VCS Methodology

VM0039

Methodology for Use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application

Version 1.0

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Sectoral Scope 6

This methodology was developed by the Smart Construction Center at the University of Maryland, in collaboration with Emissionairy, Inc., Chamberlain Contractors, Inc., and Straughan Environmental, Inc.

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1 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Performance Method
Crediting Baseline	Performance Method

This methodology provides a framework for the quantification of greenhouse gas (GHG) emission reductions associated with the production and installation of Foam Stabilized Base (FSB) and/or asphalt emulsions as substitutes for Hot Mix Asphalt (HMA) in road construction projects located in the United States[1].

For over 40 years, FSB and asphalt emulsions have been used in road projects around the world when natural resources for virgin aggregate or funding to construct and maintain roads using HMA have been limited. In North America, where virgin aggregate has historically been easily accessible within proximity to project sites, FSB has not been as widely implemented as it has in other parts of the world. FSB has, therefore, been used on a very limited basis in the United States for the last 10 to 15 years. Most projects using FSB and asphalt emulsions in the United States are pilot projects funded by various state highway agencies. While these projects have proven successful, state highway administrations have been slow to accept and develop the protocol and practices for this approach in North America. Presently there are no national or regional standards for the production or application of FSB and asphalt emulsions, which serves as a major impediment to the acceptance and application of FSB and asphalt emulsions beyond the testing phase.

GHG emission reductions are generated from producing and applying FSB and asphalt emulsions versus HMA as follows:

- FSB and asphalt emulsions consist of 50% less liquid asphalt/bitumen by weight and 2.5% less asphalt/bitumen by volume than required for HMA production, reducing the reliance on resources. No virgin aggregates are required, eliminating the energy and resources needed for excavating machines and trucking. In most applications, but especially in rural areas, the GHG emissions from trucking are significantly reduced. This is due to the fact that FSB and asphalt emulsions can be manufactured on or close to the project site.
- Aggregates in FSB and asphalt emulsions do not have to be heated, while HMA liquid, which is roughly 2.2% of the total weight of the mix, needs to be heated up to 310 ºF.

[1] Under this methodology, the project proponent may be the technology owner, FSB producer/manufacturer, road owner, contractor, or other party associated with the production of application/construction or development of paving segments paved with FSB. Given that the project proponent could be any one of entities listed above, clear project ownership must be demonstrated through contractual agreements, or other arrangements, in order to avoid the risk of double counting with other participants in the supply chain.

In this methodology, performance benchmarks have been established for the determination of additionality and the crediting baseline. These benchmarks are based on GHG emissions from the baseline scenario, which enables a measurement of emission reduction potentials through the substitution of FSB and asphalt emulsions for HMA. Data from hot mix facilities and placement projects in different geographic locations within the United States were surveyed to determine the levels of the performance benchmarks. Emission reductions of FSB and asphalt emulsions are the differences between actual project emissions and the crediting performance benchmark.

2 DEFINITIONS

Aggregate
A collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium to form asphalt. Aggregate can be from either natural or recycled sources, called virgin aggregate or recycled aggregate.

Asphalt
A cementitious material, ranging from a dark brown to black color, in which the predominating constituents are bitumens that occur in nature or are obtained by petroleum processing

Asphalt Emulsions
A dispersion of small droplets of one liquid into another liquid. Usually, asphalt emulsions contain small droplets of asphalt binder in water and emulsifying agent. Standard asphalt emulsions contain 40% to 75% asphalt binder, 0.1% to 2.5% emulsifier, and 25% to 60% water.

Asphalt Pavement
Asphalt concrete layer(s) on supporting courses such as concrete base, asphalt treated base, cement treated base, granular base, and/or granular sub-base placed over the subgrade

Bitumen
A black or dark colored organic material with adhesive properties derived from distillation of petroleum or natural asphalt. Bitumen is also called liquid asphalt, asphalt binder, and/or liquid asphalt cement.

Cold Central Plant Recycling (CCPR)
A method for producing FSB and asphalt emulsions which requires milled reclaimed asphalt pavement (RAP) to be transported from an existing jobsite to a central mixing plant. The unheated RAP is then blended with foamed asphalt and a small amount of Portland cement in a cold mixing process.

Cold In-Place Recycling (CIR)
The principal method for producing FSB and asphalt emulsions which uses one or more mobile recycling machines for milling, asphalt production, and placement in a continuous operation at the pavement site. Generally, CIR uses 100% RAP generated from the existing pavement, which is

blended with small amount of Portland cement with a treatment depth ranging from approximately 2 to 6 inches.

Foamed Asphalt
A mixture of air, water, and bitumen. When injected with a small quantity of cold water, the hot bitumen expands explosively to about fifteen times its original volume and forms a fine mist or foam. In this foamed state, the bitumen has a very large surface area and an extremely low viscosity. This expanded bitumen mist is then incorporated into the mixing drum where the bitumen droplets are attracted to and coat the finer particles of pavement material, thus forming a mastic that effectively binds the mixture together.

Foamed Stabilized Base (FSB)
A mixture of foamed asphalt binder and RAP, or a combination of RAP and recycled concrete. Unlike hot mix asphalt (HMA), the foamed binder does not coat the aggregate particles. Rather, it coats the fines (passing #200 sieve) in the aggregate, which helps serve as a bonding agent to keep the aggregate particles together. FSB is generally used as a base course layer in the pavement construction in lieu of conventional HMA in order to reduce the carbon footprint of construction operations.

Full-Depth Reclamation (FDR)
A technique in which the full thickness of the asphalt pavement and a pre-determined portion of the underlying material (base, sub base, and/or subgrade) is uniformly pulverized and blended to provide an upgraded, homogenous base material. FDR is performed on the roadway without the addition of heat, similar to CIR. Thus, the emissions from FDR can be quantified using the same method as CIR.

Hot Mix Asphalt (HMA)
A mixture of course aggregate, fine aggregate, and asphalt cement that is produced at a central facility at temperatures between 300 and 325°F. HMA can incorporate a small amount of RAP (usually 10% to 30%) into the mix.

Portland Cement
The most common type of generally used cement around the world. It is used as a basic ingredient of concrete, mortar, stucco, and most non-specialty grout. It usually originates from limestone. Portland cement is a fine powder that consists of more than 90% ground Portland cement clinker, a limited amount of calcium sulfate (which controls the set time), and up to 5% minor constituents as allowed by various standards.

Reclaimed Asphalt Pavement (RAP)
Material generated from milling existing asphalt pavement layers during the rehabilitation of paved surfaces. RAP consists of aggregates that are coated by asphalt.

Structural Layer Coefficient
The relative structural capacity of a material per inch of thickness.

Virgin Aggregate

Aggregate that has been quarried and not used in any prior asphalt applications.

Warm Mix Asphalt (WMA)

A subcategory of HMA that is produced within a target temperature discharge range using the applicable state Department of Transportation (DOT) approved WMA additives or processes. The WMA technologies may be used as coating and compaction aids without lowering the production temperature.

3 APPLICABILITY CONDITIONS

This methodology is applicable under the following conditions:

1) Project activities include the construction of any type of road and/or parking lot (including parking lot patching projects) in the United States.
2) Project activities must apply one or more of the following processes for road construction:
    a) FSB produced using the CCPR process
    b) FSB produced using the CIR process
    c) FSB produced using the FDR process
    d) Asphalt emulsions produced using the CCPR process
    e) Asphalt emulsions produced using the CIR process
    f) Asphalt emulsions produced using the FDR process
3) Production plants where the project activity occurs may serve multiple pavement types, including, but not limited to, roadways and parking lots.
4) Project activities may have an HMA or WMA surface layer, but must have at least one FSB or asphalt emulsions base layer.

This methodology is not applicable under the following conditions:

1) Project activities include only an HMA, WMA, or other non-FSB/asphalt emulsions paving material base layer.

4 PROJECT BOUNDARY

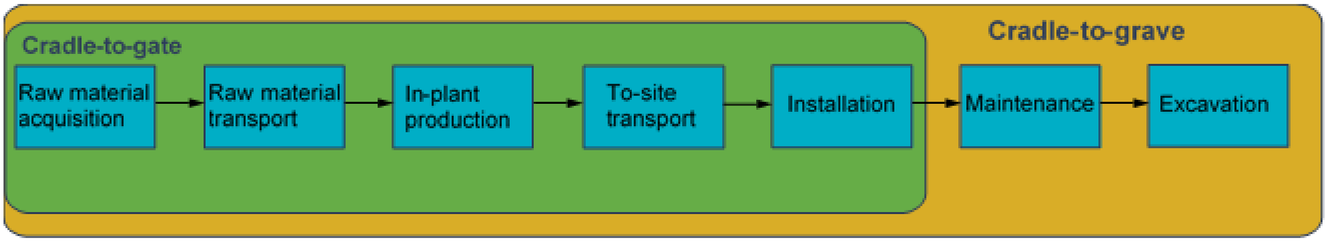
The spatial extent of the project boundary encompasses the stages from raw material acquisition to product installation and complies with the cradle-to-gate assessment principle (Sinden, 2008). As shown in Figure 1, the GHG impact of producing an asphalt mixture must be calculated by summing the following emission sources:

1) GHGs associated with manufacturing each of the constituent and ancillary materials;
2) GHGs from transporting materials from factory to mixing plant;

3) GHGs from all forms of energy involved in producing the asphalt at the mixing plant; and

4) GHGs from all forms of energy involved in milling the existing pavement and placing new pavement, including relevant transport activities.

Figure 1: Map of the Asphalt Life-Cycle

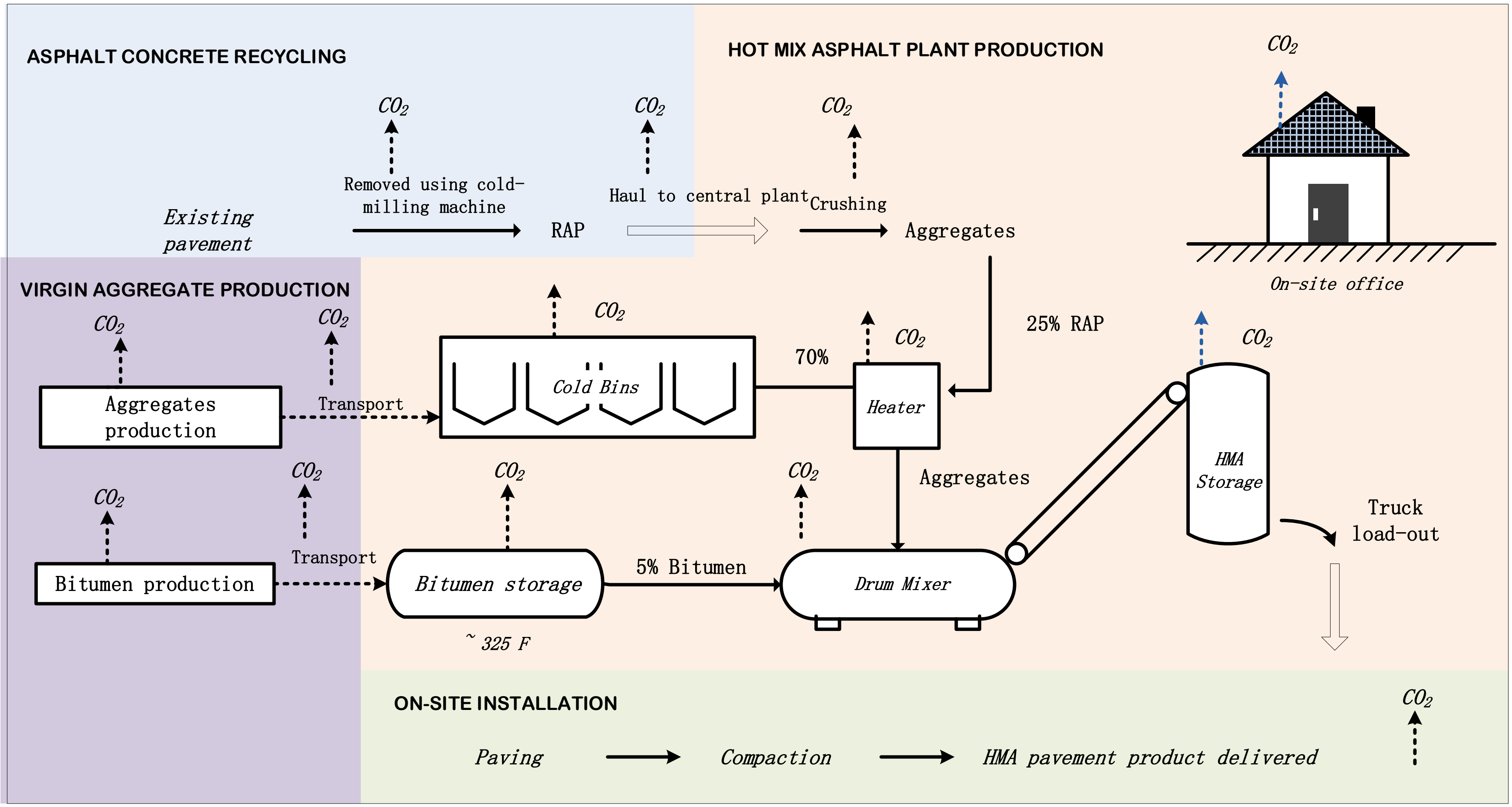


Maintenance and excavation of pavement is not included due to the high variability of maintenance practices in each region. Maintenance activities can be classified into preventive maintenance and structural improvement. Given the complexity of maintenance methods, material sources, and equipment use, associated GHG emissions vary significantly. The emission difference can only be captured after the maintenance activities are complete. As the structural performance of FSB and asphalt emulsions are comparable to the baseline HMA method, the frequency of pavement maintenance is generally the same (Bemanian et al., 2006; Morian et al., 2005). There is insignificant difference in post-installation emissions between FSB/asphalt emulsions and HMA. The boundary also excludes GHG emissions associated with the production of capital goods having lifetimes longer than one year and the transportation of employees to and from their normal place of work.

4.1 Boundary for Baseline Emissions

The estimation of baseline emissions for HMA projects begins with the production of raw materials at manufacturer sites and ends with the delivery of the final pavement product to the customer. It includes all energy-consuming activities of equipment and machinery at supplier sites, the hot mix facility, the job site, and associated transportation. The emission sources covered within the system boundary include production materials, manufacturing equipment/vehicles, operation of the plant office, and transport and storage of input materials (Sinden 2008). Specifically, the boundary for HMA systems consist of energy consumption for quarrying/producing the mineral aggregates and bitumen binder, transportation to and at the HMA production plant, storage, heating of the individual components (including aggregates and bitumen binder), mixing, and the transportation and installation of the mix at the job site, as shown in Figure 2.

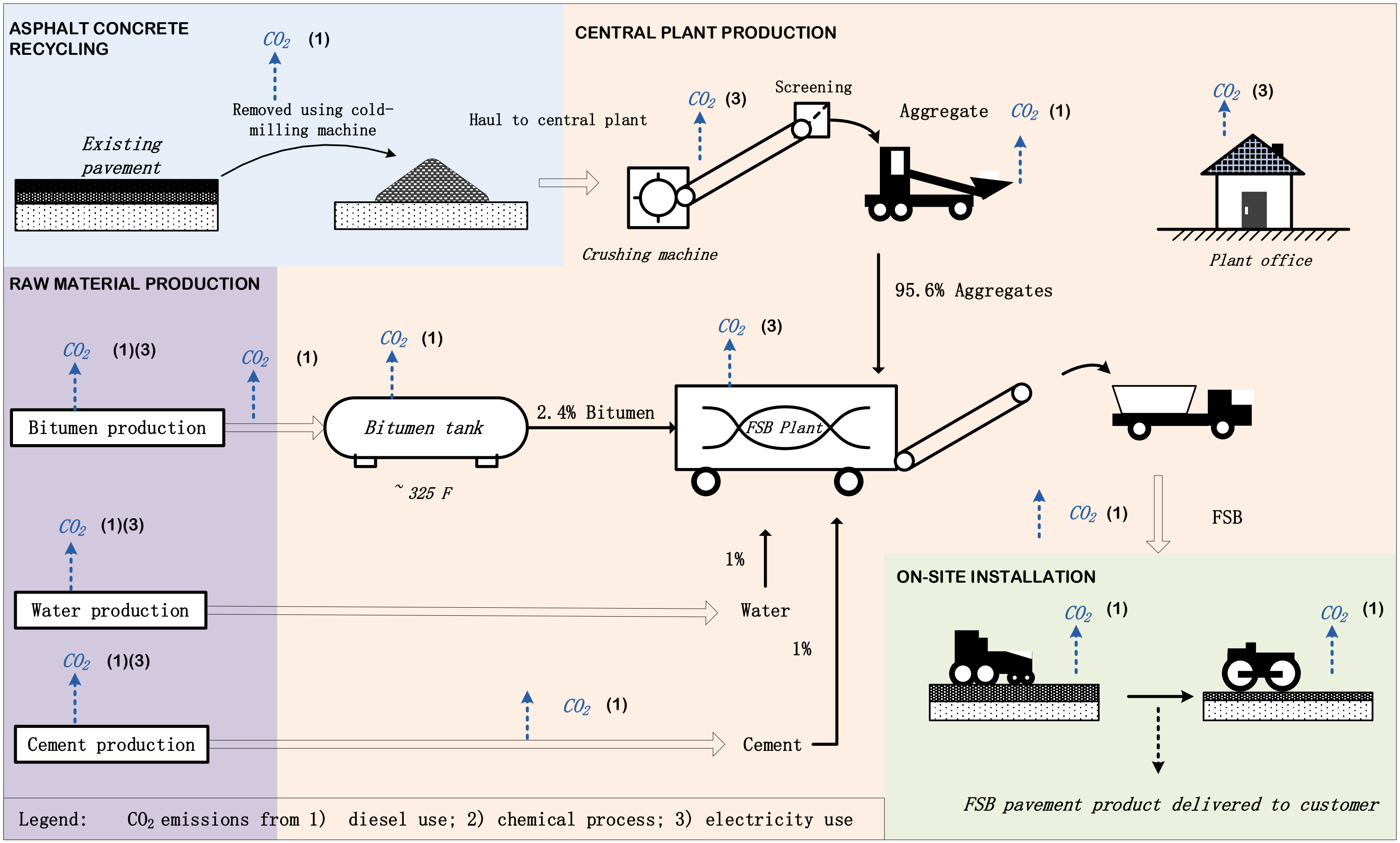
Figure 2: Diagram of HMA Production and Placement



4.2 Boundary for Project Emissions from CCPR Process

The estimation of project emissions for CCPR projects begins with the transportation of raw and recycled materials to a central plant and ends with the delivery of the final pavement product to the customer. CCPR projects transport milled materials from an existing jobsite to a central plant where FSB or asphalt emulsions are processed through a pug mill. Production of FSB begins with the crushing of RAP, which diverts waste from landfills. Once the crushed pavement is sized, the unheated RAP is then blended with foamed bitumen (or asphalt emulsions) and a small amount of Portland cement in a cold mixing process. Figure 3 shows the major processes included in a CCPR project. The boundary consists of the energy consumption for milling the existing pavement, producing bitumen binder and water, transportation to and at the FSB and asphalt emulsions production plant, heating of bitumen binder, mixing, transportation of materials and resources to the project site, and installation of the mix.

Figure 3: CCPR Project Activities and Associated GHG Sources

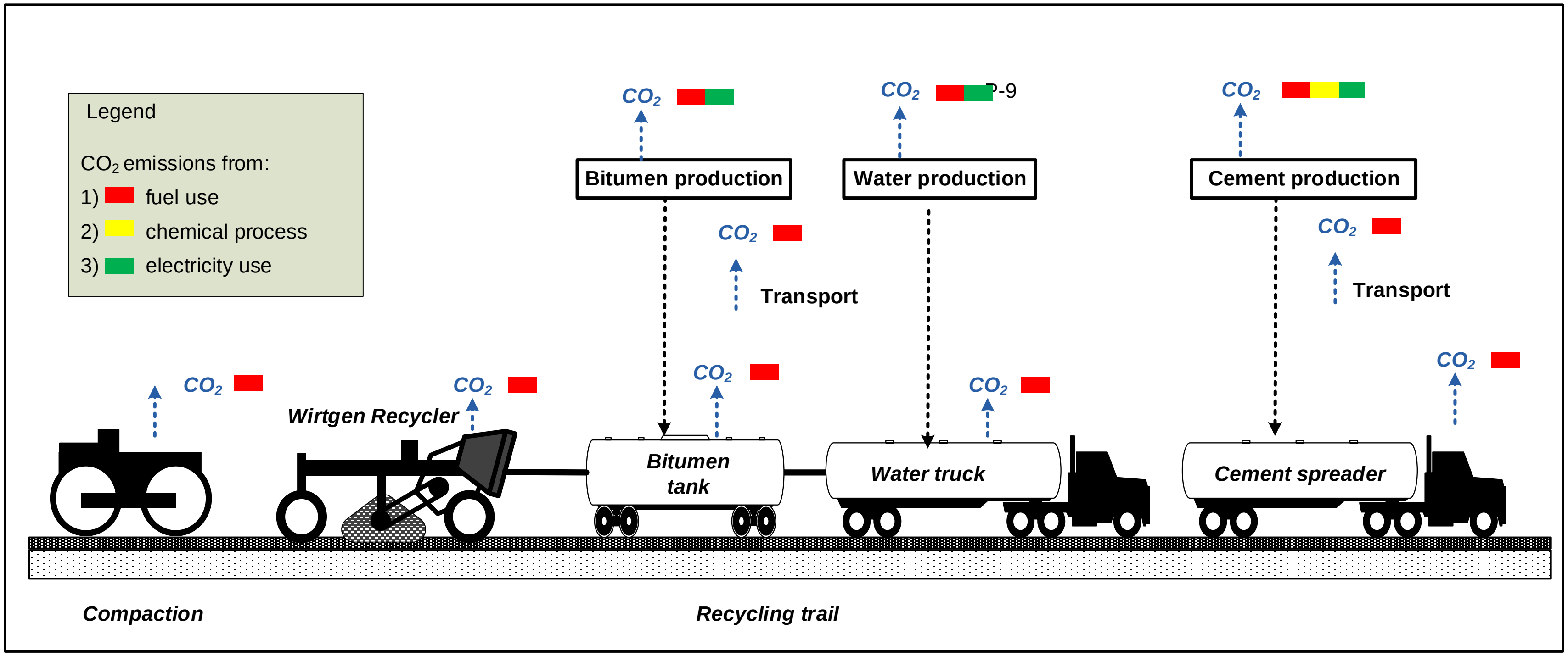


Note: Double-lined arrows signify included transportation; dashed-line arrows signify the separation of activities in different locations.

4.3 Boundary for Project Emissions from CIR and FDR Systems

The estimation of project emissions for CIR and FDR projects begins with the transportation of raw materials to a job site and ends with the delivery of the final pavement product to the customer. CIR and FDR use one or more mobile recycling machines for milling, production, and placement in a continuous operation at the pavement site. It reconstructs the roadways by using special equipment to mill up the existing pavement, mix it with hot bitumen oil (or asphalt emulsions) and additives, and then immediately place it back down on the road by permanent placement with a paver and rollers. CIR and FDR allows a paving contractor to use the aggregate from the existing road and, by adding liquid asphalt cement (consisting of under 3% of the total volume), it reduces the emissions of new aggregate materials and new liquid asphalt cement that must be shipped from the producer's plant site. Figure 4 shows the major activities included in CIR and FDR systems. The project boundary includes production of bitumen, water, and cement, operation of recycler and rollers, and transportation and storage of input materials.

Figure 4: CIR and FDR Project Activities and Associated GHG Sources



4.4 GHG Sources Included and Excluded from the Project Boundary

The greenhouse gases included in or excluded from the project boundary are shown in Table 1 below.

Table 1: GHG Sources Included or Excluded from the Project Boundary

Source		Gas	Included?	Justification/Explanation
HMA (Baseline)	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
		CH_4	No	Not applicable
		N_2O	No	
	Raw material transport	CO_2	Yes	GHGs are released from fuel consumption for transporting materials from producers to central plant.
		CH_4	No	Not applicable
		N_2O	No	
	In-plant production	CO_2	Yes	GHGs are generated from the usage of natural gas by the drum mixer, plant electricity (including electricity for plant office), and diesel equipment/vehicles operated for producing HMA at the central plant.
		CH_4	No	Not applicable
		N_2O	No	
	To-site transport	CO_2	Yes	GHGs are released from fuel consumption for transporting materials from the central plant to construction site.
		CH_4	No	Not applicable
		N_2O	No	
	Installation	CO_2	Yes	GHGs are released from diesel consumption by construction equipment/vehicles, including asphalt paving machine, backhoe, bobcat/loader, sweeper/broom, air compressor, roller, trucks, etc.
		CH_4	No	Not applicable
		N_2O	No	

Source		Gas	Included?	Justification/Explanation
	Maintenance	CO_2	No	GHGs from maintenance and rehabilitation are excluded due to uncertain traffic volume, failure type and repair options.
		CH_4	No	Not applicable
		N_2O	No	
	Excavation	CO_2	No	GHGs from excavation are excluded due to the uncertainty in determining pavement disposal options (e.g., landfill, recycling, remain in place).
		CH_4	No	Not applicable
		N_2O	No	
CCPR (Project Scenario 1)	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
		CH_4	No	Not applicable
		N_2O	No	
	Raw material transport	CO_2	Yes	GHGs are released from fuel consumption for transporting materials from producers to the central plant.
		CH_4	No	Not applicable
		N_2O	No	
	FSB/asphalt emulsions production	CO_2	Yes	GHGs are generated from the usage of electricity by plant office, bitumen heater and crusher and diesel equipment/vehicles operated for producing FSB/asphalt emulsions at the central plant.
		CH_4	No	Not applicable
		N_2O	No	
	To-site transport	CO_2	Yes	GHGs are released from fuel consumption for transporting materials from the central plant to the construction site.
		CH_4	No	Not applicable
		N_2O	No	
	Installation	CO_2	Yes	GHGs are released from fuel consumption by construction equipment/vehicles, including asphalt paving machine, backhoe,

Source		Gas	Included?	Justification/Explanation
				bobcat/loader, sweeper/broom, air compressor, roller, trucks, etc.
		CH_4	No	Not applicable
		N_2O	No	
	Maintenance	CO_2	No	GHGs from maintenance and rehabilitation are excluded due to uncertain traffic volume, failure type and repair options.
		CH_4	No	Not applicable
		N_2O	No	
	Excavation	CO_2	No	GHGs from excavation are excluded due to the uncertainty in determining pavement disposal options (e.g., landfill, recycling, remain in place).
		CH_4	No	Not applicable
		N_2O	No	
CIR or FDR (Project Scenario II)	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
		CH_4	No	Not applicable
		N_2O	No	
	Raw material transport	CO_2	Yes	GHGs are released from fuel consumption for transporting materials from producers to the job site.
		CH_4	No	Not applicable
		N_2O	No	
	FSB/asphalt emulsions Production & Placement	CO_2	Yes	GHGs are released from fuel consumption by construction equipment/vehicles, including, but not limited to a cold recycler (e.g., Wirtgen 3800 CR), a cement spreader, a water truck, a bitumen truck, a vibratory roller and a pneumatic roller.
		CH_4	No	Not applicable
		N_2O	No	
	Maintenance	CO_2	No	GHGs from maintenance and rehabilitation are excluded due to uncertain traffic volume, failure type and repair options.

Source		Gas	Included?	Justification/Explanation
		CH_4	No	Not applicable
		N_2O	No	
	Excavation	CO_2	No	GHGs from excavation are excluded due to the uncertainty in determining pavement disposal options (e.g., landfill, recycling, remain in place).
		CH_4	No	Not applicable
		N_2O	No	

5 BASELINE SCENARIO

The baseline scenario for projects applying this methodology is the application of HMA, or the subcategory WMA, to both the surface and base layers. The emissions associated with the quarry, transportation, and production of HMA or WMA serve as performance benchmarks, which are identified in Table 3 of Section 6 below.[2]

CCPR, CIR, and FDR projects replace HMA or WMA base layers with FSB or asphalt emulsions. These processes typically outperform the performance benchmarks because they can reduce the emissions from producing bitumen and producing, transporting, and heating virgin aggregates.

6 ADDITIONALITY

Project proponents applying this methodology must determine additionality using the procedure described below:

Step 1: Regulatory Surplus

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Standard.*

Step 2: Performance Benchmark

[2] More than 94% of U.S. roads are paved with HMA (EPA, 2015). The National Asphalt Pavement Association (NAPA) statistics show that approximately one third of HMA projects in the U.S. in 2014 used WMA technologies (NAPA 2017). HMA and WMA typically requires that more than 70% virgin aggregates are used in HMA production. They need to be quarried, transported to the hot mix plant, sorted into cold bins, dried by the heaters, blended with hot bitumen binders, and then fed into a mixer. The emissions associated with a series of these processes serve as performance benchmarks.

There are three strata of performance benchmarks for additionality based on project types and one-way distances between the HMA plant and job site.

Stratum 1 is for patching projects with hauling distance less than 40 miles, while Stratum 2 is for patching projects with hauling distance greater than 40 miles. Stratum 3 is for roadway projects. The performance benchmarks for all three strata are summarized in Table 2 below. Appendix A describes the calculation of the performance benchmark for additionality.

Where a project emits less than the relevant predetermined benchmark set out below, the project is deemed to be additional. This is determined by comparing the project emission intensity (derived from Section 7.2 below) to the additionality performance benchmark.

Table 2: Performance Benchmark for Patching Projects and Roadway Projects (2014)

Stratum	Project type	Hauling distance	Additionality performance benchmark
1	Patching	≤ 40 miles	121.9 $kgCO_2e/t$
2	Patching	> 40 miles	142.4 $kgCO_2e/t$
3	Roadway	Undefined	95.1 $kgCO_2e/t$

Note: 1 $kgCO_2e$ per tonne of output = 0.001 tCO_2e per tonne of output

The additionality performance benchmark is adjusted annually based on the expected changes in the use of RAP[3]. Based on NAPA (2017), the use of RAP in HMA is expected to increase by 1.1% every year. This increase can reduce carbon emissions by 0.1$kgCO_2e/t$ (NAPA, 2012). Therefore, as shown in Table 3, the performance benchmark decreases by 0.1$kgCO_2e/t$ annually.

Table 3: Performance Benchmarks from 2014 to 2025

	Patching Project (<40mile)	Patching Project (>40mile)	Roadway Project
2014	121.9	142.4	95.1
2015	121.8	142.3	95.0
2016	121.7	142.2	94.9
2017	121.6	142.1	94.8
2018	121.5	142.0	94.7
2019	121.4	141.9	94.6
2020	121.3	141.8	94.5

[3] An increased use of RAP can reduce GHG emissions due to the use of more recycled materials thus reducing the need for mining, processing, and transporting crushed stone and bitumen binder.

2021	121.2	141.7	94.4
2022	121.1	141.6	94.3
2023	121.0	141.5	94.2
2024	120.9	141.4	94.1
2025	120.8	141.3	94.0

Note: Unit is $kgCO_2e/t$, where 1 $kgCO_2e$ per tonne of output = 0.001 tCO_2e per tonne of output

7 QUANTIFICATION OF GHG EMISSION REDUCTIONS

7.1 Baseline Emissions

Baseline emissions have been predetermined by the performance benchmark for the crediting baseline, which is the same as the additionality performance benchmark. The crediting baselines from 2014 to 2025 are presented in Table 4 below.

Similar to the additionality benchmark, there are three strata of performance benchmarks based on project types and one-way distances between the HMA plant and job site. Appendix A describes the calculation of the performance benchmark for the crediting baseline.

Table 4: Crediting Baseline for Estimation of Emission Reductions

	Patching Project (<40mile)	Patching Project (>40mile)	Roadway Project
2014	121.9	142.4	95.1
2015	121.8	142.3	95.0
2016	121.7	142.2	94.9
2017	121.6	142.1	94.8
2018	121.5	142.0	94.7
2019	121.4	141.9	94.6
2020	121.3	141.8	94.5
2021	121.2	141.7	94.4
2022	121.1	141.6	94.3
2023	121.0	141.5	94.2
2024	120.9	141.4	94.1
2025	120.8	141.3	94.0

Note: Unit: $kgCO_2e/t$. 1 $kgCO_2e$ per tonne of output = 0.001 tCO_2e per tonne of output

7.2 Project Emissions

Project emissions are calculated in one of two ways, depending on production method. Where the project is performed using CCPR, the calculation of project emissions must follow the process in Section 7.2.1. Where the project is performed using CIR or FDR, the calculation of project emissions must follow the process in Section 7.2.2.

7.2.1 Emissions from CCPR

CCPR emission intensity (*CCPR EI*) represents the quantity of GHGs emitted from producing and installing one metric ton of FSB and asphalt emulsions using CCPR. It is the summation of raw material production emission intensity (EI_M), to-plant delivery emissions intensity (EI_{PD}), in-plant production emission intensity (EI_P), to-site delivery emissions intensity (EI_{SD}) and on-site installation emission intensity (EI_I). *CCPR EI* is calculated as follows:

$$CCPR\ EI = EI_M + EI_{PD} + EI_{SD} + EI_P + EI_I \quad (1)$$

Where:

CCPR EI	=	Emission intensity of CCPR (kgCO_2e/t)
EI_M	=	Emission intensity of raw material production (kgCO_2e/t)
EI_{SD}	=	Emission intensity of to-site delivery (kgCO_2e/t)
EI_P	=	Emission intensity of in-plant production (kgCO_2e/t)
EI_I	=	Emission intensity of pavement installation (kgCO_2e/t)

Raw material production emission intensity[4] (EI_M) must be calculated as follows:

$$EI_M = \frac{EF_M \times W_M}{Project\ amount} \quad (2)$$

Where:

EI_M	=	Emission intensity of raw material production (kgCO_2e/t)
EF_M	=	Material emission factor (kgCO_2e/kg)
W_M	=	Material weight (kg)
Project amount	=	Amount of FSB/asphalt emulsions manufactured (t)

To-plant delivery emissions intensity (EI_{PD}) and to-site delivery emissions intensity (EI_{SD}) must be calculated according to Equation 3 and Equation 4. Where hauling distance is not directly

[4] It is reasonable to assume zero leakage because there is no difference in site preparation activities between baseline and project scenarios. Replacing HMA with FSB or asphalt emulsions for the pavement base layer does not entail a change in carbon efflux or carbon sink at the construction site.[5] It is reasonable to assume zero leakage because there is no difference in site preparation activities between baseline and project scenarios. Replacing HMA with FSB or asphalt emulsions for the pavement base layer does not entail a change in carbon efflux or carbon sink at the construction site.

monitored, the distance can be estimated using a map distance calculator. The addresses of the start point and destination must be documented. For conservativeness, a discount factor (DF) of 0.1 must be applied when a map distance calculator is used to estimate hauling distance (Hauling distance = Map distance × (1+DF)). DF is equal to 0 where using actual logged miles.

$$EI_{PD} = \frac{Trip_p \times Distance_P \times (1+DF) \times EF_T}{Project\ amount} \qquad (3)$$

Where:

EI_{PD}	=	Emission intensity of to-plant delivery (kgCO_2e/t)
$Trip_P$	=	Number of trips from material manufacture to production plant
$Distance_P$	=	Distance to plant (mile)
DF	=	Discount factor
EF_T	=	Truck emission factor (kgCO_2e/mile)
Project amount	=	Amount of FSB/asphalt emulsions manufactured (t)

$$EI_{SD} = \frac{Trip_S \times Distance_S \times (1+DF) \times EF_T}{Project\ amount} \qquad (4)$$

Where:

EI_{SD}	=	Emission intensity of to-site delivery (kgCO_2e/t)
$Trip_S$	=	Number of trips from production plant to job site
$Distance_S$	=	Distance to site (mile)
DF	=	Discount factor
EF_T	=	Truck emission factor (kgCO_2e/mile)
Project amount	=	Amount of FSB/asphalt emulsions manufactured (t)

In-plant production emission intensity (EI_P) includes the emissions from diesel and electricity consumption by plant equipment, vehicles, and the plant office.

Diesel users are often mixing machines, loaders, and dump trucks. Their emissions are calculated using Equations 5 and 6. Relevant emission factors are provided in Appendix B. Equipment operating hours must be logged to determine the amount of time it was used in the plant.

Electricity users are often the bitumen heater, RAP crusher, and plant office. Their emissions are calculated using Equation 8. Electricity emission factors can be found at the eGRID default emission factor database provided by the EPA. The electricity consumption must be recorded according to the electric meter.

$$EI_P = EI_D + EI_E \qquad (5)$$

Where:

EI_P	=	Emission intensity of in-plant production (kgCO_2e/t)

EI_D	=	Emission intensity of diesel-consuming activities (kgCO_2e/t)
EI_E	=	Emission intensity of electricity-consuming activities (kgCO_2e/t)

$$EI_D = \frac{EF_{EQ} \times HR_{EQ}}{Project\ amount} \quad (6)$$

Where:

EI_D	=	Emission intensity of diesel-consuming activities (kgCO_2e/t)
EF_{EQ}	=	Equipment emission factor (kgCO_2e/hour)
HR_{EQ}	=	Equipment operation hours (hour)
Project amount	=	Amount of FSB/asphalt emulsions manufactured (t)

$$EI_E = \frac{EF_{EL} \times C_{EL}}{Project\ amount} \quad (7)$$

Where:

EI_E	=	Emission intensity of electricity-consuming activities (kgCO_2e/t)
EF_{EL}	=	Electricity emission factor (kgCO_2e/kWh)
C_{EL}	=	Electricity consumption (kWh)
Project amount	=	Amount of FSB/asphalt emulsions manufactured (t)

On-site installation emission intensity (EI_I) is due to diesel consumption from the equipment used for the installation project. The equipment includes milling machines, backhoes, loaders, sweepers, pavers, rollers, and trucks. Equipment emissions must be calculated using Equation 8. Relevant emission factors are provided in Appendix B. Where equipment operation hours are not available, labor hours can be used to approximate equipment operation hours according to Equation 10. Labor hours must be documented in the project daily log for verification. Conversion factors (CF) for commonly used equipment are listed in Section 9.1.1.

$$EI_I = \frac{EF_{EQ} \times HR_{EQ}}{Project\ amount} \quad (8)$$

Where:

EI_I	=	Emission intensity of pavement installation (kgCO_2e/t)
EF_{EQ}	=	Equipment emission factor (kgCO_2e/hour)
HR_{EQ}	=	Equipment operation hours (hour)
Project amount	=	Amount of FSB/asphalt emulsions installed (t)

$$HR_{EQ} = HR_{LA} \times CF \quad (9)$$

Where:

HR_{EQ}	=	Equipment operation hours (hour)

HR_{LA}	=	Labor hours (hour)
CF	=	Conversion factor

Note that CCPR projects may include more than one installation project because FSB and asphalt emulsions produced in central plants could be placed in a number of road areas. Where there are *i = 1,…, N* installation projects using FSB and asphalt emulsions from the same manufacturing process, the emission intensity of multiple CCPR projects (MCCPR EI) must be calculated as follows:

$$MCCPR\ EI = EI_M + EI_{PD} + EI_P + \frac{\sum_i^N EI_{SD,i} \cdot project\ amount_i + \sum_I^N EI_{I,i} \cdot project\ amount_i}{\sum_I^N project\ amount_i} \qquad (10)$$

Where:

MCCPR EI	=	Emission intensity of multiple CCPR projects ($kgCO_2e/t$)
EI_M	=	Emission intensity of raw material production ($kgCO_2e/t$)
EI_{PD}	=	Emission intensity of to-plant delivery ($kgCO_2e/t$)
EI_P	=	Emission intensity of in-plant production ($kgCO_2e/t$)
EI_{SD}	=	To-site delivery emission intensity ($kgCO_2e/t$)
EI_I	=	On-site installation emission intensity ($kgCO_2e/t$)
Project amount	=	Amount of FSB and asphalt emulsions manufactured (t)

7.2.2 Emissions from CIR or FDR

CIR or FDR emission intensity (*CIR EI or FDR EI*) represents the quantity of GHGs emitted from producing and installing one metric ton of FSB or asphalt emulsions using CIR or FDR. *CIR EI* or *FDR EI* must calculated as follows:

$$CIR\ EI\ (or\ FDR\ EI) = EI_M + EI_{SD} + EI_I \qquad (11)$$

Where:

CIR EI	=	Emission intensity of CIR ($kgCO_2e/t$)
FDR EI	=	Emission intensity of FDR ($kgCO_2e/t$)
EI_M	=	Material emissions intensity ($kgCO_2e/t$)
EI_{SD}	=	To-site delivery emission intensity ($kgCO_2e/t$)
EI_I	=	On-site installation emission intensity ($kgCO_2e/t$)

Material emissions intensity (EI_M) must be calculated using Equation 3 above.

To-site delivery emissions intensity (EI_{SD}) must be calculated using Equation 5 above.

On-site installation emissions intensity (EI_I) is derived from diesel consumption from the equipment used for the installation project. This equipment typically includes a cold recycler (e.g., Wirtgen 3800 CR), cement spreader, water truck, bitumen truck, vibratory roller, pneumatic roller, etc. The equipment emissions must be calculated using Equation 9 above. Relevant emission factors are provided in Appendix B.

Where project proponents cannot record the operating hours of all the equipment, the hours must be estimated using equipment running speeds according to Equation 13. The running speed of the cold recycler can be read from the screen on the machine. The water truck and bitumen truck are connected to the cold recycler to supply it with binding agents, and the rollers normally follow the train of equipment to compact the newly produced layer. Therefore, they can be assumed to run at the same speed as the cold recycler.

$$HR_{CR} = \frac{L}{S} \tag{12}$$

Where:

HR_{CR}	=	Operation hours of cold recycler (hour)
S	=	Running speed of cold recycler (mile/hour)
L	=	Project length (mile)

Note that CIR and FDR projects may include more than one installation project because FSB and asphalt emulsion produced from CIR or FDR could be placed in a number of road sections. Where there are *i = 1,…, N* road sections using FSB and asphalt emulsion from the same CIR or FDR machinery, the emission intensity of multiple CIR or FDR projects (*MCIR EI* or *MFDR EI*) must be calculated as follows:

$$MCIR\ EI\ (or\ MFDR\ EI) = EI_M + \frac{\sum_i^N \boldsymbol{EI_{SD,i} \cdot project\ amount_i} + \sum_I^N \boldsymbol{EI_{I,i} \cdot project\ amount_i}}{\sum_I^N \boldsymbol{project\ amount_i}} \tag{13}$$

Where:

MCIR EI	=	Emission intensity of multiple CIR projects (kgCO_2e/t)
MFDR EI	=	Emission intensity of multiple FDR projects (kgCO_2e/t)
EI_{SD}	=	To-site delivery emission intensity (kgCO_2e/t)
Project amount	=	Amount of FSB and asphalt emulsions manufactured (t)
EI_I	=	On-site installation emission intensity (kgCO_2e/t)

7.3 Leakage

Leakage is not considered an issue under this methodology, and is therefore set at zero.[5]

[5] It is reasonable to assume zero leakage because there is no difference in site preparation activities between baseline and project scenarios. Replacing HMA with FSB or asphalt emulsions for the pavement base layer does not entail a change in carbon efflux or carbon sink at the construction site.

7.4 Net GHG Emission Reductions and Removals

Net GHG emission reductions for FSB and asphalt emulsions are the emission intensity differences adjusted by the weight differences. The emission reductions must be calculated according to Equations 15 through 27.

A correction factor[6] (θ) of 1.02 for FSB and 1.17 for asphalt emulsions is applied. For projects that have a different structural layer coefficient and material density, the correction factor must be calculated as follows:

$$\theta = 0.0025\ DE / LC \tag{14}$$

Where:

DE	=	Density of FSB or asphalt emulsions, lb/cu.ft
LC	=	Layer coefficient of FSB or asphalt emulsions

Net GHG emission reductions for a single FSB project must be calculated as follows:

$$ER_{FSB-CCPR} = \left(\frac{CB}{\theta_{FSB}} - CCPR\ EI\right) \cdot \frac{project\ amount}{1{,}000} \tag{15}$$

Where:

$ER_{FSB\text{-}CCPR}$	=	Net emission reductions of FSB using CCPR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
Θ_{FSB}	=	Correction factor for FSB (default value is 1.02)
CCPR EI	=	Emission intensity of CCPR project ($kgCO_2e/t$)
Project amount	=	Amount of FSB manufactured (t)

$$ER_{FSB-CIR} = \left(\frac{CB}{\theta_{FSB}} - CIR\ EI\right) \cdot \frac{project\ amount}{1{,}000} \tag{16}$$

Where:

$ER_{FSB\text{-}CIR}$	=	Net emission reductions of FSB using CIR (tCO_2e)

[6] The American Association of State Highway Transportation Officials (AASHTO) Design Guide is the recommended reference for the thickness design of cold in-place recycled asphalt mixes. The composition and structural properties of central plant recycled cold mix and cold in-place recycled paving materials are virtually the same; the range of structural layer coefficients recommended for recycled cold mixes (0.25 to 0.35) is also applicable for cold in-place recycled mixes. On average, various Departments of Transportation are considering a structural layer coefficient of 0.32 for FSB and of 0.30 for asphalt emulsion mixes (Schwartz and Khosravifar, 2013). The structural layer coefficient for a 0.75 inch HMA base mix is 0.40 (AASHTO, 1998). Accordingly, substituting FSB and asphalt emulsions for HMA on a project would, on average, require the FSB and asphalt emulsions layer to be approximately 25% (or 33%) thicker than the HMA layer. The densities of FSB, asphalt emulsions, and HMA are 130 lb/cu.ft, 140 lb/cu.ft and 160 lb/cu.ft, respectively. After factoring in these density differences, the use of FSB and asphalt emulsions must be 2% and 17% more than the HMA base by weight for the same length of paved road.

CB	=	Crediting baseline ($kgCO_2e/t$)
Θ_{FSB}	=	Correction factor for FSB (default value is 1.02)
CIR EI	=	Emission intensity of CIR project ($kgCO_2e/t$)
Project amount	=	Amount of FSB manufactured (t)

$$ER_{FSB-FDR} = \left(\frac{CB}{\theta_{FSB}} - FDR\ EI\right) \cdot \frac{project\ amount}{1{,}000} \quad (17)$$

Where:

$ER_{FSB\text{-}FDR}$	=	Net emission reductions of FSB using FDR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
Θ_{FSB}	=	Correction factor for FSB (default value is 1.02)
FDR EI	=	Emission intensity of FDR project ($kgCO_2e/t$)
Project amount	=	Amount of FSB manufactured (t)

Net GHG emission reductions for multiple FSB projects must be calculated as follows:

$$ER_{FSB-CCPR} = \left(\frac{CB}{\theta_{FSB}} - MCCPR\ EI\right) \cdot \Sigma\ \frac{project\ amount_i}{1{,}000} \quad (18)$$

Where:

$ER_{FSB\text{-}CCPR}$	=	Net emission reductions of FSB using CCPR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
Θ_{FSB}	=	Correction factor for FSB (default value is 1.02)
MCCPR EI	=	Emission intensity of multiple CCPR projects ($kgCO_2e/t$)
Project amount	=	Amount of FSB manufactured (t)

$$ER_{FSB-CIR} = \left(\frac{CB}{\theta_{FSB}} - MCIR\ EI\right) \cdot \Sigma\ \frac{project\ amount_i}{1{,}000} \quad (19)$$

Where:

$ER_{FSB\text{-}CIR}$	=	Net emission reductions of FSB using CIR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
Θ_{FSB}	=	Correction factor for FSB (default value is 1.02)
MCIR EI	=	Emission intensity of multiple CIR projects ($kgCO_2e/t$)
Project amount	=	Amount of FSB manufactured (t)

$$ER_{FSB-FDR} = \left(\frac{CB}{\theta_{FSB}} - MFDR\ EI\right) \cdot \Sigma\ \frac{project\ amount_i}{1{,}000} \quad (20)$$

Where:

$ER_{FSB\text{-}FDR}$	=	Net emission reductions of FSB using FDR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
Θ_{FSB}	=	Correction factor for FSB (default value is 1.02)
MFDR EI	=	Emission intensity of multiple FDR projects ($kgCO_2e/t$)
Project amount	=	Amount of FSB manufactured (t)

Net GHG emission reductions for a single asphalt emulsion project must be calculated as follows:

$$ER_{AE-CCPR} = \left(\frac{CB}{\theta_{AE}} - CCPR\ El\right) \cdot \frac{project\ amount}{1{,}000} \tag{21}$$

Where:

$ER_{AE\text{-}CCPR}$	=	Net emission reductions of asphalt emulsions using CCPR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
θ_{AE}	=	Correction factor for asphalt emulsion (default value is 1.17)
CCPR EI	=	Emission intensity of CCPR project ($kgCO_2e/t$)
Project amount	=	Amount of asphalt emulsions manufactured (t)

$$ER_{AE-CIR} = \left(\frac{CB}{\theta_{AE}} - CIR\ El\right) \cdot \frac{project\ amount}{1{,}000} \tag{22}$$

Where:

$ER_{AE\text{-}CIR}$	=	Net emission reductions of asphalt emulsions using CIR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
θ_{AE}	=	Correction factor for asphalt emulsion (default value is 1.17)
CIR EI	=	Emission intensity of CIR project ($kgCO_2e/t$)
Project amount	=	Amount of asphalt emulsions manufactured (t)

$$ER_{AE-FDR} = \left(\frac{CB}{\theta_{AE}} - FDR\ El\right) \cdot \frac{project\ amount}{1{,}000} \tag{23}$$

Where:

$ER_{AE\text{-}FDR}$	=	Net emission reductions of asphalt emulsions using FDR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
θ_{AE}	=	Correction factor for asphalt emulsion (default value is 1.17)
FDR EL	=	Emission intensity of FDR project ($kgCO_2e/t$)
Project amount	=	Amount of asphalt emulsions manufactured (t)

Net GHG emission reductions for multiple asphalt emulsion projects must be calculated as follows:

$$ER_{AE-CCPR} = \left(\frac{CB}{\theta_{AE}} - MCCPR\ El\right) \cdot \frac{project\ amount}{1{,}000} \qquad (24)$$

Where:

$ER_{AE\text{-}CCPR}$	=	Net emission reductions of asphalt emulsions using CCPR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
θ_{AE}	=	Correction factor for asphalt emulsion (default value is 1.17)
MCCPR EI	=	Emission intensity of multiple CCPR projects ($kgCO_2e/t$)
Project amount	=	Amount of asphalt emulsions manufactured (t)

$$ER_{AE-CIR} = \left(\frac{CB}{\theta_{AE}} - MCIR\ El\right) \cdot \frac{project\ amount}{1{,}000} \qquad (25)$$

Where:

$ER_{AE\text{-}CIR}$	=	Net emission reductions of asphalt emulsions using CIR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
θ_{AE}	=	Correction factor for asphalt emulsion (default value is 1.17)
MCIR EI	=	Emission intensity of multiple CIR projects ($kgCO_2e/t$)
Project amount	=	Amount of asphalt emulsions manufactured (t)

$$ER_{AE-FDR} = \left(\frac{CB}{\theta_{AE}} - MFDR\ El\right) \cdot \frac{project\ amount}{1{,}000} \qquad (26)$$

Where:

$ER_{AE\text{-}FDR}$	=	Net emission reductions of asphalt emulsions using FDR (tCO_2e)
CB	=	Crediting baseline ($kgCO_2e/t$)
θ_{AE}	=	Correction factor for asphalt emulsion (default value is 1.17)
MFDR EI	=	Emission intensity of multiple FDR projects ($kgCO_2e/t$)
Project amount	=	Amount of asphalt emulsions manufactured (t)

8 MONITORING

The data parameters available at validation and those to be monitored are introduced and background information is provided in Sections 8.1 and 8.2, respectively. Section 8.3 describes general guidance for collecting and reporting all data and parameters listed in Section 8.2.

8.1 Parameters Available at Validation

8.1.1 Parameters available at validation for HMA and CCPR

Data / Parameter:	EF_M
Data unit	$kgCO_2e/kg$
Description	Material emission factor
Equations	2
Source of data	CMUGDI (2008)
Value applied	RAP: 0 Cement: 0.83 Bitumen: 0.48 Water: 0 Crushed rock: 0.056 Sand: 0.005 Manufactured aggregates: 0.006
Justification of choice of data or description of measurement methods and procedures applied	CMUGDI (2008) is comprised of national economic input-output models and publicly available resources use and emission data, which has been accessed over 1 million times by researchers or business users.
Purpose of Data	Calculation of material production emissions
Comments	Data to be updated when the material emissions factor is updated

Data / Parameter:	EF_T
Data unit	$kgCO_2e/mile$
Description	Truck's emission per mile travelled
Equations	3, 4
Source of data	TCR (2015)
Value applied	10.2
Justification of choice of data or description of measurement methods and procedures applied	Emission factors from TCR are compiled from publicly available data sources and updated each year to ensure that project proponents have the most accurate and up-to-date greenhouse gas data.
Purpose of Data	Calculation of baseline delivery emission Calculation of CCPR delivery emission
Comments	Data to be updated when the diesel emissions factor is updated

Data / Parameter:	EF_{EQ}

Data unit	$kgCO_2e/hr$
Description	Equipment emissions per hour
Equations	6, 8
Source of data	EPA (2012). "Engine Certification Data for Heavy Truck, Buses, and Engines."<http://www.epa.gov/oms/certdata.htm#largeng>.
Value applied	Appendix B
Justification of choice of data or description of measurement methods and procedures applied	The engine emission information is obtained from the EPA off-road engine certification database and further stratified equipment types by engine maker and horsepower rating. The database created for equipment emission estimation is presented in Appendix B
Purpose of Data	Calculation of baseline emission Calculation of CCPR emission
Comments	Data was collected one time and must be updated when more strict emission standard is implemented nationwide

Data / Parameter:	EF_{EL}
Data unit	$kgCO_2e/kWh$
Description	Electricity emission factor
Equations	7
Source of data	EPA (2017)
Value applied	Refer to EPA's eGRID summary tables for electricity emission factors for different regions
Justification of choice of data or description of measurement methods and procedures applied	Emission factors from eGRID summary tables are compiled by the EPA and updated each year to ensure that project proponents have the most accurate and up-to-date greenhouse gas data. The calculation of electricity emission must use region-specific emission factors.
Purpose of Data	Calculation of baseline emission Calculation of CCPR emission
Comments	The project proponent must use the most recent eGRID summary tables available.

Data / Parameter:	CF
Data unit	Between 0 and 1
Description	Conversion factor: the percentage of equipment operating time in the total labor time
Equations	9
Source of data	Liu et al. (2016)

Value applied	Milling machine: 0.66 Backhoe: 0.33 Loader: 0.33 Sweeper: 0.55 Paver: 0.50 Roller: 0.59 Truck: 1
Justification of choice of data or description of measurement methods and procedures applied	Three projects were observed on-site to count the effective operation time of each piece of equipment. The percentage utilization (PU) was calculated using the effective operation time divided by the total labor hours*.* The average *PU* values are 0.55 for the asphalt-milling machine; 0.10 for the backhoe; 0.10 for the bobcat/loader; 0.4 for the sweeper/broom; 0.10 for the excavator; 0.33 for the paver and 0.45 for the roller. Different *PU*s will produce different amounts of GHG emissions. According to a study by Lewis et al. (2009), the emission rate of idling equipment is about one quarter of the emission rate of the operating equipment. This difference is simplified and incorporated into the emission calculation as an average conversion factor (CF), which equals *PU+0.25(1-PU)*.
Purpose of Data	Calculation of baseline equipment emissions Calculation of CCPR equipment emissions
Comments	Data does not need to be updated

Data / Parameter:	DF
Data unit	Between 0 and 1
Description	For conservativeness, a discount factor (DF) must be applied when a map distance calculator is used to estimate hauling distance. DF is equal to 0 if using actual logged miles.
Equations	3, 4
Source of data	On-site observations
Value applied	0.1
Justification of choice of data or description of measurement methods and procedures applied	Ten projects were observed on site to count the distance between map and equipment odometer. Hauling distance = Map distance × (1+DF)
Purpose of Data	Calculation of baseline equipment emissions Calculation of CCPR equipment emissions
Comments	Data does not need to be updated

8.1.2 Parameters available at validation for CIR or FDR

Data / Parameter:	EF_T
Data unit	$kgCO_2e$/mile
Description	Truck's emission per mile travelled
Equations	3, 4
Source of data	TCR (2015)
Value applied	10.2
Justification of choice of data or description of measurement methods and procedures applied	Emission factors from TCR are compiled from publicly available data sources and updated each year to ensure that project proponents have the most accurate and up-to-date greenhouse gas data.
Purpose of Data	Calculation of CIR or FDR delivery emissions
Comments	Data to be updated when the diesel emissions factor is updated

Data / Parameter:	EF_M
Data unit	$kgCO_2e$/kg
Description	Material emission factor
Equations	1
Source of data	CMUGDI (2008)
Value applied	RAP: 0 Cement: 0.83 Bitumen: 0.48 Water: 0
Justification of choice of data or description of measurement methods and procedures applied	CMUGDI (2008) is comprised of national economic input-output models and publicly available resources use and emission data, which has been accessed over 1 million times by researchers or business users.
Purpose of Data	Calculation of material production emissions
Comments	Data to be updated when the material emissions factor is updated

Data / Parameter:	EF_{EQ}
Data unit	$kgCO_2e$/hr
Description	Equipment emission per hour
Equations	6, 7
Source of data	EPA (2012). "Engine Certification Data for Heavy Truck, Buses, and Engines."<http://www.epa.gov/oms/certdata.htm#largeng>.

Value applied	Appendix B
Justification of choice of data or description of measurement methods and procedures applied	The engine emission information is from the EPA off-road engine certification database and stratified by equipment type, engine make, and horsepower rating. The database created for equipment emission estimation is presented in Appendix B.
Purpose of Data	Calculation of CIR or FDR emission
Comments	Data was collected one time and must be updated when more strict emissions standards are implemented nationwide

8.2 Data and Parameters Monitored

8.2.1 Data and Parameters Monitored for HMA and CCPR

Data / Parameter	W_M
Data unit	Kg
Description	Quantity of each raw material used to produce HMA or FSB or asphalt emulsions
Equations	2
Source of data	Data source acquired through monitoring
Description of measurement methods and procedures to be applied	The data can be obtained from plant production records
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported quantity versus trucking manifests to confirm quality measurement.
Purpose of Data	Calculation of HMA material emissions Calculation of CCPR material emissions
Comments	

Data / Parameter	$Distance_P$
Data unit	Miles
Description	The total miles that trucks travelled to supply raw materials to HMA plant or FSB plant
Equations	3
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Distance can be obtained from the daily report of truck drivers or measured by approximation

Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported mileage versus trucking manifests to confirm quality measurement.
Purpose of Data	Calculation of HMA to-plant delivery emissions Calculation of CCPR to-plant delivery emission
Comments	

Data / Parameter	$Distance_S$
Data unit	Miles
Description	The total miles that trucks travelled to supply products to the job site
Equations	4
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Distance can be obtained from the daily report of truck drivers or measured by approximation
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported mileage versus trucking manifests to confirm quality measurement.
Purpose of Data	Calculation of HMA to-site delivery emissions Calculation of CCPR to-site delivery emission
Comments	

Data / Parameter	C_{EL}
Data unit	*kWh*
Description	Electricity consumption of the whole plant
Equations	7
Source of data	Data derived through monitoring
Description of measurement methods and procedures to be applied	The use of electricity can be obtained from plant's utility bills
Frequency of monitoring/recording	Utility bills must be collected monthly or quarterly
QA/QC procedures to be applied	Cross-checking of reported consumption versus utility bills to confirm quality measurement.
Purpose of Data	Calculation of CCPR in-plant production emissions

Comments	

Data / Parameter	Project amount
Data unit	t
Description	Output quantity of FSB and asphalt emulsions
Equations	2, 3, 4, 6, 7, 8
Source of data	Data derived through monitoring
Description of measurement methods and procedures to be applied	Data can be reported according to plant production records
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported amount versus production logs to confirm quality measurement.
Purpose of Data	Calculation of CCPR emission
Comments	

Data / Parameter	HR_{EQ}
Data unit	Hour
Description	Total operating hours of on-site use of equipment
Equations	8
Source of data	Data derived through monitoring
Description of measurement methods and procedures to be applied	Data can be obtained from daily report of on-site contractors
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported data versus labor hours to confirm quality measurement.
Purpose of Data	Calculation of HMA equipment emissions Calculation of CCPR equipment emissions
Comments	Data does not need to be updated

Data / Parameter	HR_{LA}
Data unit	Hour
Description	Total labor hours of on-site use of equipment
Equations	9

Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Labor hours can be obtained from the daily reports of contractors
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported hours versus daily reports to confirm quality measurement.
Purpose of Data	Calculation of HMA installation emissions Calculation of CCPR installation emission
Comments	

Data / Parameter	DE
Data unit	lb/cu.ft
Description	Density of FSB or asphalt emulsions
Equations	14
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Density data can be obtained from project specifications
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported data versus theoretical density to confirm quality measurement.
Purpose of Data	Calculation of CCPR emission reduction
Comments	

Data / Parameter	LC
Data unit	
Description	Layer coefficient of FSB or asphalt emulsions
Equations	14
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Layer coefficient can be obtained from project specifications
Frequency of monitoring/recording	Once per project

QA/QC procedures to be applied	Cross-checking of reported data versus DOT commonly used coefficients to confirm quality measurement.
Purpose of Data	Calculation of CCPR emission reduction
Comments	

8.2.2 Data and Parameters Monitored for CIR or FDR

Data / Parameter:	W_M
Data unit	Kg
Description	The weight of each raw material used to produce FSB or asphalt emulsions
Equations	2
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	The data can be obtained from project records.
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported quantity versus trucking manifests to confirm quality measurement.
Purpose of Data	Calculation of CIR or FDR material emissions
Comments	Data does not need to be updated

Data / Parameter	Project amount
Data unit	T
Description	Output quantity of FSB and asphalt emulsions
Equations	2, 4, 6
Source of data	Data derived through monitoring
Description of measurement methods and procedures to be applied	The data can be reported according to plant production records
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported quantity versus trucking manifests to confirm quality measurement.
Purpose of Data	Calculation of CIR or FDR emission
Comments	

Data / Parameter:	L
Data unit	Miles
Description	Length of damaged pavement
Equations	11
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	The data can be obtained from project records
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported mileage versus map distance to confirm quality measurement.
Purpose of Data	Calculation of CIR or FDR installation emissions
Comments	

Data / Parameter:	Distance
Data unit	Miles
Description	The total miles that trucks travelled to supply raw materials to the job site
Equations	6
Source of data	Data derived from monitoring on site
Description of measurement methods and procedures to be applied	Distance can be obtained from the daily report of truck drivers or measured by approximation
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported mileage versus trucking manifests to confirm quality measurement.
Purpose of Data	Calculation of CIR or FDR to-site delivery emissions
Comments	

Data / Parameter:	S
Data unit	Mph
Description	Running speed of cold recycler
Equations	11

Source of data	Data derived from monitoring project site
Description of measurement methods and procedures to be applied	The data can be obtained from project records
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported speed versus driver's log to confirm quality measurement.
Purpose of Data	Calculation of CIR or FDR installation emissions
Comments	

Data / Parameter	DE
Data unit	lb/cu.ft
Description	Density of FSB or asphalt emulsions
Equations	14
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Density data can be obtained from project specifications
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported data versus theoretical density to confirm quality measurement.
Purpose of Data	Calculation of CIR or FDR emission reduction
Comments	

Data / Parameter	LC
Data unit	
Description	Layer coefficient of FSB or asphalt emulsions
Equations	14
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Layer coefficient can be obtained from project specifications
Frequency of monitoring/recording	Once per project
QA/QC procedures to be applied	Cross-checking of reported data versus DOT commonly used coefficients to confirm quality measurement.

Purpose of Data	Calculation of CIR or FDR emission reduction
Comments	

8.3 Description of the Monitoring and Quality Assurance Plan

Project proponents must detail the procedures for collecting and reporting all data and parameters listed in Section 8.2. Input data must be checked for typical errors, including inconsistent physical units, unit conversion errors, transcription errors, and missing data for specific time periods or physical units.

All data collected as a part of monitoring process must be archived electronically and be kept at least for two years after the end of the last project crediting period. All direct measurements must be conducted with calibrated measurement equipment according to relevant industry standards. Where direct measurements are not applied, project proponents must demonstrate that the values used for the project are reasonably conservative, considering the uncertainty associated with these values.

Quality assurance/quality control procedures must also be applied to add confidence that all measurements and calculations have been made correctly. These may include, but are not limited to:

- 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 to identify any abnormal readings
- Providing sufficient training to project participants to install and maintain project devices
- Establishing minimum experience and requirements for operators in charge of project and monitoring
- Performing recalculations to make sure no mathematical errors have been made.

9 REFERENCES

AASHTO (1998). AASHTO Guide for Design of Pavement Structures, 4th edition. Relevent information is available at http://www.pavementinteractive.org/the-aashto-reliability-concept/ (July 13, 2017)

Bemanian, S., Polish, P., Maurer, G. (2006). “Cold-In-Place Recycling and Full-Depth Reclamation Projects by Nevada Department of Transportation – State of the Practice.” Transportation Research Record, Journal of the Transportation Research Board No. 1949, pages 54-71.

Carnegie Mellon University Green Design Institute (CMUGDI) (2008). "Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model ". (available at http://www.eiolca.net/cgi-bin/dft/use.pl)

Dixon, W.J. (1951). “Ratios involving extreme value”. The Annals of Mathematical Statistics 22(1): 68-78.

EPA (2000). “Hot mix asphalt plants emission assessment report”. United States Environmental Protection Agency.

EPA (2012). "Engine Certification Data for Heavy Truck, Buses, and Engines." <http://www.epa.gov/oms/certdata.htm#largeng>. (November 26, 2012).

EPA (2015). “US EPA Archive Document: Asphalt Concrete.” <https://www3.epa.gov/warm/pdfs/Asphalt_Concrete.pdf> (July 13, 2017)

EPA (2017). “Emissions & Generation Resource Integrated Database (eGRID) summary tables.”

< https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid > (March 24, 2017)

Hammond, G., and Jones, C. (2011). "Embodied carbon: The Inventory of Carbon Energy (ICE)." Building Services Research and Information Association (BSRIA), Berkshire, UK.

IPCC (2007). "Climate Change 2007: Synthesis Report ", R. K. Pachauri, and A. Reisinger, eds., International Panel on Climate Change (IPCC), Geneva, Switzerland.

Liu, X., Cui., Q., Schwartz. C. (2016). “Introduction of mechanistic-empirical pavement design into pavement carbon footprint analysis.” International Journal of Pavement Engineering 15: 1-9.

Morian, D.A., Zhao, Y., Arellano. J,, Hall, D.E. (2005). “Asphalt Pavement Rehabilitation Treatment – Analysis of 20 Years of Performance.” Transportation Research Record, Journal of the Transportation Research Board No. 1905, pages 36-43.

Mundt D.J., Marano K.M., Nunes A.P., Adams R.C. (2009). A review of changes in composition of hot mix asphalt in the United States, Journal of Occupation Environmental Hygene.

National Center for Asphalt Technology (2010). “Properties and Performance of Warm Mix Asphalt Technologies.” Auburn University, AL. volume 26 No.1.

NAPA (2006). National Asphalt Pavement Association Comments to Midwest Regional Planning Organization: Interim White Paper on Candidate Control Measures to Reduce Emissions from Hot Mix Asphalt Plants. Page 1.

NAPA (2012). Manual of NAPA’s Greenhouse Gas Calculator. National Asphalt Pavement Association, Lanham, MD.

<https://www.asphaltpavement.org/ghgc/GHGC%20v4%20instructions.pdf>. (June 21, 2014). Page 3.

NAPA (2013). Annual asphalt pavement industry survey on recycled materials and warm-mix asphalt usage: 2009-2012. National Asphalt Pavement Association.

NAPA (2017). Asphalt pavement industry survey on recycled materials and warm-mix asphalt usage:2014. National Asphalt Pavement Association.

Schwartz, C.W., Khosravifar, S. (2013). “State Highway Administration Research Report: Design and Evaluation of Foamed Asphalt Base Materials”. University of Maryland, College Park.

Sinden, G. (2008). "PAS 2050: 2008, Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services." British Standards Institute (BSI). pages 12-16.

TCR (2015). 2015 Default emission factors. The Climate Registry. < https://www.theclimateregistry.org/wp-content/uploads/2015/04/2015-TCR-Default-EF-April-2015-FINAL.pdf> (March, 2016)

UNFCCC (2006). “Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol”. Framework Convention on Climate Change. page. 17

APPENDIX A: DETERMINATION OF PERFORMANCE BENCHMARK FOR ADDITIONALITY AND CREDITING BASELINE

Quantification of Baseline Emissions

The performance benchmark determined for use in this methodology represents the quantity of GHGs emitted from producing and installing one metric ton of HMA. This was calculated based on emission intensities that sum the material emission intensity, to-plant delivery emissions intensity, in-plant production emission intensity, to-site delivery emissions intensity, and on-site installation emission intensity.

The component materials of HMA include bitumen binders, crushed rock, sand, gravel, RAP and manufactured aggregates. GHG emissions from material production and transportation include:

1) The embodied GHG emissions of construction materials, which are primarily from energy consumption and chemical combustion associated with material production; and,

2) GHG emissions from fuel consumption for transporting materials to production facilities.

Primary equipment/vehicles used for placing HMA include asphalt paving machines, backhoes, bobcat/loaders, sweeper/brooms, air compressors, rollers, trucks, etc. Equipment operation information was gathered from projects sampled using HMA. For each project, the operation information for trucks, which deliver the hot mix to the job site and carry the RAP from the job site to the hot mix plant, was obtained from truck driver reports. The truck driver reports record time in and out from the job site for each truck, the total mileage travelled, and the gallons of diesel used by each truck. The recorded information was then used for estimating the GHG emissions from the trucks when transporting the raw materials/products and loading/dumping the materials at both the job site and the hot mix plant. The operation of the rest of the equipment/vehicles was obtained from the contractor’s daily report in terms of total labor hours.

The emissions associated with materials, to-plant delivery, and in-plant production were estimated through the survey of sixteen hot mix producers from Maryland, Virginia, and Pennsylvania in 2013. The six hot mix producers included in the survey were WMA certified. The average WMA output percentage was 19%. The average percentage of RAP in our survey is 23%, higher than 2011 statistic nationwide average value of 19% reported by NAPA (2013). Higher percentage of RAP implies a more conservative benchmark. In addition, this survey covered typical fuel types for HMA facilities and the proportion of each fuel type approximately represented fuel structure of HMA plants (EPA, 2000). Out of sixteen plants in the survey, ten plants consumed natural gas, three consumed oil, and three consumed propane. This proportion is aligned with the number published by EPA that natural gas fuel is used to produce 70% to 90% of the HMA.

Each producer reported raw material consumption, delivery distance, and fuel use by the rotary dryer plus additional fuels used inside the gate by equipment and vehicles on a quarterly basis in 2013. GHG emission intensity was determined following Equations A1 to A5 below. A calculation example for an individual HMA facility is displayed in Table A1 and a summary result for the sixteen facilities is displayed in Table A2.

Raw material production:

$$EI_M = \frac{EF_M \times W_M}{Project\ amount} \tag{A1}$$

Where:

EI_M	=	Emission intensity of raw material production ($kgCO_2e/t$)
EF_M	=	Material emission factor ($kgCO_2e/kg$)
W_M	=	Material weight (kg)
Project amount	=	Amount of HMA manufactured (t)

Plant production:

$$EI_P = EI_D + EI_E \tag{A2}$$

Where:

EI_P	=	Emission intensity of in-plant production ($kgCO_2e/t$)
EI_D	=	Emission intensity of diesel-consuming activities ($kgCO_2e/t$)
EI_E	=	Emission intensity of electricity-consuming activities ($kgCO_2e/t$)

$$EI_D = \frac{EF_{EQ} \times HR_{EQ}}{Project\ amount} \tag{A3}$$

Where:

EI_D	=	Emission intensity of diesel-consuming activities ($kgCO_2e/t$)
EF_{EQ}	=	Equipment emission factor ($kgCO_2e/hour$)
HR_{EQ}	=	Equipment operation hours (hour)
Project amount	=	Amount of HMA manufactured (t)

$$EI_E = \frac{EF_{EL} \times C_{EL}}{Project\ amount} \tag{A4}$$

Where:

EI_E	=	Emission intensity of electricity-consuming activities ($kgCO_2e/t$)
EF_{EL}	=	Electricity emission factor ($kgCO_2e/kWh$)
C_{EL}	=	Electricity consumption (kWh)
Project amount	=	Amount of HMA manufactured (t)

Raw material delivery:

$$EI_{PD} = \frac{Distance_P \times EF_T}{Project\ amount} \tag{A5}$$

Where:

EI_{PD}	=	Emission intensity of to-plant delivery ($kgCO_2e/t$)
$Distance_P$	=	Distance to plant (mile)
EF_T	=	Truck emission factor ($kgCO_2e$/mile)
Project amount	=	Amount of HMA manufactured (t)

Table A1: Example Calculation of GHG Emissions from Hot Mix Facility

HMA Plant 1	Operation period: 7/1/2013 to 9/30/2013					
HMA output	83,612 t		**Type:** Drum			
Raw Material Production						
	Quantity		Mix design		$kgCO_2/kg$	tCO_2e
Crushed Rock	68562.4	t	82%		0.056	3839.50
Sand	6689.0	t	8%		0.005	33.45
Gravel	0.0	t			0.017	0.00
Rap	4180.6	t	5%		0	0.00
Other Recycled Aggregates	0.0	t			0.006	0.00
Bitumen	4180.6	t	5%		0.48	2006.70
Water	0.0	t				0.00
Subtotal						**5879.65**
Plant Production						
		Usage	Unit	Emission factor		tCO_2e
Plant Combustion	Fuel oil	158614	GAL	10.18	kg/gal	1614.69
	Natural gas		DTH	53.02	kg/MMBtu	0.00
	Recycled oil		GAL	9.99	kg/gal	0.00
Equipment & Vehicles	Diesel fuel	5336	GAL	10.21	kg/gal	54.48

	Gasoline		GAL	8.78	kg/gal	0.00
Line Power	Electricity	297000	kWh	0.51	kg/kWh	150.80
Subtotal						**1819.98**
Raw Material Delivery						
	Distance	Round	Fuel use	Emission factor		tCO_2e
Bitumen Fleet Delivery	65 km	185.8	1 gal/mi	10.2	kg/gal	153.00
Crushed Rock Fleet Delivery	11 km	3047.2	1 gal/mi	10.2	kg/gal	424.64
Sand Rock Fleet Delivery	31 km	297.3	1 gal/mi	10.2	kg/gal	116.75
Subtotal						**694.39**
Total emissions, tCO_2e	*8394.01*		**Emission intensity**, $kgCO_2e/t$			*99.39*

Table A2: Summary of GHG Emissions from Hot Mix Facilities and Their Upstream Raw Material Productions

	GHG emissions from sampling facilities, $kgCO_2e/t$ HMA															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Raw material	69.6	68.1	65.6	56.8	56.3	47.8	44.8	48.9	42.4	44.7	53.3	60.1	55.9	54.4	48.6	47.2
In-plant	21.6	18.6	25.3	14.5	17.5	20.8	15.4	2.4	10.4	16.7	17.4	17.5	19.9	22	19.5	14.7
Delivery	8.2	5.2	8.4	40.7	2.8	12.7	15.9	8.1	8.2	11.6	11.8	11.0	21.2	33.6	22.1	18.1
Total	99.4	91.9	99.3	111.9	76.8	81.3	76.2	59.4	60.8	72.9	82.4	88.5	96.9	110.1	90.2	80.0

The emissions associated with to-site delivery and on-site installation were estimated through the survey of patching and roadway projects. Ten HMA patching projects were surveyed to calculate baseline emissions for patching projects. For each project, the operation information for trucks, which deliver the hot mix to the job site and carry the RAP from the job site to the central plant, was obtained from truck driver reports. The truck driver reports recorded the time in and out from the job site for each truck, total mileage travelled, and gallons of diesel used by each truck. The recorded information was then used for estimating the GHG emissions from the trucks when transporting the recycled materials/products and loading/dumping the materials at both the job site and the central plant. The operation of the rest of the equipment/vehicles was obtained from the contractor’s daily report in terms of total labor hours.

Three out of ten projects were selected for a manual assessment of the utilization rate of each individual piece of equipment[7]. The percentage utilization (PU) was calculated using the effective operation time divided by the total labor hours. The average *PU* values are 0.55 for the asphalt-milling machine; 0.10 for the backhoe; 0.10 for the bobcat/loader; 0.4 for the sweeper/broom; 0.10 for the excavator; 0.33 for the paver and 0.45 for the roller. Different equipment utilization levels will produce different amounts of GHG emissions. According to a study by Lewis et al. (2009), the emission rate of idling equipment is about one quarter of the emission rate of the operating equipment. This difference was simplified and incorporated into the emission calculation as an average conversion factor (CF), which equals *PU+0.25(1-PU)*. Calculation equations for equipment emissions during on-site installation are provided below, and the estimation results are displayed in Table A3.

The on-site installation EI (EI_I) is calculated as follows:

$$EI_I = \frac{EF_{EQ} \times HR_{EQ}}{Project\ amount} \quad \text{(A6)}$$

Where:

EI_I	=	Emission intensity of pavement installation ($kgCO_2e/t$)
EF_{EQ}	=	Equipment emission factor ($kgCO_2e/hour$)
HR_{EQ}	=	Equipment operation hours (hour)
Project amount	=	Amount of HMA installed (t)

$$HR_{EQ} = HR_{LA} \times CF \quad \text{(A7)}$$

Where:

HR_{EQ}	=	Equipment operation hours (hour)
HR_{LA}	=	Labor hours (hour)
CF	=	Conversion factor

Baseline emissions for roadways are generated from the Project Emission Estimator (PE-2). PE-2 collected and organized construction and rehabilitation data from 11 Michigan Department of Transportation HMA pavement, re-construction, rehabilitation, and maintenance projects throughout the State of Michigan in 2011. The amount of GHG emissions from each project is summarized in Table A4.

Results show that the emissions from the hot mix facility and its upstream raw material production range from 59.4$kgCO_2e/t$ HMA to 111.9$kgCO_2e/t$ HMA with an average value of 86.1$kgCO_2e/t$ HMA; the emissions from HMA installation in patching projects range from 42.7 $kgCO_2e/t$ to 135.2 $kgCO_2e/t$ with an average value of 64.6 $kgCO_2e/t$; the emissions from HMA installation projects performed on roadways range from 4.5 $kgCO_2e/t$ to 145.1 $kgCO_2e/t$ with an average value of 55.7 $kgCO_2e/t$.

[7] The patch work was located at the Howard Crossing Apartment, Ellicott City, MD. The sizes of the three patches were 884 square feet, 6,969 square feet and 10,080 square feet.

Table A3: GHG Emissions from HMA Installation in Patching Projects

	EF(g/hr/hp)	hp	Conversion factor	Operation hours of sampled projects									
				1	2	3	4	5	6	7	8	9	10
Milling	887.1	150	0.66	7.2	31.8	8.9	0	7.9	10.9	0	0	5.3	6.2
Backhoe	1025.8	80	0.33	3.5	0	4.3	0	3.9	5.3	3.4	3.9	2.6	3.0
Loader	1025.8	142	0.33	7.1	31.0	8.7	11.7	7.8	10.7	6.8	3.9	5.2	6.1
Sweeper	940.9	115	0.55	12.1	12.1	14.8	19.8	13.2	18.1	11.5	13.2	4.4	10.4
Paver	984.7	130	0.50	5.4	9.7	6.7	17.9	5.9	8.2	10.4	5.9	3.9	4.7
Roller	1025.6	45	0.59	6.4	11.4	15.8	42.3	14.1	19.3	18.5	14.1	9.4	5.5
Truck (on-site)	886.6	255	1	15.5	99.8	0.1	0.1	4	8	0.1	0.17	10.6	0.1
Truck (off-site)	10.2kg/mi	mile	1	530	0	410	731	898	372	838	1008	956	657
Placed HMA, t				100	727	195	291	195	218	245	329	339	140
Delivery distance, mile				66	23	26	31	58	21	43	38	35	59
GHG (kgCO_2e/t)				135.2	47.3	52.6	53.3	79.1	59.6	54.3	42.7	45.0	76.5

Table A4: GHG Emissions from HMA Replacement on Roadways

		US-131	US-31	US-41	I-69	M-20	M-55	M-28	US-41
Asphaltic materials	t	20428	74784	19512	23250	23250	10939	891	13261
Equip. emission	tCO_2	252.1	874.7	1287.5	3373	303.3	48.9	127.1	592
GHG	**kgCO_2/t**	**12.3**	**11.7**	**66.0**	**145.1**	**18.8**	**4.5**	**142.6**	**44.6**

Note:

- US-131 Asphalt Crack Relief Layer; Reconstruction; Crush and Shape, 6 lane miles
- US-31 HMA Reconstruct, 13.08 lane miles
- US-41 HMA Reconstruct and Roadway Realignment, 6.04 lane miles
- I-69 Concrete Reconstruct, 40.56 lane miles
- M-20 HMA Cold Milling and Overlay, 16.64 lane miles

- M-55 HMA Cold Milling and Resurfacing, 13.66 lane miles
- M-28 Concrete Patch Repairs and HMA Resurfacing, 9.26 lane miles
- US-41 Road Reconstruction HMA and Concrete, 4.4 lane miles

Determination of Performance Benchmark for Additionality and Crediting Baseline

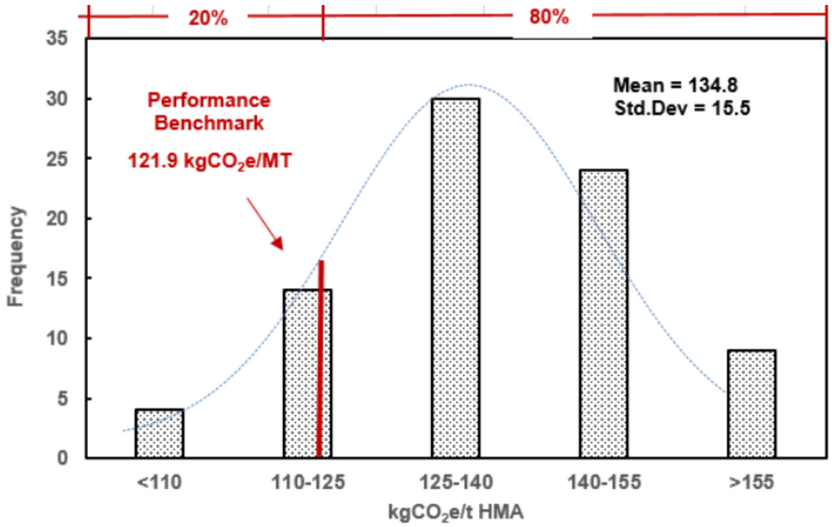
Once the baseline emissions were determined based on a sample of HMA producers and projects were surveyed to represent the sectoral emission performance, this estimation was then applied to determine the performance benchmark which is the same for both additionality and the crediting baseline.

Due to the significant impact of project type and delivery distance on the total amount of GHG emissions, performance benchmarks are proposed for specific project types and the one-way distances between a HMA plant and a job site. Out of a total of ten surveyed projects, six have a hauling distance of less than 40 miles, while four have a hauling distance of greater than 40 miles. Combined with sixteen facilities, the total sampling points were 96 (=16×6) for HMA projects (< 40mi) and 64 (=16×4) for HMA projects (>40mi). The combination covers all the possible values of emission intensities of the sampled projects. Statistical analysis of the sampling population shows that when the distance is less than 40 miles, the average baseline emission (μ) is 134.8 $kgCO_2e/t$ HMA and the standard deviation (σ) is 15.5 $kgCO_2e/t$ HMA, as represented in Figure A1 below. When the distance is larger than 40 miles, the average baseline emission (μ) is 170.3 $kgCO_2e/t$ HMA and the standard deviation (σ) is 33.6 $kgCO_2e/t$ HMA. According to UNFCCC (2006), performance benchmarks may be defined as an emission level that is exceeded by 80% of existing HMA projects. Given the sampled projects approximate a normal distribution, the performance benchmark must be 121.9 $kgCO_2e/t$ HMA (equals to μ- 0.84σ) for HMA projects (< 40mi), which is illustrated in Figure A1. The calculation follows a standard cumulative distribution function using normal distribution mean and standard deviation. The performance benchmark is 142.4 $kgCO_2e/t$ HMA for HMA projects (>40mi) as calculated as follows:

Performance benchmark = Average baseline emission – 0.84 × Standard deviation (A9)

For roadway projects, the average baseline emission (μ) is 141.8 $kgCO_2e/t$ HMA and the standard deviation (σ) is 56.2 $kgCO_2e/t$ HMA., and therefore the performance benchmark of roadway projects is 95.1$kgCO_2e/t$ HMA.

Figure A1: Illustration of performance benchmark for hauling distance less than 40 miles


20%
80%
Performance
Benchmark
121.9 kgCO2e/MT
Mean = 134.8
Std.Dev = 15.5
Frequency
35
30
25
20
15
10
5
0
<110
110-125
125-140
140-155
>155
kgCO2e/t HMA

APPENDIX B: EMISSIONS FACTORS FOR CONSTRUCTION EQUIPMENT

Equipment catalog	Manufacturer	hp	Emission rate (g/hp/hr)	Emission factor (kg CO_2e/hr)
Air Compressors	Emglo	5.0	1301.3	6.5
Air Compressors	Mi-T-M	5.5	1301.3	7.2
Air Compressors	Sullair	61.0	948.8	57.9
Air Compressors	Others	19.5	1183.8	23.8
Cement and Mortar Mixers	MultiQuip	13.0	1301.3	16.9
Cement and Mortar Mixers	Others	13.0	1301.3	16.9
Cold recycler	Wirtgen 7'	429.0	948.8	407.0
Cold recycler	Wirtgen 9'	580.0	948.8	550.3
Cold recycler	Wirtgen 12'	950.0	948.8	901.4
Cold recycler	Other	NA	NA	535.9
Dumpers/Tenders	Terex	300.0	824.4	247.3
Dumpers/Tenders	Ford	210.0	948.8	199.3
Dumpers/Tenders	Others	255.0	886.6	226.1
Excavators	JCB	128.0	1030.9	132.0
Excavators	John Deere	141.0	1020.7	143.9
Excavators	Kobelco	112.0	1067.5	119.6
Excavators	Others	127.0	1039.7	132.0
Forklifts	JCB	76.0	1030.9	78.3
Forklifts	John Deere	73.0	1020.7	74.5
Forklifts	Others	74.0	1025.8	75.9
Off-Highway Trucks	Terex	260.0	863.6	224.5
Off-Highway Trucks	Caterpillar	210.0	948.8	199.3
Off-Highway Trucks	John Deere	265.0	1020.7	270.5
Off-Highway Trucks	Others	150.7	984.0	148.3
Milling machine	Others	150.0	881.7	132.3

Equipment catalog	Manufacturer	hp	Emission rate (g/hp/hr)	Emission factor (kg CO_2e/hr)
Paver	Barber-Greene	115.0	1020.7	117.4
Paver	Wheeler Machinery	142.0	948.8	134.7
Paver	Others	128.5	984.7	126.5
Plate Compactors	Bomag	3.9	1471.1	5.7
Plate Compactors	MultiQuip	4.0	1301.3	5.2
Plate Compactors	Wacker	9.0	1301.3	11.7
Plate Compactors	Others	5.6	1357.9	7.6
Pressure Washers	Honda	9.0	1301.3	11.7
Pressure Washers	Mi-T-M	13.0	1301.3	16.9
Pressure Washers	Shark-Karcher	11.0	1301.3	14.3
Pressure Washers	Others	11.0	1301.3	14.3
Pumps	Gorman-Rupp	72.0	1301.3	93.7
Rollers	Bomag	44.0	1063.2	46.8
Rollers	Dynapac	85.0	824.4	70.1
Rollers	MultiQuip	18.0	1189.1	21.4
Rollers	Others	45.2	1025.6	46.3
Rough Terrain Forklifts	Case	73.0	824.4	60.2
Rough Terrain Forklifts	JCB	76.0	1014.7	77.1
Rough Terrain Forklifts	John Deere	73.0	1020.7	74.5
Rough Terrain Forklifts	Others	74.0	953.3	70.5
Rubber Tired Dozers	John Deere	90.0	1020.7	91.9
Rubber Tired Dozers	Others	90.0	1020.7	91.9
Rubber Tired Loaders	JCB	150.0	1030.9	154.6
Rubber Tired Loaders	John Deere	134.0	1020.7	136.8
Rubber Tired Loaders	Others	142.0	1025.8	145.7
Skid Steer Loaders	Bobcat	46.0	1179.4	54.3

Equipment catalog	Manufacturer	hp	Emission rate (g/hp/hr)	Emission factor (kg CO_2e/hr)
Skid Steer Loaders	John Deere	76.0	1020.7	77.6
Skid Steer Loaders	Toro	20.0	1189.1	23.8
Skid Steer Loaders	Others	47.3	1129.7	53.5
Sweepers/Scrubbers	Schwarz Industries	115.0	1020.7	117.4
Sweepers/Scrubbers	Schwarz Industries	250.0	824.4	206.1
Sweepers/Scrubbers	Victory	190.0	977.6	185.7
Sweepers/Scrubbers	Others	185.0	940.9	174.1
Track Loaders	John Deere	90.0	1020.7	91.9
Track Loaders	Takeuchi	81.0	1137.2	92.1
Track Loaders	Others	85.5	1078.9	92.2
Backhoes	JCB	86.0	1030.9	88.7
Backhoes	John Deere	86.0	1020.7	87.8
Backhoes	Others	81.7	1025.8	83.8
Trenchers	DitchWitch walk-behind	17.5	1020.7	17.9
Trenchers	DitchWitch ride-on	42.0	1063.2	44.7
Trenchers	Vermeer Walk-behind	23.0	1189.1	27.3
Trenchers	Vermeer ride-on	46.0	1063.2	48.9
Trenchers	Others	28.9	1084.1	31.3
Water Trucks	Ford	240.0	824.4	197.9
Water Trucks	Kenworth	475.0	948.8	450.7
Water Trucks	Freightliner	300.0	948.8	284.6

Data source: EPA (2012)

APPENDIX C: EXPERT REVIEW PANEL FOR PERFORMANCE BENCHMARKS

Expert Review Panel

An expert panel met on June 23, 2014 at the University of Maryland to review and provide feedback on the levels of performance benchmarks. Experts in attendance included the following:

- Tuncer Edil – Professor Emeritus, Geological Engineering and Civil & Environmental Engineering, University of Wisconsin-Madison
- Gerardo Flintsch – Professor of Civil and Environmental Engineering, Virginia Polytechnic Institute
- Jeff Graf – Executive Vice President, Maryland Paving Inc.
- Luke Wisniewski – Chief Climate Change, Maryland Department of Environment

Other Participants

Other participants included the following:

- Harold Green, GRR
- Dan Shaw, GRR
- Chandra Akisetty PE, GRR
- Qingbin Cui, University of Maryland
- Xiaoyu Liu, University of Maryland
- Sara Berman, Straughan Environmental
- Deborah Sward, Straughan Environmental
- Andrew Beauchamp, Verra
- John Holler, Verra

The meeting included introductions from members of the team, Verra staff, and a summary of the methodology development process. The Expert Review Panel members then asked questions, provided their feedback, and had a discussion with the methodology development team. The following is a summary of the discussion.

Expert Review Panel Discussion

Q1 Luke Wisniewski: Does the use of a thicker base cause any issues matching it to existing roads or cause logistical issues?

Response: No, usually when doing a road rehabilitation –milling out the existing pavement and constructing foam and hot mix—a project will have to mill out an inch deeper in order to compensate for the use of the FSB. If a project is removing 4” of HMA base for replacement with a 5” thick FSB layer, the road will be milled down further to compensate. It also depends on how and where the project occurs and the restrictions and specifications on the grade. If the grade is not to be changed the road will be milled deeper. If the grades can be changed, a transition will be made between the existing pavement and the sections with a layer of FSB. Each project will specify whether the grades need to match or a transition can be made.

Q2 Gerardo Flintsch: The structural layer coefficient of bitumen for cold mix being used is 0.32. Where did this value come from? Please provide further references, and I have a reference I can add (shared with the team through email).

Response: The methodology is being revised to clearly identify how the structural coefficient of 0.32 was developed. The value came from a study conducted by the University of Maryland (UMD) for the Maryland State Highway Administration (MD SHA). UMD collected core samples and had them tested at a lab. The Team conducted some falling weight deflectometer (FWD) tests to determine the resilient modulus (M_r). From the core samples tested and the FWD test the team calculated the layer coefficient. The results of the structural layer coefficient from the samples ranged from 0.38 to 0.4. The Team also conducted a Nomograph test following the Wirtgen Core Recycling Mix Manual and examined the values for the asphalt cold mix. Comparing the results allowed for a broader data source to review. In order to be more conservative in our value and to accurately represent all conditions, the team averaged the results from studies conducted throughout the world and developed 0.32 as the structural layer coefficient.

A clarification to the methodology will be made to clearly identify that FSB uses only 1.5-2% more material per cubic foot than HMA. This is because the densities are different. The density for HMA is 160 lbs per cubic ft and for FSB it is 130 lbs per cubic ft. FSB’s layer coefficient is lower than HMA, thus requiring 25% more volume while only requiring 1.5-2% more material to maintain the required specification layer coefficient. The differences between volume and weight will be clarified further within the methodology for calculating emission savings.

The methodology team will include further references supporting the methodology findings. A report by Charles Schwartz (team member) and Sadaf Khosravifar for “State Highway Administration Research Report: Design and Evaluation of Foamed Asphalt Base Materials” outlines the role of FSB.

Q3 Gerardo Flintsch: One discussion in a lifecycle assessment (LCA) is how do we address the physical stock energy of the asphalt binder? The LCA can be very high. How does the team address this?

Response: The comment is being considered and taken into account in the methodology. Materials emissions factors are coming from Environmental Protection Agency’s database Department of Energy’s, EIO-LCA and other databases publicly available and referenced in the methodology. The equipment emission factors are coming from EPA tier emission standards, and the assembly emission factors come from the Inventory of Carbon and Energy developed by University of Bath, UK. This reference provides material emission factors.

Q4 Tuncer Edil: Considering the maintenance stage produces a considerable amount of emissions, it is important to include this stage in the project boundary. The difference between HMA, CCPR CIR has a high impact on GHG emission levels and the choice of maintenance regime can extend the service life of a road thus considerably reducing GHG emissions over its lifespan.

Response: Maintenance was not included within the project boundary given the great variability of road maintenance requirements due to geographic location and ownership protocol. LCA can take a cradle to grave or a cradle to gate approach. The team decided on a cradle to gate in order to reduce potential variability of GHG emissions due to the broad range of road maintenance schedules/strategies over the 50 year lifespan of a road. Including maintenance over a 50-year period will in turn skew the calculation due to the significant amount of emissions associated with a project boundary of 50 years. 50 years would also prove difficult to monitor for a project boundary. The current project boundary meets with ISO standards and guidance. The initial designs have considered the differences between structural layer coefficients of two materials – 4 inch base using HMA and 5 inch base using FSB. The structural performance must be the same when road is constructed (or reconstructed) using the two materials. The maintenance schedule can be reasonably assumed to be same frequency and activity, accordingly.

Q5 Tuncer Edil: Is the service life of FSB the same as HMA?

Response: The service life of FSB and HMA are similar. FSB is used as base a layer with HMA as a surface layer. Under this circumstance the service life is dictated by HMA surface layer performance. The performance of roads with and without FSB as a base layer are very similar. The structural integrity was found to be the same by Schwartz & Khosravifar. The National Center for Asphalt Technology (NCAT) in their Spring 2014 (Volume 26 Number 1) report evaluates structural integrity and maintenance over a two-year period. They have completed 80% of the study. The results to date have been positive with10 million Equivalent Single Axle Load (ESALs) with no significant cracking or rutting reported in the interim report.

Q6 Gerardo Flintsch: The methodology reference data from 2002. There has been much development in the construction equipment manufacturing industry. Equipment used in manufacturing has become efficient over the past 12 years reducing GHG emissions level. However the research studies referenced date back to 2002 for EIO-LCA. However, the HMA equipment data is from 2009. Why do you continue to use data from 2002?

Response: The 2002 data is for the materials side. The 2002 data used in the model comes from the Department of Commerce. The current version of the model they developed is based on 2002 data. The team will confirm and provide further documentation within the methodology to explain why the methodology includes data from 2002.

Q7 Sara Berman: Does the Additionality threshold accurately represent the industry? Does the expert review panel believe there to be false negatives or false positives within the threshold? Is the threshold too stringent or too lenient?

Response from team: The team averaged data from HMA plants surveyed throughout MD and VA. 80% was a threshold found throughout other methodologies. Taking the survey of HMA plants conducted by the team into account and the 80% threshold used by other methodologies made sense given the industry.

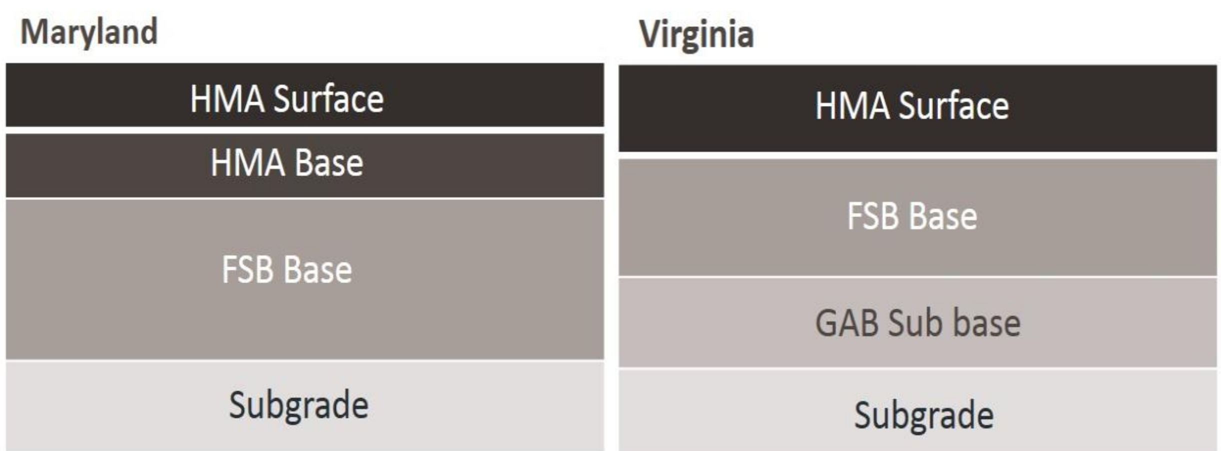
Q8 Sara Berman: Luke Wisniewski do you think there is sufficient regulatory support and/or guidance, which will allow for a market for the methodology to move forward? Could MDE support this moving forward from a regulatory standpoint?

Luke Wisniewski: There is sufficient information for the methodology to move forward. The protocol would have to be validated by an independent organization. If there is a market for offsets it can move forward. MDE will accept the use of FSB. MDE can accept it as the protocol or as an offset credit if it is approved and used appropriately.

Q9 Sara Berman: How significant is the difference between the Maryland and Virginia specifications for the use of FSB in road construction?

Response: There is a considerable difference between Maryland and Virginia FSB use specifications. The following diagram outlines the two specifications. It is important to note the use and location of FSB in relation to the other materials.

Figure C1: FSB Specification for Maryland and Virginia



Q10 Sara Berman: Are there financial incentives to use FSB?

Response: Presently, there are no financial incentives to use FSB rather than HMA.

Q11 Sara Berman: Is there a rationale for why the experts support the methodology?

Response: Tuncer Edil finds that once the team addresses the comments from this meeting the methodology will be ready to move forward. Other reviewers support the methodology moving forward.

Q12 Tuncer Edil: There has been much improvement in incorporating RAP and RAS in recent years into HMA mix designs. The methodology references 3% RAS in the HMA mix, which is surprisingly low. On page 25 change 2006 to 2010 in footnote 3.

Response: The usage of 3% RAS was found to be representative of the HMA plants surveyed in the development of the methodology. The methodology will provide further documentation supporting the use of 3% and include an additional footnote for clarification.

Q14 Gerardo Flintsch: Although the methodology is focused on FSB, emulsion is included in several places. Is emulsion going to be considered? If so, emulsion needs further clarification and documentation. Will this impact the structural layer coefficient?

Response: Emulsion will be included in the methodology. It is a similar process to foam. The difference between foam and emulsion is when the mix occurs. The methodology will be adapted to accurately represent this in the methodology. The model will address emulsion moving forward.

Questions from Jeff Graf

Jeff Graf was unable to attend the meeting. His comments and questions with the team response are listed below.

Q1: Jeff would like the group to take into account the nascent industry trend of using warm mix rather than hot mix. Warm mix allows roads to cool faster in warmer climates, and thus enables roads to open sooner to traffic and shorten project time. This would alter the baseline and change the overall accounting of GHG savings.

Response: Warm-mix is an upcoming technology and we have used warm-mix data from various plants in our calculations. Our data points include warm mix data from HMA plants and the corresponding GHG response includes warm-mix.

Q2: Jeff asked why the boundary was set as cradle-to-gate rather than cradle to grave. He believes we need to identify that in the use of the RAP the ownership remains with the construction of the road and not with the individual who ground up the road for a CCPR project.

Response: The boundary setting was discussed earlier in the report in order to feasibly observe the project lifespan and eliminate broad variability of road maintenance schedules, which are geographically specific.

Q3: Jeff indicated that CIR projects are often based on the space available to stage the project and size of project area being resurfaced. He recommends further clarification within the methodology as to when CIR projects are feasible.

Response: Three types of recycling methods are being used in pavement industry. First HIR (hot in-place recycling), which is feasible for only top 2 inches of HMA pavement. Second CCPR (cold central plant recycling), which is feasible if the HMA pavement is cracked and rutted up to 4 to 6 inches. Last one is CIR (cold in-place recycling), which is generally preferable if the pavement has to be rehabilitated until the top one inch of base course (severely cracked and rutted pavements up to 4 to 12 inches). The choice of which type to apply is dependent on the area where the recycling project is located and existing drainage conditions of the pavement and economic feasibility. Some projects without proper drainage or existing paving fabric or poor base course condition are not suitable for CIR projects, even if it is economical to do so. It will then have to be replaced with CCPR process.

Q4: Was Maryland Department of Environment's AP 42 referenced for emissions calculations?

The Economic Input-Output LCA Model was adopted to calculate material GHG emissions, which was developed by Carnegie Mellon University. The EPA engine certification database was adopted to calculate equipment GHG emissions. We used nationwide emission factor database, as opposed to state-specific emission factor database.

Q5: The methodology mentions cement in the FSB mix. Is this used across the board? Does it vary based on different State Planning and Research offices (SPR)? With new construction will you have to add more cement to the mix in order for it to adhere properly?

Response: Cement is added in FSB mixes, because it helps to increase the moisture susceptibility resistance. Each project will comply with SPR, project requirements based on specifications and road conditions.

Q6: On a new construction project using FSB, will additional binder or cement be needed to achieve the structural integrity required? If so, will this impact your calculations?

Response: No additional binder or cement is required for new projects. For either new projects or rehabilitation projects, the project team will collect the RAP samples from stockpiles or job sites respectively and develop mix design in the laboratory. Usually the binder content requires varies between 2.1% to 2.3% and cement content always stays at 1%. Portland cement helps the mix to increase the moisture susceptibility resistance and increase its wet ITS (indirect tensile strength) value in FSB mix. It also helps to add extra fines, which are required very often in RAP samples to absorb the expanded asphalt binder. If the cement content increases, the mix loses flexibility and it will become counterproductive.