REDUCING CARBON EMISSIONS ON I-64 CAPACITY IMPROVEMENT PROJECT WITH THE USE OF FSB AND EMULSION ASPHALT MIXTURES

Document Prepared by:

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Project Title	Foam Stabilized Base and Emulsion Asphalt Mixture Pavement Projects
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1 PROJECT DETAILS

1.1 Summary Description of the Project

The foam stabilized base (FSB) and emulsion asphalt mixtures project aims to enlist road construction contractors in the United States of America with the purpose of reducing Greenhouse gas (GHG) emissions during the asphalt installation process by using FSB and asphalt emulsions in place of Hot Mix Asphalt (HMA). Prior to project implementation, the road construction projects would have utilized typical HMA or Warm Mix Asphalt (WMA) installation which has a significant GHG emission footprint associated with the mining of virgin aggregates, trucking the virgin aggregate to the mix plant, heating the mix to 310°F, and then trucking the mixed product at high temperatures to the job site (further detailed in Sections 1.11 and 3.4).

FSB and asphalt emulsions, as compared to the baseline HMA or WMA scenario, greatly reduce GHG emissions by (further detailed in Section 1.11):

1) Recycling the existing roadway and eliminating the need for virgin aggregate mining.
2) Eliminating the need for long distance trucking of virgin aggregates.
3) FSB and asphalt emulsions do not need to be heated to high temperatures like HMA which reduces GHG emissions related to electricity, diesel, or natural gas consumption at the mix plant and to-site delivery.

The project activity quantifies the reduced GHG emissions associated with the use of FSB and/or asphalt emulsions as substitutes for HMA on asphalt construction projects. The project instances consist of existing highway roads in need of repair to extend the useable lifespan for conveying vehicular traffic. The initial project instance is located in the State of Virginia on Interstate Highway 64 (I-64) which began construction in April 2018.

This group of projects is submitted following VCS methodology VM0039, Methodology for Use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application V1.0, which provides the requirements for pavement projects within the United States that utilize FSB and asphalt emulsions in place of traditional HMA to issue verified carbon unit credits (VCUs). This group of projects will include completed pavement projects constructed by Allan Myers, Inc., that utilize FSB and asphalt emulsions. Global Emissionairy, LLC is the project proponent. Ultimately, projects currently under design, construction, and future projects would be added under this project description.

The estimated annual GHG emission reduction is 13,310 tonnes of CO_2 per year with an estimated total GHG emission reduction of 133,103 tonnes of CO_2 over the 10-year crediting period.

1.2 Sectoral Scope and Project Type

The project falls under Sectoral Scope 6 and should be considered a grouped project.

1.3 Project Eligibility

The project(s) includes the production and installation of FSB and/or asphalt emulsions for a road widening project in the United States. The projects produced and installed FSB and or asphalt emulsions using CCPR, CIR, and/or FDR processes.

1.4 Project Design

The project has been designed as a grouped project. New project instances will comply with the set of criteria listed below.

Eligibility Criteria

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.

1.5 Project Proponent

Provide contact information for the project proponent(s). Copy and paste the table as needed.

Organization name	Global Emissionairy, LLC
Contact person	Harold Green
Title	CEO

Address	Corporate Office: 162 Lafayette Avenue Laurel, MD 20707 Operations: 2600 Marble Court Forestville, MD 20747
Telephone	202-288-4130
Email	hg@globalemissionairy.com

1.6 Other Entities Involved in the Project

Organization name	Allan Myers, Inc.
Role in the project	Contractor, preformed the asphalt construction
Contact person	Tim Peffer
Title	Director, Quality Control
Address	1805 Berks Road Worcester, PA 19490
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Organization name	University of Maryland, Smart Construction Center
Role in the project	Technical Consultants, Methodology development
Contact person	Dr. Qingbin Cui
Title	Professor of Civil Engineering

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Organization name	Straughan Environmental, Inc
Role in the project	Project administration and management
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Role in the project	Methodology and application development
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Name	Dr. Chandra Akesitty
Role in the project	Technical Consultants, Methodology development
Title	Structural Engineer
Address	7035 Southmoor Street Hanover, MD 21076
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Organization name	Global Emissionairy, LLC
Role in the project	Verra Registry Account Administrator
Contact person	Jim Peacock
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Email	jpeacock@uhy-us.com

1.7 Ownership

The Project Proponent, Global Emissionairy, LLC, holds the rights of the GHG emissions savings achieved in construction asphalt pavement projects performed by Allan Myers, Inc. using FSB and/or asphalt emulsion as conveyed. This is consistent with VCS Standard Section 3.6.1 Ownership, clause 3 which states:

3) Project ownership arising by virtue of a statutory, property or contractual right in the plant, equipment or process that generates GHG emission reductions and/or removals (where the project proponent has not been divested of such project ownership).

1.8 Project Start Date

The Project start date is April 21, 2018, the date that asphalt installation began.

1.9 Project Crediting Period

The Project's first crediting period is 10 years, beginning on the Project start date of April 21, 2018, and ending on April 21, 2027.

1.10 Project Scale and Estimated GHG Emission Reductions or Removals

For the purposes of assessing materiality, VCS projects are disclosed across two project categories: Project category reductions may be up to 300,000 tonnes CO2e per year; Large Projects category reduction comprises more than 300k tonnes CO2e/year.
The Grouped Projects is anticipated to be under the annual 300,000 tCO2e threshold for Large Project scale and is therefore classified as Project category. In addition, a 10-year fixed crediting period has been selected for the Grouped Projects.

Project Scale	
Project	X
Large project	

Year	Estimated GHG emission reductions or removals (tCO_2e)
2018	13,103
2019	0
2020	0
2021	0
2022	20,000
2023	20,000
2024	20,000
2025	20,000
2026	20,000
2027	20,000

Total estimated ERs	133,103
Total number of crediting years	10
Average annual ERs	13,310

1.11 Description of the Project Activity

The project activity includes roadway paving projects that utilize FSB and/or asphalt emulsion instead of HMA in the production and installation of asphalt.

GHG emission reductions are generated from producing and installing FSB and asphalt emulsions instead of 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 °F.

1.12 Project Location

The Grouped Projects have been or will be constructed within the continental United States of America. The first project instance is located within the City of Newport News, James City County, and York County in the Commonwealth of Virginia on Interstate Highway 64. The project instance was part of Segment II of the I-64 capacity improvements.

1.13 Conditions Prior to Project Initiation

The conditions prior to Project initiation are consistent with the baseline scenario, as described in detail in Section 3.4 and consist of asphalt *road* surfaces in need of repair.

1.14 Compliance with Laws, Statutes and Other Regulatory Frameworks

The asphalt construction projects were or will be performed in compliance with local department of transportation and/or United States Federal Highway Administration construction specifications.

1.15 Participation under Other GHG Programs

1.15.1 Projects Registered (or seeking registration) under Other GHG Program(s)

The project instances under this grouped project are not registered and have not pursued registration under any other GHG program.

1.15.2 Projects Rejected by Other GHG Programs

The project instances under this grouped project have not been rejected by any other GHG Program.

1.16 Other Forms of Credit

1.16.1 Emissions Trading Programs and Other Binding Limits

The project instances under this grouped project is not and will not be used in activities that are included in an emissions trading program or any other mechanism that includes GHG allowance trading.

1.16.2 Other Forms of Environmental Credit

The project instances under this grouped project have not received and is not seeking any other form of GHG-related environmental credit.

1.17 Additional Information Relevant to the Project

Leakage Management

According to the applicable methodology, *VM0039 Methodology for Use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application*, 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.

Commercially Sensitive Information

Certain information related to the production and installation of the asphalt mixture may be considered sensitive and will not be included in the public version of the Project Description. Sensitive information will be provided, as needed, for validation.

Sustainable Development

The Project does not contribute to achieving any specific sustainable development priorities at the national level.

Further Information

None.

2 SAFEGUARDS

2.1 No Net Harm

No potentially negative impacts to the natural or human environment have been identified for the project instances under this grouped project.

2.2 Local Stakeholder Consultation

Local Stakeholders consultation was achieved in a number of ways; during the projects NEPA process which requires public outreach and through direct correspondence. The Project Proponent has identified the following stakeholders:

- Asphalt Contractor and Construction personnel (Allan Myers)
- Virginia Transportation Research Council, Virginia Department of Transportation
- Virginia Department of Transportation
- General public/road users

Stakeholder consultation for the project activity took place during the project implementation as part of the I-64 Peninsula Study Environmental Impact Statement. The general public were informed about the road construction projects, including aspects of the use of recycled asphalt reclaimed asphalt pavement (RAP) and asphalt emulsions, via public meetings, project mailings, and a project website that included videos that displayed the asphalt installation process. No comments specific to the use of RAP and asphalt emulsions were received or recorded in the I-64 Peninsula Study Environmental Impact Statement. https://www.virginiadot.org/projects/hamptonroads/i-64_peninsula_study.asp

The Project Proponent has been in consultation about the use of FSB and asphalt emulsions with VDOT staff prior to, during, and after the construction of the I-64, Segment II. Dr. Brian Diefenderfer of the VDOT Virginia Transportation Research Council has discussed the use of FSB and asphalt emulsions, and quantifying the reduction in emissions versus HMA, with the Project Proponent periodically over the last decade. Allan Myers, the asphalt contractor, developed the asphalt mix design, road layer configuration and structural coefficient in consultation with VDOT personnel.

The project instance has been featured in numerous local and national publications for its innovative use of RAP, asphalt emulsion, CCRP and FDR. The I-64 Project has received a 2021 *Roads & Bridges / ARRA Recycling Award.*

On-going communication with stakeholders involved with projects and interested stakeholders can be achieved by accessing the Project Proponents website (https://globalemissionairy.com/). Any comments can be sent through the websites comment form or via email (contact@globalemissionairy.com),

2.3 Environmental Impact

The project activity includes applying FSB and/or asphalt emulsion layers in place of HMA layers in asphalt paving applications. Potential environmental impacts would likely be the same as those for conventional HMA asphalt paving such as sediment and erosion control and traffic control measures.

Therefore, industry best management practices for avoidance and mitigation of environmental impacts would apply.

The first project instance was conducted as part of the Interstate 64 Peninsula Study Final Environmental Impact Statement and Record of Decision.

2.4 Public Comments

This Project Description was listed on the Verra Registry and available for public comment from XXX – XXX and XXXX comments were received. (To be completed after posting)

2.5 AFOLU-Specific Safeguards

Not applicable

3 APPLICATION OF METHODOLOGY

3.1 Title and Reference of Methodology

The project is conducted under VCS methodology VM0039, “Methodology for Use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application,” version 1.0 (VM0039). This methodology is located at https://verra.org/methodology/vm0039-methodology-for-us-of-fsb-in-pavement-application-v1-0/.

3.2 Applicability of Methodology

The methodology is applicable to the project(s) due to 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.

Project instances will meet applicability conditions of VCS methodology VM0039. Project instances will include the construction, modification, and repair of road and/or parking lots in the United States. Project instances will use FSB and asphalt emulsions in CCPR, CIR, and FDR processes. The first project instance (I-64 highway) replaces baseline scenario HMA with FSB using CCPR and FDR.

3.3 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. The GHG impact of producing an asphalt mixture should be calculated by adding up the following emission sources: 1) GHG associated with manufacturing each of the constituent and ancillary materials; 2) GHG from transporting materials from factory to mix plant; 3) GHG from all forms of energy involved in producing the asphalt at mixing plant; and 4) GHG from all forms of energy involved in milling the existing pavement and placing new pavement, including relevant transport activities.

Maintenance and excavation of the new pavement are not included due to the high variability of practices in each region. 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

There are three processes that the Grouped Projects can utilize: 1) Cold Central Plant Recycling (CCPR), 2) Cold in-place Recycling (CIR), 3) Full-Depth Reclamation (FDR). CIR and FDR have the same boundary.

Boundary for CCPR

CCPR transports 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 emulsion) and a small amount of Portland cement in a cold mixing process. Figure 3 shows the major processes included in the CCPR project. The boundary consists of energy consumption for milling the existing pavement, producing bitumen binder and water, transportation to and at the FSB production plant, heating of bitumen binder, mixing, transportation of materials and resources to the project site, and installation of the mix.

Boundary for CIR or FDR

CIR or FDR uses one or more mobile recycling machine 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 emulsion) and additives, and then immediately place it back down on the road by permanent placement with a paver and rollers. CIR or FDR allows a paving contractor to use the aggregate from the existing road and, by adding liquid asphalt cement (consisting of under 3% of 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 the CIR or FDR system. The project boundary includes production of bitumen, water, and cement, operation of recycler and rollers, and transportation and storage of input materials.

> Project instances must incorporate FSB and/or asphalt emulsions in place of traditional asphalt mixes while delivering or exceeding the baseline project structural strength design parameters. For example, the project boundary for the first project instance (I-64 highway) replaces the third layer (HMA) and fourth layer (cement treated base, CTB) in the pavement design with asphalt emulsions. Although other GHGs have been reduced in this first project instance, methodology VM0039 only calculates the reduction of CO_2 emissions.

Source			Gas	Included?	Justification/Explanation
HMA (Baseline)	Source 1 – Mainline New Roadway Source 2 – Shoulders New Roadway Source 3 – Mainline New Roadway Source 4 – Shoulder New Roadway	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		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 central plant.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		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	Not Applicable

Source			Gas	Included?	Justification/Explanation
Project (HMA)	Source 1 – Mainline New Roadway Source 2 – Shoulders New Roadway Source 3 – Mainline New Roadway Source 4 – Shoulder New Roadway	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		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 central plant.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		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	Not Applicable

Source			Gas	Included?	Justification/Explanation
CCPR (Project Instance)	Source 1 – Mainline New Roadway Source 2 – Shoulders New Roadway Source 3 – Mainline New Roadway Source 4 – Shoulder New Roadway	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		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 asphalt emulsions at the central plant.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		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	Not Applicable

Source			Gas	Included?	Justification/Explanation
FDR (Project Instance)	Source 1 – Mainline Rehabilitated Roadway And Source 2 – Shoulder Rehabilitated Roadway	Raw material acquisition	CO_2	Yes	GHGs are released from energy consumption in material manufacture process.
			CH_4	No	Not Applicable
			N_2O	No	Not Applicable
		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	Not Applicable
		Asphalt emulsions production & placement	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	Not Applicable

The Grouped Projects have been or will be constructed within the continental United States of America. The first project instance, the widening of I-64, Section II, took place in Newport News, James City, and York Counties in Virginia.

3.4 Baseline Scenario

The baseline scenario is the use of HMA technique in pavement application. The emission estimation starts 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 material. Specifically, the boundary for HMA system consists 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.

The baseline scenario for projects applying this methodology is the project where HMA, or the subcategory warm mix asphalt (WMA), is applied to both the surface and base layers. More than 94% of the U.S. roads are paved with HMA. The National Asphalt Pavement Association (NAPA) statistics show that approximately one third of HMA projects in the U.S. in 2014 used WMA technologies. 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. CCPR and CIR (or FDR) projects are to replace HMA or WMA base layers with FSB or asphalt emulsions. They typically outperform the performance benchmarks because they can reduce the emissions from producing bitumen and producing, transporting, and heating virgin aggregates.

For this first project instance, the baseline scenario includes the application of HMA for four asphalt layers installed over six traffic lanes and four shoulders of I-64.

The baseline scenario for the reconstruction and widening of the I-64 highway consists of two CO_2 emitting activities: (1) removal of existing roadway lanes that were reconstructed in the project scenario and (2) construction of new lanes using both hot mix asphalt (HMA) and cement-treated base (CTB).

For the removal of existing lanes, this project proposal sums emissions released from removing (a) four 12’ wide travel lanes (199,373 yd^2) and (b) two 12.5’ shoulder lanes (103,840 yd^2). This project proposal conservatively ignores emissions that would have been released from removing dirt and other materials from areas without pre-existing roads (for widening). Emission calculations use the Verra Methodology for Use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application (VM0039; Cui 2019) material properties, VM0039 equipment emissions rates, and two milling removal rate assumptions for HMA (5,000 yd^2 / 8 hr) and concrete (3,100 yd^2 / 8 hr). See Section 4.1 of this document for complete emission calculations associated with the removal of lanes necessary to complete the baseline scenario project.

For the construction of new lanes, this project sums emissions released from the installation of HMA and CTB according to the methods in VM0039. This project conservatively uses the VM0039 HMA emission factor for CTB because VM0039 does not provide a CTB emission factor. See Section 4.2 of this document for complete calculations of the construction of new lanes in the baseline scenario project.

3.5 Additionality

Project instance proponents follow two steps described in Section 6 of VM0039 to determine additionality. First, proponents must demonstrate regulatory surplus in accordance with the rules and requirements described in the latest version of the VCS Standard. No rules or regulations mandating the use of FSB or asphalt emulsions to reduce CO2e emissions exist. Therefore, all CO2e reductions are regulatory surplus.

Regulatory surplus is established in this project through the following aspects: 1) CCPR was not a typical practice in Virginia. The I-64 Widening Project Segment II is one of only a few highway projects in Virginia where CCPR was installed. 2) There is no regulatory requirement in Virginia to apply CCPR in highway construction. The selection of CCPR in segment II was based on a design-build selection process, where the contractor voluntarily proposed innovative design and construction methods, including selection of low-emission materials. The segment I serves as a comparison case where the contractor voluntarily selected to follow traditional methods and materials, and therefore didn't produce the same environmental benefits as the segment II.

Second, a performance benchmark determines emissions for patching and roadway scenarios. This performance benchmark depends on whether a project is a parking lot or roadway, the distance materials need to be hauled, and the year a project has been completed. Project performance exceeds the benchmark metric for baseline HMA projects when FSB pavement layers used in the project meet or exceed structural numbers of the baseline HMA design, and the harvesting, mixing, installation, and hauling of FSB materials emit less CO_2 than corresponding HMA layers.

3.6 Methodology Deviations

VM0039 describes the process of replacing a single layer of HMA in a road or parking lot with FSB or asphalt emulsions. Individual processes in the initial project instance do not deviate from this methodology. Emissions reductions from several processes, however, are summed together to form the project instance. These processes include accounting for the removal and transport of existing asphalt necessary to implement the baseline scenario. Portland cement produces about 750 to 900 kg of CO2 per every ton of its production. Whereas the asphalt produces only a third of this amount per every ton of its production (http://www.onasphalt.org/files/factsheets/Carbon%20Footprint_How%20Does%20Asphalt%20Stack%20Up.pdf). Typical HMA contains about 5 to 6% of asphalt in it, where typical cement treated base contains only 2 to 3%% of Portland cement. Therefore, we considered the HMA emission factor for cement treated base since it was not provided by the methodology VM0039. By considering this the calculations are on conservative side without having any negative effects on uncaptured carbon emissions from this cement treated base construction.

4 ESTIMATED GHG EMISSION REDUCTIONS AND REMOVALS

This Section describes the following:

1. Baseline emissions: The calculation of CO2 emissions from a conventional project to reconstruct and widening Section II of the I-64 highway using (a) hot mix asphalt and (b) cement treated base pavement layers
2. Project emissions: The calculation of CO2 emissions to reconstruct and expand Section II of the I-64 highway in accordance with Verra Methodology for Use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application (VM0039; Cui 2019).
3. Leakage: Confirmation that leakage emissions do not apply in accordance with VM0039 Section 7.3.
4. Estimated Net GHG Emission Reductions and Removals: the difference between project emissions and baseline emissions.

4.1 Baseline Emissions

Baseline emissions are the emissions resulting from the conventional practice of construction of an asphalt roadway or patching project using HMA. Baseline emissions ($e_{Baseline}$) are derived using a performance benchmark which represents the quantity of GHGs emitted from producing and installing one metric ton of HMA as described in the methodology "VM0039 Methodology for use of Foam Stabilized Base and Emulsion Asphalt Mixtures in Pavement Application" (VM0039). This is 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 as described in VM0039, Appendix A (equations A1 – A5). The performance benchmark is 94.7 kgCO_2e/t.

For projects performed on previously paved surfaces (Road Reconstruction), the existing roadway must be removed using a milling machine and transported to stockpiling location or plant before installation of the new HMA ($e_{Baseline\ Removal}$). VM0039 does not account for the removal of existing asphalt on previously paved surfaces; so it is defined below.

Emissions in the baseline scenario are estimated as the sum of the emissions created by (a) removing the existing roadway ($e_{Baseline\ Removal}$) and (b) installing a new roadway ($e_{Baseline\ Installation}$) using conventional practices (HMA) according to the following equation:

$$e_{Baseline} = e_{Baseline\ Removal} + e_{Baseline\ Installation}$$

where

$e_{Baseline}$ = Total baseline emissions from construction of an asphalt roadway or patching project using HMA (tCO_2e)

$e_{Baseline\ Removal}$ = Total emissions from removal of the existing roadway and hauling of milled roadway material (tCO_2e)

$e_{Baseline\ Installation}$ = The performance benchmark multiplied by the sum of the total weight of HMA mix installed under the conventional design condition (tCO_2e)

Where the project activities include multiple roadways, parking lots, or patch jobs, baseline emissions in the baseline scenario are estimated as the sum of the removal and installation emissions from each project instance. The calculation of the baseline removal uses the same methods and equipment emission factors described for the removal of existing asphalt under projects using CCPR, CIR, and FDR to install FSB and asphalt emulsions in Section 7.2 of VM0039.

For each new instance, it is important to determine what the baseline or business as usual asphalt construction would be in the absence of the project activity. Elements of the roadway, parking lot, or patch job under the baseline condition must be determined such as:

- Is the project new construction or rehabilitation/replacement of existing asphalt
- Road or patch depth,
- Thickness of layers,
- Layer materials, and
- Lane width and length

Where available, project construction contractors provide these details based on project requirements from the RFP or construction drawings, state department of transportation, parking lot owner, or past construction practices for similar projects.

The initial project activity instance is an interstate-highway located in Virginia. The project activity instance began construction in 2018. The project instance included the following actions:

- Removal and Reconstruction of Four (4) 12' wide Travel Lanes
  (Two eastbound (EB) lanes, two westbound (WB) lanes) [AREA 1]
- Removal and Reconstruction of Two (2) 12.5' Shoulder Lanes
  (Outside shoulders EB and WB) [AREA 2]
- New Construction of Two (2) 12' Travel Lanes
  (One EB lane, one WB lane) [AREA 3]
- New Construction of Two (2) 12.5' Shoulder Lanes
  (Inside shoulders EB and WB) [AREA 4]

The baseline scenario details were provided by Allan Myers and includes HMA installation with a cement treated base (CTB) for reconstruction and new construction of the six travel lanes and four roadway shoulders along the entire 7.08-mile length of the project.

First Project Instance Baseline Summary

In this project instance:

$$e_{Baseline} = e_{Baseline\ Removal} + e_{Baseline\ Installation}$$

$$e_{Baseline} = 3{,}745.4\ tons\ CO_2 + 51{,}602.4\ tons\ CO_2$$

$$e_{Baseline} = 55{,}347.8\ tons\ CO_2$$

In metric tons:

$$e_{Baseline} = 50{,}225\ tCO2e$$

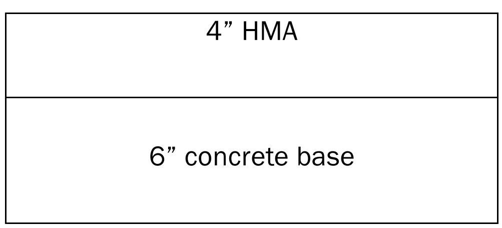
The following two sub-sections present sub-calculations for (a) $e_{Baseline\ Removal}$ and (b) $e_{Baseline\ Installation}$.

A. Baseline Removal

The removal of the existing road included the following lanes and square yardage totals:

1. Four 12’ wide travel lanes covering 199,373 yd2 (a_1) [AREA 1]
2. Two 12.5’ shoulder lanes covering 103,840 yd2 (a_2) [AREA 2]

The existing travel lanes were comprised of 4” layer of HMA on top of a 6” layer of concrete base. The existing shoulder lanes were 6” layer of HMA as shown below.



Emissions for removing the existing travel and shoulder lanes (e_{ML}) include the milling of the existing HMA and concrete base layers, and the hauling away of those layers using 20-ton dump trucks.

$$e_{Baseline\ Removal} = e_{ML-HMA} + e_{ML-Concrete} + e_{ML\ Hauling\ HMA} + e_{ML\ Hauling\ Concrete}$$

Where:

$e_{\text{Baseline Removal}}$ $= Emissions\ resulting\ from\ existing\ road\ removal$

$e_{ML\text{-}HMA}$ = *Emissions resulting from milling HMA in Travel Lanes and Shoulder Lanes*

$e_{ML\text{-}Concrete}$ = *Emissions resulting from milling concrete in Travel Lanes*

$e_{ML\ Hauling\ HMA}$ = *Emissions resulting from hauling milled HMA material*

$e_{ML\ Hauling\ Concrete}$ = Emissions resulting from hauling milled concrete

Baseline Removal of Existing Travel Lanes: Milling

Assuming the following milling removal rates for 4" HMA (t_{HMA}) and 6" concrete ($t_{concrete}$):

$$mr_{HMA} = 5{,}000\ \frac{yd^2}{8\ hr}$$

$$mr_{Concrete} = 3{,}100\ \frac{yd^2}{8\ hr}$$

And given the following density of HMA and the emission rate of the milling machine from VM0039:

$$\rho_{HMA} = 155.0\ \frac{lb}{ft^3}$$

$$e_m = 1{,}760\ \frac{lb\ CO_2}{hr}$$

Emissions for removal of the HMA layers in the travel lanes equals

$$e_{ML-HMA} = e_m \cdot \frac{a_1}{mr_{HMA}}$$

$$e_{ML-HMA} = 1760\ \frac{lb\ CO_2}{hr} \cdot \frac{199{,}373\ yd^2}{5{,}000\ yd^2/8hr} \cdot \frac{1\ ton}{2000\ lb}$$

$$e_{ML-HMA} = 280.7\ tons\ CO_2$$

Emissions for removal of the concrete layers in the main lanes equals

$$e_{ML-Concrete} = e_m \cdot \frac{a_1}{mr_{HMA}}$$

$$e_{ML-Concrete} = 1760\ \frac{lb\ CO_2}{hr} \cdot \frac{199{,}373\ yd^2}{3{,}100\ yd^2/8hr} \cdot \frac{1\ ton}{2000\ lb}$$

$$e_{ML-Concrete} = 452.8\ tons\ CO_2$$

Baseline Removal of Existing Travel Lanes: Hauling

Given the following truck emissions, truck capacity, and hauling distance:

$$e_{truck} = 22.5\ \frac{lb\ CO_2}{mi}$$

$$c_{truck} = 20\ tons$$

$$d = 32.7\ \frac{mi}{trip}$$

And given the mass of HMA in the main lanes equal

$$m_{HMA} = \rho_{HMA} * a_1 * t_{HMA}$$

$$m_{HMA} = 155 \frac{lb}{ft^3} \cdot 199{,}373\ yd^2 \cdot \frac{9\,ft^2}{1\,yd^2} \cdot 4\ in \cdot \frac{1\,ft}{12\ in} \cdot \frac{1\ ton}{2000\ lb}$$

$$m_{HMA} = 46{,}354\ tons$$

And given the mass of concrete equals

$$m_{Concrete} = \rho_{Concrete} \cdot a_1 \cdot t_{Concrete}$$

$$m_{Concrete} = 150\ \frac{lb}{ft^3} \cdot 199{,}373\ yd^2 \cdot \frac{9\,ft^2}{1\,yd^2} \cdot 6in \cdot \frac{1\,ft}{12\ in} \cdot \frac{1\ ton}{2000\ lb}$$

$$m_{Concrete} = 67{,}288\ tons$$

Emissions for hauling away the milled HMA in the main lanes equal

$$e_{ML\ Hauling\ HMA} = d \cdot \frac{m_{HMA}}{c_{truck}} \cdot e_{truck}$$

$$e_{ML\ Hauling\ HMA} = 32.7\ \frac{mi}{trip} \cdot \frac{46{,}354\ tons}{20\ tons} \cdot 22.5 \frac{lb\ CO_2}{mi} \cdot \frac{1\ ton}{2000\ lb}$$

$$e_{ML\ Hauling\ HMA} = 852.4\ tons\ CO_2$$

Emissions for hauling away the milled concrete in the main lanes equal

$$e_{ML\ Hauling\ Concrete} = 2\ trips \cdot d \cdot \frac{m_{Concrete}}{c_{truck}} \cdot e_{truck}$$

$$e_{ML\ Hauling\ Concrete} = 2\ trips \cdot 32.7\ mi \cdot \frac{67{,}288\ tons}{20\ tons} \cdot 22.5 \frac{lb\ CO_2}{mi} \cdot \frac{1\ ton}{2000\ lb}$$

$$e_{ML\ Hauling\ Concrete} = 1{,}237.3\ tons\ CO_2$$

Baseline Removal of Existing Travel Lanes: Milling and Hauling

Total emissions from milling and hauling main lane material equal

$$e_{ML} = e_{ML-HMA} + e_{ML-Concrete} + e_{ML\ Hauling\ HMA} + e_{ML\ Hauling\ Concrete}$$

$$e_{ML} = 280.7 + 452.8 + 852.4 + 1{,}237.3\ tons\ CO_2$$

$$\boldsymbol{e_{ML} = 2{,}823.2\ tons\ CO_2}$$

Baseline Removal of Existing Shoulder: Milling

Given the existing shoulder is a single 6" HMA layer

$$t_{Shoulder\ HMA} = 6$$

And assuming the following milling removal rate for 6" HMA

$$mr_{HMA} = 2{,}800\ yd^2\ HMA\ /\ 8hrs$$

Emission for milling of HMA in the shoulder equal

$$e_{Shoulder\ Milling} = e_m \cdot \frac{a_2}{mr_{HMA}}$$

$$e_{Shoulder\ Milling} = 1760\ \frac{lb\ CO_2}{hr} \cdot \frac{103{,}840\ yd^2}{2{,}800\ yd^2/8hr} \cdot \frac{1\ ton}{2000\ lb}$$

$$e_{Shoulder\ Milling} = 261.1\ tons\ CO_2$$

Baseline Removal of Existing Shoulder: Hauling

Given the mass of HMA in the shoulder equals

$$m_{Shoulder\ HMA} = \rho_{HMA} \cdot a_2 \cdot t_{Shoulder\ HMA}$$

$$m_{Shoulder\ HMA} = 155\ \frac{lb}{ft^3} \cdot 103{,}840\ yd^2 \cdot \frac{9\ ft^2}{1\ yd^2} \cdot 6in \cdot \frac{1\ ft}{12\ in} \cdot \frac{1\ ton}{2000\ lb}$$

$$m_{HMA} = 36{,}214\ tons$$

Emissions for hauling away the milled HMA in the shoulder lanes equal

$$e_{Shoulder\ Hauling\ HMA} = d \cdot \frac{m_{Sholder\ HMA}}{c_{truck}} \cdot e_{truck}$$

$$e_{ML\ Hauling\ HMA} = 32.7\ \frac{mi}{trip} \cdot \frac{36{,}214\ tons}{20\ tons} \cdot 22.5\ lb\ \frac{CO_2}{mi} \cdot \frac{1\ ton}{2000\ lb}$$

$$e_{ML\ Hauling\ HMA} = 666.1\ tons\ CO_2$$

Baseline Removal of Existing Shoulder: Milling and Hauling

Total emissions from milling and hauling shoulder material equal

$$e_{Shoulder} = e_{Shoulder\ Milling} + e_{ML\ Hauling\ HMA}$$

$$e_{Shoulder} = 261.1 + 661.1\ tons\ CO_2$$

$$e_{Shoulder} = 922.2\ tons\ CO_2$$

Baseline Removing of Existing Main Lanes and Shoulder

Total emissions for milling and hauling the existing main lane and shoulder material equal:

$$e_{Baseline\ Removal} = e_{ML} + e_{Shoulder}$$

$$e_{Baseline\ Removal} = 2{,}823.2\ tons\ CO_2 + 922.2\ tons\ CO_2$$

$$e_{Baseline\ Removal} = 3{,}745.4\ \ tons\ CO_2$$

B. Baseline Installation

The baseline design assumes that the HMA would be installed in AREA 1 – 4 as a single area section, with the layers of the roadway consistent for the entire installation area. The baseline emissions for installation of a new roadway are calculated as follows:

$$e_{Baseline\ Installation} = e_{HMA\ Roadway} \cdot \sum_{i=1}^{5} m_i$$

$$e_{Baseline\ Installation} = 51{,}602.4\ tons\ CO_2e$$

This includes emissions generated during the raw material production, transport of raw materials to the plant site, producing HMA at the plant, hauling the HMA mix to the project site, and laying down the HMA. These processes are expressed as the following baseline emission rate which is the performance benchmark for installing new roadways in 2018 (VM0039 Section 6, table 2, line 3):

$$e_{HMA\ Roadway} = \ 94.7\frac{kg\ CO2}{tonne\ HMA\ mix}$$

In U.S. units:

$$e_{HMA\ Roadway} = \ 0.0947\frac{lb\ CO2}{lb\ HMA\ mix}$$

And given the following conventional design layer thicknesses, structural numbers (SN)[1] and masses (m) covering all 506,739 yd^2 of travel lanes and shoulders in segment II of the I-64. The baseline scenario mix design is shown below.

2” HMA
2.5” HMA
3” HMA
3” HMA
8” cement treated base

1. 2 in HMA (SN 0.88; m_1 = 58,908 tons of mix)
2. 2.5 in HMA (SN 1.1; m_2 = 73,636 tons of mix)
3. 3 in HMA (SN 1.2; m_3 = 88,363 tons of mix)

[1] Structural numbers are based off of AASHTO 1993 Pavement Design Guide

4. 3 in HMA (SN 1.2; m_4 = 88,363 tons of mix)
5. 8 in Cement Treated Base (CTB) (SN 1.6; m_5 = 235,634 tons of mix)

Emission factors for CTB are not given in VM0039. The emissions for production and installation of CTB are relatively the same or slightly more than HMA production and installation. We therefore conservatively used HMA emission factors for the bottom 8" CTB layer. Note, for comparison with project emissions calculated in the next section, the total conventional baseline structural number (SN) equals 5.98, which is below the structural number of the project scenario (6.08).

4.2 Project Emissions

Project emissions are calculated in one of two ways, depending on production method. The first method is central cold plant recycling (CCPR) and includes the transportation of raw and recycled materials to a central plant and ends with the delivery of the final pavement product to the job site. 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. 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.

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 (EIM), to-plant delivery emissions intensity (EIPD), in-plant production emission intensity (EIP), to-site delivery emissions intensity (EISD) and on-site installation emission intensity (EII). CCPR EI is calculated as follows:

$$CCPR\ EI = EIM + EIPD + EISD + EIP + EII \quad (1)$$

Where:

CCPR EI	= *Emission intensity of CCPR (kgCO2e/t)*
EI_M	= *Emission intensity of raw material production (kgCO2e/t)*
EI_{SD}	= *Emission intensity of to-site delivery (kgCO2e/t)*
EI_P	= *Emission intensity of in-plant production (kgCO2e/t)*
EI_I	= *Emission intensity of pavement installation (kgCO2e/t)*

Equations for each of the above values are presented in VM0039, Section 7.2.1

The second and third production method of asphalt installation is cold in-place recycling (CIR) and full depth reclamation (FDR). CIR and FDR includes 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.

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:

$$CIR\ EI\ (or\ FDR\ EI) = EIM + EISD + EII \quad (11)$$

Where:

CIR EI	= Emission intensity of CIR (kgCO2e/t)
FDR EI	= Emission intensity of FDR (kgCO2e/t)
EIM	= Material emissions intensity (kgCO2e/t)
EISD	= To-site delivery emission intensity (kgCO2e/t)
EII	= On-site installation emission intensity (kgCO2e/t)

Equations for each of the above values are presented in VM0039, Section 7.2.1 and 7.2.2.

Emissions in the project scenario are estimated as the sum of emissions e_{al} for each project area, a, for a equals 1 to n, for each layer, l, for l equals 1 to m_a, according to the following equation:

$$e_{Project} = \sum_{a=1}^{n} \sum_{l=i}^{m_a} e_{al}$$

Each of these emissions are calculated according to methodology VM0039. HMA layer emissions are calculated with the hot mix emission factors in VM0039 Section 6. Emissions from asphalt construction using FSB and asphalt emulsions in CCPR, CIR, and FDR production methods, are calculated according to methods based on VM0039 Section 7.

First Project Instance Summary

The initial project activity instance uses CCPR and FDR production methods with an asphalt mix containing foamed asphalt in four project areas, with each project area having multiple project layers. Emissions from layers that were installed using the CCPR process to produce and install the FSB follow the equations Section 7.2.1 Emissions from CCPR. Emissions from layers that were installed using the FDR process to produce and install the FSB follow the equations included in Section 7.2.2 Emissions from CIR and/or FDR.

Emissions in the project scenario are estimated as the sum of emissions e_{al} for four project areas and different project layers in each project area according to the following equation:

$$e_{Project} = \sum_{a=1}^{n=4} \sum_{l=i}^{m_a} e_{al}$$

$$e_{Project} = \sum_{l=i}^{m_1=4} e_{a=1,l} + \sum_{l=i}^{m_2=4} e_{a=2,l} + \sum_{l=i}^{m_3=4} e_{a=3,l} + \sum_{l=i}^{m_4=4} e_{a=4,l}$$

$$e_{Project} = 41{,}177\ tons\ CO_2$$

In metric tons:

$$e_{Project} = 37{,}366\ t\ CO_2$$

Where

$\sum_{l=i}^{m_1=4} e_{a=1,l} = e_{Project\ Reconstrcuted\ Travel\ Lanes} = 12{,}629\ tons\ CO_2$ for area 1

$\sum_{l=i}^{m_2=4} e_{a=2,l} = e_{Project\ Reconstrcuted\ Right\ Shoulder} = 6{,}562\ tons\ CO_2$ for area 2

$\sum_{l=i}^{m_3=4} e_{a=3,l} = e_{New\ Travel\ Lanes} = 10{,}771\ tons\ CO_2$ for area 3

$\sum_{l=i}^{m_4=4} e_{a=4,l} = e_{New\ Shoulder} = 11{,}216\ tons\ CO_2$ for area 4

The following sections detail calculations of (a) $e_{a=1} = e_{Project\ Reconstrcuted\ Travel\ Lanes}$, (b) $e_{a=2} = e_{Project\ Reconstrcuted\ Right\ Shoulder}$, (c) $e_{a=3} = e_{New\ Travel\ Lanes}$, and (d) $e_{a=4} = e_{New\ Shoulder}$.

In these sections:

1. As described in Section 4.1 of this document, HMA layer emissions are calculated using the emission rate for installing new roadways given in VM0039 Section 6, table 2, line 3:

$$e_{HMA\ Roadway} = 0.0947 \frac{lb\ CO2}{lb\ HMA\ mix}$$

2. Emission quantifications use the methods, variable names, and units (U.S.) from the Pave Next emission calculator app (pavenext.com). Only key and final emission values are shown in both U.S. units (tons) and metric units (t).

Area 1 of 4: Project Emissions of Reconstructed Travel Lanes

FDR reconstructed travel lane: 7.08 miles long and 12' wide existing two travel lanes on each side were completely rehabilitated using below design.

2" asphalt concrete SMA 12.5
2" asphalt concrete
6" cold central plant recycled mix (CCPRM)
2" drainage layer
12" full depth reclamation (FDR)

Project emissions of the reconstructed travel lanes equal the sum of emissions for each of four layers ($m_1 = 4$) according to the following equation:

$$e_{Project\ Reconstrcuted\ Travel\ Lanes} = \sum_{l=i}^{m_1=4} e_{a=1,l}$$

Given layers one through four consisting of

1. 2in HMA (SN 0.88; $w_{Layer\ 1}$ = 23,177 tons of mix)
2. 2in HMA (SN 0.88; $w_{Layer\ 2}$ = 23,177 tons of mix)
3. 6in CCPRM (SN 1.92; $w_{Layer\ 3}$ = 58,317 tons of mix)

4. 12 in FDR (SN 2.4; $w_{Layer\ 4}$ = 116,663 tons of mix)

Area 1 of 4, Layer 1 of 4: 2in HMA Surface

Project emissions for area one ($a = 1$) layer one ($l = 1$) come from the installation of HMA. These emissions are, therefore, calculated like conventional pavement as described in Section 6 of VM0039. They do not come from any carbon-saving methods.

$$e_{a=1,l=1} = w_{Layer\ 1} \cdot e_{HMA\ Roadway}$$

$$e_{a=1,l=1} = 46{,}354{,}176\ lb\ HMA\ mix\ *\ 0.0947 \frac{lb\ CO2}{lb\ HMA\ mix}\ =\ 2{,}204\ tons\ CO_2$$

Area 1 of 4, Layer 2 of 4: 2in HMA Binder

Project emissions for area one ($a = 1$) layer two ($l = 2$) come from the installation of HMA and are calculated in the same way as area one layer one is calculated above.

$$e_{a=1,l=2} = 2{,}204\ tons\ CO_2$$

Area 1 of 4, Layer 3 of 4: 6in FSB CCPRM

Project emissions for area one ($a = 1$) layer three ($l = 3$) equal

$$e_{a=1,l=3} = \sum_{s=1}^{5} e_{a=1,l=3,s}$$

$$e_{a=1,l=3} = 3{,}906\ tons\ CO_2$$

Where $e_{a=1,l=3,s}$ equals the emissions from activities described in Section 7.2.1 of VM0039 organized into the following five s sources:

1. Raw materials s=1
2. Raw material source to mix plant hauling s=2
3. Plant energy to create the mix s=3
4. Mix plant to job site hauling s=4
5. Installation equipment s=5

Given the area, thickness, and density for this layer given by the project plans and mix:

$a =\ 1{,}794{,}355.2\ ft^2$

$t = \frac{6}{12} ft$

$$\rho = 130 \frac{lb}{ft^3}$$

And given the following i raw material percentages, source to mix plant distances, and emission factors, used in the mix:

i	Raw Material	Mix Percentage $p_i \cdot 100\%$	Source to Mix Plant Distance d_i (mi)	Emission Factor $ef_i \frac{lb\ CO_2}{lb}$
1	RAP	85	0	0.85
2	Cement	1	145	0.01
3	Bitumen	2	87.5	0.02
4	Water	5	0	0.05
5	Manufactured Aggregates	7	45	0.07

Area 1 of 4, Layer 3 of 4, Source 1 of 5: Raw Materials

Raw material emissions equal the sum of emissions for each raw material. Raw material emissions are calculated as follows:

$$e_{a=1,l=3,s=1} = a \cdot t \cdot \rho_{layer} \cdot \sum(ef_i \cdot p_i \mid i)$$

$$e_{a=1,l=3,s=1} = 1794355.2 \cdot \frac{6}{12} \cdot 130 \cdot (0 \cdot 0.85 + 0.82 \cdot 0.01 + 0.48 \cdot 0.02 + 0 \cdot 0.05 + 0.006 \cdot 0.07)$$

$$e_{a=1,l=3,s=1} = 1{,}063\ tons\ CO_2$$

Area 1 of 4, Layer 3 of 4, Source 2 of 5: Raw Material Source to Mix Plant Hauling

Raw material source to mix plant hauling emissions equal the sum of hauling emissions for each raw material. Raw material source to mix plant hauling emissions are calculated as follows:

$$e_{a=1,l=3,s=2} = \sum(2d_i \cdot \lceil w_i / c_{truck} \rceil \mid i) \cdot e_{truck}$$

$$e_{a=1,l=3,s=2} = 2 \cdot 22.49 \left(0 \cdot \left\lceil \frac{99{,}138{,}124.8}{40{,}000} \right\rceil + 145 \cdot \left\lceil \frac{1{,}166{,}330.88}{40{,}000} \right\rceil + 87.5 \cdot \left\lceil \frac{2{,}332{,}661.76}{40{,}000} \right\rceil + 0 \cdot \left\lceil \frac{5{,}831{,}654.4}{40{,}000} \right\rceil + 45 \cdot \left\lceil \frac{8{,}164{,}316.16}{40{,}000} \right\rceil \right)$$

$$e_{a=1,l=3,s=2} = 421\ tons\ CO_2$$

Where the following truck emission factor and capacity are given by VM0039:

$$e_{truck} = 10.2 \frac{kg\ CO_2}{mi} = 22.5 \frac{lb\ CO_2}{mi}$$

$$c_{truck} = 20\ tons = 40{,}000\ lbs$$

Area 1 of 4, Layer 3 of 4, Source 3 of 5: Plant Energy to Create the Mix

Emissions created by the plant equal the ratio of the material produced for the layer to the material produced for the plant period, multiplied by the emissions produced by during the plant period.

$$e_{a=1,l=3,s=3} = \frac{w}{m} \cdot \sum(i)$$

$$e_{a=1,l=3,s=3} = \frac{116{,}633{,}088}{2{,}202{,}000} \cdot (22.51 \cdot 95)$$

$$e_{a=1,l=3,s=3} = 57\ tons\ CO_2$$

Where

w = weight of the layer (lb) calculated from a, t, and ρ

Area 1 of 4, Layer 3 of 4, Source 4 of 5: Mix Plant to Job Site Hauling

Mix plant to job site hauling emissions equal the distance trucks need to travel times the truck emission factor. The distance trucks need to travel depend on the number of trips, which depends on the layer mix weight and the truck capacity.

$$e_{a=1,l=3,s=4} = d \cdot n \cdot e_{truck}$$

$$e_{a=1,l=3,s=4} = d \cdot (2 \cdot \lceil \frac{w}{c_{truck}} \rceil) \cdot e_{truck}$$

$$e_{a=1,l=3,s=4} = 32.7 \cdot (2 \cdot \lceil \frac{116{,}633{,}088}{40{,}000} \rceil) \cdot 22.49$$

$$e_{a=1,l=3,s=4} = 2{,}144\ tons\ CO_2$$

Where

n = 2 trips

w = weight of the layer (lb) calculated from a, t, and ρ

Area 1 of 4, Layer 3 of 4, Source 5 of 5: Installation Equipment

Given installation equipment operating hours and emissions factors used to install this layer in the following table:

i	Installation Equipment	Equipment Emission Rate $er_i \left(\frac{lb\ CO_2}{hr}\right)$	Operating Hours $t_i\ (hr)$
1	Paver/Spreader	297	508

2	Rollers	287	508
3	Rollers	287	508

Emissions from installation equipment are calculated as follows:

$$e_{a=1,l=3,s=5} = \sum(er_i \cdot t_i)$$

$$e_{a=1,l=3,s=5} = 297 \cdot 508 + 286.6 \cdot 508 + 286.6 \cdot 508$$

$$e_{a=1,l=3,s=5} = 221\ tons\ CO_2$$

Where

$$er_i = emission\ rate\ of\ equipment\ i\ in\ \frac{lb\ CO_2}{hr}$$

$$t_i = service\ hours\ for\ equipment\ i\ in\ hr$$

Area 1 of 4, Layer 3 of 4: Source Summation

$$e_{a=1,l=3} = \sum_{s=1}^{5} e_{a=1,l=3,s}$$

$$e_{a=1,l=3} = 1{,}063 + 421 + 57 + 2{,}144 + 221 = 3{,}906\ tons\ CO_2$$

Area 1 of 4, Layer 4 of 4: 12in FDR FSB

Project emissions for area one ($a = 1$) layer four ($l = 4$) equal

$$e_{a=1,l=4} = \sum_{s=1}^{5} e_{a=1,l=4,s}$$

$$e_{a=1,l=4} = 4{,}315\ tons\ CO_2$$

Where $e_{a=1,l=4,s}$ equals the emissions from activates described in Section 7 of VM0039 organized into the following five s sources:

1. Raw materials s=1
2. Raw material source to mix plant hauling s=2
3. Plant energy to create the mix s=3
4. Mix plant to job site hauling s=4
5. Installation equipment s=5

Given the area, thickness, and density for this layer given by the project plans and mix design:

$$a = 1{,}794{,}355.2\ ft^2$$

$$t = \frac{12}{12} ft$$

$$\rho = 130 \frac{lb}{ft^3}$$

And given the following i raw material percentages, source to mix plant distances, and emission factors, used in the mix

i	Raw Material	Mix Percentage $p_i \cdot 100\%$	Source to Mix Plant Distance d_i (mi)	Emission Factor $ef_i\ \frac{lb\ CO_2}{lb}$
1	RAP	96	11	0.85
2	Cement	1	31	0.01
3	Bitumen	2	65	0.02
4	Water	1	0	0.05

Area 1 of 4, Layer 4 of 4, Source 1 of 5: Raw Materials

Raw material emissions equal the sum of emissions for each raw material. Raw material emissions are calculated as follows:

$$e_{a=1,l=4,s=1} = a \cdot t \cdot \rho_{layer} \cdot \sum(ef_i \cdot p_i \mid i)$$

$$e_{a=1,l=4,s=1} = 1{,}794{,}355.2 \cdot \frac{12}{12} \cdot 130 \cdot (0 \cdot 0.96 + 0.82 \cdot 0.01 + 0.48 \cdot 0.02 + 0 \cdot 0.01)$$

$$e_{a=1,l=4,s=1} = 2{,}076\ tons\ CO_2$$

Area 1 of 4, Layer 4 of 4, Source 2 of 5: Raw Material Source to Mix Plant Hauling

Raw material source to mix plant hauling emissions are equal to the sum of hauling emissions for each raw material. Raw material source to mix plant hauling emissions are calculated as follows:

$$e_{a=1,l=4,s=2} = \sum(2d_i \cdot \lceil w_i/c_{truck} \rceil \mid i) \cdot e_{truck}$$

$$e_{a=1,l=4,s=2} = 2 \cdot 22.49 \left(11 \cdot \lceil\frac{223{,}935{,}528.96}{40{,}000}\rceil + 31 \cdot \lceil\frac{2{,}332{,}661.76}{40{,}000}\rceil + 65 \cdot \lceil\frac{4{,}665{,}323.52}{40{,}000}\rceil + 0 \cdot \lceil\frac{2{,}332{,}661.76}{40{,}000}\rceil\right)$$

$$e_{a=1,l=4,s=2} = 1{,}597\ tons\ CO_2$$

Where the following truck emission factor and capacity are given by VM0039:

$e_{truck} = 10.2 \frac{kg\ CO_2}{mi} = 22.5 \frac{lb\ CO_2}{mi}$

$c_{truck} = 20\ tons = 40{,}000\ lbs$

Area 1 of 4, Layer 3 of 4, Source 3 of 5: Plant Energy to Create the Mix

Emissions created by the plant equal the ratio of the material produced for the layer to the material produced for the plant period, multiplied by the emissions produced by during the plant period.

$$e_{a=1,l=4,s=3} = \frac{w}{m} \cdot \sum(i)$$

$$e_{a=1,l=4,s=3} = \frac{233{,}266{,}176}{16{,}600{,}000} \cdot (22.51 \cdot 5)$$

$e_{a=1,l=4,s=3} = 1{,}581\ tons\ CO_2$

Where

w = weight of the layer (lb) calculated from a, t, and ρ

Area 1 of 4, Layer 4 of 4, Source 4 of 5: Mix Plant to Job Site Hauling

Mix plant to job site hauling emissions are equal to the distance trucks need to travel times the truck emission factor. The distance trucks need to travel depend on the number of trips, which depends on the layer mix weight and the truck capacity. For this layer the distance is zero due to no travel.

$$e_{a=1,l=4,s=4} = d \cdot n \cdot e_{truck}$$

$$e_{a=1,l=4,s=4} = d \cdot (2 \cdot \lceil \frac{w}{c_{truck}} \rceil) \cdot e_{truck}$$

$$e_{a=1,l=4,s=4} = 0 \cdot (2 \cdot \lceil \frac{233{,}266{,}176}{40{,}000} \rceil) \cdot 22.49$$

$$e_{a=1,l=4,s=4} = 0\ tons\ CO_2$$

Where

n = 2 trips

w = weight of the layer (lb) calculated from a, t, and ρ

Area 1 of 4, Layer 4 of 4, Source 5 of 5: Installation Equipment

Given installation equipment operating hours and emissions factors used to install this layer in the following table:

i	Installation Equipment	Equipment Emission Rate $er_i\left(\frac{lb\ CO_2}{hr}\right)$	Operating Hours $t_i\ (hr)$
1	Cold Recycler	1987	508
2	Rollers	287	508
3	Rollers	248	508

Emissions from installation equipment are calculated as follows:

$$e_{a=1,l=4,s=5} = \sum(er_i \cdot t_i)$$

$$e_{a=1,l=4,s=5} = 1{,}987.2 \cdot 508 + 286.6 \cdot 508 + 248.2 \cdot 508$$

$$e_{a=1,l=4,s=5} = 641\ tons\ CO_2$$

Where

$$er_i\ =\ emission\ rate\ of\ equipment\ i\ in\ \frac{lb\ CO_2}{hr}$$

$$t_i =\ service\ hours\ for\ equipment\ i\ in\ hr$$

Area 1 of 4, Layer 4 of 4: Source Summation

$$e_{a=1,l=4} = \sum_{s=1}^{5} \quad e_{a=1,l=4,s}$$

$$e_{a=1,l=4} = 2{,}076 + 1{,}597 + 1{,}581 + 0 + 641 = 4{,}315\ tons\ CO_2$$

B. Project Emissions of Reconstructed Right Shoulder

Area 2 of 4: Project Emissions of Reconstructed Right Shoulder

Area 2: FDR reconstructed right shoulder: 7.08 miles long and 12.5' wide in each direction; existing right shoulder was completely rehabilitated using below design.

2" asphalt concrete
2" asphalt concrete
6" cold central plant recycled mix (CCPRM)
2" drainage layer

12” full depth reclamation (FDR)

Project emissions of the reconstructed right shoulder equals the sum of emissions for each of four layers ($m_1 = 4$) according to the following equation:

$$e_{Project\ Reconstrcuted\ Right\ Shoulder} = \sum_{l=i}^{m_1=4} e_{a=2,l}$$

Given layers one through four (Appendix AMXXX) consisting of

1. 2in HMA (SN 0.88; $w_{Layer\ 1}$ = 12,071 tons of mix)
2. 2in HMA (SN 0.88; $w_{Layer\ 2}$ = 12,071 tons of mix)
3. 6in CCPRM (SN 1,92; $w_{Layer\ 3}$ = 30,373 tons of mix)
4. 12 in FDR (SN 2.4; $w_{Layer\ 4}$ = 60,746 tons of mix)

Area 2 of 4, Layer 1 of 4: 2in HMA Surface

Project emissions for area two ($a = 2$) layer one ($l = 1$) comes from the installation of HMA. These emissions are, therefore, calculated like conventional pavement as described in Section 6 of VM0039. They do not come from any carbon-saving methods.

$$e_{a=1,l=1} = w_{Layer\ 1} \cdot e_{HMA\ Roadway}$$

$$e_{a=1,l=1} = 24{,}142{,}800\ lb\ HMA\ mix\ *\ 0.0947 \frac{lb\ CO2}{lb\ HMA\ mix} = 1{,}148\ tons\ CO_2$$

Area 2 of 4, Layer 2 of 4: 2in HMA Binder

Project emissions for area two ($a = 2$) layer two ($l = 2$) are calculated in the same way that project emissions for area two layer one calculated, above.

$$e_{a=1,l=2} = 1{,}148\ tons\ CO_2$$

Area 2 of 4, Layer 3 of 4: 6in FSB CCPRM

Project emissions for area two ($a = 2$) layer three ($l = 3$) equal

$$e_{a=2,l=3} = \sum_{s=1}^{5} e_{a=2,l=3,s}$$

$$e_{a=2,l=3} = 2{,}032\ tons\ CO_2$$

Where $e_{a=2,l=3,s}$ equals the emissions from activates described in Section 7 of VM0039 organized into the following five s sources:

1. Raw materials s=1
2. Raw material source to mix plant hauling s=2
3. Plant energy to create the mix s=3
4. Mix plant to job site hauling s=4
5. Installation equipment s=5

Given the area, thickness, and density for this layer given by the project plans and mix design:

$$a = 934{,}560\ ft^2$$

$$t = \frac{6}{12} ft$$

$$\rho = 130 \frac{lb}{ft^3}$$

And given the following i raw material percentages, source to mix plant distances, and emission factors, used in the mix:

i	Raw Material	Mix Percentage $p_i \cdot 100\%$	Source to Mix Plant Distance d_i (mi)	Emission Factor $ef_i\ \frac{lb\ CO_2}{lb}$
1	RAP	85	0	0.85
2	Cement	1	145	0.01
3	Bitumen	2	87.5	0.02
4	Water	5	0	0.05
5	Manufactured Aggregates	7	45	0.07

Area 2 of 4, Layer 3 of 4, Source 1 of 5: Raw Materials

Raw material emissions equal the sum of emissions for each raw material. Raw material emissions are calculated as follows:

$$e_{a=2,l=3,s=1} = a \cdot t \cdot \rho_{layer} \cdot \sum(ef_i \cdot p_i \mid i)$$

$$e_{a=2,l=3,s=1} = 934{,}560 \cdot \frac{6}{12} \cdot 130 \cdot (0 \cdot 0.85 + 0.82 \cdot 0.01 + 0.48 \cdot 0.02 + 0 \cdot 0.05 + 0.006 \cdot 0.07)$$

$$e_{a=2,l=3,s=1} = 553\ tons\ CO_2$$

Area 2 of 4, Layer 3 of 4, Source 2 of 5: Raw Material Source to Mix Plant Hauling

Raw material source to mix plant hauling emissions equal the sum of hauling emissions for each raw material. Raw material source to mix plant hauling emissions are calculated as follows:

$$e_{a=2,l=3,s=2} = \sum(2d_i \cdot \lceil w_i/c_{truck} \rceil \mid i) \cdot e_{truck}$$

$$e_{a=2,l=3,s=2} = 2 \cdot 22.49 \left(0 \cdot \lceil\frac{51{,}634{,}440}{40{,}000}\rceil + 145 \cdot \lceil\frac{607{,}464}{40{,}000}\rceil + 87.5 \cdot \lceil\frac{1{,}214{,}928}{40{,}000}\rceil + 0 \cdot \lceil\frac{3{,}037{,}320}{40{,}000}\rceil + 45 \cdot \lceil\frac{4{,}252{,}248}{40{,}000}\rceil\right)$$

$$e_{a=2,l=3,s=2} = 221\ tons\ CO_2$$

Where the following truck emission factor and capacity are given by VM0039:

$$e_{truck} = 10.2 \frac{kg\ CO_2}{mi} = 22.5 \frac{lb\ CO_2}{mi}$$

$$c_{truck} = 20\ tons = 40{,}000\ lbs$$

Area 2 of 4, Layer 3 of 4, Source 3 of 5: Plant Energy to Create the Mix

Emissions created by the plant equal the ratio of the material produced for the layer to the material produced for the plant period, multiplied by the emissions produced by during the plant period.

$$e_{a=2,l=3,s=3} = \frac{w}{m} \cdot \sum(i)$$

$$e_{a=2,l=3,s=3} = \frac{60{,}746{,}400}{2{,}202{,}000} \cdot (22.51 \cdot 95)$$

$$e_{a=2,l=3,s=3} = 29\ tons\ CO_2$$

Where

w = weight of the layer (lb) calculated from a, t, and ρ

Area 2 of 4, Layer 3 of 4, Source 4 of 5: Mix Plant to Job Site Hauling

Mix plant to job site hauling emissions equal the distance trucks need to travel times the truck emission factor. The distance trucks need to travel depend on the number of trips, which depends on the layer mix weight and the truck capacity.

$$e_{a=2,l=3,s=4} = d \cdot n \cdot e_{truck}$$

$$e_{a=2,l=3,s=4} = d \cdot (2 \cdot \lceil\frac{w}{c_{truck}}\rceil) \cdot e_{truck}$$

$$e_{a=2,l=3,s=4} = 32.7 \cdot (2 \cdot \lceil\frac{60{,}746{,}400}{40{,}000}\rceil) \cdot 22.49$$

$$e_{a=2,l=3,s=4} = 1{,}117\ tons\ CO_2$$

Where

n = 2 trips

w = weight of the layer (lb) calculated from a, t, and ρ

Area 2 of 4, Layer 3 of 4, Source 5 of 5: Installation Equipment

Given installation equipment operating hours and emissions factors used to install this layer in the following table:

i	Installation Equipment	Equipment Emission Rate $er_i\left(\frac{lb\ CO_2}{hr}\right)$	Operating Hours $t_i\ (hr)$
1	Paver/Spreader	297	254
2	Rollers	287	254
3	Rollers	287	254

Emissions from installation equipment are calculated as follows:

$$e_{a=2,l=3,s=5} = \sum(er_i \cdot t_i)$$

$$e_{a=2,l=3,s=5} = 297 \cdot 254 + 286.6 \cdot 254 + 286.6 \cdot 254$$

$$e_{a=2,l=3,s=5} = 111\ tons\ CO_2$$

Where

$$er_i\ =\ emission\ rate\ of\ equipment\ i\ in\ \frac{lb\ CO_2}{hr}$$

$$t_i =\ service\ hours\ for\ equipment\ i\ in\ hr$$

Area 2 of 4, Layer 3 of 4: Source Summation

$$e_{a=2,l=3} = \sum_{s=1}^{5} e_{a=2,l=3,s}$$

$$e_{a=2,l=3} = 553 + 221 + 29 + 1{,}117 + 111 = 2{,}032\ tons\ CO_2$$

Area 2 of 4, Layer 4 of 4: 12in FDR FSB

Project emissions for area two ($a = 2$) layer four ($l = 4$) equal

$$e_{a=2,l=4} = \sum_{s=1}^{5} e_{a=2,l=4,s}$$

$$e_{a=2,l=4} = 2{,}234\ tons\ CO_2$$

Where $e_{a=2,l=4,s}$ equals the emissions from activates described in Section 7 of VM0039 organized into the following five s sources:

1. Raw materials s=1
2. Raw material source to mix plant hauling s=2
3. Plant energy to create the mix s=3
4. Mix plant to job site hauling s=4
5. Installation equipment s=5

Given the area, thickness, and density for this layer given by the project plans and mix design:

$$a = 934{,}560\ ft^2$$

$$t = \frac{12}{12} ft$$

$$\rho = 130 \frac{lb}{ft^3}$$

And given the following i raw material percentages, source to mix plant distances, and emission factors, used in the mix:

i	Raw Material	Mix Percentage $p_i \cdot 100\%$	Source to Mix Plant Distance d_i (mi)	Emission Factor ef_i $\frac{lb\ CO_2}{lb}$
1	RAP	96	11	0.85
2	Cement	1	31	0.01
3	Bitumen	2	65	0.02
4	Water	1	0	0.05

Area 2 of 4, Layer 4 of 4, Source 1 of 5: Raw Materials

Raw material emissions equal the sum of emissions for each raw material. Raw material emissions are calculated as follows:

$$e_{a=2,l=4,s=1} = a \cdot t \cdot \rho_{layer} \cdot \sum(ef_i \cdot p_i \mid i)$$

$$e_{a=2,l=4,s=1} = 934{,}560 \cdot \frac{12}{12} \cdot 130 \cdot (0 \cdot 0.96 + 0.82 \cdot 0.01 + 0.48 \cdot 0.02 + 0 \cdot 0.01)$$

$$e_{a=2,l=4,s=1} = 1{,}081\ tons\ CO_2$$

Area 2 of 4, Layer 4 of 4, Source 2 of 5: Raw Material Source to Mix Plant Hauling

Raw material source to mix plant hauling emissions equal the sum of hauling emissions for each raw material. Raw material source to mix plant hauling emissions are calculated as follows:

$$e_{a=2,l=4,s=2} = \sum(2d_i \cdot \lceil w_i / c_{truck} \rceil \mid i) \cdot e_{truck}$$

$$e_{a=2,l=4,s=2} = 2 \cdot 22.49 \left(11 \cdot \lceil \frac{116{,}633{,}088}{40{,}000} \rceil + 31 \cdot \lceil \frac{1{,}214{,}928}{40{,}000} \rceil + 65 \cdot \lceil \frac{2{,}429{,}856}{40{,}000} \rceil + 0 \cdot \lceil \frac{1{,}214{,}928}{40{,}000} \rceil \right)$$

$$e_{a=2,l=4,s=2} = 832\ tons\ CO_2$$

Where the following truck emission factor and capacity are given by VM0039:

$$e_{truck} = 10.2 \frac{kg\ CO_2}{mi} = 22.5 \frac{lb\ CO_2}{mi}$$

$$c_{truck} = 20\ tons = 40{,}000\ lbs$$

Area 2 of 4, Layer 3 of 4, Source 3 of 5: Plant Energy to Create the Mix

Emissions created by the plant equal the ratio of the material produced for the layer to the material produced for the plant period, multiplied by the emissions produced by during the plant period.

$$e_{a=2,l=4,s=3} = \frac{w}{m} \cdot \sum(i)$$

$$e_{a=2,l=4,s=3} = \frac{121{,}492{,}800}{16{,}600{,}000} \cdot (22.51 \cdot 5)$$

$$e_{a=2,l=4,s=3} = 823\ tons\ CO_2$$

Where

w = weight of the layer (lb) calculated from a, t, and ρ

Area 2 of 4, Layer 4 of 4, Source 4 of 5: Mix Plant to Job Site Hauling

Mix plant to job site hauling emissions equal the distance trucks need to travel times the truck emission factor. The distance trucks need to travel depend on the number of trips, which depends on the layer mix weight and the truck capacity. For this layer the distance is zero due to no travel.

$$e_{a=2,l=4,s=4} = d \cdot n \cdot e_{truck}$$

$$e_{a=2,l=4,s=4} = d \cdot (2 \cdot \lceil \frac{w}{c_{truck}} \rceil) \cdot e_{truck}$$

$$e_{a=2,l=4,s=4} = 0 \cdot (2 \cdot \lceil \frac{121{,}492{,}800}{40{,}000} \rceil) \cdot 22.49$$

$$e_{a=2,l=4,s=4} = 0 \; tons \; CO_2$$

Where

n = 2 trips

w = weight of the layer (lb) calculated from a, t, and ρ

Area 2 of 4, Layer 4 of 4, Source 5 of 5: Installation Equipment

Given installation equipment operating hours and emissions factors used to install this layer in the following table:

i	Installation Equipment	Equipment Emission Rate $er_i \left(\frac{lb\ CO_2}{hr}\right)$	Operating Hours $t_i\ (hr)$
1	Cold Recycler	1987	254
2	Rollers	287	254
3	Rollers	248	254

Emissions from installation equipment are calculated as follows:

$$e_{a=2,l=4,s=5} = \sum (er_i \cdot t_i)$$

$$e_{a=2,l=4,s=5} = 1{,}987.2 \cdot 254 + 286.6 \cdot 254 + 248.2 \cdot 254$$

$$e_{a=2,l=4,s=5} = 320 \; tons \; CO_2$$

Where

$$er_i = emission \; rate \; of \; equipment \; i \; in \; \frac{lb \; CO_2}{hr}$$

$$t_i = service \; hours \; for \; equipment \; i \; in \; hr$$

Area 2 of 4, Layer 4 of 4: Source Summation

$$e_{a=2,l=4} = \sum_{s=1}^{5} e_{a=2,l=4,s}$$

$$e_{a=2,l=4} = 1{,}081 + 832 + 823 + 0 + 320 = 2{,}234\ tons\ CO_2$$

C. Area 3 of 4: Project Emissions of New Travel Lanes with CTB

Area 3: New travel lanes with CTB: 7.08 miles long and 12' wide new travel lane was constructed in each direction to the left of existing travel lanes using the below design.

2" asphalt concrete SMA 12.5
2" asphalt concrete
6" cold central plant recycled mix (CCPRM)
2" drainage layer
12" cement treated base (CTB)

Project emissions of the new travel lanes equal the sum of emissions for each of four layers ($m_1 = 4$) according to the following equation:

$$e_{Project\ New\ Travel\ Lanes} = \sum_{l=i}^{m_1=4} e_{a=3,l}$$

Given layers one through four consisting of

1. 2in HMA (SN 0.88; $w_{Layer\ 1}$ = 11,589 tons of mix)
2. 2in HMA (SN 0.88; $w_{Layer\ 2}$ = 11,589 tons of mix)
3. 6in CCPRM (SN 1,92; $w_{Layer\ 3}$ = 29,158 tons of mix)
4. 12 in CTB (SN 2.4; $w_{Layer\ 4}$ = 69,531 tons of mix)

Area 3 of 4, Layer 1 of 4: 2in HMA Surface

Project emissions for area three ($a = 3$) layer one ($l = 1$) comes from the installation of HMA. These emissions are, therefore, calculated like conventional pavement as described in Section 6 of VM0039. They do not come from any carbon-saving methods.

$$e_{a=3,l=1} = w_{Layer\ 1} \cdot e_{HMA\ Roadway}$$

$$e_{a=3,l=1} = 243{,}177{,}088\ lb\ HMA\ mix\ *\ 0.0947 \frac{lb\ CO2}{lb\ HMA\ mix} = 1{,}102\ tons\ CO_2$$

Area 3 of 4, Layer 2 of 4: 2in HMA Binder

Project emissions for area three ($a = 3$) layer two ($l = 2$) are calculated in the same way that project emissions for area three layer one calculated, above.

$$e_{a=3,l=2} = 1{,}102\ tons\ CO_2$$

Area 3 of 4, Layer 3 of 4: 6in FSB CCPRM

Project emissions for area three ($a = 3$) layer three ($l = 3$) equal

$$e_{a=3,l=3} = \sum_{s=1}^{5} e_{a=3,l=3,s}$$

$$e_{a=3,l=3} = 1{,}954\ tons\ CO_2$$

Where $e_{a=3,l=3,s}$ equals the emissions from activates described in Section 7 of VM0039 organized into the following five s sources:

1. Raw materials s=1
2. Raw material source to mix plant hauling s=2
3. Plant energy to create the mix s=3
4. Mix plant to job site hauling s=4
5. Installation equipment s=5

Given the area, thickness, and density for this layer given by the project plans and mix design:

$$a = 897{,}177.6\ ft^2$$

$$t = \frac{6}{12} ft$$

$$\rho = 130 \frac{lb}{ft^3}$$

And given the following i raw material percentages, source to mix plant distances, and emission factors, used in the mix:

i	Raw Material	Mix Percentage $p_i \cdot 100\%$	Source to Mix Plant Distance d_i (mi)	Emission Factor $ef_i \frac{lb\ CO_2}{lb}$
1	RAP	85	0	0.85
2	Cement	1	145	0.01
3	Bitumen	2	87.5	0.02
4	Water	5	0	0.05
5	Manufactured Aggregates	7	45	0.07

Area 3 of 4, Layer 3 of 4, Source 1 of 5: Raw Materials

Raw material emissions equal the sum of emissions for each raw material. Raw material emissions are calculated as follows:

$$e_{a=3,l=3,s=1} = a \cdot t \cdot \rho_{layer} \cdot \sum(ef_i \cdot p_i \mid i)$$

$$e_{a=3,l=3,s=1} = 897{,}177.6 \cdot \frac{6}{12} \cdot 130 \cdot (0 \cdot 0.85 + 0.82 \cdot 0.01 + 0.48 \cdot 0.02 + 0 \cdot 0.05 + 0.006 \cdot 0.07)$$

$$e_{a=3\ ,l=3,s=1} = 551\ tons\ CO_2$$

Area 3 of 4, Layer 3 of 4, Source 2 of 5: Raw Material Source to Mix Plant Hauling

Raw material source to mix plant hauling emissions equal the sum of hauling emissions for each raw material. Raw material source to mix plant hauling emissions are calculated as follows:

$$e_{a=3,l=3,s=2} = \sum(2d_i \cdot \lceil w_i/c_{truck} \rceil \mid i) \cdot e_{truck}$$

$$e_{a=3,l=3,s=2} = 2 \cdot 22.49 \left(0 \cdot \left\lceil\frac{49{,}569{,}062.4}{40{,}000}\right\rceil + 145 \cdot \left\lceil\frac{583{,}165.44}{40{,}000}\right\rceil + 87.5 \cdot \left\lceil\frac{1{,}166{,}330.88}{40{,}000}\right\rceil + 0 \cdot \left\lceil\frac{2{,}915{,}827.2}{40{,}000}\right\rceil + 45 \cdot \left\lceil\frac{4{,}082{,}158.08}{40{,}000}\right\rceil\right)$$

$$e_{a=3,l=3,s=2} = 212\ tons\ CO_2$$

Where the following truck emission factor and capacity are given by VM0039:

$$e_{truck} = 10.2 \frac{kg\ CO_2}{mi} = 22.5 \frac{lb\ CO_2}{mi}$$

$$c_{truck} = 20\ tons = 40{,}000\ lbs$$

Area 3 of 4, Layer 3 of 4, Source 3 of 5: Plant Energy to Create the Mix

Emissions created by the plant equal the ratio of the material produced for the layer to the material produced for the plant period, multiplied by the emissions produced by during the plant period.

$$e_{a=3,l=3,s=3} = \frac{w}{m} \cdot \sum(i)$$

$$e_{a=3,l=3,s=3} = \frac{58{,}316{,}544}{2{,}202{,}000} \cdot (22.51 \cdot 95)$$

$$e_{a=3,l=3,s=3} = 28\ tons\ CO_2$$

Where

w = weight of the layer (lb) calculated from a, t, and ρ

Area 3 of 4, Layer 3 of 4, Source 4 of 5: Mix Plant to Job Site Hauling

Mix plant to job site hauling emissions equal the distance trucks need to travel times the truck emission factor. The distance trucks need to travel depend on the number of trips, which depends on the layer mix weight and the truck capacity.

$$e_{a=3,l=3,s=4} = d \cdot n \cdot e_{truck}$$

$$e_{a=3,l=3,s=4} = d \cdot (2 \cdot \lceil\frac{w}{c_{truck}}\rceil) \cdot e_{truck}$$

$$e_{a=3,l=3,s=4} = 32.7 \cdot (2 \cdot \lceil\frac{58{,}316{,}544}{40{,}000}\rceil) \cdot 22.49$$

$$e_{a=3,l=3,s=4} = 1{,}072\ tons\ CO_2$$

Where

n = 2 trips

w = weight of the layer (lb) calculated from a, t, and ρ

Area 3 of 4, Layer 3 of 4, Source 5 of 5: Installation Equipment

Given installation equipment operating hours and emissions factors used to install this layer in the following table:

i	Installation Equipment	Equipment Emission Rate $er_i\left(\frac{lb\ CO_2}{hr}\right)$	Operating Hours $t_i\ (hr)$
1	Paver/Spreader	297	254
2	Rollers	287	254
3	Rollers	287	254

Emissions from installation equipment are calculated as follows:

$$e_{a=3,l=3,s=5} = \sum(er_i \cdot t_i)$$

$$e_{a=3,l=3,s=5} = 297 \cdot 254 + 286.6 \cdot 254 + 286.6 \cdot 254$$

$$e_{a=3,l=3,s=5} = 111\ tons\ CO_2$$

Where

$$er_i\ =\ emission\ rate\ of\ equipment\ i\ in\ \frac{lb\ CO_2}{hr}$$

$$t_i =\ service\ hours\ for\ equipment\ i\ in\ hr$$

Area 3 of 4, Layer 3 of 4: Source Summation

$$e_{a=3,l=3} = \sum_{s=1}^{5}\quad e_{a=3,l=3,s}$$

$$e_{a=3,l=3} = 531 + 212 + 28 + 1{,}072 + 111 = 1{,}954\ tons\ CO_2$$

Area 3 of 4, Layer 4 of 4: 12in CTB

Project emissions for area three ($a = 3$) layer four ($l = 4$) comes from the installation of CTB. These emissions are, therefore, calculated like conventional pavement as described in Section 6 of VM0039. They do not come from any carbon-saving methods.

$$e_{a=3,l=1} = w_{Layer\ 1} \cdot e_{HMA\ Roadway}$$

$$e_{a=3,l=1} = 23{,}177{,}088\ lb\ of HMA\ \ mix\ *\ 0.0947\frac{lb\ CO2}{lb\ HMA\ mix}\ =\ 1{,}102\ tons\ CO_2$$

D. Area 4 of 4: Project Emissions of New Shoulder with CTB

Area 4: New shoulder with CTB: 7.08 miles long and 12.5' wide new shoulder was constructed to the left of newly added travel lane on each direction with below design.

2" asphalt concrete SMA 12.5
2" asphalt concrete
6" cold central plant recycled mix (CCPRM)
2" drainage layer
12" cement treated base (CTB)

Project emissions of the new shoulder equals the sum of emissions for each of four layers ($m_1 = 4$) according to the following equation:

$$e_{Project\ New\ Shoulder} = \sum_{l=i}^{m_1=4} e_{a=4,l}$$

Given layers one through four (Appendix AMXXX) consisting of

1. 2in HMA (SN 0.88; $w_{Layer\ 1}$ = 12,071 tons of mix)
2. 2in HMA (SN 0.88; $w_{Layer\ 2}$ = 12,071 tons of mix)
3. 6in CCPRM (SN 1,92; $w_{Layer\ 3}$ = 30,373 tons of mix)
4. 12 in CTB (SN 2.4; $w_{Layer\ 4}$ = 72,428 tons of mix)

Area 4 of 4, Layer 1 of 4: 2in HMA Surface

Project emissions for area four ($a = 4$) layer one ($l = 1$) comes from the installation of HMA. These emissions are, therefore, calculated like conventional pavement as described in Section 6 of VM0039. They do not come from any carbon-saving methods.

$$e_{a=4,l=1} = w_{Layer\ 1} \cdot e_{HMA\ Roadway}$$

$$e_{a=4,l=1} = 24{,}142{,}800\ lb\ HMA\ mix\ *\ 0.0947 \frac{lb\ CO2}{lb\ HMA\ mix} = 1{,}148\ tons\ CO_2$$

Area 4 of 4, Layer 2 of 4: 2in HMA Binder

Project emissions for area four ($a = 4$) layer two ($l = 2$) are calculated in the same way that project emissions for area four layer one calculated, above.

$$e_{a=4,l=2} = 1{,}148\ tons\ CO_2$$

Area 4 of 4, Layer 3 of 4: 6in FSB CCPRM

Project emissions for area four ($a = 4$) layer three ($l = 3$) equal

$$e_{a=4,l=3} = \sum_{s=1}^{5} e_{a=4,l=3,s}$$

$$e_{a=4,l=3} = 1{,}954\ tons\ CO_2$$

Where $e_{a=4,l=3,s}$ equals the emissions from activates described in Section 7 of VM0039 organized into the following five s sources:

1. Raw materials s=1
2. Raw material source to mix plant hauling s=2
3. Plant energy to create the mix s=3
4. Mix plant to job site hauling s=4
5. Installation equipment s=5

Given the area, thickness, and density for this layer given by the project plans and mix design:

$$a = 934{,}560\ ft^2$$

$$t = \frac{6}{12} ft$$

$$\rho = 130 \frac{lb}{ft^3}$$

And given the following i raw material percentages, source to mix plant distances, and emission factors, used in the mix:

i	Raw Material	Mix Percentage $p_i \cdot 100\%$	Source to Mix Plant Distance d_i (mi)	Emission Factor $ef_i\ \frac{lb\ CO_2}{lb}$
1	RAP	85	0	0.85
2	Cement	1	145	0.01
3	Bitumen	2	87.5	0.02
4	Water	5	0	0.05
5	Manufactured Aggregates	7	45	0.07

Area 4 of 4, Layer 3 of 4, Source 1 of 5: Raw Materials

Raw material emissions equal the sum of emissions for each raw material. Raw material emissions are calculated as follows:

$$e_{a=4,l=3,s=1} = a \cdot t \cdot \rho_{layer} \cdot \sum(ef_i \cdot p_i \mid i)$$

$$e_{a=4,l=3,s=1} = 934{,}560 \cdot \frac{6}{12} \cdot 130 \cdot (0 \cdot 0.85 + 0.82 \cdot 0.01 + 0.48 \cdot 0.02 + 0 \cdot 0.05 + 0.006 \cdot 0.07)$$

$$e_{a=4,l=3,s=1} = 553\ tons\ CO_2$$

Area 4 of 4, Layer 3 of 4, Source 2 of 5: Raw Material Source to Mix Plant Hauling

Raw material source to mix plant hauling emissions equal the sum of hauling emissions for each raw material. Raw material source to mix plant hauling emissions are calculated as follows:

$$e_{a=4,l=3,s=2} = \sum(2d_i \cdot \lceil w_i / c_{truck} \rceil \mid i) \cdot e_{truck}$$

$$e_{a=4,l=3,s=2} = 2 \cdot 22.49 \left(0 \cdot \lceil \frac{51{,}634{,}440}{40{,}000} \rceil + 145 \cdot \lceil \frac{607{,}464}{40{,}000} \rceil + 87.5 \cdot \lceil \frac{1{,}214{,}928}{40{,}000} \rceil + 0 \cdot \lceil \frac{3{,}037{,}320}{40{,}000} \rceil + 45 \cdot \lceil \frac{4{,}252{,}248}{40{,}000} \rceil \right)$$

$$e_{a=4,l=3,s=2} = 221\ tons\ CO_2$$

Where the following truck emission factor and capacity are given by VM0039:

$$e_{truck} = 10.2 \frac{kg\ CO_2}{mi} = 22.5 \frac{lb\ CO_2}{mi}$$

$$c_{truck} = 20\ tons = 40{,}000\ lbs$$

Area 4 of 4, Layer 3 of 4, Source 3 of 5: Plant Energy to Create the Mix

Emissions created by the plant equal the ratio of the material produced for the layer to the material produced for the plant period, multiplied by the emissions produced by during the plant period.

$$e_{a=4,l=3,s=3} = \frac{w}{m} \cdot \sum(i)$$

$$e_{a=4,l=3,s=3} = \frac{60{,}746{,}400}{2{,}202{,}000} \cdot (22.51 \cdot 95)$$

$$e_{a=4,l=3,s=3} = 29\ tons\ CO_2$$

Where

w = weight of the layer (lb) calculated from a, t, and ρ

Area 4 of 4, Layer 3 of 4, Source 4 of 5: Mix Plant to Job Site Hauling

Mix plant to job site hauling emissions equal the distance trucks need to travel times the truck emission factor. The distance trucks need to travel depend on the number of trips, which depends on the layer mix weight and the truck capacity.

$$e_{a=4,l=3,s=4} = d \cdot n \cdot e_{truck}$$

$$e_{a=4,l=3,s=4} = d \cdot (2 \cdot \lceil \frac{w}{c_{truck}} \rceil) \cdot e_{truck}$$

$$e_{a=4,l=3,s=4} = 32.7 \cdot (2 \cdot \lceil \frac{60{,}746{,}400}{40{,}000} \rceil) \cdot 22.49$$

$$e_{a=4,l=3,s=4} = 1{,}117\ tons\ CO_2$$

Where

n = 2 trips

w = weight of the layer (lb) calculated from a, t, and ρ

Area 4 of 4, Layer 3 of 4, Source 5 of 5: Installation Equipment

Given installation equipment operating hours and emissions factors used to install this layer in the following table:

i	Installation Equipment	Equipment Emission Rate $er_i\left(\frac{lb\ CO_2}{hr}\right)$	Operating Hours $t_i\ (hr)$
1	Paver/Spreader	297	254
2	Rollers	287	254
3	Rollers	287	254

Emissions from installation equipment are calculated as follows:

$$e_{a=4,l=3,s=5} = \sum(er_i \cdot t_i)$$

$$e_{a=4,l=3,s=5} = 297 \cdot 254 + 286.6 \cdot 254 + 286.6 \cdot 254$$

$$e_{a=4,l=3,s=5} = 111\ tons\ CO_2$$

Where

$$er_i\ =\ emission\ rate\ of\ equipment\ i\ in\ \frac{lb\ CO_2}{hr}$$

$$t_i =\ service\ hours\ for\ equipment\ i\ in\ hr$$

Area 4 of 4, Layer 3 of 4: Source Summation

$$e_{a=4,l=3} = \sum_{s=1}^{5} e_{a=4,l=3,s}$$

$$e_{a=4,l=3} = 553 + 221 + 29 + 1{,}117 + 111 = 2{,}032\ tons\ CO_2$$

Area 4 of 4, Layer 4 of 4: 12in CTB

Project emissions for area four ($a = 4$) layer four ($l = 4$) comes from the installation of CTB. These emissions are, therefore, calculated like conventional pavement as described in Section 6 of VM0039. They do not come from any carbon-saving methods.

$$e_{a=4,l=1} = w_{Layer\ 1} \cdot e_{HMA\ Roadway}$$

$$e_{a=4,l=1} = 144{,}856{,}800\ lb\ of HMA\ \ mix\ *\ 0.0947 \frac{lb\ CO2}{lb\ HMA\ mix}\ =\ 6{,}888\ tons\ CO_2$$

4.3 Leakage

There is no leakage. As described in the project methodology VM0039: "Leakage is not considered an issue under this methodology and is therefore set at zero. 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."

4.4 Estimated Net GHG Emission Reductions and Removals

The net CO_2 emission reductions equal the emissions of the conventional baseline project quantified in Section 4.1 minus the emissions of the sustainable project quantified in Section 4.2 above which equals 14,170.5 tons of CO_2 or 9,460.1 tCO_2e. This total was calculated based on the following equations:

$$e_{Baseline} =\ 55{,}347.8\ tons\ CO_2 = 50{,}224.9\ tonnes\ CO_2$$

$$e_{Project} = 41{,}177\ tons\ CO_2 =\ 37{,}366\ tonnes\ CO_2$$

$$e_{Reduction} = 50{,}224.9\ tonnes\ CO_2 -\ 37{,}366\ tonnes\ CO_2 = 12{,}858.9\ tonnes\ CO_2$$

5 MONITORING

5.1 Data and Parameters Available at Validation

5.1.1 Parameters Available at Validation for HMA and CCPR

Data / Parameter	EF_M
Data unit	kgCO2e/kg
Description	Material emission factor
Source of data	CMUGDI (2008)
Value applied:	RAP: 0 Cement: 0.82 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	kgCO2e/mile
Description	Truck's emission per mile travelled

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	kgCO2e/hr
Description	Equipment emissions per hour
Source of data	EPA (2012). "Engine Certification Data for Heavy Truck, Buses, and Engines."<http://www.epa.gov/oms/certdata.htm#largeng>.
Value applied:	Paver/Spreader - Caterpillar, 8~15 ft: 134.7 Kg CO2e/hr Roller – Caterpillar, >10t: 130 Kg CO2e/hr
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 of the methodology
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	CF

Data unit	Between 0 and 1
Description	Conversion factor: the percentage of equipment operating time in the total labor time
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 PUs 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	N/A

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.
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

5.1.2 Parameters Available at Validation for FDR

Data / Parameter	EF_T
Data unit	kgCO2e/mile
Description	Truck's emission per mile travelled
Source of data	TCR (2015)
Value applied:	10.2 kgCO2e/mile
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 FDR delivery emissions
Comments	Data to be updated when the diesel emissions factor is updated

Data / Parameter	EF_M

Data unit	kgCO2e/kg
Description	Material emission factor
Source of data	CMUGDI (2008)
Value applied:	RAP: 0 Cement: 0.82 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	kgCO2e/hr
Description	Equipment emission per hour
Source of data	EPA (2012). "Engine Certification Data for Heavy Truck, Buses, and Engines."<http://www.epa.gov/oms/certdata.htm#largeng>.
Value applied:	Cold Recycler, Wirtgen, 12': 901.4 Kg CO2e/hr Roller, Caterpillar, >10t: 130.0 Kg CO2e/hr Roller, Other, >10t: 112.58 Kg CO2e/hr
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

5.2 Data and Parameters Monitored

5.2.1 Data and Parameters Monitored for HMA and CCPR

Data and parameters determined or available at validation are included in Section 5.1 (Data and Parameters Available at Validation) above.

Data / Parameter	W_M
Data unit	Kg
Description	Quantity of each raw material used to produce HMA or FSB or asphalt emulsions
Source of data	CCPR Mix tickets, project limits, material density
Description of measurement methods and procedures applied	The CCPR asphalt mix ticket provides the quantities by percentage used for each raw material. Those quantities are multiplied by the total CCPR mix produced. Allan Myers uses an internal system to track the daily production of CCPR asphalt mix produced.
Frequency of monitoring/recording	Once per project instance
Value applied:	RAP: 114,294,391 Kg Cement: 1,344,640 Kg Bitumen: 2,689,280 Kg Water: 6,723,199 Kg Crushed Rock: 0 Kg Sand: 0 Kg Manufactured Aggregate: 9,412,479 Kg
Monitoring equipment	None

QA/QC procedures applied	
Purpose of data	Calculation of HMA material emissions Calculation of CCPR material emissions
Calculation method	Quantity percentage of each raw material multiplied by total weight of mix produced.
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 The total miles that trucks travelled to bring milled asphalt from the existing road to the plant for stockpiling.
Source of data	Data derived from monitoring, supplied by Allan Myers
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
Value applied	95,735 Miles
Monitoring equipment	Distance from supplier to asphalt plant measured using online mapping software
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 emissions
Calculation method	Summation of total miles traveled
Comments	

Data / Parameter	Distances
Data unit	Miles
Description	The total miles that trucks travelled to supply products to the job site
Source of data	Data derived from monitoring, supplied by Allan Myers
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
Value applied	484,683 Miles
Monitoring equipment	Distance from the asphalt plant to the job site measured using online mapping software
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
Calculation method	Summation of total miles traveled
Comments	

Data / Parameter	Project amount
Data unit	t
Description	Output quantity of HMA, FSB and asphalt emulsions
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. The data obtained from plant production records for the project instance. Allan Myers uses an internal system software to track the daily in plant production of CCPR and HMA asphalt mix produced.
Frequency of monitoring/recording	Once per project
Value applied	

	CCPR = 134,502 tonnes, HMA = 235,730 tonnes
Monitoring equipment	Allan Myers' internal system software
QA/QC procedures to be applied	Cross-checking of reported amount versus production logs to confirm quality measurement.
Purpose of data	Calculation of HMA emissions Calculation of CCPR emissions
Calculation method	N/A
Comments	

Data / Parameter	HR_{EQ}
Data unit	Hour
Description	Total operating hours of on-site use of equipment
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. Allan Myer equipment use data.
Frequency of monitoring/recording	Once per project
Value applied	Paver/Spreader - Caterpillar, 8~15 ft: 1,270 hours Roller – Caterpillar, >10t: 2,540 hours
Monitoring equipment	Allan Myer print outs of internal time keeping data.
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
Calculation method	N/A
Comments	N/A

Data / Parameter	HR_{LA}
Data unit	Hour
Description	Total labor hours of on-site use of equipment
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Allan Myer time keeping data. Labor hours can be obtained from the daily reports of contractors.
Frequency of monitoring/recording	Once per project
Value applied	Total labor hours for duration of the project instance
Monitoring equipment	Allan Myer time keeping data.
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
Calculation method	N/A
Comments	

Data / Parameter	DE
Data unit	lb/cu.ft
Description	Density of FSB or asphalt emulsions
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Density data can be obtained from project specifications Asphalt mix tickets and design specification
Frequency of monitoring/recording	Once per project

Value applied	130 lb/cu. ft
Monitoring equipment	
QA/QC procedures to be applied	Cross-checking of reported data versus theoretical density to confirm quality measurement.
Purpose of data	Calculation of CCPR emissions and emissions reduction
Calculation method	
Comments	

Data / Parameter	LC
Data unit	
Description	Layer coefficient of FSB or asphalt emulsions
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
Value applied	0.32
Monitoring equipment	
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 emissions and emissions reduction
Calculation method	
Comments	

5.2.2 Data and Parameters Monitored for FDR

Data / Parameter	W_M
Data unit	Kg
Description	The weight of each raw material used to produce FSB or asphalt emulsions
Source of data	FDR raw material quantities, project limits, material density
Description of measurement methods and procedures applied	The project instance raw material quantities were provided by Allan Myers. Those quantities are multiplied by the total FDR mix produced. Allan Myers uses an internal system to track the daily production of FDR asphalt mix produced.
Frequency of monitoring/recording	Once per project instance
Value applied:	RAP: 154,479,085 Kg Cement: 1,609,157 Kg Bitumen: 3,218,314 Kg Water: 1,609,157 Kg Crushed Rock: 0 Kg Sand: 0 Kg Manufactured Aggregates: 0 Kg
Monitoring equipment	
QA/QC procedures applied	
Purpose of data	Calculation of FDR material emissions
Calculation method	Quantity percentage of each raw material multiplied by total weight of mix produced.
Comments	

Data / Parameter	Project amount

Data unit	t
Description	Output quantity of FSB and asphalt emulsions
Source of data	project limits, FDR density
Description of measurement methods and procedures to be applied	Data can be reported according to plant production records. The data obtained from plant production records for the project instance. Allan Myers uses an internal system software to track the daily in plant production of FDR asphalt mix produced.
Frequency of monitoring/recording	Once per project
Value applied	177,379 tonnes
Monitoring equipment	Allan Myers' internal system software
QA/QC procedures to be applied	Cross-checking of reported amount versus production logs to confirm quality measurement.
Purpose of data	Calculation of FDR emissions
Calculation method	
Comments	

Data / Parameter	L
Data unit	Miles
Description	Length of damaged pavement
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Data obtained from project records – Design Plans, Typical Pavement Sections
Frequency of monitoring/recording	Once per project
Value applied	7.08 Miles
Monitoring equipment	

QA/QC procedures to be applied	Cross-checking of reported mileage versus map distances to confirm quality measurement.
Purpose of data	Calculation of FDR emissions and emissions reduction
Calculation method	N/A
Comments	

Data / Parameter	Distance
Data unit	Miles
Description	The total miles that trucks travelled to supply raw materials to the job site
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
Value applied	216,050 Miles
Monitoring equipment	Distance that trucks travelled to supply raw materials to the job site measured using online mapping software
QA/QC procedures to be applied	Cross-checking of reported mileage versus trucking manifests to confirm quality measurement.
Purpose of data	Calculation of FDR to-site delivery emission
Calculation method	Summation of total miles traveled
Comments	

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

Source of data	Data derived through monitoring project site
Description of measurement methods and procedures to be applied	Data can be obtained from project records. Allan Myer equipment use data.
Frequency of monitoring/recording	Once per project
Value applied	Total operating hours for duration of the project instance.
Monitoring equipment	Allan Myer print outs of internal time keeping data.
QA/QC procedures to be applied	Cross-checking of reported speed versus driver's log to confirm quality measurement.
Purpose of data	Calculation of FDR equipment emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	DE
Data unit	lb/cu.ft
Description	Density of FSB or asphalt emulsions
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
Value applied	130 lb/cu. ft
Monitoring equipment	
QA/QC procedures to be applied	Cross-checking of reported data versus theoretical density to confirm quality measurement.
Purpose of data	Calculation of FDR emissions and emissions reduction

Calculation method	
Comments	

Data / Parameter	LC
Data unit	
Description	Layer coefficient of FSB or asphalt emulsions
Source of data	Data derived from monitoring
Description of measurement methods and procedures to be applied	Layer coefficient obtained from project specifications provided by Allan Myers
Frequency of monitoring/recording	Once per project
Value applied	0.2
Monitoring equipment	
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 FDR emissions and emissions reduction
Calculation method	
Comments	

5.3 Monitoring Plan

The monitoring plan involves detailing the procedures for collecting and reporting all data and parameters listed in Section 5.2. Monitored data and parameters will depend on the baseline, the materials used (FSB or asphalt emulsions), and the process used (CCPR, CIR, or FDR) for the calculations. The project proponents monitoring plan consists of the collection of project data relating to travel distances, energy and equipment usage, quantity of asphalt materials produced; asphalt material composition; and equipment type and usage. The project proponent provides a spreadsheet that can be filled out by the asphalt contractors and access to a web based protected folder for uploading all project documentation. The project proponent reviews data for 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. Project data requested for quantifying and reporting GHG emissions are typical of the data that asphalt contractors are required to monitor, collect, and have on hand as part of any asphalt installation project. Therefore, specialized measurements or data procedures are not anticipated.

For the first project instance, project data collection was achieved by obtaining project documents from the asphalt contractor in electronic format. The data required for the calculation of net carbon emissions reductions were collected by the asphalt contractor in electronic form through the asphalt contractor's internal software system or as electronic copies of design documentation (Design files, asphalt mix tickets). The asphalt contractor personnel are responsible for collecting data monitored at the asphalt production facility and at the construction site.

The asphalt contractor provided the project QA/QC plan which was required, reviewed, and approved by VDOT.

The asphalt mix composition undergoes through testing before and during its production and before, during, and after it is installed

All project data inputs were reviewed by the project proponent, and as stated previously, in cases where data was unknown, conservative estimates were applied. Project data values were input into the project proponent's proprietary software PaveNext Application which performs the GHG quantification equations present in the methodology.

6 ACHIEVED GHG EMISSION REDUCTIONS AND REMOVALS

6.1 Data and Parameters Monitored

Complete the table below for all data and parameters monitored during the monitoring period (copy the table as necessary for each data/parameter). The values provided are used to quantify actual GHG emissions and removals achieved for the monitoring period. Data and parameters determined or available at validation which remain fixed throughout the project crediting period are included in Section 5.1 (Data and Parameters Available at Validation) above.

Data / Parameter	
Data unit	*Indicate the unit of measure*
Description	*Provide a brief description of the data/parameter*
Value applied:	*Provide the monitored value for the data/parameter*
Comments	*Provide any additional comments*

6.2 Baseline Emissions

Quantify the baseline emissions and/or removals for this monitoring period, providing sufficient information to allow the reader to reproduce the calculation. Attach electronic spreadsheets as an appendix or separate file to facilitate the verification of the results.

6.3 Project Emissions

Quantify project emissions and/or removals for this monitoring period, providing sufficient information to allow the reader to reproduce the calculation. Attach electronic spreadsheets as an appendix or separate file to facilitate the verification of the results.

6.4 Leakage

Quantify leakage emissions for this monitoring period, providing sufficient information to allow the reader to reproduce the calculation. Attach electronic spreadsheets as an appendix or separate file to facilitate the verification of the results.

6.5 Net GHG Emission Reductions and Removals

Quantify the net GHG emission reductions and removals achieved for this monitoring period, summarizing the key results using the table below. Specify breakdown of GHG emission reductions and removals by vintages where the intent is to issue each vintage separately in the VCS registry system.

For non-AFOLU projects, use the following table:

Year	Baseline emissions or removals (tCO_2e)	Project emissions or removals (tCO_2e)	Leakage emissions (tCO_2e)	Net GHG emission reductions or removals (tCO_2e)
Year A				
Year…				
Total				

APPENDIX X: <TITLE OF APPENDIX>

Use appendices for supporting information. Delete this appendix (title and instructions) where no appendix is required.