2020 National Emissions Inventory Technical Support Document: Solvents – Consumer and Commercial: Asphalt Paving

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U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
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31.1 Sector Descriptions and Overview

Liquid asphalt is a petroleum-derived substance used in paving applications, such as the construction of roads, parking lots, driveways, and airport runways, as well as non-paving applications, such as the manufacturing of roofing shingles. While liquid asphalt can be found in natural deposits, most is produced from crude oil. Vacuum distillation separates components of crude oil based on boiling point. Products generated from this process include naptha, gasoline, diesel, and liquid asphalt, the last of which has a boiling point greater than 500 °C. As a result, most volatile, light fractions of organics are separated from liquid asphalt during distillation and prior to use.

In paving applications, liquid asphalt can be applied cold or heated. If applied cold, additional components must be added to lower the viscosity of the material, which allows it to be spread upon a surface (e.g., roadway surface). Cutback asphalt (SCC: 2461021000) is a cold application process that involves mixing the liquid asphalt with petroleum solvents (e.g., naphtha, kerosene, fuel oil, diesel, etc.). Following application, these higher volatility solvents evaporate, leaving the asphalt in place. Due to this increased organic emissions potential, cutback asphalts have grown less common over time and this process now constitutes ~1% of liquid asphalt is use [ref 1]. Emulsified asphalt (SCC: 2461022000) is a separate cold application process that utilizes water-based solvents and an emulsifying agent. The result is a stable liquid suspension with asphalt globules. Following application, the additives evaporate and leave the asphalt in place. In contrast to cutback asphalts, emulsified asphalts have become more common in recent years and ~10% of liquid asphalt is now used in these applications.

Liquid asphalt can also be applied heated, which both lowers the viscosity of the material and minimizes the need for added solvents. Hot-mix asphalt application (SCC: 2461025100), which is the traditional method for asphalt pavement production, involves combining the liquid asphalt with aggregate at a hot-mix plant and heating the mixture to +150 °C. The mixture is then hauled to the usage site heated, where it is placed, compacted, and ambiently cooled. This process does not require any solvent additions. Warm-mix asphalt application (SCC: 2461025200) is a more recent technology that enables asphalt pavement production to occur at 20 – 40 °C cooler temperatures than hot-mix asphalt application. Warm-mix asphalt applications at reduced temperatures now constitute ~18% of asphalt paving applications [ref 2]. These lower production temperatures promote energy savings through reductions in fuel use and lower emissions at the hot-mix plant. To reduce the viscosity of the liquid asphalt in warm-mix applications, water, water-bearing minerals, chemicals, waxes, organic additives, or a combination of technologies must be added [ref 3].

While heated applications processes represent most liquid asphalt paving applications, it has historically been assumed that emissions were sparse due to the removal of the more volatile organics during distillation. Recent research has demonstrated that less volatile organic vapors from liquid asphalt do evaporate at temperatures associated with hot-mix application (~140 °C), warm-mix application (120 °C), and post-application, or "in-use" temperatures [ref 4]. Emission during the "in-use" period diffuse from the pavement over time following application. Starting with the 2020 NEI, EPA will estimate emissions from cutback, emulsified, hot-mix and warm-mix asphalt use.

The table below notes all SCCs covered in this source category and the SCCs for which the EPA generates default emissions.

Table 31-1: Asphalt Paving SCCs in the 2020 NEI

SCC	SCC Level 1	SCC Level 2	SCC Level 3	SCC Level 4	EPA
2461021000	Solvent Utilization	Misc Non-industrial: Commercial	Cutback Asphalt	Total: All Solvent Types	X
2461022000	Solvent Utilization	Misc Non-industrial: Commercial	Emulsified Asphalt	Total: All Solvent Types	X
2461025000	Solvent Utilization	Miscellaneous Non-industrial: Commercial	Asphalt Paving: Hot and Warm-mix	Hot and Warm-mix Total: All Solvent Types	
2461025100	Solvent Utilization	Miscellaneous Non-industrial: Commercial	Asphalt Paving: Hot and Warm-mix	Hot-mix Total: All Solvent Types	X
2461025200	Solvent Utilization	Miscellaneous Non-industrial: Commercial	Asphalt Paving: Hot and Warm-mix	Warm-mix Total: All Solvent Types	X
2461026000	Solvent Utilization	Miscellaneous Non-industrial: Commercial	Asphalt Paving: Road Oil	Total: All Solvent Types	

31.2 EPA-developed estimates

Usage of liquid asphalt at the state-level for each process is calculated and subsequently allocated to the county-level using estimated vehicle miles traveled on paved roads. Emission factors consider both application and in-use processes. Net county-level emissions are quantified by multiplying the SCC-specific liquid asphalt usage by SCC-specific emission factors. The sources of data, calculation of state-level, SCC-specific usage results, allocation of state-level usage to the county-level, emission factors, and emission estimates are all discussed in subsequent sections.

31.2.1 Activity Data

Activity data for these sources are the amount of liquid asphalt used in each process. Each year, the Asphalt Institute releases an asphalt usage survey for the Unites States and Canada that reflects usage among their membership [ref 1]. The Asphalt Institute estimates that their membership captures 90% of the United States market and the total asphalt usage they report (~22.5 million tons) for 2020 is consistent with the asphalt and road oil usage for 2020 reported by the United States Energy Information Administration (~22.8 million tons) [ref 5]. This survey reports paving usage by paving process (i.e., for cutback, emulsified, and a summation of heated application processes) at the Petroleum Administration for Defense Districts (PADD) and sub-PADD level. PADDs are geographic aggregations of the 50 states and the District of Columbia that were generated during World War II for purposes of administering oil allocation. At the sub-PADD level, usage resolution is provided in aggregations that include up to six states.

State-level 2020 data on the production of asphalt pavement for heated applications and the proportions used in warm-mix processes at reduced temperatures are available from a National Asphalt Pavement Association (NAPA) report [ref 2]. The state-level heated application usage and reduced temperature (i.e., warm-mix usage) proportions are used to allocate cutback, emulsified, hot-mix, and warm-mix usage from the Asphalt Institute survey, which is at the sub-PADD and application type-level. Therefore, it is assumed that the state-level proportions of liquid asphalt used in heated applications within a sub-PADD match the state-level proportions of liquid asphalt used in cold application (i.e., cutback and emulsified) within a sub-PADD. The derivation of state-level, per-application usage is as follows:

$$Usage_{s,a} = SPU_{sp,a} \times {}^{HA_s}\!/_{HA_{sp}} \qquad (1)$$

Where:

$Usage_{s,a}$	=	Liquid asphalt usage in state *s* for application *a*, in short tons.
$SPU_{sp,a}$	=	sub-PADD usage of liquid asphalt in sub-PADD *sp* associated with state *s* for application *a* from the Asphalt Institute survey, in short tons.
HA_s	=	Heated application usage in state *s* from the NAPA survey, in short tons.
HA_{sp}	=	Heated application usage in sub-PADD *sp* associated with state *s* from the NAPA survey, in short tons.
a	=	Application types include hot-mix, warm-mix, cutback, and emulsified.
sp	=	sub-PADD associated with state *s*. sub-PADDs include the 11 districts included in the Asphalt Institute survey [ref 1].

An additional transformation must be done to split the state-level, heated application usage into hot-mix and warm-mix application, respectively.

$$Usage_{s,a} = \begin{cases} Usage_s \times {}^{WMA_s}\!/_{HA_s} & if\ a\ is\ warm-mix\ application \\ Usage_s \times {}^{(1-WMA_s)}\!/_{HA_s} & if\ a\ is\ hot-mix\ application \end{cases} \qquad (2)$$

Where:

$Usage_{s,a}$	=	Liquid asphalt usage in state *s* for application *a*, in short tons.
$Usage_s$	=	Liquid asphalt usage in state *s* for heated application, as derived in Eqn. 1, in short tons.
WMA_s	=	Warm-mix application usage at reduced temperatures in state *s* from the NAPA survey, in short tons.
HA_s	=	Heated application usage in state *s* from the NAPA survey, in short tons.
a	=	Application types include hot-mix and warm-mix. State-level summation across application types in Eqn. 2 yield the state-level application usage for heated application from Eqn. 1.

31.2.2 Allocation Procedure

State-level asphalt usage at the county-level is estimated using county-level vehicular miles traveled on paved roads as a proxy. Therefore, it is assumed that county-level paving activity is proportional to the estimated vehicular miles traveled on paved roads within each county in a state.

The U.S. EPA's Motor Vehicle Emissions Simulator (MOVES) model incorporates county-level estimates of vehicle miles traveled for various road types when estimating emissions. These road types include (1) urban interstates, freeways, and expressways, (2) urban other principal arterial, minor arterial, major collector, minor collector, and local roads, (3) rural interstates, freeways, and expressways, and (4) rural other principal arterial, minor arterial, major collector, minor collector, and local roads. The vehicle miles traveled by road type input data that will be used in the 2020 NEI MOVES simulations will be used here. In addition, the functional systems length of these road types on a per-state basis is annually provided by the U.S. Department of Transportation's Federal Highway Administration (FHWA) [ref 6]. These two datasets are combined to estimate the county-level paved vehicular miles traveled by paved road type as follows:

$$PVMT_{c,r} = VMT_{c,r} \times \frac{PFSL_{s,r}}{TFSL_{s,r}} \quad (3)$$

Where:

$PVMT_{c,r}$	=	Estimated paved vehicular miles traveled in county *c* on road type *r*, in miles.
$VMT_{c,r}$	=	Estimated vehicular miles traveled from MOVES in county *c* on road type *r*, in miles.
$PFSL_{s,r}$	=	Paved functional system length in state *s* associated with county *c* on road type *r* from the FHWA, in miles.
$TFSL_{s,r}$	=	Total functional system length in state *s* associated with county *c* on road type *r* from the FHWA, in miles.
r	=	Road types include (1) urban interstates, freeways, and expressways, (2) urban other principal arterial, minor arterial, major collector, minor collector, and local roads, (3) rural interstates, freeways, and expressways, and (4) rural other principal arterial, minor arterial, major collector, minor collector, and local roads.

County-level paved vehicular miles traveled estimates are summed across all road types and proportioned using the results for all counties within a state. These proportions, paired with the usage estimates from Equations 1-2, yield county-level asphalt usage for each process (hot-mix, warm-mix, cutback, and emulsified) as follows:

$$Usage_{c,a} = Usage_{s,a} \times {\sum_r PVMT_{c,r}}\Big/{\sum_r PVMT_{s,r}} \quad (4)$$

Where:

$Usage_{c,a}$	=	Liquid asphalt usage in county *c* for application *a*, in short tons.
$Usage_{s,a}$	=	Liquid asphalt usage in state *s* associated with county *c* for application *a*, in short tons (from Eqn. 1-2).
$PVMT_{c,r}$	=	Estimated paved vehicular miles traveled in county *c* on road type *r*, in miles (from Eqn. 3).
$PVMT_{s,r}$	=	Estimated paved vehicular miles traveled in state *s* associated with county *c* on road type *r*, in miles (from Eqn. 3).

a	=	Application types include hot-mix, warm-mix, cutback, and emulsified.
r	=	Road types include (1) urban interstates, freeways, and expressways, (2) urban other principal arterial, minor arterial, major collector, minor collector, and local roads, (3) rural interstates, freeways, and expressways, and (4) rural other principal arterial, minor arterial, major collector, minor collector, and local roads.

31.2.3 Emission Factors

Emission factors for all paving processes (hot-mix, warm-mix, cutback, and emulsified) captures emissions that occur during application and in-use. Both application and in-use emission factors for hot-mix and warm-mix asphalt, as well as the in-use emission factors for cutback and emulsified asphalt, were retrieved from Khare et al., 2020 [ref 4]. Emission factors associated with application for cutback and emulsified asphalt paving were not updated.

During the hot-mix application process, the asphalt pavement (i.e., mixture of liquid asphalt and aggregate) is heated and applied at elevated temperatures (~150 °C). Emissions are highest when sustained heating is initiated and exponentially decline thereafter. Measurements indicate that the exponential function below (Eqn. 5) fits the dynamic change in emissions over a prolonged experiment (> 6 days). However, hot-mix asphalt is not heated for prolonged periods. Here, it is assumed that the application process takes 5 hours and is meant to capture the time between transport, paving, and ambient cooling.

$$EF = 7.7 \times exp^{-0.016 \times t} + 16 \times exp^{-0.5 \times t} \quad (5)$$

Where:

EF	=	Emission factor of gas-phase organics, in mg min^{-1} kg^{-1} asphalt
t	=	Time, in hours

Integrating Equation 5 over a period of 5 hours yields an emission factor of 4 g/kg asphalt, or 8.04 lb/short ton asphalt (i.e., 0.4% emissions by weight), and represents the emissions from hot-mix asphalt during the application process. The warm-mix asphalt application process generally occurs at 20 – 40 °C cooler temperatures than hot-mix asphalt application. Reducing the asphalt temperature from 140 °C to 120 °C reduced the initial pulse of emissions by ~46% (Fig. S5 of Khare et al., 2020). As such, a warm-mix application emission factor of 2 g/kg asphalt, or 4.32 lb/short ton asphalt (i.e., 0.2% emissions by weight), is adopted.

Cutback and emulsified application emission factors are developed using compositional information from material safety and data sheets (MSDS) for cutback [ref 7] and emulsified [ref 8] asphalt. Assuming a volatilization fraction of 95% for all components yields an emission factor of 813.96 lb/short ton asphalt (407 g/kg asphalt) for cutback applications and 195.51 lb/short ton asphalt (98 g/kg asphalt) for emulsified applications.

In-use emissions follow application and occur under ambient temperatures. Since emissions are strongly influenced by temperature, climatological variation can impact the speed in which emissions occur. Measurements associated with a sustained heating experiment at 60 °C feature an exponential decline and fit the function below (Eqn. 6). While 60 °C is above ambient conditions for all locations within the

United States, measurements show that emissions flatten within a day and remain near-constant for more than 2 additional days. Here, it is assumed that emissions within 72-hours under 60 °C will occur within 1-year under ambient conditions at all locations within the United States. Integrating Equation 6 over a period of 72 hours yields an emission factor of 1 g/kg asphalt, or 2.01 lb/short ton asphalt (i.e., 0.1% emissions by weight), and represents the emissions from all in-use asphalt paving process.

$$EF = 0.1 + 3.3 \times exp^{-0.35 \times t} \tag{6}$$

Where:

EF	=	Emission factor of gas-phase organics, in mg min^{-1} kg^{-1} asphalt
t	=	Time, in hours

Taken together, the VOC emission factors for all asphalt paving process are the summation of emissions associated with application and in-use. Emissions factors are provided in the "Wagon Wheel Emission Factor Compendium" on the 2020 NEI Supporting Data and Summaries site.

31.2.4 Controls

There are no controls assumed for this category.

31.2.5 Emissions

Emissions are quantified using county-level liquid asphalt usage, per application, and the emissions factors provided above as follows:

$$E_{c,a} = {Usage_{c,a} \times EF_a}/{2000} \tag{7}$$

Where:

$E_{c,a}$	=	Annual emissions in county *c* for application *a*, in short tons
$Usage_{c,a}$	=	Liquid asphalt usage in county *c* for application *a*, in short tons
EF_a	=	Emission factor for application *a*, in lb/ton asphalt
a	=	Application types include hot-mix, warm-mix, cutback, and emulsified

31.2.6 Sample Calculations

The table below includes sample calculations for VOC emissions from emulsified asphalt (SCC: 2461022000). The values in these equations are demonstrating program logic and are not representative of any specific NEI year or county.

Table 31-2: Sample calculations for emulsified asphalt usage

Eq. #	Equation	Values	Result
1	$Usage_{s,a} = SPU_{sp,a} \times {HA_s}/{HA_{sp}}$	$172 \times {6.5}/{19.9}$	56 short tons of liquid asphalt usage for emulsified applications.

Eq. #	Equation	Values	Result
2	n/a; only applicable for hot- and warm-mix asphalt	–	–
3	$PVMT_{c,r} = VMT_{c,r} \times \frac{PFSL_{s,r}}{TFSL_{s,r}}$	$1767595240 \times \frac{27845}{29637}$	1.66E+9 vehicular miles traveled on paved urban other roads.
3	–	Repeat Eqn. 3 for other road types.	2.38E+9 vehicular miles traveled on paved roads.
4	$Usage_{c,a} = Usage_{s,a} \times \sum_r PVMT_{c,r} / \sum_r PVMT_{s,r}$	$56\ short\ tons \times 2.38E9\ \text{VMT} / 5.16E10\ \text{VMT}$	2.58 short tons of liquid asphalt usage for emulsified applications
5	$E_{c,a} = Usage_{c,a} \times EF_a / 2000$	$2.58\ short\ tons \times 197.52 / 2000$	0.26 short tons of VOC emissions from emulsified asphalt

31.2.7 Improvements/Changes in the 2020 NEI

Methodological updates for the 2020 NEI include methodological updates, as well as changes to activity data and emission factors. Methodological updates include emission estimates from heated paving applications (i.e., hot-mix and warm-mix asphalt application). Updated activity data for previously considered processes (i.e., cutback and emulsified asphalt application) and activity data for new processes are both generated from usage data reported by the Asphalt Institute [ref 1] and allocated by process and state using data from the National Asphalt Pavement Association [ref 2]. Further allocation to the county-level is performed using estimates of vehicle miles traveled on paved surfaces, which is generated using data from the U.S. EPA's MOVES model and data from the Federal Highway Administration [ref 6]. Emission factors for each asphalt process now span both application and post-application time periods [ref 4].

31.2.8 Puerto Rico and U.S. Virgin Islands

Insufficient data exists to calculate emissions for the counties in Puerto Rico and the US Virgin Islands. As such, emissions are based on two proxy counties in Florida: 12011 (Broward County) for Puerto Rico and 12087 (Monroe County) for the U.S. Virgin Islands. Per-capita emission factors from Broward County and Monroe County are applied to Puerto Rico and the U.S. Virgin Islands, respectively.

31.3 References

1. 2020 Asphalt Usage Survey for the United States and Canada. The Asphalt Institute, Lexington, KY.
2. Williams, B.A., J.R. Willis, & Shacat, J. (2021). Annual Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2020, 11th Annual Survey (IS 138). National Asphalt Pavement Association, Greenbelt, Maryland. doi:10.13140/RG.2.2.14846.46409.
3. U.S. Department of Transportation, Federal Highway Administration, Center for Accelerating Innovation. Warm Mix Asphalt FAQs.
4. Khare, P., Machesky, J., Soto, R., He, M., Presto, A.A., Gentner, D.R., Asphalt-related emissions

are a major missing nontraditional source of secondary organic aerosol precursors. Science Advances, 6, 35, doi:10.1126/sciadv.abb9785.

5. U.S. Energy Information Administration, Petroleum & Other Liquids, Product Supplied: https://www.eia.gov/dnav/pet/PET_CONS_PSUP_A_EPPA_VPP_MBBL_M.htm.
6. U.S. Department of Transportation, Federal Highway Administration, Functional System Length, Table HM-51 – Highways Statistics 2020.
7. Cutback Asphalt MSDS

Product Supplier	MSDS/SDS ID
Valero	2013V04
Asphalt Emulsion Industries	CUT-SDS-1
Martin Asphalt Company	Jan 2007
Mohawk Asphalt Emulsions	UN1999
Asphalt & Fuel Supply	211
Valero	211
Valero	210

Pollutant	Avg. % by Weight	Emission Factor [lb/ton]*
Naphtha	40	760
Naphthalene & PAH***	0.58	11.02
Toluene***	0.59	11.21
Xylene***	0.99	18.81
Benzene***	0.19	3.61
Ethylbenzene***	0.49	9.31
Hydrogen Sulfide***	0.09	1.71
Total VOC**	--	813.96

*Assumes 95% volatilization
**Excludes hydrogen sulfide (not organic)
***Is a Hazardous Air Pollutant

8. Emulsified Asphalt MSDS

Product Supplier	MSDS/SDS ID
Marathon	0137MAR019
Marathon	0138MAR019
Asphalt Emulsion Industries	EMU-SDS-1
U.S. Oil & Refining Co.	951

Pollutant	Avg. % by Weight	Emission Factor [lb/ton]*
Naphtha	10	190
Naphthalene & PAH***	0.29	5.51
Hydrogen Sulfide***	0.09	1.71
Total VOC**	--	195.51

*Assumes 95% volatilization
**Excludes hydrogen sulfide (not organic)
***Is a Hazardous Air Pollutant

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