NATIONAL ASPHALT PAVEMENT ASSOCIATION

Asphalt Pavement Industry Survey on

Recycled Materials and Warm-Mix Asphalt Usage 2016

Information Series 138

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16. Abstract

A shared goal of the Federal Highway Administration (FHWA) and the National Asphalt Pavement Association (NAPA) is to support and promote sustainable practices, such as the use of recycled materials and warm-mix asphalt (WMA). The use of recycled materials, primarily reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS), in asphalt pavements conserves raw materials and reduces overall asphalt mixture costs, as well as reduces the stream of material going into landfills.

WMA technologies have been introduced to reduce production and compaction temperatures for asphalt mixtures, which reduces the energy needed and emissions associated with mixture production. Additional benefits include improved low-temperature compaction of asphalt mixtures leading to improved pavement performance, as well as a longer paving season. WMA was chosen for accelerated deployment in federal-aid highway, state department of transportation, and local road projects as part of FHWA's 2010 Every Day Counts initiative.

The objective of this survey, first conducted for the 2009 and 2010 construction seasons, is to quantify recycled materials used and WMA produced annually by the asphalt pavement industry to document the deployment of these technologies to understand where they are being used and where they are underutilized. Results show significant growth in the use of RAP, RAS, and WMA technologies since 2009, although the rate of year-over-year growth has generally slowed since 2013.

The asphalt industry remains the country's most diligent recycler with more than 99 percent of reclaimed asphalt pavement being put back to use. The average percentage of RAP used in asphalt mixtures has increased from 15.6 percent in 2009 to 20.5 percent in 2016. In 2016, the estimated RAP tonnage used in asphalt mixtures was 76.9 million tons. This represents more than 3.8 million tons (21.5 million barrels) of asphalt binder conserved, along with the replacement of some 73 million tons of virgin aggregate.

Similarly, the use of RAS in asphalt pavement mixtures has increased from 701,000 tons in 2009 to an estimated 1.39 million tons in 2016; however, the use of RAS declined significantly (27.9 percent) from 2015 to 2016.

The combined savings of asphalt binder and aggregate from using RAP and RAS in asphalt mixtures is estimated at more than $2.1 billion.

More than 768,000 tons of other recycled materials were reported as being incorporated into nearly 6.5 million tons of asphalt pavement mixtures during the 2016 construction season, including ground tire rubber, blast furnace slag, steel slag, and cellulose fibers.

The estimated total production of WMA for the 2016 construction season was 116.8 million tons. This was a decline of 2.5 percent from the estimated 119.8 million tons of WMA in 2015, due largely to a 10.2 million ton decrease in DOT tonnage for the year, but is still a greater than 595 percent increase from the estimated 16.8 million tons in the 2009 construction season. WMA made up 31.2 percent of the total estimated asphalt mixture market in 2016. Production Plant foaming, representing nearly 77 percent of the market, is the most commonly used warm-mix technology; chemical additive technologies accounted for a little more than 21 percent of the market.

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Table of Contents

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
CCPR	Cold Central Plant Recycling
CIR	Cold In-Place Recycling
CRM	Crumb Rubber Modifier
DOT	Department of Transportation
FDR	Full-Depth Reclamation
FHWA	Federal Highway Administration
GTR	Ground Tire Rubber
HIR	Hot In-Place Recycling
HMA	Hot-Mix Asphalt
MWAS	Manufacturing Waste Asphalt Shingles
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCAUPG	North Central Asphalt User/Producer Group
NEAUPG	North East Asphalt User/Producer Group
NSA	National Slag Association
PCAS	Post-Consumer Asphalt Shingles
PCCAS	Pacific Coast Conference on Asphalt Specifications
RAP	Reclaimed Asphalt Pavement
RAS	Reclaimed Asphalt Shingles
RBR	Recycled Binder Ratio
RMA	Rubber Manufacturers Association
RMAUPG	Rocky Mountain Asphalt User/Producer Group
SAPA	State Asphalt Pavement Association
SEAUPG	Southeastern Asphalt User/Producer Group
UPG	User/Producer Group
WMA	Warm-Mix Asphalt

On the Cover

In 2015, the Indiana Department of Transportation was working to complete the final segment of Interstate 69 linking Bloomington and Evansville, Ind. In a 3-mile project through Greene County, Milestone Contractors of Bloomington placed nearly 87,675 tons of asphalt pavement mixture incorporating recycled materials, including 20 percent RAP and 26 percent blast furnace slag aggregates in the surface course. Most of the other pavement layers included 17 percent RAP and 3 percent RAS. An open-graded levelling course used on the project included 3.5 percent RAS. Milestone Contractors won a NAPA 2016 Quality in Construction Green Paving Award for its work on the I-69 project.

Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2016

Executive Summary

The results of the asphalt pavement industry survey for the 2016 construction season show that asphalt mixture producers have a strong record of employing sustainable practices and continue to increase their use of recycled materials and warm-mix asphalt (WMA). The use of recycled materials, particularly reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS), conserves raw materials and reduces overall asphalt mixture costs, allowing road owners to achieve more roadway maintenance and construction activities within limited budgets. WMA technologies can improve compaction at reduced temperatures, ensuring pavement performance and long life; conserve energy; reduce emissions from production and paving operations; and improve conditions for workers.

The objective of this survey, first conducted for the 2009 and 2010 construction seasons, was to quantify the use of recycled materials, primarily RAP and RAS, as well as the production of WMA by the asphalt pavement industry. For the 2016 construction season, the National Asphalt Pavement Association (NAPA) conducted a voluntary survey of asphalt mixture producers across the United States on tons produced, along with a survey of state asphalt pavement associations (SAPAs) regarding total tons of asphalt pavement mixture produced in their state.

Asphalt mixture producers from all 50 states completed the 2016 construction season survey. A total of 229 companies with 1,146 production plants were represented in the survey.

The following are highlights of the survey of usage during the 2016 construction season:

Reclaimed Asphalt Pavement

- Asphalt mixture producers remain the country's most diligent recyclers, with more than 99 percent of asphalt mixture reclaimed from old asphalt pavements being put back to use in new pavements.
- The total estimated tons of RAP used in asphalt mixtures reached 76.9 million tons in 2016. This is a 3.6 percent increase from the 2015 construction season and represents a greater than 37 percent increase from the total estimated tons of RAP used in 2009. During the same time frame, total asphalt mixture tonnage increased only 4.6 percent.
- The percentage of producers reporting use of RAP decreased slightly from 99 percent of respondents in 2015 to 98 percent in 2016. Four producers reported landfilling a small amount of RAP during 2016.
- RAP usage during the 2016 construction season is estimated to have reduced the need for 3.8 million tons (21.5 million barrels) of asphalt binder and more than 73 million tons of aggregate, with a total estimated value of more than $2 billion.
- The total estimated amount of RAP stockpiled nationwide at the end of the 2016 construction season was about 93.6 million tons.
- Fractionated RAP represents about 22 percent of RAP use nationwide, and the tons of RAP mixtures produced using softer binders are estimated at 24 percent while tons produced using recycling agents is estimated at 7 percent.
- Reclaiming 81.7 million tons of RAP for future use saved about 49.6 million cubic yards of landfill space.

Reclaimed Asphalt Shingles

- The total estimated tons of RAS used in asphalt mixtures decreased 28 percent to an estimated 1.39 million tons in 2016. Still, the use of RAS in the 2016 construction season increased 98 percent from the estimated 702,000 tons used in asphalt mixtures in 2009.
- RAS usage during the 2016 construction season is estimated to have reduced the need for 278,000 tons (1.5 million barrels) of asphalt binder and nearly 695,000 tons of aggregate, with an estimated value of more than $103 million.

Other Findings

- The use of softer binders and recycling agents with mixtures incorporating RAP and RAS was reported nationwide. There was little correlation between the level of RAP used and the use of softer binders and/or recycling agents, but their use with RAS was more consistent.
- A reported total of 768,470 tons of other recycled materials was used in nearly 6.5 million tons of asphalt mixtures by 53 companies in 29 states during the 2016 construction season.
- Other recycled materials commonly reported as being used in asphalt mixtures during the 2016 construction season were ground tire rubber, blast furnace slag, steel slag, and cellulose fibers. Recycled materials less commonly reported as being used in asphalt mixtures included fly ash, foundry sand, and poly fibers.

Warm-Mix Asphalt

- The estimated total production of WMA for the 2016 construction season was 116.8 million tons. This was a 2.5 percent decrease from the estimated 119.8 million tons of WMA in 2015. WMA saw increased tonnage in the Commercial & Residential and the Other Agency sector; however, this was insufficient to offset decreased asphalt mixture tonnage in the DOT sector.
- WMA made up 31.2 percent of the total estimated asphalt mixture market in 2016.
- Production plant foaming, representing nearly 77 percent of the market, is the most commonly used warm-mix technology; chemical additive technologies accounted for a little more than 21 percent of the market.

Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2016

Background

A shared goal of the Federal Highway Administration (FHWA) and the National Asphalt Pavement Association (NAPA) is to support and promote sustainable practices, such as incorporation of recycled materials in pavement mixtures and the use of warm-mix asphalt (WMA). Reclaimed asphalt pavement (RAP) is recycled at a greater rate than any other material in the United States and helps lower overall material costs, allowing road owners to achieve more roadway maintenance and construction activities within limited budgets. Another recycled material used in asphalt mixtures is reclaimed asphalt shingles (RAS) from both manufacturing waste (MWAS) and post-consumer asphalt shingles (PCAS). The use of RAP and RAS in asphalt pavements can reduce the amount of new asphalt binder and aggregates required in mixtures, which can help stabilize the price of asphalt mixtures and save natural resources. Other recycled materials commonly incorporated into asphalt pavements include ground tire rubber (GTR), steel slag, blast furnace slag, and cellulose fibers, among others. By putting waste materials and byproducts to a practical use, the asphalt pavement industry helps reduce the amount of material going to landfills while improving the sustainability of asphalt mixtures.

WMA technologies reduce the mixing and compaction temperatures for asphalt mixtures. Environmental benefits include reductions in both fuel consumption and air emissions. Construction benefits include the ability to extend the paving season into the cooler months, haul material longer distances, improve compaction at lower temperatures, and use higher percentages of RAP (Prowell et al., 2012; West et al., 2014). As part of FHWA's original group of Every Day Counts initiatives, WMA was chosen in 2010 for accelerated deployment in federal-aid highway, state department of transportation (DOT), and local road projects (FHWA, 2013). In 2013, WMA was honored with the Construction Innovation Forum's NOVA Award for its engineering, economic, and environmental benefits (CIF, 2013).

FHWA works closely with the pavement industry through associations and other stakeholders to promote pavement recycling technologies and WMA. From 2007 to 2011, the American Association of State Highway and Transportation Officials (AASHTO) conducted a biennial survey of state DOTs' use of recycled materials (Copeland, 2011; Copeland et al., 2010; Pappas, 2011). The results of the AASHTO survey were presented at FHWA Expert Task Group meetings. FHWA partners with NAPA to document industry use of RAP, RAS, other recycled materials, as well as WMA technologies used by asphalt mixture producers. These efforts have established a baseline for RAP, RAS, and WMA usage, and have tracked growth in the use of these sustainable practices in the highway industry since 2009.

FHWA first partnered with NAPA to capture annual RAP, RAS, and WMA use for the 2009 construction season (Hansen & Newcomb, 2011; Hansen & Copeland, 2013a; 2013b; 2014; 2015; 2017). Compared to the findings of the first survey (Hansen & Newcomb, 2011), asphalt mixture producers have shown significant growth in the use of these technologies, although the year-over-year rate of growth has slowed since the 2013 construction season. Since 2012, the survey has also asked about other recycled materials used in asphalt mixtures. This report documents the results of the industry survey for the 2016 construction season, including the survey methodology, results, trends, and changes from 2009 through 2016. The survey questions and data by state are included in the appendices.

Objective and Scope

The objective of this effort is to quantify the use of recycled materials and WMA technologies by the asphalt pavement industry. During 2017, NAPA conducted a voluntary survey of asphalt mixture producers in the United States on tons produced, along with a survey of state asphalt pavement associations (SAPAs) regarding total tons of asphalt pavement

mixture produced in their state during the 2016 construction season. While keeping specific producer data confidential, NAPA staff compiled the amount of asphalt mixtures produced; the amount of RAP, RAS, and other recycled material used; and the amount of WMA produced in the United States. Not measured in this survey is the use of in-place asphalt pavement recycling techniques, such as full-depth reclamation (FDR), cold in-place recycling (CIR), and hot in-place recycling (HIR). Some cold central plant recycling (CCPR) of RAP may be included in Table 4 among the tons reported as "Used in Other" or "Used in Cold-Mix Asphalt."

Survey Methodology

The survey methodology used to collect and analyze the data in this report is detailed in Appendix A. Note that when reporting data at the state level, to keep specific producer information confidential, no state-specific results are provided in the tables or appendixes if fewer than three producers from that state responded to the survey. Information from states with fewer than three responding companies is included in the estimated national values, however.

Producer Survey Results

Asphalt mixture producers from all 50 states completed the survey for the 2016 construction season. No production plants in the District of Columbia or other U.S. territories contributed data for 2016. A total of 229 companies with 1,146 production plants are represented in the 2016 survey. This is a slight decrease from the 2013 and 2014 construction season surveys, but is an increase in participation from 2015 and is equal to or greater than other construction seasons surveyed. The total asphalt mixture tons reported for 2016 was 155.8 million tons; despite fluctuations in the number of companies participating in the survey, the total tons reported has continued to increase each year. Table 1 summarizes the number of asphalt mixture production companies and the number of production plants reporting for each state. Branches, subsidiaries, and operating units are counted as unique companies in Table 1 and throughout this report. Table 2 summarizes the total number of production plants responding in previous years.

Table 1: Number of Companies Completing 2016 Construction Season Survey by State/Territory

State	Cos.	Prod. Plants	State	Cos.	Prod. Plants	State	Cos.	Prod. Plants
Alabama	5	33	Kentucky	5	34	Ohio	5	66
Alaska	*	*	Louisiana	3	10	Oklahoma	5	16
American Samoa	NCR	NCR	Maine	3	17	Oregon	5	12
Arizona	3	21	Maryland	6	15	Pennsylvania	10	50
Arkansas	6	18	Massachusetts	5	19	Puerto Rico	NCR	NCR
California	4	52	Michigan	4	27	Rhode Island	*	*
Colorado	5	23	Minnesota	5	19	South Carolina	6	19
Connecticut	3	15	Mississippi	4	22	South Dakota	*	*
Delaware	*	*	Missouri	4	24	Tennessee	4	24
District of Columbia	NCR	NCR	Montana	*	*	Texas	7	46
Florida	6	30	Nebraska	*	*	U.S. Virgin Islands	NCR	NCR
Georgia	5	45	Nevada	3	4	Utah	11	25
Guam	NCR	NCR	New Hampshire	3	17	Vermont	*	*
Hawaii	*	*	New Jersey	3	12	Virginia	7	42
Idaho	5	17	New Mexico	4	8	Washington	4	19
Illinois	10	19	New York	10	60	West Virginia	5	18
Indiana	3	33	North Carolina	6	44	Wisconsin	4	67
Iowa	7	23	North Dakota	*	*	Wyoming	6	6
Kansas	4	19	No. Mariana Islands	NCR	NCR			

NCR = No Companies Responding * = Fewer than 3 Companies Reporting

Table 2: Summary of Jurisdictions (States or Territories), Companies, and Production Plants Represented, 2009–2016

Year	No. Jurisdictions Reporting	No. of Companies Reporting	No. of Production Plants Represented in Survey	Average Tons Produced per Plant
2009	48	196	1,027	121,000
2010	48	196	1,027	117,000
2011	49	203	1,091	121,000
2012	49	213	1,141	122,000
2013	52	249	1,281	115,000
2014	50	228	1,185	127,000
2015	49	214	1,119	137,000
2016	50	229	1,146	136,000

Table 3 includes state-by-state 2016 construction season total estimated asphalt mixture tonnage, as estimated by the SAPA or from Equation A1 (see Survey Methodology in Appendix A); tonnage reported by survey respondents; and the percentage of reported tons included in estimated tons. The closer a state's percentage is to 100 percent indicates the completeness of reported tonnage compared to estimated tonnage. At the national level, the survey responses make up 41.5 percent of the estimated total tons for the 2016 construction season.

Table 3: Summary of 2016 Estimated and Reported Asphalt Mixture Tons by State

State	Tons, Millions		Reported % of Estimated	State	Tons, Millions		Reported % of Estimated
	Estimated	Reported			Estimated	Reported	
Alabama	7.50	3.76	50%	Montana	3.92	*	*
Alaska	4.64	*	*	Nebraska	2.72	*	*
Arizona	7.14	2.42	34%	Nevada	3.28	0.95	29%
Arkansas	5.50	2.31	42%	New Hampshire	1.43	1.50	105%
California	25.00	9.68	39%	New Jersey	4.50	2.73	61%
Colorado	7.50	2.38	32%	New Mexico	3.47	0.99	29%
Connecticut	4.55	2.48	55%	New York	17.00	5.68	33%
Delaware	1.59	*	*	North Carolina	15.00	4.77	32%
District of Columbia	1.38	NCR	NCR	North Dakota	2.10	*	*
Florida	15.00	5.36	36%	Ohio	19.00	10.41	55%
Georgia	10.00	6.95	70%	Oklahoma	5.21	2.21	42%
Hawaii	1.10	*	*	Oregon	5.40	1.61	30%
Idaho	2.68	1.27	47%	Pennsylvania	19.00	7.32	39%
Illinois	14.10	2.18	15%	Puerto Rico	1.00	NCR	NCR
Indiana	10.00	4.79	48%	Rhode Island	1.90	*	*
Iowa	3.92	2.20	56%	South Carolina	6.50	3.11	48%
Kansas	3.50	1.65	47%	South Dakota	1.60	*	*
Kentucky	6.90	3.23	47%	Tennessee	8.24	2.36	29%
Louisiana	2.65	1.85	70%	Texas	24.00	7.97	33%
Maine	1.59	2.07	130%	Utah	3.60	4.06	113%
Maryland	7.50	3.34	45%	Vermont	1.72	*	*
Massachusetts	6.40	3.02	47%	Virginia	12.00	7.39	62%
Michigan	14.00	5.92	42%	Washington	5.83	1.87	32%
Minnesota	13.00	4.64	36%	West Virginia	4.12	2.17	53%
Mississippi	4.72	2.69	57%	Wisconsin	12.00	7.14	60%
Missouri	6.30	1.82	29%	Wyoming	2.22	0.34	15%
				Total	374.90	155.80†	42%

NCR No Companies Responding

* Fewer than 3 Companies Reporting

† Total Reported Tons includes values from state with fewer than 3 Companies Reporting

SAPA Estimated Tons

Figure 1 shows the number of production plants, as well as the average tons produced per production plant, separated by User/Producer Group (UPG) region. The number of production plants responding from each UPG region showed a good deal of variability from 2015 to 2016, with notable increases in the North East Asphalt User/Producer Group (NEAUPG) and the combined Rocky Mountains Asphalt User/Producer Group (RMAUPG) and Pacific Coast Conference on Asphalt Specification (PCCAS) regions and a notable decline in the North Central Asphalt User/Producer Group (NCAUPG) region. Similarly, there is variability in the tonnages reported for 2016 compared to previous years with NEAUPG seeing a decline in tons per production plant despite more production plants reporting and the Southeastern Asphalt User/Producer Group (SEAUPG) seeing a large increase in tons per production plant despite one fewer production plant reporting. The combined RMAUPG/PCCAS regions reached an all-time high for participation in the survey with 214 production plants responding for the 2016 construction season.

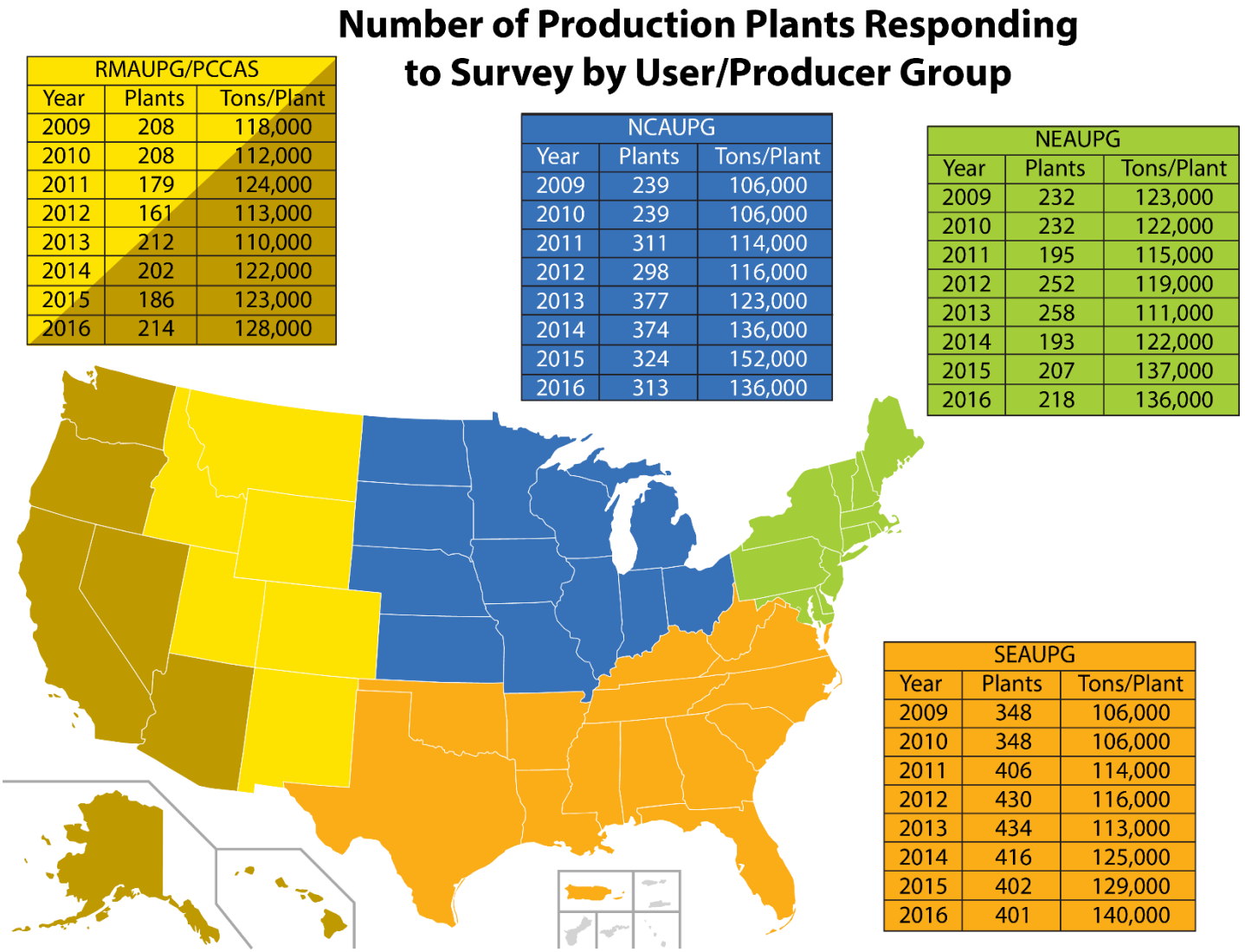


Figure 1: Number of Production Plants Responding to Survey by User/Producer Group Regions and Estimated Tonnage, 2009–2016

Data Summary and National Estimates

Table 4 summarizes the RAP, RAS, and WMA data from the 2016 construction season survey alongside data from the 2015 construction season survey (Hansen & Copeland, 2017) for comparison. The information requested in the survey is summarized in Appendix A. In the column labeled “Reported Values” in Table 4 are national summaries of the values

from asphalt mixture producers completing the survey. The column labeled "Estimated Values" for the category labeled "Tons of HMA/WMA Produced" was determined as outlined in the Survey Methodology (Appendix A).

Table 4: Summary of RAP, RAS, WMA Data

NATIONAL SUMMARY	Reported Values		Estimated Values	
	2015	2016	2015	2016
Tons of HMA/WMA Produced	Tons, Millions		Tons, Millions	
Total	152.8	155.8	364.9	374.9
DOT	68.5	62.9	163.6	151.5
Other Agency	40.0	42.4	95.5	102.1
Commercial & Residential	44.3	50.4	105.8	121.4
Companies Reporting	214	229		
RAP	Tons, Millions		Tons, Millions	
Accepted	33.2	35.6	78.0	81.8
Used in HMA/WMA Mixtures	32.7	32.8	74.2	76.9
Used in Aggregate	1.7	1.3	5.5	3.7
Used in Cold-Mix Asphalt	0.1	0.1	0.2	0.2
Used in Other	0.4	0.2	1.6	0.4
Landfilled	0.4	0.0	1.0	0.1
Total Tons of RAP Stockpiled at Year-End	37.62	41.15	85.13	93.59
	Avg. % Used in Mixtures		Avg. % Used in Mixtures	
Average % for DOT Mixtures[1]	17.8%	19.3%		
Average % for Other Agency Mixture[1]	18.2%	19.7%		
Average % for Commercial & Residential Mixtures[1]	22.3%	24.2%		
National Average All Mixtures Based on RAP Tons Used in HMA/WMA[2]	21.4%	21.0%	20.3%	20.5%
Companies Reporting Using RAP	211	224		
RAS	Tons, Millions		Tons, Millions	
Unprocessed Shingles Accepted	0.456	0.386	1.129	1.027
Processed Shingles Accepted	0.375	0.274	0.842	0.846
Used in HMA/WMA Mixtures	0.819	0.499	1.931	1.390
Used in Aggregate	0.004	0.004	0.009	0.009
Used in Cold-Mix Asphalt	—	—	—	—
Used in Other	—	—	—	—
Landfilled	—	0.002	—	0.005
	Avg. % Used in Mixtures		Avg. % Used in Mixtures	
Average % for DOT Mixtures[1]	0.580%	0.341%		
Average % for Other Agency Mixtures[1]	0.461%	0.274%		
Average % for Commercial & Residential Mixtures[1]	0.525%	0.334%		
National Average All Mixtures Based on RAS Tons Used in HMA/WMA[2]			0.540%	0.371%
Companies Reporting Using RAS	89	76		
WMA	% of Total Production		Tons, Millions	
Total			119.8	116.8
DOT	37.4%	36.3%	60.9	50.7
Other Agency	34.0%	32.4%	28.5	31.5
Commercial & Residential	34.3%	30.5%	30.4	34.6
Companies Reporting Producing WMA	166	165		

[1] Average percent based on contractor's reported percentage for each sector, adjusted based upon reported tonnage.

[2] Average percent based on total reported tons of RAP or RAS used in HMA/WMA divided by reported total tons HMA/WMA produced.

For the amount of RAP accepted, asphalt mixture producers were asked, "How many tons of removed asphalt pavement and asphalt millings were accepted/delivered to your facilities in the state in 2016?" For the amount of RAS accepted, producers were asked, "How many tons of unprocessed shingles (manufacturing waste and post-consumer/tear-off) were accepted/delivered to your facilities in the state in 2016?" Producers were also asked how many tons of processed RAS were acquired from shingle processors. These data are reported in Table 4 as the tonnage of material accepted. Producers were also asked for the tonnage of RAP and RAS used in the production of asphalt pavement mixtures, cold-mix asphalt, as aggregate, or for other purposes, such as in a chip seal. The tons of reclaimed material sent to landfills were also requested.

For each state, the tons of RAS and RAP reported as accepted and used were multiplied by the ratio of estimated production to total production, and these values were summed to arrive at the national estimated tons for these materials, which is reported in the "Estimated Values" column of Table 4.

To understand the average percentage of recycled material used in mixtures, producers were asked to report the average recycled content of mixtures produced for each sector (DOT, Other Agencies, Commercial & Residential). If precise data were not available, respondents were asked to provide their best estimate. These responses are reported in the "Average % Used in Mixtures" section of Table 4 for RAP and RAS. To control for inaccuracies in producer estimates of sector-by-sector percentages, a "National Average All Mixtures Based on Tons Used in HMA/WMA" was calculated and reported in Table 4 for both RAP and RAS based on reported tonnage of each material used in HMA/WMA mixtures divided by the total reported tons produced. Producers were not asked about allowable RAP limits or binder replacement requirements, which can influence demand for mixtures that incorporate these materials.

Producers were asked to give their best estimate of the percentage of asphalt paving mixtures produced for each sector when WMA technology resulted in a temperature reduction of 10°F to 100°F. These percentages were multiplied by the total mixture production for each sector to determine the total estimated tons of WMA produced for each sector. The survey methodology was designed so that only mixtures produced at reduced temperatures are reported. Some WMA additives are also used for construction benefits unrelated to the goal of reducing production temperatures; therefore, for the 2016 construction season producers were also asked if they used WMA additives to produce mixtures at HMA temperatures.

Total HMA/WMA Production

Table 4 includes the national summary of asphalt mixture production data from the 2014 and 2015 construction season surveys. The information requested in the survey is detailed in Appendix A and summarized in Table A1, Section 2. State-level data are reported in Appendix B.

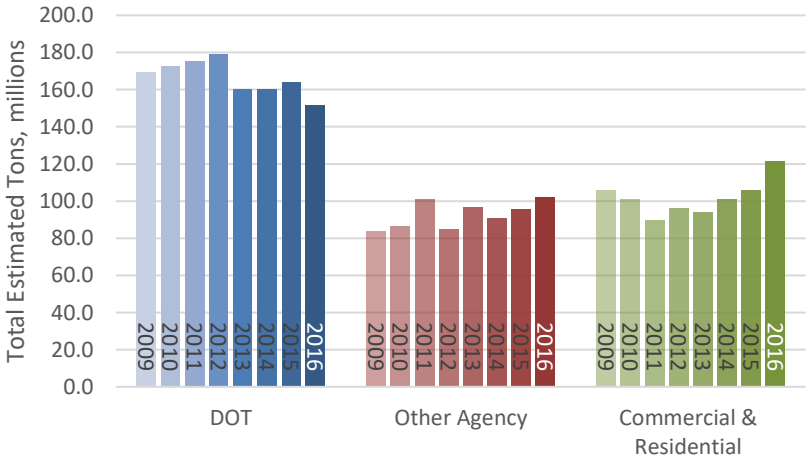


Figure 2: Percent of Estimated Total HMA/WMA Asphalt Mixture Production by Sector, 2009–2016

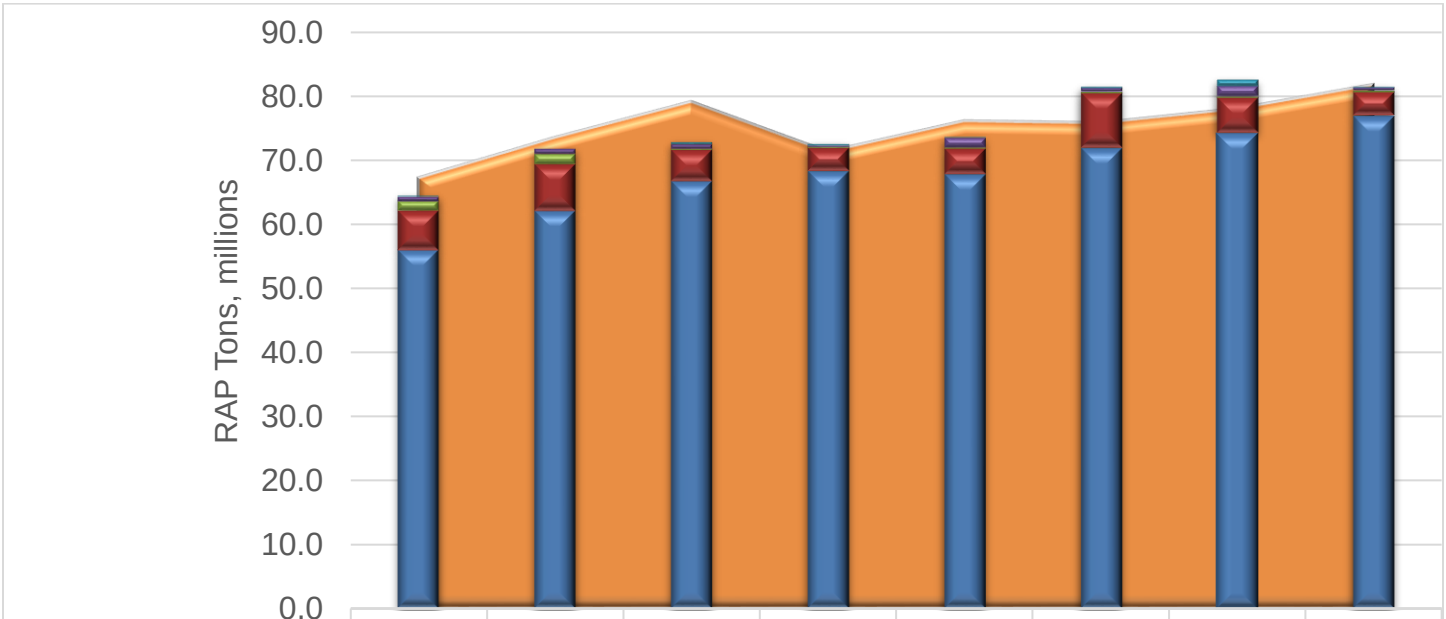
From 2015 to 2016, the estimated total amount of asphalt mixture produced in the United States increased from 364.9 million tons to 374.9 million tons, an increase of 2.7 percent. Asphalt mixture tonnage produced for the Commercial & Residential and the Other Agency sectors saw increases of 14.7 percent and 6.9 percent respectively; however, mixture production for the DOT sector decreased by nearly 7.4 percent. This decrease in total tonnage for DOT customers had a cascading effect throughout the survey, particularly in terms of WMA tonnage as DOTs have traditionally made greater use of WMA mixtures compared to other sectors.

Reclaimed Asphalt Pavement

Table 4 includes the national summary of RAP data from the 2015 and 2016 construction season surveys. The information requested in the survey is detailed in Appendix A and summarized in Table A1, Section 2. State-level data is reported in Appendix B. Figure 3 is a visual representation of the estimated total tons of RAP used in asphalt mixtures, aggregate, cold-mix asphalt, and other uses, as well as the amount landfilled, from the 2009 to 2016 construction season surveys. The overwhelming majority of RAP is used in hot-mix asphalt (HMA) or warm-mix asphalt (WMA), which is the most optimal use of RAP. The tons used in cold-mix asphalt data may include some CCPR of RAP, but the survey is not intended to record the use of in-place recycling technologies.

From the 2015 to 2016 construction season, the amount of RAP used in HMA/WMA increased from 74.2 million to 76.9 million tons. The average percent RAP used in asphalt mixtures increased marginally from 20.3 percent in 2015 to 20.5 percent in 2016. For 2016, 98 percent of companies responding to the survey reported using RAP. This is a slight decrease from the 100 percent of companies reporting using RAP in 2013 and 2014 and the 99 percent of companies reporting RAP use in the 2015 survey.

Placement of RAP in construction and demolition landfills is rare. Since the beginning of the survey in 2009, the average amount of RAP landfilled is less than 150,000 tons per year, or 0.2 percent. In 2015, the amount of RAP landfilled increased significantly to 1 percent due to three producers reporting sending RAP to a landfill. In 2016, the amount of RAP landfilled was 0.1 percent, which is in line with previously recorded levels. Reclaiming 81.7 million tons of RAP for future use saved about 49.6 million cubic yards of landfill space in 2016.



	2009	2010	2011	2012	2013	2014	2015	2016
Accepted	67.2	73.5	79.1	71.3	76.1	75.8	78.0	81.8
Landfilled	0.1	0.0	0.3	0.2	0.1	0.2	1.0	0.1
Used in Other	0.7	0.8	0.7	0.2	1.5	0.6	1.6	0.4
Used in Cold Mix	1.5	1.6	0.2	0.2	0.2	0.2	0.2	0.2
Used in Aggregate	6.2	7.3	4.9	3.6	4.0	8.5	5.5	3.7
Used in HMA/WMA	56.0	62.1	66.7	68.3	67.8	71.9	74.2	76.9

Figure 3: Comparison of Tons of RAP Accepted and Tons of RAP Used or Landfilled (Million Tons), 2009–2016

RAP Use by Sector

Asphalt pavement mixture producers' customers can be divided into two broad sectors: the private sector (Commercial & Residential) and the public sector (DOT or Other Agency). The "Other Agency" sector includes mixture produced for public works agencies, including city, county, and tribal transportation agencies, as well as the U.S. military and federal agencies, such as the Federal Aviation Administration, National Park Service, and U.S. Forest Service.

Figure 4 shows the total estimated amount of RAP used in each sector. These values were calculated using the average percentages of RAP reported by producers for each sector and adjusted to account for differences between reported RAP tonnage and tons calculated from the percentage by sector.

Figure 5 shows the average percentage of RAP used by each sector and total percentage of RAP used. The average percent RAP used by all sectors has seen variable growth from 2009 to 2016. The change in total percentage of RAP use has seen a decreased growth rate from 2009 to 2016. The growth rate decreased from 1.8 percent between 2009 and 2010 to 0.1 percent between 2015 and 2016.

Since the 2012 construction season, the tonnage of RAP used by each sector has generally moved up or down with the total tonnage used by the sector. This is shown in Figure 6. For the 2016 construction season, the percent RAP in the

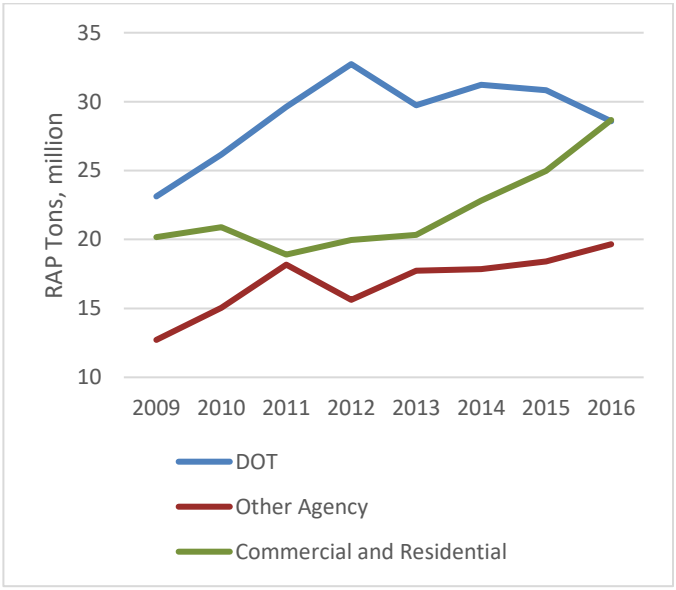


Figure 4: RAP Use by Sector (Million Tons)

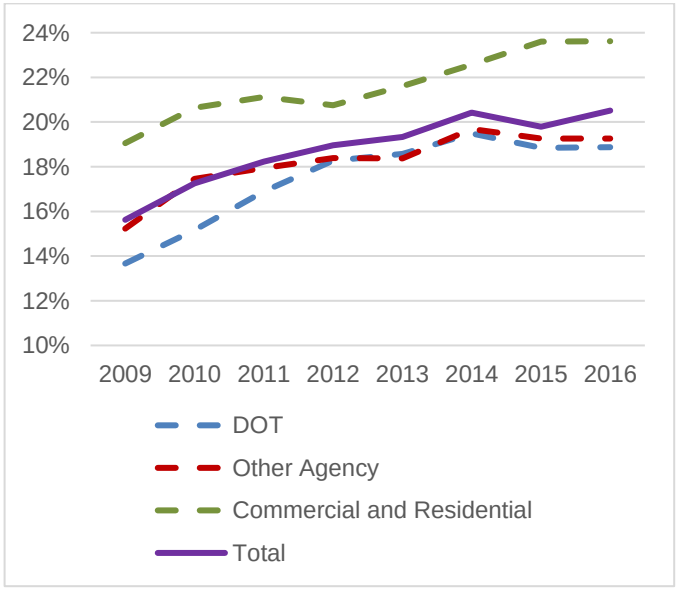


Figure 5: Average Percent RAP Used by Sector

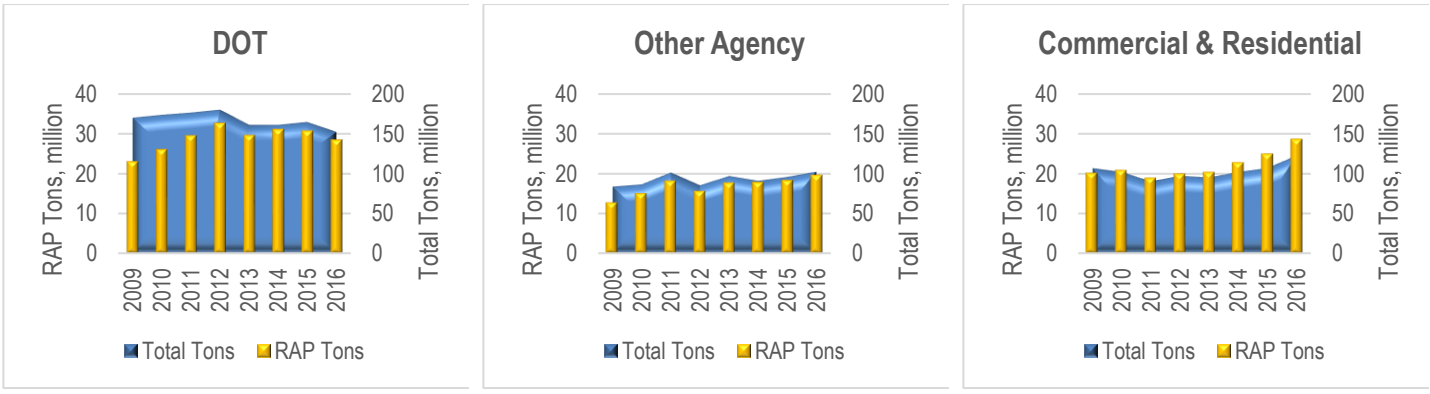


Figure 6: RAP Tons and Total Mixture Tons Comparison (Million Tons)

DOT sector declined from 2015 to 2016, but it increased for the Other Agency and Commercial & Residential sectors. The increased percentage of RAP used in the Commercial & Residential sector, combined with an increase in the tons of mixture used for this sector, offset declines in the DOT sector, resulting in a slight gain (0.2 percent) in the national average percentage of RAP used.

RAP Use by State

Figure 7 and Table 5 show the average percentage of RAP used in HMA/WMA mixtures in each state by construction season based on reported RAP tons used in HMA/WMA mixtures and total reported tonnage. It should be noted that the accuracy of data for individual states varies depending on the number of responses received from producers in each state and the total number of tons accounted for in the responses.

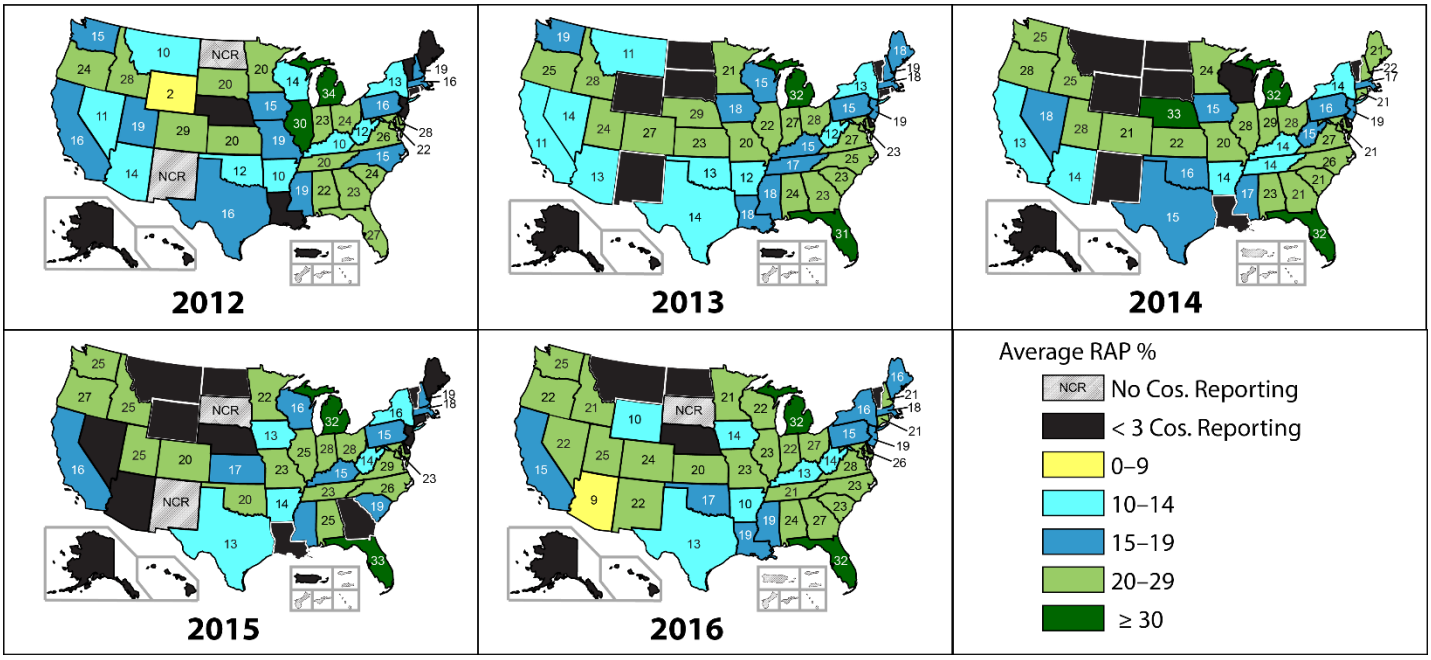


Figure 7: Estimated Average Percent of RAP by State for Each Construction Season Survey

Figure 8 revisualizes the Table 5 data, showing the number of states reporting average RAP percentages at the various ranges by construction seasons. The number of states reporting average RAP percentages 20 percent or greater has increased significantly, rising from 10 states in 2009 to 27 states in 2014; after a decrease to 21 states in the 2015 construction season, the number of states with an average RAP percentage of 20 percent or greater rebounded to 29 in 2016. The number of states reporting RAP percentages less than 15 percent has decreased from 23 states in 2009 to just two states in 2014 and then remained steady at 10 states in 2015 and 2016.

Table 5: Average Estimated RAP Percent

State	Average RAP Percent					State	Average RAP Percent				
	2012	2013	2014	2015	2016		2012	2013	2014	2015	2016
Alabama	22%	24%	23%	25%	24%	Montana	10%	11%	*	*	*
Alaska	*	*	*	*	*	Nebraska	*	29%	33%	*	*
Arizona	14%	13%	14%	*	9%	Nevada	11%	14%	18%	*	22%
Arkansas	10%	12%	14%	14%	10%	New Hampshire	19%	19%	22%	19%	21%
California	16%	11%	13%	16%	15%	New Jersey	*	19%	19%	*	19%
Colorado	29%	27%	21%	20%	24%	New Mexico	NCR	*	*	NCR	22%
Connecticut	*	*	21%	*	21%	New York	13%	13%	14%	16%	16%
Delaware	28%	*	*	*	*	North Carolina	15%	25%	26%	26%	23%
Dist. of Columbia	NCR	*	NCR	NCR	NCR	North Dakota	NCR	*	*	*	*
Florida	27%	31%	32%	33%	32%	Ohio	24%	28%	28%	28%	27%
Georgia	23%	23%	21%	*	27%	Oklahoma	12%	13%	16%	20%	17%
Hawaii	*	*	*	*	*	Oregon	24%	25%	28%	27%	22%
Idaho	28%	28%	25%	25%	21%	Pennsylvania	16%	15%	16%	15%	15%
Illinois	30%	22%	28%	25%	23%	Puerto Rico	*	*	NCR	*	NCR
Indiana	23%	27%	29%	28%	22%	Rhode Island	*	*	*	*	*
Iowa	15%	18%	15%	13%	14%	South Carolina	24%	23%	21%	19%	23%
Kansas	20%	23%	22%	17%	20%	South Dakota	20%	*	*	NCR	*
Kentucky	10%	15%	14%	15%	13%	Tennessee	20%	17%	14%	23%	21%
Louisiana	*	18%	*	*	19%	Texas	16%	14%	15%	13%	13%
Maine	*	18%	21%	*	16%	Utah	19%	24%	28%	25%	25%
Maryland	22%	23%	21%	23%	26%	Vermont	*	*	*	*	*
Massachusetts	16%	18%	17%	18%	18%	Virginia	26%	27%	27%	29%	28%
Michigan	34%	32%	32%	32%	32%	Washington	15%	19%	25%	25%	25%
Minnesota	20%	21%	24%	22%	21%	West Virginia	12%	12%	15%	14%	14%
Mississippi	19%	18%	17%	17%	19%	Wisconsin	14%	15%	*	16%	22%
Missouri	19%	20%	20%	23%	23%	Wyoming	2%	*	*	*	10%

No Companies Reporting	< 3 Companies Reporting	0–9%	10–14%	15–19%	20–29%	≥ 30%

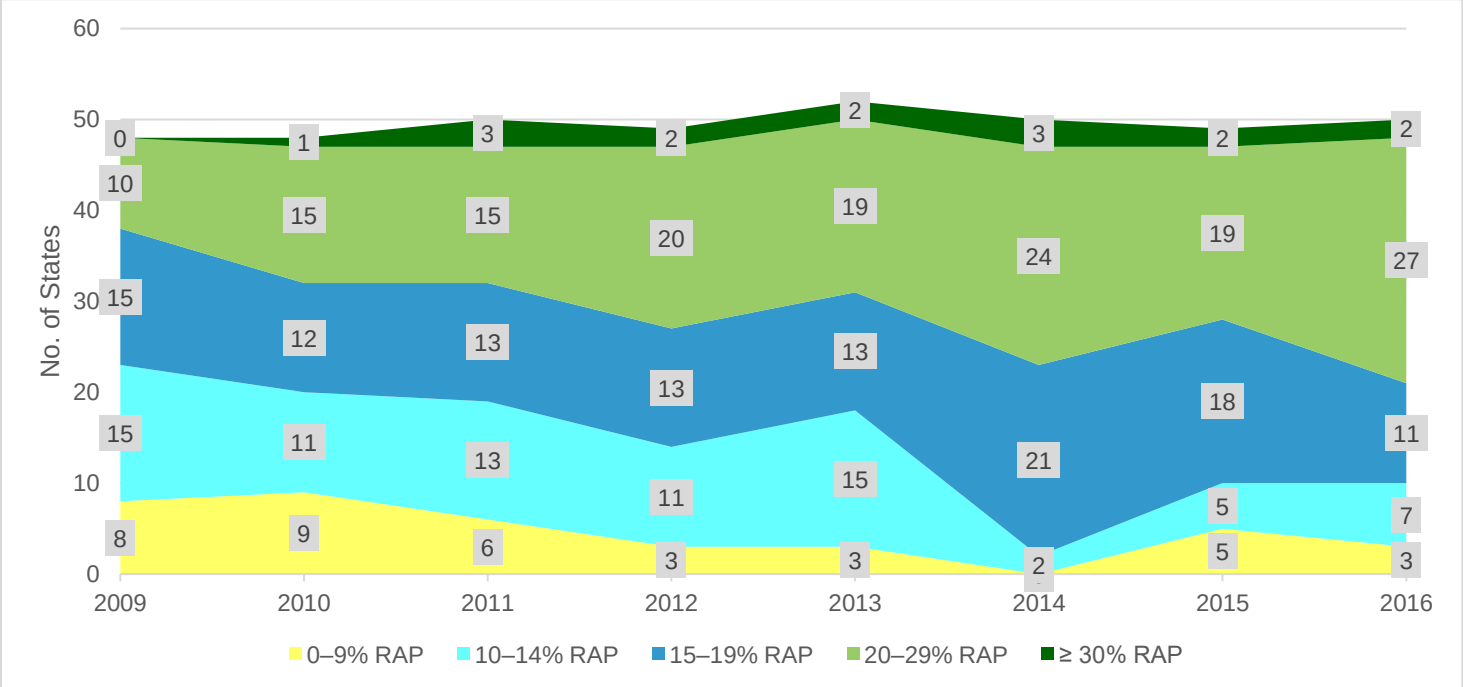


Figure 8: Count of States at Different Average RAP Percentages in HMA/WMA Mixtures

RAP Stockpiles

During the 2016 construction season, an estimated 500,000 tons more RAP was accepted by asphalt mixture producers than was used across all purposes during the year. In 2012, 2014, and 2015, more RAP was used than was received, indicating producers were drawing upon stockpiled RAP in those years.

The estimated amount of RAP stockpiled nationwide increased by 9.9 percent from 85.13 million tons at the end of the 2015 construction season to 93.59 million tons at the end of the 2016 construction season. For 2016, 89.5 percent of producers reported having stockpiled RAP, up slightly from 88 percent of producers in 2015.

Table 6 shows the reported and estimated amount of RAP stockpiled by state at the end of the 2016 construction season. To calculate the estimated values, reported tons of RAP stockpiled were divided by the ratio of total reported tons of mixture produced to estimated tons of mixture produced. The total tonnage row in Table 6 includes stockpiled tonnages from states with fewer than three producers reporting. Georgia has an estimated 7.58 million tons of RAP stockpiled, significantly more than any other state, much of it reportedly generated and stored in the Metro Atlanta region. Outside of Georgia, the more densely populated states with large urban areas show the highest amount of RAP stockpiled, as would be expected.

Table 6: Reported Tons of RAP Stockpiled

State	Reported Tons Stockpiled (Million) 2015	2016	Estimated Tons Stockpiled (Million) 2015	2016	State	Reported Tons Stockpiled (Million) 2015	2016	Estimated Tons Stockpiled (Million) 2015	2106
Alabama	0.92	1.14	1.85	2.28	Montana	*	*	*	*
Alaska	*	*	*	*	Nebraska	*	*	*	*
Arizona	*	0.36	*	1.05	Nevada	*	0.23	*	0.79
Arkansas	0.20	0.23	0.34	0.54	New Hampshire	0.10	0.08	0.13	0.08
California	2.17	1.63	5.93	4.20	New Jersey	*	2.33	*	3.84
Colorado	0.24	0.72	1.15	2.28	New Mexico	NCR	0.10	NCR	0.35
Connecticut	*	1.02	*	1.86	New York	1.11	1.37	2.58	4.10
Delaware	*	*	*	*	North Carolina	1.63	1.10	3.02	3.46
District of Columbia	NCR	NCR	NCR	NCR	North Dakota	*	*	*	*
Florida	1.55	1.08	3.68	3.02	Ohio	1.98	2.17	3.13	3.96
Georgia	*	5.27	*	7.58	Oklahoma	0.55	0.39	1.67	0.91
Hawaii	*	*	*	*	Oregon	0.52	0.65	1.51	2.19
Idaho	0.26	0.34	0.72	0.73	Pennsylvania	0.97	1.59	4.11	4.12
Illinois	1.13	0.59	3.43	3.79	Puerto Rico	*	NCR	*	NCR
Indiana	1.69	1.75	3.51	3.65	Rhode Island	*	*	*	*
Iowa	0.20	0.42	0.48	0.76	South Carolina	0.11	0.46	0.35	0.95
Kansas	0.51	0.56	1.07	1.19	South Dakota	NCR	*	NCR	*
Kentucky	0.71	0.44	1.13	0.94	Tennessee	1.98	0.85	2.80	2.98
Louisiana	*	0.18	*	0.25	Texas	1.29	0.48	3.13	1.44
Maine	*	0.44	*	0.34	Utah	1.72	1.41	1.84	1.25
Maryland	0.77	1.18	1.76	2.64	Vermont	*	*	*	*
Massachusetts	0.51	0.97	1.10	2.04	Virginia	1.65	2.20	3.06	3.57
Michigan	2.32	1.80	4.14	4.26	Washington	0.56	0.54	0.87	1.67
Minnesota	1.64	0.93	3.61	2.61	West Virginia	0.05	0.13	0.11	0.24
Mississippi	0.57	0.48	1.22	0.83	Wisconsin	1.27	1.46	1.71	2.45
Missouri	0.20	1.11	0.76	3.84	Wyoming	*	0.03	*	0.21
					Total†	37.62	41.15	85.13	93.59

NCR No Companies Responding

* Fewer than 3 Companies Reporting

† Includes Values from States with Fewer than 3 Companies Reporting

RAP Fractionation

Table 7 shows the average percentage of RAP fractionated into two or more sizes by state, as reported by survey participants. **These results are representative *only* of the survey participants and do not completely reflect practices in a given state.** This also helps explain the state-level variability from year to year. Producers and SAPAs were not questioned about state specifications regarding fractionation and recycled material content.

As the scatter plot in Figure 9 shows, there does not seem to be a clear correlation between fractionation and the percentage of RAP used by a state. For example, Kentucky reports 75 percent of RAP is fractionated and averages 13 percent RAP in mixtures, while Nevada reported no fractionation but averages 22 percent RAP.

Table 7: Reported Percentage of RAP Fractionated, by State, 2015–2016

State	% Fractionated		State	% Fractionated		State	% Fractionated	
	2015	2016		2015	2016		2015	2016
Alabama	45%	13%	Louisiana	*	80%	Ohio	19%	6%
Alaska	*	*	Maine	*	0%	Oklahoma	83%	50%
Arizona	*	0%	Maryland	0%	0%	Oregon	3%	7%
Arkansas	18%	1%	Massachusetts	6%	4%	Pennsylvania	19%	2%
California	0%	31%	Michigan	10%	20%	Puerto Rico	*	NCR
Colorado	26%	71%	Minnesota	0%	3%	Rhode Island	*	*
Connecticut	*	0%	Mississippi	43%	27%	South Carolina	24	63%
Delaware	*	*	Missouri	0%	32%	South Dakota	NCR	*
Dist. of Columbia	NCR	NCR	Montana	*	*	Tennessee	20%	22%
Florida	0%	6%	Nebraska	*	*	Texas	50%	15%
Georgia	*	1%	Nevada	*	0%	Utah	6%	13%
Hawaii	*	*	New Hampshire	0%	0%	Vermont	*	*
Idaho	8%	12%	New Jersey	*	16%	Virginia	34%	34%
Illinois	56%	89%	New Mexico	NCR	52%	Washington	18%	0%
Indiana	46%	72%	New York	15%	12%	West Virginia	0%	15%
Iowa	0%	3%	North Carolina	34%	39%	Wisconsin	2%	14%
Kansas	0%	3%	North Dakota	*	*	Wyoming	*	0%
Kentucky	50%	75%			**Average, Where Used†**		23%	22%

NCR No Companies Responding

* Fewer than 3 Companies Reporting

† Includes Values from States with Fewer than 3 Companies Reporting

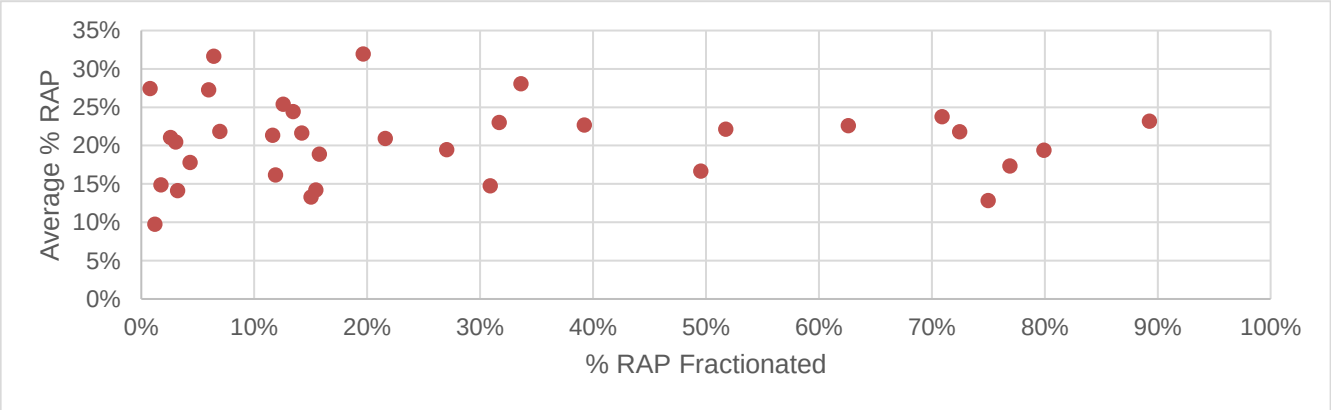


Figure 9: Scatter Plot Showing Reported Average Percentage of RAP in Asphalt Mixtures Relative to Reported Percent of RAP Fractionated, 2016

RAP Recycling Agent Use

Table 8 shows the percentage of reported tons of RAP-containing mixtures produced using softer binder or recycling agents by state. **These results are representative *only* of the survey participants and do not completely reflect practices in a given state.** While there is no strong relationship between the amount of RAP mixtures using softer binder or recycling agents and percentage of RAP used by the state, it should be noted that of the 25 states using more than 20 percent RAP, seven of them report using softer binders in more than 40 percent of their RAP mixtures and four of these states reported no use of softer binders or recycling agents in RAP mixtures.

Table 8: Percentage of RAP Mixes Using Softer Binder and/or Recycling Agents by State, 2016

State	Softer Binder	Recyc. Agent	State	Softer Binder	Recyc. Agent	State	Softer Binder	Recyc. Agent
Alabama	0%	0%	Louisiana	15%	0%	Ohio	24%	0%
Alaska	*	*	Maine	4%	0%	Oklahoma	4%	0%
Arizona	9%	0%	Maryland	12%	8%	Oregon	32%	31%
Arkansas	0%	0%	Massachusetts	9%	½%	Pennsylvania	3%	5%
California	14%	13%	Michigan	24%	0%	Puerto Rico	NCR	NCR
Colorado	44%	0%	Minnesota	5%	3%	Rhode Island	*	*
Connecticut	0%	0%	Mississippi	0%	0%	South Carolina	0.5%	0%
Delaware	*	*	Missouri	4%	0%	South Dakota	*	*
Dist. of Columbia	NCR	NCR	Montana	*	*	Tennessee	0%	0%
Florida	73%	4%	Nebraska	*	*	Texas	14%	NCR
Georgia	0%	0%	Nevada	12%	0%	Utah	50%	2%
Hawaii	*	*	New Hampshire	0%	0%	Vermont	*	*
Idaho	76%	0%	New Jersey	7%	0%	Virginia	5%	½%
Illinois	58%	¼%	New Mexico	28%	0%	Washington	13%	0%
Indiana	37%	0%	New York	1%	6%	West Virginia	0%	0%
Iowa	8%	½%	North Carolina	49%	0%	Wisconsin	7%	6%
Kansas	73%	2%	North Dakota	*	*	Wyoming	0%	0%
Kentucky	2%	16%				**Average, When Used†**	24%	7%

NCR No Companies Responding for the State to the Survey

* Fewer than 3 Companies Reporting

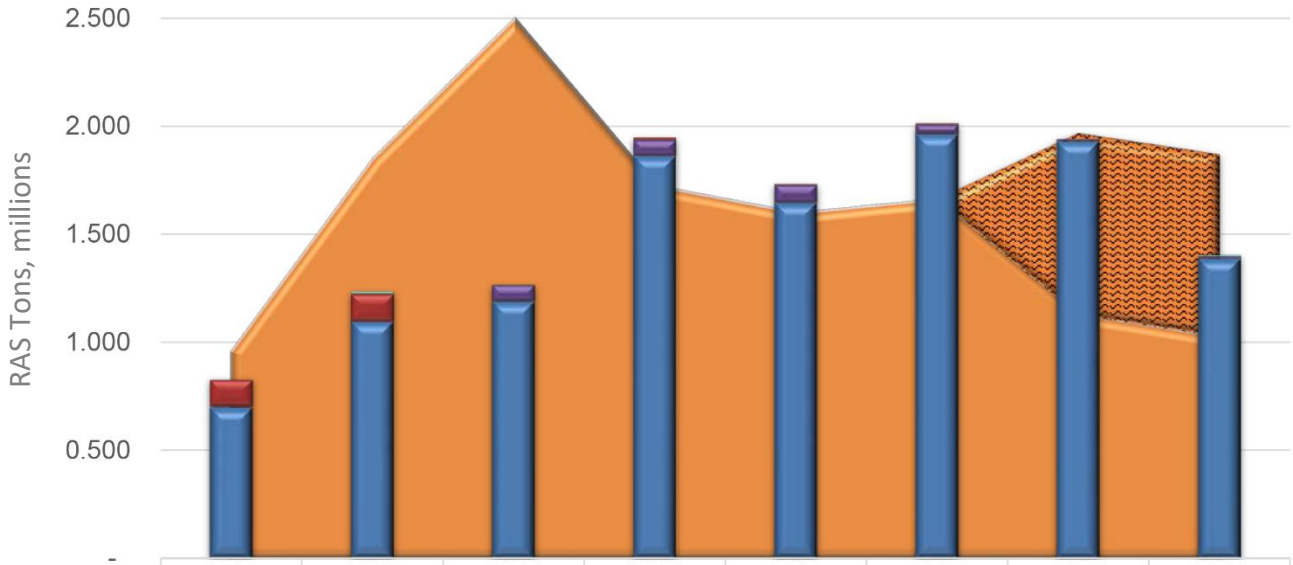
† Includes Values from States with Fewer than 3 Companies Reporting

Although the data is highly dependent upon the companies responding to the survey each year, in states where recycling agents are reportedly used, the average percentage of RAP mixtures incorporating softer binders was 24 percent during the 2016 construction season, which is unchanged from the 2015 survey. The percentage of RAP mixtures incorporating recycling agents, however, more than doubled to 7 percent in 2016, compared to 3 percent in 2015.

Reclaimed Asphalt Shingles

Table 4 includes the national summary of RAS data from the 2015 and 2016 construction season surveys. The information requested in the survey is detailed in Appendix A and summarized in Table A1, Section 3. State-level data is reported in Appendix B. Producers and SAPAs were not asked about allowable RAS limits or binder replacement requirements for their states. Figure 10 is a visual representation of the estimated total tons of RAS used in asphalt mixtures, aggregate, cold-mix asphalt, and other uses, as well as the amount landfilled, from the 2009 to 2016 construction season surveys.

During the 2016 construction season, the total estimated amount of unprocessed and processed shingles received by producers was 1.873 million tons, which is more than combined amount of RAS used in asphalt mixtures (1.390 million tons) and in aggregate (9,000 tons). This is a 27.9 percent decline from the 1.93 million total tons of RAS used during the 2015 construction season and it correlates with an across-the-board decrease in the use of RAS in asphalt pavement mixtures among all sectors. About 5,000 tons of RAS accepted by producers were landfilled during the 2016 construction season. An estimated 13.2 million tons of waste shingles are produced annually;[1] therefore, asphalt mixture producers in 2016 accepted about 14 percent of the total available supply of waste shingles.



	2009	2010	2011	2012	2013	2014	2015	2016
Processed Shingles Accepted	0	0	0	0	0	0	0.842	0.846
Unprocessed Shingles Accepted	0.957	1.851	2.500	1.724	1.599	1.664	1.129	1.027
Landfilled	-	0.007	0.000	-	-	-	-	0.005
Used in Other	0.123	0.125	-	0.012	0.005	0.006	-	-
Used in Cold Mix	-	-	-	-	-	-	-	-
Used in Aggregate	0.006	0.003	0.074	0.073	0.082	0.043	0.009	0.009
Used in HMA/WMA	0.702	1.100	1.192	1.863	1.647	1.964	1.931	1.390

Figure 10: Comparison of Tons of RAS Accepted and Tons of RAS Used or Landfilled (Million Tons), 2009–2016. Processed RAS Acceptance First Tracked in 2015

[1] According to the Asphalt Roofing Manufacturers Association (ARMA, 2015), about 13.2 million waste shingles are generated annually — about 12 million tons of post-consumer asphalt shingles (PCAS) and 1.2 million tons of manufacturing waste (MWAS). This is an increase from the commonly cited figure of 11 million tons (NAHB, 1998), reflecting changes in housing stock and the housing market since 1998.

As shown in Figure 10, beginning in the 2012 construction season, producers began reporting using RAS in greater quantities than they accepted. When this trend was first noticed, producers were contacted to confirm the reported values. All producers contacted indicated they either had RAS stockpiled or were purchasing RAS from shingle processors. To capture the volume of processed shingles accepted by producers, the 2015 survey began asking producers "How many tons of processed shingles were accepted/delivered to your facilities in the state in 2015?" During the 2016 construction season, the estimated amount of unprocessed shingles accepted by producers declined 9 percent from 1.129 million tons in 2015 to 1.027 million tons in 2016. There was a slight (0.5 percent) increase in the acceptance of processed shingles in 2016 compared to 2015, but this was not a large enough difference to offset the 5 percent decrease in the total amount of RAS (processed + unprocessed) accepted during the 2016 construction season compared to 2015.

The number of companies using RAS fell from 89 in 2015 to 76 during the 2016 construction season. The percentage of producers reporting use of RAS decreased from 41.6 percent of respondents in 2015 to 33.2 percent in 2016.

RAS Use by Sector

Figure 11 shows the total estimated amount of RAS used in each of the three sectors of the paving market. These values were calculated using the average percentages of RAS reported by producers for the sectors and adjusted to account for differences between reported RAS tonnage and tons calculated from the percentage by sector. There was a notable across-the-board decrease in the tons of RAS used by DOTs from the 2015 to 2016 construction. The Other Agencies and the Commercial & Residential sectors saw continued decrease in RAS use from 2015 to 2016.

Figure 12 shows the average RAS percent used in asphalt mixtures for the three sectors. These values were calculated using the average percentages of RAS reported for the different sectors and adjusted to account for differences between reported RAS tonnage and tons calculated from the percentage by sector. Although previous years' surveys saw relatively steady growth across all sectors from 2009 to 2014 with some year-to-year variation, there was a leveling of total RAS use from 2012 to 2015 and notable decline in the 2016 construction season with the average percentage RAS used falling from 0.54 percent in 2015 to 0.37 percent in the 2016 construction season. A significant increase in DOT usage of RAS in 2015 masked a reduced usage of the material in the Other Agency and Commercial and Residential sectors that year.

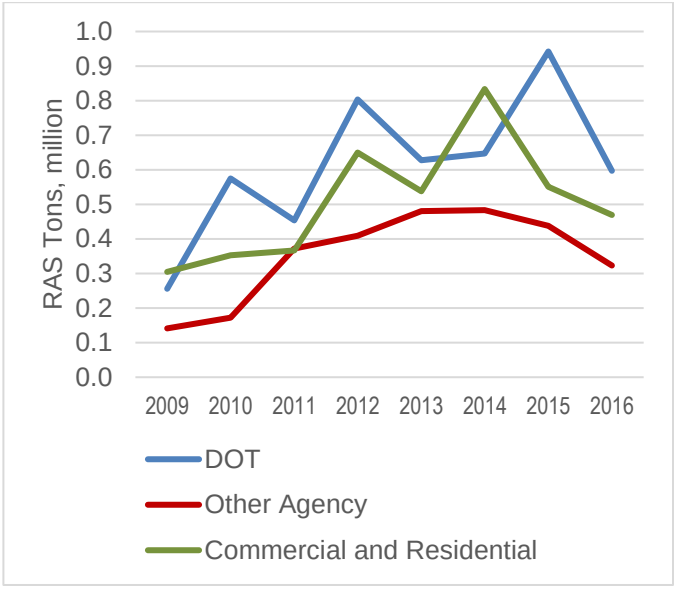


Figure 11: Estimated RAS Use by Sector (Million Tons)

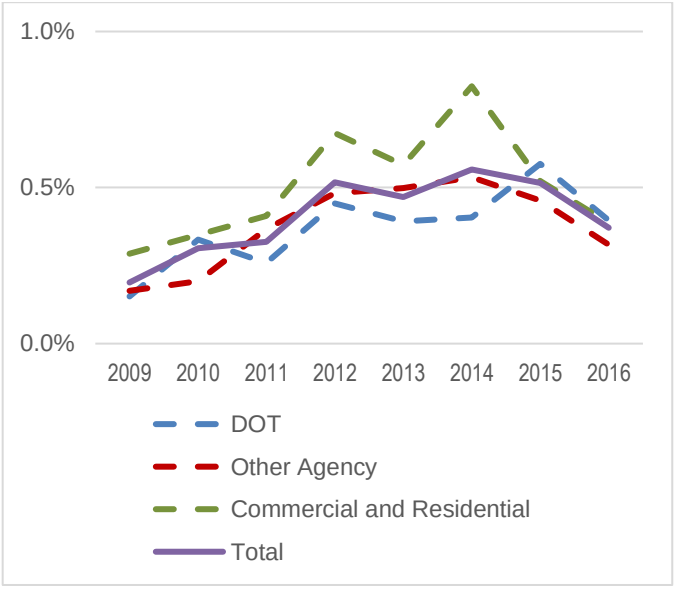


Figure 12: Average Percent RAS Used by Sector

In 2016, producers and SAPAs were asked which sectors allow RAS to be included in asphalt mixtures. Forty-six states provided responses, and this information is summarized in Table 9. In cases where conflicting answers were provided, a middle ground was assumed with SAPA responses being given greater weight in regard to the public sectors' RAS use and contractors' responses being given greater weight for the private sector. Most states reported that RAS is allowed in at least some mixtures and sectors. Twenty-six DOTs reportedly allow RAS in some asphalt pavement mixtures, and eight other DOTs allow it in all mixtures. According to SAPA responses, DOTs allow RAS use most commonly in base and intermediate courses. RAS use is allowed in some Other Agency sector mixtures in 27 states, with an additional eight states allowing RAS in all mixtures for that sector. Similarly, RAS is allowed in at least some Commercial & Residential sector mixtures in 42 states. Seven states — Idaho, Indiana, Iowa, Minnesota, Nebraska, Oregon, and Virginia — allow RAS in all mixtures, while five other states — Hawaii, Nevada, North Dakota, Utah, and West Virginia — do not allow the use of RAS. In Nevada, RAS acceptance for stockpiling was reported.

Table 9: Sectors Allowing RAS, 2016

State	RAS Allowed In?			State	RAS Allowed In?		
	DOT Mixtures	Other Agency Mixtures	Commercial & Residential Mixtures		DOT Mixtures	Other Agency Mixtures	Commercial & Residential Mixtures
Alabama	Some	Some	Some	Montana	Some	None	None
Alaska	DNA	DNA	DNA	Nebraska	All	All	All
Arizona	Some	Some	All	Nevada	None	None	None
Arkansas	Some	Some	Some	New Hampshire	None	None	Some
California	None	Some	Some	New Jersey	Some	Some	All
Colorado	None	Some	All	New Mexico	Some	All	All
Connecticut	Some	None	All	New York	Some	Some	All
Delaware	Some	Some	All	North Carolina	Some	Some	All
District of Columbia	NCR	NCR	NCR	North Dakota	None	None	None
Florida	None	None	Some	Ohio	Some	Some	All
Georgia	Some	Some	All	Oklahoma	None	Some	All
Hawaii	None	None	None	Oregon	All	All	All
Idaho	All	All	All	Pennsylvania	Some	Some	All
Illinois	Some	Some	All	Puerto Rico	NCR	NCR	NCR
Indiana	All	All	All	Rhode Island	None	None	Some
Iowa	All	All	All	South Carolina	Some	Some	All
Kansas	Some	Some	All	South Dakota	None	Some	All
Kentucky	Some	Some	All	Tennessee	Some	None	All
Louisiana	None	Some	None	Texas	Some	Some	All
Maine	Some	None	All	Utah	None	None	None
Maryland	Some	Some	All	Vermont	Some	None	All
Massachusetts	Some	Some	All	Virginia	All	All	All
Michigan	Some	Some	All	Washington	Some	Some	All
Minnesota	All	All	All	West Virginia	None	None	None
Mississippi	None	None	All	Wisconsin	All	Some	All
Missouri	Some	Some	All	Wyoming	None	Some	All

DNA Did Not Answer
NCR No Companies Responding

RAS Use by State

Table 10 shows states where asphalt pavement mixture producers reported using RAS in 2009 through 2016. Figure 13 shows states where producers reported using RAS from 2011 through 2016. Red indicates a state where RAS use was not reported that construction season. The number of states where producers reported using RAS increased annually

Table 10: States Reporting RAS Use

State	RAS Used?							
	2009	2010	2011	2012	2013	2014	2015	2016
Alabama	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alaska	No	No	No	No	No	No	No	No
Arizona	No	No	No	No	No	No	No	No
Arkansas	No	No	Yes	Yes	Yes	Yes	Yes	Yes
California	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Colorado	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Connecticut	No	No	No	No	Yes	Yes	Yes	Yes
Delaware	Yes	Yes	NCR	Yes	Yes	Yes	Yes	Yes
District of Columbia	NCR	NCR	NCR	NCR	No	NCR	NCR	NCR
Florida	Yes	Yes	No	No	Yes	Yes	Yes	No
Georgia	No	No	Yes	Yes	Yes	No	No	Yes
Hawaii	No	No	No	No	No	No	No	No
Idaho	No	No	No	No	No	No	No	No
Illinois	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Indiana	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Iowa	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kansas	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Kentucky	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Louisiana	No	No	No	No	Yes	No	No	Yes
Maine	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Maryland	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Massachusetts	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Michigan	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Minnesota	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mississippi	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Missouri	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Montana	No	No	No	No	No	No	No	No
Nebraska	NCR	NCR	No	Yes	Yes	No	No	Yes
Nevada	No	Yes	No	No	No	No	No	Yes
New Hampshire	No	No	Yes	Yes	Yes	Yes	Yes	Yes
New Jersey	No	No	No	No	Yes	No	No	No
New Mexico	NCR	NCR	No	NCR	No	No	NCR	Yes
New York	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
North Carolina	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
North Dakota	NCR	NCR	No	NCR	No	No	No	No
Ohio	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Oklahoma	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Oregon	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pennsylvania	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Puerto Rico	No	No	No	No	No	NCR	No	NCR
Rhode Island	No	No	No	No	No	No	No	No
South Carolina	No	No	Yes	No	Yes	Yes	No	Yes
South Dakota	No	No	Yes	Yes	Yes	Yes	NCR	Yes
Tennessee	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Texas	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Utah	No	No	No	No	No	No	No	No
Vermont	No	No	No	Yes	Yes	Yes	Yes	No
Virginia	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Washington	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
West Virginia	Yes	Yes	No	No	No	No	No	No
Wisconsin	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Wyoming	No	No	No	No	Yes	No	No	Yes

NCR	= No Companies Responding
Yes	= RAS Use Reported
No	= No RAS Use Reported

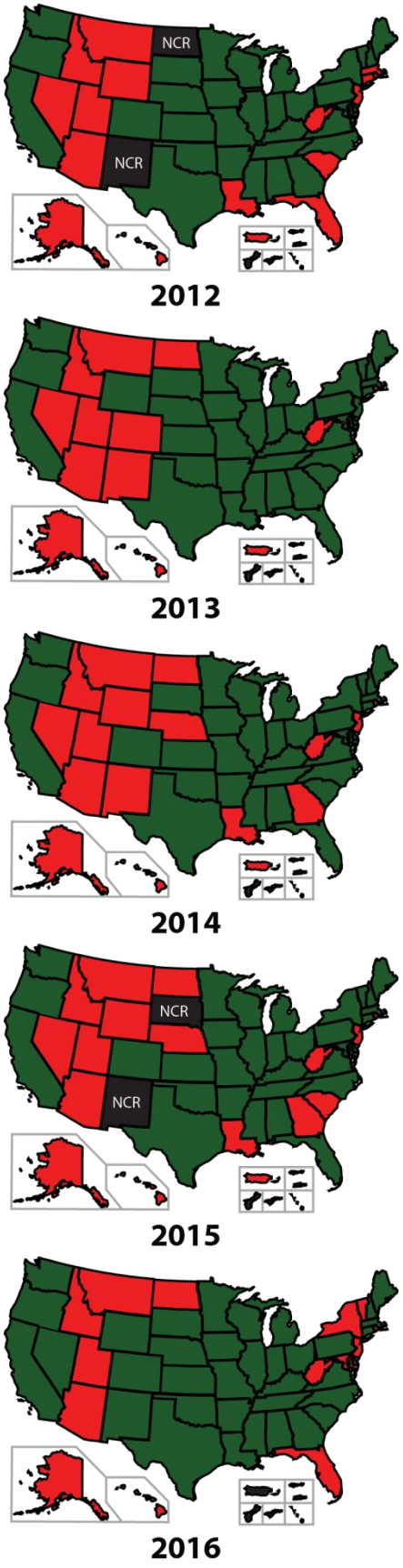


Figure 13: States with Companies Reporting Using RAS by Construction Season

from 22 in 2009 to 38 in 2013, but decreased to 34 in 2014 and 32 in 2015. During the 2016 construction season, 36 states reported RAS use. Maryland and New York for the first time since 2009 reported no RAS use during the 2016 construction season survey, while New Mexico reported its first RAS use in 2016.

Presumed RAS Binder Blending

Producers were also asked what percentage of the RAS binder is assumed to blend with virgin asphalt binders when performing mixture designs. The maximum recycled binder ratio (RBR) is dependent upon the properties of the aged asphalt in the RAS and is important to assure there is enough blended binder in mixtures to resist cracking (West, 2016). Lower blending values normally increase the amount of virgin asphalt required in a mixture, and indicate that the amount of RAS added to mixtures could increase. Note that higher percentages of RAS will normally require the use of softer binders and/or recycling agents.

Table 11 shows the minimum and maximum amount of assumed blending reported by producers in 2016. As was the case in 2015, most responses fell between 60 and 80 percent, with a low of 30 percent and a high of 100 percent during 2016. It is important to note that these are reported assumptions used in mixture designs, not formal design guidance or state specifications. **The reported values are highly dependent upon the practices of the companies responding.**

Table 11: Reported Percent Presumed RAS Binder Blending with New Asphalt Binder

State	2016		State	2016	
	Min.	Max.		Min.	Max.
Alabama	71	80	Montana	DNA	DNA
Alaska	DNA	DNA	Nebraska	*	*
Arizona	60	60	Nevada	DNA	DNA
Arkansas	60	85	New Hampshire	60	67
California	60	60	New Jersey	DNA	DNA
Colorado	60	60	New Mexico	78	78
Connecticut	70	70	New York	66	75
Delaware	*	*	North Carolina	75	90
District of Columbia	NCR	NCR	North Dakota	DNA	DNA
Florida	DNA	DNA	Ohio	60	80
Georgia	75	90	Oklahoma	75	80
Hawaii	DNA	DNA	Oregon	40	80
Idaho	DNA	DNA	Pennsylvania	70	90
Illinois	60	85	Puerto Rico	NCR	NCR
Indiana	65	90	Rhode Island	*	*
Iowa	67	84	South Carolina	65	65
Kansas	60	80	South Dakota	*	*
Kentucky	70	75	Tennessee	80	100
Louisiana	75	75	Texas	65	100
Maine	67	80	Utah	60	60
Maryland	70	70	Vermont	*	*
Massachusetts	50	75	Virginia	65	65
Michigan	100	100	Washington	60	85
Minnesota	50	65	West Virginia	DNA	DNA
Mississippi	60	60	Wisconsin	30	80
Missouri	60	100	Wyoming	75	75

DNA = Did Not Answer
NCR = No Companies Responding
* Fewer Than 3 Companies Reporting

RAS Recycling Agent Use

Table 12 shows the percentage of reported tons of RAS-containing mixtures produced using softer binder or recycling agents by state. **These results are representative *only* of the survey participants and do not completely reflect practices in a given state.** Unlike with RAP, there does appear to be a relationship between the amount of RAS mixtures using softer binder or recycling agents and percentage of RAS used by the state; four states — Arkansas, Illinois, Kansas, and North Carolina — reported using more than 1 percent RAS on average, and all but Arkansas report using softer binders in more than half of their RAS mixtures. Of these states, only Illinois reported using a recycling agent in a small percentage of RAS mixtures. Oregon reported high usage of both softer binders and recycling agents in RAS mixtures, despite using only 0.75 percent RAS on average in asphalt mixtures.

Table 12: Percentage of RAS Mixtures Using Softer Binder and/or Recycling Agents by State, 2016

State	Softer Binder	Recyc. Agent	State	Softer Binder	Recyc. Agent	State	Softer Binder	Recyc. Agent
Alabama	0%	0%	Louisiana	27%	14%	Ohio	0%	0%
Alaska	*	*	Maine	0%	0%	Oklahoma	39%	0%
Arizona	0%	0%	Maryland	0%	0%	Oregon	72%	75%
Arkansas	0%	0%	Massachusetts	0%	0%	Pennsylvania	0%	21%
California	28%	0%	Michigan	4%	0%	Puerto Rico	NCR	NCR
Colorado	0%	0%	Minnesota	0%	0%	Rhode Island	*	*
Connecticut	0%	0%	Mississippi	0%	0%	South Carolina	0%	0%
Delaware	*	*	Missouri	0%	0%	South Dakota	*	*
Dist. of Columbia	NCR	NCR	Montana	*	*	Tennessee	0%	0%
Florida	0%	0%	Nebraska	*	*	Texas	17%	0%
Georgia	0%	1½%	Nevada	0%	0%	Utah	0%	0%
Hawaii	*	*	New Hampshire	0%	0%	Vermont	*	*
Idaho	0%	0%	New Jersey	0%	0%	Virginia	0%	0%
Illinois	64%	⅓%	New Mexico	2%	0%	Washington	53%	0%
Indiana	9%	0%	New York	0%	0%	West Virginia	0%	0%
Iowa	19%	½%	North Carolina	54%	0%	Wisconsin	32%	29%
Kansas	91%	0%	North Dakota	*	*	Wyoming	0%	0%
Kentucky	0%	11%				**Average, When Used†**	37%	19%

NCR No Companies Responding for the State to the Survey

* Fewer than 3 Companies Reporting

† Includes Values from States with Fewer than 3 Companies Reporting

Although the data is highly dependent upon the companies responding to the survey each year, in states where recycling agents are reportedly used, the average percentage of RAS mixtures incorporating softer binders was 37 percent during the 2016 construction season, while the percentage of RAS mixtures incorporating recycling agents was at 19 percent. This question was first asked in the 2016 survey; therefore, prior-year data is not available.

Cost Savings from RAP and RAS

The use of RAP and RAS both reduce the need for virgin materials, conserving valuable asphalt and aggregates. Beyond the environmental benefit of resource preservation, the use of RAP and RAS can help lower up-front material costs for road construction, allowing road owners to achieve more roadway maintenance and construction activities within limited budgets. Table 13 summarizes the individual and cumulative savings realized during the 2016 construction season from the use of RAP and RAS in asphalt mixtures. In total, the use of RAP and RAS saved more than $2.1 billion during the 2016 construction season compared to the use of all virgin materials. This is about $500 million less than in 2015 due primarily to lower asphalt binder prices (Table 14).

Table 13: Material Savings, 2015–2016

Material	Material Quantity, Million Tons		% Agg.	% AC	Aggregate Cost Savings, $ Billion		Asphalt Binder Cost Savings, $ Billion		Total Cost Savings, $ Billion	
	2015	2016			2015	2016	2015	2016	2015	2016
RAP	74.2	76.9	95	5	$0.663	$0.713	$1.787	$1.333	$2.450	$2.046
RAS	1.931	1.390	50*	20	$0.009	$0.007	$0.186	$0.096	$0.195	$0.103
				Total	$0.672	$0.720	$1.973	$1.430	$2.645	$2.149

* Includes granules and mineral filler

The estimated savings shown in Table 13 were based on the cost factors shown in Table 14. Asphalt binder prices were estimated based upon an average of 2016 asphalt price indexes from 10 states (New Jersey, Maryland, Virginia, Ohio, Louisiana, Illinois, Georgia, Oregon, Missouri, and Florida). The average price of unmodified asphalts from these states for 2016 was about $333.46 per ton, down from the 2015 average price of $468.45. Three of the states (Florida, Louisiana, and Virginia) also included price indexes for modified asphalts. The average modified asphalt prices from these states for 2016 was $466.16 per ton, down from about $600.10 in 2015. Assuming that 10 percent of asphalt mixtures use modified asphalt binders, the 2016 average price of asphalt binders used in asphalt mixtures was $346.73 per ton, down 28 percent from 2015.

Most asphalt mixtures today use crushed stone as the primary aggregate, but they often include a small percentage of natural sand. The U.S. Geological Survey (USGS) reports the average price of Stone (Crushed) at $9.96 per ton, and Sand and Gravel (Construction) at $7.98 per ton for 2016 (USGS, 2017). Assuming the average asphalt pavement mixture contains 10 percent natural sand and 90 percent crushed stone, the average price of aggregate in an asphalt mixture is $9.76 per ton for the 2016 construction season, up 3.7 percent from 2015.

Table 14: Material Cost Factors, 2015–2016

Material		% of Market	Cost/Ton	
			2015	2016
Asphalt	Unmodified	90	$468.45	$333.46
	Modified	10	$600.10	$466.16
	Weighted Average		$481.62	$346.73
Aggregate	Crushed Stone	90	$9.58	$9.96
	Sand and Gravel	10	$7.78	$7.98
	Weighted Average		$9.41	$9.76

Minor additional cost savings, not calculated for this report, are associated with the use of RAS in stone-matrix asphalt and other specialty asphalt mixtures where the shingle fibers can replace mineral or cellulose fibers.

Warm-Mix Asphalt

Table 4 includes the national summary of WMA data from the 2015 and 2016 construction season surveys. The information requested in the survey is detailed in Appendix A and summarized in Table A1, Section 4. State-level data is reported in Appendix B. Producers were asked primarily about their tons of asphalt mixture produced at reduced temperatures (at least a 10°F reduction from typical mixture production temperatures). Producers were also asked about the different WMA technologies used. In addition, because WMA technologies are sometimes used without a reduction in production temperatures, producers were asked whether or not they used WMA technologies in the production of HMA; however, because the focus of this section of the survey is the production of reduced-temperature asphalt mixtures, producers were not asked to quantify the tonnage of HMA produced using WMA technologies.

The percentage of companies reporting the production of WMA saw rapid increases from the 2009 to 2011 construction seasons, but has held at between 70 and 80 percent of respondents from the 2011 to 2016 construction seasons, as shown in Figure 14. Increases in WMA tonnage as a percent of total tonnage have generally plateaued since 2013, as seen in Figure 15, with only modest increases through 2015. The 2016 construction season, however, saw a decrease in the production of WMA to 116.8 million tons, 31.2 percent of total tonnage, due largely to a significant decrease in total tonnage produced for DOT customers. A total of 165 companies, 72 percent of respondents, reported using WMA technologies during the 2016 construction season.

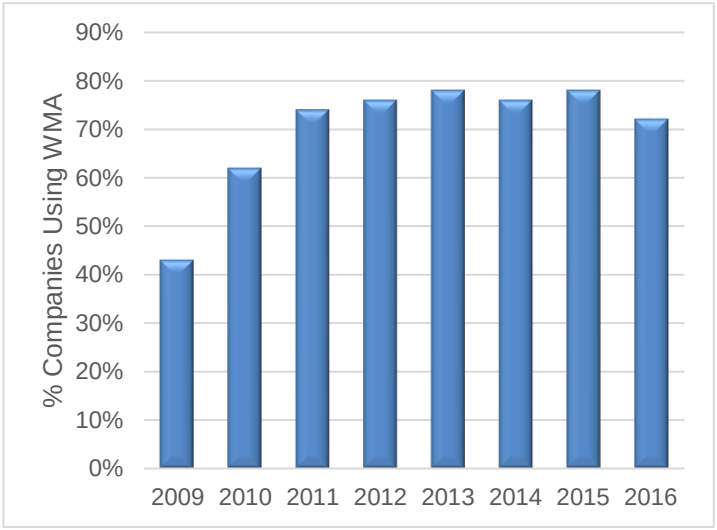


Figure 14: Percent of Companies Using WMA

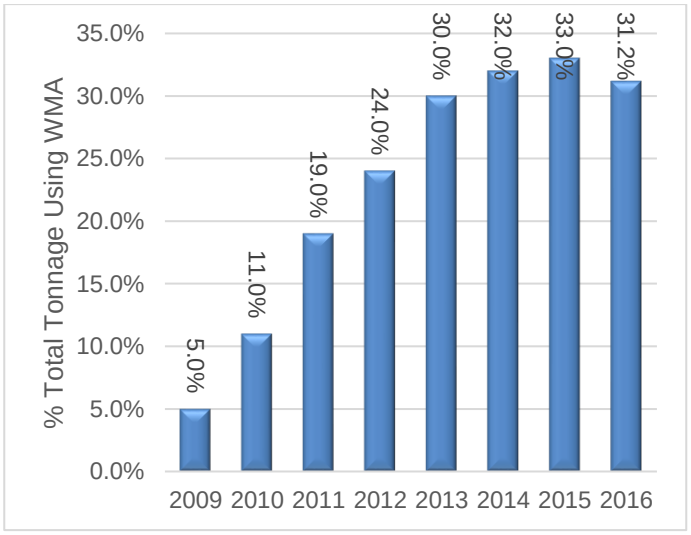
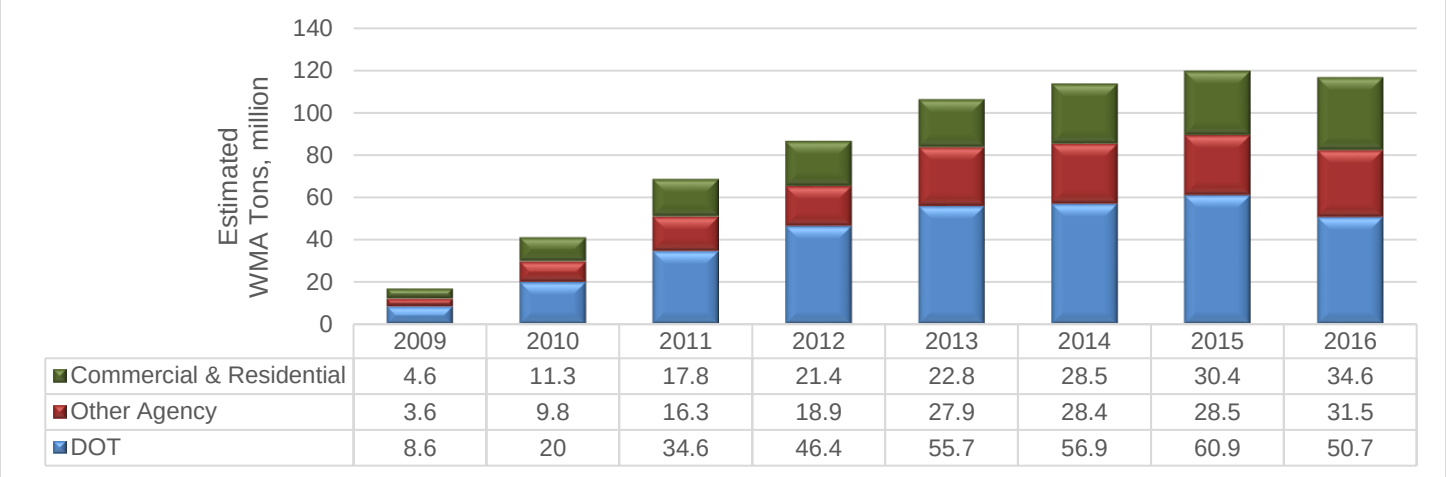


Figure 15: Percent Total Tonnage Produced Using WMA

WMA Use by Sector

Figure 16 shows a steady increase in the number of tons of WMA produced for each customer sector from 2011 to 2013, with modest increases continuing for the 2014 though 2015 construction seasons. For the 2016 construction season, WMA tonnage was down 2.5 percent from 2015. During 2016, growth in the production of WMA was driven by a 13.8 percent increase in WMA tonnage for the Commercial & Residential sector and a 10.5 percent increase in Other Agency sector mixtures; however, those gains could not offset a more than 16.7 percent decrease in WMA tonnage in the DOT sector from 2015 to 2016. It should be noted that overall DOT tonnage was down by 7.4 percent in 2016 (see Figure 2), so a commiserate decrease in the sector's WMA tonnage is understandable. All in all, during the 2016 construction season, 36.3 percent of all DOT sector tonnage, 32.4 percent of Other Agency sector tonnage, and 30.5 percent of Commercial & Residential sector tonnage was produced using WMA technologies.



	2009	2010	2011	2012	2013	2014	2015	2016
Commercial & Residential	4.6	11.3	17.8	21.4	22.8	28.5	30.4	34.6
Other Agency	3.6	9.8	16.3	18.9	27.9	28.4	28.5	31.5
DOT	8.6	20	34.6	46.4	55.7	56.9	60.9	50.7

Figure 16: Estimated Tons (Millions) of WMA by Sector, 2009–2016

WMA Use by State

Figure 17 shows the estimated percentage of total tons produced as WMA in each state. The national trend from 2009 through 2016 shows increased tons of asphalt mixture produced as WMA; however, a degree of fluctuation year-to-year is seen at the state level. The accuracy of data for individual states varies noticeably depending on the number of responses received from each state and the total number of tons represented by the respondents each year.

From 2015 to 2016, 14 states saw an increase of 5 percentage points or more in WMA production, while 17 states had a decrease of 5 percentage points or more in WMA production. Four states — Florida, Indiana, Mississippi, and Nebraska — had an increase of 25 percentage points or more in WMA production. Four states — Alaska, Georgia, Michigan, and Wyoming — had a decrease of 25 percentage points or more in WMA production. The reasons for these fluctuations are uncertain, but are likely tied, at least in part, to which companies participated in the 2016 construction season survey versus those who participated in the 2015 survey.

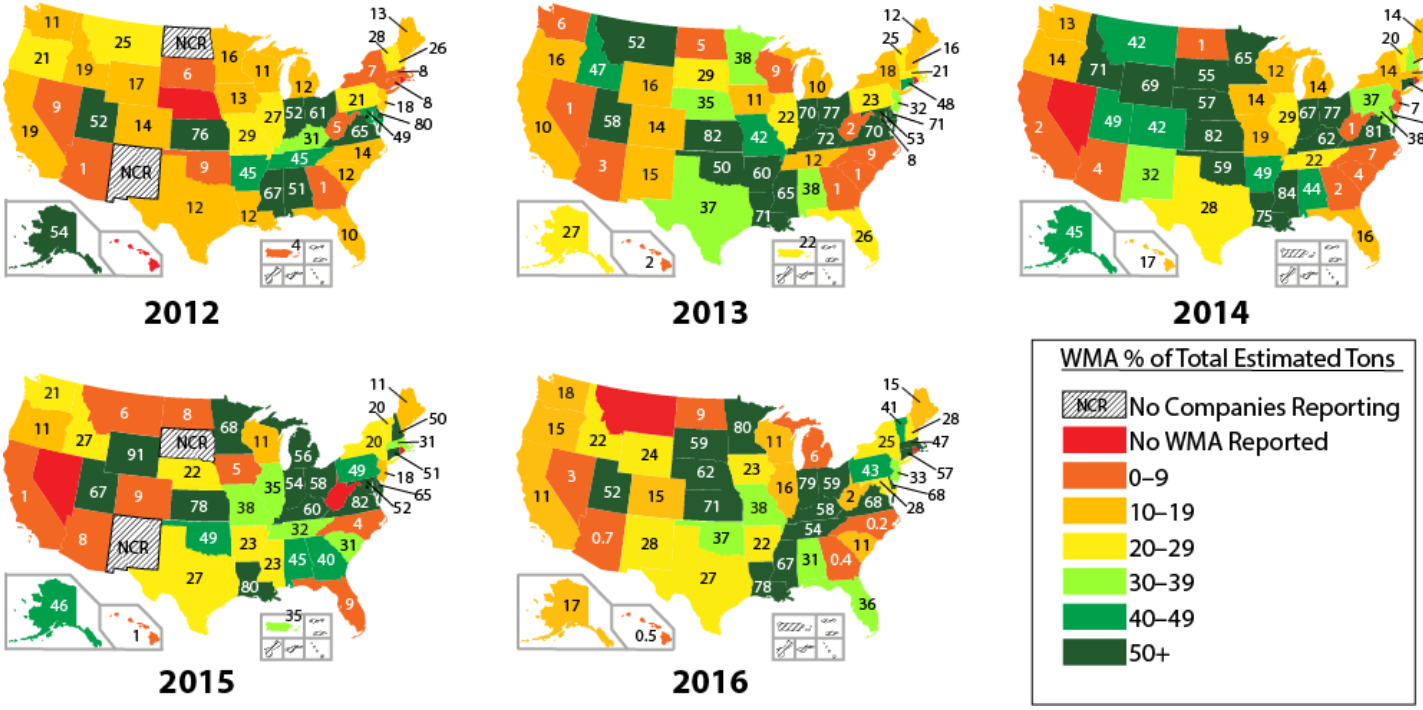


Figure 17: Estimated Percent of Total Production Using WMA by State, 2012–2016

As in 2015, WMA made up over half of the total asphalt mixture production in 14 states during 2016, and three of these states — Indiana, Louisiana, and Minnesota — reported WMA as 75 percent or more of total production in 2016. Montana and Rhode Island did not report the production of WMA in 2016.

WMA Technologies

As Table 15 and Figure 18 show, production plant foaming remains the most commonly used technology for the production of WMA, being used for nearly 77 percent of the WMA produced in 2016. The use of chemical additive technologies at 21.1 percent was down slightly in 2016 compared to 2015. Organic additives make up the remainder of the market; there was no reported use of additive foaming technologies during 2016. The percentage of WMA produced with additive technologies has grown significantly since 2011 when they made up less than 5 percent of the WMA technologies used.

Table 15: WMA Technologies Used as Percent of WMA Production, 2009–2016

WMA Technology	% of WMA Production							
	2009	2010	2011	2012	2013	2014	2015	2016
Production Plant Foaming %	83.0%	92.0%	95.4%	88.3%	87.0%	84.5%	72.0%	76.9%
Additive Foaming %	2.0%	1.0%	0.2%	2.0%	0.3%	0.0%	2.1%	0.0%
Chemical Additive %	15.0%	6.0%	4.1%	9.4%	12.1%	15.0%	25.2%	21.1%
Organic Additive %	0.3%	1.0%	0.3%	0.2%	0.0%	0.5%	0.7%	1.9%

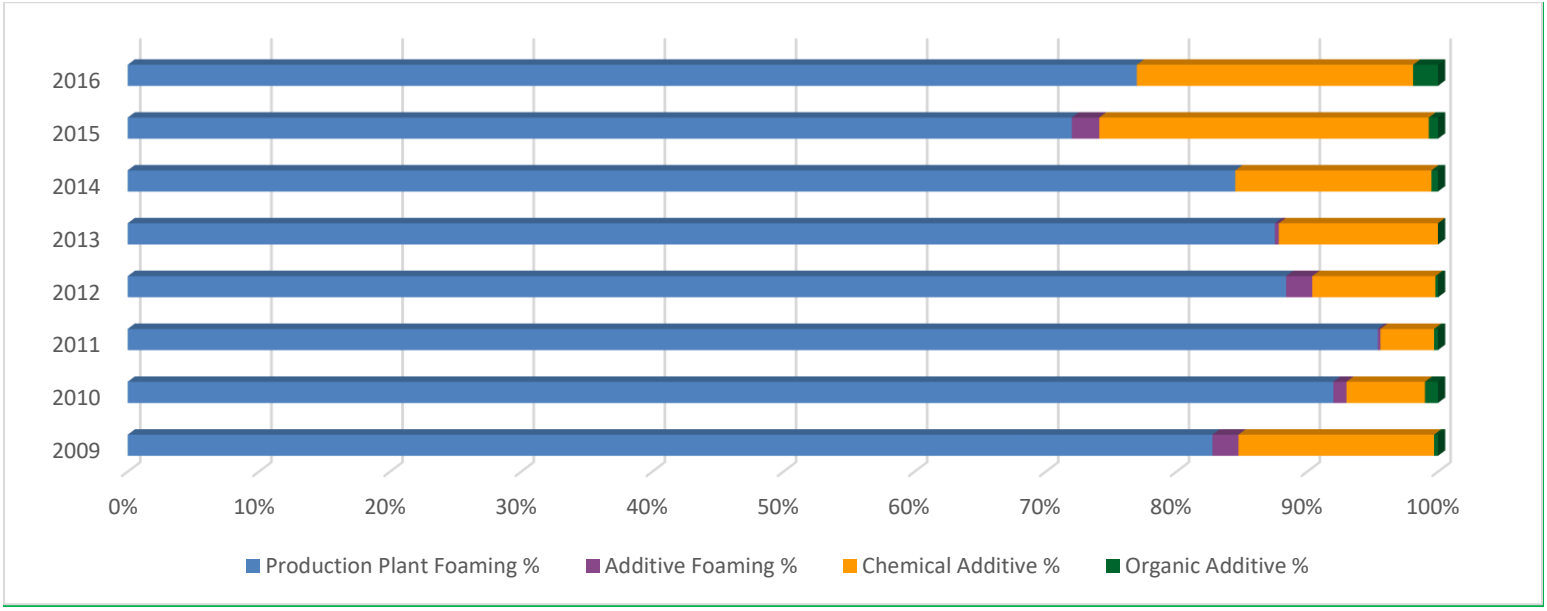


Figure 18: WMA Technologies Used as Percent of WMA Production, 2009–2016

WMA additives can have compaction, workability, antistrip, and other benefits that encourage their use even when a reduction in production temperature is not sought or achieved by the producer. For this reason, producers were asked if they use WMA additives to produce asphalt mixtures at HMA temperatures. One hundred and twelve producers in 45 states, about 68 percent of respondents who produce WMA, reported using WMA additives at HMA temperatures. Because this survey seeks to quantify only the use of WMA technologies to produce reduced-temperature WMA mixtures, survey respondents were instructed to report tons of asphalt pavement mixtures produced as HMA with WMA technologies as part of the total tons of HMA/WMA produced, but not with the tons of WMA produced.

Other Recycled Materials

Starting with the 2012 construction season survey, a series of questions was asked about the use of other recycled materials in asphalt mixtures. The information requested in the survey is detailed in Appendix A and summarized in Table A1, Section 5.

Producers were asked how many tons of mixture were produced that incorporated other recycled materials, as well as how many tons of specific materials were used in mixture production during the 2016 construction season. In some cases, respondents provided only the tons of asphalt mixture produced using other recycled materials or only the tons of the other recycled materials used, not both. Four recycled materials — ground tire rubber (GTR), steel slag, blast furnace slag, and cellulose fibers — were specifically listed in the survey. Respondents could specify up to two additional recycled materials used in mixtures.

Because the response rate to these questions about other recycled materials was expected to be low and because producers may not track the use of these materials, state and national estimates of total quantities used for these materials were not calculated. **All values in this section are reported values *only* and do not represent estimates of the total quantity of these materials used by state or nationally.** Year-to-year variation in reported values is entirely dependent upon the makeup of the respondents to each year's survey. Where available, third-party data is referenced to provide an understanding of the estimated total usage of these materials.

A total of 53 companies from 29 states, about 23 percent of survey respondents, reported using 768,470 tons of other recycled materials in nearly 6.5 million tons of asphalt mixtures during the 2016 construction season.

Ground Tire Rubber

Table 16 summarizes reported information on the use of ground tire rubber. Twenty-six producers from 15 states reported using GTR in some asphalt mixtures. Information about the use of GTR in surface treatments, such as chip seals, was not within the scope of this survey. About two-thirds of the total reported asphalt mixture tonnage produced using GTR came from California. The total reported tons of asphalt mixture using GTR jumped nearly 25 percent to 1,541,459 tons in 2016.

While the tonnage produced that incorporates GTR is relatively straightforward to track and report, the tons of GTR used is harder to document due to different methods of producing mixtures that incorporate GTR — the wet process, which uses GTR as an asphalt cement (AC) modifier, and the dry process, which incorporates GTR as a fine aggregate (Bahia, 2011) — and the likelihood that GTR is either preblended with AC at the terminal or blended onsite by a third party. Given these factors, producer reports of tons of GTR used versus tons of asphalt mixture produced using GTR were given a heightened level of scrutiny to determine if the reported data was within a reasonable range. When reported tons of GTR fell outside the expected range, producers were contacted to obtain correct values.

To give a picture of the total market size for GTR, the U.S. Tire Manufacturers Association[2] (USTMA) reports that 25.8 percent of U.S. scrap tires were processed into GTR in 2015. The total market for GTR was estimated at 1.02 million tons, with 15 percent (153,100 tons) used in asphalt pavement mixtures and surface treatments, such as seal coats, in 2015 (USTMA, 2017). USTMA conducts its scrap tire analysis biennially, so there is no data for 2016; however, using the 2015 USTMA estimate, the GTR use reported by 2016 construction season survey respondents makes up about 13.4 percent of the total GTR use in asphalt.

[2] In May 2017, the Rubber Manufacturers Association (RMA) rebranded as the U.S. Tire Manufacturers Association.

Table 16: Reported Tons of Asphalt Mixtures Using Ground Tire Rubber and Reported Tons of GTR Used

State	Reported Tons of Asphalt Mixtures Using GTR					Reported Tons of GTR Used				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Arizona	33,590	26,300	12,000	11,500	273,200	532	380	142	100	3,412
California	101,000	523,213	623,953	936,100	1,042,976	—	3,748	9,173	13,514	15,840
Delaware	—	—	—	—	8,000	—	—	—	—	40
Florida	86,441	250,779	198,046	110,000	32,288	195	531	419	356	135
Georgia	281,958	65,000	162,000	—	50,000	—	260	750	—	200
Illinois	—	4,500	—	3,500	15,500	—	20	—	36	79
Indiana	—	13,000	—	5,000	—	—	30	—	140	—
Louisiana	25,000	104,395	—	—	—	—	550	—	—	—
Maine	—	14,000	—	—	—	—	219	—	—	—
Massachusetts	—	24,897	81,882	79,680	71,500	—	324	1,146	1,090	841
Michigan	2,400	12,000	9,300	2,780	1,350	20	71	51	17	0.7
Missouri	100,000	50,000	—	—	—	300	180	—	—	—
New Hampshire	—	28,000	50,000	8,400	365	—	358	780	114	—
New Mexico	—	—	—	—	15,000					—
New York	—	10	—	—	—	—	—	—	—	—
Ohio	36,200	1,500	23,000	6,000	—	—	8	150	60	—
Oregon	—	—	—	5,000	6,000	—	—	—	—	—
Pennsylvania	—	18,000	—	—	5,260	—	140	—	—	25
Puerto Rico	—	10,000	NCR	—	NCR	—	170	NCR	—	NCR
South Carolina	—	—	—	—	10,000	—	—	—	—	18
Tennessee	—	—	—	—	10,000	—	—	—	—	50
Texas	25,000	50,000	40,000	50,000	—	—	—	200	—	—
Utah	—	—	—	3,500	—	—	—	—	61	—
Washington	—	—	—	6,500	—	—	—	—	—	—
Wisconsin	—	—	—	5,000	—	—	—	—	30	—
Total	691,589	1,195,594	1,200,181	1,234,960	1,541,439	1,047	6,989	12,811	17,518	20,641
No. of Producers	15	29	19	22	26					

NCR = No Companies Responding

— = No Use Reported

Steel & Blast Furnace Slag

Table 17 summarizes the reported use of steel slag and blast furnace slag in asphalt mixtures. Seven states reported using steel slag, and five states reported using blast furnace slag during the 2016 construction season; of these three states — Alabama, Indiana, and Ohio — reporting both. Also reported in Table 17 is the use of foundry sand, another byproduct material generated by metal-casting processes at foundries. Not surprisingly, the reported use of slags in asphalt pavement mixtures is most common in regions with steel and iron production industries and thus a relatively available supply of slag aggregates (NSA, 2017b), as seen in Figure 19.

While the total tons of asphalt mixture and materials for each slag type vary from year to year, there was a consistent increase in the reported combined use of both slags through 2014, as illustrated in Figure 20, but a continuing decrease through 2016. The decline is despite a 27.6 percent uptick in reported use of blast furnace slag, and is likely the result of which companies did and did not participate in the survey. For example, Michigan reported nearly half of the total asphalt mixture tons produced using steel slag and more than a fifth of the total asphalt mixture tons using blast furnace slag in 2015; however, no Michigan producers reported using slags in 2016. Missouri has consistently reported the use of a modest amount of foundry sand each year of the survey.

Table 17: Reported Tons for Steel Slag, Blast Furnace Slag, & Foundry Sand and Tons of Asphalt Mixture Using Each Material, 2012–2016

State & Material	Reported Tons of Mixture Using Material					Reported Tons of Material Used				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Steel Slag										
Alabama	625,000	750,000	837,083	400,000	475,000	133,441	165,000	112,480	95,000	55,000
Arkansas	120,000	25,000	84,900	229,800	60,210	12,000	2,500	12,735	60,000	9,109
Illinois	23,000	43,700	56,407	70,000	5,271	8,000	16,300	21,991	19,000	2,600
Indiana	70,000	161,115	111,800	245,000	140,000	44,000	61,985	41,500	90,000	64,000
Iowa	20,000	97,500	57,689	27,623	—	—	10,200	9,432	4,111	—
Kentucky	5,714	508,000	125,000	—	—	800	173,265	15,000	—	—
Michigan	—	750,000	754,131	1,549,291	—	—	95,000	136,382	225,819	—
Minnesota	145,500	200,000	238,000	268,000	134,000	21,800	30,000	34,000	37,500	17,800
Mississippi	—	—	—	22,803	35,000	—	—	—	3,000	500
Ohio	150,000	185,319	185,125	220,000	85,000	42,030	79,085	60,133	40,000	18,000
Tennessee	30,000	—	—	40,000	—	6,000	—	—	8,000	—
Washington	450,000	586,000	416,000	305,000	—	80,000	82,954	60,000	56,700	—
Total	1,639,214	3,306,634	2,866,135	3,382,517	934,481	348,071	716,289	503,653	639,130	167,009
Blast Furnace Slag										
Alabama	100,000	110,000	100,000	15,000	210,000	10,100	12,500	10,000	10,000	30,000
Illinois	—	—	40,000	20,000	—	—	—	10,000	15,000	—
Indiana	1,487,000	116,500	375,000	—	1,007,000	304,000	57,000	150,000	—	179,900
Iowa	—	5,000	15,000	—	—	—	500	1,500	—	—
Kentucky	—	16,000	828,243	100,000	500,000	—	7,500	191,067	25,000	80,000
Michigan	500,000	700,000	329,000	500,000	—	50,000	107,000	43,750	2,000	—
Ohio	208,028	416,250	794,6000	884,000	696,219	72,400	110,613	145,105	208,268	176,333
Virginia	54,520	—	—	—	—	16,356	—	—	—	—
West Virginia	588,120	504,704	1,065,382	748,922	695,572	180,308	155,032	190,000	183,357	100,987
Wisconsin	—	—	—	5,500	—	—	—	—	795	—
Total	2,937,668	1,868,454	3,547,225	2,273,422	3,108,791	633,164	450,145	741,422	444,420	567,220
Foundry Sand										
Missouri	5,000	15,130	22,310	10,000	15,960	500	1,514	2,231	500	1,596

— = No Use Reported

The National Slag Association estimates that more than 20 million tons of slag is produced and marketed annually (NSA, 2017a). With 734,229 tons of slag reported as being used in asphalt mixtures during the 2016 construction season, the asphalt pavement mixture production industry used about 3.7 percent of the total available slag, based upon reported usage alone. For the states reporting slag use, 11 percent of their total reported asphalt pavement mixture tonnage includes steel and/or blast furnace slag. According to the Industrial Resources Council, more than 9 million tons of foundry sand are produced annually (IRC, n.d.), which means only a very small portion of its potential use in asphalt pavement mixtures is captured by this survey.

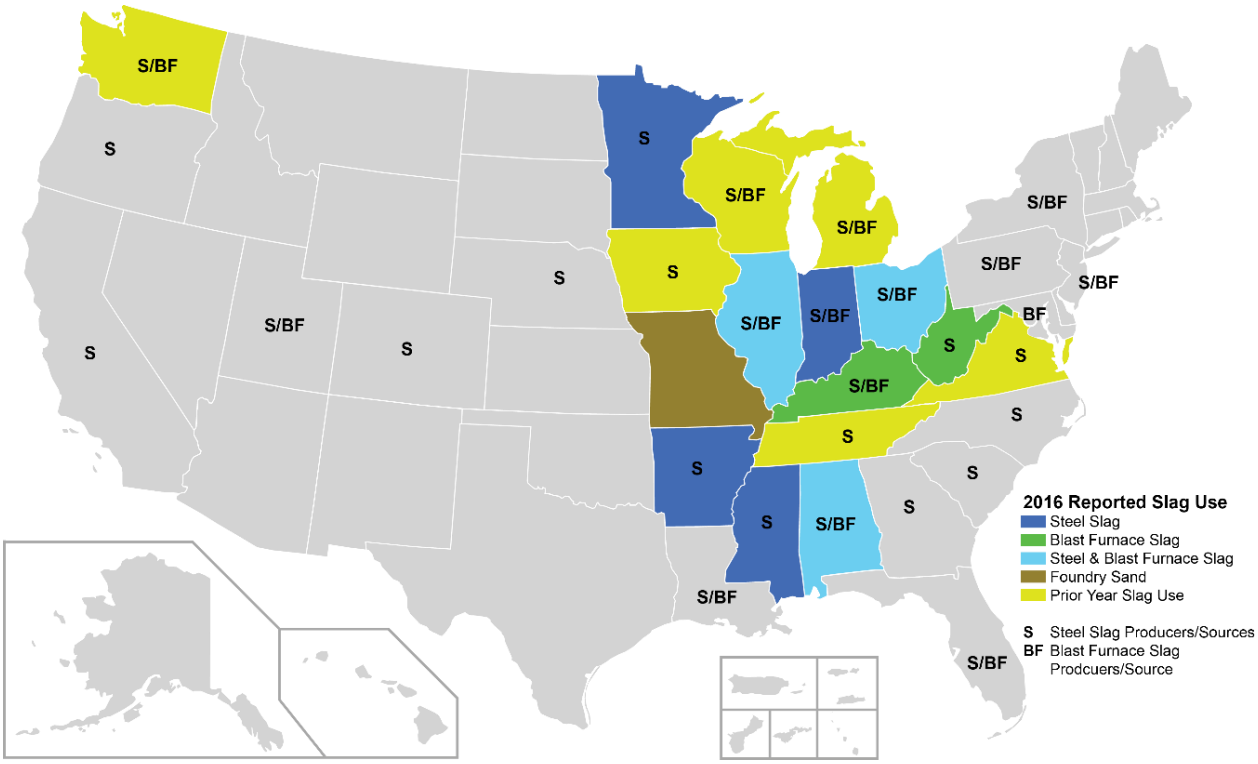


Figure 19: States Reporting Steel and/or Blast Furnace Slag Use and Slag Producers/Sources

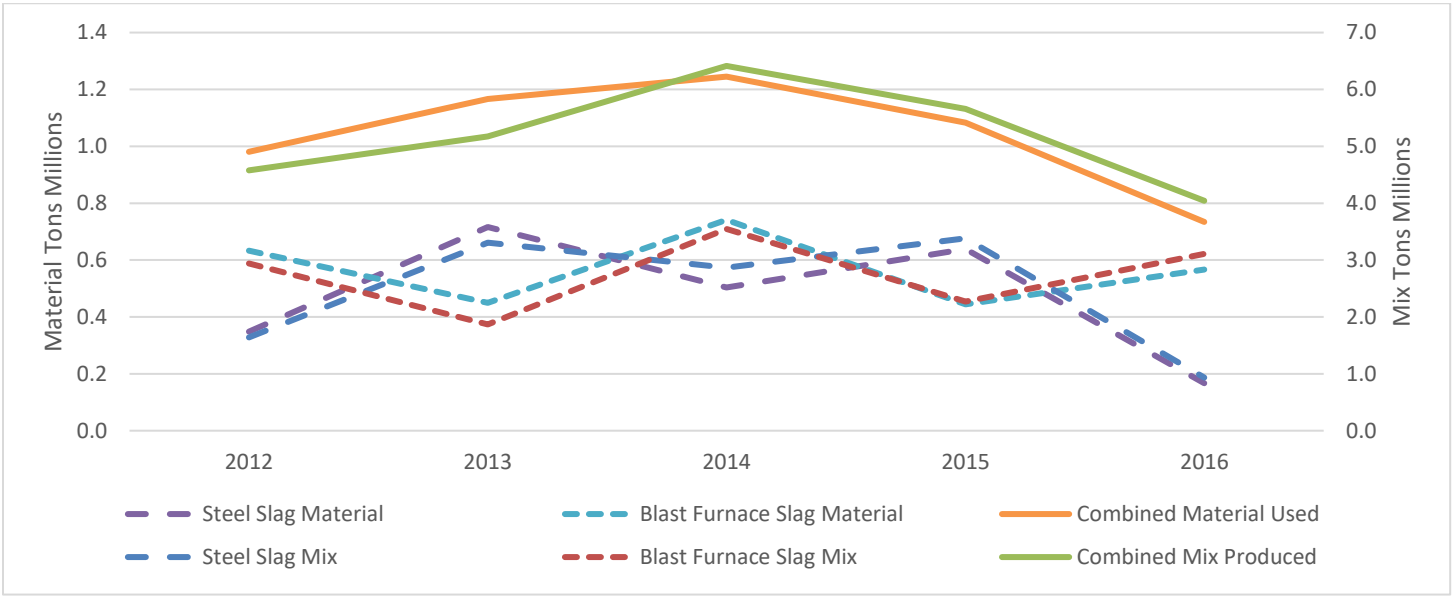


Figure 20: Steel and Blast Furnace Slag Use, 2012–2016

Coal Combustion Products

Several waste and by-products associated with the burning of coal to produce electricity, including fly ash, bottom ash, boiler slag and flue-gas desulfurization (FGD) materials. In the 2016 construction season survey, fly ash was the only coal combustion product (CCP) reported as being used, as shown in Table 18. In previous surveys, limited use of bottom ash has been reported.

To give a picture of the total use of CCP in asphalt pavement mixtures, the American Coal Ash Association found that some 40,969 tons of fly ash, no bottom ash, 10,592 tons of boiler slag, and 8,912 tons of flue-gas desulfurization (FGD) material from dry scrubbers were used as mineral filler in asphalt in 2016 (ACAA, 2017). This indicates that the fly ash usage reported for the 2016 construction season survey makes up 25 percent of fly ash used in asphalt pavements during the 2016 construction season; however, only a very small amount (0.038 percent) of the 37.8 million tons of fly ash produced in 2016 was used in asphalt mixtures, according to ACAA (2017).

Table 18: Reported Tons of Asphalt Mixtures Using Coal Combustion Products and Reported Tons of CCP Used

State & Material	Reported Tons of Asphalt Mixtures Using CCP*					Reported Tons of CCP Used*				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Fly Ash										
Michigan	—	—	—	50,000	—	—	—	—	—	—
Mississippi	50,000	50,000	15,000	—	19,000	2,400	2,500	600	—	750
Tennessee	—	—	—	15,940	—	—	—	—	616	—
Texas	18,000	25,000	20,000	—	30,000	1,200	1,700	1,000	—	—
Wisconsin	—	—	26,000	102,500	160,000	—	—	1,500	6,150	9,500
Total	68,000	75,000	61,000	168,440	209,000	3,600	4,200	3,100	6,766	10,250
Bottom Ash										
South Dakota	52,000	—	—	NCR	—	4,280	—	—	NCR	—
Texas	—	—	—	1,000	—	—	—	—	—	—
Total	52,000	—	—	1,000	—	4,280	—	—	—	—

*Not all producers reporting tonnages of mixtures using other recycled materials provided quantities of recycled materials used and vice versa.
NCR = No Companies Responding
— = No Use Reported

The Importance of Engineering Recycled Asphalt Mixtures for Quality

For more than three decades, two guiding principles of asphalt recycling have been: 1) asphalt mixtures containing RAP should meet the same requirements as asphalt mixtures with all virgin materials, and 2) asphalt mixtures containing RAP should perform equal to or better than asphalt mixtures with all virgin materials. This is at the heart of the "Three E's of Recycling," which state that recycled materials should provide Environmental, Economic, and Engineering benefits.

Quality recycled mixes have been successfully designed and produced for many years. When successfully engineered, designed, produced, and constructed, the proof is in performance. A recent study comparing the performance of recycled versus virgin mixes based on Long-Term Pavement Performance (LTPP) data from 16 U.S. states and two Canadian provinces shows that overlays containing at least 30 percent RAP performed equal to overlays using virgin mixtures (Carvalho et al., 2010; West et al., 2011). At the NCAT Test Track, test sections containing 50 percent RAP using Superpave mix design procedures for each layer outperformed companion test sections with all virgin materials in all pavement performance measures.

However, as the amount and mix of recycled materials in asphalt pavement mixtures increase, additional considerations for material handling, engineering, mixture design, quality, and performance testing become more important. In particular, RAP and RAS should be tested and classified to determine the amount and qualities of available asphalt cement. The absorbability of RAP aggregate should also be tested and determined. These values have an impact on pavement performance and are important to assess when developing a high recycled content mix design. In some cases, it may be necessary to make use of recycling agents or a softer asphalt binder to ensure the final mix design delivers the desired level of product performance.

For more information about processing and using reclaimed asphalt pavement and recycled asphalt shingles, consult the NAPA publication *Best Practices for RAP and RAS Management* (Quality Improvement Series No. 129).

Other Recycled Materials

Table 19 summarizes other recycled materials used in asphalt mixtures. For the 2016 construction season, only the use of cellulose fibers and polyester fibers were reported. In previous years, producers have also reported the use of recycled glass, and petroleum-contaminated soil in asphalt pavement mixtures. The reported use of cellulose fiber increased significantly in the 2015 and 2016 construction season surveys, due to the specific request for data about cellulose fiber beginning with the 2015 construction season survey. As explained in Appendix A, in previous years, reporting data about cellulose fiber use was at the discretion of the respondent. Since the change in methodology, producers in 22 states have reported the use of recycled cellulose fiber. The use of a small amount of recycled poly fibers was reported for the first time in 2016.

Table 19: Other Recycled Materials

State & Material	Reported Tons of Mixture Produced Using Other Recycled Material*					Reported Tons of Other Recycled Material Used*				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Cellulose Fiber										
Alabama	—	—	—	100,000	—	—	—	—	500	—
Alaska	—	—	—	1,000	—	—	—	—	—	—
Delaware	—	—	—	—	20,000	—	—	—	—	60
Florida	—	20,204	73,600	92,000	94,903	—	71	311	147	71
Georgia	—	43,000	—	—	—	—	129	—	—	—
Illinois	—	—	—	126,150	—	—	—	—	240	—
Indiana	—	6,000	—	22,000	—	—	60	—	1	—
Louisiana	—	31,651	1,500	22,260	—	—	63	30	45	—
Maryland	—	145,000	120,000	85,000	100,000	—	440	360	230	300
Massachusetts	—	—	—	—	2,000	—	—	—	—	3
Minnesota	—	5,000	—	—	—	—	15	—	—	—
Mississippi	76,000	—	—	—	53,998	250	—	—	—	153
Missouri	—	—	—	56,000	—	—	—	—	100	—
New Jersey	—	—	—	5,000	—	—	—	—	—	—
New York	—	—	700	1,605	1,640	—	—	1	—	9
North Dakota	—	—	—	—	65,000	—	—	—	—	195
Ohio	—	—	—	10,220	3,000	—	—	—	90	—
Oregon	—	—	—	20,000	—	—	—	—	8	—
Pennsylvania	—	—	—	12,952	45,000	—	—	—	—	90
South Carolina	—	—	—	20,000	—	—	—	—	—	—
Tennessee	—	—	—	175,940	127,845	—	—	—	80	201
Texas	—	30,600	36,000	50,300	—	—	90	44	15	—
Utah	—	—	—	—	122,317	—	—	—	—	570
Virginia	—	—	74,000	61,000	30,000	—	—	120	183	90
Total	76,000	281,455	305,800	861,427	665,703	250	868	866	1,643	1,744
Poly Fibers										
Maine	—	—	—	—	—	—	—	—	—	2
New Hampshire	—	—	—	—	—	—	—	—	—	5
Vermont	—	—	—	—	—	—	—	—	—	3
Total	—	—	—	—	—	—	—	—	—	10
Petroleum-Contaminated Soil										
Massachusetts	—	—	—	35,000	—	—	—	—	1,050	—
Recycled Glass										
Florida	—	—	—	1,000	—	—	—	—	200	—
Virginia	173	—	—	—	—	34	—	—	—	—
Total	173	—	—	1,000	—	34	—	—	200	—

*Not all producers reporting tonnages of mixtures using other recycled materials provided quantities of recycled materials used and vice versa.
NCR = No Companies Responding; — = No Use Reported

Summary and Conclusions

The objective of this survey was to quantify the use of recycled materials and WMA produced by the asphalt pavement mixture production industry during the 2016 construction season. Asphalt mixture producers from all 50 states completed the 2016 survey, and data was collected from 229 companies with data from 1,146 production plants. Data collected was compared to annual data from previous surveys since the 2009 construction season.

The survey findings for 2016 regarding the use of RAP, RAS, and WMA are summarized in Table 4.

Comparing the 2016 results to 2015 construction season, estimated total asphalt mixture production saw a slight increase from 364.9 million tons to 374.9 million tons, a 2.7 percent increase. DOT tonnage was down 7.4 percent, but this was offset by a 14.7 percent increase in tonnage for the Commercial & Residential sector and a 6.9 percent increase in tonnage for the Other Agency sector.

The use of recycled material has risen dramatically since the 2009 construction season survey; although, year-over-year growth has slowed in recent years. The 2016 construction season survey shows:

Reclaimed Asphalt Pavement

- The total estimated tons of RAP used in asphalt mixtures reached 76.9 million tons in 2016. This represents a greater than 37 percent increase in the total estimated tons of RAP used in 2009. During the same time frame, total asphalt mixture tonnage increased only 4.6 percent.
- The percentage of producers reporting use of RAP decreased slightly from 99 percent of respondents in 2015 to 98 percent in 2016.
- The average percent RAP used by all sectors has seen variable growth from 2009 to 2016. The year-to-year growth in the average percentage of RAP use has slowed from 2009 to 2016, decreasing from a 1.8 percent increase from 2009 to 2010 to 0.2 percent increase from 2015 to 2016. The average estimated percentage of RAP used in asphalt mixtures has increased from 15.6 percent in 2009 to 20.5 percent in 2016.
- Companies reporting having stockpiled RAP on hand at year-end increased slightly from 88 percent in 2015 to 89.5 percent in 2016. Unlike in the 2014 and 2015 construction seasons, more RAP was accepted by producers during the 2016 construction season than was used for all purposes, including landfilling. In total, producers accepted an estimated 500,000 tons more RAP than was used in 2016.
- Reclaiming 81.7 million tons of RAP for future use saved about 49.6 million cubic yards of landfill space.
- The total estimated amount of RAP stockpiled nationwide at the end of the 2016 construction season was 93.59 million tons.
- Producers from 38 states reported fractionating RAP. Nationally, a reported 22 percent of RAP is fractionated.
- Producers from 34 states reported using softer binders and 11 states reported using recycling agents in RAP mixtures. There was little correlation between the percentage of RAP used in asphalt pavement mixtures and the use of softer binders and/or recycling agents in a given state.

Reclaimed Asphalt Shingles

- Use of both recycled manufacturing waste and post-consumer asphalt shingles in asphalt mixtures decreased significantly (27.9 percent) from an estimated 1.93 million tons in 2015 to 1.39 million tons in 2016. Declines were seen in the use of RAS in mixtures for all three sectors.

- The amount of unprocessed RAS accepted by asphalt mixture producers decreased from 1.13 million tons in 2015 to 1.03 million tons in 2016. During the 2016 construction season, an estimated 846,000 tons of processed RAS was accepted by producers, which was about 4,000 tons more processed than was accepted in 2015. The combined amount of unprocessed and processed RAS accepted in 2016 was 1.87 million tons, which was 469,000 tons more RAS than was used for all purposes, including landfilling.
- Of the RAS used in 2016, more than 99 percent was used in asphalt mixtures. The remainder was combined with aggregates. Two producers reported landfilling a small amount of RAS during the 2016 construction season.
- The percent of producers reporting use of RAS decreased from 41.6 percent of respondents in 2015 to 33.6 percent in 2016.
- About 91 percent of the 76 companies using RAS reported having stockpiled RAS on hand at the end of the 2015 construction season.
- The number of states with reported RAS use increased to 36 states in 2016. New Mexico producers reported their first use of RAS in 2016; Maryland and New York producers reported not using RAS for the first time in this survey.
- In 2016, producers were asked which sectors allow RAS in asphalt mixtures. Most states allow the use of RAS in Commercial & Residential sector mixtures, with more limited use in DOT and Other Agency public sector mixtures. Seven states reportedly allow the use of RAS in all sectors, and five states reportedly do not approve the use of RAS in asphalt pavement mixtures.
- Producers from 15 states reported using softer binders and eight states reported using recycling agents in RAS mixtures.

Material Cost Savings

- The use of RAP and RAS saved more than $2.1 billion during the 2016 construction season compared to the use of all virgin materials. This is about $500 million less than in 2015 due primarily to lower asphalt binder prices. These savings help reduce material costs for asphalt pavement mixtures, allowing road owners to achieve more roadway maintenance and construction activities within limited budgets.

Other Recycled Materials

- A reported total of 768,470 tons of other recycled materials was used in nearly 6.5 million tons of asphalt mixtures by 53 companies in 29 states during the 2016 construction season.
- The number of states reporting use of ground tire rubber (GTR) in asphalt mixtures held steady at 14 during the 2016 construction season. The total reported tons of asphalt mixture using GTR grew 24.8 percent from 2015 to 1.541 million tons in the 2016 construction season.
- Nine states reporting use of steel or blast furnace slags and one state reported the use of foundry sand in 2016. Compared to reported use in 2015, the reported tons of mixtures including steel slag decreased dramatically during the 2016 construction season, but there was also a significant increase in the tons of asphalt pavement mixture incorporating blast furnace slag. Reported use of these materials was greatest along the Mississippi and Ohio River Valleys, where much of U.S. steel and iron production is concentrated.
- Producers in two states, Mississippi and Wisconsin, reported using fly ash in asphalt mixtures in 2016. In both the 2015 and 2016 construction seasons, Wisconsin producers reported a significant increase in the use of fly ash. Fly ash was the only coal combustion product (CCP) reported as being used in asphalt pavement mixtures during the 2016 construction season.

- Twelve states reported use of cellulose fiber and three reported using recycled poly fibers in asphalt pavement mixtures during 2016.

Warm Mix Asphalt

The use of WMA continues to increase, but at a slower rate. The 2016 construction season survey shows:

- The estimated total production of WMA for the 2016 construction season was about 116.8 million tons. This was a 2.5 percent decrease from the estimated 119.8 million tons of WMA in 2015 but still a more than 595 percent increase from the estimated 16.8 million tons in the 2009 construction season.
- WMA was 31.2 percent of the total estimated asphalt mixture market in 2016.
- Production plant foaming, representing nearly 77 percent of the market, is the most commonly used warm-mix technology; chemical additive technologies accounted for a little more than 21 percent of the market.
- One hundred and twelve producers in 45 states, about 68 percent of respondents who produce WMA, reported also using WMA technologies at HMA temperatures.

Conclusions

The 2016 survey results show that the asphalt pavement mixture production industry has a strong record of sustainable practices and continues to innovate through the use of recycled materials and WMA. Since the initial industry survey of the 2009 construction season, producers have increased significantly their use of recycled materials and WMA; however, since the 2013 survey, indicators are that the rate of increase in the adoption of RAP, RAS, and WMA may be plateauing.

Slightly more RAP was received than used during the 2016 construction season, and 89.5 percent of producers indicated they have stockpiled RAP on hand. With an estimated 93.59 million tons of RAP stockpiled nationwide at year-end 2016, a 9.9 percent increase over year-end 2015, opportunities remain to increase the amount of RAP used in asphalt mixtures through engineering, performance-based specifications, education, and improved RAP processing, production equipment, and procedures.

RAS use saw a significant 27.9 percent decrease in 2016 in asphalt pavement mixtures; however, by accepting 1.873 million tons of waste shingles during 2016, producers reserved 14 percent of the nation's available waste shingles for use in asphalt mixtures. As with RAP, performance-based specifications, education, and improved processing, production equipment, and procedures will help increase the amount and percentages of RAS used in asphalt mixtures.

The asphalt pavement mixture production industry repurposes many products from other industries. The survey shows that, for the 2016 construction season, slags and other metal foundry byproducts were reported in 10 states, GTR use was reported in 14 states, recycled cellulose and poly fiber use was reported in 15 states, and fly ash use in two states.

WMA saw a 2.5 percent decline during the 2016 construction season with a total production of 116.8 million tons, which represents 31.2 percent of total estimated asphalt mixture production for the year. Only producers in Montana and Rhode Island reported not using WMA in 2016. The decline in WMA use during 2016 correlates with a decline in overall tonnage for DOT customers; therefore, as demand for asphalt pavement mixtures increases in the public sector, WMA use is expected to similarly increase.

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IS 138