for SEAM versus conventional paving mix with emissions of H₂S being equivalent²¹. While the PM and SO₂ emissions recorded were slightly higher for SEAM paving, they were still well below provincial limits. As part of annual reporting requirements, emissions are carefully monitored, which would ensure there are no undo effects associated with SEAM production or use.

A study conducted in California of the effect of temperature on emissions from hot mix asphalt concluded that emissions are highly dependant on temperature²². Further, a study conducted by the International Society for Asphalt Pavements (IMAP) specifies that the temperature during hot mixing must be maintained below 140 °C to avoid emissions during paving and compaction. This is important to ensure that hydrogen sulphide (H₂S) and sulphur dioxide (SO₂) emissions are managed and are within their respective short and long-term exposure limits²³. Manufacturing and handling protocols for SEAM have been developed that include control of the temperature at 140 °C. Use of SEAM plus would serve to further reduce risks by reducing the required mix temperature by an additional ten degrees.

To ensure that all risks associated with the use of sulphur pellets in paving mix were considered, IMAP implemented an HSE Management System. As part of this initiative,

²⁰ Shell Canada Ltd. (2005). Emissions from Plant Recycling of a SEAM Paving Mix.

²¹ Maxxam Analytics Inc. (2004). Source Emission Survey for Shell Canada Ltd and LaFarge Construction.

²² Kirro et al. (1996). Emissions of Volatile and Semi-Volatile Organic Compounds and Particulate Matter from Hot Asphalts. University of Southern California.

²³ Strickland et al. (2008). Performance Properties of Paving Mixtures made with Modified Sulphur Pellets. International Society for Asphalt Pavements (ISAP).

product-abuse trials were conducted to determine safe operating temperatures and ensure that gaseous emissions complied with local regulation on Occupational Exposure Limits (OEL)²⁴. Worse case scenario trials and air monitoring were also conducted at temperatures and using storage factors set much higher than typical operational levels, for paving mixture made with modified sulphur pellets in comparison with conventional asphalt paving mix. The objective of these trials was to assess worst-case scenario hydrogen sulphide (H₂S), sulphur dioxide (SO₂) and total hydrocarbons emissions. Trial results indicate that H₂S and SO₂ emissions as a function of the overall moving average and time-weighted average exposures were below the occupational exposure limits defined in Canada and the United States²⁵.

Field testing also indicates that the odors associated with SEAM mix are slightly stronger than for conventional paving mix. Given that 65% of hot mix facilities in Alberta and British Columbia are located in urban areas, odors must be closely monitored to avoid complaints²⁶. Further, worker eye irritation when close to the mix was recorded. It was indicated that this risk was mitigated through the use of protective eye wear²⁷.

In terms of positive impacts, the project activity may yield a benefit via incremental revenue and reduced fuel costs from lower mix temperatures and reduced use of bitumen asphalt binder. In addition, project developers may record reduced air emissions during asphalt storage, hot mixing and paving due to the lower asphalt content of the paving mix.

B.9 Assessment of Baseline Scenarios

An assessment of potential baseline scenarios based on the recommended methodology from best practice guidance was conducted. Results of the assessment are presented in Table 2.3.

TABLE 2.3: Assessment of Possible Baseline Scenarios

| 1. Baseline Options | 2. Description | 3. Static / Dynamic Baseline | 4. Accept or Reject and Justify |
|-------------------------|---|------------------------------|---|
| Projection Based | Projection of the baseline scenario based on modeling the future emissions from road resurfacing projects | Dynamic. | Reject. This method would require modeling emissions as a function of historical and forecasted future paving mix production, stack emissions and fuel consumption. This approach relies on the use of an appropriate model and measured facility data. Given the potential for emissions and fuel usage to change significantly |

²⁴ *ibid*

²⁵ *ibid*

²⁶ Environment Canada and the Canadian Council of Ministers of Environment (CCME). (2002). Multi-pollutant Emission Reduction Analysis Foundation (MERAF) for the Hot-mix Asphalt Sector.

²⁷ Standard General Inc. (2002). Volatile Organic Constituent Measurements at the Asphalt Paver – Asphalt vs. SEAM Paving.

| | | | |
|-----------------------------|---|----------|--|
| | | | depending on weather conditions, mix formulation, aggregate source and other conditions Modelling would not provide a reasonable representation of baseline emissions. This approach is not applicable. |
| Historic Benchmark | Assessment of the baseline scenario based on data from the operation of the site prior to project implementation. | Static. | Reject. A historic benchmark approach would use historical fuel usage and emissions data to quantify the baseline. Data would be adjusted for the quantity of paving mix produced in the project. This approach is not recommended as fuel consumption and emissions have the potential to change significantly for each project depending on the mix formulation, source of aggregate, etc. As such, historic data would not be an accurate representation of emissions at the site. This approach is not applicable. |
| Performance Standard | Assessment of the baseline scenario based on the emissions profile of a typical hot mix facility in terms of fuel consumption and the typical emissions profile for fugitive emissions. | Dynamic. | Accept. The performance standard approach would assess the emissions from the emission profile of a typical hot mix facility. While emissions will vary depending on efficiency, age and other characteristics at the site, this approach represents the most accurate values available. Data is available to allow for the modeling of emissions using emissions factors for the production and storage of each component. Further equations exist to allow for the calculation of the energy required to heat each component. |
| Comparison | Assessment of baseline scenario based on the emissions from a control group to compare with the project. | Dynamic. | Reject. This method is analytically and data intensive, and there is significant variation between different sites and potential data confidentiality concerns. This approach is not applicable. |
| Other | Other quantification that may be applicable to the site-specific circumstances that can be justified with reasonable assurance. | Unknown. | Not Applicable. Project specific. |

B.10 Selection of Baseline Scenario

The baseline condition for this protocol is the production and usage of conventional hot mix asphalt. The baseline configuration would be the use of conventional hot mix asphalt, whose composition of aggregate versus bitumen binder will vary depending on the type of road paved (i.e. highway versus city street) produced at a temperature ranging from 130 to a maximum of 155 degrees Celsius.

The recommended baseline approach is a performance based approach. Under this scenario, the emissions from production and handling of bitumen and aggregate and hot mix asphalt production would be calculated from direct measurement of the quantities of each component consumed and using emission factors published by Environment Canada, the Canadian Association of Petroleum Producers (CAPP), the Canadian Council of Ministers (CCME) of Environment, the US Environmental Protection Agency (EPA) and other sources.

The baseline condition is dynamic as it will vary depending on the quantity of hot mix asphalt produced. This dynamic approach accounts for the market forces, weather and energy demand and operational parameters without adding multiple streams of material management. There are suitable models that can provide reasonable certainty.

Facility data for the proportions of aggregate and bitumen binder in conventional hot mix asphalt used at the facility prior to use of SEAM is used to quantify the relative quantities of aggregate and binder consumed. If the specific mix formulation and mix temperature used at a facility prior to use of SEAM are not tracked, default values for each type of road be substituted for the above site-specific values. These values have been provided by Alberta Transportation and are included in Appendix B of the protocol document.

Emissions from bitumen production and handling are accounted for from direct measurement of SEAM usage and hot mix asphalt output in the project activity and displacement of an equivalent quantity of bitumen binder in the baseline. Baseline emissions are then quantified using emission factors for heavy crude oil thermal production published by the Canadian Association of Petroleum Producers (CAPP) and emission factors for silo-filling and load-out using emission factors published by Environment Canada / CCME²⁸.

Emissions from fuel consumption are calculated using a heat equation, with aggregate moisture content also being considered. In this approach the quantity of heat required to produce the paving mix is determined based on the quantities of asphalt and aggregate consumed, the initial and final temperatures of each, the moisture content of the aggregate and the specific heat capacity of each component. In this case:

- It is assumed that the heat capacity of the SEAM product is equal to that of sulphur. This is reasonable given that sulphur makes up approximately 98% of the SEAM product;
- Default values are used for the heat capacities of aggregate and bitumen;
- Aggregate, asphalt and ambient temperatures would be selected by the facility operator as a function of the operational and climatic conditions at the facility; and
- Manufacturer's specifications for the quantity of energy / fuel required to dry aggregate depending on its moisture content would be used.

²⁸ Environment Canada and the Canadian Council of Ministers of Environment (CCME). (2002). Multi-pollutant Emission Reduction Analysis Foundation (MERAFA) for the Hot-mix Asphalt Sector.

Emissions from hot mixing include the emissions associated with fuel combustion and fugitive emissions of methane from bitumen use. Emissions from fuel combustion are calculated as a function of the volume of fuel required for aggregate drying and hot mixing, and using emission factors from Environment Canada and the Canadian Association of Petroleum Producers (CAPP). Hot mix stack emissions from bitumen use are accounted for by direct measurement of the quantity of bitumen consumed and using emission factors from the US EPA and CCME.

- US EPA Emission factors are delineated for drum and batch mixers at hot mix asphalt plants on a per unit of bitumen basis. These factors were calculated based on the following assumptions;
 1. Hot mix production temperature of 145 °C, which is reasonable since conventional hot mix asphalt is produced at approximately 130 to 150 °C and at an average temperature of 144 °C in Canada; and
 2. Methane emissions are directly correlated to the quantity of bitumen in the hot mix asphalt.

Alternatively, emissions from bitumen use may be determined from stack sampling conducted using conventional hot mix asphalt and following implementation of the project. This quantification method is included as a flexibility mechanism as hot mix facilities in Alberta are not required to conduct annual sampling or report emissions of CO₂ or total organics.

- Note that stack sampling of emissions from the hot mix stack should include only mixing process emissions. This parameter would not be calculated for CH₄ at facilities where stack emission monitoring is conducted at a point that includes both process emissions from mixing and ducted emissions from fuel combustion. In this case these emissions would already have been accounted for under the fuel usage variable, described above.

Note that the emissions associated with upgrading heavy crude to asphalt are likely significant, however there is a lack of publically available emissions data. In addition, it is difficult to delineate the emissions associated with upgrading to asphalt versus production of other hydrocarbon products. It is conservative to exclude these emissions since the quantity of asphalt consumed in the project condition is less than that consumed in the baseline.

Further, methane emissions from paving using conventional versus SEAM pavement may be significant, however significant sampling has not been conducted. These emissions may be re-assessed if an in-depth sampling program is conducted to assess the methane emissions from conventional versus SEAM asphalt during paving. Based on the higher asphalt content of conventional paving mix, and field sampling conducted to date, baseline methane emissions from paving application will likely be higher in the baseline condition. It is therefore conservative to exclude these emissions from quantification.

A life-cycle process flow diagram of the baseline condition is provided in Figure 2.1. Emission sources and sinks (SS's) that will be included in the quantification approach are highlighted.

B.11 Definition of the Project Condition

The project condition is defined as the production and usage of hot mix asphalt paving mix with the substitution of a proportion of the bitumen binder for a sulphur extended asphalt modifier (SEAM) product. This SEAM product may also include the addition of a wax additive designed to reduce paving mix production and compaction temperatures by approximately 10 °C.

A life-cycle process flow diagram of the project condition is provided in Figure 2.2. Emission sources and sinks (SS's) that will be included in the quantification approach are highlighted.

B.12 Functional Equivalence

Functional equivalence means that the Project and the Baseline provide the same function and quality of products or services. This type of comparison requires a common metric or unit of measurement (such as the fuel use per unit of production) for comparison between the Project and Baseline activity.

In this protocol the common unit of measurement is the quantity of fuel consumed to dry aggregate and heat the various hot mix components to required temperatures at specific SEAM to asphalt binder ratios and quantities of asphalt and aggregate between the project and baseline, and the volume of fugitive gases emitted in the project versus baseline conditions.

As such, the relevant sources and sinks in both the project and baseline are for fuel extraction and processing, hot mix dryer and mixer operation, and vent gases from asphalt storage, silo-filling and load-out. In particular, the volumes of fossil fuels consumed for facility operation in the project condition, the quantity of aggregate, asphalt and SEAM product produced and consumed at the project site and the composition and quantity of gas emissions from hot mixing are compared. All other sources and sinks are excluded from quantification on the basis of not being a significant source of emissions or functional equivalence.

In terms of magnitude, GHG emission reductions achieved from avoided asphalt production will be of the highest magnitude in projects that use the SEAM binder, followed by savings related to reduced fuel consumption.

B.13 Flexibility Mechanisms

Flexibility in applying the quantification protocol is provided to project developers in four ways:

1. Site specific emission factors may be substituted for the generic emission factors indicated in this protocol document. The methodology for generation of these emission factors must ensure accuracy; and be robust enough to provide uncertainty ranges in the factors;
2. If the project developer has records of historical mix formulation data (i.e. weight percent of bitumen binder used per tonne of hot mix asphalt) prior to SEAM use, this value may be substituted for the default values of bitumen and aggregate content included in Appendix B;
3. If hot mix stack emission testing has been conducted at the facility to characterize methane emissions from bitumen usage for conventional and SEAM hot mix asphalt, this data may be used to quantify the Emissions_{Hot Mix Stack} for SS's P15 and B11. The methodology for calculation of site-specific emission factors is included as Appendix C; and
4. The sources and sinks (SS's) B18 and P22 may be added back into the protocol if further sampling and characterization of emissions is conducted and / or appropriate data, calculation methodologies, etc. become available.

The project proponent will have to justify their approach in detail to apply any of these flexibility mechanisms.

FIGURE 2.1: Process Flow Diagram for Baseline Condition

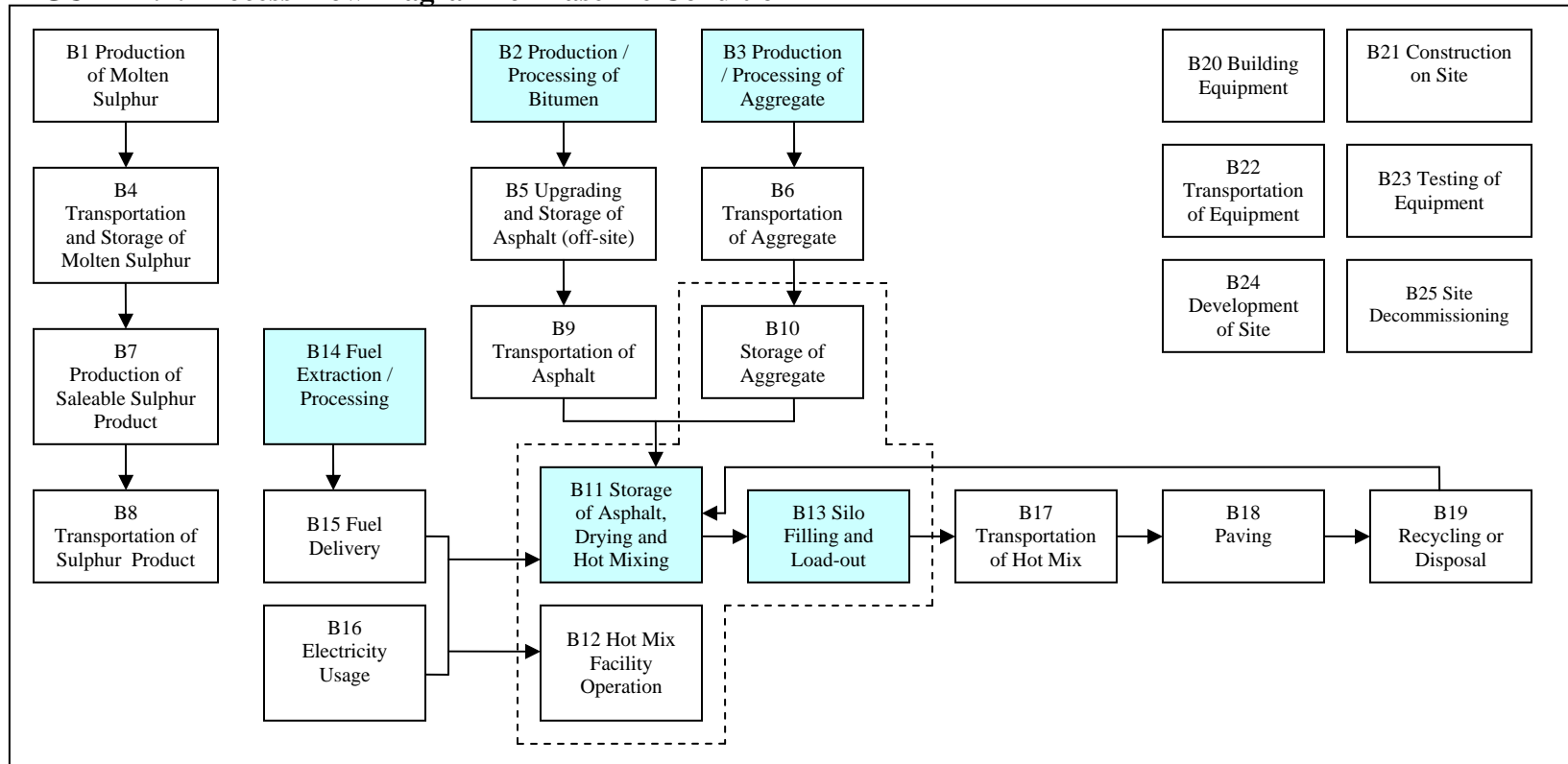


FIGURE 2.2: Process Flow Diagram for Project Condition

