ASTEC ENGINEERING MEMO

Date: July 30, 2012

To: Tom Peterson, Colorado Asphalt Pavement Association

Cc: Richard Draheim; Mark Conte; Tom Baugh; Steve Claude

From: Mike Varner

Subject: Performance Experience with Astec WMA Systems (June 12, 2012)

4101 JEROME AVENUE • PO BOX 72787 • CHATTANOOGA, TN 37407

The Astec Warm Mix Systems (Double Barrel® Green, Green Pac™ for Continuous, and/or Green Pac™ for Batch) have been available commercially since September of 2007. To date, over 450 units have been installed on asphalt production plants of all types on every populated continent.

Many states quickly performed trials and adopted mechanically foamed WMA technology.
Unlike chemical, physical, and water-bearing additives, mechanically foamed WMA does not require significant mix design adjustment because 98.8% of the 0.9 liters of water (typical amount injected per mix ton) does not remain in the mix.[1] Also, mechanically foamed WMA does not increase the cost per mix ton beyond the initial equipment costs. These benefits have lead to a widespread acceptance. Because there are virtually no additive costs, many hot mix producers in North America are running the Astec Warm Mix Systems on hot mix as a compaction aid.

Test results and studies that have been prepared on specific projects and for state acceptance of Astec Warm Mix Systems technology are included with this report for reference. Articles and slides are also presented to show how widely mechanically foamed WMA (specifically the Astec System) is used in North America. None of the studies included in this document were prepared by Astec, Inc. All sample gathering, testing, analysis, and evaluations were conducted by independent entities. Comments and highlights have been added to some of the reports by Astec for clarity. Refer to Appendices.

We hope that this information helps.

With kindest regards,

Mike Varner
Director of Thermal Systems and Research
Astec, Inc.

[1] Refer to "Astec Warm Mix Systems Technical Reference Document" in Appendix A1, pp 9-11.

Index to Appendices

No.	Title	Description
A1	Astec Warm Mix Systems Technical Reference Document	Generic version of the technical reference document provided to states, upon request, for Astec Warm Mix Systems. This document is a shortened version of the Astec Warm Mix System Operator Manual.
B1	Asphalt Tops the Charts	Journal article that summarizes the amount of warm mix asphalt (WMA) produced in the United States by technology type. This article is included to show how widely mechanically foamed WMA is used.
C1	One Year Review of the Anthony Henday Drive Warm Mix Project	Test report detailing the resurfacing of Anthony Henday Drive in Edmonton Alberta (Canada). This long range test shows the performance of mechanically foamed WMA using the Astec Warm Mix System in a cold climate.
D1	Warm Mix Project List (Florida)	Series of slides summarizing WMA projects in Florida (United States) to November 2010. These presentation slides are included to show how widely mechanically foamed WMA, specifically the Astec Warm Mix System (also known as “Double Barrel® Green).
D2	Florida DOT Report 09-527 (excerpt)	Excerpt from FDOT report 09-527 (pages 9 – 15) detailing testing performed on a WMA project on State Route 11 (SR-11).
E1	New York State DOT Approval Memo	Letter of approval from the New York State Department of Transportation for the Astec Warm Mix System.
E2	New York State DOT HMA and WMA Approval Testing	Test results from plant-produced specimens. These test results were the basis for NYSDOT approval.
F1	CalTrans (California Department of Transportation) Submission for Technology Approval	Report submitted to CalTrans to gain approval of Astec Warm Mix Systems in California. Provisionally approved 1-5-12. This report relies heavily on the report shown in Appendix C1 and Appendix H1.
G1	Texas DOT Approved Technology List	Texas DOT approved WMA technologies. This list is included to show the acceptance of Astec Warm Mix Systems in the state of Texas.
H1	NCAT Report 10-01	Detailed comparison of alternative WMA technologies performed during a demonstration project in Nashville, Tennessee USA in October 2007.
I1	Technical Update from the Ohio LTAP Center	The Ohio Local Technical Assistance Program (LTAP) released a technical update regarding WMA in the state of Ohio. This document is included to show that the only WMA technology allowed in the State of Ohio is mechanical foaming.
J1	Asphalt Pavement Mix Production Survey (2009-2010)	Publication IS138. Survey and report prepared by the National Asphalt Pavement Association (NAPA) detailing the use of recycled asphalt pavement (RAP), recycle asphalt shingles (RAS) and warm mix asphalt (WMA). The results of this survey are included to provide details of the data in Appendix B1.

Appendices Attached

Return to Index of Appendices

DESCRIPTION OF THE ASTEC GREEN SYSTEM

Double Barrel Green®, Green Pac™ for Continuous, Green Pac™ for Batch

The Astec Green Pac™ systems, based upon the same technology as the Double Barrel Green®, are designed to work on all types of asphalt plants from all manufacturers. The Double Barrel Green® is merely a configuration of the Astec Green Pac™ system specifically designed for the Astec Double Barrel®. The units may be installed on both new equipment or as a retrofit package.

What comes with the system?

All Astec Green Pac™ systems come complete with:

1. Green Pac™ manifold. This manifold is mounted either directly on the mixing device or inline with the AC delivery piping. The manifold includes all valving, hot oil, piping sections and spool pieces, flanges, offsets, and/or any other fitting(s) necessary to appropriately integrate it with existing equipment. If not a retrofit, the Green Pac ™ manifold is already fully integrated with the new plant.
2. Green Pac™ Skid. The skid is a metal skid that comes in two standard sizes: a) large to accommodate a 550gallon (2080 liter) opaque water tank and b) small to accommodate a 165 gallon (624 liter) opaque water tank. The skid serves as a mounting platform for:
   a. Control Cabinet (NEMA 4) containing
      i. Power shutoff switch (external).
      ii. Variable Frequency Drive (VFD) for water pump (VFD interface remote mounted in panel door to enhance arc flash compliance).
      iii. Control signal conditioning equipment (I/O)
      iv. Circuit protection.
      v. 480VAC to 120VAC transformer providing power to a weatherproof 4-gang receptacle box (all GFI) for providing power to an optional cold weather package.
      vi. Remote dual output tachometer if plant is equipped with a pump-to-pump AC metering package. Tachometer is remote mounted on AC flowmeter.
   b. Water tank (opaque polyurethane) including
      i. Fill valve and float for connecting tank to continuous water supply.
      ii. Water level sensor for alarming operator if water level becomes low.
      iii. Drain
      iv. Inspection port
   c. Direct drive piston water pump and motor including
      i. Inlet strainer
      ii. Water flowmeter
      iii. Outlet piping including calibration lines and valves.
      iv. Water bypass pressure relief valve and bypass switch
3. Green Pac™ Touch Panel (unless integrated into plant control)
4. All necessary power, communication cable, and software.
5. High pressure water line between skid-mounted water pump and Green Pac™ system manifold.
6. 24/7 service and support.

General Description of the Astec System

The Astec Green System (Double Barrel Green®, Green Pac™ for Continuous and Green Pac™ for Batch) consists of multiple water injectors, foaming standpipes, and nozzles supplied by integrated liquid asphalt cement (AC) and water manifolds

1. Water is injected via water injectors into foaming standpipes/foaming nozzles.
2. The water flow rate (Double Barrel Green® and Green Pac™ for Continuous) is maintained by feedback control of the PLC trimming the speed of a positive displacement water pump to maintain measured water flow equal to a calculated target flow rate
    a. Target water flowrate is calculated based upon the output of the AC flowmeter.
    b. Actual water flow is determined from the output of a water flow measurement device.
3. The multi-nozzle foaming assembly has matched water injectors/ foaming standpipes/foaming valves.
4. Water flow is calibrated via a calibration routine detailed in Appendix 4: "Calibration Instructions".

Description of Operation (Double Barrel Green and Green Pac™ for Continuous)

1. The foaming assembly is typically plumbed into the AC metering system as a primary dispensing point.
2. When the foam system is enabled, water is injected into and intimately mixed with the liquid AC. Refer to Appendix 2: "Green System Water Injection".

Sequence of Operation, Continuous

When the system is enabled, the water pump starts and begins controlling flow. Once the unit reaches its targeted water flow within a settable tolerance, water nozzles open allowing water and AC to mix together within the unit. Upon disabling the system or performing a mid-stream stop, the unit ceases spraying water into the foaming standpipes by closing the water injectors and stopping the water pump.

Green Pac™ for Batch

The Green Pac™ for Batch may be installed on either positive displacement or gravity feed plant configurations from any manufacturer. In the case of a positive displacement system, the green system manifold is installed between the AC injection pump and the pugmill spraybar. In the case of a gravity feed system, an AC injection pump is added to provide the motive force to push the AC through the foaming manifold thus adding positive displacement capability to the plant for the production of both warm mix asphalt (WMA) and hotmix asphalt (HMA) without affecting the plant capability of employing the existing gravity feed system.

Sequence of Operation, Batch

Green Pac™ for Batch is controlled by setting the pump to run at the appropriate speed via a manual calibration. Once in operation and enabled, the water pump runs at this speed continuously with the flowmeter output displayed for reference. The Green Pac™ for Batch PLC receives signals from the existing plant batch control to determine when water is to be injected into the foaming manifold or bypassed back to the water reservoir.

If the plant uses gravity to dispense AC into the pugmill, the Green Pac™ for Batch PLC also receives signals from the existing weigh system to control the filling and emptying of the plant's weighpot.

WATER SUPPLY AND METERING
(Double Barrel Green® and Green Pac™ for Continuous Plants)

A positive displacement piston pump is used as part of a feedback-controlled PID within a PLC to meter water at the target rate via VFD control.

1. A target water flow rate is calculated based upon the current AC flow rate as measured by the AC metering pump or AC flow meter.
2. The speed of the water metering pump is controlled by the PID control using the output of the water flow meter.
3. Water is **typically** injected at a rate of 2% of AC flow by weight. However, greater water flow rates **are not** detrimental to the mix and have been shown to enhance foaming at low production rates (see Appendix 1, "Green System Water Injection").
4. For example, a virgin mix being produced at 300TPH (272MTPH) with 5%AC requires 15TPH (13.6MTPH) of liquid AC.
   - Fifteen (15) TPH (13.6 MTPH) of AC is approximately 60 GPM (227 LPM) of AC assuming specific gravity of AC near 1.0.
   - If water having a specific gravity of 1.0 is injected at a rate of 2% of liquid AC flow, the required water flow rate will be 1.20 GPM (4.54 LPM).

WATER SUPPLY AND METERING
(Green Pac™ for Batch Plants)

All of the water supply and metering components are essentially the same for Green Pac™ for Batch as for Double Barrel Green® and Green Pac™ for continuous plant configurations.

1. Green Pac™ for Batch uses a larger water pump and larger relief valve of the same type to achieve the high water flowrate required during AC injection.
2. Water flow relieves back to the water reservoir when not being injected to ensure accurate metering of water into the liquid AC as it is delivered into the pugmill.
3. Green Pac™ for Batch water flowrate (based upon the rate at which AC leaves the weighpot) is set by setting pump speed to particular level via a calibration routine using the flowmeter as a reference. Refer to Appendix 4: "Calibration Instructions".

Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

What is warm mix?
Warm mix asphalt (WMA) is similar to hot mix asphalt (HMA) except that it is produced and placed at lower temperatures (typically 50°F to 100 °F [28°C to 56°C] cooler). The liquid AC is temporarily made to have a lower viscosity by either the introduction of a wax, chemicals or water. Water may be introduced via a number of carriers. Rather than using a mineral carrier, Astec Green Systems inject water via water injectors/foaming nozzles.

How does the Astec Green System work?
The Astec Green System intimately mixes water and liquid AC to form a foam containing microscopic steam bubbles. The presence of microscopic steam bubbles lowers viscosity of the liquid AC until the mix until it is compacted and drops below 212°F (100°C).

How will warm mix change my mix design?
Using the Astec Green Systems, mix design is unaffected. The same mix designs used for hot mix may be used for warm mix since nothing is added to the mix except a very small amount of water. Only a very small amount of this water (a maximum of 0.0012%) remains in the mix after compaction. Refer to Appendix 2: “Green System Water Injection”.

What is the HMA Producer’s responsibility to purchase or provide?
The HMA producer need only supply a water supply hose from a suitable water source to the water tank.

What are the electrical requirements of the plant?
Provision is made for any line voltage upon ordering the system. Overall power requirement of the system is minimal. As such, it is typically energized from an existing adjacent power source.

How is the water attached to the system? Is the water required to be used from a holding tank, or can the system be directly connected to a municipal water supply?
All Astec Green Systems include a water reservoir to provide low-pressure uninterrupted water supply to the pump. Municipal water may be hooked directly to the fill valve on the tank. To maintain metering accuracy, municipal water should not be connected directly to the inlet of the pump.

Depending upon requirement, loss of water flow may be used to trigger midstream stop.

What is the dosage rate?
Water dosage rate may be manually varied between 1.5% and 5.0% of the virgin liquid flow. A 2% to 3.5% dosage rate is typical and widely used with 2% being the most common dosage rate. Refer to the Appendix 2 “Green System Water Injection” for a more detailed discussion of dosage rate. There is no deleterious effect associated with injecting excess water.

How is the water dosage controlled? This dosage also needs to be calibrated according to specifications, how will this be accomplished?
Green Pac™ water dosage rate is controlled based upon

1. Operator input (operator may choose the desired water injection dosage rate on the touch screen or on an integrated control screen if the Green Pac™ control is integrated into the plant’s operating system).
2. AC Flowrate. AC flowrate is measured via the existing AC flowmeter. The Green Pac™ PLC uses this flowrate along with the desired dosage rate to calculate a “target” water flowrate.
3. Green Pac™ PLC trims the speed of the water pump using feedback from the water flowmeter to maintain actual water flow at the desired target rate.

A calibration routine is included in the Green Pac™ PLC Control and is accessible from the touch screen in the control house. Refer to Appendix 4 “Water Calibration”. A data recording function, per request, is available that utilizes the PLC and/or plant blending system software for recording and “time stamping” water dosage rate.

Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Can the dosage rate vary with the type of mix being used? Mix with 20% RAP versus a mix with no RAP?
Though dosage rate has been varied manually at higher RAP percentages, no noticeable effect has been observed. Typically, dosage rate is maintained at 2% of the virgin liquid flow rate. Increasing the dosage rate will not result in any deleterious effect.
Are there other reasons to vary the water dosage rate?
At very low production rates and high RAP percentages, dosage rate may be manually increased to enhance mechanical mixing of liquid AC and water. Typically, flow is maintained at or above 1 gpm (3.78 lpm).
If some of the water remains in the mix, won't I show a high AC content?
A small amount of water remains in the mix after compaction; so theoretically, this could show up as AC content. However, since a maximum of 0.0012% of the water remains, the amount of water that remains is beyond the measurement accuracy of AC content (typically reported to the nearest 0.1%). The amount of injected water, at a maximum that remains is about 11ml per mix ton. Refer to Appendix 2: "Green System Water Injection".
Can (or should) I put anti-freeze in the water?
The effect of anti-freeze of any type on the mix, even at low concentrations, is unknown. As such, adding any type of antifreeze to the water is not advised. Refer to Appendix 5: "Cold Weather and Winterizing".
How clean should the water be?
Non-potable well water has been used without adverse affect. However, most installations use Municipal water and some have chosen to filter the water via a duplex filter arrangement. Elaborate filtering is unnecessary. As long as the water is clean and free of contaminants, there will be no problem as the pumps and water injectors/foaming valves are designed to pass small particulate.
Should the injected water be metered and accounted for in the same manner as an anti-strip additive (ASA) or mineral filler?
Absolutely not. To do so is not correct and introduces potential AC content discrepancies. Adding water for the purpose of mechanical foaming in the same manner as an ASA or mineral filler demands that it be accounted for in the same manner. ***Since the majority of the injected water does not remain in the mix after compaction, accounting for it as if it does causes either AC content or aggregate content to be very slightly over reported***. If accounted for in this manner, the maximum effect on actual AC content would be 0.1% reduction -- a significant difference. By comparison, the maximum effect on aggregate would be approximately 0.01%. Given this, it is more accurate with respect to AC content for water to be controlled separately from the blending system and NOT included as an add mixture.
Can I start up on warm mix?
Generally, it is better to start hot then go warm so that the first two loads of WMA are at HMA temperature. This serves to heat soak the metal surfaces at the plant, the paver, and material transfer vehicles to help reduce adhesion to metal surfaces and lower equipment amperage draw. Water may be injected from the beginning regardless of mix temperature. Refer to Appendix 3 "WMA Production Temperatures".
Won't the baghouse temperature be too low when I lower mix temperature?
It depends on a number of factors. If your baghouse temperature is already low, running warm mix may push it to a level at which condensation within the baghouse may begin. Typically baghouse temperature decreases about 35℉ (19.4℃) to 40℉ (22.2℃) when running warm mix in a counter-flow dryer (all other factors constant). Warm mix works best with higher RAP usage as the higher baghouse temperature associated with the higher RAP percentage is offset by the lower baghouse temperature afforded by running the warm mix.

Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Will coating be affected?
Coating is affected by many factors: aggregate, mix temperature, AC type, and/or fines content to name a few. Generally, coating decreases with mix temperature. However, good coating has been observed with Astec Green Systems producing mix at 250°F (121°C). Depending upon the aggregate and fines content, coating typically worsens below 240°F (115.5°C). Good coating has been observed below 200°F (93.3°C). At higher temperatures, use of the Green System has significantly improved coating if coating initially appeared less complete.

What mix temperature should I run?
Run 240°F to 250°F (115.5°C to 121°C) for virgin mixes. Run 270°F to 280°F (132.2°C to 137.7°C) for mixes containing RAP. Refer to Appendix 3: "WMA Production Temperatures" for a more detailed explanation.

Is WMA mix temperature a set temperature or a drop of XX degrees from the HMA mixture?
Since circumstance and environmental conditions play a major role in establishing a rational production temperature (for both HMA and WMA alike), the temperatures provided above should be considered a typical target temperature for ideal conditions. The ability to adjust target temperature up or down based upon mix-specific experience, environmental conditions, and logistics should be considered rather than establishing a fixed target temperature without regard to these factors.

Can I run warm mix at higher temperatures?
Yes. There is no danger in running Green System warm mix at the same temperature as ordinary hot mix. The mix will simply remain workable longer.

Won't I experience a drop in mix temperature since I am adding water?
No. Significant drops in mix temperature for ordinary hauls in moderate weather are caused by internal moisture. Internal moisture is evidenced by steam and water at the silo tops, water running out of the truck beds, and a drop in mix temperature. The amount of water injected by the Green System is insignificant by comparison. For a virgin mix having 5% AC, only 2lb per mix ton is injected (0.1%). After compaction, water remaining in the mix from the warm mix process is 0.0012% (refer to Appendix 2). Many states allow up to 0.5% remaining moisture in the mix (over 400 times the maximum possible amount of water remaining in the mix from the water injection process).

Can warm mix produced with the Green System be stored?
In 2007, storage tests were performed using a 30% RAP mix made with PG64-22. The mix was stored for 24 hours in Astec silos in storage mode. At 24 hours, a small drop was made to ensure that all was well. The mix was then stored an additional 24 hours and sold to a private customer without issue. Since this test, WMA produced with the Astec Green System has been stored for up to 4 days. ***If the hot mix is a mix design that may be stored, the warm mix version of that mix design may be stored as well.***

Are there any equipment maintenance issues?
None on Generation 2.X units. Generation 1 units may require periodic nozzle and water orifice cleaning. A cold weather package is included to prevent freezing when running mix in cold weather when temperatures fall below freezing. Refer to Appendix 5: "Cold Weather Package and Winterizing" for detailed instructions.

Are there special handling requirements?
None.

Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Does the sample need to be aged or conditioned before performing volumetric mix testing? (For example, some technologies require the mixture be placed in an oven for 2 hours before testing.)
No. However, the sample may be held in an oven to maintain temperature.
Will rolling patterns change?
It is likely. Generally paving crews have found that they do not need to hold the rollers off of the mat – rolling can begin immediately. Also, compaction has been achieved at some locations with less rolling required. Of course, specific mixes and materials will exhibit different characteristics so, as with HMA, it is best to experiment to determine what compaction effort is sufficient.
Are there special handling requirements?
None.
At what temperature(s) should the mixtures be arriving at the paver?
Expect the temperature differential between the plant and the road to be the same for WMA as that of HMA under similar environmental and logistical conditions.
When compared to conventional mixtures, can the contractor expect to laydown the same loose thicknesses to achieve a specified compacted thickness? (For example, the contractor places the mixture 2 ½ inches thick, expecting to have a 2 inch thick mat after final compaction.)
Yes. The mix acts like HMA without smoke and smell.
At what temperature should the mix be compacted during placement?
This depends upon the mix design. As a rule-of-thumb, consider the compaction temperature differential to be the same as that of the production temperature differential between HMA and WMA given similar environmental and logistical factors.
At what temperature should Marshall and gyratory samples be compacted in the laboratory?
Laboratory compaction temperatures should match placement compaction temperatures to within ±5℉ to best achieve compaction similitude with placed mix. However, for consistency and expediency, a set differential from production temperature (see Appendix 3) may also be used. [1] Samples may be reheated or maintained at temperature via a conditioning oven.
Is there a temperature at which the mix returns to acting like a conventional mix?
At approximately 212℉ (100℃).
At what temperature is it safe to return traffic to the road?
The same as that of HMA for the same mix design.
If multiple lifts of material are being placed, what temperature should the first lift be at before placing the second lift?
The same as that of HMA for the same mix design.
Are there any concerns with handwork?
In some cases, performing handwork in cold weather (wind, little or no sun, cold ambient temperatures) has become more difficult. In other cases there has been little or no difference in handwork. This appears to be a function of mix design, RAP percentage, and/or environmental conditions.

[1] The National Center for Asphalt Technology (NCAT uses a sample compaction temperature of 30℉ less than production temperature for mechanically foamed WMA samples – a differential that would tend to match typical placement compaction temperatures. By contrast, in 2007 one state adopted a sample compaction temperature of 10℉ less than production temperature for mechanically foamed WMA samples. Though there have been no known issues with this approach, it would tend to result in laboratory compaction temperatures consistently higher than field compaction temperatures.

Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Does WMA produced with the Astec System look any different than regular HMA?
Most mixes look exactly the same as their hot mix equivalent except that there is no smoke and no smell. On a few occasions, the mix has look slightly richer at the same target AC content as hot mix – especially virgin mixes. The slightly richer look is likely due to the expansion of the film thickness due to the presence of microscopic foam bubbles and/or the presence of light ends that would have escaped as smoke and fumes had the mix been made at higher temperatures.

Do all liquid AC grades from various sources foam equally?
There is reason to believe not all liquid asphalt binders foam in the same manner. Currently, this appears to be associated with the source of the crude oil from which the liquid AC is derived. The phenomena may be associated with less viscous grades, but this HAS NOT been confirmed. Research is currently underway to determine a “marker” that may be used predict the tendency to foam. Current experience indicates a large majority of AC in North America and elsewhere foams sufficiently to produce mechanically foamed WMA.

Is it possible to run stone matrix asphalt (SMA) using mechanically foamed WMA?
Foaming asphalt in Stone Matrix Asphalt (SMA) designs has also been accomplished with the Astec Green System. Virginia runs all of their mix designs with mechanically foamed WMA including SMA since 2008. As such, several projects in Virginia have been placed with mechanically foamed PG 76-22 in an SMA. A contractor producing the mix claimed “we have had zero complaints with this mix.” Although it has **not been observed in either the field or laboratory**, it is conceivable that drain down sensitivity could increase in the event the binder grade has been modified via the addition of a significant amount of light ends. The drain down propensity of the mix may be tested using Drain Test AASHTO T305. Also, to quantify the light end content of the liquid, an ASTM D255 Steam Distillation Test may be performed on the liquid.

APPENDIX 2: GREEN SYSTEM WATER INJECTION (STANDARD UNITS)

Introduction
The ASTEC Green System produces WMA by injecting a small amount of water into the liquid AC as it is injected into the mixing chamber of a Double Barrel. Mixing water into the AC results in foam; however, the controlled injection of water via specialized nozzles creates microscopic bubbles of steam that increase film thickness and decrease the viscosity of the AC film. As a result, the workability of the mix remains that of hot mix asphalt until it cools below 212°F, or the microscopic bubbles are broken via compaction.
Water is injected in proportion to liquid AC. Typically, the water flow rate is 2% of the liquid AC flow as measured by the AC Flowmeter. This rate is adjustable by the operator. Accurate metering is maintained by the system via a programmable logic controller (PLC). For a virgin mix having 5% AC, the water injected by the Green System is 2% X 5% = 0.1% of the mix. It will be shown that amount of this water that remains in the mix prior to compaction is very small. Compaction reduces this proportion of remaining water.

Is the proportion of water critical?
Green System WMA uses water to temporarily alter the physical properties of the mix as it is being produced.

- Mix designs are not altered for WMA production.
- Mechanically, the mix design is the same as HMA produced at higher temperatures without the introduction of water to temporarily alter workability.
- Since the mix design is not altered, the pre-compaction and post-compaction volume of WMA is the same as that of HMA.

The Volumetrics physically limit the amount of water that foams the AC in the mix.

To clarify how mix volumetrics limit the development of foamed AC, consider a mix design that has the following properties: AC Content = 5%, Voids = 5% (post-compaction), Mix Density = 110 lb/ft^3 (pre-compaction) or 140 lb/ft^3 (post-compaction).
Prior to compaction, the mix would consist, by volume, of 75% solids (aggregate and AC) and 25% air voids. One ton[2] (2000 lb) of this uncompacted mix would occupy the following volume:

$$\textbf{Volume of uncompacted mix (ft}^3\textbf{/ton)} = \frac{\textbf{2000 lb/ton}}{\textbf{110 lb/ft}^3} = \textbf{18.2 ft}^3\textbf{/ton}$$

Of this 18.2ft^3, 25% (4.54ft^3) consists of air voids. As the density of AC is 65 lb/ft^3, the volume of AC in one ton of mix may be calculated as follows:

$$\textbf{Volume of AC (ft}^3\textbf{/ton)} = \frac{\textbf{5\% X 2000 lb/ton}}{\textbf{65 lb/ft}^3} = \textbf{1.54 ft}^3\textbf{/ton}$$

The total volume that is available for the development of foamed AC is the sum of the uncompacted air void volume and the volume of liquid AC

$$\textbf{Available volume for foamed AC (ft}^3\textbf{/ton) = 4.54 ft}^3\textbf{/ton + 1.54 ft}^3\textbf{/ton = 6.08 ft}^3\textbf{/ton}$$

The mass of injected water per ton is

Mass of water injected (lb/ton) = %AC X %Water X 2000 lb/ton

Substituting,

Mass of water injected (lbm/ton) = 0.05 X 0.02 X 2000 lb/ton = 2 lb/ton

[2] For brevity, "ton" is used in lieu of "mix ton" throughout.

APPENDIX 2:GREEN SYSTEM WATER INJECTION (STANDARD UNITS)

The ambient temperature water that is injected instantly flashes to steam as it contacts the hot liquid AC. Presuming that the liquid AC arrives at the foaming nozzle at near 300°F, the injected water would expand from

0.016 ft^3/lb (ambient temperature liquid) to 30.53 ft^3/lb (superheated vapor at 300°F)

If every drop of the water injected (2% of the liquid AC) flashes to steam, the maximum possible expansion of the foamed liquid AC may calculated as follows:

$$\textbf{Maximum possible expansion} = \frac{\text{Volume of Steam/ton + Volume of Liquid AC/ton}}{\text{Volume of Liquid AC/ton}}$$

Substituting,

$$\textbf{Maximum possible expansion} = \frac{(2\ \text{lb/ton X } 30.53\ \text{ft}^3/\text{lb}) + 1.54\ \text{ft}^3/\text{ton}}{1.54\ \text{ft}^3/\text{ton}} = \frac{62.66\ \text{ft}^3/\text{ton}}{1.54\ \text{ft}^3/\text{ton}}$$

$$= 40.6 \text{ times}$$

Clearly, the combination of water and liquid AC does not expand over 40 times, as the texture and consistency of the mix would be drastically different than that of ordinary HMA. Numerous field trials reveal mix that looks exactly the same as ordinary mix or has the appearance of being slightly richer than ordinary mix.[3] At the very maximum, the foamed AC fills the remaining void volume as foam in excess of this available volume simply collapses releasing the excess steam to be scavenged by the plant exhaust fan. In the example mix used above, the actual expansion of the combination of water and liquid AC would be

$$\textbf{Actual expansion} = \frac{\text{Available volume for foamed AC}}{\text{Volume of Liquid AC/ton}}$$

$$= \frac{6.08\text{ft}^3/\text{ton}}{1.54\ \text{ft}^3/\text{ton}} = 3.95 \text{ times}$$

The volume (4.54 ft^3/ton) of air voids in the uncompacted mix physically limits the amount of water that exists as steam in the matrix of microscopic bubbles that comprise the film thickness of WMA. The mass of water that is in the uncompacted WMA may be calculated as follows:

$$\textbf{Mass of water (lb/ton)} = \frac{4.54\ \text{ft}^3/\text{ton}}{30.53\ \text{ft}^3/\text{lb}} = 0.149\ \text{lb/ton}$$

As a mass percentage of the mix, the injected water remaining in the uncompacted WMA is

$$\textbf{Mass \% of remaining injected water} = \frac{0.149\ \text{lb/ton} \ \ \text{X } 100\%}{2000\ \text{lb/ton}} = 0.0075\%$$

Such a small percentage of remaining moisture is insignificant compared to AC content and the potential for internal moisture in any drying process. However, compaction further reduces the mass % of remaining water. When the mix is compacted, voids are reduced to 5% of the mix volume. One ton (2000 lb) of compacted mix would occupy the following volume:

[3] The first field trials of the Green System used a virgin surface mix and resulted in mix that appeared very rich "to the eye". Tests showed that the AC content of the mix matched the 5.3% target.

APPENDIX 2: GREEN SYSTEM WATER INJECTION (STANDARD UNITS)

$$\textbf{Volume of compacted mix } (ft^3/ton) = \frac{2000\ lb/ton}{140\ lb/ft^3} = 14.3\ ft^3/ton$$

The volume of the voids (5%) in one ton of compacted mix is

$$\textbf{Remaining void volume } (ft^3/ton) = 0.05 \times 14.3\ ft^3/ton = 0.715\ ft^3/ton$$

The available volume for steam is now 0.715 ft^3/ton. Since compaction occurs above 212°F, the matrix of microscopic steam bubbles that exceed the available volume collapses and the steam is released to the atmosphere. Once the mix is compacted, the mass of remaining water is

$$\textbf{Mass of remaining water } (lbm/ton) = \frac{0.715\ ft^3/ton}{30.53\ ft^3/lb} = 0.0234\ lb/ton$$

As a mass percentage of the mix, the injected water remaining in the WMA is

$$\textbf{Mass \% of remaining injected water} = \frac{0.0234\ lb/ton \times 100\%}{2000\ lb/ton} = 0.0012\%$$

From this exercise one may conclude that the proportion of water injected to create WMA is indeed critical as long as this proportion exceeds 0.149 lb/ton. The amount typically injected is far in excess of this amount. More importantly, it may be concluded that retained injected water constitutes only 0.0012% of the final mix at a maximum.

Why inject so much water if so little is needed?
The most common Double Barrel asphalt plant is rated to run 400tph (6.7 tons per minute). Ordinarily such a plant might run a production rate of 300tph (5 tons per minute) due to transportation, paving and/or market constraints. If running the mix considered in the example above, the mass of water that remains in one ton of mix would be:

Mass flow of remaining injected water @ 300tph = 0.149 lb/ton X 5 tons/min = 0.745 lbm/min.

This is equivalent to 0.089 gpm, a very low flow rate. Since the mix will only hold the amount of foamed AC sufficient to fill the voids in the uncompacted mix, excess water escapes as steam into the mixing chamber and is exhausted via the induced draft of the plant exhaust fan.

Much in the same way burners require excess air for sufficient mixing of fuel with oxygen for adequate combustion, the Green System uses excess water to ensure that water and liquid AC are sufficiently mixed to result in the appropriate formation of microscopic steam bubbles in the foamed AC. Injecting more water than necessary for the formation of WMA, though theoretically unnecessary affords:

- A violent, explosive mechanical mixing of liquid AC and injected water within the foaming nozzles.
- Use of pumps, water flowmeters and water delivery hardware of commonly available sizes and configurations.
- A margin of safety to ensure that the liquid AC is sufficiently foamed to achieve the desired affect on workability in the lower temperature range.

APPENDIX 3: WMA Production Temperatures

As the use of Warm Mix Asphalt (WMA) becomes more prevalent across the United States, contractors and manufacturers of WMA producing equipment have been asked to establish temperature limits that define WMA. Generally this temperature range has extended from about 220ºF to about 290ºF. The different technologies that comprise the spectrum of technically viable WMA production methods each have specific temperature ranges within which each performs well –each occupying some range within the broad temperature range that defines WMA. Since Astec, Inc. designs manufactures and tests equipment that employs water injection to produce WMA, this and similar technology will be the focus of this discussion.

Early in the development of the Double Barrel Green System, the intent was to be able to mix water and liquid AC together such that the subsequent flashing of the water in concert with the intimate mixing of flashing water with individual streams of liquid AC would produce a completely foamed liquid AC. The extent of the foaming was studied via bench tests first. Subsequently its viability for producing WMA was studied in field trials using full-scale equipment. Since there was little if any field experience that could be used to predict what might occur in full-scale equipment, Astec thought it prudent to proceed with caution.

Full-scale tests began with hot mix asphalt (HMA) being produced at typical HMA temperatures (300ºF+). After enabling the system to inject water, mix temperature was reduced while plant operation, process parameters, and mix quality were observed. From these experiments, there came two key learnings:

1. As temperature decreased below approximately 285ºF the blue smoke normally visible at the discharge point of the process equipment disappeared. Likewise, the odor associated with this smoke also greatly diminished.
2. As temperature was further lowered to below 240 ºF some incomplete coating was observed at the discharge point of the process equipment ***in some*** cases. However, WMA produced these lower temperatures continued to coat through subsequent process equipment and achieved desired compaction.[4]

Over the course of several field trials using full-scale equipment, guidelines were developed to identify which temperatures worked best. Recognizing that specialized mix designs might require special consideration, conventional mixes appeared to completely coat and handle adequately when produced at 250ºF and below (virgin and low recycle) and 280ºF and below (high-recycle). Running WMA above approximately 280ºF was not given serious consideration because of the aforementioned smoke point of the liquid AC and the loss of fuel savings associated with running higher mix temperatures. Based upon these observations and experiences, Astec recommended mix production temperature guidelines of 240ºF to 250 ºF for virgin and low-RAP mixes; 270ºF to 280 ºF for high-RAP mixes. Due to the plethora of aggregates available for making mix, producers were encouraged to test these limits for themselves to determine how low temperatures could be lowered while still achieving acceptable compaction.

Since this time, Astec has been asked both by contractors and regulating authorities to define the temperature range for WMA for the Astec water injection process. The lower WMA production temperature (220ºF) was deemed representative of the full range of field observation of coating and ability to achieve compaction. The top end of the temperature range was set at 285ºF due to the field observations of the typical smoke point of the liquid AC. On one occasion, however, a slight amount of smoke was observed at 240ºF. Such a very low smoke

[4] This appears to be a shared result among all of the technologies that employ water as the agent to temporarily reduce the viscosity of the binder. Mix has been observed to coat well as low as 220℉; however, not all mixes may exhibit the same tendency to coat.

APPENDIX 3: WMA Production Temperatures

point was considered atypical and not included in the development of an upper range of WMA temperatures.

Unfortunately, establishing a temperature range for WMA between 220ºF and 285ºF and the aforementioned mix temperature guidelines has resulted in some misunderstanding and subsequent misinterpretation of the temperature range and temperature guidelines and what they imply. These misunderstandings and misinterpretations are essentially:

1. The misinterpretation that the range establishes a limit of acceptability
2. The misunderstanding that production guidelines establish a limit of acceptability of mix production temperature not to be mitigated by circumstances normally applied to HMA.

To address these misuses of "ranges" and "guidelines" provided for WMA temperatures, each will be addressed separately.

1: Range Defining WMA Does Not Equate to a Limit of Acceptability

For WMA produced via water injection (foaming), there is no adverse affect on the mix from producing mix at temperatures in excess of the established WMA temperature range other than the obvious increase in fuel consumption and emissions. The water that remains suspended as steam in microscopic bubbles within the film of AC coating the aggregate remains there at the higher temperatures. This will result in the same increase in compactability as the mix cools to the WMA temperature range. Some might point out that mix produced at the higher temperature oxidizes more than that produced at WMA temperatures. Of course this is true, but it oxidizes no worse than the same HMA. A similar argument might be made concerning the "grade-bumping" of AC. Some states have established WMA specifications that allow a greater level of recycle usage as long as it is produced using WMA technology. Here it is important to remember that the original reason that AC grade was bumped lower when running higher levels of recycle was to achieve compaction. As long as the viscosity of the liquid is sufficiently decreased at the lower WMA compaction temperature due to the continuing effect of the steam bubbles remaining in the virgin liquid, the temperature of the mix does not have a bearing on the compactability. This has been shown to be the case in many field trials.

2: Production Temperature Guidelines: It is a Guideline.

As with HMA, WMA is not immune from environmental and logistical considerations. Jobs that have a long transit time in cool and/or windy weather will, just as HMA, require that the WMA be produced at a temperature commensurate with the expected temperature loss due to these effects. If a similar job with HMA might require a higher production temperature, the WMA work will require the same increase in production temperature. Though this seems at first consideration obvious, inspectors in some locations have rejected mix due to it being produced at higher temperatures than the WMA guideline during cold weather paving. Again, the key point is that the WMA produced via water injection maintains compactability at lower temperatures – even if it has been produced at a higher temperature.

Certainly, producers have strong incentives to make WMA at as low a temperature as feasible. The ability to extend the compaction window, shorten the time between placing with mix with the paver and commencement of rolling as well as the reduced smoke and smell are all very good reasons to reduce mix temperature when running WMA. However, the strongest incentive is the reduction in fuel consumption and green house gas emissions afforded by running at lower temperature. Table 1 shows expected percent reductions in fuel consumption for WMA as compared to HMA at maximum production. As fuel usage contributes significantly to the production cost, mix producers will very quickly realize that producing mix at lower temperatures will increase their bottom line. This has been evidenced by producers that are

APPENDIX 3: WMA Production Temperatures

making all private mixes as WMA unless otherwise specified. Likewise, green house gas reduction incentives from regulating authorities and utilities may also serve to sweeten the bottom line.

Table 1. Expected Fuel Savings, WMA versus HMA[5] at Maximum Production

RAP %	0%	10%	20%	30%	40%	50%
Stack Temp. (°F)	225	230	235	240	285	335
% aggregate moisture						
1	19	18	18	17	17	16
2	17	16	16	16	16	15
3	15	15	15	15	15	15
4	13	13	14	14	14	14
5	12	12	13	13	13	13
6	11	12	12	12	12	13
7	11	11	11	11	12	12
8	10	10	10	11	11	12
9	9	10	10	10	11	11
10	9	9	9	10	10	11

Dispensation of Hot WMA

Since production of WMA produced via water injection at temperatures greater than 285°F using water injection does not result in a co ndition deleterious to the mix and since the mix continues to retain its increased compactability consistent with WMA at lower temperatures, mix should not normally[6] be rejected if produced at elevated temperatures. Of course, mix produced at temperatures in excess of established temperature limits for HMA should be rejected. Rejection of WMA produced via water injection due to it being at acceptable HMA temperature, even though it can be again utilized as recycle, wastes processing energy. In fact, for every load of WMA rejected while in an acceptable HMA temperature range, approximately 8 additional loads of WMA at lower temperatures would have to be produced offset the wasted processing energy.

[5] HMA produced at 330°F, WMA at 275°F during continu ous steady-state operation. A stack temperature reduction of 35°F is assumed at all levels of RAP usage (this approximates field observations). RAP moisture is assumed to be 3%. Other operational factors are assumed typical. Since other operational factors may affect fuel consumption, these approximations may be considered for budgetary estimates only and do not constitute a guarantee.

[6] Some joint materials expand when subjected to HMA temperatures resulting in pavement failure or the increased potential for failure at the joint. Under such circumstances, hot WMA should be rejected for these reasons. Of course, any rejected mix should be diverted to other jobs if possible to reduce the environmental impact.

APPENDIX 4: Calibration Instructions (Green Pac™ for Continuous and Double Barrel Green®)

1. Water calibration requires a 5 gallon (19 liter) container and access to a calibrated laboratory scale capable of weighing with sufficient accuracy up to approximately 45 lb (20kg).
2. Tare the bucket and write the tare weight on the bucket for reference.
3. From the "Home screen", press [H2O], then [CAL]
4. At the water skid, open the 2-way ball valve on the calibration leg of the water line and close the 2-way ball valve on the water supply to the manifold. Set the "H2O Cal Spd", (water calibration speed) to 30 %of the pump output (this pump speed may need to be adjusted based upon the calibration bucket size). **Note: Some systems may be fitted with a single 3-way valve in lieu of two (2) 2-way valves.**
5. Enter a time, in seconds, into H2O Cal Time. Choose a time that will fill the bucket at least 80% full at the calibration speed.
6. Press and hold [Start] until the timer begins to time countdown. It is important to HOLD your finger on [Start] until the counter begins (approximately 2 seconds).
7. The calibrator is calculating a "Computed Weight"
8. When the timer reaches 0 seconds, remove the bucket and weigh it.
   a. Actual Water Weight = Gross Weight - Bucket (tare) Weight
9. Enter the Actual Water Weight (lbs) in the "Actual Weight" field on the touch screen.
10. The built-in water calibration screen calculates the error and makes the calibration correction automatically.
11. If error is above acceptable limits, try steps 2 -10 again.
12. Press [Home] to exit the "Calibration" screen.

APPENDIX 4: Calibration Instructions (Green Pac™ for Batch)

1. Water calibration requires a 5 gallon (19 liter) container, a stop watch, and access to a calibrated laboratory scale capable of weighing up to approximately 45 lb (20kg).
2. Tare the bucket. Write the tare weight on the bucket for reference.
3. At the water skid, open the 2-way ball valve on the calibration leg of the water line and close the 2-way ball valve on the water supply to the manifold. **Note: Some systems may be fitted with a single 3-way valve in lieu of two (2) 2-way valves.**
   a. Place the Danfoss drive in "Hand On" instead of "Auto On". Refer to the Danfoss drive manual located in the document sleeve inside the PLC panel mounted on the water skid.
4. Set a water pump speed (Hz) using the Danfoss drive. This will be the *"Calibration Frequency"*
5. Using the stopwatch, time how long it takes to fill 5-gallon (19 liter) container to near 80% of its capacity *(Calibration Time).*
6. Weigh the bucket (*Gross Water Weight).*
7. Calculate *Calibrated Flow Rate* according to the following formula:

Standard Units (shortTPH, lb, gallons, GPM):

$$Calibrated\ Flow\ Rate\ (GPM) = \frac{Gross\ Water\ Weight - Bucket\ Tare}{8.337} \div Calibration\ Time\ (\min)$$

Metric Units (MTPH, kg, liters, LPM):

$$Calibrated\ Flow\ Rate\ (LPM) = \frac{Gross\ Water\ Weight - Bucket\ Tare}{Calibration\ Time\ (\min.)}$$

APPENDIX 4: Calibration Instructions (Green Pac™ for Batch)

8. From any screen: Press [Home]/[System]/[Config].
9. Use the built in calculator to get the required flow rate for this plant.
10. First determine the number of pounds of asphalt the weigh-pot holds, next determine how many seconds it takes to empty the weigh-pot.
11. Enter these numbers and the percentage of water desired (default is 2%) from the touch panel into the appropriate fields on the "Config" screen. The calculator will give you "*Calculated Rate (H2O)"* in GPM/LPM. H2O Manual Speed (percentage) may be calculated by the following formula (shown on the next page).
12. Input "H2O Manual Speed" into the field on the "Config" screen. The system is now calibrated.

APPENDIX 4: Calibration Instructions (Green Pac™ for Batch)

$$H2O\ Manual\ Speed = \frac{Calibration\ Frequency}{Calibrated\ Flowrate} \quad X \quad \frac{Calculated\ Rate\,(H2O)}{120} \quad X \quad 100$$

Where,

Calibration Frequency = the frequency in Hz at which you performed the calibration.
Calibrated Flow Rate = the flow rate (GPM/LPM) that determined at during the calibration.
Calculated Rate (H2O) = the rate of flow calculated using the built-in calculator on the touch screen.

APPENDIX 5: COLD WEATHER PACKAGE AND WINTERIZING

Cold Weather Package

Often the production of WMA will coincide with temperatures that fall far below freezing overnight. Such low temperatures could result in catastrophic damage to system components due to water freezing within them. A "Cold Weather Package" is available through Astec Parts if the package was not originally included with the system.[7] The cold weather package consists of

1. Electric heat trace for waterlines and pump.
2. Foam insulation for the water lines
3. Tank heater to prevent the tank from icing.
4. Insulating pump and manifold jacket.
5. Installation hardware.

[7] Since the cold weather package consists mostly of commonly available components, some HMA producers wish to configure their own using their own preferred components.

APPENDIX 5: COLD WEATHER PACKAGE AND WINTERIZING

CAUTION!
The Cold Weather Package is NOT meant as a "winterizing" package. Catastrophic damage to system components may occur if the Cold Weather Package is used as a "winterizing" package.

Winterizing the Unit
To winterize the unit over extended shutdown periods in cold weather, displace the water in the system components and piping with a suitable fluid with freezing point below the lowest temperature expected. Ordinary windshield wiper fluid works well in most regions.

Preparation for Winter:

1. You will need approximately 2-gallons of commonly available windshield wiper fluid and a helper to monitor the level of wiper fluid remaining in the container.
2. Disconnect the inlet hose from the tank. Leave the other end connected to the pump.
3. Drain the water tank (close the ball valve at the tank outlet when finished).
4. Place the tank side of the inlet hose into a container of windshield wiper fluid.
5. Navigate to the "H2O Manual" screen. Input "10" into the "H2O Manual Speed" field. This is 10% pump speed. You may wish to try a higher speed to expedite the process.
6. Press [Manual ON].
7. Press and hold [START] for about 2 seconds. The pump will begin running.
8. Press [H2O 1] to open the water injectors. The pump will draw the wiper fluid into the inlet hose and pump it through the injectors.
9. Have your helper monitor the level of wiper fluid in the container.

CAUTION
DO NOT allow the pump to gulp air as the pump may be damaged.

10. Continue until the fluid is visible in the flow indicators. Continue a few more seconds to ensure that fluid has reached and filled the water injectors.
11. Press and hold [STOP] for about 2 seconds. The pump will cease running.
12. Press [Manual OFF].
13. Shut the unit off at the PLC panel mounted on the skid. Reattach the supply hose to the water tank.

Appendix 6: Revision Summary

Revision#	Description	Effective Date
1	Added FAQ regarding the observed tendency of some liquid binders to foam differently than others.	3-18-11
2	• Added FAQ on compaction temperatures of plant-produced laboratory specimens for Marshall and gyratory samples. • Added "Revision Summary" appendix – Appendix 6.	5-9-11
3	• Added FAQ regarding SMA mixes using PG76-22 to Appendix 1.	9-23-11

Asphalt Tops the Charts for Environmental Stewardship — Again

New FHWA-Sponsored Survey Shows a Surge in Asphalt's Green Side

By Kent Hansen, PE; Dave Newcomb, PhD, PE; and Margaret Cervarich

New research sponsored by the Federal Highway Administration (FHWA) and conducted by the National Asphalt Pavement Association (NAPA) shows significant growth in the use of green technologies – reclaimed asphalt pavement (RAP), recycled asphalt shingles (RAS), and warm-mix asphalt (WMA) in 2009 and 2010.

Atop the findings: the use of warm mix soared to 47.2 million tons in 2010 from 16.7 million tons in 2009 – an astounding 180 percent increase in one year. The use of RAP increased by 10 percent while the use of RAS boomed by 57 percent.

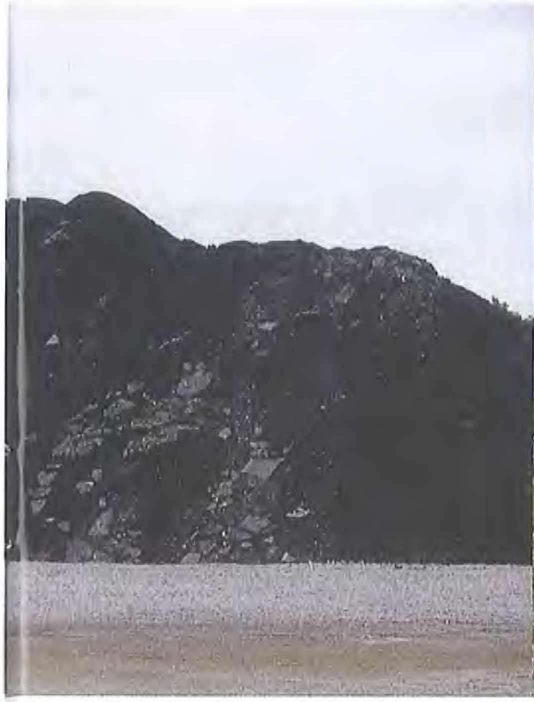
Another remarkable finding: over 99 percent of all RAP is now being reused or recycled in highway applications. Also, an overwhelming 96 percent of asphalt producers reported using RAP.

Growth of reuse/recycling

In 2005, a NAPA survey of contractors and DOTs found that about 12.5 percent of the asphalt pavement material used at the time was made up of RAP. Today, that figure has increased to 17.6 percent. As a side note, by reducing the need to acquire and process virgin binder and aggregates, the industry could avoid 1 million or more tons of CO_2 emissions with just a slight increase in the rate of RAP use.

A previous authoritative publication on the subject of RAP usage was a June 1993 *Report to Congress* from FHWA and the Environmental Protection Agency, which reported an 80 percent reuse/recycle rate for RAP. The 80 percent rate documented in 1993 was higher than for any other construction material.

In terms of reuse/recycling rates, the 2009-2010 numbers bested the 1993 numbers significantly. In 1993, when highway construction activity was significantly higher than during the current economic downturn, a total of 91 million tons of RAP was reclaimed and 73 million tons was recycled or reused in highway applications; again, this was an 80



Notes on the survey method

In 2010 and 2011, under an FHWA contract, NAPA conducted a survey of asphalt mix producers in the United States to determine the quantities of RAP, RAS, and WMA used in 2009 and 2010. The survey did not include in-place recycling. Asphalt mix producers from 48 states/districts completed the survey. The District of Columbia, Nebraska, New Mexico, and North Dakota are the only states/districts with no survey information. More than 1,000 plants, or 25 percent of all U.S. asphalt plants, responded. These plants represent 34 percent of all U.S. tonnage.

percent rate. The 1993 report did not attempt to estimate how much RAP was reused in hot mix versus other highway construction such as shoulders and base.

In 2009, 67 million tons of RAP was reclaimed, and 56 million tons went directly back into asphalt plants to make hot-mix or warm-mix material, a rate of 86 percent. In 2010, when 73 million tons of RAP was reclaimed, 62 million tons went into hot or warm mix, an 84 percent rate. Of the small amount of material not going back into hot or warm mix, all but .005 percent was recycled into shoulders, base, or other highway uses.

"Highest and best use"

The highest and best use of RAP – giving the biggest environmental bang for the ton of reclaimed material – is reusing it in hot mix or warm mix. This is because the asphalt cement in the RAP is reactivated as binder. This cannot be done with any other pavement material. Thus RAP replaces, one for one, both virgin binder (5 percent of the material by weight) and virgin aggregates (the other 95 percent).

Not only does RAP help conserve precious natural resources and lower emissions, it provides economic benefits. When prices of both asphalt binder and aggregates are in flux, RAP can help stabilize prices for contractors and their customers.

Helping to boost the numbers for putting RAP through an asphalt plant for hot mix or warm mix: Base and intermediate pavement courses in some states have been produced with 100 percent RAP. In addition, RAP is being used in higher and higher levels in surface courses.

New research under way at the National Center for Asphalt Technology at Auburn University, and planned by the National Cooperative Highway Research Program, will help develop hot-mix/warm-mix asphalt designs that will greatly increase RAP contents in mixes without sacrificing performance.

RAS on the rise

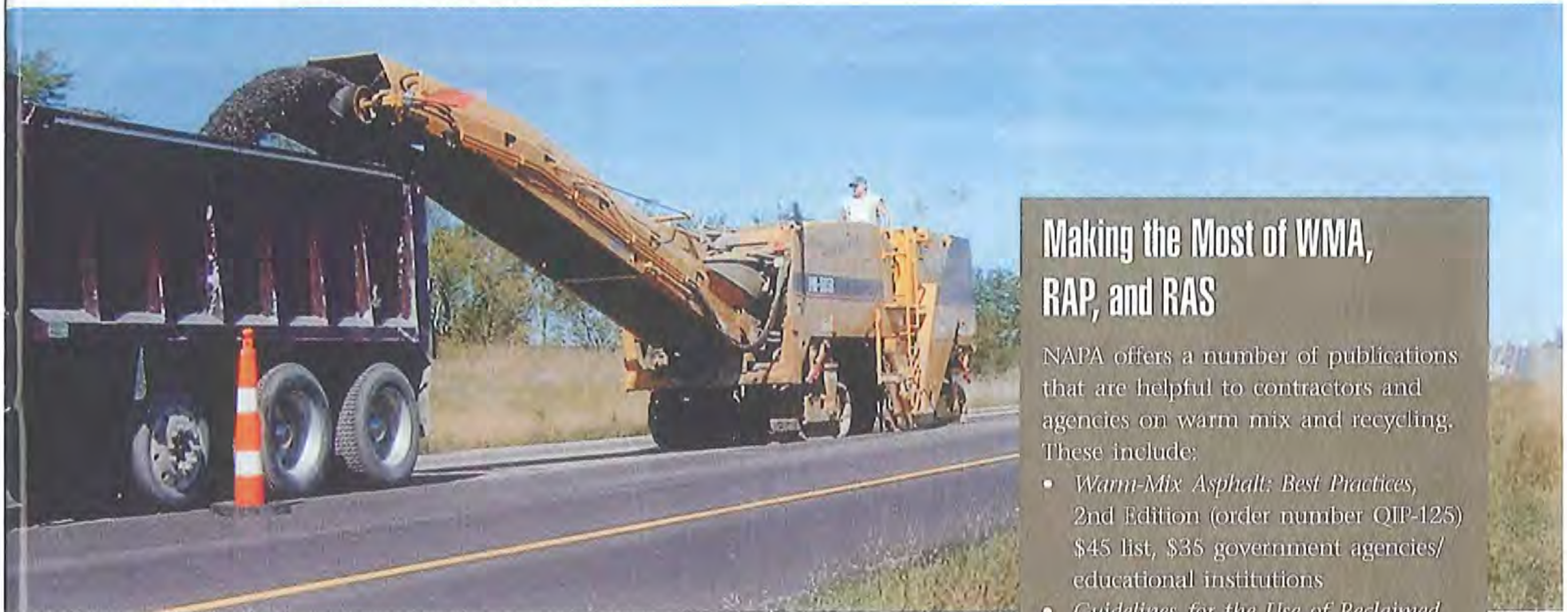
Reclaimed shingles from manufacturing waste as well as reroofing projects contain binder that can be used to reduce the amount of virgin binder used in asphalt mixtures. RAS typically has 20 to 30 percent binder.

RAS use increased 57 percent from 2009 to 2010. The study found that 724,000 tons was used in 2009, rising to 1.14 million tons in 2010. Assuming a conservative asphalt content of 20 percent binder in the shingles, this represents a saving of 234,000 tons (1.5 million barrels) of virgin asphalt binder. (In the 1993 report, reuse/recycling of roofing shingles was not known.) Recent advances in technology for reclaiming, testing, and utilizing shingles are credited with boosting the reuse of this valuable resource.

It is estimated that there are about 11 million tons of waste shingles available in the US each year. Therefore the amount of RAS being used in asphalt pavement production represents about 10 percent of the total available asphalt shingles (manufacturer waste and tear-offs).

Warm-mix use soars

The first public demonstration of warm-mix asphalt in the U.S. was a 2004 project at World of Asphalt



Making the Most of WMA, RAP, and RAS

NAPA offers a number of publications that are helpful to contractors and agencies on warm mix and recycling. These include:

- *Warm-Mix Asphalt: Best Practices*, 2nd Edition (order number QIP-125) $45 list, $35 government agencies/ educational institutions
- *Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements* (order number IS-136) $20 list, $15 government agencies/ educational institutions
- *Designing HMA Mixtures With High RAP Content: A Practical Guide* (order number QIP-124) $20 list, $15 government agencies/ educational institutions
- *Recycling Hot-Mix Asphalt Pavements* (order number IS-125) $16 list, $12 government agencies/ educational institutions

All are available from the NAPA online store at http://store.hotmix.org.

in Nashville. Today, warm mix has been tried in all but three of the 50 states and at least 29 states have specifications for WMA.

Initially, warm mix was heralded as a way to enhance conditions for workers at the paving site. As contractors and agencies explored the use of WMA technologies, however, they discovered construction benefits including the potential to extend the paving season in cold climates, enhance compactability, increase haul distances, reduce energy use and emissions at the plant, and even use higher percentages of RAP.

In 2009, the survey estimates the total tonnage of WMA at 16.7 million tons. This grew to 47.2 million tons in 2010, for a 180 percent increase. Worth noting is that less than 100,000 tons was produced in the U.S. in 2004. Plant foaming is used for the majority of WMA production; however, the use of chemical and organic additives also increased between 2009 and 2010.

The public-private partnership represented by the FHWA's Warm-Mix Asphalt Technical Working Group deserves much of the credit for the rapid deployment of warm mix. Manufacturers of both foaming equipment and additives also have contributed mightily by creating more and more technologies for producing warm mix. In 2004, only three WMA technologies were available in the U.S., while today at least 20 technologies are represented on the Web site at www.WarmMixAsphalt.com.

Also worth noting is that, based on anecdotal evidence from around the world, the U.S. rate of utilization of warm mix is far ahead of any other country.

Summary

Table 1 summarizes reported and estimated total values from the survey. The estimated total values were determined by factoring the values for the reported tons to the total state tons. The percent of DOT, other agency, and commercial/ residential mixes using WMA increased from 6.3 to 15.0 percent, 4.4 to 11 percent, and 4.5 to 10 percent, respectively.

In conclusion, the survey clearly shows that the asphalt pavement industry continues to lead the nation in environmental stewardship. Increases in the use of RAP, RAS and WMA score successes for both the environment and the economy. Precious natural resources are conserved. Workers have a more comfortable work environment.

Not only does RAP help conserve precious natural resources and lower emissions, it provides economic benefits. When prices of both asphalt binder and aggregates are in flux, RAP can help stabilize prices for contractors and their customers.

Table 1: Summary of RAP, RAS, WMA Survey

	Reported Values		Estimated Total Values	
	2009	2010	2009	2010
Tons of HMA/WMA Produced				
Total, Million	124.0	119.8	358.4*	358.0*
DOT, Million	56.9	55.6	169.2*	171.6*
Other Agency, Million	28.1	27.8	83.5*	85.8*
Commercial & Residential, Million	35.6	32.6	105.8*	100.7*
RAP				
Companies/branches Using RAP	186	186		
Tons Accepted, Million	23.2	24.0	67.2	72.9
Tons in HMA/WMA, Million	20.0	21.6	56.0	61.6
Tons Used in Aggregate, Million	1.4	1.6	6.2	7.3
Tons Used in Cold Mix, Million	0.4	0.4	1.5	1.6
Tons Used in Other, Million	0.1	0.1	0.7	0.8
Tons Landfilled, Million	0.1	<0.1	0.1	<0.1
Avg % for DOT Mixes	12.5%	13.2%	Same	Same
Avg % for Other Agency Mixes	14.0%	15.2%	Same	Same
Avg % for Commercial & Residential	17.5%	18.0%	Same	Same
National Average All Mixes	15.6%	17.2%	Same	Same
RAS				
Companies/branches Reporting Using RAS	44	61		
Tons Accepted, Thousand	332.1	558.7	957.4	1,1851.0
Tons Used in HMA/WMA, Thousand	245.8	392.7	723.9	1,136.1
Tons Used in Aggregate, Thousand	5.0	2.5	6.1	3.2
Tons Used in Cold Mix, Thousand	-	-	-	-
Tons Used in Other, Thousand	39.0	34.5	123.2	124.8
Tons Landfilled, Thousand	-	0.5	-	6.7
Avg % for DOT Mixes	0.33%	1.44%	Same	Same
Avg % for Other Agency Mixes	0.37%	0.47%	Same	Same
Avg % for Commercial & Residential Mixes	0.63%	0.81%	Same	Same
WMA				
Companies/branches Reporting Using WMA	85	121		
Avg % for DOT Tons	6.3%	15.0%	Same	Same
Avg % for Other Agency Tons	4.4%	21.7%	Same	Same
Avg % for Commercial & Residential Tons	4.5%	11.6%	Same	Same
Total Tons, Million	6.4	18.2	16.7	47.2
% Using Chemical Additive	15%	20%	Same	Same
% Using Additive Foaming	2%	1%	Same	Same
% Using Plant Foaming	83%	79%	Same	Same
% Using Organic Additives	0	1%	Same	Same

*These are very approximate values.

Pavements can be of higher quality at less cost, and can last longer. Ultimately, the American public is the biggest beneficiary of asphalt's push for green technologies. HMAT

The survey was conducted on behalf of the Federal Highway Administration by Kent Hansen, PE, NAPA Director of Engineering, and Dave Newcomb, PhD, PE, NAPA Vice President for Research and Technology. This article was written by Margaret Cervarich, NAPA Vice President for Marketing and Public Affairs.

A One Year Review of the Anthony Henday Drive Warm Mix Project

R.W. Forfylow, P.Eng.
Director of Quality – Asphalt, Paving & Construction
Lafarge Canada Inc.
Calgary, Alberta

Mauricio Reyes, Ph.D.
Manufacturing Coordinator – Asphalt, Paving & Construction
Lafarge Canada Inc.
Calgary, Alberta

Matt Grimm, P. Eng.
General Manager – Transportation Systems Management Inc.
& Lafarge Asphalt Edmonton
Lafarge Canada Inc.
Edmonton, Alberta

Acknowledgements

The authors express their gratitude to the University of Calgary, the City of Edmonton, EBA and GECAN laboratories for their help during the preparation of this paper.

ABSTRACT

The Anthony Henday Drive Southeast Leg Ring Road project consisted of 11.5 kilometres (approximately 125 lane-kilometres) of grading, base and paving, and the construction of 20 bridge structures. Alberta Transportation awarded a design, build, finance and 30 year maintenance contract for the work through a Private Public Partnership Project (P3). Lafarge Canada Inc. was awarded the construction of the granular base course, asphalt concrete the maintenance contract.

The initial construction of the freeway occurred between 2005 and 2007 with the final wearing surface completed during the 2010 construction season. The final wearing surface was comprised of 98,500 tonnes of asphalt concrete - 66,000 tonnes was mixed and placed as Warm Mix Asphalt (WMA). The paper presents the initial evaluation of the WMA after one year of service at the Equivalent Single Axle Load (ESAL) level of approximately 1.2 million ESAL's, as well as observations and experiences gained during WMA production and placement.

A visual condition survey, the Tensile Strength Ratio (TSR), Asphalt Pavement Analyzer (APA), low temperature cracking, Resilient Modulus, binder rheology, and Falling Weight Deflectometer (FWD) measurements on road sections comparing the WMA and the conventional hot mix asphalt (HMA) placed and the results are discussed.

RÉSUMÉ

1.0 INTRODUCTION

Anthony Henday Drive (AHD) circles the perimeter of the City of Edmonton and is part of the North/South trade corridor between Canada, the United States, and Mexico. Based on a Private Public Partnership (P3) model, Alberta Transportation awarded the design, construction, finance and 30-year maintenance contract of the Anthony Henday Drive Southeast Leg Ring Road (AHD SELRR) to Access Roads Edmonton Ltd. Lafarge Canada Inc. was awarded the construction of the AHD SELRR granular base course and asphalt concrete surface layers, as well as the maintenance contract. The AHD SELRR project consisted of 11.5 kilometres (approximately 125 lane-kilometres) of grading, base and paving, and construction of 20 bridge structures. The project was opened to the public on October 28th, 2007. The initial construction of this freeway occurred between 2005 and 2007 with the final wearing surface completed during the 2010 construction season. As part of the original pavement design, a 50mm overlay was completed in summer 2010 to bring the paved surface to its final elevation.

The final wearing surface comprised 91,000 tonnes of 16.0 mm asphalt mix and 7500 tonnes of 12.5 mm asphalt mix. Of this, 66,000 tonnes of the 16.0 mm surface course mix was placed as Warm Mix Asphalt (WMA) containing 10 percent Reclaimed Asphalt Pavement (RAP). The AHD WMA mix was produced in an Astec Double Barrel Green® asphalt plant. This paper presents the initial evaluation of the AHD WMA mix after one year of service at an Equivalent Single Axle Load (ESAL) level of approximately 1.2 million ESAL's. Observations about experiences gained with the use of Astec Double Barrel Green® process WMA technology for the mix production and placement are also described.

In recent years, WMA technology has gained acceptance as a feasible and reliable alternative to Hot Mix Asphalt (HMA) paving. With the use of WMA technologies, conventional HMA mixes can be produced at reduced manufacturing temperatures. The benefits derived from the use of lower manufacturing temperatures with WMA technology usage are described elsewhere [1-7]. The Astec Double-Barrel® Green System (DBG) requires an Astec Double Barrel® drum asphalt plant and uses a multi-nozzle foaming device to microscopically foam a standard grade asphalt binder with water [4, 5] as shown in Figure 1. In the process, a small amount of water is introduced through the nozzles, causing the asphalt binder to foam. This foam temporarily lowers mixture viscosity and allows for the production, placement, and compaction of a high quality mix at lower temperatures than conventional HMA [4, 5].

Figure 1. Astec Double Barrel® Drum and Green System

2.0 SCOPE AND OBJECTIVE

The objective of this study is to evaluate the initial performance of the AHD WMA mix placed at the AHD SELRR after one year of service (approximately 1.2 million ESAL's), as well as to describe observations and experiences gained from the use of WMA technology in the overlay of a major freeway in the City of Edmonton.

3.0 PROJECT DESCRIPTION

As part of the North/South Trade Corridor, Anthony Henday Drive is designated as a truck route and dangerous goods corridor. The Transportation Utility Corridor (TUC) was originally planned by the Province of Alberta and the City of Edmonton in the late 1970s and is commonly referred to as the Edmonton Ring Road. The AHD SELRR was awarded to Access Roads Edmonton Ltd. and the contract was signed on January 25th, 2005.

The 11 km long project formed the south east section of the Edmonton Ring Road and connects Highway 2 to Highway 14/216. The AHD SELRR is classified by the Province as control section 216:04 and 14:04. The infrastructure consists of approximately 11.5 km of 4 and 6 lane divided controlled access freeway with auxiliary lanes from Highway 216/14 to Highway 2, along with associated intersecting roadways, interchanges, property access roads and bridge structures. The pavement structure was designed based on an Average Annual Daily Traffic (AADT) of 35,000 with a growth rate of 2.0 percent; the structure is as follows:

H1 surface course	50mm,
H1 upper binder course	50mm,
H1 intermediate binder course	50mm,
S3 lower binder course	70mm, and
Granular base course	610mm

Transportation Systems Management Inc. (TSMI) began providing operations, maintenance, and rehabilitation services on the AHD SELRR with traffic availability in October 2007. As part of the original pavement design, the final stage paving comprising of 50 mm H1 surface course mix occurred in summer 2010 to bring the paved surface to its final elevation. Figure 2 depicts a typical 3-lane road cross section and Figure 3 describes the project location.

For the AHD SERLL 2010 overlay project, it was decided to produce a H1 surface course mix containing 10 percent RAP by using WMA (water-foaming technology) and conventional HMA technology. All mainlines (eastbound and westbound) from the Parsons Road Bridge to the Highway 14 interchange were paved using WMA technology, as well as the Highway 14 interchange including all ramp work. The Calgary Trail/Highway 2 interchange and all other interchanges were paved to the gores of the mainline with conventional HMA technology. Out of a total of 91,000 tonnes of asphalt overlay, 66,000 tonnes were placed as WMA on main lines.

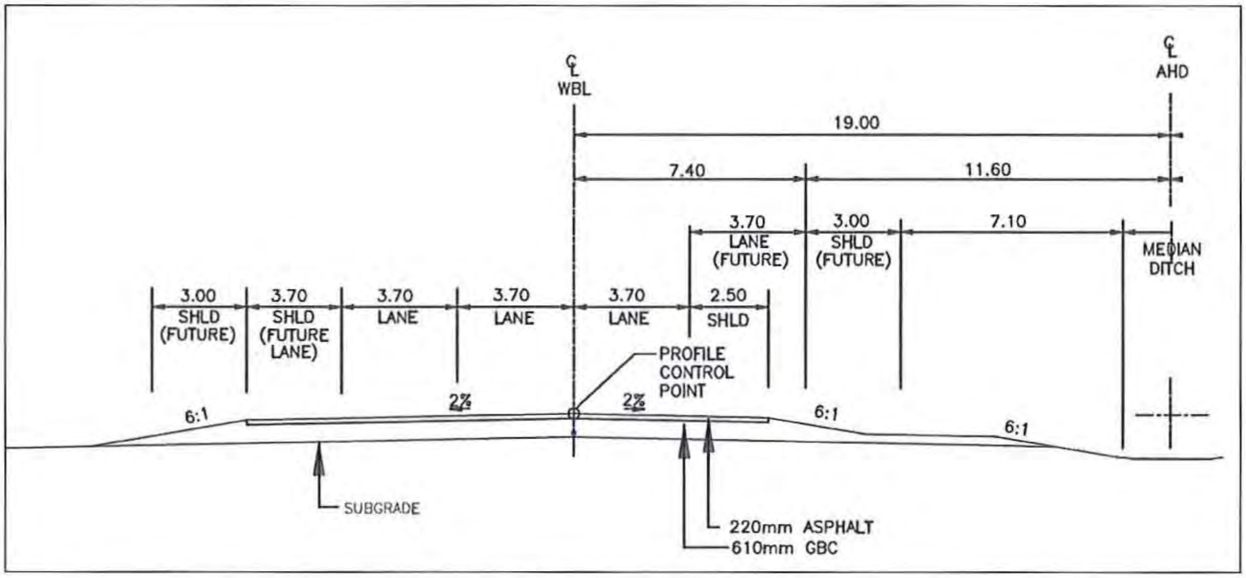


Figure 2. Anthony Henday Drive Southeast Leg Ring Road Typical 3-lane Road Section

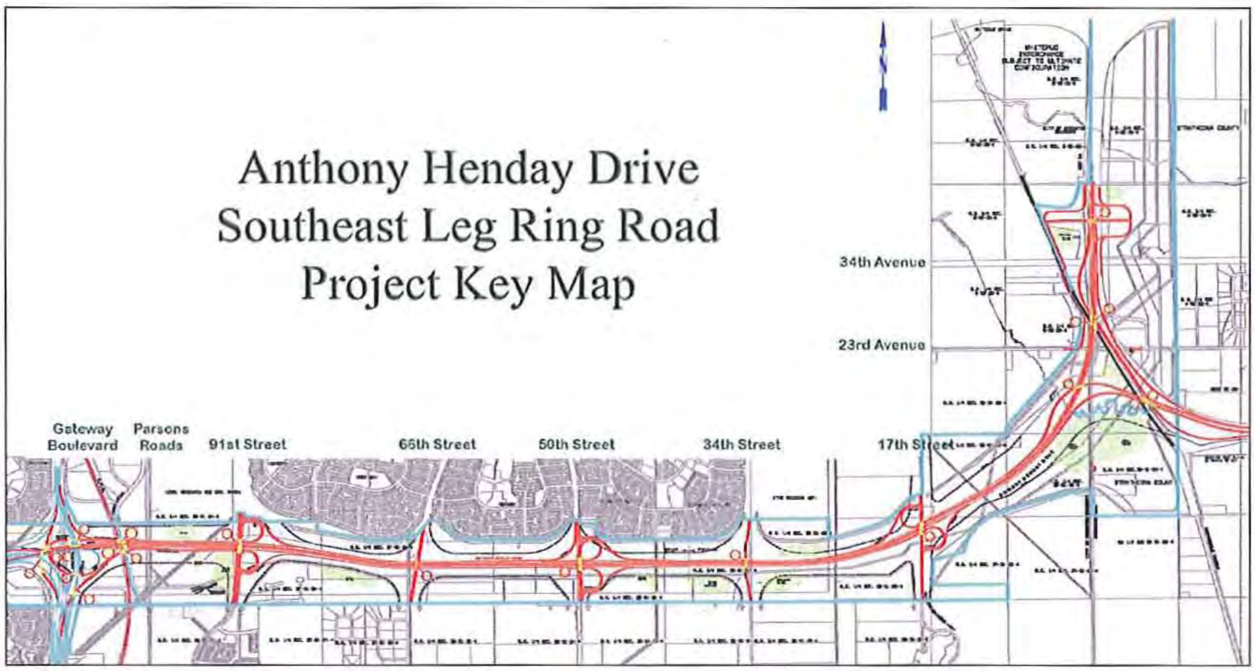


Figure 3. Anthony Henday Drive Southeast Leg Ring Road Project Location

4.0 MIX DESIGN

For the AHD SELRR top lift paving, a Marshall mix design was prepared in accordance with Alberta Transportation (AT) specifications for Designation 1 Class 16, Type H1 asphalt concrete mix. The design incorporated 10 percent RAP. Preparation of the asphalt mix samples was in accordance with the Marshall

Method of Mix Design as outlined in the latest edition of the Asphalt Institute Manual Series No.2 (MS-2), ASTM D6926-04, D6927-06 and AT design procedure TLT-301 (03). The design was based on a Marshall Hammer 75 blow per-face compactive effort incorporating Husky Oil PG 58-37 grade asphalt cement. At a design asphalt content of 5.1 percent by mass of dry aggregate, the Marshall properties provided in Tables 1 and 2 were obtained.

Table 1. Mix Design Properties

Marshall Property	Mix Design Results	Specification
Asphalt Cement Content, by Dry Agg, (%)	5.1	-
Bulk Density, (kg/m^3)	2357	-
Marshall Stability, (kN)	17.3	12.0 min
Marshall Flow, (mm)	2.4	2.0 to 3.5
Air Voids, (%)	3.7	3.5 to 4.0
Voids in Mineral Aggregates, (%)	13.6	13.0 to 13.5
Voids Filled with Asphalt, (%)	72.6	65 to 75
Tensile Strength Ratio, (%)	89.4	80.0 min
Film Thickness, (μm)	6.8	6.1 min

Table 2. Mix Design Gradation

Sieve Sizes (mm)	Mix Design Results	Specification
25.000	100	100 – 100
20.000	100	100 – 100
16.000	99	100 – 100
12.500	89	82 – 92
10.000	80	75 – 84
5.000	63	58 – 65
2.500	44	40 – 48
1.250	35	31 – 39
0.630	29	26 – 32
0.315	19	16 – 22
0.160	10.1	8.1 – 12.1
0.080	6.0	4.5 – 7.5

5.0 PLANT PRODUCTION AND ROAD CONSTRUCTION

The AHD WMA and conventional HMA mixes were produced at an Astec Double Barrel plant. For the AHD WMA mix, the asphalt plant settings were adjusted to produce WMA mixes at mix temperatures of 125±5°C. The average production temperature for the AHD conventional HMA was 156.1°C and for the WMA 127.0°C, approximately 30°C lower. The advantages of the use of WMA technology were noticed during the plant production where reduced plant emissions and visible smoke were witnessed. Also, at this lower mix temperature, a uniform coating of the asphalt mix was evident. Table 3 contains a typical plant production record data for the AHD WMA and conventional HMA mixes.

Table 3. Plant Production Data for Anthony Henday Drive (AHD)

Measurement	AHD Warm Mix Asphalt (WMA)	AHD Hot Mix Asphalt (HMA)
Date	07/20/2010	05/17/2010
Mix temperature, (°C)	128.0	157.0
Mix production, (TPH)	335.7	314.2
Aggregate belt, (TPH)	280.1	263.7
Recycle belt, (TPH)	38.9	33.3
Total Asphalt Cement, (TPH)	16.8	16.2

Note: TPH is Tonnes Per Hour

The Quality Control and Quality Assurance (QC/QA) testing for the project was carried out by J.R. Paine & Associates Ltd. As part of the testing procedure, loose mix and core samples were taken for laboratory testing. Bulk density, air voids, mix moisture content, asphalt cement content, sieve analysis, core thickness, core moisture, core bulk density, percentage of compaction, and core air voids were measured. Table 4 contains a typical QC record data for the AHD WMA and conventional HMA mixes. Notice that the AHD WMA mix has the same moisture content and quality properties as the AHD HMA mix. Although the mix split proportions were the same for both WMA and HMA, the WMA mix gradation was slightly finer at the "bottom end" of the gradation sieves. This has been observed as well on other projects where more of the fine fractions are retained in the WMA mix and not collected in the baghouse. This slight change in the gradation did not affect the Marshall properties.

The advantages of the use of WMA technology were also evidenced during paving where improved comfort and working environment for the paving crew was evident, as well as reduced thermal segregation and better workability. It was also observed that the WMA mix does not require any special consideration with respect to haulage, material handling, placement and compaction. Also, the window for compacting the WMA mix extended for a longer period of time and that the mix remained more workable to a lower temperature than compared to the conventional mix. This could prove very beneficial in achieving mat density with harsh mixes or mixes that are difficult to compact; increased production rates if mixes compact more readily; increased haul distances; and the ability to pave in cooler temperatures as mentioned elsewhere [4-7].

Table 4. Plant Produced Mix Properties for Anthony Henday Drive (AHD)

Sieve Sizes (mm)	Mix Design	AHD Warm Mix Asphalt (WMA)	AHD Hot Mix Asphalt (HMA)
20.000	100 – 100	100	100
16.000	100 – 100	99	99
12.500	82 – 92	91	89
10.000	75 – 84	82	82
5.000	58 – 65	62	60
2.500	40 – 48	46	45
1.250	31 – 39	37	35
0.630	26 – 32	31	29
0.315	16 – 22	21	19
0.160	8.1 – 12.1	12.0	10.1
0.080	4.5 – 7.5	7.0	6.0
Bulk density, (kg/m3)	2357	2358	2355
Asphalt Cement Content (%)	5.10	5.17	5.11
Air Voids (%)	3.7	3.6	3.8
Mix Moisture, (%)	-	0.03	0.04
Mix Voids in the Mineral Aggregate, (%)	13.6	13.7	13.7
Core Density, (kg/m3)	-	2317	2307
Core Air Voids, (%)	-	5.1	5.6
Core Compaction, (%)	-	98.3	97.8

6.0 LABORATORY EVALUATION

In order to evaluate the performance of the HMA and WMA mixes, core samples for each type of mix were extracted from different road sections. After bulk density and air voids were measured on all core samples, the cores were grouped for the various laboratory tests programs. Moisture resistance, rutting susceptibility, resilient modulus, and critical cracking temperature were evaluated on the core samples. Additionally, the rheological properties of the asphalt binders were measured on recovered samples for each type of mix.

6.1 Moisture Susceptibility

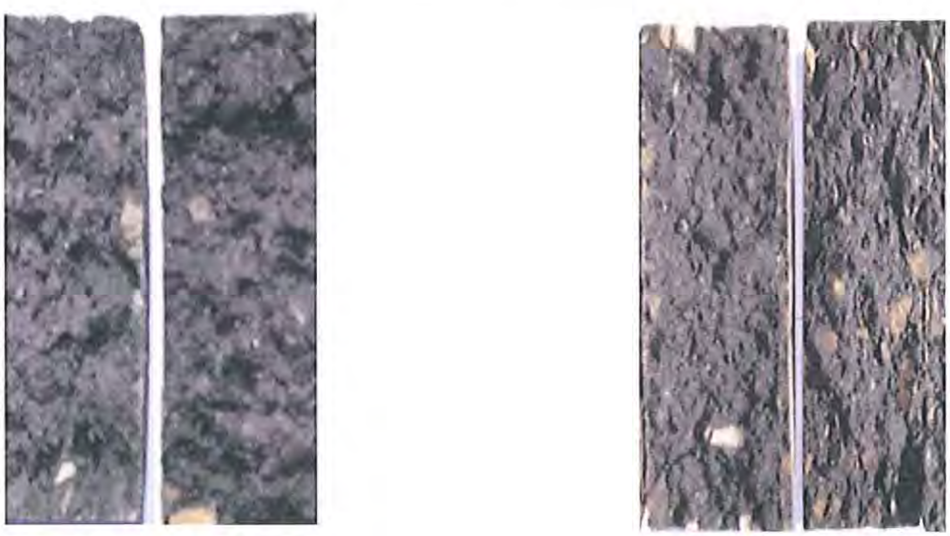
Moisture susceptibility was evaluated using AASHTO T283 "Standard Method of Test for Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage (TSR)" [8] on extracted cores. For each type of mix the extracted cores were divided in two groups in order to test them in a dry and freeze/thaw (wet) conditions. As per the standard followed, all samples were tested at 25°C. The ratio of the average tensile strengths of the conditioned specimens to the average tensile strengths of the unconditioned specimens is defined as the Tensile Strength Ratio (TSR). Table 5 provides a summary of the moisture susceptibility test results.

Based on a minimum TSR requirement of 80 percent, both the HMA and the WMA mixes meet the minimum required. Also, the WMA mix moisture content measured during the production was similar to the content of the conventional mix (below 0.1 percent); see Table 4. Although both mixes exceed the limiting value of 80 percent for a TSR test, the WMA mix has slightly lower TSR value than the conventional HMA, which is typical for WMA results.

Figure 4 shows photographs of broken cores for both the conditioned and the unconditioned AHD WMA and conventional HMA cores.

Table 5. Summary of Moisture Susceptibility Testing

Mix Type	Treatment	Average Air Voids (%)	Tensile Strength (kPa)	Tensile Strength Ratio, TSR (%)
AHD Warm Mix Asphalt (WMA)	Conditioned	7.97	389	83
	Unconditioned	8.07	324	
AHD Hot Mix Asphalt (HMA)	Conditioned	6.57	550	87
	Unconditioned	6.49	480	



Hot Mix Asphalt (HMA)
Dry (Left) and Wet (Right)

Warm Mix Asphalt (WMA)
Dry (Left) and Wet (Right)

Figure 4. Broken Core Samples after Tensile Strength Ratio (TSR) Testing.

It was also noted that although the AHD WMA core samples exceed the minimum of 80 percent TSR threshold value, visual examination of the tested cores does indicate an increase in the amount of stripping on the coarse aggregates compared to the conventional AHD HMA core samples. It was also noted that the AHD WMA tensile strength values were lower in the conditioned and unconditioned samples compared to the AHD conventional HMA samples. As part of the best practices for the manufacturing of WMA mixes, the addition of an anti-stripping additive is recommended.

6.2 Rutting Resistance

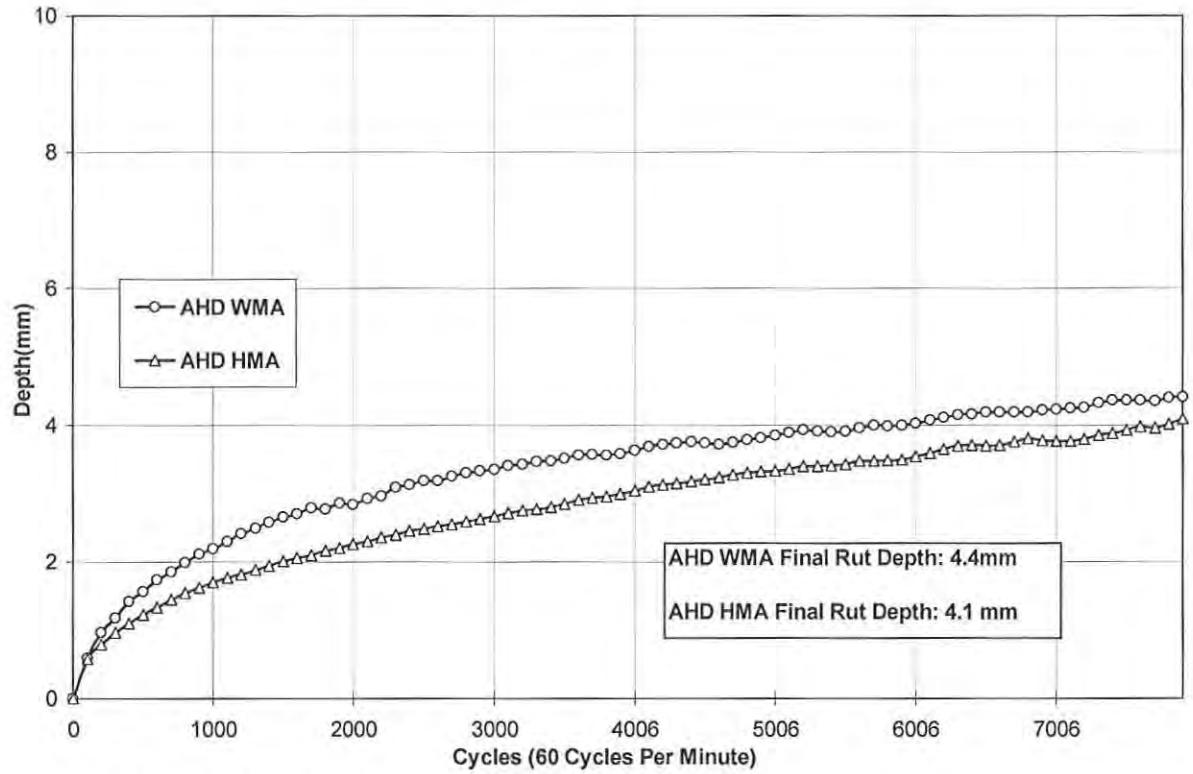
One of the most important characteristics of asphalt mixes is the rutting resistance. The rutting susceptibility of the AHD WMA and conventional HMA mixes was evaluated using the Asphalt Pavement Analyzer (APA) conducted in accordance with AASHTO TP 63 [9]. The APA is a multifunctional loaded wheel tester that uses pneumatic cylinders on a concave metal wheel to apply a repetitive load through a pressurized rubber hose. Typically, 8000 repetitions are applied to specimens. APA testing was conducted at 64°C on core samples for each type of asphalt mix.

Table 6 and Figure 5 provide a summary of the APA testing results. The APA test results indicate similar rutting behaviour of the AHD WMA and the conventional HMA mixes. Both mixes attained a final accumulated rut depth lower than 5.0 mm which is considered to be the accepted maximum accumulated rut depth for this type of roadway [4, 6]. Although both mixes showed similar rutting resistance, the AHD WMA indicated a slightly higher rutting rate and final accumulated rut depth than the AHD HMA, which is typical for WMA mixes using the water foaming technology when tested at a very early age.

Recent field evaluations conducted by NCAT indicate that the mix stiffness increases with time to a similar level as that of conventional HMA mixes after two years [10, 11]. Of note also, is that test was conducted at 64°C and not at 58°C for the binder specified (PG 58-37). The total accumulated rut depth would therefore be reduced further had the test been conducted at 58°C. This also indicates that these types of H1 mixes both WMA and HMA are rut resistant.

Table 6. Summary of Asphalt Pavement Analyzer (APA) Testing at 64°C

Mix Type	Stroke Count	Rutting Rate (mm/hr)	Rut Depth (mm)	Final Rut Depth (mm)
AHD Warm Mix Asphalt (WMA)	25	26.815	0.186	4.4
	4,000	3.216	3.737	
	8,000	0.543	4.441	
AHD Hot Mix Asphalt (HMA)	25	36.253	0.252	4.1
	4,000	2.565	3.084	
	8,000	0.896	4.090	



Note: WMA is Warm Mix Asphalt and HMA is Hot Mix Asphalt

Figure 5. Asphalt Pavement Analyzer (APA) Rutting Test Results

6.3 Low Temperature Cracking

The critical cracking low temperature for the AHD WMA and the conventional HMA mixes was determined based on thermal stresses and tensile stress data. The testing was performed using a digital servo-hydraulic controlled 500 kN testing frame equipment with an environmental chamber. Two LVDT's were placed on each face of the specimen along the horizontal and vertical axes with a centre to centre spacing of 38mm. Specimens were conditioned and tested according with AASHTO T-322 "Determining the Creep Compliance and Strength of Hot-Mix Asphalt Using the Indirect Tensile Test Device". The testing was carried out at temperatures of -20, -30, and -35°C.

The sample test setup is depicted in Figure 6. The critical cracking temperatures were estimated using Monarch PIDT (Process Indirect Tensile Test Data) software. The Monarch program analyzes low temperature IDT creep and strength tests, and estimates pavement surface thermal stress from the results.

Table 7 and Figure 7 depict the WMA and the HMA surface thermal stress and the critical low temperatures. The critical low temperature test results indicate similar low temperature behaviour for the AHD conventional HMA and the WMA mixes. The AHD WMA cracking temperature is slightly lower than the HMA mix due to the use of lower production temperatures with WMA mixes. Lower production temperatures reduce the amount of light volatiles being driven off during the mixing process resulting in a slightly less stiff mix in the WMA.

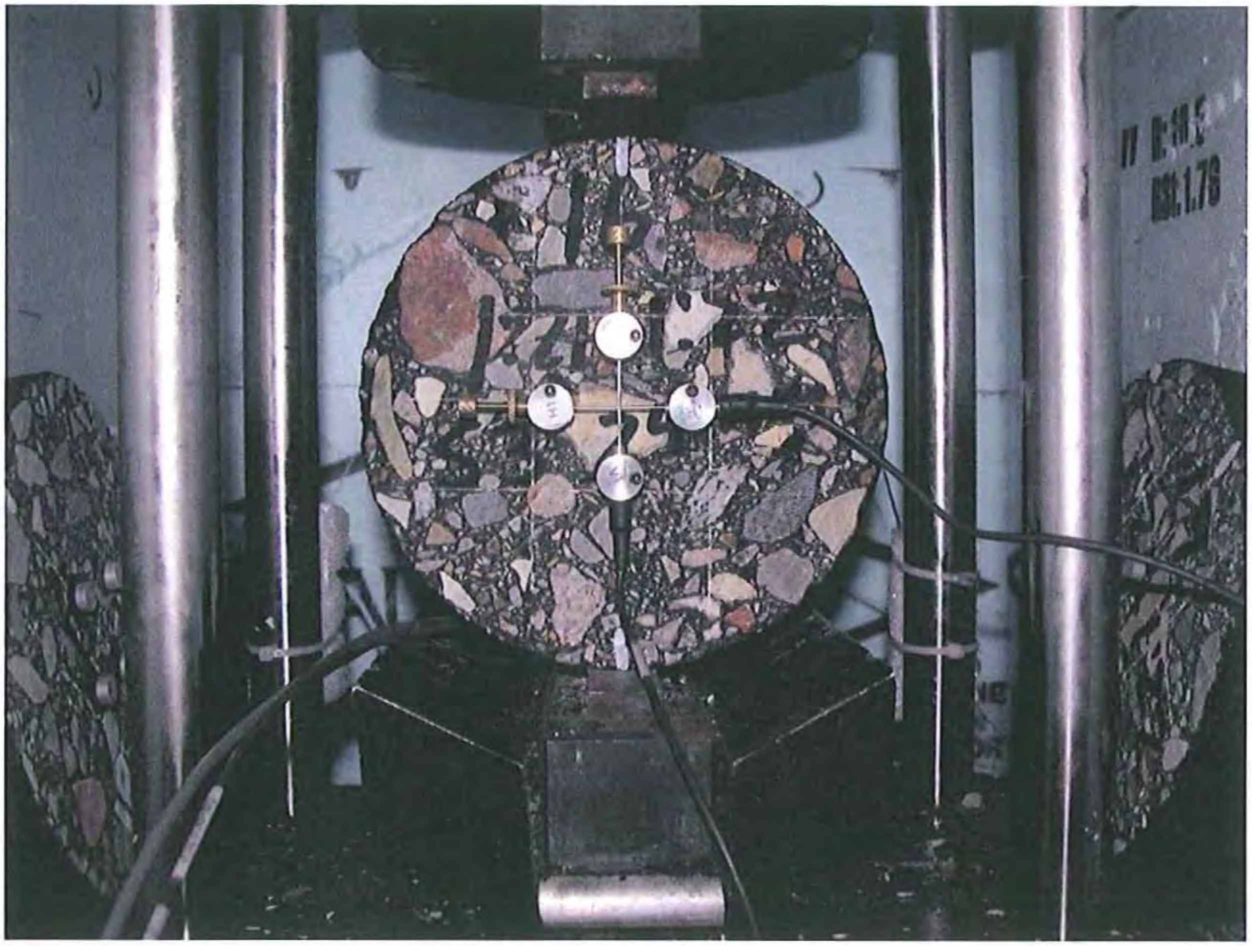
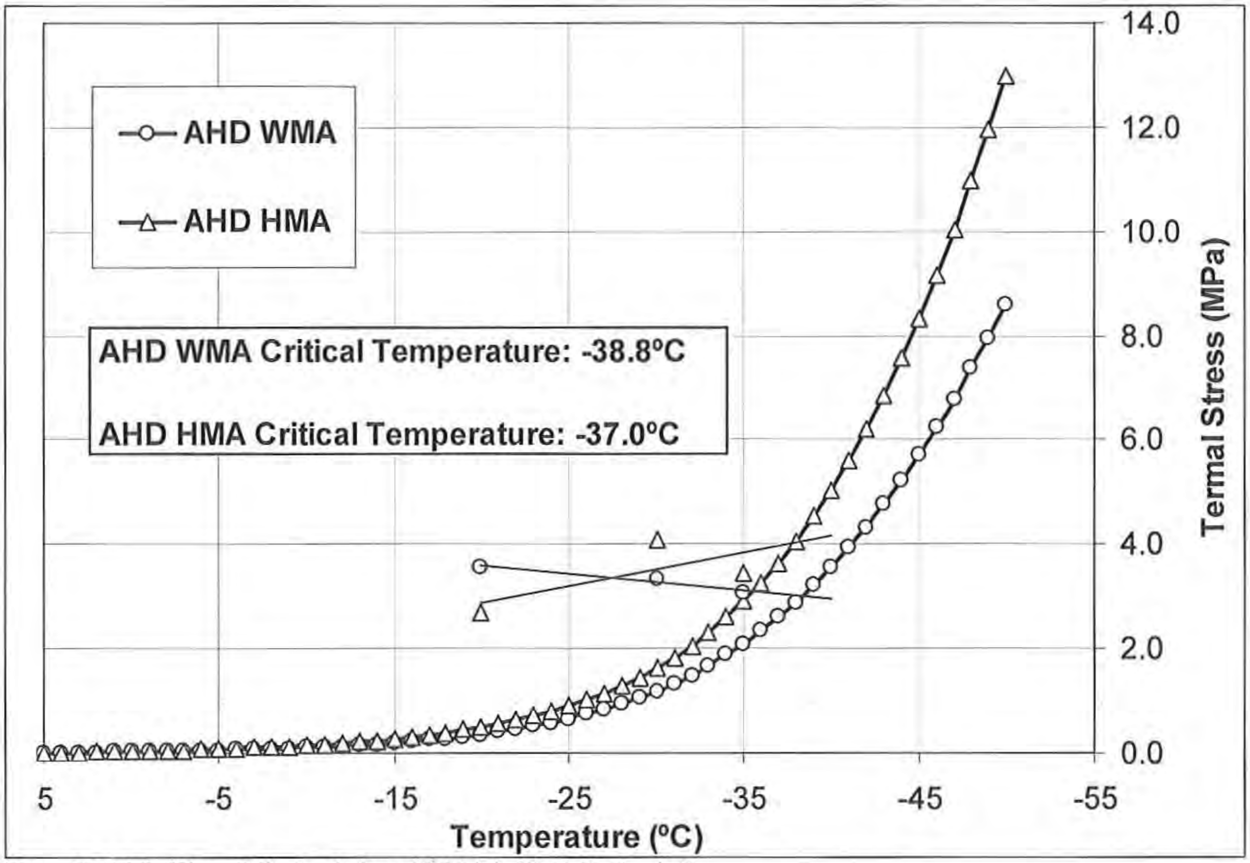


Figure 6. Indirect Tensile Test (IDT) Sample

Table 7. Summary of Critical Low Temperature Testing

Mix Type	Test Temperature (°C)	Fracture Strength (MPa)	Thermal Stress (MPa)	Critical Low Temperature (°C)
AHD Warm Mix Asphalt (WMA)	- 20.0	3.56	0.36	- 38.8
	- 30.0	3.33	1.18	
	- 35.0	3.07	2.09	
AHD Hot Mix Asphalt (HMA)	- 20.0	2.67	0.50	- 37.0
	- 30.0	4.09	1.63	
	- 35.0	3.44	2.91	



Note: WMA is Warm Mix Asphalt and HMA is Hot Mix Asphalt

Figure 7. Critical Low Temperature Cracking

6.4 Mix Stiffness

The stiffness of the two asphalt mixes was estimated by using resilient modulus at different temperatures from cores obtained from the road section. The resilient modulus for the AHD WMA and the conventional HMA mixes was determined by using a universal testing machine UTM-100 (IPC Global). The UTM-100 tester is a servo-hydraulic asphalt mix tester machine with a maximum load capacity of 100kN. Resilient modulus values were measured at temperatures of 5, 25 and 40°C. Testing was conducted by starting with the lowest testing temperature and continued to the highest temperature. Two Linear Variable Distance Transducers (LVDT's) were placed on each face along the horizontal and vertical axis of core samples. Tensile strength and resilient modulus tests were performed according with AASHTO TP31-96 "Standard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension" [12, 13].

Table 8 and Figure 8 contain the resilient modulus test results. The resilient modulus data from the core samples depict a slightly lower stiffness for the AHD WMA mix. This slight lower stiffness in the AHD WMA mix was also noticed in the rheological test results of the recovered asphalt binder from the mix; however, recent field evaluations conducted by NCAT indicate that the mix stiffness increases with time to a similar level as that of conventional HMA mixes after two years [10, 11].

Table 8. Summary of Resilient Modulus Testing

Mix Type	Average Air Voids (%)	Test Temperature (°C)	Resilient Modulus (MPa)
AHD Warm Mix Asphalt (WMA)	3.81	5.0	9,510
		25.0	1,836
		40.0	987
AHD Hot Mix Asphalt (HMA)	3.70	5.0	12,400
		25.0	2,183
		40.0	1,035

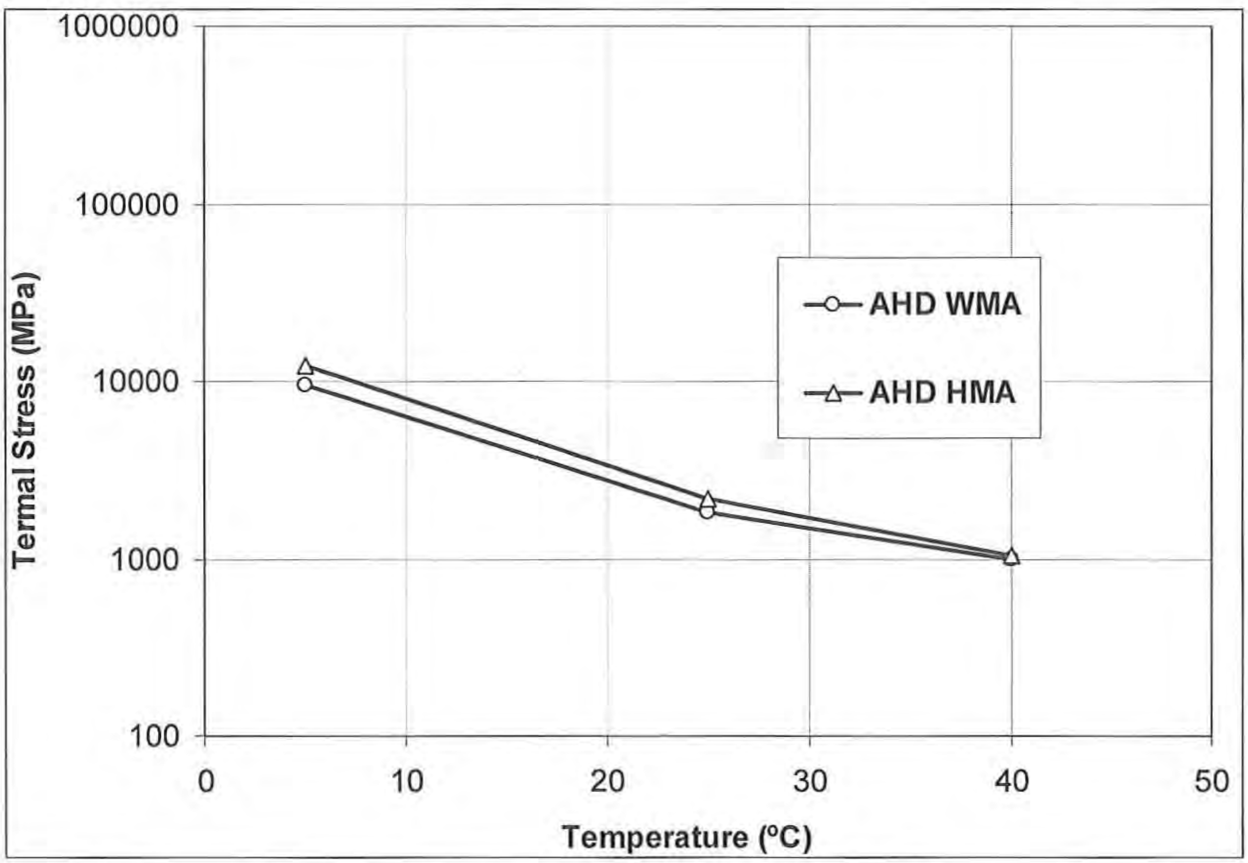


Figure 8. Resilient Modulus of Warm Mix Asphalt (WMA) and Hot Mix Asphalt (HMA)

6.5 Asphalt Binder Characteristics

The rheological evaluation of the recovered binders from the asphalt mixes was done in accordance with the American Association of State Highway and Transportation Officials (AASHTO) M320 specifications. As the binders were recovered from the road way core samples, the Rolling Thin Film

Oven (RTFO) was eliminated from the testing. A stress-controlled Dynamic Shear Rheometer (DSR) from TA Instruments (AR 2000ex) was used for the asphalt binder evaluation. Small amplitude oscillations were performed at temperatures of 64 and 70°C. At fixed temperature, small amplitude oscillations were performed at a fixed frequency of 10 rad/s by using plate-plate geometry with diameter of 25 mm and a gap of 1.0 mm. For the Bending Beam Rheometer (BBR) test, rectangular Pressure Aging Vessel (PAV) beams were tested in order to measure the amount that an asphalt binder deflects or creeps under a constant load and temperature. Based on the deflection and force data, asphalt binder stiffness, *S(t)* and tensile creep compliance, *D(t)* were calculated. BBR experiments were performed at temperatures of -24 and -30°C. Table 9 contains the DSR and BBR test results. The results are also compared to the original binder test results.

Table 9. Recovered Asphalt Binder Characteristics

Tests on Recovered Asphalt Binder		Binders Extracted from Core Samples		
		AHD WMA	**AHD HMA**	**Original binder**
Dynamic Shear Rheometer				
G*/Sin δ, KPa	@ 64 °C	2.868	3.268	2.649
>=2.2 KPa	@ 70 °C	1.444	1.687	
Predicted Failure Temperature (°C)		66.32	67.59	65.61
Pressure Aging Vessel Residue (AASHTO R28)				
Bending Beam Rheometer				
Creep Stiffness, MPa	@ -24°C	215	224	
<=300 MPa	@ -30°C	443	472	437
Predicted Failure Temperature (°C)		-36.76	-36.35	-37.03
Slope, m - value, MPa	@ -24°C	0.321	0.317	
>=0.300	@ -30°C	0.273	0.260	0.283
Predicted Failure Temperature (°C)		-36.63	-35.79	-37.17
Performance Grade (PG)		***64-34***	***64-34***	***64-37***

Note: WMA is Warm Mix Asphalt and HMA is Hot Mix Asphalt

The lower plant production temperature was reflected in the rheology of the AHD WMA recovered binder, which showed slightly lower stiffness at high and low temperatures than the recovered binder from the conventional HMA mix. Of more significance is the low temperature data comparing the WMA and the HMA to the original binder; the higher stiffness of the HMA binder may result in decreased resistance to thermal cracking over time. The slightly lower initial stiffness of the AHD WMA is also reflected in the APA and critical cracking low temperature test results. However, the recovered binders have the same Performance Grade (PG) classification. As mentioned before, recent field evaluations conducted by

NCAT indicate that the tensile strength of WMA increases with time to a similar tensile strength as that of conventional HMA mixes after two years [10, 11].

7.0 ROAD PERFORMANCE

The initial road performance of the AHD WMA mix was evaluated after a full year cycle. For the purpose of evaluating the road performance, surface distress evaluation and Falling Weight Deflectometer (FWD) measurements were performed.

The Visual Condition Index (VCI) was used as an indicator of pavement surface condition [14, 15]. This index combines surface distress data into an overall distress related index on a scale of zero to ten, with ten being a perfect score. The following distresses were considered: alligator cracking, block cracking, edge cracking, longitudinal and transverse cracking, bleeding, distortion, rutting, shoving, ravelling, and potholes. These distresses were measured at three defined levels of severity (low, medium, and high). The road was divided into sections, according to the recommendations of the Pavement Surface Condition Rating Manual of the Ministry of Transportation and Highways – Province of British Columbia [16]. Data collection was conducted using manual procedures for all of the sections. For each distress/severity combination, the Distress Value (DV) was calculated. All the individual distresses were then combined into an overall Adjusted Distress Value (ADV) based on the Equivalent Number of Distresses (END). The ADV was then subtracted from 100 and divided by 10 to obtain the VCI (Table 10). Notice that the AHD WMA mix shows a visual condition similar to a conventional HMA mix.

Table 10. Anthony Henday Drive (AHD) Visual Condition Index after 1-Year

Item	AHD Warm Mix Asphalt (WMA)	AHD Hot Mix Asphalt (HMA)
Distress Value (Transversal Cracking) - Low	3.0	3.2
Distress Value (Transversal Cracking) - Medium	0.0	0.0
Distress Value (Transversal Cracking) - High	0.0	0.0
Total Distress Value	3.0	3.2
Equivalent Number of Distresses (END)	1.0	1.0
Adjusted Distress Value (ADV)	3.0	3.0
Visual Condition Index (VCI)	9.7	9.7

The FWD is designed to impart a load pulse to the pavement surface which simulates the load produced by a rolling vehicle wheel. The load is produced by dropping a large weight, and transmitted to the pavement through a circular load plate - typically 300mm diameter. A load cell measures the load applied to the pavement surface. Deflection sensors mounted radially from the center of the load plate measure the pavement deformation. Based on collected and input data, the stiffness modulus of the pavement structure can be estimated. Table 11 depicts the estimated modulus of the H1 surface course mix for the WMA and conventional HMA mix.

Table 11. Falling Weight Deflectometer (FWD) Estimated Mix Stiffness for the H1 Surface Course

AHD Hot Mix Asphalt (HMA)					AHD Warm Mix Asphalt (WMA)				
Station	Drop	E1 (MPa)	E2 (MPa fixed)	E3 (MPa)	Station	Drop	E1 (MPa)	E2 (MPa fixed)	E3 (MPa)
0.153	1	1251	600	98	0.069	1	2285	600	107
0.221	1	2908		113	0.1	1	1754		100
0.296	1	2984		108	0.14	1	1257		114
0.583	1	1086		114	0.305	1	2630		138
0.153	2	1536		95	0.069	2	2492		102
0.221	2	2991		122	0.1	2	2115		105
0.296	2	2326		131	0.14	2	2084		93
0.583	2	1256		117	0.305	2	3393		133
0.153	3	1842		97	0.069	3	3088		99
0.221	3	3997		124	0.1	3	2139		124
0.296	3	2500		113	0.14	3	2337		102
0.521	3	1196		117	0.069				
0.583	3	1524		113	0.1				
Average E1 (MPa) : 2107.5					Average E1 (MPa): 2325.0				

Note: E1 layer thickness: 75mm. E2 layer thickness: 805mm (145mm asphalt concrete, 660mm granular base). E2 modulus fixed at 600MPa. Radius of curvature method was used to calculate moduli.

After one year of road service, some minor transverse cracks have appeared on the road surface. Although the severity of the transverse cracking is low, there appears that distress mechanisms such as settlement of the road structure, low temperature and reflecting cracking (Figure 9) may explain the transverse cracking observed. There are long sections (longer than 3km) where no cracking is evident, and there is a relatively short section where more frequent cracking was observed. Of note was during the previous winter months there were extended periods (in one week intervals) where the air temperature was in excess of -30°C and another period where air temperature was in excess of -35°C which may explain the transverse cracks observed.

Overall, the AHD WMA mix depicts similar road performance and mix stiffness as the AHD conventional HMA mix.

Figure 9. Core Samples Taken at Transverse Crack Locations

8.0 CONCLUSIONS

An 11.5 kilometre overlay was constructed on the Anthony Henday Drive Southeast Leg Ring Road in The City of Edmonton. The surface course mix containing 10 percent Reclaimed Asphalt Pavement (RAP) was produced as conventional Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) utilizing an Astec's Double Barrel® Green Plant.

The advantages of the use of WMA technology were evident during the mix manufacturing and road construction stages where reduced plant emissions, reduced visible smoke, better aggregate coating, lower thermal segregation, and higher mix workability was observed.

The laboratory evaluation of core samples indicated that the WMA mix has similar performance properties compared to the conventional HMA mix. Additionally, the recovered binder depicted that the use of lower plant production temperatures of the WMA mix was reflected in the rheology of the recovered binder. The recovered binder from the WMA mix indicated slightly lower stiffness at high and low temperatures than the recovered binder from the conventional HMA mix.

The road condition survey and the Falling Weight Deflectometer (FWD) measurements indicate that after one year of service, the WMA and HMA mixes have similar field performance.

REFERENCES

1. D'Angelo J, Harm E, Bartoszek J, Baumgardner G, Corrigan M, Cowsert J, Harmon T, Jamshidi M, Jones W, Newcombe D, Prowell B, Sines R, Yeaton B. "Warm-Mix Asphalt: European Practice". FHWA-PL-08-007, U.S. Department of Transportation, Federal Highway Administration (FHWA), American Association of State Highway and Transportation Officials, National Cooperative Highway Research Program, Washington, D.C., 1998.
2. Prowell B., Hurley G. "Warm-Mix Asphalt: Best Practices". National Asphalt Pavement Association, Lanham, M.D., 2007.
3. Corteau J.M., Tessier B. "An Overview of Warm Mix Asphalt Paving Technologies". Proceedings of the Fifty-Third Annual Conference of the Canadian Technical Asphalt Association (CTAA). Saskatoon, Saskatchewan, 2008.
4. Forfylow R.W., Middleton B. "Experiences with Warm Mix Asphalt – A Contractors Perspective". Proceedings of the Fifty-Third Annual Conference of the Canadian Technical Asphalt Association (CTAA). Saskatoon, Saskatchewan, 2008.
5. Astec Industries, Inc. Double Barrel Green System. Hot Mix Asphalt Magazine. 13, No. 1, 2008.
6. Kvasnak A., Taylor A., Signore J. M., and Bukhari S. A. "Evaluation of Gencor Green Machine Ultrafoam GX Final Report". National Center for Asphalt Technology NCAT Report 10-03, July, 2010.
7. Manolis S., Decoo T., Lum P., and Greco M. "Cold Weather Paving Using Warm Mix Asphalt Technology. Proceedings of the Fifty-Third Annual Conference of the Canadian Technical Asphalt Association (CTAA). Saskatoon, Saskatchewan, 2008.
8. Standard Method of Test for Determining the Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage. AASHTO T 283, AASHTO Provisional Standards, 2005.
9. Standard Method of Test for Determining Rutting Susceptibility of Hot-Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA). AASHTO TP 63-07, 2005.
10. Hurley G., Prowell B., and Kvasnak A. Ohio Field Trial of Warm Mix Asphalt Technologies: Construction Summary. NCAT Report 09-04. Auburn, AL, 2009.
11. Hurley G., Prowell B., and Kvasnak A. Missouri Field Trial of Warm Mix Asphalt Technologies: Construction Summary, Auburn, Al, 2009.
12. Roberts F. L., Kandhal P. S., Brown E. R., Lee D-Y., and Kennedy T. W. Hot Mix Asphalt Materials, Mix Design, and Construction. Second Edition, NAPA Education Foundation, Lanham, Maryland, 1996.
13. Standard Method of Test for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension. AASHTO TP 31-96, AASHTO Provisional Standards, 2005.
14. Pavement Management Systems Limited – Alberta Municipal Pavement Management System (MPMS), 1989.
15. Shahin M. Y., and Kohn S. D. Pavement Maintenance Management for Roads and Parking Lots. U.S. Army Corps of Engineering, Technical Report M-294, 1981.
16. Pavement Surface Condition – Ministry of Transportation and Highways Geotechnical and Materials Engineering Branch, Victoria, British Columbia, 1994.

WARM MIX PROJECT LIST

District	Project	Route / County	Mix Type	Approx. Tonnage	Additive/ Technology	Date	Contractor	Mix Temp[1]	Comp Temp[1]	Mix Temp[2]	Comp Temp[2]	Location
1	197259-2	US-92/Polk	SP-12.5	1883.00	Evotherm	10/2007	Lane Construction	250	230	325	315	Mainline
	195983-2	SR-37/Manatee	FC-12.5	7222.25	Meeker	10/2009	Ajax Paving	280	280	315	310	Mainline
	197373-2	US-92/Polk	SP-9.5	2000.00	Evotherm	08/2009	Lane Construction	250	240	310	300	Mainline
			FC-9.5	2000.00		09/2009		250	240	320	310	Mainline
	197707-1	U-27/Polk	FC-5	6579.20	Astec DBG	04/2009	Orlando Paving	260	260	320	320	Mainline
	197753-2	SR-780/Sarasota	SP-9.5	3020.15	Meeker	08/2009	Ajax Paving	265	265	305	300	Mainline
			SP-9.5	4000.00	Terex	09/2009		270	270	305	305	
			SP-9.5	3156.00		10/2009		270	270	305	305	
			FC-12.5M	16095.80		01/2010		290	290	310	310	
	422498-1	I-75/Manatee	FC-5	2856.00	Meeker	11/2009	Ajax Paving	290	290	320	315	Mainline
	420238-1	US-301/Manatee	SP-12.5	8779.11	Meeker	11/2009	Ajax Paving	290	290	325	325	Mainline
			FC-5	3744.38		10/2009	Ajax Paving	290	290	320	315	Mainline
			FC-5	767.89		10/2009	Ajax Paving	290	290	320	315	Mainline
	420655-1	I-75/Collier	SP-12.5	173.43	Meeker	--	Ajax Paving	275	275	300	300	Shoulders
			SP-12.5	4884.54		05/2009		275	275	305	305	
			SP-12.5	26563.24		08/2009		265	265	305	305	
			FC-5	12283.38		10/2009		290	285	325	315	Mainline
			FC-5	42180.66		10/2009		275	270	325	315	Mainline
			SP-12.5	408.64		11/2009		265	265	305	305	Mainline
	417244-2	SR-82 / Lee	SP-12-5	6000.00	Meeker	03/2010	Ajax Paving	270	270	305	305	Mainline
			SP-9.5	7968.40		03/2010		270	270	305	300	Mainline
	406314-3	I-75/Sarasota	SP-12.5	2556.73	Meeker	10/2010	Ajax Paving	300	300	320	320	Mainline
			SP-12.5	1731.98		10/2010		280	280	305	305	Mainline
			SP-12.5	1411.37		10/2010		280	280	305	305	Mainline
	422407-1	SR-789 / Sarasota	SP-12.5	6000.00	Meeker	10/2010	Ajax Paving	265	265	300	300	Mainline
	423369-1	SR-780 / Sarasota	SP-12.5	4000.00	Astec DBG	12/2010	APAC Southeast	260	260	300	300	Mainline
	426743-2	CR-832 / Hendry	SP-9.5	2000.00	Meeker	01/2011	Ajax Paving	270	270	305	300	Mainline
2	209733-4	SR 202/Duval	SP-12.5	5134.95	Astec DBG	08/2009	Duval Asphalt	265	265	325	325	Shoulders
	210883-2	US-98/Taylor	SP-12.5	4427.72	Astec DBG	12/2009	Anderson Columbia	260	250	325	325	Mainline
			FC-12.5	1070.83		01/2010		260	260	325	325	Mainline
	210878-3	US-19 / Taylor	SP-12.5	2000.00	Astec DBG	02/2010	Anderson Columbia	260	260	315	315	Mainline
			SP-12.5	36057.87		04/2010		260	260	315	315	Mainline
	207914-4	US-90 / Baker	SP-12.5	6000.00	Astec DBG	08/2010	APAC Southeast	270	270	315	315	Mainline
			SP-12.5	11320.22		08/2010		290	290	315	300	Mainline
			SP-12.5	2000.00		09/2010		290	290	315	300	Mainline
			SP-12.5	1139.03		08/2010		295	295	315	305	Mainline
	207756-4	US-301 / Alachua	SP-12.5	10000.00	Astec DBG	09/2010	APAC Southeast	270	270	330	330	Mainline
	209537-6	US-301 / Duval	FC-12.5	5792.31	Astec DBG	09/2010	Duval Asphalt	280	280	325	325	Mainline
3	415257-1	I-10/Gadsen	SP-12.5	6000.00	Astec DBG	09/2009	CW Roberts	270	260	310	310	Shoulders
			FC-5	1562.89		11/2009		285	275	330	330	Mainline
	415258-1	I-10/Jackson	SP-12.5	8906.50	Astec DBG	02/2008	Anderson Columbia	260	250	310	310	Shoulders
			SP-12.5	1511.21		01/2008		260	250	310	305	
	416909-1	I-10/Walton	SP-12.5	1127.38	Astec DBG	08/2008	Anderson Columbia	260	250	310	310	Shoulders
			SP-12.5	3619.63		08/2008		260	250	310	310	
	419295-1	US-98 / Jefferson	SP-12.5	13731.50	Terex	06/2010	CW Roberts	275	265	325	325	Mainline
			FC-9.5	2504.18		07/2010		275	265	325	325	Mainline
			SP-9.5	2504.70		08/2010		275	265	325	325	Mainline
			FC-12.5	3399.67		10/2010		275	265	325	325	Mainline
	220499-1	US-98 / Wakulla	SP-12.5	1190.34	Astec DBG	09/2010	Anderson Columbia	260	260	315	315	Mainline
	419307-1	SR-263 / Leon	SP-12.5	2000.00	Astec DBG	01/2011	P & S Paving	280	270	310	305	Mainline
5	417141-1	SR-11/Flagler	SP-12.5	2000.00	Astec DBG	12/2007	P & S Paving	270	260	310	300	Mainline
			SP-12.5	3973.20				270	260	310	300	Mainline
	421981-1	SR-25/Lake	FC-5	8258.50	Astec DBG	03/2009	Orlando Paving	250	250	320	320	Mainline
			SP-12.5	13897.96				265	265	310	300	Mainline
	423347-1	SR-50/Lake	SP-9.5	704.55	Astec DBG	01/2010	Orlando Paving	270	270	315	300	Mainline
			FC-12.5	9288.40		01/2010		280	280	320	310	Mainline
	422013-1	SR-15/Seminole	FC-9.5	1770.47	Gencore*	12/2009	Middlesex	260	260	315	310	Mainline
	405506-8	I-95/Brevard	SP12.5	1372.67	Eco-Foam II	07/2010	Community Asphalt	270	260	300	300	Mainline
			SP-12.5	384.95		08/2010		270	260	300	300	Mainline
	411665-3	SR-44 / Sumter	SP-12.5	1999.78	Terex	11/2010	CW Roberts	275	275	305	305	Mainline
	411665-4	US-301 / Sumter	SP-12.5	1830.55	Terex	11/2010	CW Roberts	275	275	305	305	Mainline
7	257070-1	US-19/Pinellas	SP-12.5	536.59	Astec DBG	07/2009	APAC Southeast	260	260	300	300	Mainline
			SP-12.5	8000.00				260	260	320	320	Mainline
	258415-1	I-275 / I-4 / Hillsborough	FC-12.5	1225.65	Astec DBG	07/2010	APAC Southeast	260	260	300	300	Mainline
	255599-1	SR-676/Hillsborough	SP-12.5	160.67	Astec DBG	09/2009	APAC Southeast	260	260	300	300	Mainline
	415489-2	US-301 / Hillsborough	SP-12.5	24274.91	Meeker	08/2010	Ajax Paving	265	265	300	300	Mainline
	416834-1	SR-200 / Citrus	SP-12.5	11285.70	Terex	08/2010	CW Roberts	275	275	305	305	Mainline
	416845-1	US-92 / Hillsborough	SP-12.5	13028.23	Astec DBG	08/2010	APAC Southeast	260	260	300	300	Mainline
			SP-12.5	3448.43		10/2010		260	260	300	300	Mainline
	416839-1	US-98/Pasco	FC-12.5	9124.54	Astec DBG	08/2009	APAC Southeast	260	260	310	300	Mainline
			SP-12.5	1709.84		03/2009		260	260	310	300	Mainline
	421831-4	I-275 / I-75 / Pasco	FC-5	7225.80	Evotherm	06/2010	Lane Construction	270	260	310	300	Mainline
8	413669-1	SR-417/Seminole	FC-5	730.49	Aspha-min	03/2006	Orlando Paving	270	270	320	320	Mainline
	Total Projects:	**Total Designs:**	**Total Tonnage:**		** In Testing*		**Average Temps:**	270	267	313	310	
	41	73	439498.96									

[1] *Warm Mix Temperatures* [2] *Hot Mix Temperatures*

** No Projects in Districts 4/6*

FDOT Contact: State Materials Office	**Latest Update:**
Danny Sanchez @ (352) 955-1838	02/01/11

WARM MIX STATISTICS

Additive/Technology Usage vs. Districts

District	Aspha-Min	Evotherm DAT	Terex	Meeker	Astec DBG	Gencor* The Green Machine	Eco-Foam II
1		2	1	9	2		
2					6		
3			1		5		
4							
5			2		3	1	1
6							
7		1	1	1	5		
8	1						

Total Projects*	Aspha-Min	Evotherm DAT	Terex	Meeker	Astec DBG	Gencor	Eco-Foam II
41	2%	7%	12%	24%	51%	2%	2%

*Note: Project 197753-2 in District 1 used two types of WMA (Terex/Meeker) - Therefore, one extra project added to number of Total Projects

Additive/Technology Contractor Usage vs. Districts

District	Aspha-Min	Evotherm DAT	Terex	Meeker	Astec DBG	Gencor* The Green Machine	Eco-Foam II
1		Lane A	jax	Ajax	OPC APAC		
2					Anderson Duval Asphalt APAC		
3			CW Roberts		Anderson CW Roberts P & S		
4							
5			CW Roberts		P&S Paving OPC	Middlesex	Community
6							
7		Lane CW	Roberts	Ajax	APAC		
8	OPC						

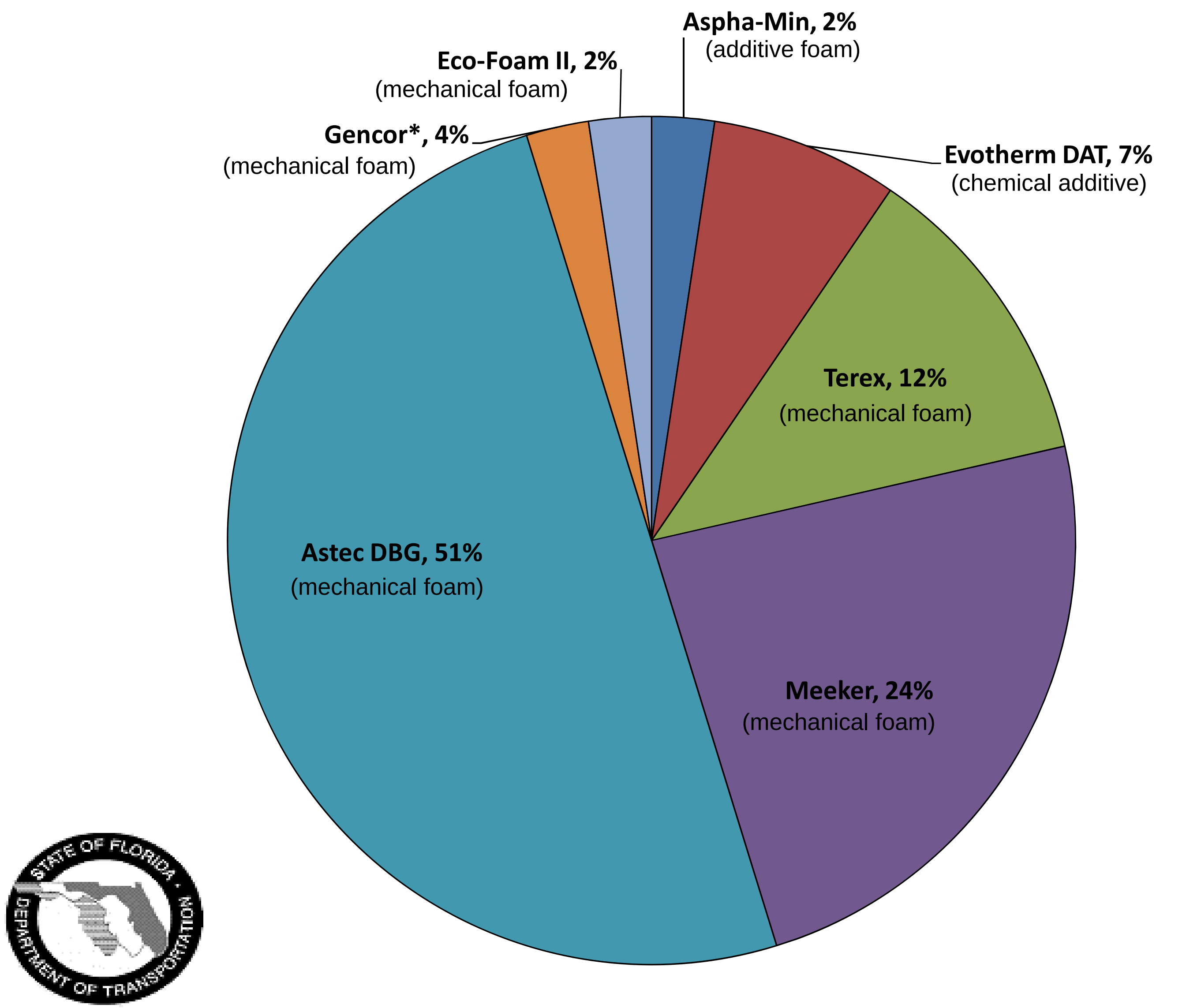
*Gencore is in testing -- Not a FDOT approved WMA Process.

Total Number of Projects, Additives/Technologies, and Tonnages vs. Districts

District	1	2	3	4	5	6	7	8	Totals
Projects	13	6	6		7		8	1	41
Technologies	4	1	2		4		4	1	
Tonnage	180,266	84,943	48,058		45,481		80,020	730	439,499

Warm Mix Asphalt

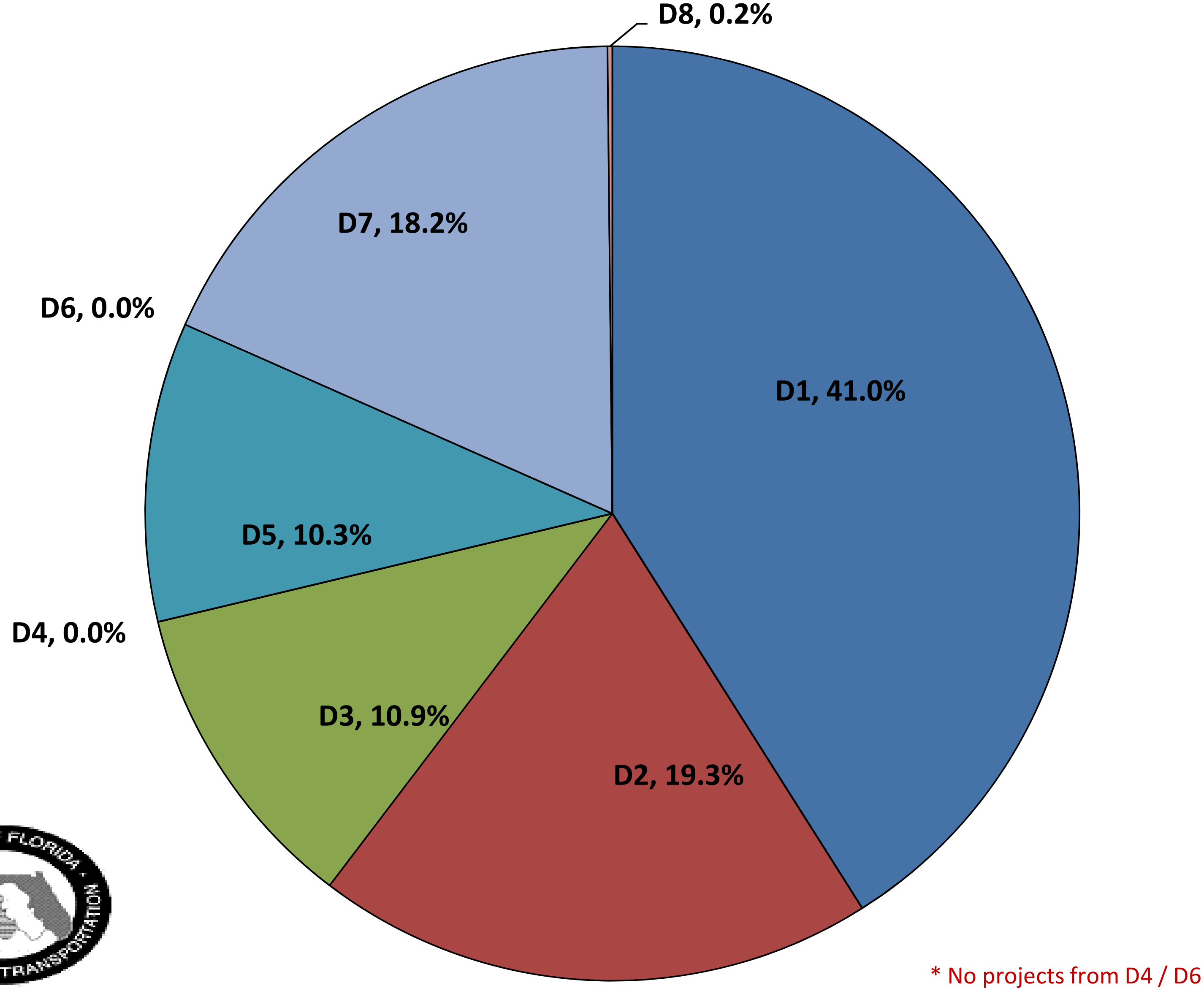
Percent of Total Projects Using Each Technology (see note)



Note: Chart labels have notes added by Astec, Inc. for clarity.

Warm Mix Asphalt

Percent of Total Tonnage by District



STATE OF FLORIDA

FDOT's Experience with Warm Mix Asphalt

Research Report
FL/DOT/SMO/09-527

Gregory A. Sholar
Tanya M. Nash
James A. Musselman
Patrick B. Upshaw

October 30, 2009

STATE MATERIALS OFFICE

The Astec Double Barrel Green WMA process is a foaming process that injects water into the asphalt binder supply line at a rate of 2% by weight of binder (see Figure 6). Astec claims that a large proportion of the water vaporizes instantly, leaving approximately 0.5% water by weight of binder to provide the enhanced mixture workability.

Figure 6 - Astec Double Barrel Green Warm Mix Process

The mixing temperature for the HMA control mixture was 310°F and the mixing temperature for the WMA mixture was 270°F. During construction, the temperature readings of the warm mix measured in the haul trucks varied substantially (from 250 to 290°F) due to the Contractor producing several mixture types for several projects within the same day. However, no issues with placement of the WMA mixture were noted.

Samples of each mixture type were tested for their cracking properties utilizing the Energy Ratio concept, their rutting performance utilizing the Asphalt Pavement Analyzer (APA), and their resistance to moisture damage utilizing the retained tensile strength approach per test method FM 1-T 283. The performance test results are presented in Table 6 and the results show that the WMA mixture performed slightly better than the HMA mixture with respect to cracking and rutting and nearly as well with respect to moisture damage resistance.

Table 6 – Laboratory Performance Test Results for SR-11 Project

Performance Measurement		Mixture Type	
		HMA SP-12.5	WMA SP-12.5
Energy Ratio		1.70	1.85
APA Rut Depth (mm)		4.1	2.7
Moisture Damage Testing	Dry Strength (psi)	211.5	198.2
	Conditioned Strength (psi)	129.0	115.1
	Tensile Strength Ratio (%)	61	58

Pavement condition surveys were performed in June 2008 and July 2009, evaluating the rutting, cracking, and ride rating performance of each section. Results of each survey are presented in Table 7 and show that there are no practical differences between the HMA and WMA sections.

Table 7 – PCS Test Results for SR-11 Project

Performance Measurement	PCS Test Date and Mixture Type (Results are from Traffic Lane)			
	June 2008		July 2009	
	HMA SP-12.5	WMA SP-12.5	HMA SP-12.5	WMA SP-12.5
Rutting (inches)	0.03	0.05	0.04	0.06
Crack Rating (max = 10.0)	10.0	10.0	10.0	10.0
Ride Number (max = 5.0)	4.32	4.36	4.29	4.34

SUMMARY OF ALL WARM MIX PROJECTS CONSTRUCTED TO DATE

The previous section of this report presented detailed laboratory performance test data and pavement condition survey data for the first three WMA projects constructed, which utilized three different WMA technologies, encompassing the major types of WMA processes used in Florida to date. Table 8 provides a summary of every WMA project constructed by the

Department, as of October 2009. To date, nearly 226,000 tons of WMA have been placed in six of the eight Districts in the state, utilizing five different WMA technologies. Note that three of the five WMA technologies (Astec Double Barrel Green, Meeker, and Terex) are all foaming processes that inject water into the asphalt binder supply stream. There have been no construction or performance problems noted on any of the WMA projects.

Table 8 – Summary of All WMA Projects Constructed as of October 2009

District	Project Number	Route / County	Mix Type	Quantity (tons)	Additive/ Technology	Construction Date	Contractor	Mixing Temperature	Compaction Temperature	Location
1	197259-2	US-92/Polk	SP-12.5	2383	Evotherm	10/2007	Lane Construction	250	230	Mainline
	197373-2	US-92/Polk	SP-9.5	4000	Evotherm	Current	Lane Construction	250	230	Mainline
			SP-9.5	2000				250	240	Mainline
			FC-9.5	2000				250	240	Mainline
	197707-1	U-27/Polk	FC-5	6579	Astec DBG	04/2009	Orlando Paving	260	260	Mainline
	197753-2	SR-780/Sarasota	SP-9.5	3020	Meeker	Current	Ajax	265	265	Mainline
			SP-12.5	4000	Terex			270	270	
			SP-9.5	8000				270	270	
			FC-12.5	1174				290	290	
	420238-1	US-301/Manatee	SP-12.5	8000	Meeker	Current	Ajax	290	290	Mainline
			FC-5	3744			Ajax	290	290	Mainline
	420655-1	I-75/Collier	SP-12.5	173	Meeker	Current	Ajax	275	275	Shoulders
			SP-12.5	4885				275	275	
			SP-12.5	26405				265	265	
			FC-5	7159				290	285	Mainline
2	209733-4	SR-202/Duval	SP-12.5	9775	Astec DBG	Current	Duval Asphalt	265	265	Shoulders
3	415257-1	I-10/Gadsen	SP-12.5	4000	Astec DBG	Current	CW Roberts	270	260	Shoulders
	415258-1	I-10/Jackson	SP-12.5	8907	Astec DBG	02/2008	Anderson-Columbia	260	250	Shoulders
			SP-12.5	1511		01/2008		260	250	
	416909-1	I-10/Walton	SP-12.5	1127	Astec DBG	08/2008	Anderson-Columbia	260	250	Shoulders
			SP-12.5	3650		08/2008		260	250	
5	417141-1	SR-11/Flagler	SP-12.5	2000	Astec DBG	12/2007	P & S Paving	270	260	Mainline
			SP-12.5	3973				270	260	Mainline
	421981-1	SR-25/Lake	FC-5	36259	Astec DBG	03/2009	Orlando Paving	250	250	Mainline
			SP-12.5	51898				265	265	Mainline
7	257070-1	US-19/Pinellas	SP-12.5	537	Astec DBG	Current	APAC Southeast	260	260	Mainline
			SP-12.5	8000				260	260	Mainline
	416839-1	US-98/Pasco	FC-12.5	8000	Astec DBG	Current	APAC Southeast	260	260	Mainline
8	413669-1	SR-417/Seminole	FC-5	2730	Aspha-min	02/2006	Orlando Paving	270	270	Mainline
			Total Tonnage	225,889						

ANALYSIS OF CONSTRUCTION VARIABILITY

To ascertain the difference in construction variability between WMA and HMA, an analysis of construction test data was conducted between WMA mixtures and HMA mixtures that were placed on the same project. Similar mixtures, within the same layer, were analyzed. A total of 11 projects and 12 mixture types were examined (three FC-5 mixtures, eight SP-12.5 mixtures, and one FC-12.5 mixture). A summary of the projects and mixture types is provided in Table 9.

Table 9 – Summary of WMA and HMA Projects Used for Analysis of Construction Variability

Project Number	Mixture Type	Warm Mix Process
1	FC-5 Open Graded	Aspha-min
2	SP-12.5 Dense Graded	Evotherm DAT
3	SP-12.5, FC-12.5 Dense Graded	Astec DBG
4	SP-12.5 Dense Graded	Astec DBG
5	SP-12.5 Dense Graded	Astec DBG
6	SP-12.5 Dense Graded	Astec DBG
7	SP-12.5 Dense Graded	Astec DBG
8	SP-12.5 Dense Graded	Meeker
9	FC-5 Open Graded	Astec DBG
10	SP-12.5 Dense Graded	Astec DBG
11	FC-5 Open Graded	Astec DBG

The standard deviation of the test results for gradation and asphalt binder content are graphically presented for both WMA and HMA FC-5 open graded friction course mixtures in Figure 7. The standard deviation of the test results for gradation, asphalt binder content, air voids, and roadway density are graphically presented for both WMA and HMA dense graded mixtures in Figure 8. The horizontal bars in Figures 7 and 8 represent the average standard deviation for each type of production (WMA and HMA).

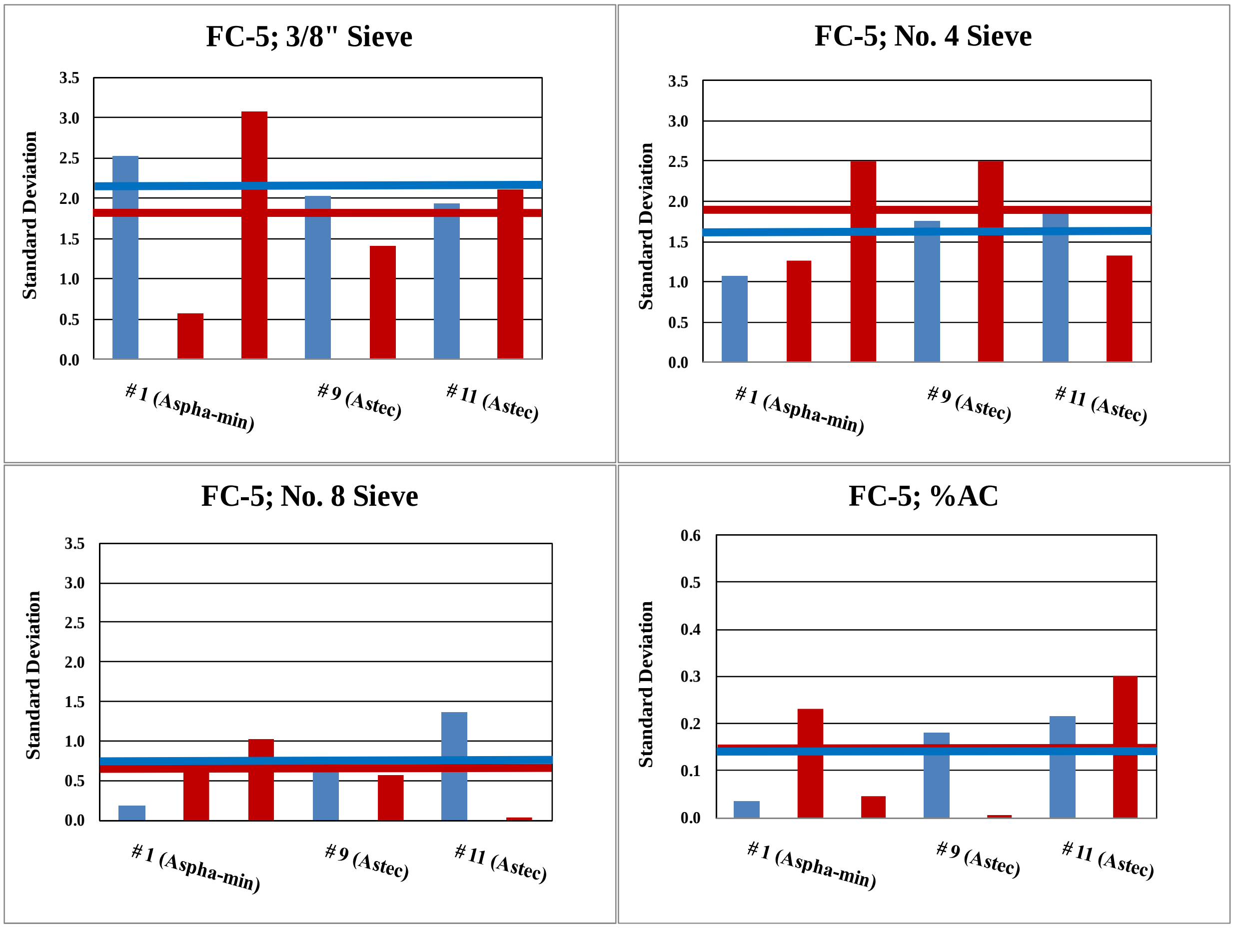


Figure 7 - Construction Variability for FC-5 Open Graded Friction Course Mixtures (Blue = Warm Mix Asphalt; Red = Hot Mix Asphalt)

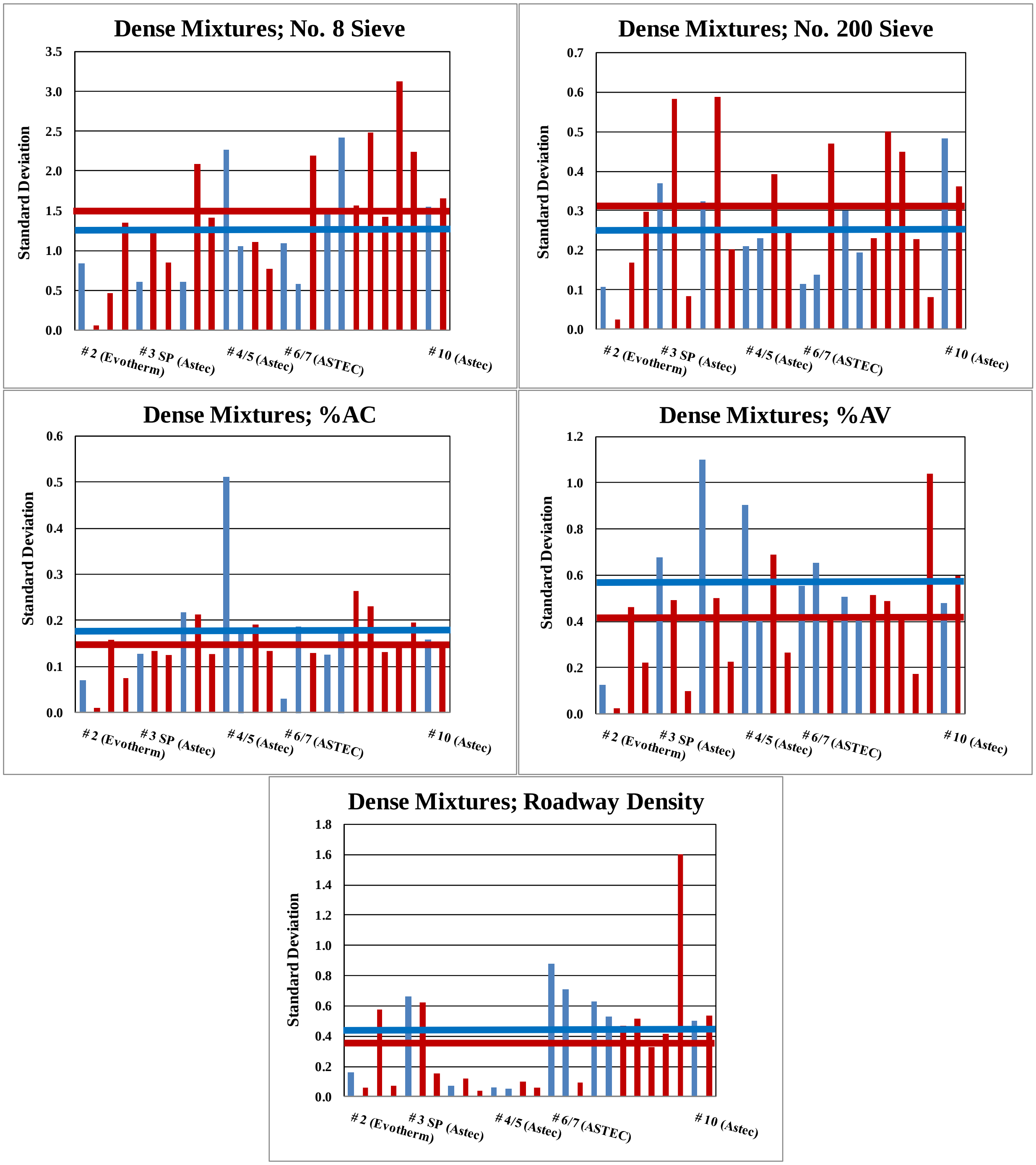


Figure 8 - Construction Variability for Dense Graded Friction Course Mixtures (Blue = Warm Mix Asphalt; Red = Hot Mix Asphalt)

As can be seen in Figures 7 and 8, the construction variability is similar between WMA and HMA, with some properties/projects having lower variability with WMA and some having higher variability.

CONCLUSIONS

This report has provided a summary of the Department's experience with WMA to date. A detailed analysis of the first three projects was provided indicating that there is no significant difference in laboratory performance or in measured pavement condition survey data (rutting, cracking and ride evaluation) between the WMA and HMA sections of the same mixture. Additionally, a listing of all of the WMA projects constructed to date was presented showing that nearly 226,000 tons of WMA has been placed in structural mixtures, dense graded friction course mixtures, and open graded friction course mixtures, utilizing five different WMA processes. To date, there have been no construction or performance problems noted on any of the projects. An analysis of construction variability indicated that there is no significant difference in the variability of measured quality control properties (binder content, air voids, gradation and roadway density) between companion WMA and HMA mixtures in the same project.

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION
ALBANY, N.Y. 12232
www.nysdot.gov

JOAN McDONALD
COMMISSIONER

ANDREW M. CUOMO
GOVERNOR

July 6, 2011

Mr. Ben Brock, President
ASTEC Industries, Inc.
PO Box 72787
4101 Jerome Ave.
Chattanooga, TN 37407

Dear Mr. Brock,

I am pleased to inform you that your company's Double Barrel Green, Green Pac for Continuous, and Green Pac for Batch warm mix asphalt systems are approved for use on New York State Department of Transportation projects. The technologies will be added to the list of approved Warm Mix Asphalt Technologies in our Approved List of Materials and Equipment as follows:

WARM MIX ASPHALT (WMA) TECHNOLOGIES

C. FOAMING PROCESSES

TECHNOLOGY	TECHNOLOGY PROVIDER	CONTACT PERSON	DETAILS (APPROVAL DATE)
ASTEC Double Barrel Green, Green Pac for Continuous, and Green Pac for Batch	ASTEC Industries, Inc. PO Box 72787 4101 Jerome Ave. Chattanooga, TN 37407	For sales: Tom Baugh 423-867-4210 tbaugh@astecinc.com For service and technical questions: Astec Service 423-867-4210 service@astecinc.com	ASTEC (7/6/11)

This change will appear in the next update of the Approved List available on the Internet @ http://www.nysdot.gov under **Business Center>Top Publication Downloads>9. Materials Approved List>Asphalt/Bituminous Materials**. Until this change appears on the list, a copy of this letter will constitute that part of the Evidence of Acceptability requiring appearance on the Department's Approved List.

If there are any changes to this technology, you must inform the Materials Bureau immediately for action on continued acceptability.

We wish to also inform you that this letter shall in no way be used for promotional purposes, such as using a copy of this letter in any form as an advertisement in any sales literature or trade magazines.

If there are any questions, please contact me at (518) 457-4581.

Very Truly Yours,

Christopher R. Euler, P.E.
Materials Bureau, Field Engineering II

CRE
File: 19.4

c: All Regional Materials Engineers
M. Ballien, FE I

BR 254 (6/98)

DESIGN ESAL LEVEL
0.3 - < 30

NEW YORK STATE DEPARTMENT OF TRANSPORTATION MATERIALS BUREAU

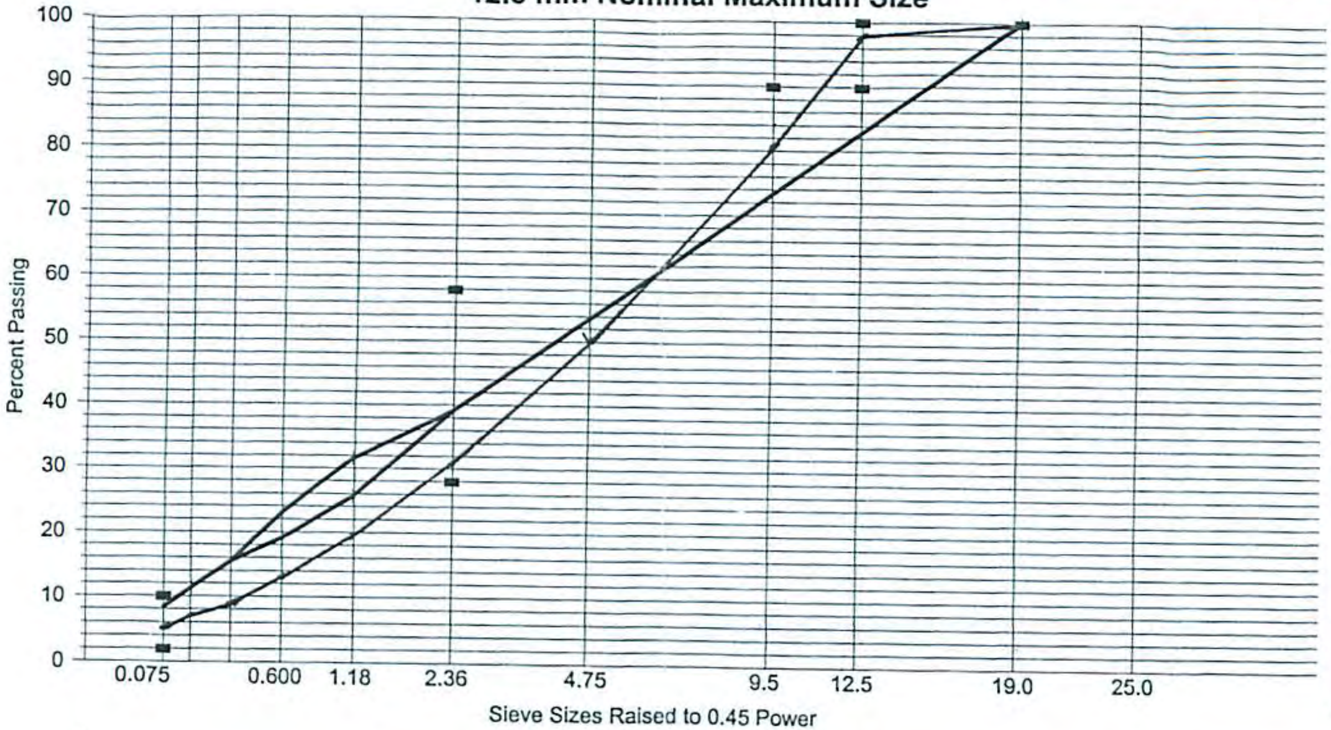
SUPERPAVE Job Mix Formula

12.5 mm Nominal Maximum Size

Verification Status

REGION	8	JMF No.	H028211441
PRODUCER	Callanan Ind.		
LOCATION	East Kingston		

12.5 mm Nominal Maximum Size



	Aggregates	Source Number	Blend %	
Coarse	No. 1 Stone	8-15RS	36	1 Fric. Blend 100
	No. 1 Non-Carbonate Stone			
	No. 1A Stone	8-15RS	20	1A Fric. Blend 100
	No. 1A Non-Carbonate Stone			
Fine	Manufactured	8-15RS	44	Sand Blend
	Natural Sand			
	Mineral Filler			
	RAP			

	Aggregates	Blend Limits to Maintain C.A.P.'s		
		C. A. A.	F. A. A.	Flat / El.
Coarse	No. 1 Stone	100		3.2
	No. 1 Non-Carbonate Stone			
	No. 1A Stone	100		
	No. 1A Non-Carbonate Stone			
Fine	Manufactured		51.7	
	Natural Sand			
	RAP			

Sieve Size (mm)		0.075	0.150	0.300	0.600	1.18	2.36	4.75	9.5	12.5	19.0	25.0	% PGB	Binder Grade
% Passing	General Limits	2 - 10					28 - 58		< 90	90 - 100	100			As per PG - Job
	JMF Range	3.7-7.7	4-10	6-12	10-16	16-24	27-35	46-54	76-86	93-100	100		N/A	
	Target Value	5.7	7	9	13	20	31	50	81	98	100		5.3	

Submitted for Review by: ______________________ Date: __________

Accepted for Verification / ~~Production~~ by: [signature] Date: 5/12/11

Revised

12.5 < 30 (HMA)

BR 328 M (2/09)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
MATERIALS BUREAU
COMPUTATION OF VOLUMETRIC PROPERTIES

Facility No	H0282
Plant	Callanan Industries Inc.
Location	East Kingston
Sample Point (Tons)	100
QCT or QAT	QCT
Technician Name	David Dachenhausen

Formula No	H028211441
Mix Size	12.5 < 30
ESAL	<30
Lot/Sublot	1 Hot Mix
AC %	5.3
RAP %	0
Date	5/7/2011

Sample ID	Compaction Temp C	Weight (grams) In air	In water	SSD	Volume	Maximum SpGr Gmm	@N design = gyrations Sample Height mm	Bulk SpGr Gmb	% Gmm	% Air Voids	@N initial = gyrations Sample Height mm	Bulk SpGr Gmb	% Gmm	VMA	VFB
		a	b	c	d	e	f	g	h	i	j	k	l	m	n
					c - b			a/d	100(g/e)	100 - h		g(f/j)	100(k/e)	15.80	77.20
1	290	4802.7	2805.4	4808.7	2003.3		115.2	2.397	96.27	3.73	129.8	2.127	85.42		
2	290	4795.9	2805.7	4802.5	1996.8		115.1	2.402	96.47	3.53	130	2.127	85.42		
AVG						2.490		2.400	96.37	3.61		2.127	85.42	15.80	77.20

Max Spec Grav		
Sample	1A	1B
A	2012.7	2022.6
D	1209	1380.7
E	2412.9	2591.4
Gmm	2.489	2.491
Avg Gmm	2.490	

Gsb= 2.700 Ps= 94.7

Combined Bulk SG (Gsb) Agg	Bulk SG Gi	% Agg Pi	Consensus Properties CA Ang	FA Ang	Flat _ Elong	Sand Equiv
No 3	2.707	0	100.00			
No 2	2.707	0	100.00		2.27	
No.1	2.707	36	100.00		2.07	
No1 NC						
No 1A	2.707	20	100.00			
No. 1A NC						
No. 1B	2.707	0				
Man Snd	2.69	44		51.10		
Wash Scr.	2.69	0		48.70		
Min Fil						
RAP	2.739	0				

Volumetric Property Descriptions

Gmm = Maximum Sp Gr of HMA Mixtures
- A = Wt of dry sample in air (g)
- D = Wt of flask filled with airless water at 25 C (g)
- E = Wt of flask filled with airless water and sample at 25 C (g)

Gmm = A/[A+D-E]

VMA = 100 - [(Gmb X Ps)/Gsb]

VFB = 100 X [(VMA-Pa)/VMA]

Gmb = Bulk Sp Gr for the total HMA Mixture

Gsb = Bulk Sp Gr for the total aggregate
[Ps]/[P1/G1+P2/G2+ ...+Pn/Gn]

Ps = Aggregate. Percent by total weight of HMA mixture

Pa = % voids in total HMA mixture

Pi = % of individual agg. Component in total HMA mixture

Gi = Sp Gr of individual agg. Component in total HMA mixture

Technician Signature: [signature] Date: 5/7/2011

12.5 < 30 (Green Syslem) — WMA

BR 28 M (2/09)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
MATERIALS BUREAU
COMPUTATION OF VOLUMETRIC PROPERTIES

Facility No	H0282
Plant	Callanan Industries Inc.
Location	East Kingston
Sample Point (Tons)	100
QCT or QAT	QCT
Technician Name	David Dachenhausen

Formula No	H028211441
Mix Size	12.5 < 30
ESAL	<30
Lot/Sublot	2 Warm mix
AC %	5.3
RAP %	0
Date	5/24/2011

Sample ID	Compaction Temp C	Weight (grams) In air	In water	SSD	Volume	Maximum SpGr Gmm	@N design = gyrations Sample Height mm	Bulk SpGr Gmb	% Gmm	% Air Voids	@N initial = gyrations Sample Height mm	Bulk SpGr Gmb	% Gmm	VMA	VFB
		a	b	c	d	e	f	g	h	i	j	k	l	m	n
					c - b			a/d	100(g/e)	100 - h		g(f/j)	100(k/e)	15.50	77.70
1	250	4796.2	2814	4804.4	1990.4		114.9	2.41	96.55	3.45	129.5	2.138	85.66		
2	250	4809.2	2820.5	4816	1995.5		115.4	2.41	96.55	3.45	130.3	2.134	85.5		
AVG						2.496		2.410	96.55	3.45		2.136	85.58	15.50	77.70

Max Spec Grav		
Sample	1A	1B
A	2038.7	2041.9
D	1209	1380.7
E	2429.8	2605.2
Gmm	2.493	2.498
Avg Gmm	2.496	

Gsb= 2.700 Ps= 94.7

Combined Bulk SG (Gsb) Agg	Bulk SG Gi	% Agg Pi	Consensus Properties CA Ang	FA Ang	Flat _ Elong	Sand Equiv
No. 3	2.707	0	100.00			
No. 2	2.707	0	100.00		2.27	
No 1	2.707	36	100.00		2.07	
No1 NC						
No 1A	2.707	20	100.00			
No. 1A NC						
No. 1B	2.707	0				
Man Snd	2.69	44		51.10		
Wash Scr	2.69	0		48.70		
Min Fil						
RAP	2.739	0				

Volumetric Property Descriptions

Gmm = Maximum Sp Gr of HMA Mixtures

A = Wt of dry sample in air (g)

D = Wt of flask filled with airless water at 25 C (g)

E = Wt of flask filled with airless water and sample at 25 C (g)

Gmm = A/[A+D-E]

VMA = 100 - [(Gmb X Ps)/Gsb]

VFB = 100 X [(VMA-Pa)/VMA]

Gmb = Bulk Sp Gr for the total HMA Mixture

Gsb = Bulk Sp Gr for the total aggregate

[Ps]/[P1/G1+P2/G2+. . .+Pn/Gn]

Ps = Aggregate, Percent by total weight of HMA mixture

Pa = % voids in total HMA mixture

Pi = % of individual agg. Component in total HMA mixture

Gi = Sp Gr of individual agg. Component in total HMA mixture

Technician Signature: [signature] Date: 5/24/2011

12.5 < 30 Virgin
H.M.A.

BR 157 (2/09)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION-MATERIALS BUREAU
DRUM MIX PLANT PRODUCTION TEST - Volumetric

[X] Ignition Oven

Facility No H0282 **Producer** Callanan Industries Inc. **Location** East Kingston
Formula No H028211441 **Mix Size** 12.5 < 30 **ESAL** <30 **A/C %** 5.3
RAP % 0 **QCT or QAT** QCT **Technician Name** David Dachenhausen
Lot / Sublot: 1 H.M.A. **Sample Point (Tons)** 100 **Sample Date** 5/7/2011

MOISTURE CONTENT

Calculation	Aggregate	Mixture	RAP
Wet Wt. (A)	1.00	2228.3	
Dry Wt. (B)	1.00	2225.7	
Diff. Wt. (A - B)	0.00	2.60	
$\frac{A-B}{B} \times 100$	0.0	0.1	

SAMPLE TIME

Aggregate Moisture		RAP Moisture	
Mixture % Binder		RAP % Binder	
Mixture Moisture			

BINDER CONTENT

Calculation	Mixture	RAP
Sample Wt. (A)	2225.2	
Aggregate Wt. (B)	2104.7	
Filter Gain Wt. (C)		
$\frac{A-(B+C)}{A} \times 100$	5.1	
% Binder	5.3	
% Binder Target	5.3	

Sieve Size (mm)	QC/QC Gradation Weight (g)	% Ret.	% Pass.	% Agg.	% Min. Fill	Total % Pass.	Daily Target	Upper Daily Production Limit	Lower Daily Production Limit
2 in (50)	0	0	100			100	100	100	95
1 1/2 in (37.5)	0	0.0	100.0			100	100	100	95
1 in (25)	0	0.0	100.0			100	100	100	95
3/4 in (19)	0	0.0	100.0			100	100	100	95
1/2 in (12.5)	25.7	1.2	98.8			98.8	98	100	93
3/8 in (9.5)	248.5	11.8	87.0			87	81	86	76
No. 4 (4.75)	667.2	31.7	55.3			55.3	50	55	45
No. 8 (2.36)	417.8	19.9	35.4			35.4	31	36	26
No. 16 (1.18)	245.7	11.7	23.7			23.7	20	25	15
No. 30 (0.600)	161.1	7.7	16.0			16	13	18	8
No. 50 (0.300)	123.3	5.9	10.1			10.1	9	14	4
No. 100 (0.150)	88.4	4.2	5.9			5.9	7	12	2
No. 200 (0.075)	48.8	2.3	3.6			3.6	5.7	10.7	0.7
PAN	75.7	3.6							
TOTAL	2102.2								

Technician Signature: [signature] **Date** 5/7/2011

WMA

12.5 < 30 (Green System)
NO RAP

BR 157 (2/09)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION-MATERIALS BUREAU
DRUM MIX PLANT PRODUCTION TEST - Volumetric

[X] Ignition Oven

Facility No H0282 *Producer* Callanan Industries Inc. *Location* East Kingston
Formula No H028211441 *Mix Size* 12.5 < 30 *ESAL* <30 *A/C %* 5.3
RAP % 0 *QCT or QAT* QCT *Technician Name* David Dachenhausen
Lot / Sublot: 2 Warm Mix *Sample Point (Tons)* 100 *Sample Date* 5/24/2011

MOISTURE CONTENT			
Calculation	Aggregate	Mixture	RAP
Wet Wt. (A)	1.00	2213.4	
Dry Wt. (B)	1.00	2210.5	
Diff. Wt. (A - B)	0.00	2.90	
$\frac{A-B}{B} \times 100$	0.0	0.1	

SAMPLE TIME

Aggregate Moisture		RAP Moisture	
Mixture % Binder		RAP % Binder	
Mixture Moisture			

BINDER CONTENT		
Calculation	Mixture	RAP
Sample Wt. (A)	2207.6	
Aggregate Wt. (B)	2092.6	
Filter Gain Wt. (C)		
$\frac{A-[B+C]}{A} \times 100$	5.2	
% Binder	5.3	
% Binder Target	5.3	

Sieve Size (mm)	QC/QC Gradation Weight (g)	% Ret.	% Pass.	% Agg.	% Min Fill	Total % Pass.	Daily Target	Upper Daily Production Limit	Lower Daily Production Limit
2 in (50)	0	0	100			100	100	100	95
1 1/2 in (37.5)	0	0.0	100.0			100	100	100	95
1 in (25)	0	0.0	100.0			100	100	100	95
3/4 in (19)	0	0.0	100.0			100	100	100	95
1/2 in (12.5)	17.8	0.9	99.1			99.1	98	100	93
3/8 in (9.5)	291.7	14.0	85.1			85.1	81	86	76
No. 4 (4.75)	647.6	31.0	54.1			54.1	50	55	45
No. 8 (2.36)	358.4	17.1	37.0			37	31	36	26
No. 16 (1.18)	243.4	11.6	25.4			25.4	20	25	15
No. 30 (0.600)	172.5	8.3	17.1			17.1	13	18	8
No. 50 (0.300)	127.6	6.1	11.0			11	9	14	4
No. 100 (0.150)	90.1	4.3	6.7			6.7	7	12	2
No. 200 (0.075)	53.9	2.6	4.1			4.1	5.7	10.7	0.7
PAN	86.8	4.2							
TOTAL	2089.8								

Technician Signature: [signature] *Date* 5/24/2011

CALLANAN

INDUSTRIES, INC.

"BUILDING NEW YORK'S INFRASTRUCTURE SINCE 1883"

Resistance to Moisture Induced Damage (Anti-Stripping Test)

Test Method : AASHTO T283

Plant Id	CALLANAN IND INC		
Mix Type	HMA 12.5MM<30 No RAP		
Sample Location	EAST KINGSTON FACALITY #10282		
Date Sampled	5/7/2011	Sample By	DAVE DAUCHENHAUSEN
Date Tested	5/25/2011	Tested By	BRIAN BARRETT

Sample Id.		D1	D2	D3	C1	C2	C3
Diameter, mm	D	150	150	150	150	150	150
Thickness, mm	t	95	95	95	95	95	95
Dry Mass in Air, g	A	3786	3786	3792.2	3790.4	3784.2	3779.8
SSD Mass, g	B	3799	3801.6	3810.4	3817.8	3805.4	3806.7
Mass in Water, g	C	2171.8	2166	2178.2	2191	2179	2178.2
Volume (B-C), cm3	E	1627.2	1635.6	1632.2	1626.8	1626.4	1628.5
Bulk Specific Gravity (A/E)	Gmb	2.327	2.315	2.323	2.330	2.327	2.321
Maximum Specific Gravity	Gmm	2.49	2.49	2.49	2.49	2.49	2.496
% Air Voids (100(Gmm-Gmb)/Gmm)	Pa	6.56	7.04	6.69	6.43	6.56	7.01
Volume of Air Voids (Pa*E/100), cm3	Va	106.72	115.12	109.23	104.55	106.64	114.16
Load, psi	P	4300	4505	4300			
Saturated	10	Min @		kPa (psi) or mm Hg (in. Hg)			
Thickness, mm	t'				95	95	95
SSD Mass, g	B'				3863	3845.8	3866.8
Volume of Absorbed Water (B'-A), cm3	J'				72.6	61.6	87
% Saturation (100*J'/Va)	S'				69.4	57.8	76.2
Load, psi	P'				4000	4600	4500
Dry Strength (2*P/∏*t*D)), psi	S1	123.81	129.71	123.81			
Wet Strength (2*P'/∏*t'*D), psi	S2				115.17	132.45	129.57
Visual Moisture Damage * (0 to 5 rating)							
Crack/Break Aggregate							
TSR (S2/S1)					93.02	102.11	104.65
					AVERAGE TSR		**99.93**
					Specification		**>80**

Comments:

Reviewed By:

MATERIALS • CONSTRUCTION

Post Office Box 15097 • Albany, New York 12212-5097 • (518) 374-2222 • Fax (518) 374-1721

Callanan Industries Inc.

P.O. Box
Albany, NY

Resistance to Moisture Induced Damage (Anti-Stripping Test)

Test Method AASHTO T283

Plant Id	East kingston Callanan ind. Inc.		
Mix Type	12.5mm<30 LIMA NO RAP		
Sample Location	east kingston		
Date Sampled	5/7/2011'	Sample By	dd
Date Tested	5/25/2011	Tested By	bb

		Dry Test Samples				Partial Saturation/Conditioned Samples			
	Sample Number	1	2	3	Average	Average	1	2	3
D	Deameter, mm	150	150	150			150	150	
t	Thickness, mm	95	95	95			95	95	
A	Dry Mass	3786	3786	3792.2			3790.4	3784.2	37
B	SSD Mass	3799	3801.6	3810.4			3817.8	3805.4	38
C	Mass in Water	2171.8	2166	2178.2			2191	2179	21
E	Volume - (B-C)	1627.2	1635.6	1632.2			1626.8	1626.4	16
F	Bulk SpGr (A/E)	2.327	2.315	2.323			2.330	2.327	2
G	Max SpGr	2.49	2.49	2.49			2.49	2.49	
H	% Air Void (100x(G-F)/G	6.56	7.04	6.69			6.43	6.56	
I	Vol.Air Vd (H*E/100)	106.72	115.12	109.23			104.55	106.64	11
P	Load (lbs)	4300	4505	4300					

		Saturated	10	Min @	70
B'	SSD Mass		3869	3859	38
C'	Mass in Water		2241.9	2222.5	22
E'	Volume (B'-C')		1627.1	1636.5	16
J'	Vol Abs Water (B'-A)		78.6	74.8	8
	% Saturation (100*J'/I)		75.18	70.14	7
	% Swell (100*(E'-E)/E)		0.02	0.62	-(

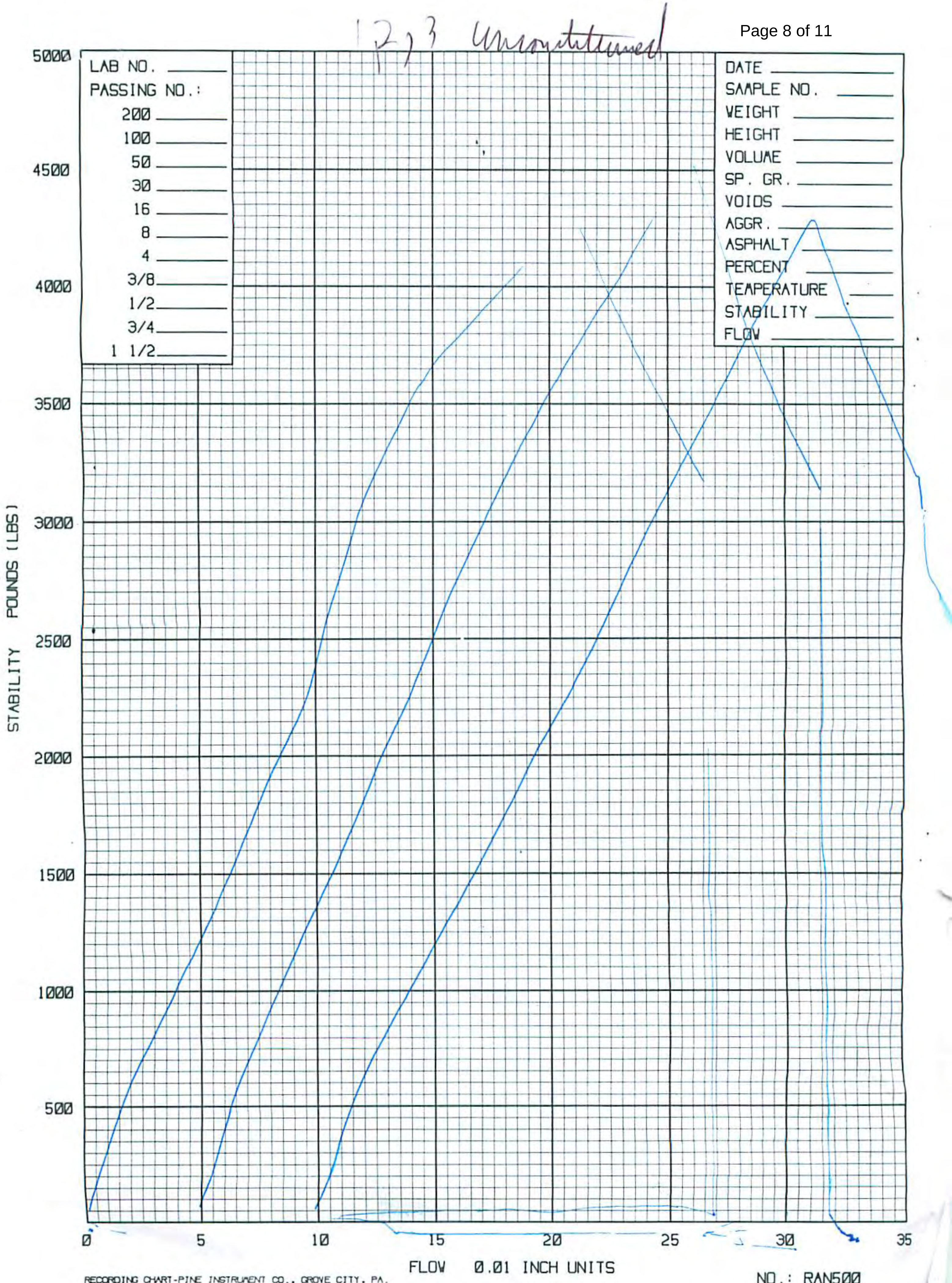
Conditioned 24hrs in 140°F Water

		Dry 1	Dry 2	Dry 3	Dry Average	Average	1	2	3
t''	Thickness								
B''	SSD Mass						3863	3845.8	38
C''	Mass in Water						2231.8	2213.8	22
E''	Volume (B''-C'')						1631.2	1632	16
J''	Vol Abs Water (B''-A)						72.6	61.6	
	% Saturation (100*J''/I)						69.43979227	57.763919	78.72730
	% Swell (100*(E''-E)/E)						0.270469634	0.34431874	0.718452
p''	Load (lbs)						4000	4600	4
s(td)	Dry Strength, psi (2*P/3.14*t*D)	39028662	40889331	39028662	39648885				
s(tm)	Wet Strength, psi (2*P/3.14*t*D)					39633757.96	36305732	41751592	408439
	TSR[1] (100*S™/S(td))				99.96				
	Visual Moisture Damage *								
	Crack/Break Aggregate								

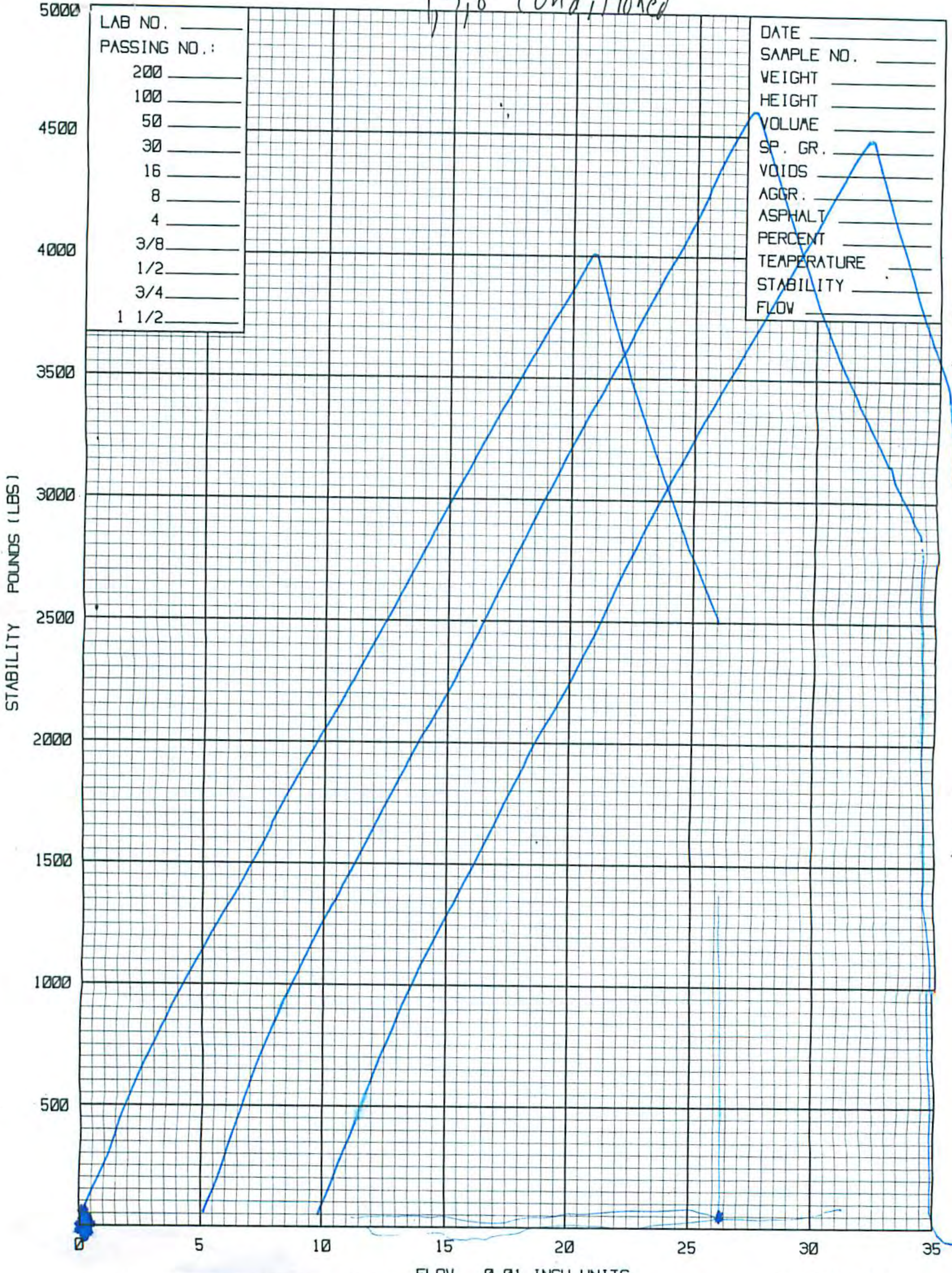
Measured Tensile Strength Ratio	**99.96**
Specification	

Reviewed By	

[2]Visual Moisture Damage Codes	
1	None
2	Slight
3	Moderate
4	Severe


1, 2, 3 Unconditioned
LAB NO.
PASSING NO.:
200
100
50
30
16
8
4
3/8
1/2
3/4
1 1/2
DATE
SAMPLE NO.
WEIGHT
HEIGHT
VOLUME
SP. GR.
VOIDS
AGGR.
ASPHALT
PERCENT
TEMPERATURE
STABILITY
FLOW
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
STABILITY POUNDS (LBS)
0
5
10
15
20
25
30
35
FLOW 0.01 INCH UNITS
RECORDING CHART-PINE INSTRUMENT CO., GROVE CITY, PA.
NO.: RAN500

4,5,6 Conditioned



RECORDING CHART-PINE INSTRUMENT CO., GROVE CITY, PA.

NO.: RAN500

CALLANAN
INDUSTRIES, INC.

"BUILDING NEW YORK'S INFRASTRUCTURE SINCE 1883"

Resistance to Moisture Induced Damage (Anti-Stripping Test)
Test Method : AASHTO T283

Plant Id	CALLANAN IND INC		
Mix Type	WMA 12.5MM<30 No RAP		
Sample Location	EAST KINGSTON FACALITY #10282		
Date Sampled	5/24/2011	Sample By	DAVE DAUCHENHAUSEN
Date Tested	6/9/2011	Tested By	BRIAN BARRETT

Sample Id.		D1	D2	D3	C1	C2	C3
Diameter, mm	D	150	150	150	150	150	150
Thickness, mm	t	95	95	95	95	95	95
Dry Mass in Air, g	A	3807.6	3810.5	3813.9	3812.2	3809.4	3813.8
SSD Mass, g	B	3825.6	3827.1	3837.6	3828.4	3822.5	3829.3
Mass in Water, g	C	2190.3	2192.2	2203.2	2194.2	2189.6	2197.3
Volume (B-C), cm3	E	1635.3	1634.9	1634.4	1634.2	1632.9	1632
Bulk Specific Gravity (A/E)	Gmb	2.328	2.331	2.334	2.333	2.333	2.337
Maximum Specific Gravity	Gmm	2.496	2.496	2.496	2.496	2.496	2.496
% Air Voids (100(Gmm-Gmb)/Gmm)	Pa	6.72	6.62	6.51	6.54	6.53	6.37
Volume of Air Voids (Pa*E/100), cm3	Va	109.82	108.26	106.40	106.88	106.70	104.04
Load, psi	P	3800	3885	4200			
Saturated	10	Min @		kPa (psi) or mm Hg (in. Hg)			
Thickness, mm	t'				95	95	95
SSD Mass, g	B'				3874.5	3869	3868.3
Volume of Absorbed Water (B'-A), cm3	J'				62.3	59.6	54.5
% Saturation (100*J'/Va)	S'				58.3	55.9	52.4
Load, psi	P'				3525	3493	3499
Dry Strength (2*P/∏*t*D)), psi	S1	109.41	111.86	120.93			
Wet Strength (2*P'/∏*t'*D), psi	S2				101.50	100.58	100.75
Visual Moisture Damage * (0 to 5 rating)							
Crack/Break Aggregate							
TSR (S2/S1)					92.76	89.91	83.31

AVERAGE TSR	88.66
Specification	>80

Comments:

Reviewed By:

MATERIALS • CONSTRUCTION

Post Office Box 15097 • Albany, New York 12212-5097 • (518) 374-2222 • Fax (518) 374-1721

Advance Testing

3348 Route 208, Campbell Hall, NY 10916
Phone: 845-496-1600 Fax: 845-496-1398
42 Day Farm Road, West Stockbridge, MA 01266
Phone/Fax: 413-232-8566

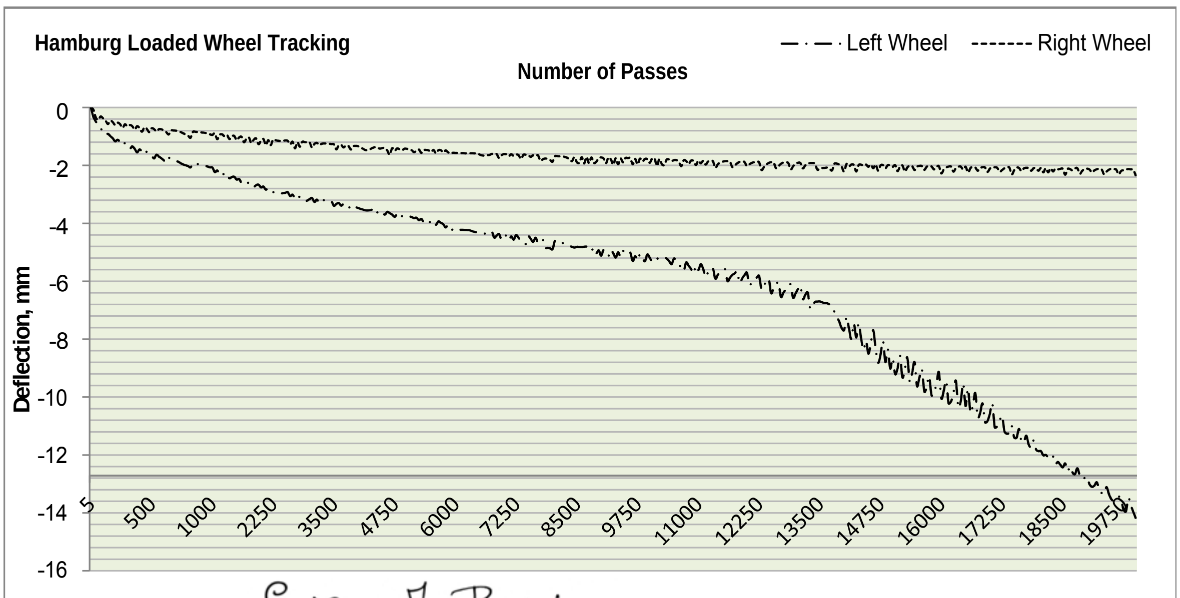
Hamburg Wheel-Track Testing of Compacted HMA

Test Method AASHTO T 324

Client:	Callanan Industries	**Project**	Quality Control
Material:	12.5 mm <30	**Project Number:**	090554
Source:	Callanan Industries	**Lab Number:**	11-0205
Location:	East Kingston, NY	**Item Number:**	12.5 mm <30 WMA
Date Sampled:	5/24/2011	**Sampled By:**	David Dachenhausen
Date Tested:	6/2/2011	**Tested By:**	Rich Hamilton

WMA Add/Dosage	Green System	**Anti-Strip/Dosage**	NA
RAP %	0	**Aggregate Source**	Callanan Industries
Mix Production	Lab	**Test Temperature**	50 C
Mix Compaction	Gyratory		

	LEFT WHEEL		RIGHT WHEEL	
	Warm Mix		Hot Mix	
Sample Number	2W	5W	2H	4H
Diameter	150.0	150.0	150.0	150.0
Thickness	60.0	60.0	60.0	60.0
Dry Mass	2454.5	2450.8	2450.3	2450.0
SSD Mass	2457.8	2459.6	2459.3	2460.4
Mass in Water	1409.6	1412.8	1412.2	1413.3
Volume	1048.2	1046.8	1047.1	1047.1
Bulk SpGr	2.342	2.341	2.340	2.340
Max SpGr	2.496	2.496	2.490	2.490
% Air Void	6.17	6.21	6.02	6.02
Vol. Air Vd	0.30	0.80	0.90	1.00
Max Impression (mm)	3.37		3.74	
PassNo./Point	19150/8		19950/7	
Creep Slope	-0.00031556		-4.48542E-05	
Strip Slope	-0.001068937		0	
Stripping Inflection Point	12,900		NA	
Fail Depth	12.7		12.7	
Pass?	YES		YES	



Report Reviewed By: Emily J. Rodriguez

September 2010

Summary of Astec *Double Barrel*® *Green* Warm-Mix Asphalt Laboratory and Field Testing

Authors:
W. Norman Smith, P.E.; Group Vice President, Asphalt, Astec Industries, Inc.
Michael C. Varner; Director of Thermal Systems and Research, Astec, Inc.

PREPARED FOR:

California Department of Transportation
Division of Pavement Management
Sacramento, CA

PREPARED BY:

Astec Inc.
Chattanooga, TN

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
Symbol	**Convert From**	**Convert To**	**Symbol**	**Conversion**
LENGTH				
mm	millimeters	inches	in	mm x 0.039
m	meters	feet	ft	m x 3.28
km	kilometers	mile	mile	km x 1.609
AREA				
mm^2	square millimeters	square inches	in^2	mm^2 x 0.0016
m^2	square meters	square feet	ft^2	m^2 x 10.764
VOLUME				
m^3	cubic meters	cubic feet	ft^3	m^3 x 35.314
kg/m^3	kilograms/cubic meter	pounds/cubic feet	lb/ft^3	kg/m^3 x 0.062
L	liters	gallons	gal	L x 0.264
L/m^2	liters/square meter	gallons/square yard	gal/yd^2	L/m^2 x 0.221
MASS				
kg	kilograms	pounds	lb	kg x 2.202
TEMPERATURE (exact degrees)				
C	Celsius	Fahrenheit	F	°C x 1.8 + 32
FORCE and PRESSURE or STRESS				
N	newtons	pound force	lbf	N x 0.225
kPa	kilopascals	pound force/square inch	lbf/in^2	kPa x 0.145
*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)				

1 INTRODUCTION

This report summarizes the laboratory and full-scale field experiments undertaken to compare the performance of the Astec Double Barrel® Green warm-mix technology (referred to as Astec DBG in this report) with conventional hot-mix asphalt. The report covers work undertaken in the following states:

- Tennessee
- California
- Alberta, Canada

1.1 Structure and Content of this Report

This report is organized as follows:

- Chapter 2 provides an overview of how Astec DBG works, how it is added to the mix, and how Caltrans Material Plant Quality Program (MPQP) requirements are met.
- Chapter 3 summarizes laboratory testing comparing the performance of Astec DBG and HMA.
- Chapter 4 summarizes accelerated pavement testing comparing the performance of an Astec DBG mix against an HMA control mix.
- Chapter 5 summarizes full-scale field testing comparing the performance of Astec DBG mixes against HMA mixes.
- Chapter 6 contains a list of reports prepared on the work completed on Astec DBG to date.
- Chapter 7 contains a list of individuals in state departments of transport and research organizations that can be contacted to verify the results presented in this report.

1.2 Terminology

The term “asphalt concrete” is used in this report as a general descriptor for the asphalt wearing courses on roads or test tracks. The terms “hot-mix asphalt (HMA)” and “warm-mix asphalt (WMA)” are used as descriptors to differentiate between the two types of asphalt concrete discussed in this report.

2 OVERVIEW OF THE ASTEC DBG TECHNOLOGY

The Generation 2.X Green System (Double Barrel Green®, Green Pac™ for Continuous and Green Pac™ for Batch) consists of multiple water injectors, foaming standpipes, and nozzles supplied by common liquid Asphalt Cement (AC) and water manifolds. Water is injected via water injectors into a foaming standpipe. The water percentage injected is typically 2% by weight of liquid AC flow. The water flow rate (Double Barrel Green® and Green Pac™ for Continuous) is maintained by feedback control of the PLC trimming the speed of a positive displacement water pump to maintain measured water flow equal to calculated target flow rate, which is calculated based upon the output of the AC flowmeter. Actual water flow is determined from the output of a water flow measurement device (various types). The multi-nozzle foaming assembly has six matched water injectors and foaming standpipes.

The Double Barrel® Green system is shown in Figure 2.1.

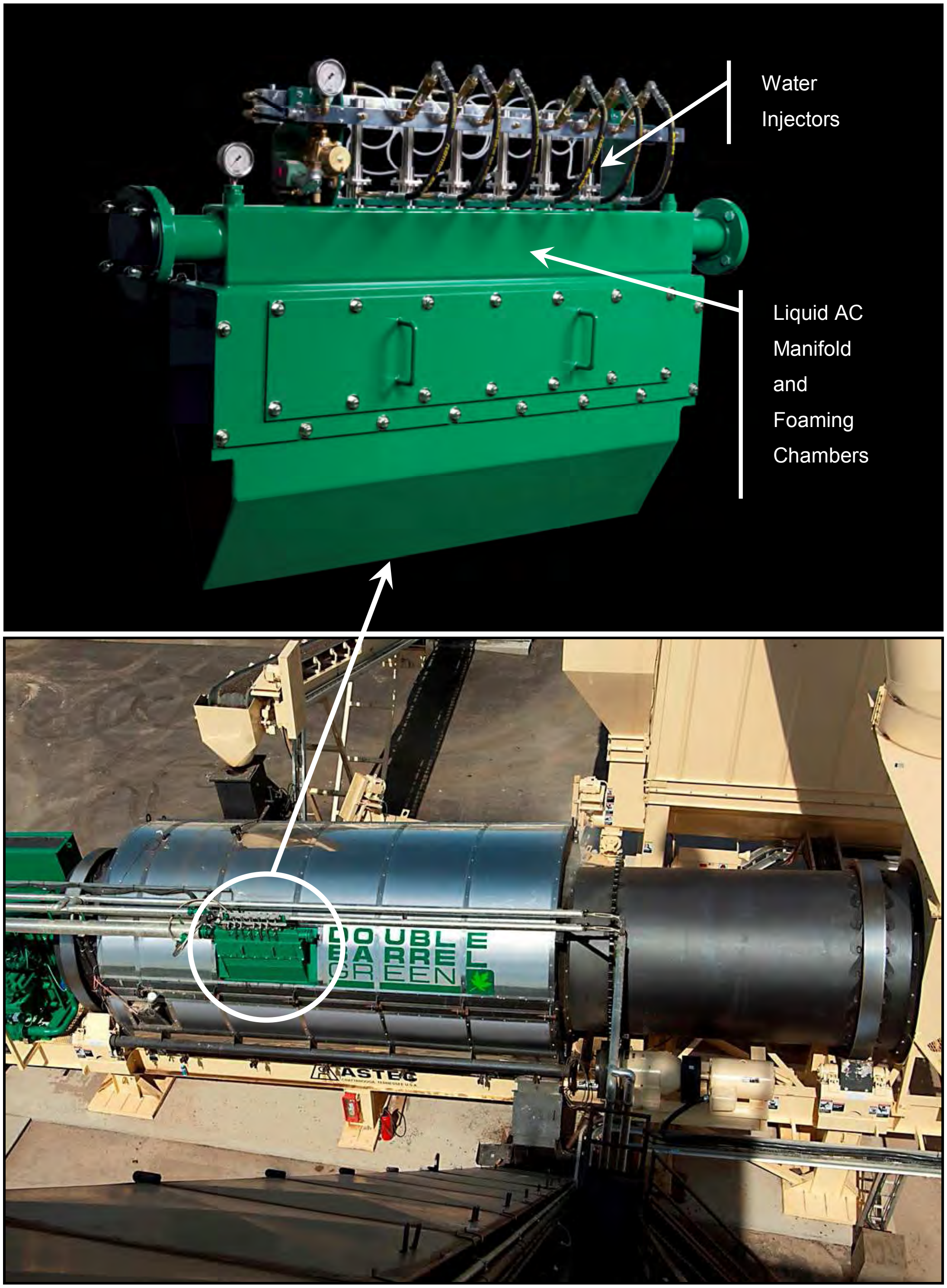


Figure 2.1: Astec Generation 2.X Warm Mix System installed on a Double Barrel®.

2.1 Continuous Plants (Double Barrel Green and Green Pac™ for Continuous)

The foaming assembly is typically plumbed into the AC metering system as a primary dispensing point. When the foam system is enabled, water is injected into and mixed with the liquid AC.

2.2 Batch Plants (Green Pac™ for Batch)

The Green Pac™ for Batch may be installed on either positive displacement or gravity feed plant configurations. In the case of a positive displacement system, the green system manifold is installed between the AC injection pump and the pugmill spraybar. In the case of a gravity feed system, an AC injection pump is added to provide the motive force to push the AC through the foaming manifold thus adding positive displacement capability to the plant for the production of both WMA and HMA without affecting the plants capability of continuing to use the gravity feed system.

2.3 Material Plant Quality Program Compliance

The measurement of water and confirmation of water flow is accomplished by the Green System control. Figure 2.2 shows the interaction of the Green System control with plant process control. If target water flow is not achieved, an automatic control action is initiated and an alarm will sound.

The Green System can be "enabled" prior to the production of mix. Once enabled, the system is "ready" to make WMA even though neither HMA nor WMA are being produced. Once the plant operator starts production and the blending control actuates the AC Divert Valve from the divert position to the spray position, the Green System begins making WMA if it is already enabled. If the Green System is not enabled prior to AC Divert Valve being in the "spray" position, HMA is produced. When the Green System is "enabled" and the AC Divert Valve is actuated to the "spray "position via a request from the blending control, the Green System PLC begins making WMA:

- Water injectors open and the water pump starts.
- By default, a water tolerance limit exists. If the tolerance level is exceeded, an alarm is displayed and a control action (mid-stream stop) is initiated.
- At this point, the system is making WMA and will continue to do so until it is manually disabled.

2.3.1 Ingredients Indicators

The water flow rate is set and shown on the Green System control panel located in the plant control room and is adjusted in proportion to the asphalt metering system. If no asphalt is being metered, the water flow valve will shut off automatically.

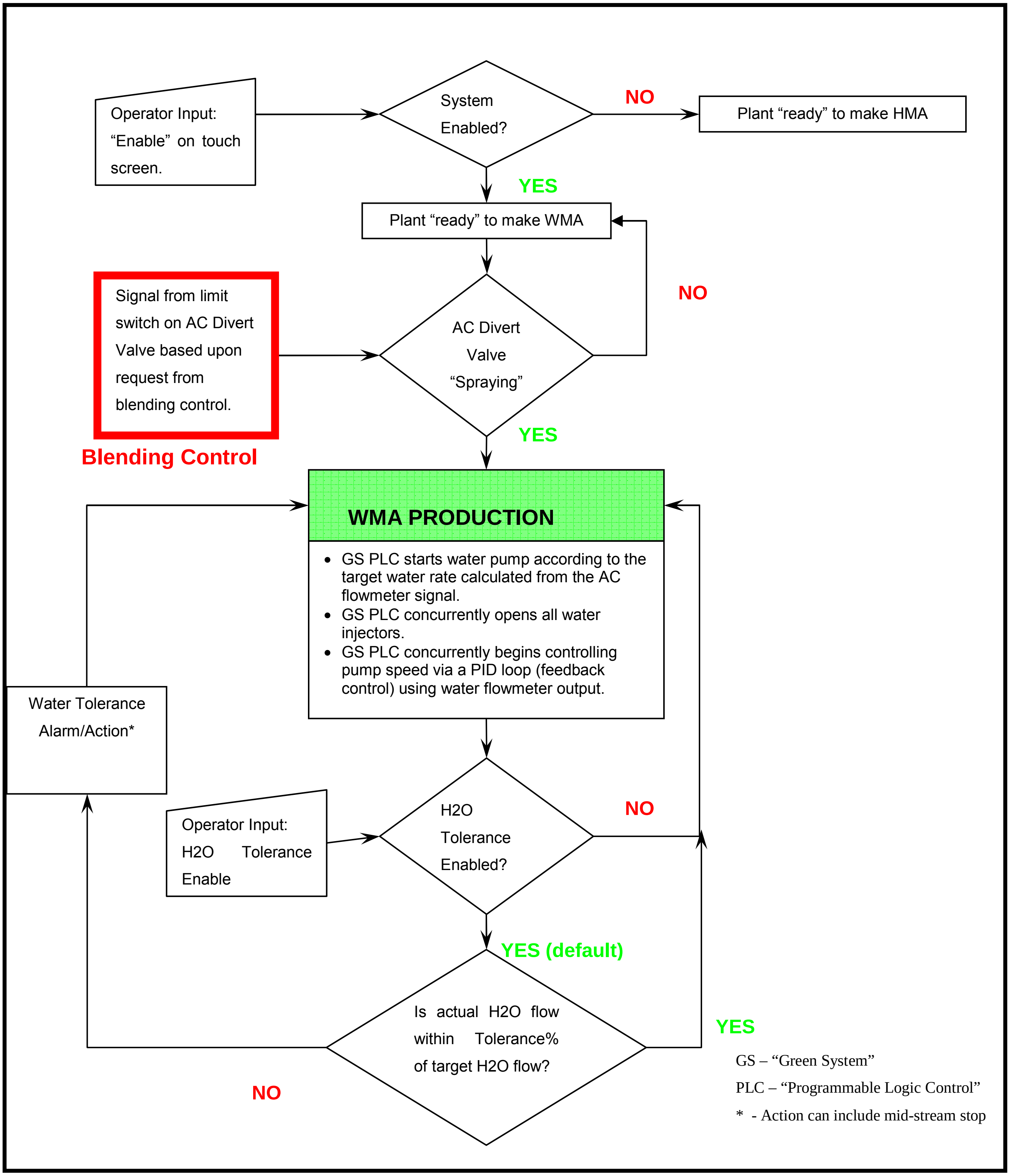


Figure 2.2: Flowchart showing control interaction between blending control and Green System.

2.3.2 Liquid Measurement

Water flow is measured with a Coriolis flow meter.

2.3.3 Dry Ingredients Measurement

This section is not applicable.

2.3.4 Ingredients Cutoffs

The Green System controller has an automated tolerance level monitor linked to flow meter and if this is exceeded (too much/too little), an alarm is displayed and a control action (mid-stream stop) is initiated.

2.3.5 Operational Tolerances

The Green System has an accuracy of +/- 0.1% of the water application rate (i.e., 0.1% of between 1.5% and 2.0%, which is the typical water application rate on warm-mix asphalt mixes).

2.3.6 WMA additive in Continuous Mixing Plants

When the system is enabled, the water pump starts and begins controlling flow. Once the unit reaches its targeted water flow within a settable tolerance, water nozzles open allowing water and AC to mix together within the unit. Upon disabling the system or performing a mid-stream stop, the unit ceases spraying water into the foaming standpipes by closing the water injectors and stopping the water pump. Production data logs can be saved/printed as required.

2.3.7 WMA additive in Batch Plants

Water flowrate (based upon the rate at which AC leaves the weighpot) is controlled by setting the pump to run at the appropriate speed via a manual calibration. Once in operation and enabled, the water pump runs at this speed continuously with the flowmeter output displayed for reference. The Green Pac™ for Batch PLC receives signals from the existing plant batch control to determine when water is to be injected into the foaming manifold or bypassed back to the water reservoir. If the plant uses gravity to dispense AC into the pugmill, the Green Pac™ for Batch PLC also receives signals from the existing weigh system to control the filling and emptying of the plant's weighpot. Production data logs can be saved/printed as required.

3 LABORATORY TESTING

Laboratory test results are provided from two studies, one completed by the National Center for Asphalt Technology on mix obtained from a project in Tennessee, and one completed by the University of California Pavement Research Center on specimens sampled from an accelerated pavement test track. Only beam fatigue test results are presented from the California study.

3.1 Tennessee Study

The laboratory testing program discussed below has been summarized from a report titled "*Preliminary Evaluation of Warm Mix Asphalt Field Demonstration: Franklin, Tennessee*" prepared by A. Kvasnak, J. Moore, A. Taylor, and B. Prowell of the National Center for Asphalt Technology for Astec Industries (NCAT) *(1)*.

3.1.1 Experiment Design

Mix testing was conducted on material sampled during construction. The WMA specimens were compacted in the field without reheating, while the HMA specimens were compacted from reheated mix. The mix tests evaluated compactability, mositure sensitivity (Tensile Strength Ratio [ASTM D 4867] and Hamburg Wheel Track [AASHTO T 324]), rutting susceptibility (Asphalt Pavement Analyzer [AASHTO TP 63]), and low temperature cracking resistance (Indirect Tensile Creep Compliance Test [AASHTO T322]).

3.1.2 Compactability

Compactability was determined at a constant compaction of 60 gyrations. The control and warm mixes both had air void contents of 2.9 percent. The warm mix had slightly lower binder content than the control, but had a slightly higher fines content, which appears to have compensated for the lower binder content.

3.1.3 Moisture Sensitivity: Tensile Strength Ratio

Moisture sensitivity was conducted in accordance with ASTM D 4867 without a freeze-thaw cycle. Results are summarized in Table 3.1. The warm mix had a lower dry tensile strength than the control, similar wet tensile strength, and consequently a higher tensile strength ratio. These test results indicate that the warm mix technology did not have any significant influence on the moisture sensitivity of the mix.

Table 3.1: Moisture Sensitivity Test Results: TSR.

Parameter	Control	Astec DBG
Dry ITS Indirect Strength (psi) Wet Indirect Strength (psi)	156 115	130 110
Tensile Strength Ratio (%)	73	83

3.1.4 Moisture Sensitivity: Hamburg Wheel Track Test

Hamburg Wheel Track Testing was conducted in accordance with AASHTO T324. Six-inch cyclindrical specimens were compacted with a gyratory compactor to 7±0.5 percent air voids. All specimens were conditioned and tested in 50°C water bath. The test was run for 10,000 cycles (20,000 passes) or until the specimens failed. The stripping inflection point and total rut at 10,000 cycles were determined for each set of specimens. Acceptance criteria were set at 10 mm rut at 10,000 cycles and a 5,000 cycle inflection point. Results are summarized in Table 3.2. These test results indicate that the warm mix technology did not have any significant influence on the moisture sensitivity of the mix.

Table 3.2: Moisture Sensitivity Test Results: Hamburg Wheel Track.

Parameter	Control	Astec DBG	Limit	Control	Astec DBG	Limit
Inflection Point (cycles)	7,500	8,200	>5,000	-	-	-
Rut depth (mm)	-	-	-	20	25	<10

3.1.5 Rutting Susceptibility

Rutting susceptibility was determined using the Asphalt Pavement Analyzer (APA) according to AASHTO TP 63. Six cylindrical specimens per mix were tested in an air chamber heated to 64°C. Specimens for both mixes were prepared from reheated mix to ensure that the correct air void content of 7.0±0.5 percent was achieved. Average rut depths for the Control and warm mixes were 7.5 mm and 5.0 mm, respectively, both below the 8.0 mm failure criterion.

3.1.6 Mix Stiffness

Dynamic modulus testing was conducted in accordance with AASHTO TP62 to evaluate the stiffness of the two mixes. The test was run at multiple temperatures (4.4°C through 54.4°C) and frequencies (25 Hz though 0.1 Hz) within the elastic range of a mix. Confining pressure was set at 138 kPa (20 psi). All specimens were compacted from reheated mix. Test results were used to construct a master curve for each mix (Figure 3.1). The results indicate that the warm-mix had marginally lower stiffness than the hot-mix control as expected.

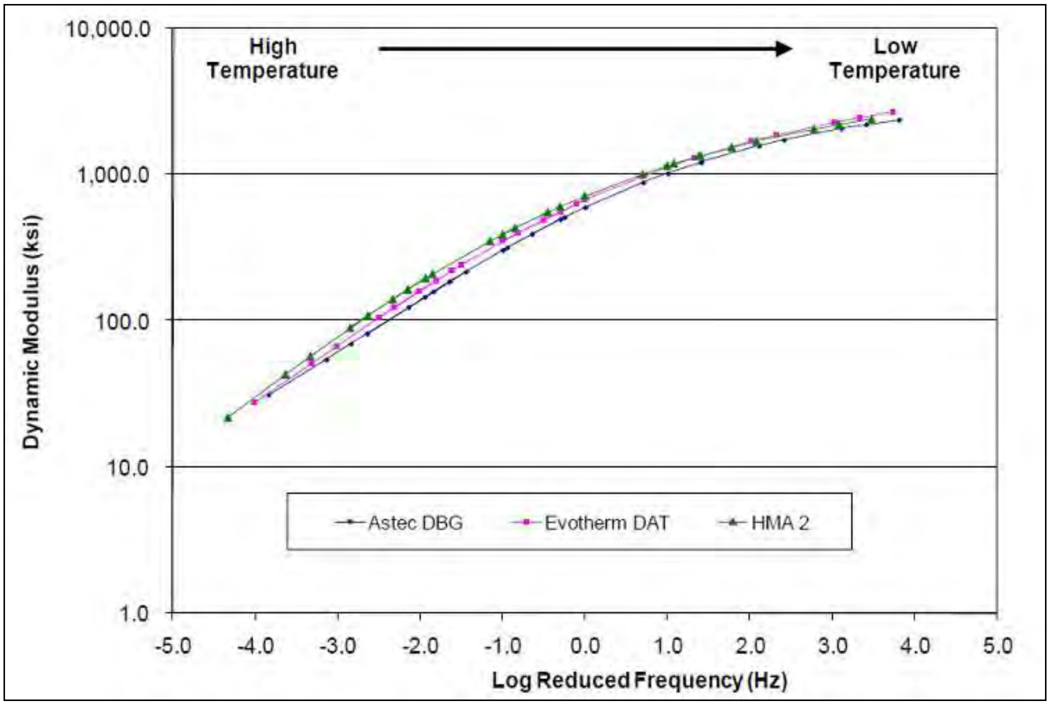


Figure 3.1: Dynamic modulus.

3.1.7 Indirect Tensile Creep Compliance

The influence of the warm-mix technology on low temperature cracking was assessed using an indirect tensile creep compliance test, conducted in accordance with AASHTO T322. The results (Figure 3.2) indicate that the warm-mix was more compliant than the hot-mix conrol at -10°C and 0°C, while the hot-mix was slightly more compliant at -20°C. The warm-mix thus had a positive effect on the dissipation of thermal stresses.

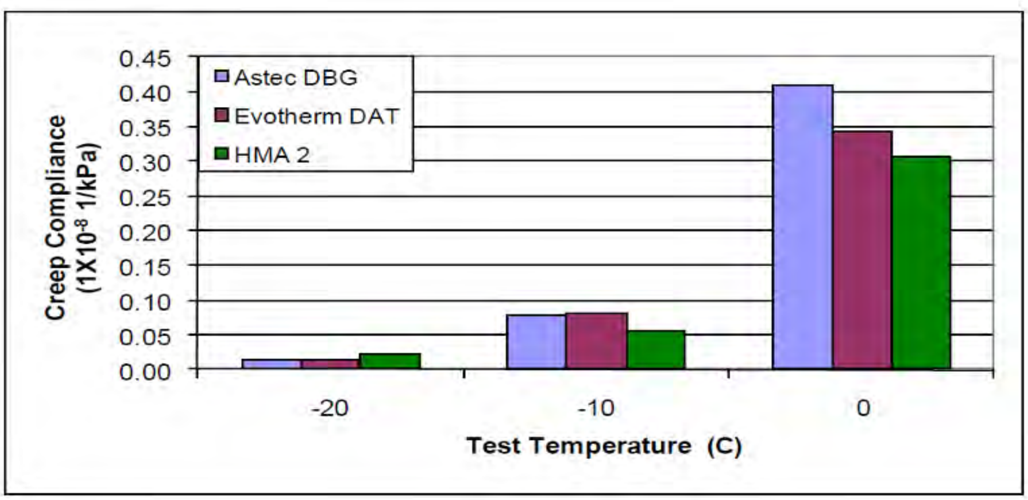


Figure 3.2: Creep compliance.

3.1.8 Durability of Open-Graded Mixes

Durability testing of open-graded mixes has not been undertaken.

3.2 California Study

A comprehensive laboratory study was undertaken in conjunction with the accelerated pavement testing study as part of the third phase of the California warm-mix asphalt investigation *(2)*. The study included tests to compare rutting and fatigue cracking performance, and moisture sensitivity between the hot and warm mixes. All testing was undertaken on specimens removed from the test track. The fatigue cracking performance component of the study is discussed below.

3.2.1 Experiment Design

Mix testing was conducted on specimens sampled from the test track. Fatigue cracking was evaluated with a beam fatigue test (AASHTO T 321).

3.2.2 Mix Design

Mix details are summarized in Table 3.3 based on results from quality control checks on the mix during production. The gradations of the two mixes were similar; however, the binder content on the Astec DBG mix was considerably higher (0.8 percent) than the Control. This influenced the Hveem stability and air void content. There was no difference in the moisture content of the two mixes.

Table 3.3: Mix Details, California Study

Parameter	Specification	Actual	
		Control	Astec DBG
Grading			
3/4"	100	100	100
1/2"	88-100	99	99
3/8"	79-91	87	87
#4	31-45	39	39
#8	14-22	21	24
#16	-	13	16
#30	-	9	10
#50	-	6	7
#100	-	5	5
#200	0-4	4	4
Sand equivalent	>47	73	74
AC Binder Type	-	PG 64-16	PG 64-16
AC Binder Content (%)	8.1 – 8.5	7.6	8.4
Rubber content (%)	18-20%	19	19
Hveem Stability (no cure)	>23	40	35
Bulk Specific Gravity	-	2.369	2.377
Rice Specific Gravity	-	2.485	2.485
Air-void Content (%)	-	4.7	4.4
Moisture (before plant) (%)	-	3.0	3.2
Moisture (after silo) (%)	<1.0	0.1	0.1

3.2.3 Air Void Content

Air void contents for the specimens tested are shown in Figure 3.3. The Astec DBG specimens had significantly lower air void contents than the Control specimens. This was attributed to poor compaction on the hot-mix control associated with the loss in temperature during hauling when constructing the test track. The same rollers and same rolling pattern were used on both sections.

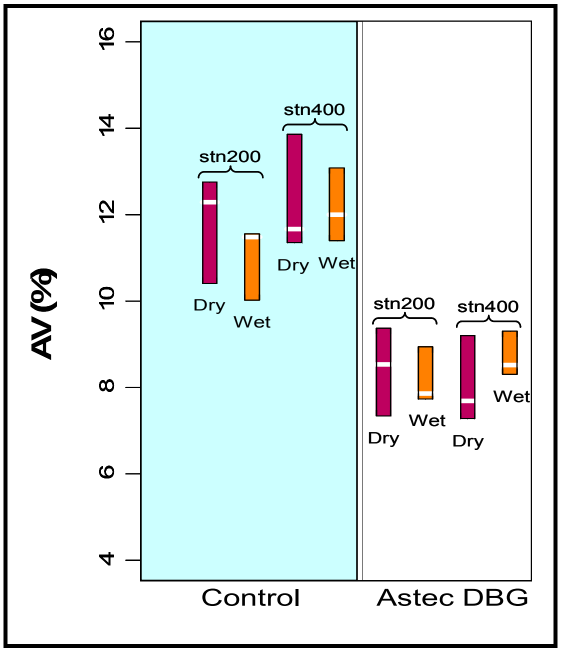


Figure 3.3: Air Void Content.

3.2.4 Initial Stiffness

Figure 3.4 illustrates the initial stiffness comparison at various strain levels, temperatures, and conditioning for the different mix types. The following observations were made:

- Initial stiffness was generally strain-independent for both the dry and wet tests.
- There was a significant difference between the two mixes in terms of initial stiffness in both the dry and wet conditions, attributed to the difference in air void contents. A statistical analysis to normalize the effect of air void content indicated that there would not have been a significant difference in stiffness between the two mixes if the air void contents were the same. The results therefore indicate that the use of the Astec DBG technology and associated lower production and compaction temperatures did not negatively influence the performance of the mix in this test.
- Lower initial stiffness values were recorded on soaked specimens as expected.

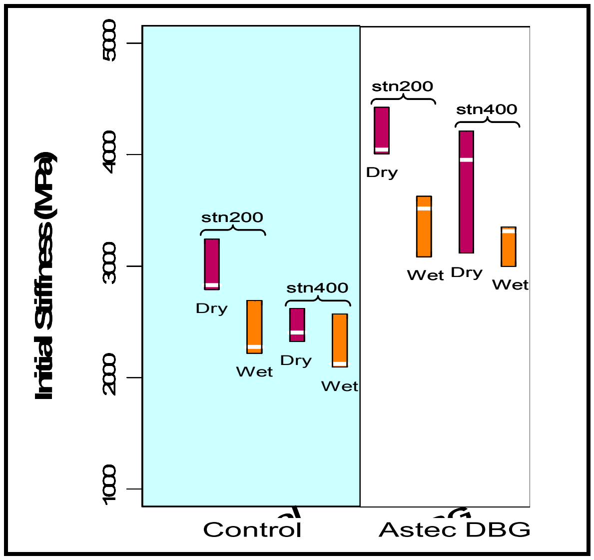


Figure 3.4: Summary boxplots of initial stiffness.

3.2.5 Fatigue Life at 50 Percent Stiffness Reduction

Mix stiffness typically decreases with increasing test-load repetitions. Conventional fatigue life is defined as the number of load repetitions when 50 percent stiffness reduction has been reached. A high fatigue life implies a slow fatigue damage rate and consequently higher fatigue-resistance for a given tensile strain. The side-by-side fatigue life comparison of dry and wet tests is plotted in Figure 3.5. The following observations were made:

- Fatigue life was strain-dependent. In general, lower strains will result in higher fatigue life and vice versa.
- Water soaking had no significant effect on fatigue life in this study. The results of initial stiffness testing implied that a shorter fatigue life was expected, especially at the lower testing strain.
- There was no significant difference between the two mixes in terms of fatigue life at 50 percent stiffness reduction indicating that the use of the Astec DBG technology and lower production and compaction temperatures did not negatively influence the performance of the mix in this test.

3.2.6 Flexural Frequency Sweep

The average stiffness values were used to develop a flexural complex modulus (*E**) master curve. This is considered a useful tool for characterizing the effects of loading frequency (or vehicle speed) and temperature on the initial stiffness of an asphalt mix (i.e., before any fatigue damage has occurred). The shifted master curve with minimized residual-sum-of-squares derived using a genetic algorithm approach was fitted with a modified Gamma function.

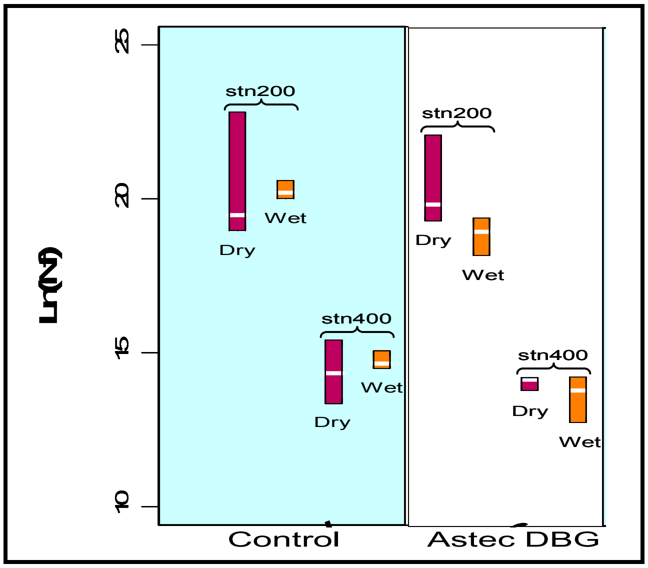


Figure 3.5: Summary boxplots of fatigue life.

Figure 3.8 through Figure 3.9 show the shifted master curves with Gamma-fitted lines and the temperature-shifting relationships for the frequency sweep tests. The temperature-shifting relationships were obtained during the construction of the complex modulus master curve and can be used to correct the temperature effect on initial stiffness. The following observations were made from the frequency sweep test results:

- The two mixes followed similar (and typical) trends, with the Astec DBG mix exhibiting higher stiffness at higher frequencies compared to the Control mix, which was again attributed to the difference in air void content. At lower frequencies (i.e., more viscous binder properties under slower moving traffic), the performance was similar, with both mixes having low stiffnesses, as expected.
- A slight loss of stiffness attributed to moisture damage was apparent in both mixes, as expected.
- There were no apparent temperature-sensitivity differences between the two mixes.

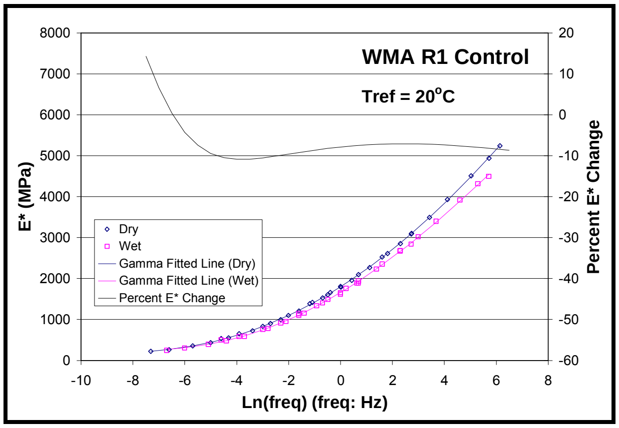


Figure 3.6: Control complex modulus (*E) master curves (dry).**

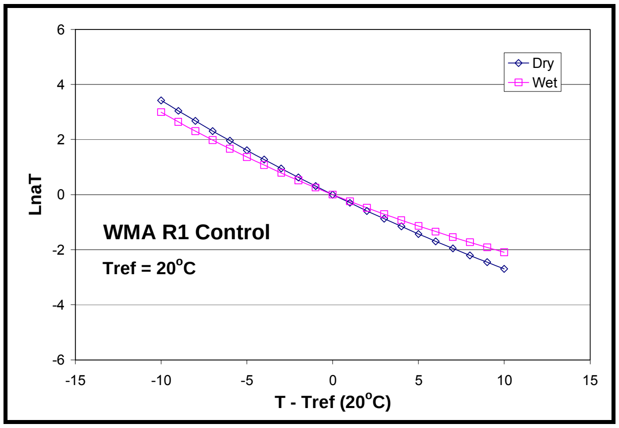


Figure 3.7: Control temperature-shifting relationship (dry).

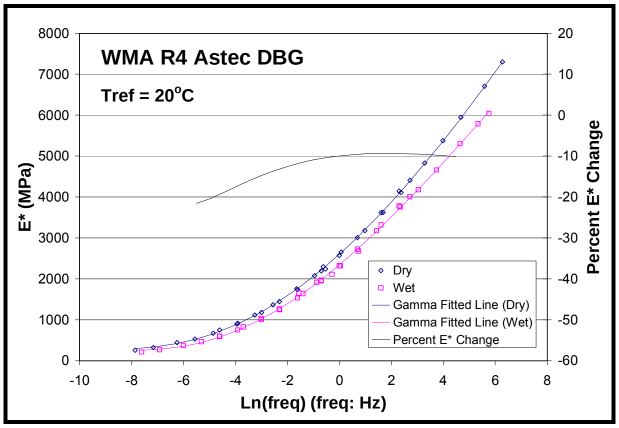


Figure 3.8: Astec DBG complex modulus (*E) master curves (dry).**

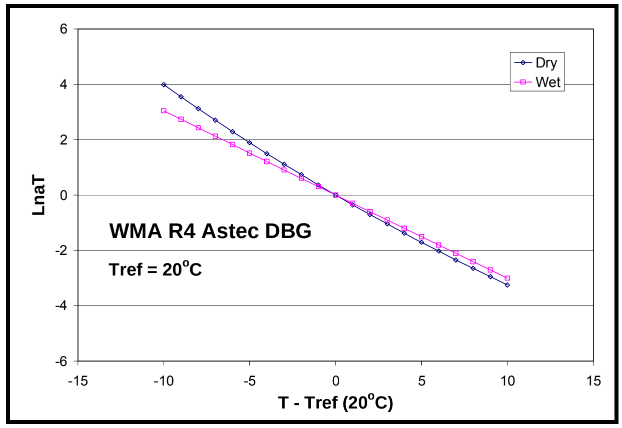


Figure 3.9: Astec DBG temperature-shifting relationship (dry).

4 ACCELERATED PAVEMENT TESTING

The accelerated pavement testing study discussed below has been summarized from a report prepared by the University of California Pavement Research Center on behalf of the California Department of Transportation *(3)*, which details accelerated pavement testing of seven different rubberized warm-mix asphalt technologies and two rubberized hot-mix asphalt control sections.

The test track constructed for the study was located at the UCPRC facility at UC Davis. The design and construction of the test track was a cooperative effort between Caltrans, the UCPRC, the asphalt and paving contractors, and seven warm-mix technology providers. The test track is 110 m by 15.0 m (360 ft by 50 ft) divided into nine equal test sections. The pavement structure consists of the existing subgrade, which was ripped to a depth of 300 mm (12 in.) and then recompacted, 400 mm (16 in.) of imported aggregate base, one 60 mm (2.4 in.) lift of conventional hot-mix asphalt, and one 60 mm (2.4 in.) lift of rubberized warm-mix asphalt. The warm-mix asphalt was placed in April 2010.

4.1 Mix Design

The rubberized HMA mix design was prepared by George Reed Inc and met the specifications for Caltrans "Half-Inch Maximum Gap-Graded Type II Rubberized Hot-Mix Asphalt (RHMA-G)". The mix design was not adjusted for accommodation of the warm-mix additives. A PG 64-16 binder was used and the crumb-rubber content was 19 percent. The Astec DBG water application rate was set at 1.5 percent by mass of binder.

4.2 Asphalt Concrete Production

4.2.1 Plant Modifications

No modifications to the plant were required.

4.2.2 Mix Production

Production began with the Control mix, followed by the warm mixes. At least 100 tonnes of each mix was produced and then stored in insulated silos. The first approximately 20 tonnes of each mix was "wasted" to ensure that a consistent mix was used on the test track. The Control and Astec DBG mixes were produced at 166°C (335°F) and 145°C (295°F) respectively. Water was added to the mix at 1.5 percent by mass of mix. Haul time from the asphalt plant to the test track was approximately 120 minutes.

4.2.3 Quality Control

Asphalt Mix

Quality control of the mixes produced for the test track was undertaken by George Reed Inc. on mix sampled from the trucks at the silos. The results are summarized in Table 4.1.

Table 4.1: Quality Control of Mix after Production

Parameter	Specification	Actual	
		Control	Astec DBG
Grading			
3/4"	100	100	100
1/2"	88-100	99	99
3/8"	79-91	87	87
#4	31-45	39	39
#8	14-22	21	24
#16	-	13	16
#30	-	9	10
#50	-	6	7
#100	-	5	5
#200	0-4	4	4
Sand equivalent	>47	73	74
AC Binder Type	-	PG 64-16	PG 64-16
AC Binder Content (%)	8.1 – 8.5	7.6	8.4
Hveem Stability (no cure)	>23	40	35
Bulk Specific Gravity	-	2.369	2.377
Rice Specific Gravity	-	2.485	2.485
Air-void Content (%)	-	4.7	4.4
Moisture (before plant) (%)	-	3.0	3.2
Moisture (after silo) (%)	<1.0	0.1	0.1

The following observations were made:

- The aggregate gradations of the Control and Astec DBG mixes were similar and generally met the specification requirements. The percent material passing the #8 sieve on the Astec DBG mix was slightly above the maximum specification limit.
- The binder content of the Astec DBG mix (8.4 percent) was slightly above the target (8.3 percent), but higher than the Control mix (7.6 percent) binder contents.
- The bulk and Rice specific gravities of the Astec DBG mix were very similar to those of the Control mix.
- The air-void content of the Astec DBG mix (4.4 percent) was slightly lower than the Control mix (4.7 percent).
- The Hveem stability of the Astec DBG mix (35) was lower than the Control mix (40). This was attributed to the slightly higher binder content and less oxidation of the binder due to the lower production temperatures in the Astec DBG mix. The stabilities of both mixes were, however, well above the minimum limit of 23.
- The moisture content of the aggregate used in the Astec DBG mix was slightly higher (3.2 percent) than that used in the Control mix (3.0 percent). However, the moisture contents of both mixes after production were the same and well within the Caltrans end-of-drum moisture content specification of 1.0 percent.

4.2.4 Asphalt Concrete Placement

The test track sections were constructed in the same order as asphalt production, using conventional equipment and following conventional procedures. Haze/smoke was visible during construction of both sections, but was considerably worse on the Control section compared to the Astec DBG section. Ambient temperatures during placement of the Control and Astec DBG sections were 10°C (50°F) and 15°C (59°F), respectively. Breakdown compaction temperatures for the Control and Astec DBG mixes were 137°C (279°F) and 125°C (257°F), respectively. Construction procedures and final pavement quality of the Astec DBG section did not appear to be influenced by the lower construction temperatures. Compaction on the Astec DBG section (air-void content of 14.0 percent) was similar to that on the Control (air-void content of 14.2 percent). Interviews with the paving crew after construction revealed that they did not note any significant differences in placement and compaction between the two mixes and no problems were experienced with construction at the lower temperature. Improved working conditions were identified as an advantage.

4.2.5 HVS Testing

Heavy Vehicle Simulator (HVS) test section layout, test setup, trafficking, and measurements followed standard UCPRC protocols. An average maximum rut of 12.5 mm (0.5 in.) over the full monitored HVS test section was set as the failure criteria for the experiments.

The pavement temperature at 50 mm (2.0 in.) was maintained at 50°C±4°C (122°F±7°F) to assess rutting potential under typical pavement conditions. Infrared heaters inside a temperature control chamber were used to maintain the pavement temperature. The pavement surface received no direct rainfall as it was protected by the temperature control chamber.

The HVS loading program for each section is summarized in Table 4.2. Equivalent Standard Axle Loads (ESALs) were determined using the following Caltrans conversion (Equation 4.1):

$$\text{ESALs} = (\text{axle load}/18000)^{4.2} \qquad \textbf{(4.1)}$$

All trafficking was carried out with a dual-wheel configuration, using radial truck tires (11R22.5- steel belt radial) inflated to a pressure of 720 kPa (104 psi), in a channelized, unidirectional loading mode. Load was checked with a portable weigh-in-motion pad at the beginning of each test and after each load change.

Table 4.2: Summary of HVS Loading Program

Section	Overlay	Wheel Load[1] (kN)	Repetitions	ESALs[2]
624HB	Control	40	160,000	160,000
		60	100,000	550,000
		80	30,000	551,000
		Total	290,000	1,261,000
627HB	Astec DBG	40	160,000	160,000
		60	43,000	236,000
		80	0	0
		Total	203,000	396,000

[1] 40 kN = 9,000 lb. 60 kN = 13,500 lb 80 kN = 18,000 lb
[2] ESAL: Equivalent Standard Axle Load

Rutting was measured with a laser profilometer and pavement temperatures were monitored using thermocouples imbedded in the pavement. A dedicated nearby weather station monitored ambient temperature, rainfall, relative humidity, wind speed and direction, and solar radiation.

4.2.6 Phase 3 Test Results Summary

Rutting behavior (average maximum rut) for the two sections is compared in Figure 4.1. The duration of the embedment phase (in terms of load repetitions) on the Astec DBG section was similar to the Control; however, the rut depth on the Astec DBG section was approximately 1.1 mm deeper than the Control indicating that the lower production and compaction temperature may have had some influence on early rutting behavior. This behavior is typical for warm-mix asphalt accelerated pavement testing experiments if testing is carried out within about 12 months of construction.

Rutting behavior on the Astec DBG section after the embedment phase followed the same trend as the Control in terms of rut rate (rutting per load repetition) until the load change to 60 kN, after which the rut rate increased at a faster rate than the Control. The Astec DBG section required approximately 90,000 less load repetitions than the Control to reach the failure point of 12.5 mm.

Rainfall was recorded on most days during the Astec DBG test, but not during testing of the Control, and although very little water contacted the surface of the test section, the surrounding areas were exposed, including the unsurfaced and lightly compacted shoulder close to the test section. A forensic investigation, which included a test pit and Dynamic Cone Penetrometer (DCP) measurements, conducted after completion of all HVS testing revealed that the base and subgrade where wetter than expected (and wetter than conditions just prior to paving) on all sections, with moisture contents in the base layer close to the laboratory determined optimum moisture content. DCP measurements indicated that the penetration per blow was higher in the area around the test section at the time of the forensic investigation compared to the measurements taken prior to placement of the asphalt concrete layers. This was attributed to the higher moisture content in the base and subgrade. A visual assessment and profile measurements in the test pit in the Astec DBG section showed that while most of the deformation was in the asphalt concrete layers, there was also up to 2.0 mm deformation in the base and subgrade. The same assessment in the test pit in the Control section revealed that deformation occurred only in the asphalt concrete layers.

The difference in performance between the Control and Astec DBG sections after the 60 kN load change was therefore mostly attributed to this difference in moisture conditions.

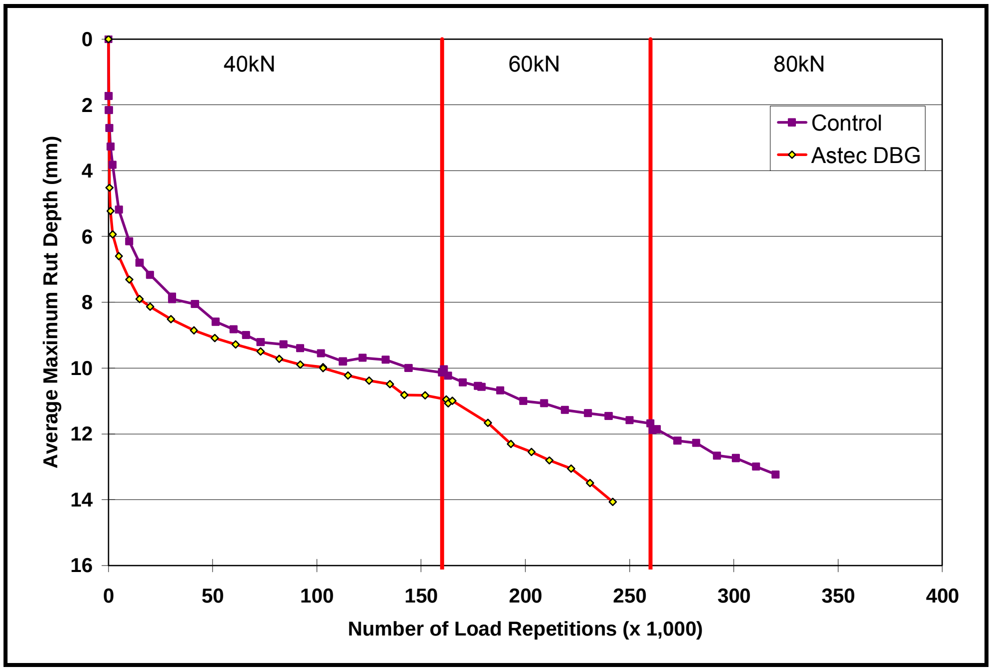


Figure 4.1: Comparison of average maximum rut for HVS testing.

5 FIELD TESTING: FULL SCALE FIELD TRIALS

5.1 Introduction

Despite use of the Astec DBG warm-mix asphalt system in many states, there are very few documented field trials comparing hot-mix and warm-mix performance over a period of 12 months or more. Most early experiments were constructed on relatively low-volume traffic roads that are not representative of California state highway or Interstate highway traffic volumes.

Summaries of the following two trials are discussed below:

- Tennessee (State Route 46)
- Alberta, Canada (Edmonton Ring Road)

5.2 Tennessee (State Route 46)

Summarized from a report titled "*Preliminary Evaluation of Warm Mix Asphalt Field Demonstration: Franklin, Tennessee*" prepared by A. Kvasnak, J. Moore, A. Taylor, and B. Prowell *(1)*.

5.2.1 Introduction

This overly project was conducted in Franklin, TN on State Route 46 (SR-46), a two lane road with mostly automobile traffic. The average daily traffic volume is 10,500 vehicles per day with about 10 percent heavy vehicles. Prior to overlay, the existing asphalt pavement surface was cracked and crack sealant had been applied in several locations. A 1.25 inch overlay was placed over the cracked surface.

5.2.2 Mix Design and Mix Production

The gradation and extracted binder contents for Marshall mix design used for the project are summarized in Table 5.1. Design binder content was 5.3 percent. The mix design was not altered to accommodate the warm-mix. The mixes were produced at the Murfreesboro Plant. Water was added at 0.5 by mass of mix. A liquid anti-strip (Pavegrip-650) was added at 0.3 percent by mass of the asphalt binder. The control mix was produced at 320°F and the warm-mix at 260°F. There was significantly less smoke observed during the warm-mix production and load out compared to the hot-mix. Haul time to the project was approximately 45 minutes.

Table 5.1: Gradation and Binder Content for Franklin Study

Sieve Size		Percent Passing	
English	Metric	JMF	Astec DBG
2"	50	100	100
1 1/2"	37.5	100	100
1"	25	100	100
3/4"	19	100	100
1/2"	12.5	99	98
3/8"	9.5	85	86
#4	4.75	59	57
#8	2.36	46	43
#16	1.18	--	33
#30	0.6	26	24
#50	0.3	10	10
#100	0.15	6	6
#200	0.075	4.0	5.1
Extracted AC Content		5.3	4.8

5.2.3 Construction

Construction followed standard procedures. No problems were encountered with either mix and compaction of the warm-mix section did not appear to be influenced by the lower temperatures. Mat temperature was consistent on both sections (warm-mix section in Figure 5.1)

Figure 5.1: Thermal image of WMA section showing consistent mat temperature.

Densities were determined from cores removed from the sections. AASHTO T166 was followed and densities were 93.0 percent and 92.0 percent for the HMA and WMA sections respectively.

5.2.4 Performance

The sections were monitored after 13 months of trafficking. Apart from some raveling on both sections, no other distresses were observed (Table 5.2). There was no observable difference between the two sections. Photographs of the control section are shown in Figure 5.5 and Figure 5.6. Densities determined from cores removed in the wheelpaths were 93.9 percent on both the control and warm-mix sections.

Table 5.2: Summary of Monitoring Observations for Tennessee SR46

Parameter	Control		Astec DBG	
	Oct 07	Nov 08	Oct 07	Nov 08
Overall performance	Good	Good	Good	Good
Texture	Good	Good	Good	Good
Void clogging	No	No	No	No
Mechanical damage	No	No	No	No
Other damage	No	No	No	No
Bleeding/flushing	No	No	No	No
Surface cracks	No	No	No	No
Binder condition	Good	Good	Good	Good
Aggregate loss	No	Yes	No	Yes
Cracks – block	No	No	No	No
Cracks - longitudinal	No	No	No	No
Cracks - transverse	No	No	No	No
Cracks - alligator	No	No	No	No
Pumping	No	No	No	No
Rutting	No	No	No	No
Ravelling/stone loss	No	Yes	No	Yes
Undulation/settlement	No	No	No	No
Edgebreak	No	No	No	No
Potholes	No	No	No	No
Delamination	No	No	No	No
Patching	No	No	No	No
Other repairs	No	No	No	No
Riding quality	Good	Good	Good	Good
Skid resistance	Good	Good	Good	Good
Surface drainage	Good	Good	Good	Good
Side drainage	Good	Good	Good	Good

Figure 5.2: General view of the Control section.

Figure 5.3: Close-up view of the Control section.

5.3 Alberta, Canada (Edmonton Ring Road)

Summarized from a paper titled *"A One Year review of the Anthony Henday Drive Warm Mix Project"* prepared by R.W. Forfylow, M. Reyes and M. Grimm of LaFarge Canada *(4)*.

5.3.1 Introduction

Anthony Henday Drive (AHD) circles the perimeter of the City of Edmonton and is part of the North/South trade corridor between Canada, the United States, and Mexico. Based on a Private Public Partnership (P3) model, Alberta Transportation awarded the design, construction, finance and 30-year maintenance contract of the Anthony Henday Drive Southeast Leg Ring Road to Access Roads Edmonton Ltd. Lafarge Canada Inc. was awarded the construction of the granular base course and asphalt concrete surface layers, as well as the maintenance contract. The project consisted of 11.5 km (approximately 125 lane-km) of grading, base and paving, and construction of 20 bridge structures. The project was opened to the public on October 28th, 2007. The initial construction of this freeway occurred between 2005 and 2007 with the final wearing surface completed during the 2010 construction season. As part of the original pavement design, a 50mm overlay was completed in summer 2010 to bring the paved surface to its final elevation. The final wearing surface comprised 91,000 tonnes of 16.0mm asphalt mix and 7,500 tonnes of 12.5mm asphalt mix. Of this, 66,000 tonnes of the surface course mix was placed as Warm Mix Asphalt (WMA) containing 10 percent Reclaimed Asphalt Pavement (RAP). The WMA mix was produced in an Astec Double Barrel Green® asphalt plant. This paper presents the initial evaluation of the WMA mix after one year of service at an Equivalent Single Axle Load (ESAL) level of approximately 1.2 million ESALs.

5.3.2 Mix Design

For the top lift paving, a Marshall mix design was prepared in accordance with Alberta Transportation (AT) specifications for Designation I Class 16, Type H1 asphalt concrete mix. The design incorporated 10 percent RAP. Preparation of the asphalt mix samples was in accordance with the Marshall Method of Mix Design as outlined in the latest edition of the Asphalt Institute Manual Series No.2 (MS-2), ASTM 06926-04, 06927-06 and AT design procedure TL T-301 (03). The design was based on a Marshall Hammer 75 blow per-face compactive effort incorporating Husky Oil PO 58-37 grade asphalt cement. At a design asphalt content of 5.1 percent by mass of dry aggregate, the Marshall properties provided in Table 5.3 and Table 5.4 were obtained.

Table 5.3: Mix Design Properties

Marshall Property	Mix Design Results	Specification
Asphalt Cement Content, by Dry Agg, (%)	5.1	-
Bulk Density, (kg/m^3)	2357	-
Marshall Stability, (kN)	17.3	12.0 min
Marshall Flow, (mm)	2.4	2.0 to 3.5
Air Voids, (%)	3.7	3.5 to 4.0
Voids in Mineral Aggregates, (%)	13.6	13.0 to 13.5
Voids Filled with Asphalt, (%)	72.6	65 to 75
Tensile Strength Ratio, (%)	89.4	80.0 min
Film Thickness, (μm)	6.8	6.1 min

Table 5.4: Mix Design Gradation

Sieve Sizes (mm)	Mix Design Results	Specification
25.000	100	100 – 100
20.000	100	100 – 100
16.000	99	100 – 100
12.500	89	82 – 92
10.000	80	75 – 84
5.000	63	58 – 65
2.500	44	40 – 48
1.250	35	31 – 39
0.630	29	26 – 32
0.315	19	16 – 22
0.160	10.1	8.1 – 12.1
0.080	6.0	4.5 – 7.5

5.3.3 Production and Construction

The WMA and conventional HMA mixes were produced at an Astec Double Barrel plant. For the WMA mix, the asphalt plant settings were adjusted to produce WMA mixes at mix temperatures of 125±5°C. The average production temperature for the conventional HMA was 156.1°C and for the WMA 127.0°C, approximately 30°C lower. The advantages of the use of WMA technology were noticed during the plant production where reduced plant emissions and visible smoke were witnessed. Also, at this lower mix temperature, a uniform coating of the asphalt mix was evident. Table 5.5 contains a typical plant production record data for the WMA and conventional HMA mixes.

The mix was placed following conventional construction practice.

Table 5.5: Plant Production Data

Measurement	AHD Warm Mix Asphalt (WMA)	AHD Hot Mix Asphalt (HMA)
Date	07/20/2010	05/17/2010
Mix temperature, (°C)	128.0	157.0
Mix production, (TPH)	335.7	314.2
Aggregate belt, (TPH)	280.1	263.7
Recycle belt, (TPH)	38.9	33.3
Total Asphalt Cement, (TPH)	16.8	16.2

Note: TPH is Tonnes Per Hour

The Quality Control and Quality Assurance (QCIQA) testing was carried out on loose mix and core samples. Bulk density, air voids, mix moisture content, asphalt cement content, sieve analysis, core thickness, core moisture, core bulk density, percentage of compaction, and core air voids were measured.

Table 5.6 contains a typical QC record data for the WMA and conventional HMA mixes. Note that the WMA mix has the same moisture content and quality properties as the HMA mix. Although the mix split proportions were the same for both WMA and HMA, the WMA mix gradation was slightly finer at the "bottom end" of the gradation sieves. This has been observed on other projects where more of the fine fractions are retained in the WMA mix and not collected in the baghouse. This slight change in the gradation did not affect the Marshall properties.

Table 5.6: Plant Produced Mix Properties

Sieve Sizes (mm)	Mix Design	AHD Warm Mix Asphalt (WMA)	AHD Hot Mix Asphalt (HMA)
20.000	100 – 100	100	100
16.000	100 – 100	99	99
12.500	82 – 92	91	89
10.000	75 – 84	82	82
5.000	58 – 65	62	60
2.500	40 – 48	46	45
1.250	31 – 39	37	35
0.630	26 – 32	31	29
0.315	16 – 22	21	19
0.160	8.1 – 12.1	12.0	10.1
0.080	4.5 – 7.5	7.0	6.0
Bulk density, (kg/m3)	2357	2358	2355
Asphalt Cement Content (%)	5.10	5.17	5.11
Air Voids (%)	3.7	3.6	3.8
Mix Moisture, (%)	-	0.03	0.04
Mix Voids in the Mineral Aggregate, (%)	13.6	13.7	13.7
Core Density, (kg/m3)	-	2317	2307
Core Air Voids, (%)	-	5.1	5.6
Core Compaction, (%)	-	98.3	97.8

5.3.4 Laboratory Evaluation

Core samples from the HMA and WMA mixes were extracted from the different road sections. After bulk density and air voids were measured on all core samples, the cores were grouped for the various laboratory tests programs. Moisture resistance, rutting susceptibility, resilient modulus, and critical cracking temperature were evaluated on the core samples. Additionally, the rheological properties of the asphalt binders were measured on recovered samples for each mix type.

Moisture Susceptibility

Moisture susceptibility was evaluated using AASHTO T283 "Standard Method of Test for Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage (TSR)" on extracted cores. Table 5.7 provides a summary of the moisture susceptibility test results. Based on a minimum TSR requirement of 80 percent, both the HMA and the WMA mixes met the minimum required. Also, the WMA mix moisture content measured during the production was similar to the content of the conventional mix (below 0.1 percent). Although both mixes exceed the limiting value of 80 percent for a TSR test, the WMA mix had a slightly lower TSR value than the conventional HMA, which is typical for WMA results.

Table 5.7: Summary of Moisture Susceptibility Testing

Mix Type	Treatment	Average Air Voids (%)	Tensile Strength (kPa)	Tensile Strength Ratio, TSR (%)
AHD Warm Mix Asphalt (WMA)	Conditioned	7.97	389	83
	Unconditioned	8.07	324	
AHD Hot Mix Asphalt (HMA)	Conditioned	6.57	550	87
	Unconditioned	6.49	480	

Although the WMA core samples exceeded the minimum of 80 percent TSR threshold value, visual examination of the tested cores did indicate an increase in the amount of stripping on the coarse aggregates compared to the conventional HMA core samples. It was also noted that the WMA tensile strength values were lower in the conditioned and unconditioned samples compared to the conventional HMA samples.

5.3.5 Rutting Performance

The susceptibility of the WMA and conventional HMA mixes was evaluated using the Asphalt Pavement Analyzer (APA) conducted in accordance with AASHTO TP 63. APA testing was conducted at 64°C on core samples for each type of asphalt mix.

Table 5.8 provides a summary of the APA testing results. The APA test results indicate similar rutting behavior of the WMA and the conventional HMA mixes. Both mixes attained a final accumulated rut depth lower than 5.0mm which is considered to be the accepted maximum accumulated rut depth for this type of roadway. Although both mixes showed similar rutting resistance, the WMA indicated a slightly higher rutting rate and final accumulated rut depth than the HMA, which is typical for WMA mixes using the water foaming technology when tested at a very early age. Of note also, is that test was conducted at

64°C and not at 58°C for the binder specified (PG 58-37). The total accumulated rut depth would therefore be reduced further had the test been conducted at 58°C.

Table 5.8: Summary of Asphalt Pavement Analyzer Testing at 64°C

Mix Type	Stroke Count	Rutting Rate (mm/hr)	Rut Depth (mm)	Final Rut Depth (mm)
AHD Warm Mix Asphalt (WMA)	25	26.815	0.186	4.4
	4,000	3.216	3.737	
	8,000	0.543	4.441	
AHD Hot Mix Asphalt (HMA)	25	36.253	0.252	4.1
	4,000	2.565	3.084	
	8,000	0.896	4.090	

5.3.6 Low Temperature Cracking

The critical cracking low temperature for the WMA and the conventional HMA mixes was determined based on thermal stresses and tensile stress data according with AASHTO T-322 "*Determining the Creep Compliance and Strength of Hot-Mix Asphalt Using the 1J1direct Tensile Test Device*". The testing was carried out at temperatures of -20°C, -30°C, and -35°C. Table 7 summarizes the WMA and the HMA surface thermal stress and the critical low temperatures. The results indicate similar low temperature behavior for the conventional HMA and the WMA mixes. The WMA cracking temperature is slightly lower than the HMA mix due to the use of lower production temperatures with WMA mixes, which reduce the amount of light volatiles being driven off during the mixing process resulting in a slightly less stiff mix in the WMA.

Table 5.9: Summary of Critical Low Temperature Testing

Mix Type	Test Temperature (°C)	Fracture Strength (MPa)	Thermal Stress (MPa)	Critical Low Temperature (°C)
AHD Warm Mix Asphalt (WMA)	- 20.0	3.56	0.36	- 38.8
	- 30.0	3.33	1.18	
	- 35.0	3.07	2.09	
AHD Hot Mix Asphalt (HMA)	- 20.0	2.67	0.50	- 37.0
	- 30.0	4.09	1.63	
	- 35.0	3.44	2.91	

5.3.7 Road Performance after 12 Months

The initial road performance of the WMA mix was evaluated after a 12 month cycle and consisted of a surface distress evaluation and Falling Weight Deflectometer (FWD) assessment. A visual Condition Index (VCI) was used as an indicator of pavement surface condition. This index combines surface distress data into an overall distress related index on a scale of zero to ten, with ten being a perfect score. The following distresses were considered: alligator cracking, block cracking, edge cracking, longitudinal and transverse cracking, bleeding, distortion, rutting, shoving, raveling, and potholes. These distresses were measured at three defined levels of severity (low, medium, and high). The road was divided into sections, according to the recommendations of the Pavement Surface Condition Rating Manual of the Ministry of Transportation and Highways - Province of British Columbia. Data collection was conducted using manual procedures for all of the sections. For each distress/severity combination, the Distress Value (DV) was calculated. All the individual distresses were then combined into an overall Adjusted Distress Value (ADV) based on the Equivalent Number of Distresses (END). The ADV was then subtracted from 100 and divided by 10 to obtain the VCI (Table 5.10). The WMA mix shows a visual condition similar to the conventional HMA mix.

Table 5.10: Visual Condition Index after 12 Months

Item	AHD Warm Mix Asphalt (WMA)	AHD Hot Mix Asphalt (HMA)
Distress Value (Transversal Cracking) - Low	3.0	3.2
Distress Value (Transversal Cracking) - Medium	0.0	0.0
Distress Value (Transversal Cracking) - High	0.0	0.0
Total Distress Value	3.0	3.2
Equivalent Number of Distresses (END)	1.0	1.0
Adjusted Distress Value (ADV)	3.0	3.0
Visual Condition Index (VCI)	9.7	9.7

Table 5.11 summarizes the estimated modulus of the surface course mix for the WMA and conventional HMA mix. The WMA sections had slightly higher moduli than the HMA sections.

After one year of road service, both the HMA and WMA sections are performing well (Table 5.12 and Figure 5.4 through Figure 5.6) with only minor transverse cracks observed on the road surface on both sections. The severity of the transverse cracking is low and is probably attributed to settlement of the road structure and low temperature cracking (Figure 5.7). There are long sections (longer than 3 km) where no cracking is evident, and there is a relatively short section where more frequent cracking was observed. Ambient temperatures of between -30°C and -35°C were recorded in the vicinity of the road during the first winter of trafficking, which probably contributed to low temperature cracking.

Table 5.11: Estimated Modulus of the Surface Course Mix

AHD Hot Mix Asphalt (HMA)					AHD Warm Mix Asphalt (WMA)				
Station	Drop	E1 (MPa)	E2 (MPa fixed)	E3 (MPa)	Station	Drop	E1 (MPa)	E2 (MPa fixed)	E3 (MPa)
0.153	1	1251		98	0.069	1	2285		107
0.221	1	2908		113	0.1	1	1754		100
0.296	1	2984		108	0.14	1	1257		114
0.583	1	1086		114	0.305	1	2630		138
0.153	2	1536		95	0.069	2	2492		102
0.221	2	2991		122	0.1	2	2115	600	105
0.296	2	2326	600	131	0.14	2	2084		93
0.583	2	1256		117	0.305	2	3393		133
0.153	3	1842		97	0.069	3	3088		99
0.221	3	3997		124	0.1	3	2139		124
0.296	3	2500		113	0.14	3	2337		102
0.521	3	1196		117	0.069				
0.583	3	1524		113	0.1				
Average E1 (MPa) : 2107.5					Average E1 (MPa): 2325.0				

Note: E1 layer thickness: 75mm. E2 layer thickness: 805mm (145mm asphalt concrete, 660mm granular base). E2 modulus fixed at 600MPa. Radius of curvature method was used to calculate moduli.

Table 5.12: Summary of Monitoring Observations for Edmonton Ring Road

Parameter	Control		Astec DBG	
	Aug 10	Aug 11	Aug 10	Aug 11
Overall performance	Good	Good	Good	Good
Texture	Good	Good	Good	Good
Mechanical damage	No	No	No	No
Other damage	No	No	No	No
Bleeding/flushing	No	No	No	No
Surface cracks	No	No	No	No
Binder condition	Good	Good	Good	Good
Aggregate loss	No	No	No	No
Cracks – block	No	No	No	No
Cracks - longitudinal	No	No	No	No
Cracks - transverse	No	Yes	No	Yes
Cracks - alligator	No	No	No	No
Pumping	No	No	No	No
Rutting	No	No	No	No
Ravelling/stone loss	No	No	No	No
Undulation/settlement	No	No	No	No
Edgebreak	No	No	No	No
Potholes	No	No	No	No
Delamination	No	No	No	No
Patching	No	No	No	No
Other repairs	No	No	No	No
Riding quality	Good	Good	Good	Good
Skid resistance	Good	Good	Good	Good
Surface drainage	Good	Good	Good	Good
Side drainage	Good	Good	Good	Good

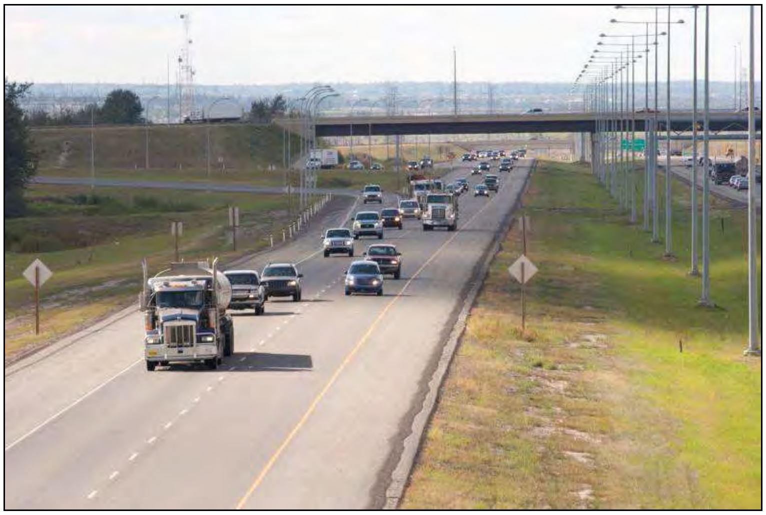


Figure 5.4: General view of roadway.

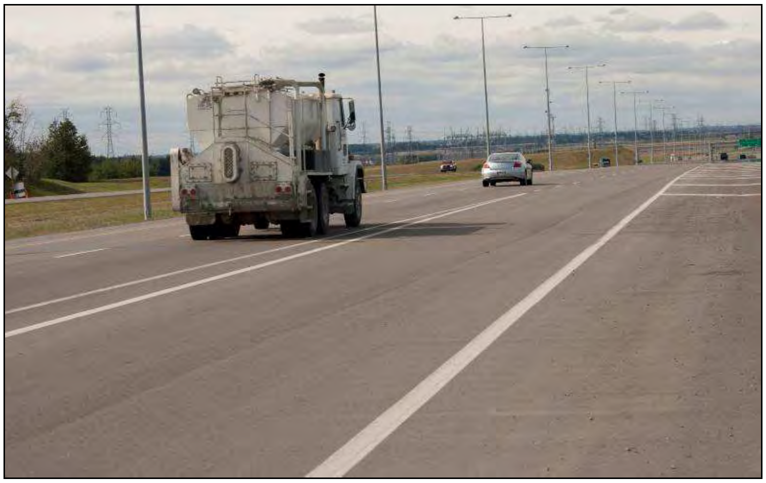


Figure 5.5: Close-up view of HMA section.

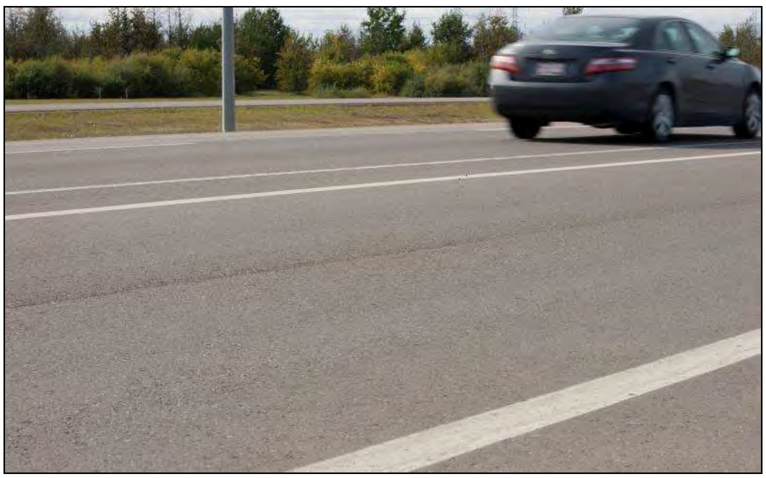


Figure 5.6: Close-up view of WMA section.

Figure 5.7: Core samples taken at transverse crack locations.

6 LIST OF REPORTS

1. KVASNAK, A., Moore, J., Taylor, A. and Prowell, B. 2010. **Preliminary Evaluation of Warm Mix Asphalt Field Demonstration: Franklin, Tennessee.** Auburn, AL: National Center for Asphalt Technology. (NCAT Report 10-01).
2. JONES, D., Wu, R., Tsai, B.W., and Harvey, J.T. 2011. **Warm-Mix Asphalt Study: Test Track Construction and First-Level Analysis of Phase 3a HVS and Laboratory Testing, and Forensic Assessment. (Mix Design #2).** Davis and Berkeley, CA: University of California Pavement Research Center. (RR-2011-03).
3. JONES, D. and Wu, R. 2010. **Warm-Mix Asphalt Study: Summary of Phase 3 HVS Testing on Rubberized Mixes using *Astec Double Barrel® Green*.** Davis and Berkeley, CA: University of California Pavement Research Center. (TM-2010-10).
4. FORFYLOW, R.W., Reyes, M. and Grimm, M. 2011. **A One Year Review of the Anthony Henday Drive Warm Mix Project.** Calgary, Alberta: Lafarge Canada Inc

7 LIST OF CONTACTS

7.1 Alabama

- National Center for Asphalt Technology
  - Randy West, PhD, PE. (334-844-6244, westran@auburn.edu)

7.2 California

- University of California Pavement Research Center
  - David Jones, PhD. (530-574-0724, djjones@ucdavis.edu)

7.3 Alberta Canada

- Lafarge Canada Inc
  - R.W. Forfylow, P.Eng (Bob.Forfylow@lafarge-na.com).

7.4 Washington

- Washington State Department of Transportation
  - Joseph R. DeVol (360-709-5421, DeVolJ@wsdot.wa.gov)

Return to Index of Appendices

Caltrans Warm Mix Asphalt Technology Approval

Company	*Astec*	Technology		*Double Barrel Green*		
Contact	*N. Smith/M. Varner*	Date Reviewed		*1/5/12*		
Documents Submitted	Summary Report	**Yes**	No			
	Supporting Reports	**Yes**	No			
	Other	Yes	No			
MPQP adherence information		**Yes**	No	MSDS	**Yes**	No
Name of organization doing testing		*National Center for Asphalt Technology, UC PRC*				
Experiment designs		**Yes**	No			
Mix designs		**Yes**	No	Method	Marshall Mix Design	
Specimen preparation		**Yes**	No	LMLC	FMLC	FMFC
Rutting performance		**Yes**	No	Method	AASHTO TP 63	
Fatigue performance		**Yes**	No	Method	AASTHO TP 62	
Hamburg Wheel Track		**Yes**	No	Method	AASHTO T 321	
Tensile Strength Retained		**Yes**	No	Method	ASTM D 4867	
OGFC durability		Yes	**No**	Method		
Other	Indirect Tensile Creep	Yes	No	Method	AASHTO T322	
Other		Yes	No	Method		
Performance better or equal to HMA		Yes	No	Need more information		
Number of states with tests		*3*	Number of tests in report		*3*	
Field test in California		**Yes**	No	Test with TI>11	**Yes**	No
Satisfactory evaluation		**Yes**	No			
Performance ~~better or~~ equal to HMA		**Yes**	No			
DoT contact names		**Yes**	No	Reference list	**Yes**	No
Recommendation		~~Approved~~		Provisional	~~Reject~~	

Reasons/comments

We have received the additional information as requested. Provisional approval is given for use on CT projects. Full approval will be based on the submission of OGFC durability tests or an evaluation of an OGFC field section in California as stated in comments on 12/21/11.

Review Panel Chairperson (C Barros)	

Warm Mix Asphalt (WMA)

The following Warm Mix Asphalt (WMA) additives and processes are pre-approved for use on department projects. Contact Dale Rand, P.E. of the Flexible Pavements Branch of CST/M&P at (512) 506-5836 for any information and status.

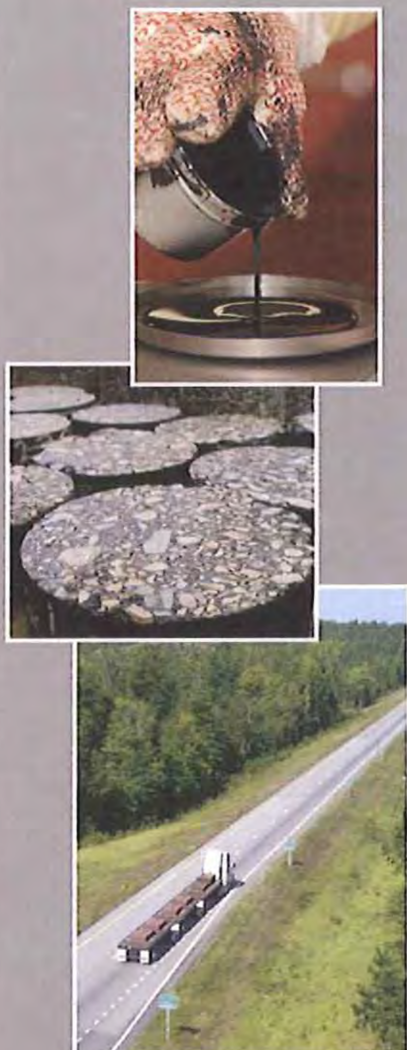
Approval requires the submittal of documentation from a minimum of 3 construction projects using the WMA technology, preferably a minimum of 1 in the State of Texas. Documentation must include a mixture design with mechanical property test results and Quality Control/Quality Assurance (QC/QA) test results measured during production. The following information must be included with the documentation:

- Contact Name & Telephone Number;
- Product Name & Supplier;
- Dates of construction for each project;
- Project Control-Section-Job (CSJ) Number for each project, if available; and
- Location and Highway for each project submitted.

WMA Technology	Process Type	WMA Supplier
Advera (Synthetic Zeolite)	Chemical Additive	PQ Corporation
Aspha-Min (Synthetic Zeolite)	Chemical Additive	Aspha-Min
Double Barrel Green	Foaming Process	Astec Industries, Inc.
Evotherm	Chemical Additive	MeadWestvaco Asphalt Innovations
Redi-Set WMX	Chemical Additive	Akzo Nobel Surfactants
Sasobit	Organic Additive	Sasol Wax Americas, Inc.
Terex	Foaming Process	Terex Roadbuilding
Maxam	Foaming Process	Maxam Equipment
Ultrafoam GX	Foaming Process	Gencor Industries

Return to Index of Appendices

NCAT REPORT 10-01



PRELIMINARY EVALUATION OF WARM MIX ASPHALT FIELD DEMONSTRATION: FRANKLIN, TENNESSEE

FINAL REPORT

By
Andrea Kvasnak
Jason Moore
Adam Taylor
Brian Prowell

June 2010

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

277 Technology Parkway ▪ Auburn, AL 36830

EVALUATION OF WARM MIX ASPHALT FIELD DEMONSTRATION: NASHVILLE, TENNESSEE

FINAL REPORT

By

Andrea Kvasnak
Lead Research Engineer
National Center for Asphalt Technology
Auburn, University, Auburn, Alabama
334-844-7303
ank0004@auburn.edu

Jason Moore
Laboratory Manager
National Center for Asphalt Technology
Auburn, University, Auburn, Alabama

Adam Taylor
Assistant Research Engineer
National Center for Asphalt Technology
Auburn, University, Auburn, Alabama

Brian Prowell
Principal Engineer
Advanced Material Services, LLC
Auburn, Alabama

Sponsored by
FHWA

NCAT Report 10-01

June 2010

DISCLAIMER

ABSTRACT

The Tennessee Department of Transportation hosted a warm mix asphalt (WMA) demonstration. The production and constructability of four WMA technologies was demonstrated. Two control hot mix asphalt (HMA) mixes were also produced. The National Center for Asphalt Technology documented the demonstration and evaluated the mixes produced. The production, construction, and performance of the WMA to HMA were compared. The results of the comparison are detailed in this report.

TABLE OF CONTENTS

INTRODUCTION

The Tennessee Department of Transportation (TDOT) hosted a warm mix asphalt (WMA) field demonstration in October 2007. Four WMA technologies were included in the WMA demonstration. The four technologies were Advera® WMA, Astec Double Barrel Green® (DBG), Evotherm™ Dispersed Asphalt Technology (DAT), and Sasobit®. Two hot mix asphalt (HMA) mixes were produced to compare to the constructability and performance of the WMA technologies. This report summarizes the construction, laboratory performance testing, and one year field evaluations of the mixes produced as part of the WMA field demonstration.

BACKGROUND

WMA is an new technology that allows for the production of asphalt mixes at lower temperatures than traditionally employed for HMA. The production of an asphalt mix at temperatures less than 275°F can result in lower emissions, decreased fuel usage, and reduced oxidation of the asphalt compared to mixes produced at 300°F and above (*1*). The reduced emissions and fuel usage can be environmentally beneficial and reduced fuel usage can be economically beneficial. The question that arises is: Is the performance of the asphalt mix affected by using a WMA technology? If it is adversely affected, then the environmental and economic benefits are negated. If the performance of WMA pavements is as good as or better than HMA then the change in production practices is worthwhile.

The asphalt mix properties that are typically of interest when evaluating a new WMA technology are moisture susceptibility, rutting susceptibility, strength, and stiffness. Moisture susceptibility is of concern since the reduced temperatures may result in incomplete drying of aggregate. Any moisture remaining in or on the aggregate could affect the bond between the asphalt and aggregate, thus leading to premature pavement failure. The reduced mixing temperature of the WMA may also result in a softer asphalt than the same mix produced at HMA temperatures since there is less oxidation of the asphalt. The softer asphalt has raised some concern that WMA may be more prone to rutting and poor tensile strength. However, there may also be benefits to a softer asphalt. One of the benefits of a softer binder is a less stiff mix, which may improve the resistance to fatigue and thermal cracking.

Previous laboratory research (*1-4*) has shown that WMA is often more susceptible to moisture damage and rutting than HMA. The tensile strengths of WMA also tend to be lower than HMA. However, recent field evaluations conducted by NCAT indicate that the tensile strength of WMA increases with time to a similar tensile strength as that of HMA after two years of trafficking. It should also be noted that at these recent field evaluations, there has been no substantial difference in the WMA rutting compared to rutting in control HMA sections and no evidence of moisture damage has been observed (*7* and *8*).

PURPOSE AND SCOPE

The purpose of this study was to evaluate the constructability and performance of WMA. Four WMA technologies were evaluated and compared to two HMAs. Construction information, laboratory performance data, and field performance after one year have been documented in this report.

PROJECT DESCRIPTION

The field project was conducted in Franklin, Tennessee on State Road 46 (SR-46). SR-46 is a two-lane road with mostly automobile traffic. The average daily traffic volume is 10,492. TDOT surveyed the condition of the existing pavement before the overlay was constructed. TABLE 1 summarizes the pavement condition measurements obtained by TDOT. The existing asphalt pavement surface was cracked and crack sealant had been applied in several locations.

TABLE 1 Existing Pavement Condition (courtesy of TDOT)

Beginning Mile	End Mile	Roughness Index (PSI)	IRI	Rut Depth	Distress Index (PDI)	Pavement Quality Index (PQI)
0	1	2.31	146.33	0.15	5	3.97
1	2	2.47	129.9	0.16	5	4.04
2	3	2.91	99.98	0.14	4.88	4.18
3	4	3.11	87.82	0.15	4.97	4.32
4	5	3.03	91.81	0.15	4.97	4.28
5	5.64	2.71	118.87	0.17	4.84	4.07

The construction consisted of a 1.25 inch overlay. Six Marshall mixes were produced for the overlay. There was a mix design for each of plants. Two of the mix designs were the same with the exception that one was approved for the Danley Plant and the other was approved for the Murfeesboro plant. The two HMA mixes were placed first followed by Astec Double Barrel Green (DBG), Advera WMA, Evotherm DAT, and Sasobit mixes. HMA 1 is the same base mix as the Advera WMA and Sasobit mixes and all three were produced at the LoJac Inc. Franklin plant. HMA 2 is the same base mix as the Evotherm DAT and Astec DBG. HMA 2 and Evotherm DAT were produced at the Danley plant and the Astec DBG mix was produced at the Murfeesboro plant.

Construction

Material for all sections was delivered to the site in dump trucks. The mix was then emptied into a materials transfer device (Roadtec® SB-2500D), which transferred material to the hopper of the paver. The breakdown roller was a steelwheel Ingersoll Rand DD130 roller compactor. The intermediate and finishing rollers were also an Ingersoll Rand DD130.

FIGURE 1 Paving Train

The two HMAs were placed prior to the WMA pavement sections on October 1, 2007. The placement of the HMA pavement sections was not observed by NCAT personnel. Notes from the contractor indicated that the HMA mixes were produced at 320°F (based on control tower reading) and there were no problems during construction.

NCAT personnel were on site when the WMA pavement sections were placed. The first WMA section that was placed was the Astec DBG on October 2, 2007. The plant where the Astec DBG was produced in was an Astec Double Barrel plant that used natural gas. The plant was rated for 400 tons per hour; however, the WMA was produced at a rate of 250 tons per hour. Approximately 775 tons of the Astec DBG mix were produced. The target mixing temperature for the Astec DBG mix was 260°F (based on control tower readings). The haul time from the Murfeesboro plant to the site was approximately 45 minutes. The mat temperature at the start of compaction was 230°F. The mix was compacted with three steel-wheel rollers. There were no issues observed during the placement of the mix. The mat temperature was fairly consistent (see FIGURE 2).

FIGURE 2 Thermal Image of Astec DBG Mat (Picture courtesy of Becky Smith)

The second mix placed was Advera WMA and it was produced at the Franklin plant on October 3, 2007. The Franklin plant was an Astec Double Barrel plant that used natural gas. The plant was rated for 350 tons per hour; however, the WMA was produced at 250 tons per hour. Approximately 1150 tons of the Advera WMA mix were produced. The target mixing temperature for the Advera WMA was 250°F (based on control tower reading). The haul time from the Franklin plant to the paving site was approximately 10 minutes. The compaction temperature was 230°F. There were only two rollers compacting the Advera WMA pavement section for the majority of the day due to one roller being removed due to mechanical issues. Other than the reduced number of rollers, there were no issues observed with the placement of the Advera WMA pavement. FIGURE 3 illustrates the consistent temperature of the mat.

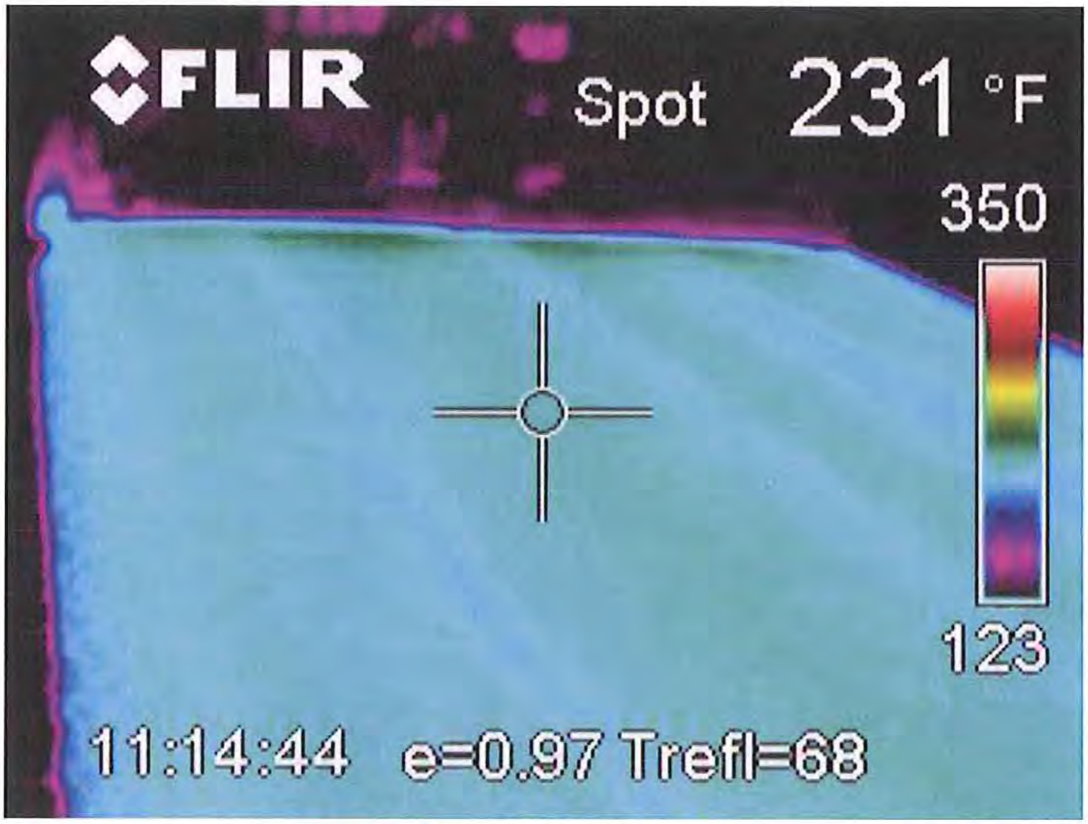


FIGURE 3 Thermal Image of Advera WMA Mat (Picture courtesy of Becky Smith)

On October 4, 2007, the Evotherm DAT was produced from the Danley plant. The Danley plant was an Astec Double Barrel plant that used natural gas. It was rated for 350 tons per hour; however, the WMA was produced at 250 tons per hour. Approximately 750 tons of Evotherm DAT mix were produced. The target mixing temperature for the Evotherm DAT mix was 240°F (based on control tower reading). The haul time from the Danley plant to the site was about 25 minutes. The compaction temperature was 230°F. The Evotherm DAT was placed on top of a section of pavement that exhibited alligator cracking in numerous locations see (FIGURE 4). The Evotherm DAT overlay was compacted with three rollers. There were no observed issues with placing the mix. The mat temperature for the Evotherm DAT mix was consistent (see FIGURE 5).

FIGURE 4 Pavement Distress Under Evotherm DAT Lift

On October 5, 2007 the Sasobit mix was produced at the Franklin plant. Approximately 705 tons of the Sasobit mix were produced. The target mixing temperature of the Sasobit was 250°F (based on control tower reading). The compaction temperature was 230°F. There were two steel wheel rollers compacting the Sasobit mix. There were no observed issues with the placement of the Sasobit mix. The temperature was consistent (see FIGURE 6).

Construction Summary

Six mixes were evaluated in the WMA demonstration conducted in Franklin, Tennessee. Four of the mixes were produced as WMA with production temperatures that ranged between 240 to 260°F. Two mixes were produced as HMA at a production temperature of 320°F.

TABLE 2 lists each mix, production temperature, production facility, aggregate source, and whether or not the material was reheated for laboratory testing.

FIGURE 5 Thermal Image of Evotherm DAT Mat (Picture courtesy of Becky Smith)

FIGURE 6 Thermal Image of Sasobit Mat (Picture courtesy of Becky Smith)

TABLE 2 Materials Summary

	Production Temperature	Production Facility	Aggregate Source	Reheated
		Mix Design 1		
HMA 1	320°F	Franklin	BonAqua, TN limestone	yes
Advera	250°F	Franklin	BonAqua, TN limestone	no
Sasobit	250°F	Franklin	BonAqua, TN limestone	no
		Mix Design 2		
HMA 2	320°F	Danley	Springfield, TN limestone	yes
Evotherm DAT	240°F	Danley	Springfield, TN limestone	no
		Mix Design 3		
Astec DBG	260°F	Murfeesboro	Springfield, TN limestone	no

In-Place Densities

Cores were obtained for each section and densities of the cores were determined by the contractor in accordance with AASHTO T 166. The cores on this project were not randomly selected throughout the length of the pavement, but all obtained within the first 100 ft of each section. Initially, the cores were obtained from the beginning of the pavement sections. However, the initial core densities were poor for all of the WMA sections and a second set of cores were obtained further into each WMA section. FIGURE 7 illustrates the field densities for each set of cores extracted from the pavement. The whiskers represent plus and minus one standard deviation. The first core set for each pavement section consisted of 10 cores. The contractor selected the number of cores obtained for the second set of cores. The number of cores obtained for the second core set ranged between two to ten. Ten cores were obtained for Astec DBG. Five cores were obtained from the Advera WMA. Four cores were obtained for the Evotherm DAT. Two cores were obtained for the Sasobit. The densities increased with the second set of cores. In most cases, with the exception of the Evotherm DAT, the variability also decreased with the second set of cores. The change in densities may be attributed to the paving crew working out the rolling pattern for the day at the beginning of each section or the removal of one roller on the Advera section.

The first set of cores for the WMA sections exhibited densities that were lower than those determined for both HMA sections. In general, the densities of the second set of cores from the WMA sections were similar to the densities of the HMA sections.

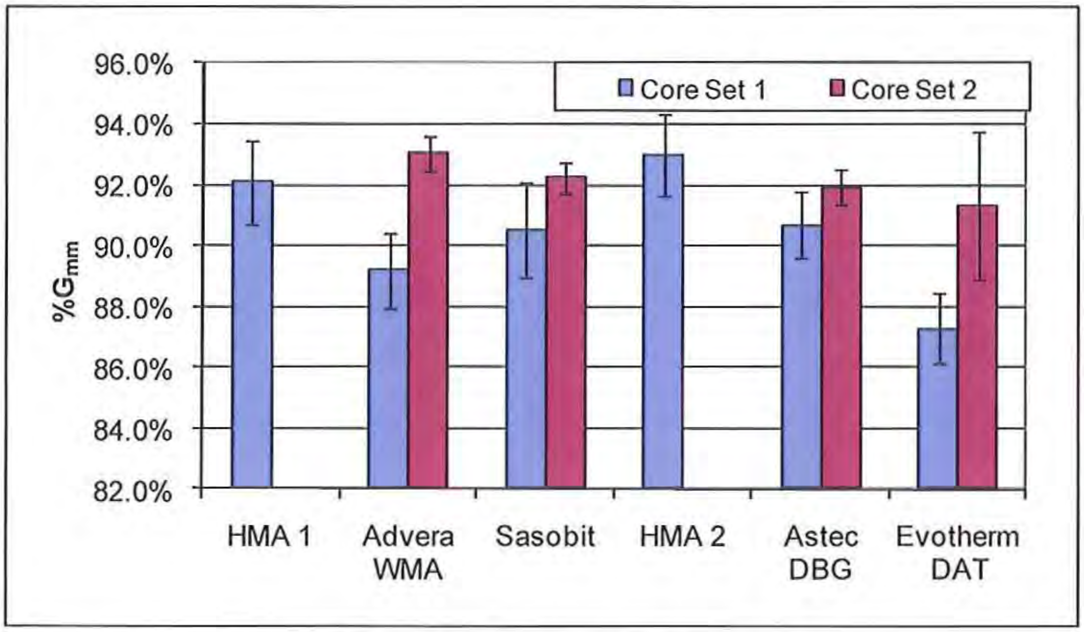


FIGURE 7 Field Densities After Construction

Asphalt Aging

Asphalt binders were extracted and recovered from plant produced mix to evaluate the aging that occurred at the different mix production temperatures. Binders were extracted and recovered in accordance with AASHTO T 319-03 and ASTM D 5404-03, respectively. The recovered binders were graded in accordance with AASHTO R 29-02. TABLE 3 summarizes average binder properties based on two performance grade (PG) classifications per mix. The HMA that corresponds to the Advera WMA and Sasobit is HMA 1. The continuous grade of both the Sasobit and Advera WMA exhibited a high temperature grade softer than HMA 1; however, both had low temperature grades slightly higher than HMA 1. Based on the continuous grade classification, HMA 1 may be less prone to thermal cracking than the Sasobit and Advera WMA mixes. The HMA that corresponds to the Astec DBG and Evotherm DAT is HMA 2. However, it should be noted that the Astec DBG mix was produced in a different plant than HMA 2, which may also have an effect on the asphalt aging. Binders from the Astec DBG and the Evotherm DAT sections exhibited slightly lower high PG temperatures than the binder from HMA 2. The Astec DBG had a slightly lower low temperature grade than HMA 2, which may be an indication that it is more resistant to thermal cracking. The Evotherm DAT had a slightly higher low temperature grade, indicating that it may be less resistant to thermal cracking. Overall, the asphalt binder data indicates that WMA reduces the aging of the binder compared to HMA, however the magnitude of the change depends on the WMA technology, mixing temperature, and possibly plant in which the mix was produced.

TABLE 3 Asphalt Performance Grade After Construction

	HMA 1	Advera	Sasobit	HMA 2	Astec DBG	Evotherm DAT
Continuous Grade	76.2-22.5	70.4-20.9	74.1-22.1	74.2-23.1	73.0-24.0	72.8-22.0
PG Grade	76-22	70-16	70-22	70-22	70-22	70-22

MATERIALS

Three Marshall mix designs were used. All three of the designs were 12.5 mm nominal maximum aggregate size 75 blow Marshall mixes. The SBS modified PG 70-22 asphalt used in all of the mixes was supplied by Ergon Asphalt & Emulsions, Inc.

Murfeesboro Plant

One mix was produced at the LoJac, Inc. Murfeesboro plant. The mix was the Astec Double Barrel Green. Water was injected into the asphalt binder to create a foamed binder. The amount of water injected was 0.1% of the total weight of the mix. The asphalt contained the anti-strip agent Pavegrip 650. The dosage rate of the anti-strip agent was 0.3% by weight of asphalt. The design asphalt content of the mix was 5.3% by weight of the mix. The predominant aggregate of the mix was a limestone from Rinker Materials in Springfield, Tennessee. TABLE 4 summarizes aggregate gradations and asphalt contents of the job mix formula (JMF) and solvent extractions of the plant mix. The mix design can be found in Appendix A. The solvent extraction and recoveries were conducted in accordance with AASHTO T 319-03 and ASTM D 5404-03, respectively. The aggregate gradations of the JMF and Astec DBG mix were similar. The asphalt content of the plant produced mix was 0.5% less than the target asphalt content. The reduced asphalt content may have affected the in-place densities.

TABLE 4 Sieve Analysis of Murfeesboro Plant Mix

Sieve Size		Percent Passing	
English	Metric	JMF	Astec DBG
2"	50	100	100
1 1/2"	37.5	100	100
1"	25	100	100
3/4"	19	100	100
1/2"	12.5	99	98
3/8"	9.5	85	86
#4	4.75	59	57
#8	2.36	46	43
#16	1.18	--	33
#30	0.6	26	24
#50	0.3	10	10
#100	0.15	6	6
#200	0.075	4.0	5.1
Extracted AC Content		5.3	4.8

Franklin Plant

Three mixes were produced at the LoJac, Inc. Franklin Plant. One mix was a HMA and two mixes were WMAs: Advera WMA and Sasobit. The Advera WMA zeolite was added in at 0.3% by weight of the mix by a pneumatic system, which introduced the additive in the outer mixing drum of the plant. The Sasobit prills were added at 1.5% by weight of the asphalt. The same base asphalt was used for all three of the mixes. The asphalt content was 5.3% by weight of the mix. The asphalt contained AD-Here 77-00 as an antistripping agent using a dosage rate of 0.3% by weight of asphalt. The predominant aggregate was a limestone from Bon Aqua, Tennessee. The mix design for the three mixes can be found in Appendix A. The solvent extraction and recoveries were conducted in accordance with AASHTO T 319-03 and ASTM D 5404-03, respectively. TABLE 5 summarizes the aggregate gradations and asphalt contents of the JMF and three plant produced mixes.

TABLE 5 Sieve Analysis for Franklin Plant Mixes

Sieve Size		Percent Passing			
English	Metric	JMF	HMA 1	Advera WMA	Sasobit
2"	50	100	100	100	100
1 1/2"	37.5	100	100	100	100
1"	25	100	100	100	100
3/4"	19	100	100	100	100
1/2"	12.5	98	97	97	98
3/8"	9.5	86	84	85	84
#4	4.75	56	57	58	52
#8	2.36	41	46	42	40
#16	1.18	--	37	32	30
#30	0.6	24	28	24	22
#50	0.3	10	10	10	8
#100	0.15	6	6	6	4
#200	0.075	4.1	4.5	5.2	4.1
Extracted AC Content		5.3	5.2	5.1	4.9

Danley Plant

The Evotherm DAT and the second control mix were produced at the LoJac, Inc. Danley Plant. The same mix design was used for these two mixes as was used at the Murfreesboro plant. TABLE 6 summarizes the aggregate gradations and asphalt contents of the JMF and two plant produced mixes. The gradations for the Evotherm DAT and HMA mixes were similar with the exception of the 9.5, 4.75, and 0.075 mm sieves. The asphalt content of the HMA mix was similar to the JMF asphalt content. The Evotherm DAT mix asphalt content was lower than the JMF and control by 0.4%. The lower asphalt content for the Evotherm DAT was unintentional and may have contributed to the poor field densities.

Mix Testing

Mix testing was conducted for the material sampled. The WMA specimens were compacted in the field without reheating while the HMA specimens were compacted from reheated mix. The mix tests selected evaluated compactability, moisture susceptibility, rutting susceptibility, and low temperature cracking resistance. The following sections describe the testing and results from the mix evaluations.

TABLE 6 Sieve Analysis of Danley Plant Mixes

Sieve Size		Percent Passing		
English	Metric	JMF	HMA 2	Evotherm DAT
2"	50	100	100	100
1 1/2"	37.5	100	100	100
1"	25	100	100	100
3/4"	19	100	100	100.0
1/2"	12.5	99	98	98
3/8"	9.5	85	88	83
#4	4.75	59	60	55
#8	2.36	46	44	43
#16	1.18	--	33	34
#30	0.6	26	24	25
#50	0.3	10	10	10
#100	0.15	6	5	6
#200	0.075	4.0	4.4	5.1
Extracted AC Content		5.3	5.3	4.9

Compactability

The air voids at a constant compaction effort were evaluated. Since Tennessee does not use the gyratory, the design level of gyrations could not be used. A set number of gyrations of 60 was selected for evaluating the difference in compaction. The WMA specimens were compacted hot and the HMA specimens were compacted from reheated mix. FIGURE 8 illustrates the compaction differences of gyratory compacted specimens. The whiskers represent plus and minus one standard deviation. HMA 1 had lower average air voids than both the Advera WMA and Sasobit, which may be partially a result of the difference in asphalt contents.

HMA 2 and the Astec DBG had similar air voids. The Astec DBG had less asphalt than HMA 2; however, it has more fines, which can fill in voids. The Evotherm DAT mix yielded higher air voids than HMA 2, however, the difference was within 0.5%. The lower asphalt content in the Evotherm may have been the primary cause of the higher air void content.

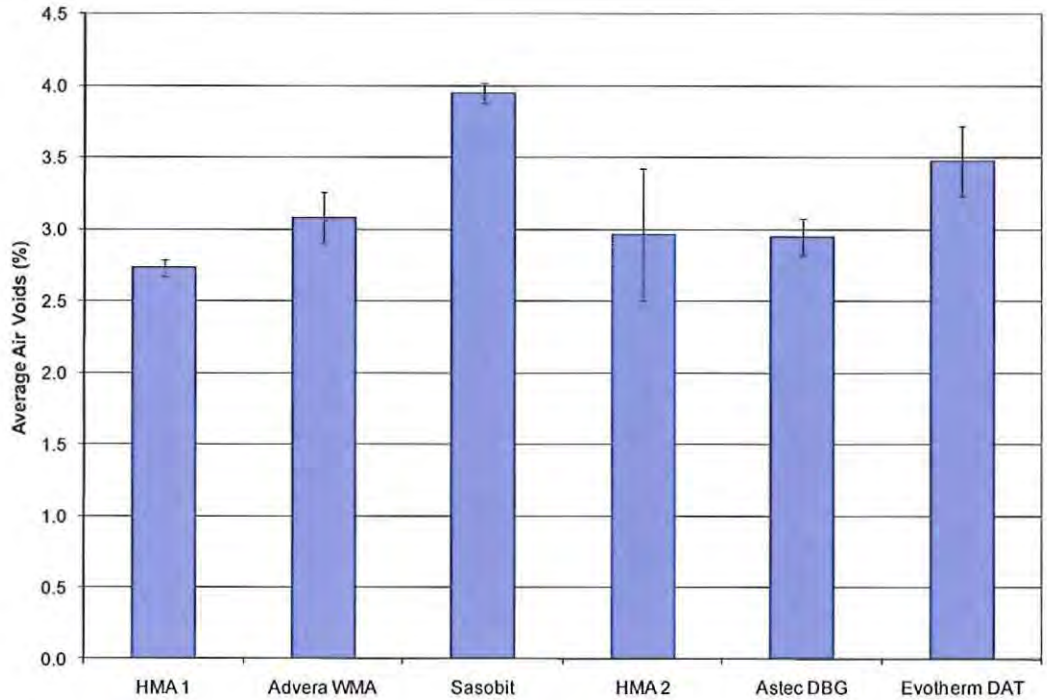


FIGURE 8 Air Voids at a Set Compaction Effort

The air void content trend for laboratory compacted specimens partially coincided with the in-place densities. The HMA in the laboratory and in the field exhibited lower air voids than the WMA sections. The mixes with lower asphalt contents than the HMAs yielded high air void contents in both the field and laboratory.

Moisture Susceptibility

Moisture susceptibility testing was conducted in accordance with ASTM D 4867 without a freeze-thaw cycle. Conditioned specimens were moisture saturated with no freeze-thaw cycle. Specimens were six inches in diameter. The HMA mixes were compacted from reheated mix and the WMA specimens were compacted on site without any reheating. FIGURE 9 illustrates the indirect tensile strength results of the two WMA mixes and the corresponding HMA mix produced at the Franklin plant. The columns represent the average of three indirect tensile strength results. The whiskers represent plus and minus one standard deviation. The red triangles represent the average air voids. The Sasobit and HMA 1 had average dry indirect tensile strengths that were similar. The wet indirect tensile strengths for both of the WMAs were less than 100 psi while the HMA 1 wet indirect tensile strengths was greater than 100 psi. The tensile strength ratio (TSR) for Advera WMA, Sasobit, and HMA 1 were 59%, 45%, and 88%, respectively. The TSR results indicate that the two WMAs produced at the Franklin plant may be prone to moisture damage based on an acceptable TSR of 80%. However, previous research has shown that indirect tensile strength results and TSRs from reheated mix tend to be better than those from mix not reheated prior to compaction; therefore, reheating the WMA for the moisture susceptibility testing could result in improved indirect tensile strength and TSR results.

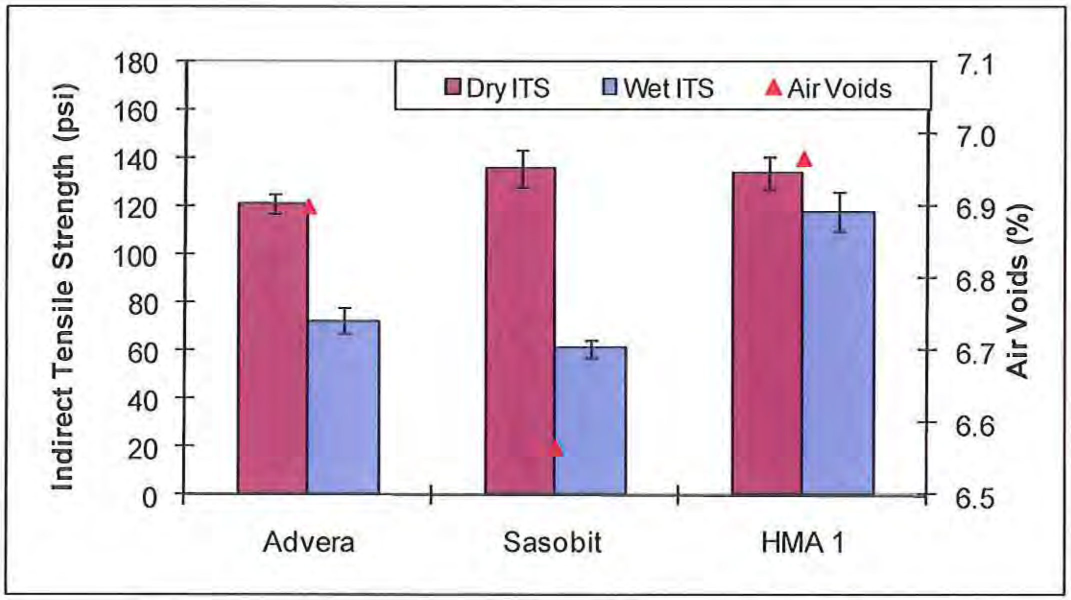


FIGURE 9 Indirect Tensile Strength of Franklin Plant Mixes

FIGURE 10 illustrates the results of the indirect tensile testing of mixes produced at the Danley and Murfeesboro plants. The Astec DBG and Evotherm DAT mixes had similar dry indirect tensile strengths, which were lower than the dry strengths of HMA 2. The wet indirect tensile strengths of HMA 2 were similar to the wet indirect tensile strength of the Astec DBG mix. The TSR values for the Astec DBG, Evotherm DAT, and HMA 2 mixes were 83%, 53%, and 73%, respectively.

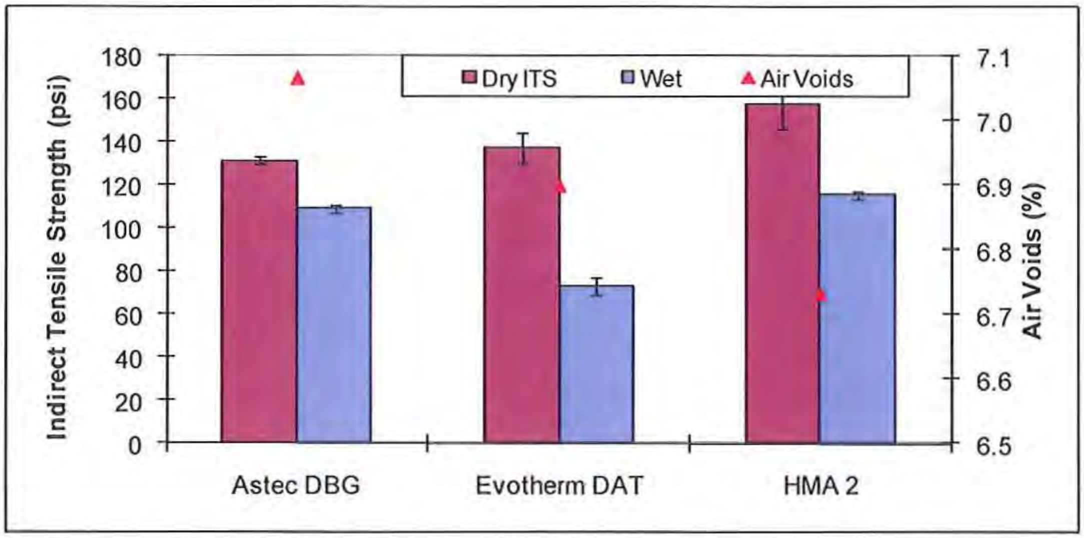


FIGURE 10 Indirect Tensile Strength of Danley and Murfeesboro Plant Mixes

Tukey's studentized range test was used to compare the mean indirect tensile strengths (α=0.05). The data was grouped by unsaturated and saturated. The mean indirect tensile strength comparisons for the unsaturated specimens indicated that there was no significant difference between the corresponding Franklin plant mixes. The dry indirect tensile strengths of HMA 2 were significantly higher than the mean dry indirect tensile strengths of the Astec DBG and Evotherm DAT mixes. The mean comparisons conducted on the mean saturated indirect tensile strengths suggested that HMA 2, and Astec DBG were not statistically different. However, the mean saturated strengths of all other corresponding WMA and HMA mixes indicated that there was a statistical difference between the WMA and HMA saturated strengths.

The moisture susceptibility testing indicated that the mixes with all of the WMA technologies except Astec DBG do not meet the TSR criterion of 0.80. The Astec DBG most likely exhibited better results than the other WMAs because of the higher mixing temperature, which may have allowed for more complete drying of the aggregate. The differences in plants may have affected the moisture susceptibility of the mixes. If the flighting in the Murfeesboro plant resulted in a longer dwell time than the other plants, it could have resulted in drier aggregates.

Hamburg Wheel Track Test

The Hamburg testing was conducted in accordance with AASHTO T 321 "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)". Six inch cylindrical gyratory specimens were compacted to 7±0.5% air voids. Two sets of Hamburg specimens were tested and each set consisted of two specimens. The WMA specimens were compacted on site without reheating. The HMA mixes were reheated and compacted. All sets of specimens were conditioned and tested in a 50°C water bath. The test was run for 10,000 cycles (20,000 passes) or until the specimens failed. The stripping inflection point and total rut depth at 10,000 cycles (20,000 passes) were determined for each set of specimens. Preliminary criteria for the Hamburg stripping inflection point is equal to or greater than 5,000 cycles (10,000 passes), and a total rut depth at 10,000 cycles (20,000 passes) of less than 10 mm. The criteria was established based on a current practice of WMA researchers and DOT agencies.

FIGURE 11 illustrates the average stripping inflection points of the mixes produced at the Franklin plant. Both the Sasobit and HMA 1 exceeded the minimum criterion of 5000 cycles; thus indicating that the Sasobit did not negatively affect the mix. Advera WMA had an average stripping inflection point of 4325 cycles, which did not meet the preliminary criterion. The lower stripping inflection point may be an indication that the Advera negatively affected the mix.

FIGURE 12 depicts the average stripping inflection points for the mixes produced at the Danley and Murfeesboro plants. Both Astec DBG and HMA 2 exhibited stripping inflection points greater than the minimum requirement. The Astec DBG stripping inflection point was lower than the HMA 2 stripping inflection point indicating that either the additional moisture or lower production temperature may have slightly affected the mix. However, the difference may also be an effect of using a different plant. The Evotherm DAT had an average stripping inflection point of 3513 cycles, which did not meet the preliminary criterion. The Evotherm DAT may be more prone to moisture damage than the HMA 2 mix

The Hamburg stripping inflection point results ranked the moisture susceptibility of the mixes differently than the TSR results. The mix containing Sasobit was ranked as the least moisture resistant based on TSR but exhibited a better stripping inflection point than all of the other WMAs and the two HMA mixes. This indicates that the addition of Sasobit should improve the moisture resistance of the mix.

The rutting susceptibility of each mix was also determined from the Hamburg data. FIGURE 13 illustrates the average rut depths for the mixes produced at the Franklin plant. The Advera and HMA 1 both had average rut depths that exceeded the preliminary maximum rut depth criterion of 10 mm. The Sasobit mix had a rut depth that was well below 10 mm. FIGURE 14 depicts the average rut depths at 10,000 cycles for the mixes produced at the Danley and Murfeesboro plants. All three of the mixes exceeded the maximum allowable rut depth of 10 mm. HMA 2 exhibited the greatest rut depth of the three mixes.

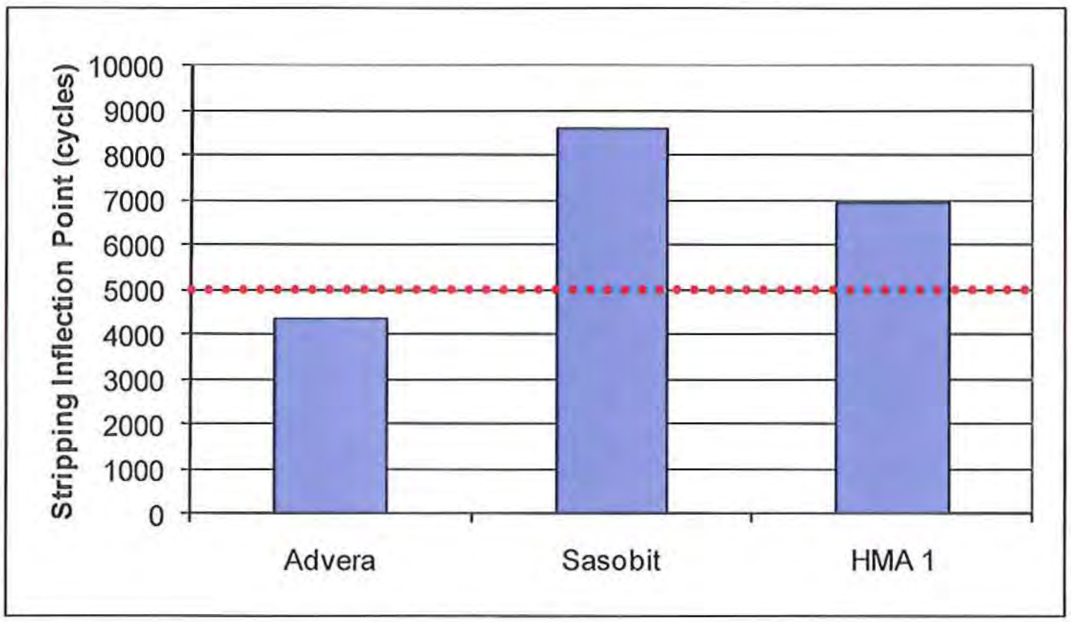


FIGURE 11 Stripping Inflection Points for Franklin Plant Mixes

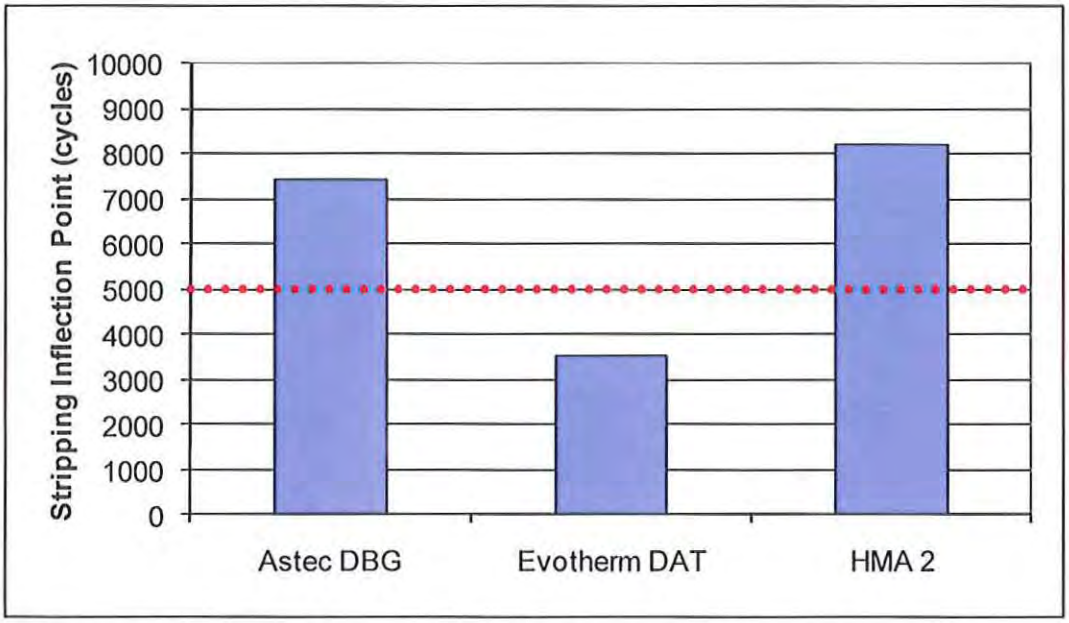


FIGURE 12 Stripping Inflection Points for Danley and Murfeesboro Plant Mixes

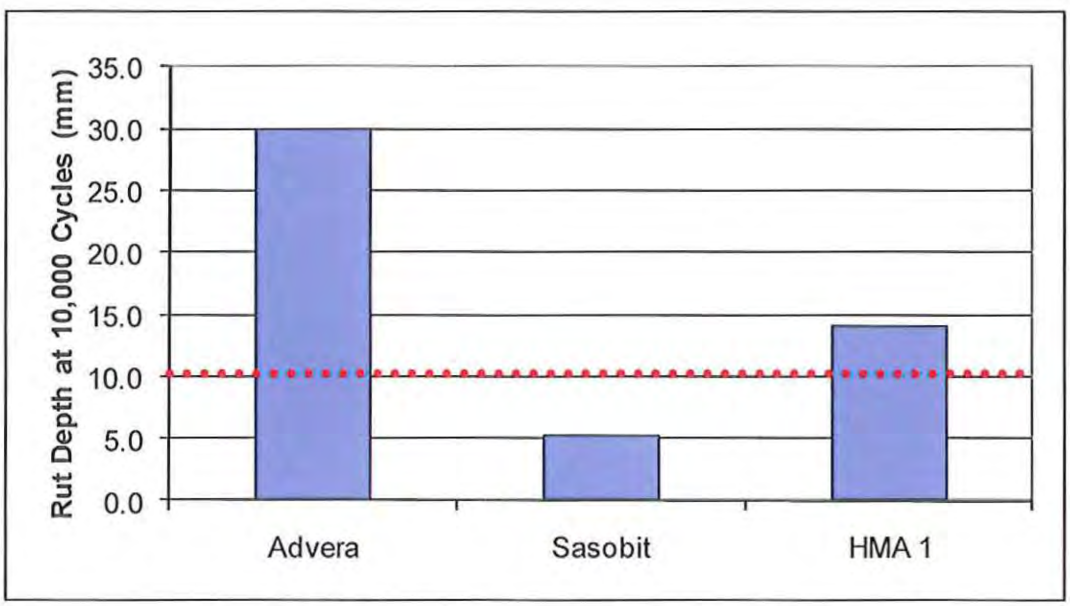


FIGURE 13 Hamburg Rut Depths for Franklin Plan Mixes

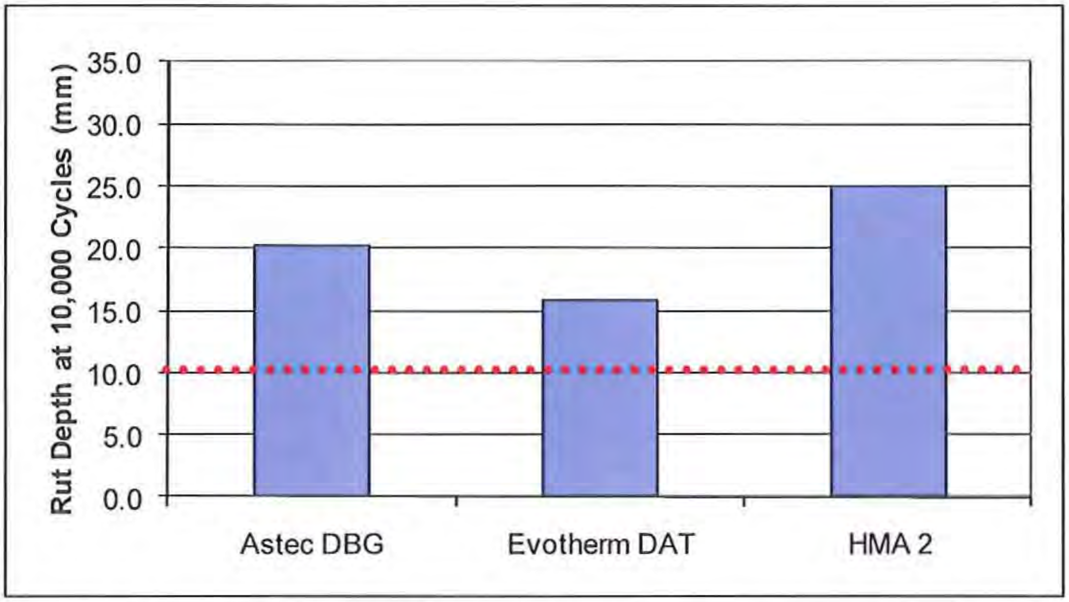


FIGURE 14 Hamburg Rut Depths for Danley and Murfeesboro Plant Mixes

The Hamburg is a severe rutting test. Based on the preliminary criteria of 10 mm, the only one of the six mixes that would have been deemed acceptable was the WMA mix that contained Sasobit. Since both HMA mixes failed to meet the rut depth criterion, it is not considered detrimental that most of the WMA mixes also failed to meet the preliminary criterion. The Advera WMA mix was the only WMA technology that did not perform as well as its corresponding control mix in the rutting test.

Asphalt Pavement Analyzer

The Asphalt Pavement Analyzer (APA) is another loaded wheel-rutting test. APA testing was conducted in accordance with AASHTO TP 63. Six cylindrical specimens per mix were tested in a heated air chamber. The test temperature was 64°C. The WMA APA specimens made on site did not have air voids within the AASHTO TP 63 range of 7±0.5%; therefore, field sampled mixes were reheated and a second set of specimens were compacted to the appropriate air void content. The HMA specimens were also made from reheated mix. Manual rut depth measurements were used in this report.

FIGURE 15 depicts the average rut depth measurements for the mixes produced at the Franklin plant. The dashed red line indicates a maximum allowable rut depth criterion of 8 mm. The HMA 1 mix exhibited an unaccepted average rut depth. The

Advera WMA mix exhibited an average rut depth that passed; however, there were samples that did not meet the criterion. The Sasobit mix had an average rut depth that was acceptable, which is similar to the results from the Hamburg testing. FIGURE 16 depicts the average APA rut depth results for the mixes produced at the Danley and Murfeesboro plants. Both the Evotherm DAT and HMA 2 barely met the maximum allowable rut depth of 8 mm. The Astec DBG exhibited an average rut depth of less than 8 mm.

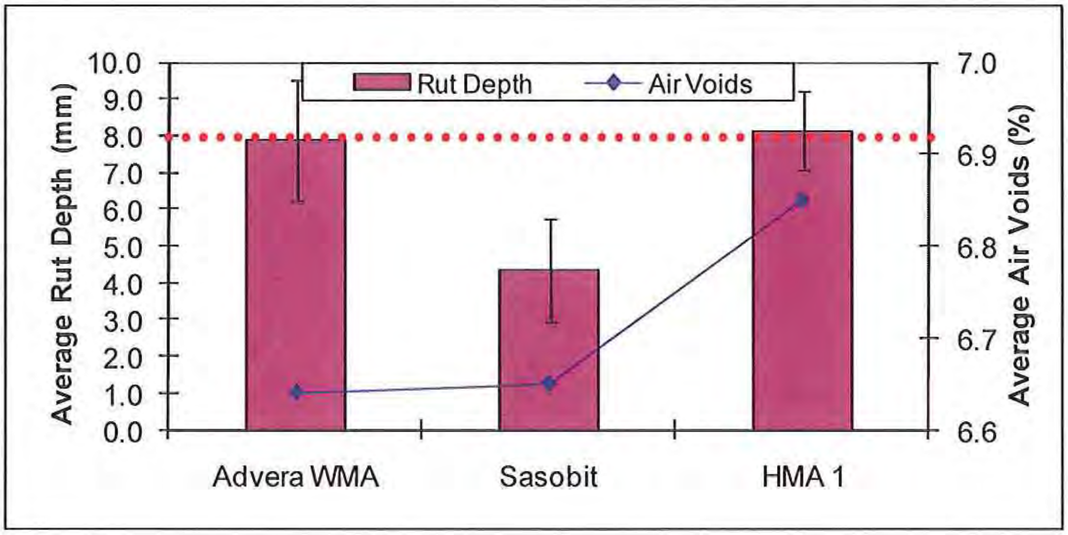


FIGURE 15 APA Rut Depths for Franklin Plant Mixes

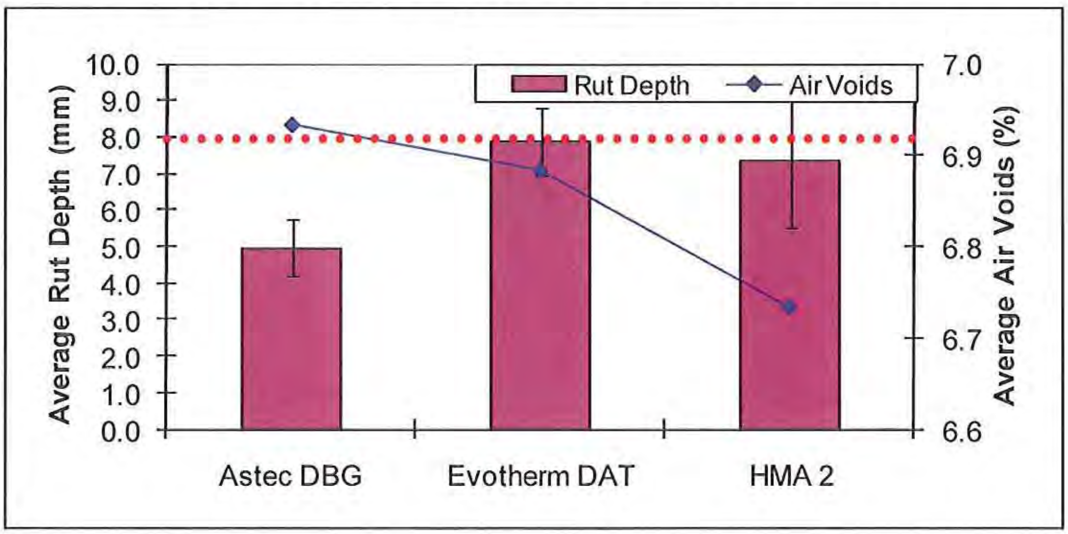


FIGURE 16 APA Rut Depths for Danley and Murfeesboro Plant Mixes

Tukey's studentized range was used to statistically compare the mean rut depths. TABLE 7 summarizes the results of the mean comparisons. If there was no significant difference between two mixes, then NS was entered into the corresponding cell. If there was a significant difference, then SD was entered. The mean rut depth of the Advera WMA was not significantly different than the mean rut depth of HMA 1. The mean Sasobit rut depth was significantly lower than the mean HMA 1 rut depth, indicating that the Sasobit mix may be less prone to rutting. The mean rut depth of the Astec DBG mix was significantly lower than the mean rut depth of HMA 2, indicating that using the WMA technology may result in improved rutting resistance. The mean rut depth of the Evotherm DAT mix was not found to be significantly different than the mean rut depth of HMA 2. It should be noted that in all cases, the WMA technology either resulted in improved or equal rutting resistance based on the APA results.

TABLE 7 APA Mean Comaprison Results

Mix	HMA 1	HMA 2
Advera WMA	NS	
Sasobit	SD	
Astec DBG		SD
Evotherm DAT		NS

Dynamic Modulus Testing

Dynamic modulus testing was conducted in accordance with AASHTO TP 62 to evaluate the stiffness of the WMA mixes compared to HMA. The test is run at multiple temperatures and frequencies, shown in TABLE 8, within the elastic response range of a mix. Tall cylindrical specimens were tested and were confined for this evaluation. The confining pressure was 138 kPa (20 psi). Three specimens per mix were tested. All specimens were compacted from reheated mix.

TABLE 8 Frequencies and Temperatures for Dynamic Modulus Testing

Frequency, Hz	Temperatures, °C
25	4.4
10	21.1
5	37.8
1	54.4
0.5	
0.1	

The data from the dynamic modulus test was used to construct a master curve for each mix, which relates a material's stiffness over a range of frequencies. Master curves were developed to compare the response of the HMA to that of the WMAs. Master curves are developed by shifting dynamic modulus test results from different testing temperatures and frequencies to form one continuous curve. A reference temperature of 21.1°C was employed to build the master curves. The data towards the -4.0 Hz log frequency region of the master curves was obtained from the high test temperatures; therefore, the first set of data points on each curve originate from the test results obtained at the 54.4°C test temperature. The lowest test temperature results, 4.4°C, are located along the x-axis around 2.0 Hz log frequency. Master curves and the shift factors used to create the master curves yield information about the loading and temperature dependency, respectively, of the material (*6*).

FIGURE 17 illustrates the dynamic modulus master curves for the Franklin plant mixes using on a reference temperature of 21.1°C. The stiffest mix was HMA 1 and the least stiff mix was the Sasobit mix. FIGURE 18 illustrates the master curves for the mixes produced at the Danley and Murfeesboro plants. For this set of mixes, HMA 2 was the stiffest and Astec DBG was the least stiff. However, the difference in stiffness between these three mixes was much less than that observed with the Franklin plant mixes. Overall, both HMAs were stiffer than their respective WMAs, thus indicating that WMAs tend to result in less stiff mixes regardless of technology type.

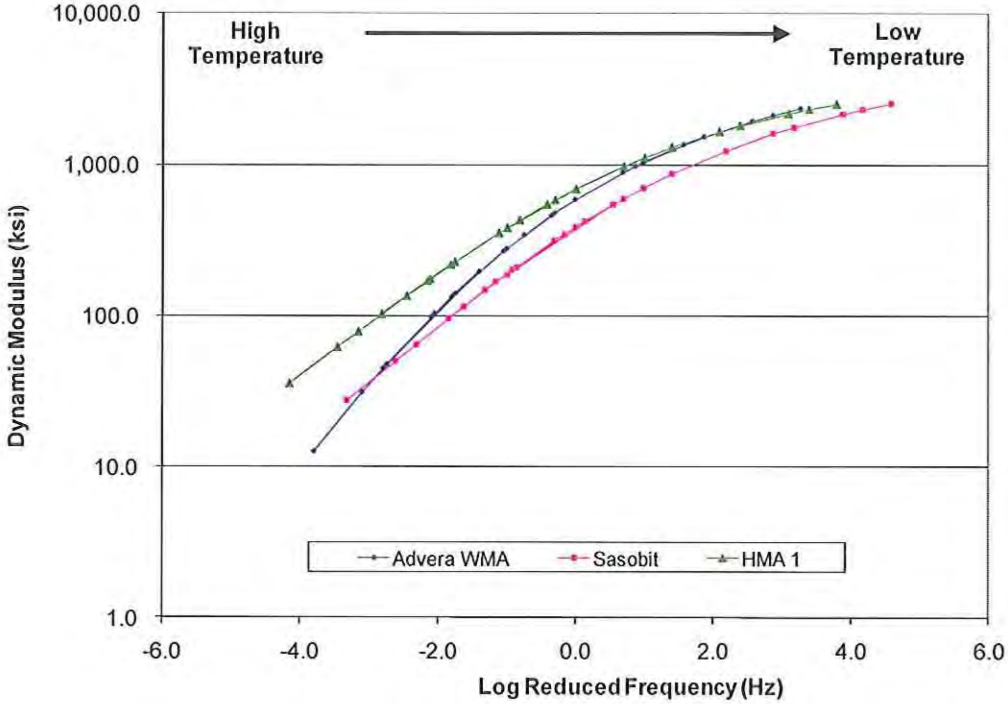


FIGURE 17 Dynamic Modulus for Franklin Plant Mixes

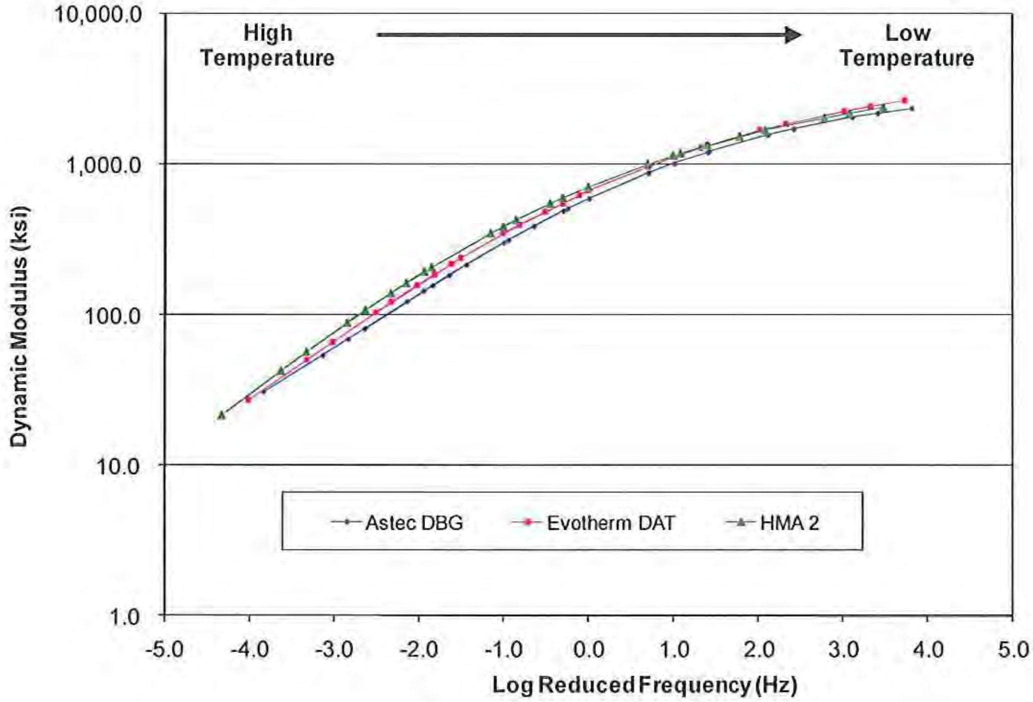


FIGURE 18 Dynamic Modulus for Danley and Murfeesboro Plant Mixes

The shift factors used to develop the master curves are affected by the response of a mix to changes in test temperatures. A large shift factor number indicates that a mix is sensitive to changes in temperature, while a small shift factor indicates that a mix less sensitive to changes in temperatures. FIGURE 19 illustrates the shift factors for the mixes produced at the Franklin plant. The two WMAs have similar shift factors and those shift factors tend to be smaller than the ones for HMA 1. The shift factor analysis indicates that HMA 1 is more temperature dependent than the two Franklin plant WMAs. FIGURE 20 illustrates the shift factors for the Danley and Murfeesboro plants. HMA 2 tends to be less temperature dependent at the low temperatures than the WMAs but more temperature dependent at the high test temperatures. Overall, the two HMAs tend to be slightly more temperature dependent at the high temperatures than the WMAs.

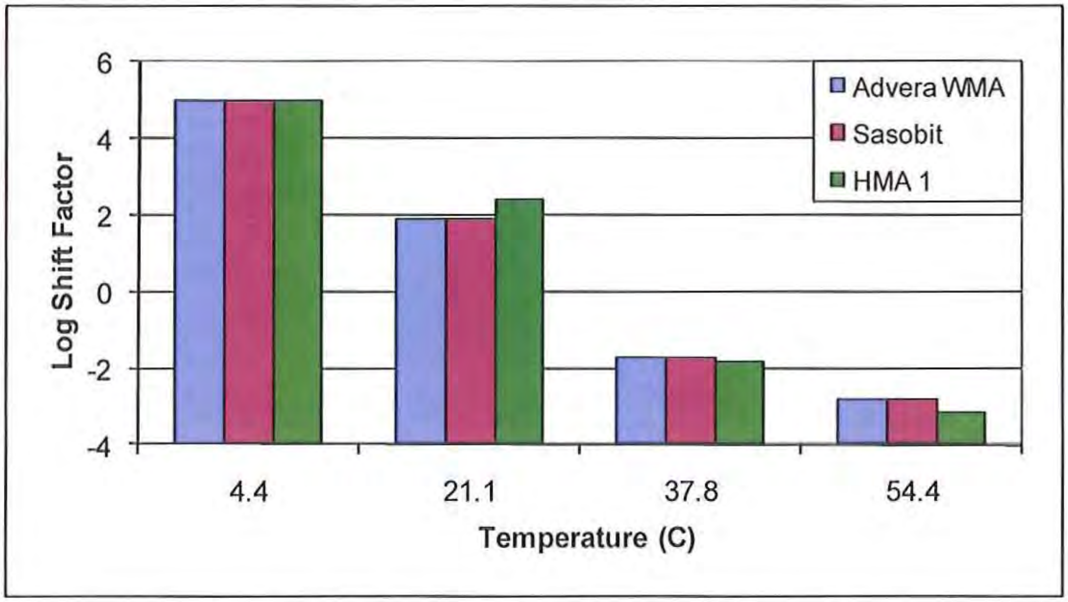


FIGURE 19 Log Shift Factors for Franklin Plant Mixes

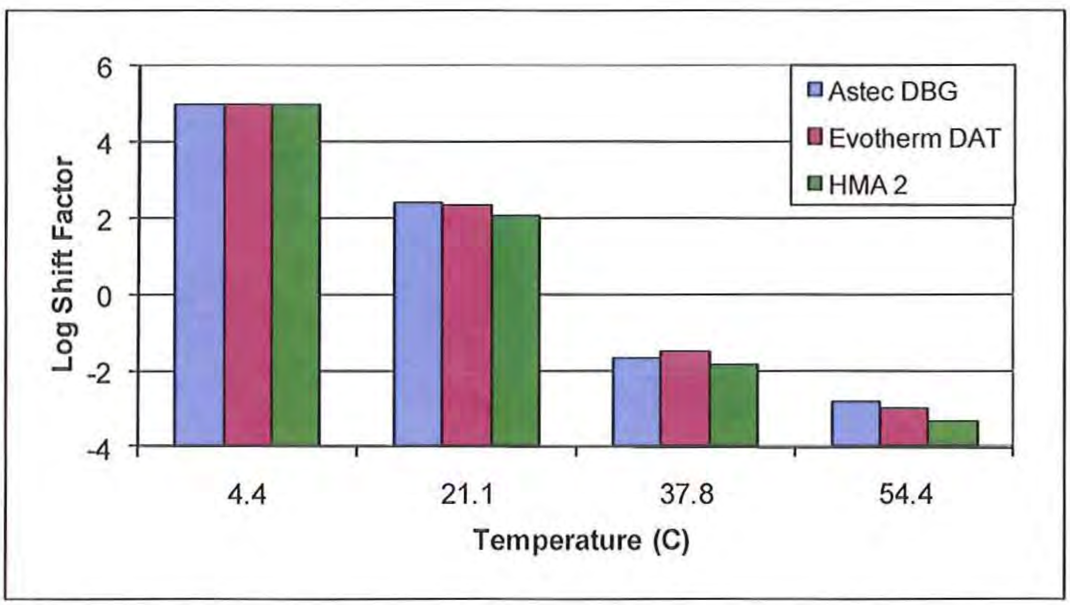


FIGURE 20 Log Shift Factors for Danley and Murfeesboro Plant Mixes

Indirect Tensile Creep Compliance

Indirect tensile creep compliance testing was conducted in accordance with AASHTO T 322. Comparisons of indirect tensile creep compliance testing can indicate if using a

WMA technology may improve resistance to thermal cracking. It has been hypothesized that the lower mixing temperatures used for WMA will reduce low temperature cracking during the early stages of a pavements life since the asphalt will be less oxidized compared to HMA. FIGURE 21 illustrates the creep compliance results for the mixes produced at the Franklin plant. HMA 1 has the greatest compliance value at -20 and 0°C indicating that it is more compliant than the two WMAs. The Sasobit WMA mix had the lowest compliance of the three Franklin mixes at -10 and 0°C, indicating that it may be more prone to thermal cracking than HMA 1. The creep compliance results indicate that the Advera WMA and Sasobit may affect the dissipation of thermal stresses since the two mixes yielded creep compliance results that are lower than HMA 1 results. At -10 and 0°C the Advera WMA and Sasobit were less compliant indicating that both may be more prone to low temperature distresses.

FIGURE 22 depicts the creep compliance results for the mixes produced at the Danley and Murfeesboro plants. The Astec DBG and Evotherm DAT mixes were more compliant than HMA 2 at -10 and 0°C. HMA 2 is the most compliant at -20°C. However, the differences at -20°C are relatively small. The creep compliance results indicate that the Astec foaming process and Evotherm DAT positively affect the dissipation of thermal stresses. The lower mixing temperatures of the Astec DBG and Evotherm DAT may have improved thermal cracking performance of the mixes. The benefits of the lower mixing temperatures may not have been realized for Sasobit and Advera WMA because of the nature of the additives, which tend to stiffen the lower grade of an asphalt.

The method of processing the data by combining the results of three samples to calculate the creep compliance prevents the usage of a statistical analysis to compare differences between the mixes.

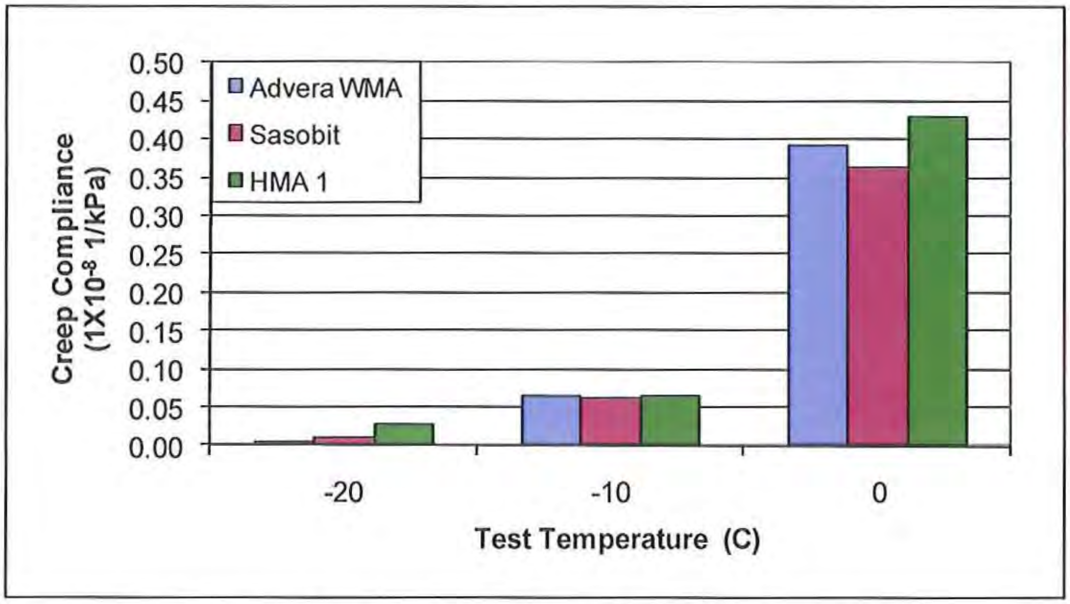


FIGURE 21 Creep Compliance of Franklin Plant Mixes

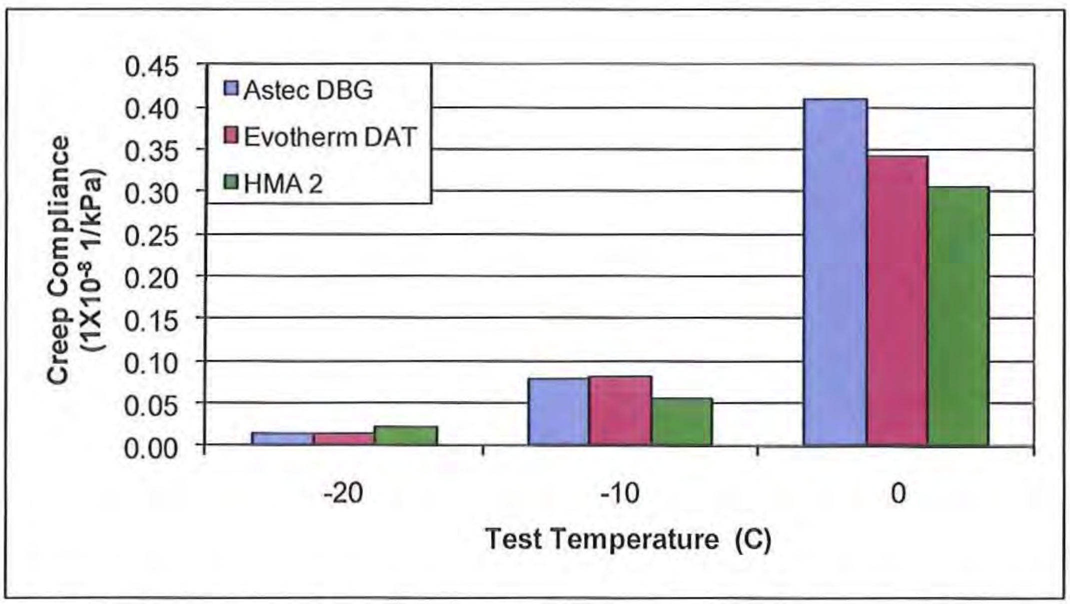


FIGURE 22 Creep Compliance of Danley and Murfeesboro Plant Mixes

One Year Evaluation

In November 2008, visual inspections of the pavement sections were conducted. Asphalt pooling on the surface in the shape of small circular spots (most approximately the size of a half dollar) was observed in both HMA sections (see FIGURE 23 and FIGURE 24) and in the Advera WMA section (FIGURE 25). HMA 1 and HMA 2 sections exhibited raveling along with asphalt and fines surfacing. Raveling was observed around the centerline of both the Astec DBG and Evotherm DAT mixes. Sasobit exhibited less raveling than the Astec DBG and Evotherm DAT section. The Advera WMA section exhibited the most severe raveling, which appeared to be worse under the tree coverage.

FIGURE 23 HMA 2 Pavement Condition

FIGURE 24 HMA 1 Pavement Condition

FIGURE 25 Advera Pavement Condition

For each section, three cores were obtained in the wheelpath and one core was obtained from between the wheelpaths. Two additional cores were obtained for the Advera WMA section because two of the original cores broke apart leaving a core that was too thin to test. The removal of the cores from the Advera WMA section indicated that there may be issues with the section since the underlying material tended to crumble in some sections. The material in the core hole was granular and broke apart easily. The densities of the cores were determined (see FIGURE 26). The error bars represent plus and minus one standard deviation. In four of the six cases, the between wheelpath densities were greater than the average within wheelpath densities. In the majority of these cases, the between wheelpaths density falls within the range of densities determined for the within wheelpath densities.

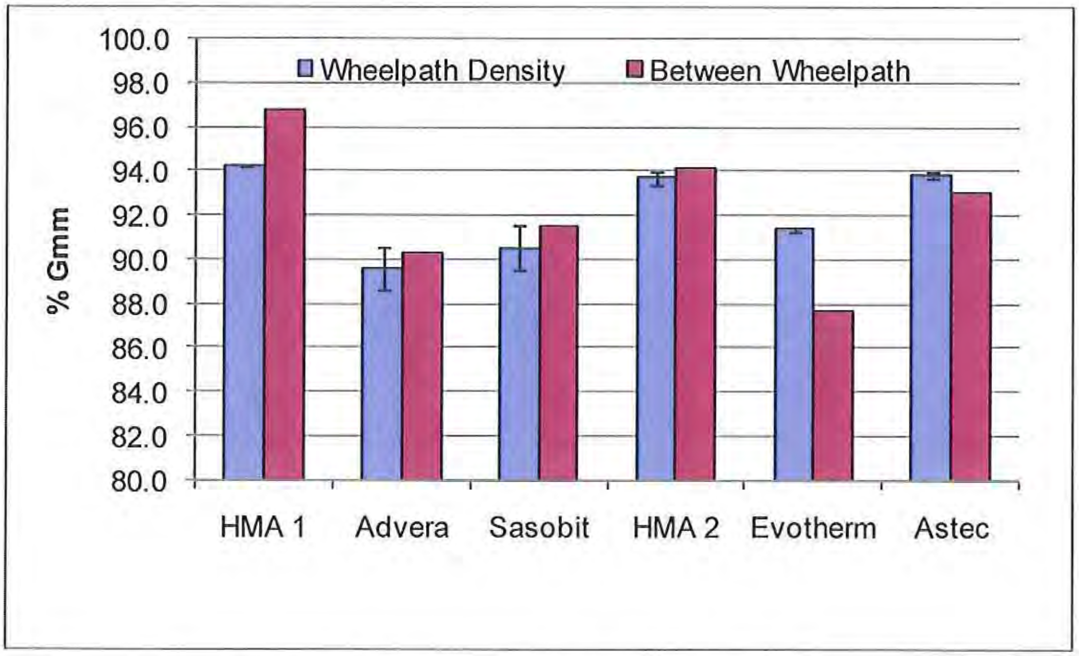


FIGURE 26 Densities After One Year of Trafficking

FIGURE 27 illustrates the average indirect tensile strengths and air void content for the mixes produced at the Franklin plant. The HMA 1 mix exhibited the lowest air void content and highest indirect tensile strength. FIGURE 28 illustrates the average indirect tensile strength and air void content of the cores from sections from the Danley and Murfeesboro plants. The HMA 2 mix exhibited the highest indirect tensile strength. The air void content of the Astec DBG and HMA 2 were similar. The Astec DBG mix exhibited high variability in the indirect tensile strengths. The cores from the Evotherm DAT section exhibited the least amount of variability in terms of indirect tensile strength. Overall, the two HMAs are exhibiting higher indirect tensile strengths than the WMAs after one year and appear to have compacted more than the WMAs. It should be noted that the cores with low indirect tensile strengths often had substantially higher air void contents than the HMA cores.

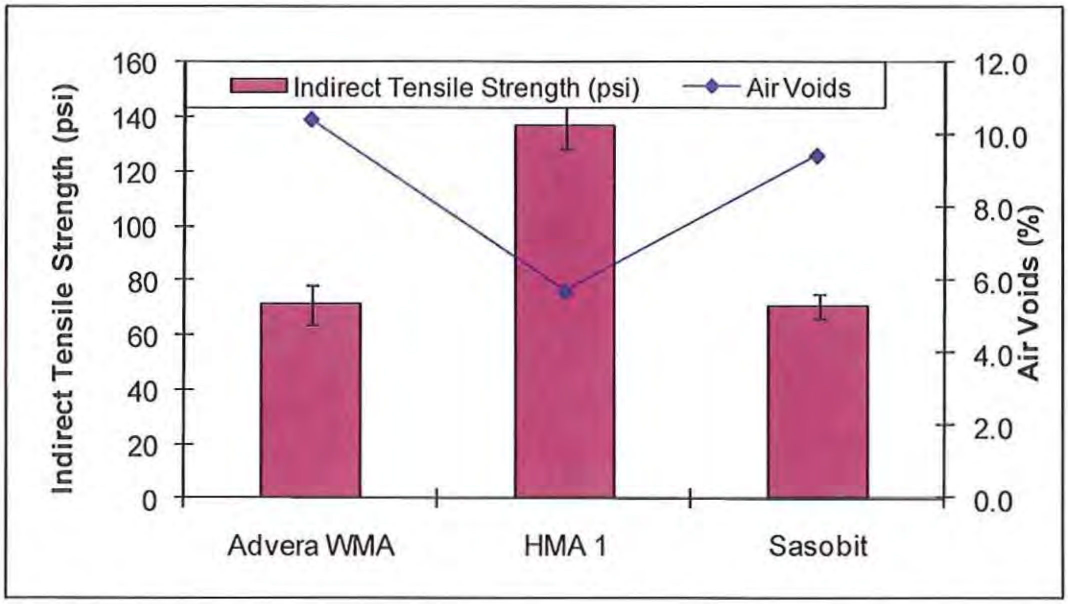


FIGURE 27 Indirect Tensile Strength of Wheelpath Cores for Franklin Plant Mixes

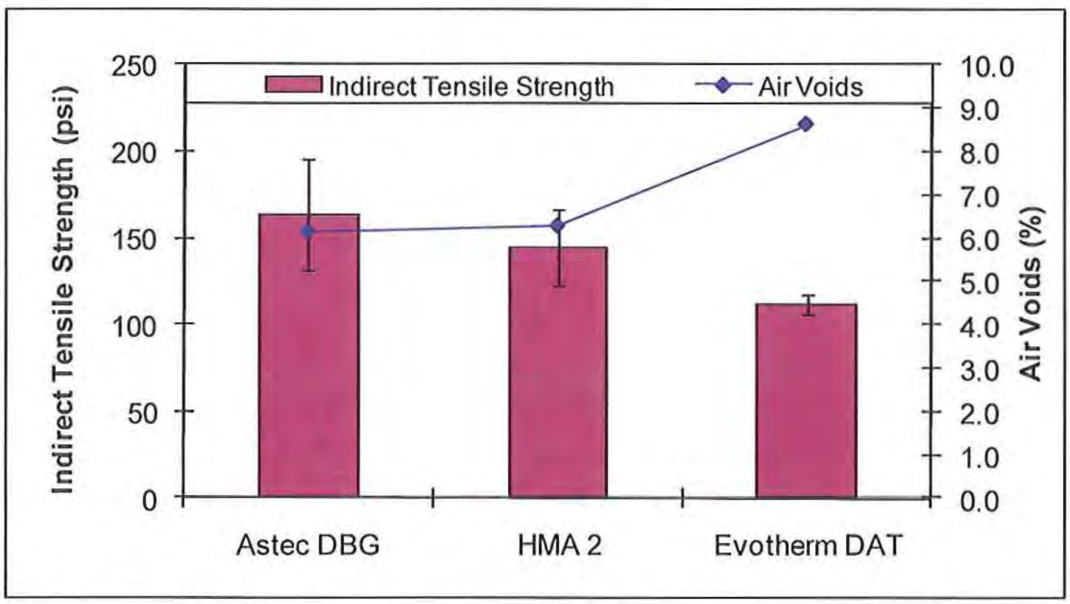


FIGURE 28 Indirect Tensile Strength of Wheelpath Cores for Danley and Murfeesboro Plant Mixes

Tukey's studentized range was used to statistically compare the mean indirect tensile strengths of the field cores. TABLE 9 summarizes the mean comparisons. The Advera WMA and Sasobit mixes were significantly different than the HMA 1 results.

Both mixes exhibited significantly lower tensile strengths. The differences in indirect strength between HMA 2 and Astec DBG and Evotherm DAT were not statistically significant.

TABLE 9 Mean Comparison Results of Field Core Indirect Tensile Strengths

Mix	HMA 1	HMA 2
Advera WMA	SD	
Sasobit	SD	
Astec DBG		NS
Evotherm DAT		NS

SD = Significant Difference; NS=Not Significantly Different

After the cores were tested, solvent extractions and recoveries were conducted. TABLE 10 lists the sieve analysis results for the Franklin plant produced mixes. There were slight differences between the three mixes, but overall the gradations were similar. TABLE 11 lists the sieve analysis results for the mixes produced at Danley and Murfeesboro plants. Overall the aggregate gradations are similar.

TABLE 10 Sieve Analysis of Cores from Franklin Plant Mixes

Sieve Size		After 1-Year			After Construction		
std.	metric	HMA 1	Advera	Sasobit	HMA 1	Advera	Sasobit
3/4"	19.0	100	100	100	100	100	100
1/2"	12.5	96	98	99	97	97	98
3/8"	9.5	84	83	86	84	85	84
#4	4.75	54	54	55	57	58	52
#8	2.36	40	40	42	46	42	40
#16	1.18	32	32	33	37	32	30
#30	0.600	23	25	25	28	24	22
#50	0.300	11	11	10	10	10	8
#100	0.150	10	7	6	6	6	4
#200	0.075	5.4	5.4	5	4.5	5.2	4.1
Asphalt Content		4.9	5.3	4.9	4.9	5.2	5.1

TABLE 11 Sieve Analysis of Cores from Danley and Murfeesboro Plant Mixes

Sieve Size		After 1-Year			After Construction		
std.	metric	HMA 2	Astec DBG	Evotherm DAT	HMA 2	Astec DBG	Evotherm DAT
3/4"	19	100	100	100	100	100	100
1/2"	12.5	98	99	98	98	98	98
3/8"	9.5	88	91	89	88	86	83
#4	4.75	59	63	62	60	57	55
#8	2.36	47	48	47	44	43	43
#16	1.18	38	36	36	33	33	34
#30	0.6	29	26	26	24	24	25
#50	0.3	11	12	11	10	10	10
#100	0.15	6	8	7	5	6	6
#200	0.075	4.8	6.3	5.2	4.4	5.1	5.1
Asphalt Content		5.4	5.1	4.7	5.3	4.8	4.9

The asphalt contents were also determined for the cores. The asphalt content of the Franklin plant mixes; Advera WMA, Sasobit, and HMA 1 were 4.92, 4.87, and 5.31, respectively. The higher asphalt content of the HMA 1 mix may account partially for its higher indirect tensile strengths. The asphalt contents for Astec DBG, Evotherm DAT, and HMA 2 were 5.07, 4.68, and 5.41, respectively. Once again the asphalt content of the HMA was higher than that of the WMAs. The difference in asphalt content between the Evotherm DAT and HMA 2 mixes was 0.73%, which is a significant difference and could partially explain the difference in indirect tensile strength results.

The recovered asphalt binders were classified. The extraction and recoveries from the cores did not yield enough asphalt to classify both the high and low performance grade; therefore, only the high performance grade was classified. TABLE 12 lists the continuous high grade and the high performance grade for the Franklin plant mixes. The binder from the Sasobit mix exhibited the highest temperature grade and HMA 1 mix had the lowest. TABLE 13 lists the results of the binder testing for the Danley and Murfeesboro plant mixes. Astec DBG exhibited the lowest high temperature grade and Evotherm DAT exhibited the highest. Differences between binder grades of HMA and WMA observed at the time of construction does not appear to be permanent. Field aging of the WMA mixes appears to erase the reduced aging of WMA during production.

Additional cores will be obtained at the two year revisit to evaluate if the aging trend continues or slows.

TABLE 12 Recovered Asphalt High PG after One Year for Franklin Plant Mixes

Mix	High True Grade	High PG
Advera WMA	77.4	76
HMA 1	75.6	70
Sasobit	82	82

TABLE 13 Recovered Asphalt High PG after One Year for Danley and Murfeesboro Plant Mixes

Mix	High True Grade	High PG
Astec DBG	70.1	70
HMA 2	76.6	76
Evotherm DAT	79.6	76

CONCLUSIONS

Six field test sections were produced as part of a TDOT demonstration project for WMA technologies. Four sections with different WMA technologies and two sections with HMA mixes were produced, tested, and evaluated. The production, constructability, and performance of the mixes were documented. The following observations were made concerning the mixes produced:

- No problems were encountered during production of any of the WMA mixes.
- There were no observed issues with placing the WMAs. Initial core density results indicated that the WMAs did not meet the target density. A second set of cores were obtained that marginally met the density requirement.
- Results of solvent extractions indicate that WMA mixes with Sasobit and Evotherm DAT had 0.4% less asphalt than required by the JMF. This reduction in asphalt may affect the performance of those two mixes. The other four mixes contained the appropriate amount of asphalt.

- Recovered asphalt grading indicates that the asphalt does not age to the same extent during WMA production as it does during HMA production. The WMAs overall were less stiff than the HMAs because of the reduced oxidation. The difference in continuous grades was dependent upon the mixing temperature and WMA technology.
- Moisture susceptibility testing using the modified Lottman test indicated that WMAs may be more prone to moisture damage than the HMAs. However, the reheating of the HMA may have improved the HMA results in comparison to the WMA which was not reheated.
- Hamburg testing indicated that all of the mixes except Advera and Evotherm WMA mixes are moisture resistant. The results of the Hamburg testing contradict the results of the modified Lottman testing. Therefore, the test section will be monitored to determine which test appropriately ranks the moisture damage resistance mixes. Reheating of the HMA may have resulted in better HMA results than if the mix had been compacted on site.
- Results of the Hamburg rut depths indicate that only the Sasobit mix was able to meet the preliminary rutting criterion, indicating that Sasobit improved the rutting resistance of the mix. The other WMA technologies did not result in increased rutting resistance compared to their respective HMAs.
- Results of the APA indicate that two mixes, Sasobit and Astec DBG, of the six mixes are the most rut resistant. HMA 1 failed the rut criterion, while the associated WMA technologies, Advera and Sasobit, passed the average rut depth criterion. The Advera did not significantly improve the rutting resistance of the mix. The addition of Sasobit, however, did improve the rutting resistance of the mix. HMA 2 passed the APA criterion. The Evotherm DAT appeared to negatively affect the rutting resistance while Astec DBG improved the rutting resistance. However, the differences in plants may partially explain the differences observed in the mixes.
- Dynamic modulus testing indicated that the two HMAs were stiffer than the four WMAs. The initial stiffness of the mixes was most likely affected by the oxidation of the asphalt during production.

- Creep compliance testing indicated that two of the WMAs were less compliant than the associated HMA and this may be due to the affect of the additive on the mix. The other two WMA were more compliant than the associated HMA indicating that in those two cases the reduced oxidation of the binder may improve the dissipation of thermal stresses.
- One year field evaluations revealed asphalt bleeding and raveling in the two HMA sections and the Advera WMA section. It should be noted that the WMA sections did not appear darker than the HMA.
- Cores obtained at the one-year evaluations indicated that the HMAs had higher indirect tensile strengths than the WMAs. The indirect tensile strengths of the WMAs were still low after one year. The in-place densities of many of the WMAs were also lower.
- Absorption was also evaluated and the WMAs did not appear negatively affect the absorption process.
- Tests on the recovered asphalt from the one year cores indicated that the WMA aged more rapidly than the HMA during the first year.

Overall, the production of the WMA was comparable to that of HMA. The construction of the WMA sections could have been improved with establishing a rolling pattern for each mix. The WMA process does reduce the oxidation of the asphalt; however, the difference in aging does not appear to be maintained. The WMA appears to age more rapidly than the HMA initially. The laboratory test results of the WMA mixes indicates that moisture susceptibility and rutting may be an issue for some of the WMA technologies.

ACKNOWLEDGEMENTS

The authors would like to thank FHWA for sponsoring this research. The cooperation of both LoJac, Inc. and the Tennessee Department of Transportation is also much appreciated by the authors.

REFERENCES

1. D'Angelo, J., E. Harm, J. Bartoszek, G. Baumgardner, M. Corrigan, J. Cowsert, T. Harman, M. Jamshidi, W. Jones, D. Newcomb, B. Prowell, R. Sines and B. Yeaton. *Warm Mix Asphalt: European Practice*. United States Department of Transportation and Federal Highway Administration. Report No. FHWA-PL-08-007. 2008.
2. G. C. Hurley and B. D. Prowell, "Evaluation of Evotherm for use in Warm Mix Asphalt", NCAT Report 06-02 (2006).
3. G. C. Hurley and B. D. Prowell, "Evaluation of Sasobit for use in Warm Mix Asphalt", NCAT Report 05-06 (2005).
4. G. C. Hurley and B. D. Prowell, "Evaluation of Aspha-Min Zeolite for use in Warm Mix Asphalt", NCAT Report 05-04 (2005).
5. G. C. Hurley, "Evaluation of New Technologies for Use in Warm Mix Asphalt", MS Thesis Auburn University (2006).
6. R. Bonaquist and D.W. Christensen, "Practical Procedure for Developing Dynamic Modulus Master Curves for Pavement Structural Design", Transportation Research Record No. 1929, pp. 208-217, (2005).
7. Hurley, G., Prowell, B., and A. Kvasnak. *Missouri Field Trial of Warm Mix Asphalt Technologies: Construction Summary*. Unpublished. Auburn, Al, 2009.
8. Hurley, G., Prowell, B., and A. Kvasnak. Michigan *Field Trial of Warm Mix Asphalt Technologies: Construction Summary*. Unpublished. Auburn, Al, 2009.

APPENDIX A: MIX DESIGNS

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V8.0

L-13, L-20

Project Ref. No.		**Date**	09/04/2007
Project No.	14019-4203-04	**Region**	3
Contract No.	CNF172	**County**	Williamson
Contractor	LoJac Ent	**Date of Letting**	06/01/07
State Route No.	SR 46	**Roadway Surface**	Yes
Hot-mix Producer	LOJAC, INC., MURFREESBORO PLANT		

Type ACS-HM **Mix** 411-D PG 70-22 **Item** 411-02.10

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate	Rinker Springfield,TN	47.350
#10 (Soft)	Screenings	Vulcan Danley Antioch,TN	9.470
Natural Sand	Natural Sand	Ingram Mtls Nashville,TN	23.675
#10 (Soft)	Washed Screenings	Vulcan Danley Antioch,TN	14.205
Asphalt Cement	PG 70-22	ERGON ASPHALT CO., NASHVILLE TERMINAL	5.300

Percent AC in RAP:		**Optimum AC Content:**		5.3		**Total**	100.000
Anti-Strip Additive:			Pavegrip 650		**Dosage:**		0.3%
AC Contribution:	**Virgin AC**	5.30	**RAP AC**		**Percent Virgin AC:**		
Asphalt Sp. Gravity:		1.03		**Dust to Asphalt Ratio:**			0.75

% Fracture Face on CA:	100	**% Glassy Particles on CA:**	
Theo.Gravity of RAP:		**Eff. Gravity of Agg:**	2.628

Theo. Gravity of Mix:	2.428	**T.S.R.:**	85.4	**Lbs/Ft^3:**	151.5
L.O.I.:	20.5	**Ignition Oven Corr. Factor:**			
ADT	**Log Miles**	**Beginning:**		**Ending:**	

Lab Temperature		**Plant Temperature**	
Mixing Temperature (± 5 °F):	320	**Mixing Temp Range(°F):**	320°F ≤ T ≤ 350°F
Lab Compaction Temp (± 5 °F):	305	**Delivery Temperature(°F):**	320°F ≤ T ≤ 350°F

Sieve Size	Percents Used							% Req.	Design Range
			D Rock(Limestone)	#10 (Soft)	Natural Sand	#10 (Soft)			
			50.0	10.0	25.0	15.0		100	
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"			100	100	100	100		100	100
1/2"			97	100	100	100		99	95-100
3/8"			70	100	100	100		85	80-93
No.4			21	93	99	99		59	54-76
No.8			7	63	94	84		46	35-57
No.16									
No.30			5	29	63	29		26	17-29
No.50			4	22	13	19		10	10-18
No.100			3.5	19.0	2.0	9.0		5.5	3-10
No.200			2.5	16.0	1.5	5.0		4.0	0-6.5

Requested: LoJac Ent. Mike Ford LT020
Contractor Personnel and Lab Tech Cert No.

Approved: ____________
Regional Materials and Tests Supervisor

Date last lab inspection 2/28/2007

Approved: ____________
Headquarters Materials and Tests

Job #32517 6,305 Tons

1/31/2007 V6.0

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

L-13, L-20

Project Ref. No.		Date	09/14/2007
Project No.	94019-4203-04	Region	3
Contract No.	CNF172	County	Williamson
Contractor	LoJac Ent.	Date of Letting	06/01/07
State Route No.	SR 46	Roadway Surface	Yes
Hot-mix Producer	LOJAC, INC., FRANKLIN PLANT #1		

Type ACS-HM Mix 411-D PG 70-22 Item 411-02.10

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate	RGI,BonAqua,TN.	47.350
#10 (Soft)	Screenings	Vulcan Mtls. Franklin,TN	9.470
Natural Sand	Natural Sand	Ingram Mtls Nashville,TN	23.675
#10 (Soft)	Washed Screenings	Vulcan Danley Antioch,TN	14.205
Asphalt Cement	PG 70-22	ERGON ASPHALT CO., NASHVILLE TERMINAL	5.300

Percent AC in RAP:		Optimum AC Content:	5.3	Total	100.000
Anti-Strip Additive:	AD-Here 77-00		Dosage:		0.3%
AC Contribution:	Virgin AC 5.30	RAP AC		Percent Virgin AC:	
Asphalt Sp. Gravity:	1.03	Dust to Asphalt Ratio:			0.77

% Fracture Face on CA:	100	% Glassy Particles on CA:	
Theo.Gravity of RAP:		Eff. Gravity of Agg:	2.612

Theo. Gravity of Mix:	2.415	T.S.R.:	89.6	Lbs/Ft^3:	150.7
L.O.I.:	22.5	Ignition Oven Corr. Factor:			
ADT	Log Miles	Beginning:		Ending:	

Lab Temperature		Plant Temperature	
Mixing Temperature (± 5 °F):	320	Mixing Temp Range(°F):	320°F ≤ T ≤ 350°F
Lab Compaction Temp (± 5 °F):	295	Delivery Temperature(°F):	320°F ≤ T ≤ 350°F

Sieve Size	Percents Used	D Rock(Limestone)	#10 (Soft)	Natural Sand	#10 (Soft)			% Req.	Design Range
		50.0	10.0	25.0	15.0			100	
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"		100	100	100	100			100	100
1/2"		95	100	100	100			98	95-100
3/8"		72	100	100	100			86	80-93
No.4		15	93	98	99			56	54-76
No.8		6	65	93	55			41	35-57
No.16									
No.30		5	30	63	17			24	17-29
No.50		4	26	13	12			10	10-18
No.100		3.5	21.0	2.0	8.0			5.6	3-10
No.200		2.5	17.0	1.0	6.0			4.1	0-6.5

Requested: LoJac Ent. Mike Ford LT020
Contractor Personnel and Lab Tech Cert No.

Approved: ______
Regional Materials and Tests Supervisor

Date last lab inspection 3/20/2007

Approved: ______
Headquarters Materials and Tests

Job#32517 6,305 Tons

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V6.0

L-13, L-20

Project Ref. No.		Date	09/04/2007
Project No.	14019-4203-04	Region	3
Contract No.	CNF172	County	Williamson
Contractor	LoJac Ent	Date of Letting	06/01/07
State Route No.	SR 46	Roadway Surface	Yes
Hot-mix Producer	LOJAC, INC., DANLEY PLANT		

Type ACS-HM **Mix** 411-D PG 70-22 **Item** 411-02.10

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate	Rinker Springfield,TN	47.350
#10 (Soft)	Screenings	Vulcan Danley Antioch,TN	9.470
Natural Sand	Natural Sand	Ingram Mtls Nashville,TN	23.675
#10 (Soft)	Washed Screenings	Vulcan Danley Antioch,TN	14.205
Asphalt Cement	PG 70-22	ERGON ASPHALT CO., NASHVILLE TERMINAL	5.300

Percent AC in RAP:	Optimum AC Content: 5.3	Total	100.000
Anti-Strip Additive:	Pavegrip 650	Dosage:	0.3%
AC Contribution: Virgin AC 5.30	RAP AC	Percent Virgin AC:	
Asphalt Sp. Gravity:	1.03	Dust to Asphalt Ratio:	0.75

% Fracture Face on CA:	100	% Glassy Particles on CA:	
Theo.Gravity of RAP:		Eff. Gravity of Agg:	2.628

Theo. Gravity of Mix: 2.428	T.S.R.: 85.4	Lbs/Ft^3:	151.5
L.O.I.: 20.5		Ignition Oven Corr. Factor:	
ADT	Log Miles Beginning:	Ending:	

Lab Temperature		Plant Temperature	
Mixing Temperature (± 5 °F):	320	Mixing Temp Range(°F):	320°F ≤ T ≤ 350°F
Lab Compaction Temp (± 5 °F):	305	Delivery Temperature(°F):	320°F ≤ T ≤ 350°F

Sieve Size	Percents Used							% Req.	Design Range
			D Rock(Limestone)	#10 (Soft)	Natural Sand	#10 (Soft)			
			50.0	10.0	25.0	15.0		100	
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"			100	100	100	100		100	100
1/2"			97	100	100	100		99	95-100
3/8"			70	100	100	100		85	80-93
No.4			21	93	99	99		59	54-76
No.8			7	63	94	84		46	35-57
No.16									
No.30			5	29	63	29		26	17-29
No.50			4	22	13	19		10	10-18
No.100			3.5	19.0	2.0	9.0		5.5	3-10
No.200			2.5	16.0	1.5	5.0		4.0	0-6.5

Requested: LoJac Ent. Mike Ford LT020
Contractor Personnel and Lab Tech Cert No.

Approved: ______________________
Regional Materials and Tests Supervisor

Date last lab inspection 2/28/2007

Approved: ______________________
Headquarters Materials and Tests

Job #32517 6,305 Tons

Return to Index of Appendices

Technical Update from the Ohio LTAP Center

Warm Mix Asphalt

WHAT IS IT? [i]

Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that allow asphalt mixtures to be produced, transported, placed, and compacted at lower temperatures. WMA technologies typically result in temperatures 30 to 75 degrees Fahrenheit lower than traditional hot-mix asphalt (HMA). Because less energy is needed to heat the asphalt mix, in many cases, less fuel is required to produce WMA. Fuel consumption during WMA production may be reduced by 20 percent with proper production plant modifications. It is a proven technology that can:

- Improve compaction that improves pavement performance.
- Reduce fuel or energy usage.
- Improve worker comfort by reducing exposure to higher temperatures, fuel emissions, fumes, and odors.

In addition, WMA technologies allow asphalt mixtures to be hauled longer distances and can extend the paving season due to WMA's ability to maintain workability at lower temperatures. The proper use of WMA may result in reduced overall paving costs.

WMA technologies enhance mixture workability through the addition of additives (organic, chemical, water-based, or hybrids). Asphalt mixtures are primarily composed of aggregates and asphalt binder. Aggregates are hard materials such as crushed stone. Asphalt binder is a dark brown to black, sticky liquid that holds together the aggregates when mixed. Some WMA technologies work by reducing the viscosity, which increases the ability to flow or pour the asphalt binder. This allows the aggregates to be properly coated with asphalt binder at lower temperatures. WMA also improves workability during construction allowing the mixture to be properly transported, paved, and compacted at lower temperatures. Proper compaction provides increased pavement density and is necessary for pavement performance.

WARM MIX ASPHALT IN OHIO

The Ohio Department of Transportation's Office of Materials Management has established specifications for Warm Mix Asphalt (WMA). The specifications set forth the foaming method to be used when WMA is made for Ohio, as this method only utilizes water instead of other costly additives – making it more cost effective and ecologically friendly.

Since the adoption of WMA specifications in 2008, approximately 33% of all asphalt on ODOT projects has gone down as WMA. This technical update includes the details from sections 402.09, 401.05 and 441.09 (C) 1st paragraph (quality control) from the ODOT specifications.

For additional information regarding the Safety Edge technique, please contact Ohio LTAP [614-387-7358, 877-800-0031, or email: ltap@dot.state.oh.us] or ODOT's Office of Materials Management [614-275-1387].

Ohio Department of Transportation Materials Section: Warm Mix Asphalt Specifications

402.09 Water Injection System for Warm Mix Asphalt. [ii]

When allowed by specification use a Department approved water injection system for the purpose of foaming the asphalt binder and lowering the mixture temperature. Only use equipment that has been proven stable and effective thru project use on non-ODOT projects. Ensure equipment for water injection meets the following requirements:

1. Injection equipment computer controls are in the plant control room and are tied to the plant computer metering.
2. Injection equipment has variable water injection control controlled by the plant operation rate and the water injection can never exceed 1.8% by weight of asphalt binder.
3. Water injection rate cannot be manually overridden by the plant operator once in the computer.
4. Injection equipment stops water flow when a control or equipment failure in the injection system occurs.
5. The water injects into the asphalt binder flow before the asphalt binder spray hits aggregate. Do not allow water to touch aggregate before the binder spray.
6. Injection equipment includes water storage and pump control tied to the injection computer controls.
7. Water storage low water alarm installed in the control room.
8. Provide a PG binder sampling valve between the last piping tee on the tank side of the line and the injection equipment to sample PG binder before water is injected.
9. Provide a PG Binder sampling valve at the injection equipment to sample binder prior to spray.

401.05 Mixing Plants. [iii]

The Department will approve mixing plants before preparation of the mixtures. General requirements for asphalt concrete mixing plants are specified in Item 402.

Set the asphalt binder controls for the computerized plant at the virgin asphalt binder content of the JMF at all times unless change is authorized by the Laboratory.

Asphalt mixtures may be produced using the warm mix asphalt method according to 402.09 except as restricted by specification.

441.09 (C) Air Voids and MSG. [iv]

Determine the air voids of the asphalt concrete by analyzing a set of compacted specimens and a corresponding MSG determination. Use the MSG to calculate the air voids of the compacted specimens. Ensure that the cure temperature and specimen compaction temperature are the same. Use a 1-hour cure for all mix samples used in voids analysis. The Contractor may use a 2-hour cure time if voids are consistently near the low void warning band. In this case, use the 2-hour cure for all voids testing through the remainder of the project. For hot mix asphalt use the JMF lab compaction temperature. For warm mix asphalt according to 402.09 use a lab compaction temperature 30.0 ºF (16.7 ºC) less than the JMF lab compaction temperature for hot mix asphalt. Use a compaction temperature tolerance of +/- 5.0 ºF (3.0 ºC). Record on the TE-199 if the mixture produced was ran at the asphalt plant as a hot mix asphalt (HMA) or as a warm mix asphalt (WMA) produced according to 402.09 or another approved method.

…

[i] Copied in whole from the Every Day Counts FHWA program website, available at: http://www.fhwa.dot.gov/everydaycounts/summit/asphalt.cfm (Last visited 3/17/2011).
[ii] Available on line at: http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Specifications/2010CMS/400/402.htm (Last visited 3/22/2011).
[iii] Available on line at: http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Specifications/2010CMS/400/401.htm (Last visited on 3/22/2011).
[iv] Available on line at: http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Specifications/2010CMS/400/441.htm#a_441_09 (Last visited 3/22/2011).

Note: Appendix A of this paper is not included as it is the survey form which was used to gather the data. Appendix B of this paper is included at end.

Information Series 138

Refer to Index of Appendices

Asphalt Pavement Mix Production Survey

Reclaimed Asphalt Pavement, Reclaimed Asphalt Shingles, Warm-mix Asphalt Usage: 2009-2010

NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

NAPA

NATIONAL ASPHALT
PAVEMENT ASSOCIATION

NAPA Building ■ 5100 Forbes Blvd. ■ Lanham, MD 20706-4407
Tel: 301-731-4748 ■ Fax: 301-731-4621
Toll free: 1-888-468-6499 ■ www.AsphaltPavement.org
Publication Sales: napa-orders@abdintl.com ■ Toll free: 888-600-4474
Tel: 412-741-6314 ■ Fax: 412-741-0609

Asphalt Pavement Mix Production Survey
IS 138
Produced 11/11

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Asphalt Pavement Mix Production Survey on Reclaimed Asphalt Pavement, Reclaimed Asphalt Shingles, and Warm-mix Asphalt Usage: 2009-2010	5. Report Date November 2011 6. Performing Organization Code
7. Author(s) Kent R. Hansen and David E. Newcomb	8. Performing Organization Report No.
9. Performing Organization Name and Address National Asphalt Pavement Association 5100 Forbes Boulevard Lanham, MD 21054	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH-61-10-P-00084
12. Sponsoring Agency Name and Address Federal Highway Administration Federal Highway Administration Office of Pavement Technology (HIPT-10) 1200 New Jersey Avenue, S.E. Washington, DC 20590	13. Type of Report and Period Covered Final Report 2009 - 2010 14. Sponsoring Agency Code

15. Supplementary Notes
FHWA Project Contact John Bukowski

16. Abstract

The asphalt pavement industry and its partners have maintained a focus on continuous product improvement, including versatility in application. The use of reclaimed asphalt pavement (RAP) in asphalt mixtures began in earnest in the 1970s in response to the oil embargo. Other improvements over the years include polymer-modified asphalt, Superpave PG binder specification and mix design procedures, stone-matrix asphalt (SMA), improvements in open-graded friction courses (OGFCs), and long-life asphalt pavement. Warm-mix asphalt (WMA), which was first used in the U.S. in 2004, has provided both enhancements in working conditions and numerous construction benefits. The recycling of asphalt shingles into plant-mix asphalt has grown rapidly in recent years. Such innovations have done much to improve performance, safety, and longevity. In many ways, they have also improved the economics of producing the material and/or the environmental aspects of material production.

Over the last 10 years, the asphalt pavement industry has seen unprecedented challenges in both economic and regulatory issues that have called for technical responses in order to maintain a competitive position in the marketplace. These responses have focused on ways of continually reducing emissions from asphalt production, improving working conditions, and conserving the natural resources – both virgin asphalt binder and aggregates – being used in pavement mixes.

In 2009 and 2010, the Federal Highway Administration contracted with the National Asphalt Pavement Association for a systematic survey of implementation/adoption of three key areas: reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), and warm-mix asphalt (WMA). This document presents the results of that survey. The survey clearly shows that the asphalt pavement industry continues to improve its already outstanding record of environmental stewardship through its increasing use of RAP, RAS, and WMA. These technologies conserve raw materials; conserve energy; cut emissions from production and paving operations; and improve conditions for workers.

- RAP: The asphalt industry remains the country's number one recycler. About 96 percent of the contractors/ branches reported using RAP. The amount of RAP used in HMA/WMA was 56.0 million tons in 2009 and 62.1 million tons in 2010. Assuming 5 percent liquid asphalt in RAP, this represents over 3 million tons (19 million barrels) of asphalt binder conserved. Less than 1 percent of RAP was sent to landfills.
- RAS: Use of reclaimed asphalt shingles (both manufacturer's waste and tear-offs) increased from 702,000 to 1.10 million tons from 2009 to 2010, a 57 percent increase. Assuming a conservative asphalt content of 20 percent for the shingles, this represents 234,000 tons (1.5 million barrels) of asphalt binder conserved.
- WMA: Total tonnage of WMA is estimated at 19.2 million tons in 2009 and 47.6 million tons in 2010. This was a 148 percent increase. Plant foaming is used most often in producing WMA. Additives accounted for about 17 percent of the total WMA production in 2009 and 8 percent in 2010.

17. Key Words Reclaimed asphalt pavement, reclaimed asphalt shingles, warm-mix asphalt, RAP, RAS, WMA	18. Distribution Statement No restrictions

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Asphalt Pavement Mix Production Survey on Reclaimed Asphalt Pavement, Reclaimed Asphalt Shingles, and Warm-mix Asphalt Usage: 2009-2010

Introduction

Background

The asphalt pavement industry and its partners have maintained a focus on continuous product improvement, including versatility in application. The use of reclaimed asphalt pavement (RAP) in asphalt mixtures began in earnest in the 1970s in response to the oil embargo. During the 1980s, use of polymer-modified asphalt binder increased, and its use was furthered by the advent of the Superpave PG binder specification in the 1990s. The Superpave volumetric mix design procedure also began to be adopted during the early 1990s and has undergone many improvements since. Stone-matrix asphalt (SMA) was presented to the U.S. as a premium asphalt surfacing during the 1990s. The mix design procedure for open-graded friction courses (OGFCs) was improved during that time and today these materials provide safe, quiet riding surfaces all over the country. Long-life asphalt pavement structures are possible through the application of Perpetual Pavement design practices. Warm-mix asphalt (WMA), which was first used in the U.S. in 2004, has provided both enhancements in working conditions and numerous construction benefits. The recycling of asphalt shingles (RAS) into plant-mix asphalt has grown rapidly in recent years. Such innovations have done much to improve performance, safety, and longevity. In many ways, they have also improved the economics of producing the material and/or the environmental aspects of material production.

Over the last 10 years, the asphalt pavement industry has seen unprecedented challenges in both economic and regulatory issues that have called for technical responses in order to maintain a competitive position in the marketplace. These responses have focused on ways of continually reducing emissions from asphalt production, improving working conditions, and conserving the natural resources – both virgin asphalt binder and aggregates – being used in pavement mixes.

In 2009 and 2010, the Federal Highway Administration contracted with the National Asphalt Pavement Association for a systematic survey of implementation/adoption of three key areas: reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), and warm-mix asphalt. This document presents the results of that survey.

Highlights

The survey clearly shows that the asphalt pavement industry continues to improve its already outstanding record of environmental stewardship through its increasing use of RAP, RAS, and WMA. These technologies conserve raw materials; conserve energy; cut emissions from production and paving operations; and improve conditions for workers.

- RAP: The asphalt industry remains the country's number one recycler. About 96 percent of the contractors/ branches reported using RAP. The amount of RAP used in HMA/WMA was 56.0 million tons in 2009 and 62.1 million tons in 2010. Assuming 5 percent liquid asphalt in RAP, this represents over 3 million tons (19 million barrels) of asphalt binder conserved. Less than 1 percent of RAP was sent to landfills.

- RAS: Use of reclaimed asphalt shingles (both manufacturer's waste and tear-offs) increased from 702,000 to 1.10 million tons from 2009 to 2010, a 57 percent increase. Assuming a conservative asphalt content of 20 percent for the shingles, this represents 234,000 tons (1.5 million barrels) of asphalt binder conserved.
- WMA: Total tonnage of WMA is estimated at 19.2 million tons in 2009 and 47.6 million tons in 2010. This was a 148 percent increase. Plant foaming is used most often in producing WMA. Additives accounted for about 17 percent of the total WMA production in 2009 and 8 percent in 2010.

Reclaimed Asphalt Pavement

Although the widespread use of reclaimed asphalt pavement (RAP)in asphalt pavements began in the 1970s, and by the 1980s there had been some field trials with very high RAP contents, it is estimated that the average amount of RAP actually being incorporated in mixtures leveled off at about 12 percent by 2008 **(Copeland, Jones, & Bukowski, 2010)**. There were a number of reasons for this relatively low RAP content in mixtures. As recycling was starting, it was found that high RAP contents could result in increased “blue smoke” emissions from plants, because in certain types of plants the RAP was being fed directly into the path of the hot gasses and the RAP binder was being volatilized. Modern plant designs have evolved to effectively shield the RAP from direct contact with the flame. Also, in the 1980s, it was found that RAP could adversely affect the volumetric proportions of the resulting asphalt mixtures, especially the amount of fines in the mix. Recent practice has led to screening the RAP in order to size the material so that it can be more effectively proportioned into the mix. As the Superpave mix design procedure was initially developed, it did not include a method for incorporating RAP. As a result, agencies were reluctant to allow much, if any, RAP in Superpave mixes until a method could be identified to account for the recycled material. This was eventually accomplished in National Cooperative Highway Research Program (NCHRP) project 9-12, but the guidelines for RAP content were still relatively conservative. Recently, there has been a revival of interest in increasing RAP usage, and a new NCHRP project (9-46) is under way at the National Center for Asphalt Technology (NCAT) as well as efforts at the Federal Highway Administration.

The interest in increasing the amount of RAP used in mixtures occurred during the same time period that warm-mix asphalt was being introduced. There appears to be a synergism between the use of warm mix and increased RAP contents. In many cases, it appears that warm mix reduces the amount of initial oxidation in virgin liquid binder so that it interacts with the RAP binder more readily. With the rapid rise in petroleum prices in 2008 and the availability of improved technology to produce higher RAP content asphalt mixtures, the industry has recommitted itself to increasing the amount of RAP used.

Reclaimed Asphalt Shingles

The use of reclaimed asphalt shingles (RAS) in asphalt paving mixtures is not a new concept. Research into the use of shingle manufacturers’ waste dates back the mid-1980s and permissive specifications for the use of waste shingles in paving began to appear in the early 1990s. The combination of a high asphalt binder content, high-quality fine aggregate, mineral filler, and fibers makes roofing shingles very compatible with asphalt pavement mixtures. The fact that the asphalt cement in shingles is generally harder than that employed in paving mixtures, and that the other ingredients impact the volumetric properties of the final mix, generally limits its incorporation in asphalt mixtures to 5 percent or less. However, even at a relatively lower RAS content, there is somewhere on the order of 15 to 20 percent binder replacement in the final paving mixture. Currently, 12 states allow the use of manufacturers’ waste in asphalt mix and 10 states allow either manufacturers’ waste or roofing tear-offs in their mixtures. It is estimated that there are 10 million tons of tear-off waste and 1 million tons of manufacturer waste available on an annual basis. If all these could be incorporated into asphalt paving mixtures, it would amount to approximately 1.8 million tons of asphalt binder replacement. Thus, there is great interest in utilizing waste asphalt roofing shingles in asphalt paving mixtures.

Warm-Mix Asphalt

Asphalt mix production plants were delisted as major sources of hazardous air pollutants by the Environmental Protection Agency (EPA) in 2002. In a quest for continuous improvement, the industry began looking for technologies that allowed for lowering temperatures during asphalt mix production and placement. This effort began in Europe as contractors searched for technologies that would help their countries achieve emissions reductions goals set by the Kyoto Agreement. In the U.S., warm-mix asphalt was initially seen as part of the industry’s ongoing efforts to continually reduce emissions and improve working conditions. Since then, numerous unanticipated construction benefits of warm mix have come to light, and many of these are as compelling as the environmental benefits.

After the first demonstration of warm mix in the U.S. in 2004, the number of technologies and the number of field trials grew at a very rapid rate. The National Asphalt Pavement Association (NAPA) and the Federal Highway Administration (FHWA) formed a technical working group to help facilitate the implementation of warm mix. In 2005, there were three technologies being marketed. This increased to over 20 by 2010. By 2010, over half of the states had specifications that permitted the use of warm-mix asphalt. FHWA predicts that this will increase to 47 states and all Federal Lands offices by the end of 2011. As will be shown in this report, the growth in warm-mix tonnage indicates that it will be the direction of the asphalt pavement industry in the future.

Great strides have been made in the implementation of warm-mix asphalt, the use of higher RAP contents in mixtures, and the use of roofing shingles in asphalt. A systematic approach to quantifying the progress of these technologies and the rate of their adoption was, however, lagging. Surveys of the industry needed to be conducted to capture progress on the implementation of RAP, RAS and WMA.

Objective

The objective of this survey was to estimate the quantities of reclaimed asphalt pavement and reclaimed asphalt shingles being used in asphalt mixtures, and to estimate the amount of warm-mix asphalt being produced in the U.S., by state and by market sector.

Scope

In order to accomplish this work, it was necessary to:

1. Design a survey that enabled an analysis of the quantities of RAP and RAS being used in asphalt mixtures as well as the total amount of warm-mix asphalt produced nationally.
2. Conduct a voluntary survey of asphalt mix producers throughout the U.S. This was done by posting a survey on a public Web site, notifying producers, and following up with verbal requests for information in locations where responses were low.
3. Estimate the total market in each state or territory by using data from responding State Asphalt Pavement Associations and the U.S. Census Bureau to determine a weighting factor for each state and reconciling the total U.S. asphalt mix tonnage with national estimates.
4. Summarize the information and prepare this report.

Survey Methods

The survey was conducted using a Web survey service called SurveyMonkey™. Once the draft survey was prepared and before it was posted, it was sent out for review by the NAPA Warm-Mix Asphalt Task Force and the NAPA Energy and Recycling Task Force. After the comments were received and revisions to the survey made, it was posted on SurveyMonkey. Producers were notified of the survey through several forums and electronic media. A notice was posted in NAPA's e-newsletter, *ActionNews*, informing members of the survey and asking for their participation. State Asphalt Pavement Associations participated by placing notices on their Web sites and in their newsletters. Announcements were made at NAPA meetings as well as at several state asphalt conferences. Asphalt mix producers then went to the Web site and completed the survey form. After the initial data were gathered and analyzed, anomalies in individual producer records were identified and reconciled.

The survey was broken into four sections for 2009 and 2010. These sections were General Information, Reclaimed Asphalt Pavement (RAP), Reclaimed Asphalt Shingles (RAS) and Warm-Mix Asphalt (WMA). Table 1 summarizes the questions asked in each section.

Table 1: Survey Question Summary

General Information	RAP & RAS	WMA
Number of Plants	Tons Accepted	Avg. % for DOT Tons
DOT Tons	Tons Use in HMA/WMA	Avg. % for Other Agency Tons
Other Agency Tons	Tons Used in Aggregate	Avg. % for Commercial & Residential Tons
Commercial & Residential Tons	Tons Used in Cold Mix	Chemical Additive %
	Tons Used in Other	Additive Foaming %
	Tons Landfilled	Plant Foaming %
	Avg. % for DOT Mixes	Organic Additive %
	Avg. % for Other Agency Mixes	
	Avg. % for Commercial & Residential Mixes	

Most surveys were completed online. An exception was that one multi-state contractor collected data from their different operations and submitted them in spreadsheet form.

Asphalt mix producers from 47 states and Puerto Rico completed the survey. The District of Columbia, New Mexico, North Dakota, and Nebraska are the only states/territories with no survey information. A total of 196 companies/branches with 1,027 plants are represented in the survey. Table 2 summarizes the number of companies/branches completing the survey.

A copy of the survey is included in Appendix A.

Review of Data and Follow-Up

Data from the online survey was imported into a spreadsheet and checked for accuracy and missing data. When anomalies in the data were noted, the person submitting the data was contacted to resolve the data.

Estimates of Missing Data

To determine the total amount of RAP, RAS, and WMA produced in each state and the nation, the total amount of asphalt mix produced in each state needed to be determined. Estimated tonnages were provided by state asphalt pavement associations in 28 states totaling about 265 million tons. This included seven state associations which supplied DOT tonnages and the total tonnage was estimated by dividing this by the percent of DOT tons provided by asphalt mix producers in that state who completed the survey. To estimate the total tons in the remaining states, relationships between the tonnages supplied by the associations and population, federal apportionment and miles paved were determined and compared. All relationships resulted in a power curve function with different factors each year. Figures 1 through 4 show the relationships between tons and population and federal apportionment since these resulted in less variation than miles paved. The relationship based on apportionment was selected since there was little difference from a population-based estimate and it was felt that tonnage would be more a function of available funds than of population. There is little difference in the total estimated tons between these predictors.

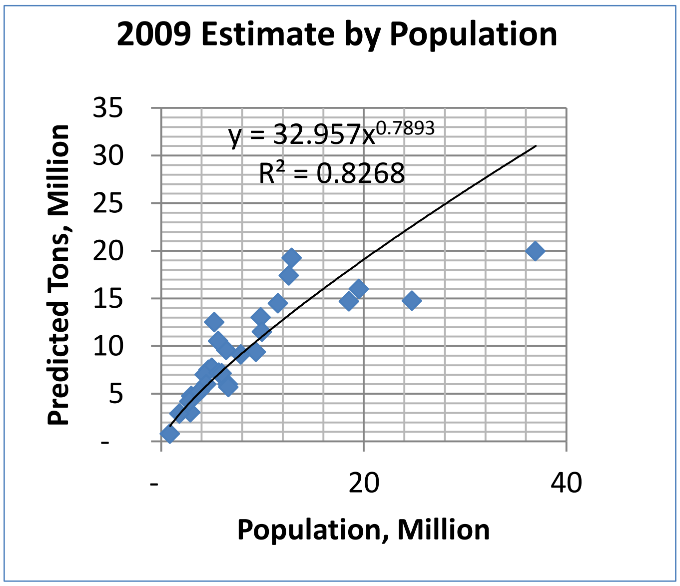


Figure 1: 2009 Asphalt Mix Tons by Population

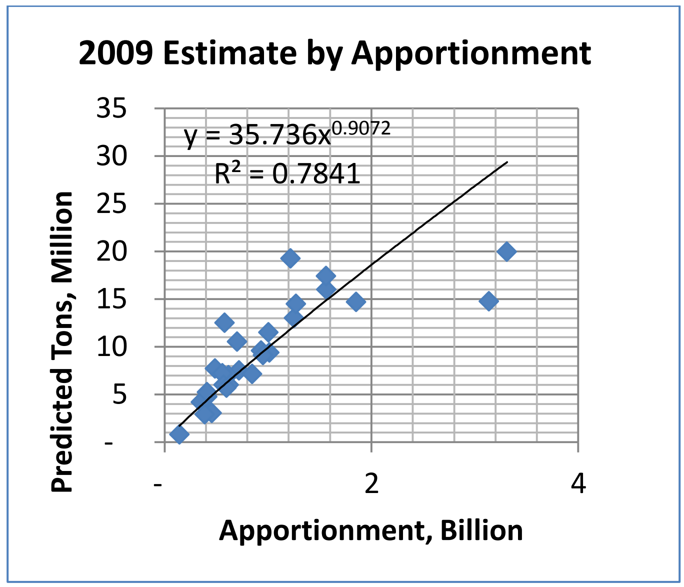


Figure 2: 2009 Asphalt Mix Tons by Federal Apportionment

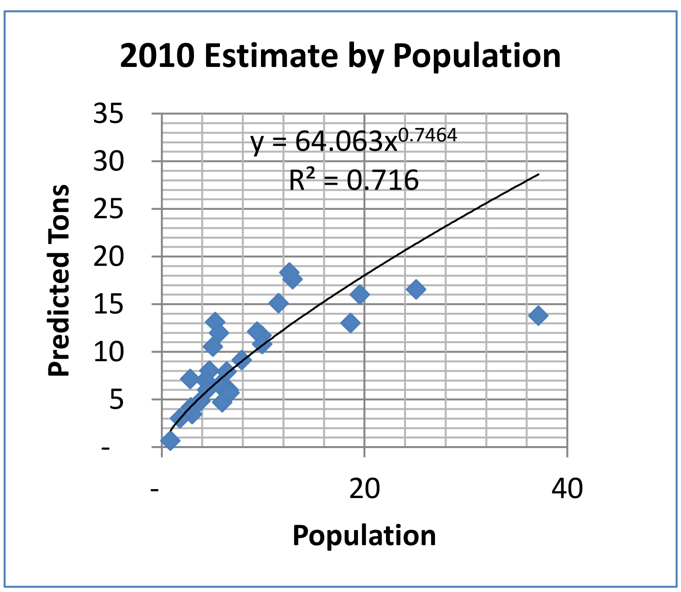


Figure 3: 2010 Asphalt Mix Tons by Population

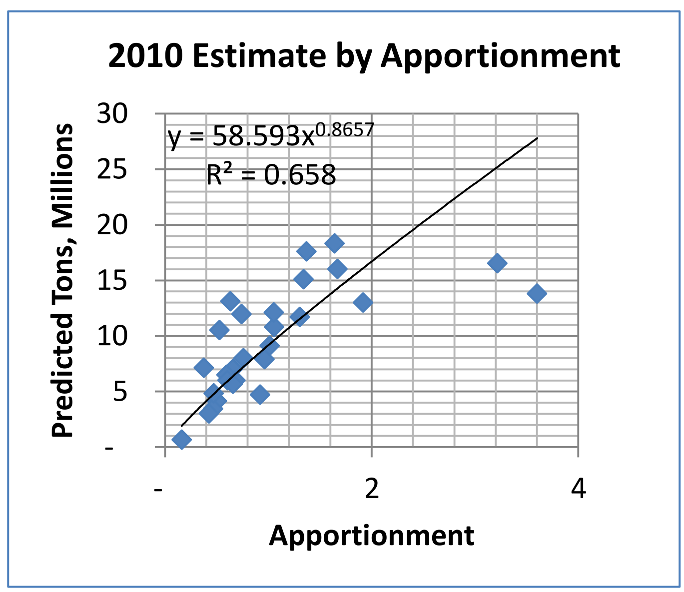


Figure 4: 2010 Asphalt Mix Tons by Apportionment

General Information

State Responses

Figure 5 summarizes the number of plants represented by the companies/branches responding to the survey. Asphalt mix producers from 47 states and Puerto Rico completed the survey. The District of Columbia, New Mexico, North Dakota, and Nebraska are the only states/territories with no survey information. A total of 196 companies/branches with 1,027 plants are represented in the survey. Table 2 summarizes the number of companies/branches completing the survey.

Table 2: No. of Companies/Branches Completing Survey in State

Number of Companies/Branches Completing Survey in State	Number of States
1	9
2	13
3	5
4	4
≥ 5	17
Total States Completing Survey	48

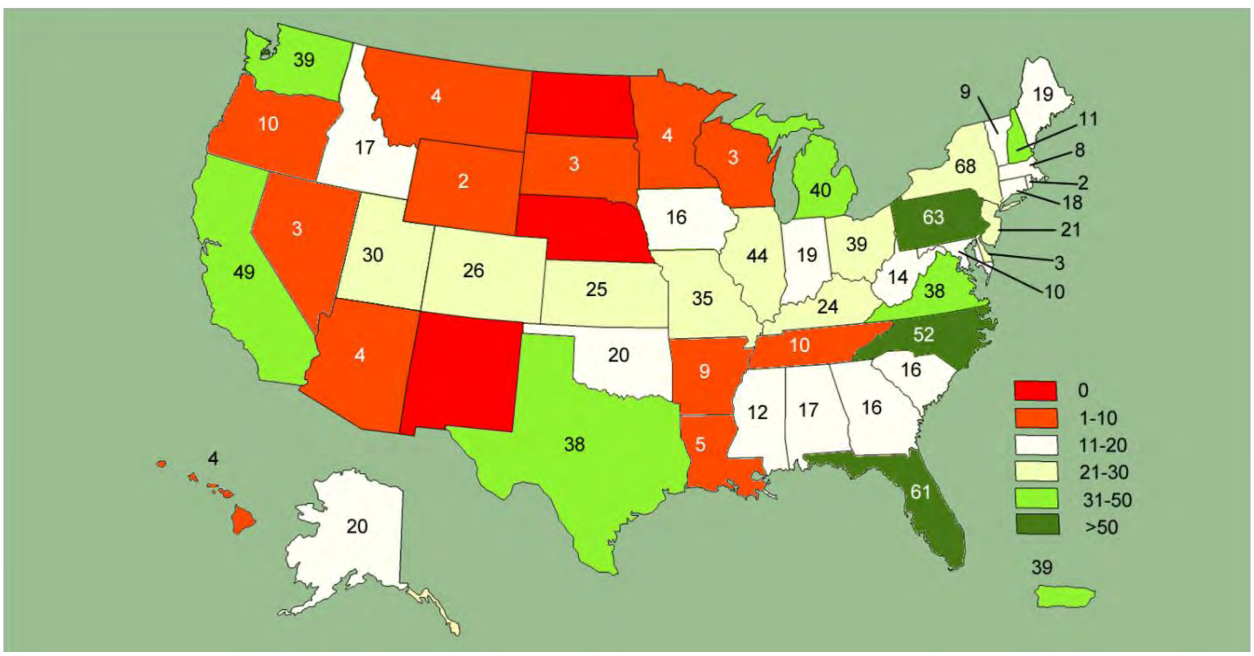


Figure 5: Number of Plants Represented by Companies/Branches Responding to Survey

Figures 6 and 7 provide another perspective of the response to the survey based on the percent of the tons reported in each state to the total estimated tons. The returned survey results represent about 34 percent of the total US tonnage. If we assume there are 4,000 plants in the US, the survey represents about 25 percent of the plants.

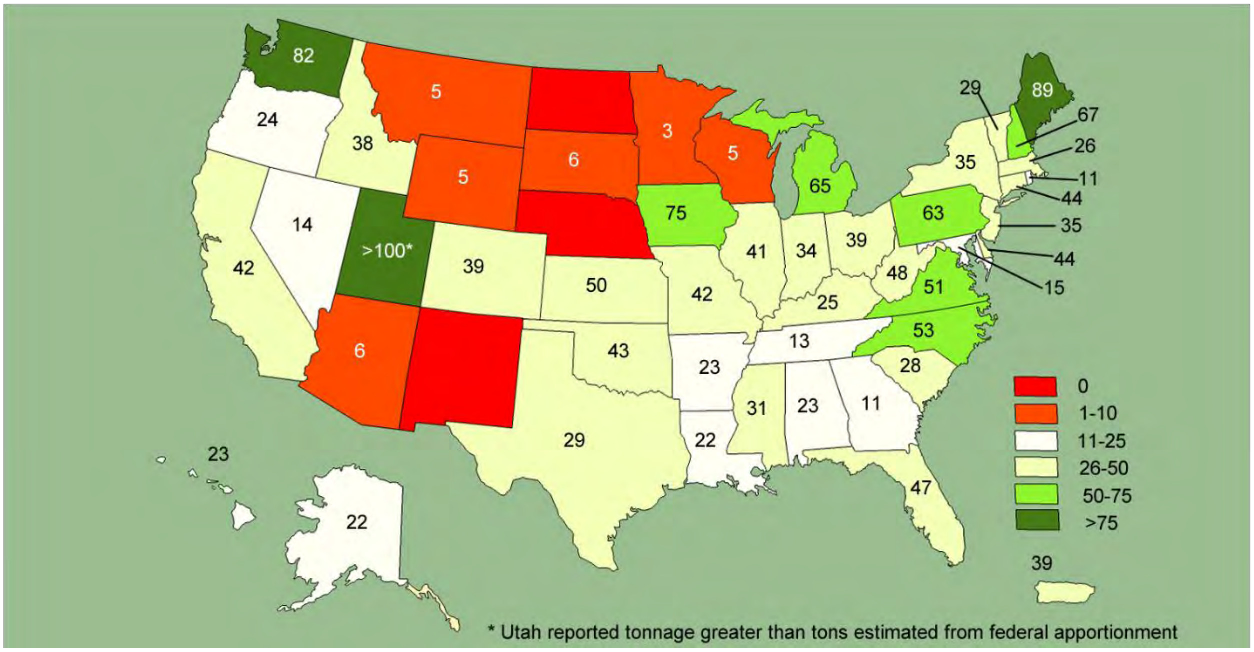


Figure 6: 2009 Reported tons as a percent of estimated total tons

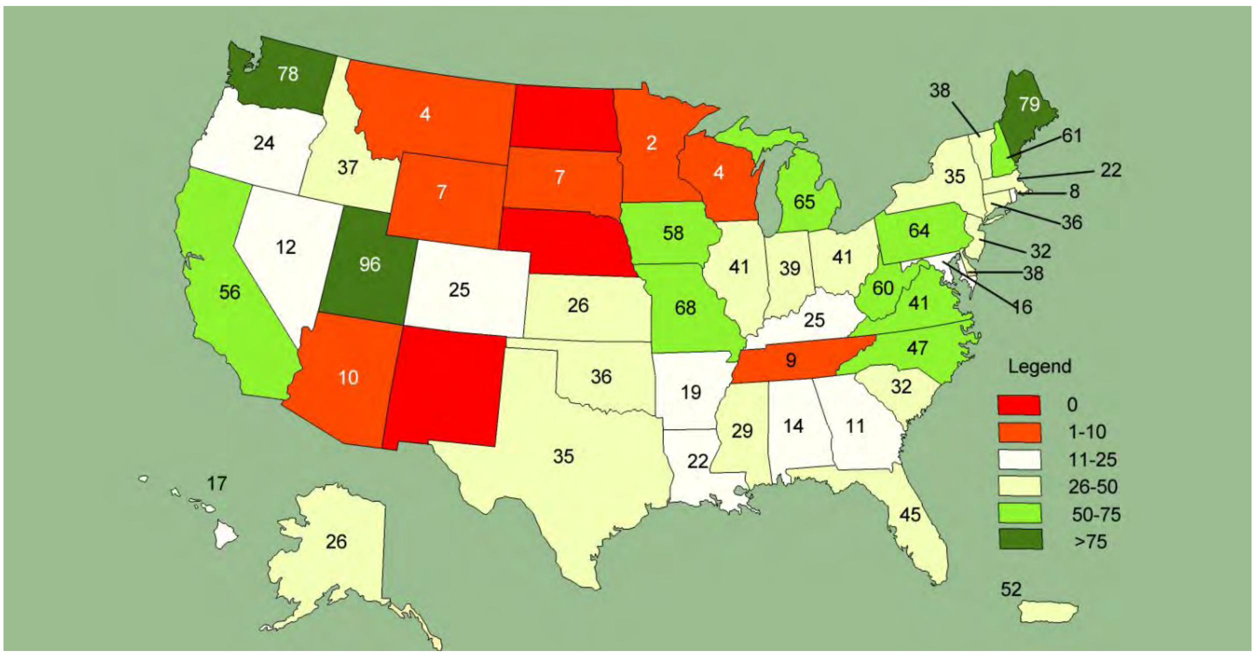


Figure 7: 2010 Reported tons as a percent of estimated total tons

Responder Profile

The survey represents 1,027 plants. The average tons per plant are 121,000 and 117,000 for 2009 and 2010, respectively. Figure 8 shows the number of plants separated by different user/producer group regions.

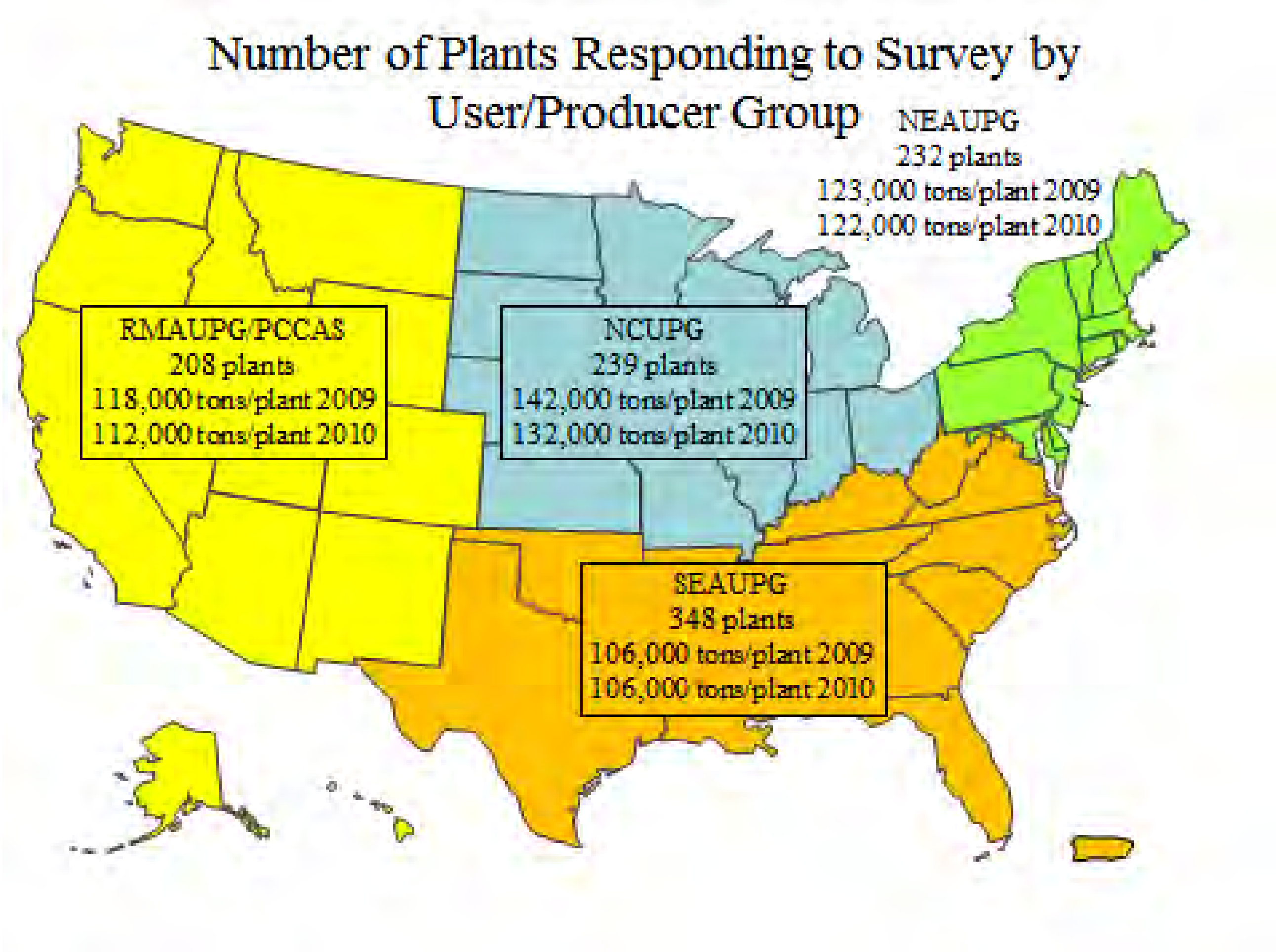


Figure 8: Number of plants responding to survey by User/Producer Group regions.

Table 3: Summary of Estimated and Reported Plant-mix Asphalt Tons by State

State	Tons, Millions			
	2009		2010	
	Estimated	Reported	Estimated	Reported
Alabama	7.50	1.75	8.00	1.09
Alaska	3.67	0.82	4.41	1.15
Arizona	7.50	0.42	7.14	0.71
Arkansas	3.05	0.71	4.15	0.78
California	19.97	8.44	13.79	7.68
Colorado	7.72	3.00	10.52	2.62
Connecticut	4.96	2.20	5.01	1.79
Delaware	0.79	0.35	0.65	0.25
District of Columbia	1.62	-	1.81	-
Florida	14.70	6.91	13.00	5.81
Georgia	13.00	1.39	11.70	1.34
Hawaii	1.73	0.40	1.91	0.33
Idaho	3.00	1.13	3.09	1.14
Illinois	19.25	7.81	17.60	7.17
Indiana	9.60	3.28	7.90	3.06
Iowa	4.74	3.54	3.45	1.99
Kansas	4.17	2.08	7.12	1.85
Kentucky	7.00	1.72	7.00	1.74
Louisiana	6.00	1.30	6.00	1.30
Maine	1.80	1.61	2.03	1.60
Maryland	7.20	1.07	6.50	1.06
Massachusetts	6.00	1.54	6.00	1.34
Michigan	11.50	7.49	10.80	7.03
Minnesota	12.50	0.42	13.10	0.29
Mississippi	4.62	1.45	4.79	1.41
Missouri	7.13	3.02	4.70	3.19
Montana	3.78	0.19	3.99	0.17
Nebraska	2.96	-	3.09	-
Nevada	3.11	0.43	3.57	0.43
New Hampshire	1.86	1.25	1.94	1.18
New Jersey	9.33	3.28	9.09	2.87
New Mexico	3.78	-	3.84	-
New York	16.00	5.65	16.00	5.54
North Carolina	9.37	4.95	12.11	5.66
North Dakota	2.55	-	2.70	-
Ohio	14.50	5.69	15.10	6.23
Oklahoma	5.74	2.47	5.99	2.16
Oregon	5.22	1.27	4.81	1.16
Pennsylvania	17.40	10.97	18.30	11.66
Puerto Rico	2.49	0.97	1.44	0.75
Rhode Island	2.07	0.22	2.34	0.19
South Carolina	6.23	1.77	6.14	1.98
South Dakota	2.73	0.16	2.96	0.22
Tennessee	7.95	1.07	7.87	0.73
Texas	14.77	4.23	16.54	5.73
Utah	3.14	3.71	3.35	3.23
Vermont	1.74	0.51	2.12	0.80
Virginia	9.10	4.64	10.90	4.51
Washington	5.70	4.65	5.70	4.46
West Virginia	2.90	1.40	3.00	1.79
Wisconsin	10.52	0.50	11.96	0.50
Wyoming	2.77	0.15	2.83	0.20
Total	358.43	123.98	359.85	119.87

Note: Shaded rows indicate states where the state asphalt pavement association provided data used to compute total estimated value. A relationship between tons and federal apportionment was used to estimate the total tons for states where no data was available on total tons.

Reclaimed Asphalt Pavement

Table 4 summarizes the RAP data from the survey. Based on the total estimated tons received and the amount used for all purposes, including landfilling, there was an excess of 2.5 and 1.8 million tons in 2009 and 2010, respectively, out of a total of 67.2 and 73.5 tons, respectively.

Table 4: Summary of RAP data

	Reported Tons Million		Total Estimated Tons Million	
	2009	2010	2009	2010
Companies/branches Reporting Using RAP	189	189		
Tons Accepted	23.2	24.0	67.2	73.5
Tons Used in HMA/WMA	20.1	21.6	56.1	62.1
Tons Used in Aggregate	1.5	1.6	6.2	7.3
Tons Used in Cold Mix	0.4	0.4	1.5	1.6
Tons Used in Other	0.1	0.07	0.7	0.8
Tons Landfilled	0.06	0.001	0.1	0.004
Avg. % for DOT mixes	12.5%	13.2%		
Avg. % for Other Agency mixes	14.0%	15.2%		
Avg. % for Commercial & Residential	17.5%	18.0%		
National Average All Mixes Based on % Reported For Different Sectors	15.6%	17.2%		
National Average All Mixes Based on RAP Tons Used In HMA/WMA	16.2%	18.0%		

Figure 9 shows the estimated total tons of RAP used in HMA/WMA, aggregate, cold mix, other, and landfilled. The majority of RAP is used in HMA/WMA followed by aggregate and cold mix. It is estimated that less than 0.1 percent was sent to landfills in both 2009 and 2010.

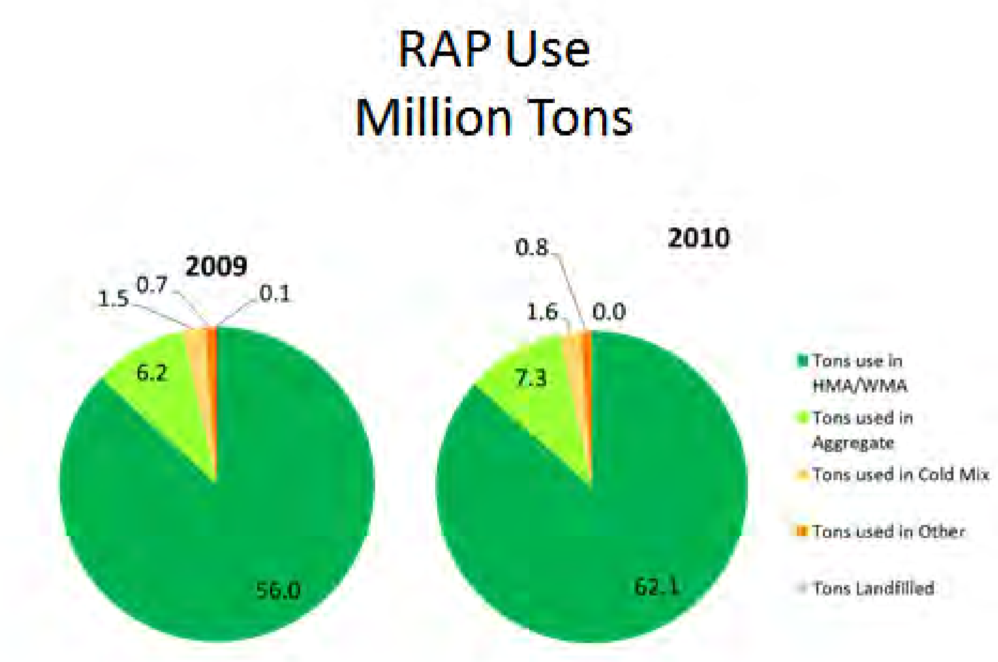


Figure 9: RAP tons by final use.

Figure 10 shows the total estimated amount of RAP used in the different sectors. These values were calculated using the average percentages of RAP reported for the different sectors and adjusted to account for the difference in reported RAP tons and the tons calculated from the percentage by sector.

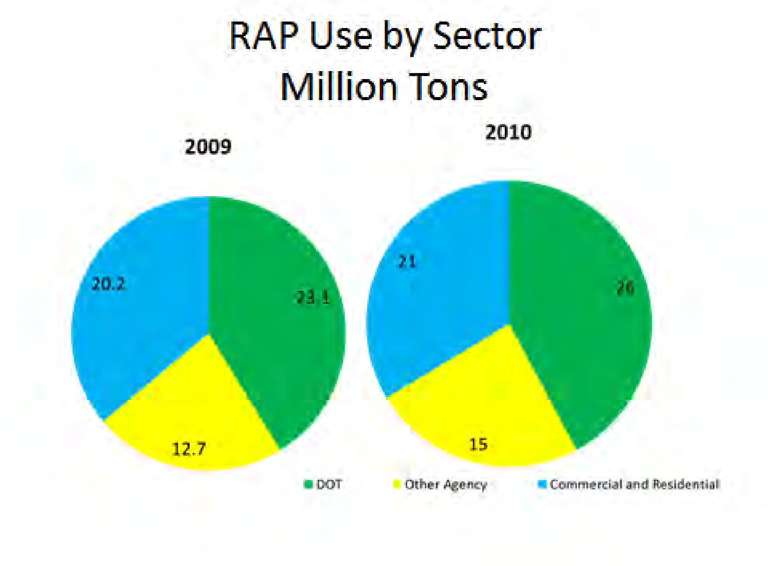


Figure 10: RAP Use by Sector

Figures 11 and 12 show the average percent of RAP used in the different states based on reported RAP and total tons. It should be noted that the accuracy of data for individual states will vary depending on the number of responses received from each state and the total number of tons represented by the responses.

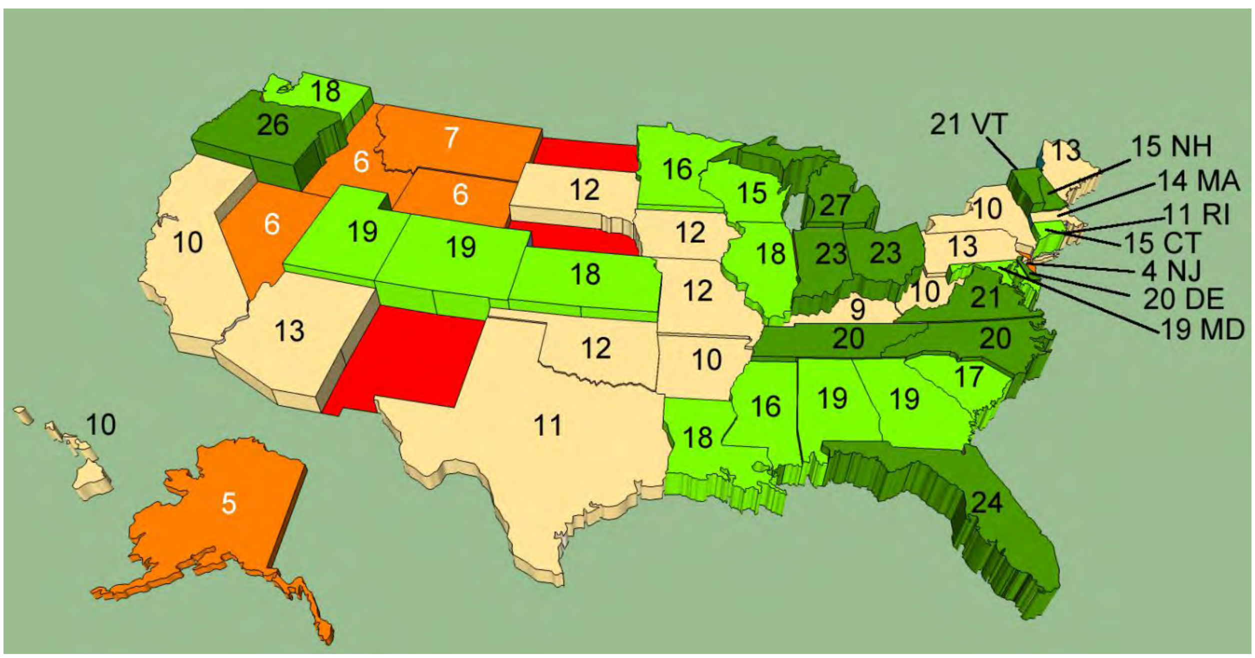


Figure 11: Estimated average percent of RAP by state for 2009

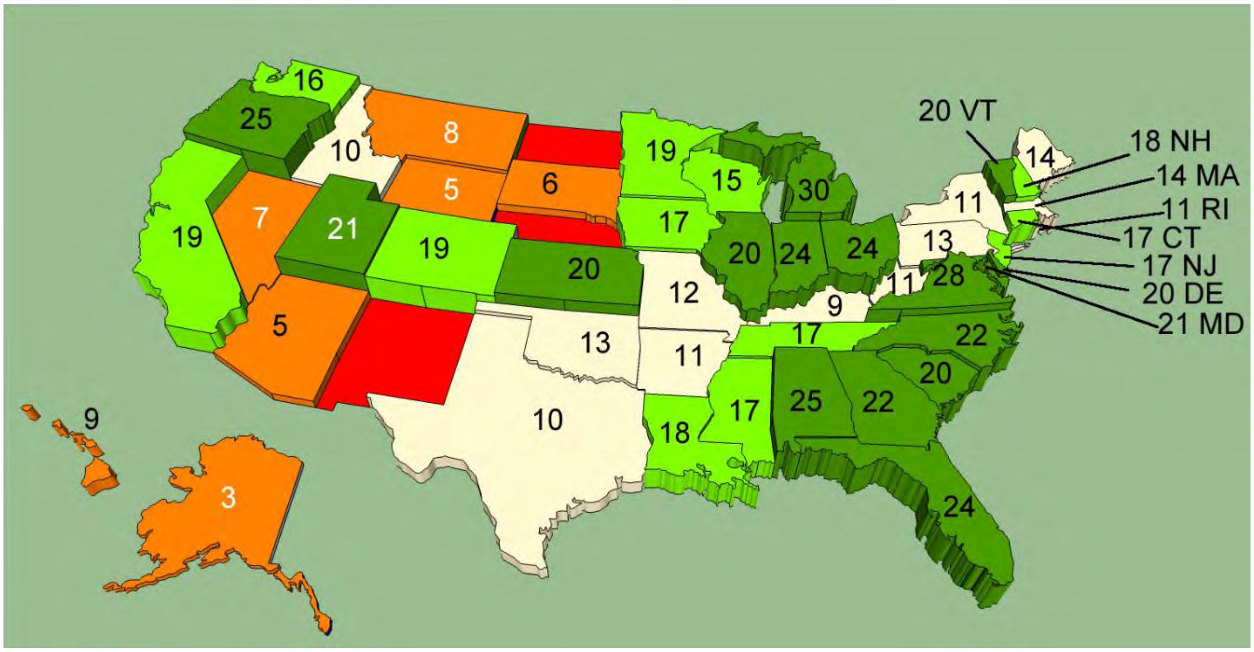


Figure 12: Estimated average percent of RAP by state for 2010

RAP use began in the 1970s. Today, most contractors are using RAP in mixes, with 96 percent of the contractors/branches reporting using RAP and over 86 percent of these contractors reporting excess RAP. From 2009 to 2010, the amount of RAP used in HMA/WMA increased from 56.0 to 62.1 million tons for a 10 percent increase. The average percent RAP used in mixes has increased about from about 16 to 18 percent between 2009 and 2010.

Reclaimed Asphalt Shingles

Table 5 summarizes the RAS data from the survey. Based on the total estimated tons received and the amount used for all purposes, including landfilling, there was an excess of 126,000 and 616,000 tons in 2009 and 2010, respectively.

Table 5: Summary of RAS Data

	Reported Tons Thousand		Total Estimated Tons Thousand	
	2009	2010	2009	2010
Companies/branches Reporting Using RAS	44	61		
Tons Accepted	332	558	957	1,851
Tons Used in HMA/WMA	245	392	701	1,099
Tons Used in Aggregate	5	2	6	3
Tons Used in Cold Mix	-	-	-	-
Tons Used in Other	39	34	123	124
Tons Landfilled	-	0.5	-	6
Avg. % for DOT Mixes	0.33%	0.78%		
Avg. % for Other Agency Mixes	0.37%	0.47%		
Avg. % for Commercial & Residential Mixes	0.63%	0.81%		
National Average All Mixes Based on RAS Tons Used in HMA/WMA	0.27%	0.33%		

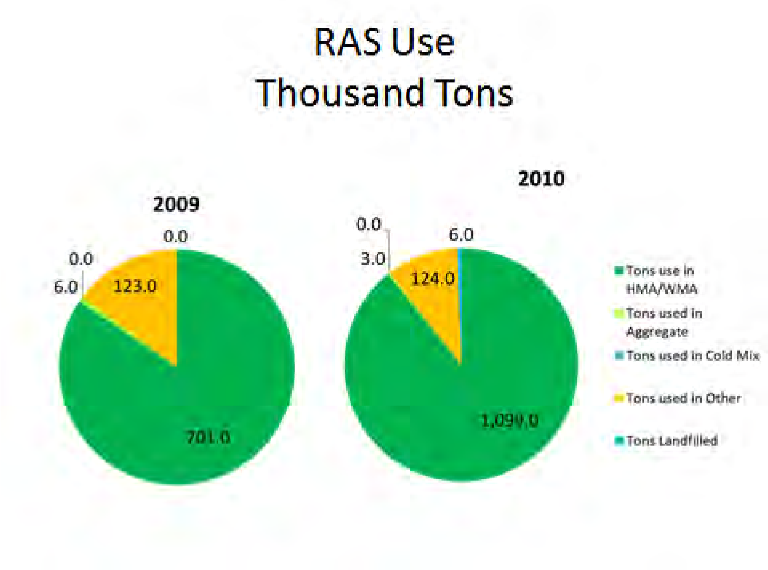


Figure 13: Summary of RAS use.

Figure 13 shows the total estimated amount of RAS used. Figure 14 summarizes how RAS was used in the different sectors of the paving market. These values were calculated using the average percentages of RAS reported for the different sectors and adjusted to account for the difference in reported RAP tons and the tons calculated from the percentage by sector.

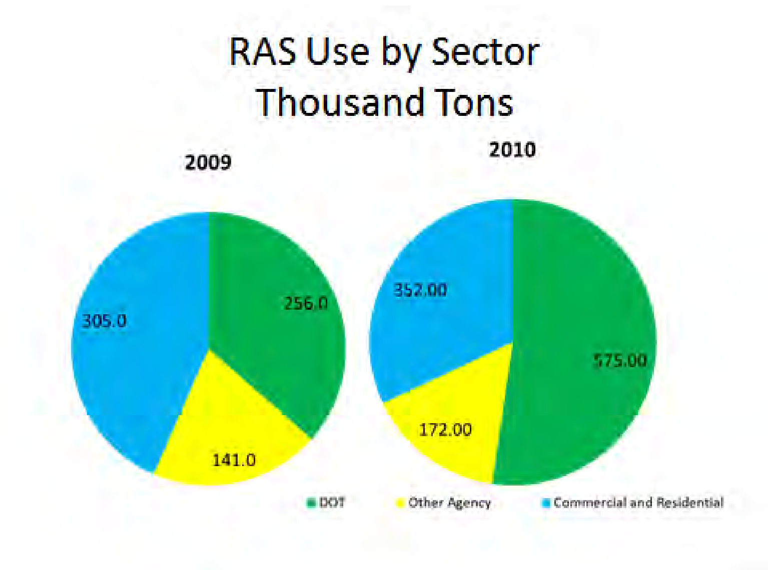


Figure 14: Summary of RAS use by sector.

Figure 15 shows states where plant-mix producers reported using RAS in 2009 and/or 2010.

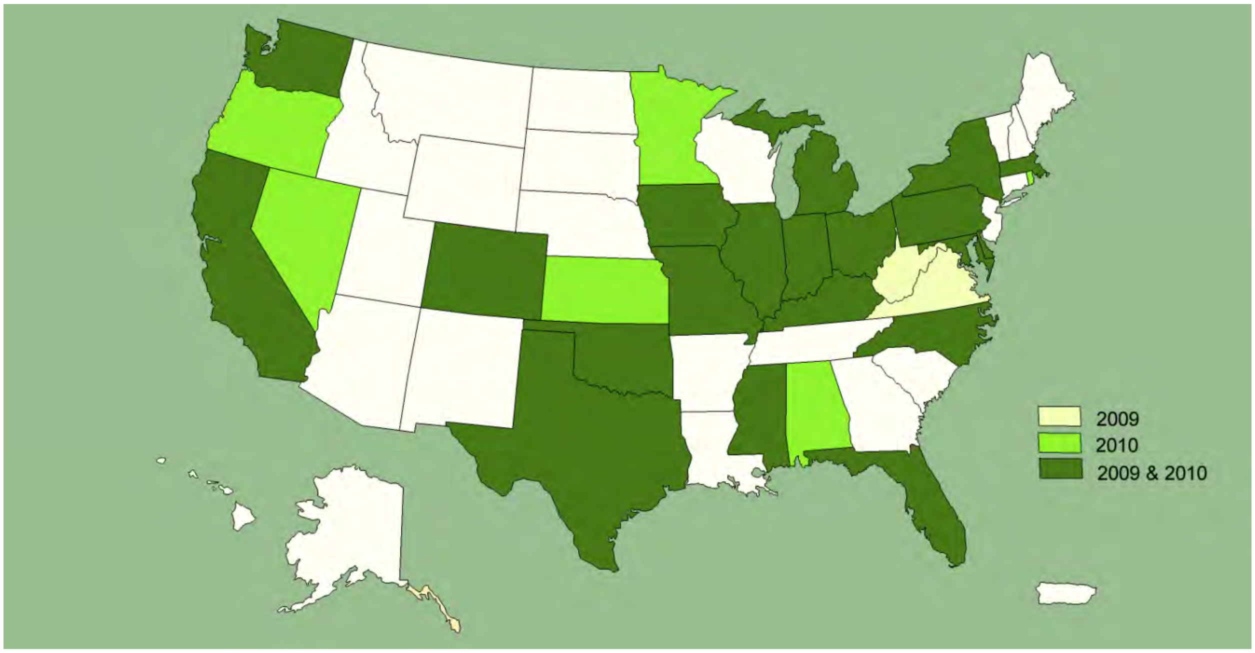


Figure 15: States with companies/branches reporting using RAS

RAS use increased from 702,000 to 1.10 million tons from 2009 to 2010, a 57 percent increase. The number of companies/branches using RAS increased from 44 to 61, a 39 percent increase. The number of states where plant mix producers reported using RAS increased from 23 to 26 from 2009 to 2010.

Warm-Mix Asphalt

Table 6 summarizes WMA data from the survey. The survey asked producers their estimated percentages of tons produced for the different sectors and the percent of which technologies were used. It is not necessary to calculate estimated values since the percent will not change.

WMA saw a tremendous increase between 2009 and 2010. The number of companies/branches using WMA increased from 85 to 121. The percent of DOT, other agency, and commercial/residential mixes using WMA increased from 6.3 to 15.0, 4.4 to 11.7, and 4.5 to 11.6, respectively.

Table 6: Summary of WMA data.

	Reported % of Sector		Estimated Total Tons, million	
	2009	2010	2009	2010
Companies/Branches Reporting Using WMA	85	121		
DOT	6.3%	15.0%	10.7	25.8
Other Agency	4.4%	11.7%	3.7	10.1
Commercial & Residential	4.5%	11.6%	4.8	11.7
Chemical Additive %	15%	6%		
Additive Foaming %	2%	1%		
Plant Foaming %	83%	92%		
Organic Additive %	0.3	1%		

Figures 16 through 19 show the estimated total tons of WMA produced in each state. It should be noted that the accuracy of data for individual states varies depending on the number of responses received from each state and the total number of tons represented by the responses. Nationally, the total tons of WMA increased from 19.2 million tons to 47.6 million tons, a 148 percent increase. Plant foaming is used most often in producing WMA. Additives accounted for about 17 and 8 percent of the total WMA production in 2009 and 2010, respectively.

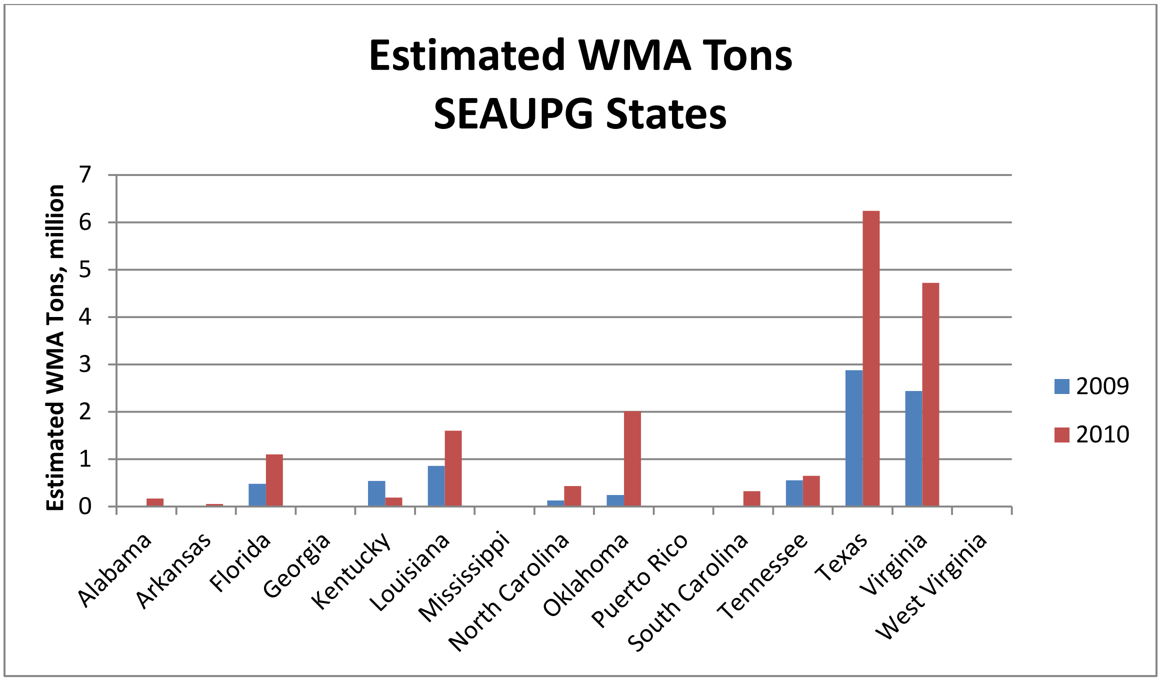


Figure 16: Estimated total WMA tons for Southeast Asphalt User Producer Group states/territories

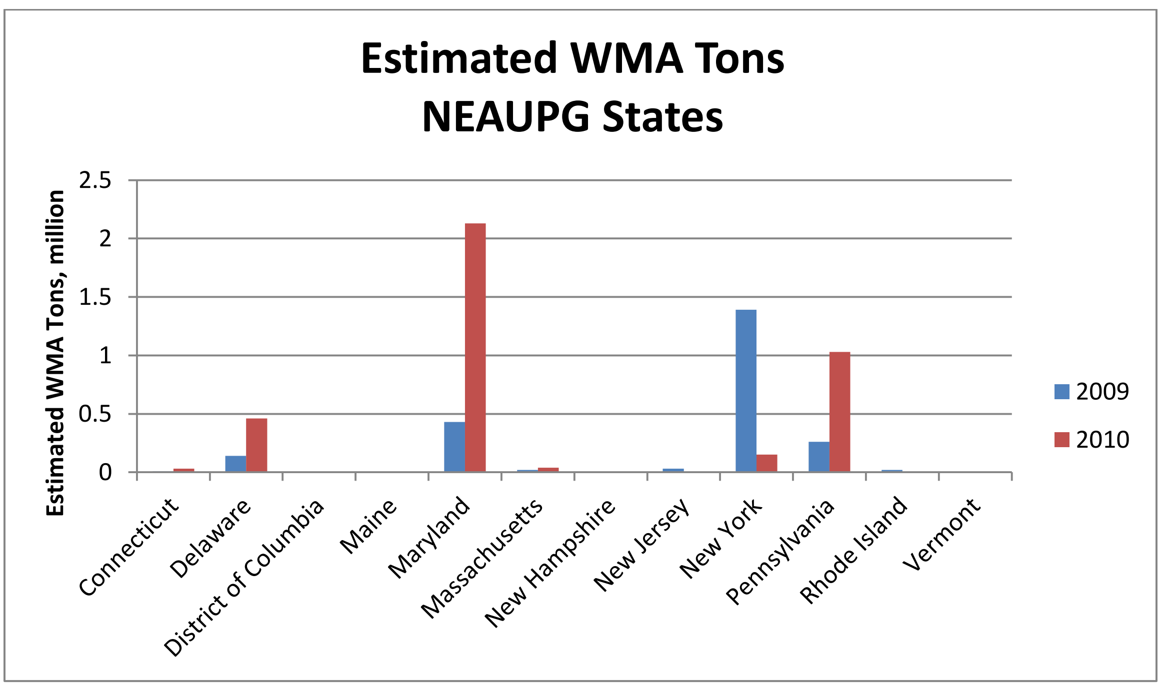


Figure 17: Estimated total WMA tons for Northeast User Producer Group states

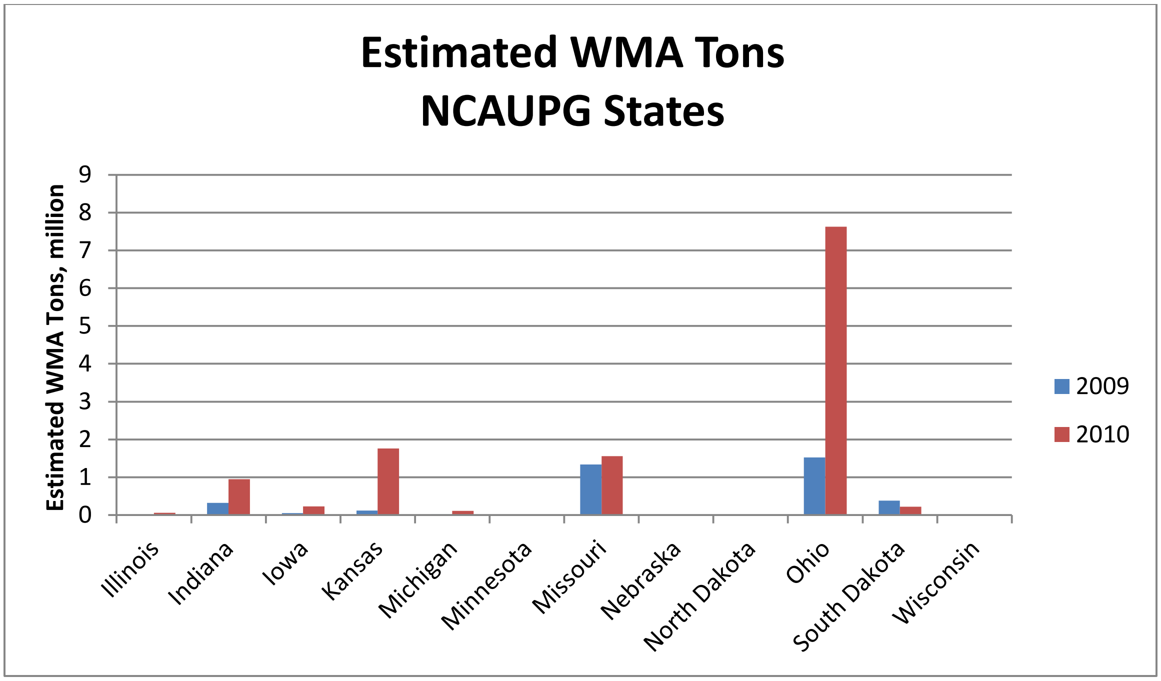


Figure 18: Estimated total WMA tons for North Central Asphalt User Producer Group states

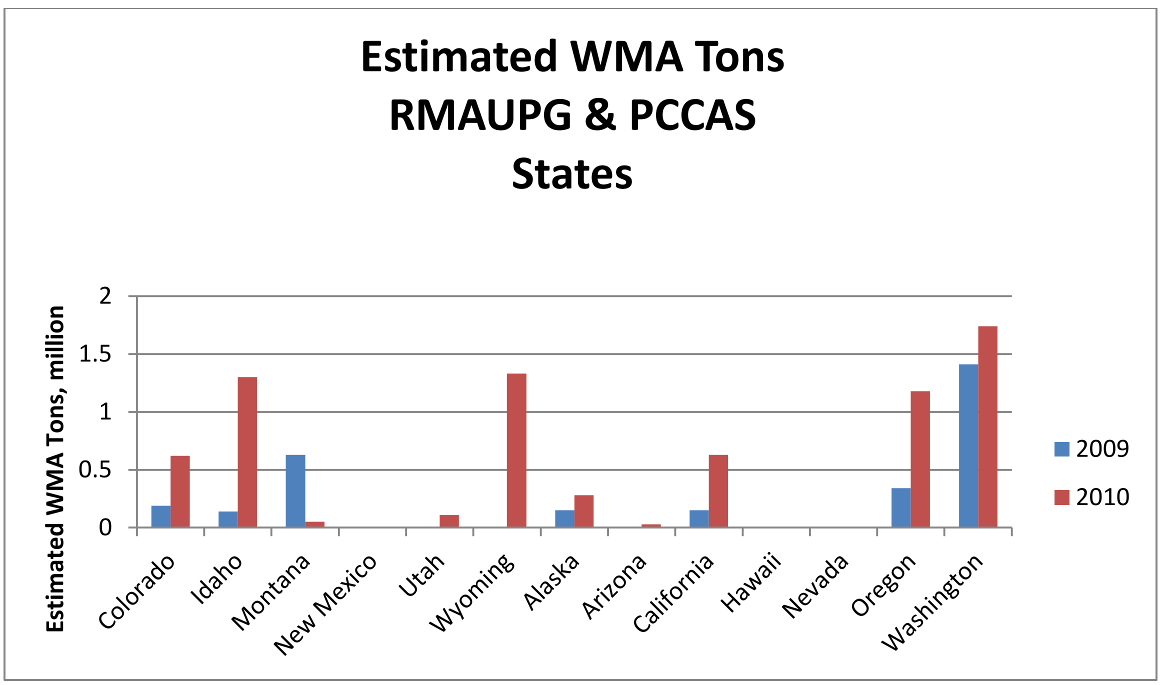


Figure 19: Estimated total WMA tons for Rocky Mountain Asphalt User Producer Group and Pacific Coast Conference on Asphalt Specification states

Summary and Conclusions

The survey clearly shows the asphalt pavement industry continues to improve its environmental stewardship through its increasing use of RAP, RAS, and WMA. These technologies reduce the need for new materials, especially asphalt binders, and energy use.

RAP use began in the 1970s and now most contractors are using RAP in mixes, with 96 percent of the contractors/branches reporting using RAP and over 86 percent of these contractors reporting excess RAP. From 2009 to 2010 the amount of RAP used in HMA/WMA increased from 56.0 to 62.1 million tons, for a 10 percent increase.

Assuming 5 percent liquid asphalt in RAP, this represents over 3 million tons (19 million barrels) of asphalt binder conserved.

RAS use increased from 702,000 to 1.10 million tons from 2009 to 2010, a 57 percent increase. Assuming a conservative asphalt content of 20 percent for the shingles, this represents 234,000 tons (1.5 million barrels) of asphalt binder.

WMA was first used in the U.S. in 2004, with the market growing tremendously since that time. In 2009 the total tonnage of WMA is estimated at 19.2 million tons. This grew to 47.6 million tons in 2010, for a 148 percent increase. Plant foaming is used most often in producing WMA. Additives accounted for about 17 and 8 percent of the total WMA production in 2009 and 2010, respectively.

Bibliography

Copeland, A., Jones, C., & Bukowski, J. (2010, March/April). *Public Roads.* Retrieved September 20, 2011, from Federal Highway Administration: http://www.fhwa.dot.gov/publications/publicroads/10mar/06.cfm

NAPA

NATIONAL ASPHALT
PAVEMENT ASSOCIATION

National Asphalt Pavement Association
NAPA Building
5100 Forbes Blvd.
Lanham, Maryland 20706-4407
www.AsphaltPavement.org
napa@AsphaltPavement.org
Tel: 301-731-4748
Toll Free: 1-888-468-6499
Fax: 301-731-4621
Publication Sales:
http://store.AsphaltPavement.org
napa-orders@abdintl.com
Toll Free: 888-600-4474
Tel: 412-741-6314
Fax: 412-741-0609

Asphalt Pavement Mix Production Survey

IS 138

ASPHALT
100% RECYCLABLE

Asphalt Pavement Mix Production Survey On Reclaimed Asphalt Pavement, Reclaimed Asphalt Shingles, And Warm-mix Asphalt Usage: 2009-2010

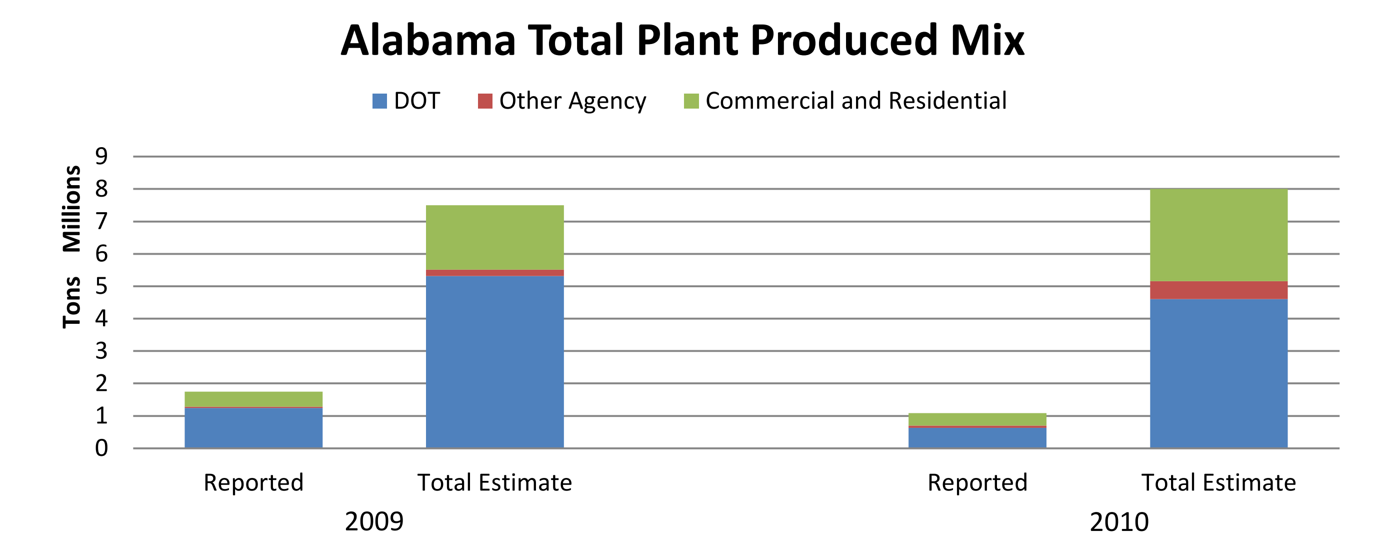
Appendix B

Alabama

Table B1 summarizes the results received from asphalt mix producers in Alabama. The charts are used to summarize information calculated from information provided by the survey respondents.

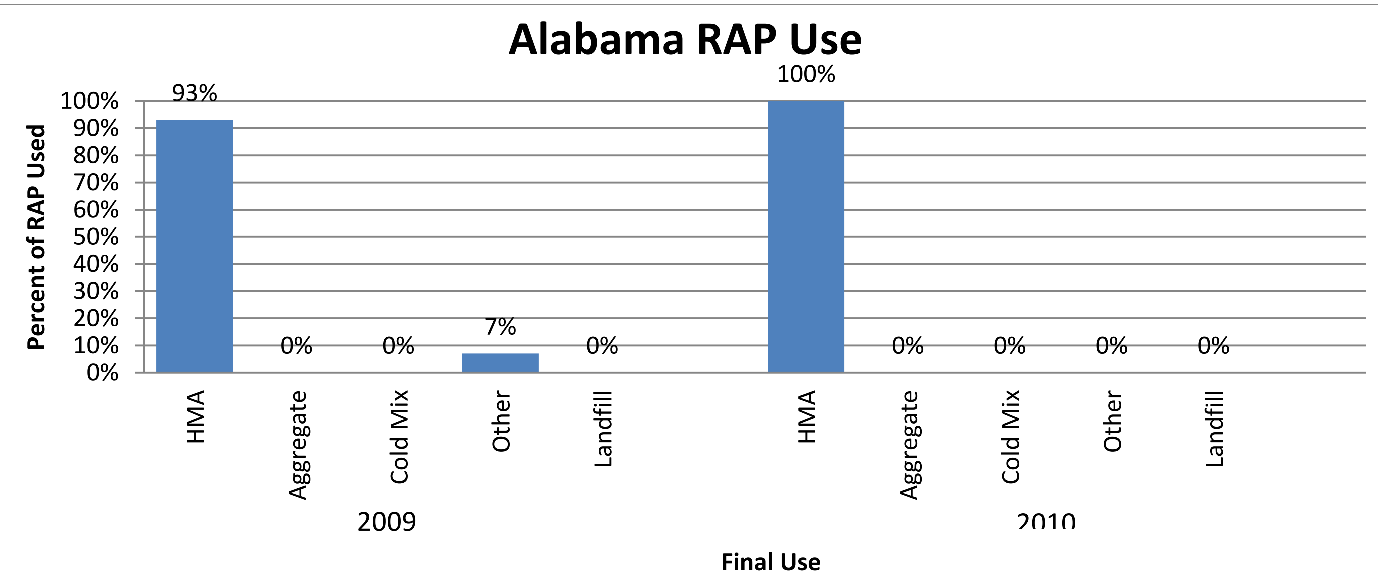
Total Asphalt Mix Tonnage

Companies responding: 3

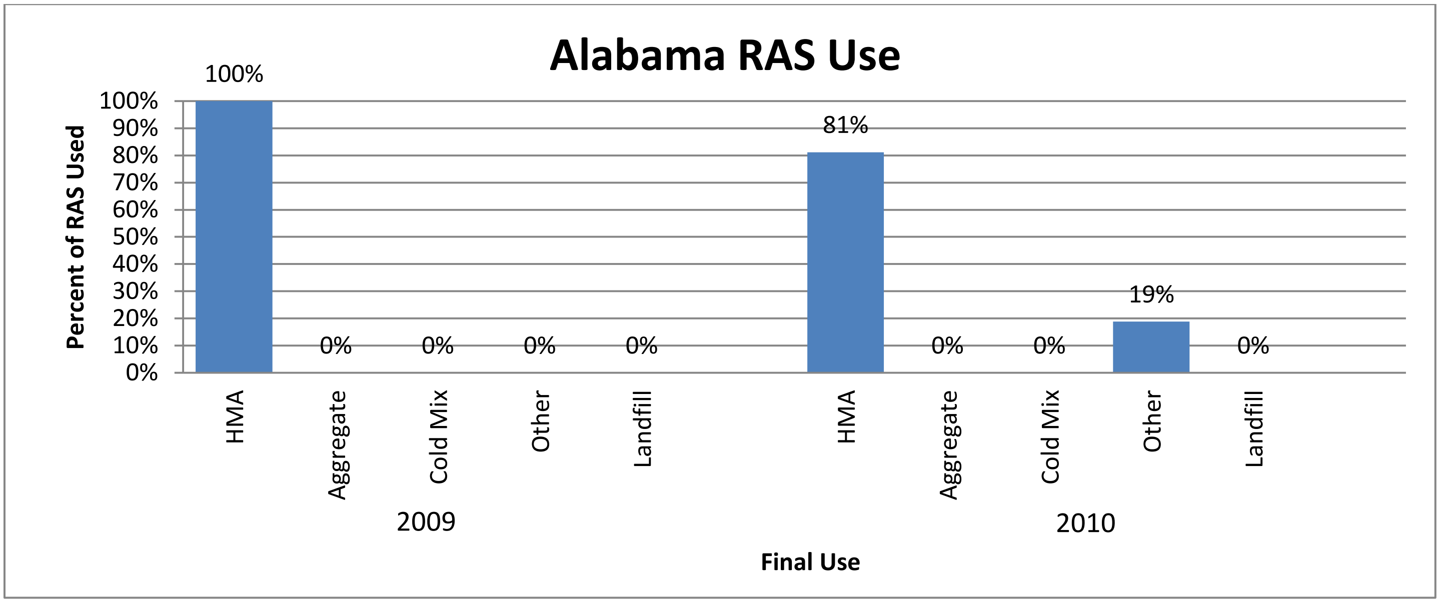


The total estimated tonnage for the state was provided by the Alabama Asphalt Pavement Association. The ratios of DOT, other agency, and commercial and residential tons to the reported values were used to calculate total tonnages for these three categories.

RAP Use



RAS Use



WMA Use

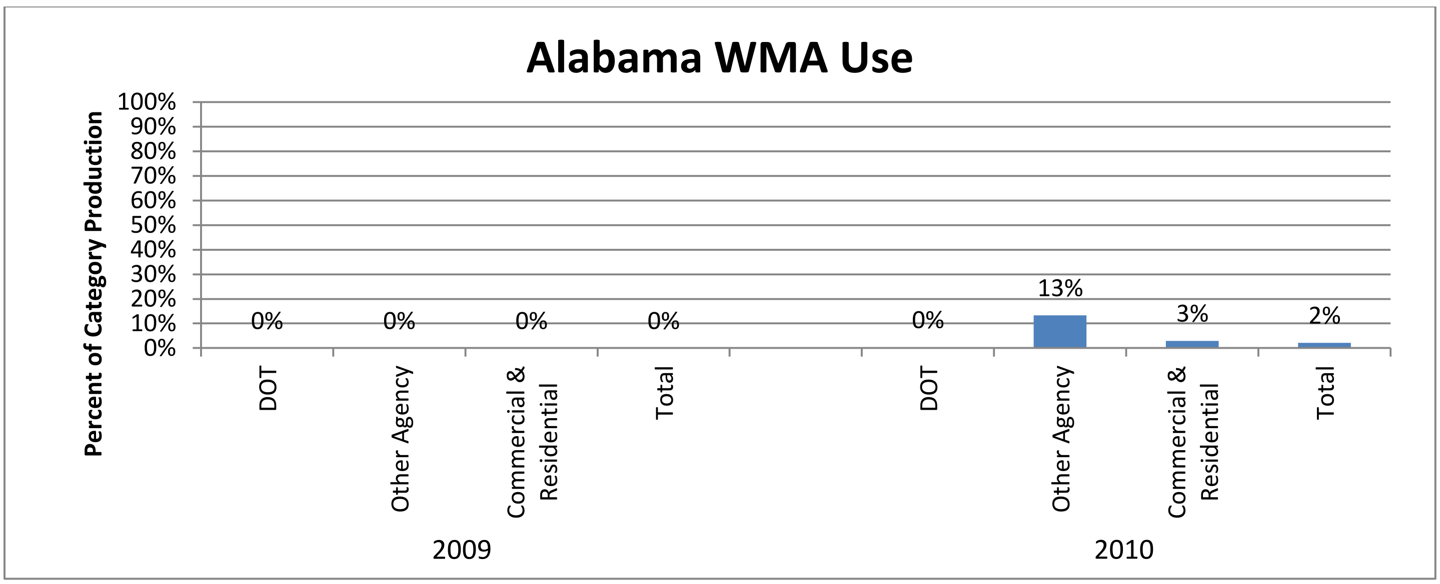


Table B 1 Summary of Alabama Data

Companies Reporting 3

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,241,200	626,900	5,319,125	4,603,212
Total Other Agency Tonnage	45,000	75,000	192,846	550,711
Total Commercial & Residential Tonnage	463,900	387,600	1,988,029	2,846,076
Total Tonnage	1,750,100	1,089,500	7,500,000	8,000,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	501,400	420,900	2,148,734	3,090,592
RAP Tons used in HMA/WMA	332,000	277,400	1,422,776	2,036,898
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	25,000	-	107,137	-
RAP Tons Landfilled	20	20	86	147
Average % RAP in DOT Mixes	16%	21%		
Average % RAP in Other Agency Mixes	21%	24%		
Average % RAP in Commercial & Residential Mixes	22%	26%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	33%	67%		
RAS Tons Received	16,000	16,000	68,568	117,485
RAS Tons used in HMA/WMA	13,500	10,800	57,854	79,302
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	2,500	-	18,357
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	2%	3%		
Average % RAS in Other Agency Mixes	2%	0%		
Average % RAS in Commercial & Residential Mixes	2%	2%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	67%		
WMA DOT Tonnage	-	2,238	-	16,433
WMA Other Agency Tonnage	-	10,000	-	73,428
WMA Commercial & Residential Tonnage	-	11,528	-	84,648
Total WMA Tonnage	-	23,766	-	174,509
Percent WMA Tons using Chemical Additives	0.0%	0.0%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	0.0%	100.0%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

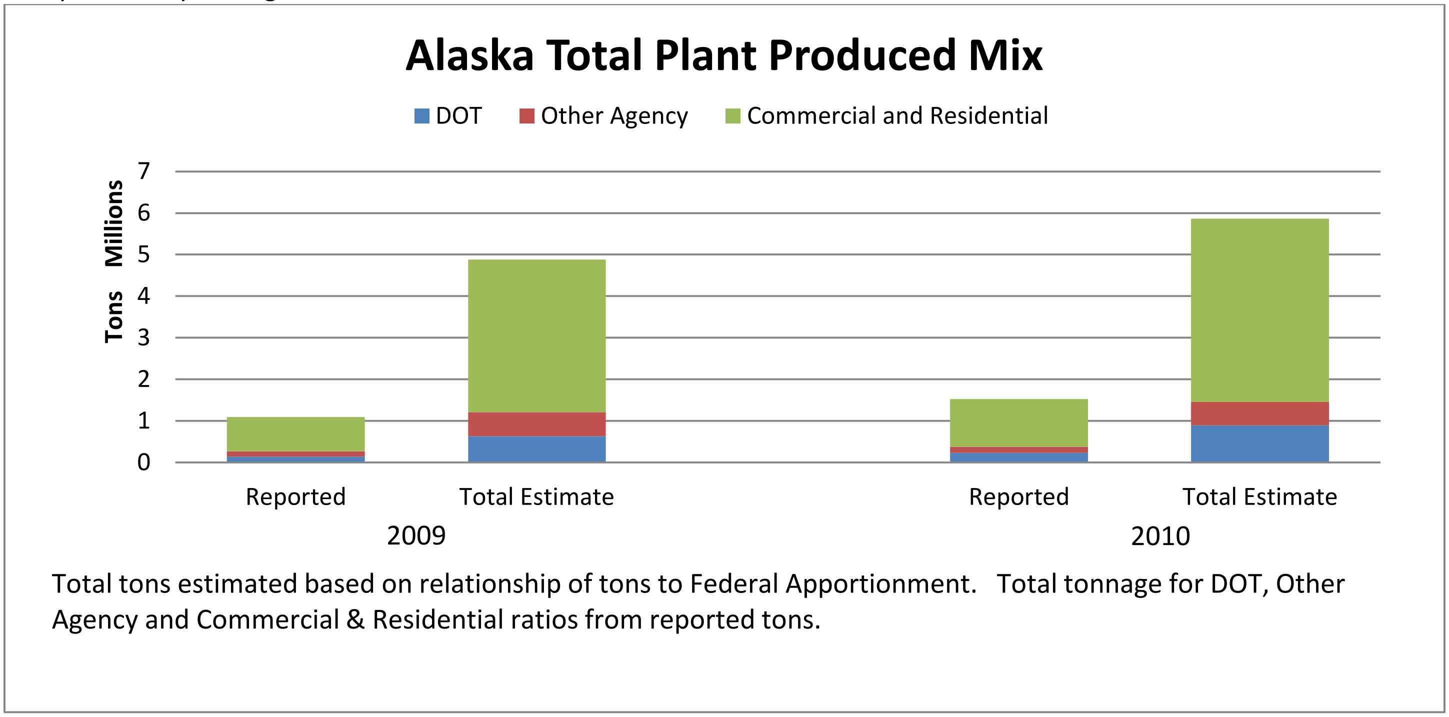
1. Total tonnage of HMA/WMA provided by Alabama Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential calculated based on ratios from reported tons.

Alaska

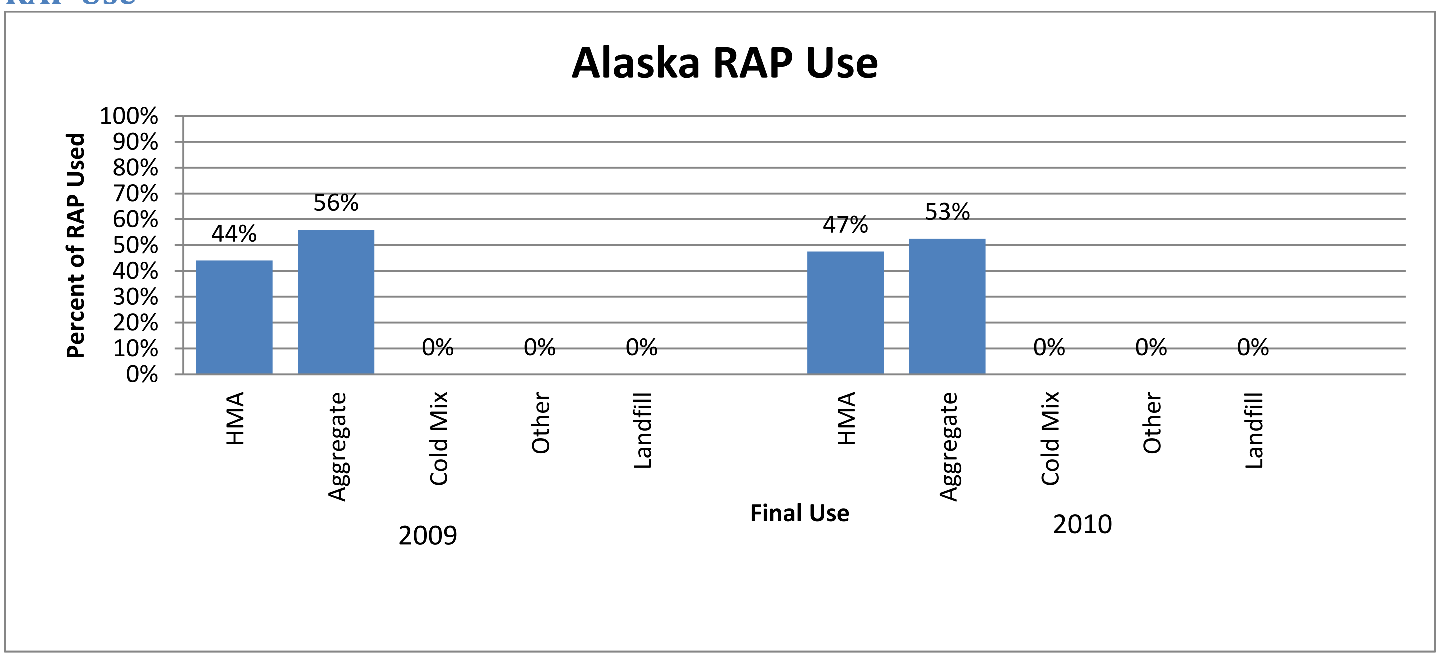
Table B2 summarizes the results received from asphalt mix producers in Alaska.

Total Asphalt Mix Tonnage

Companies responding: 3



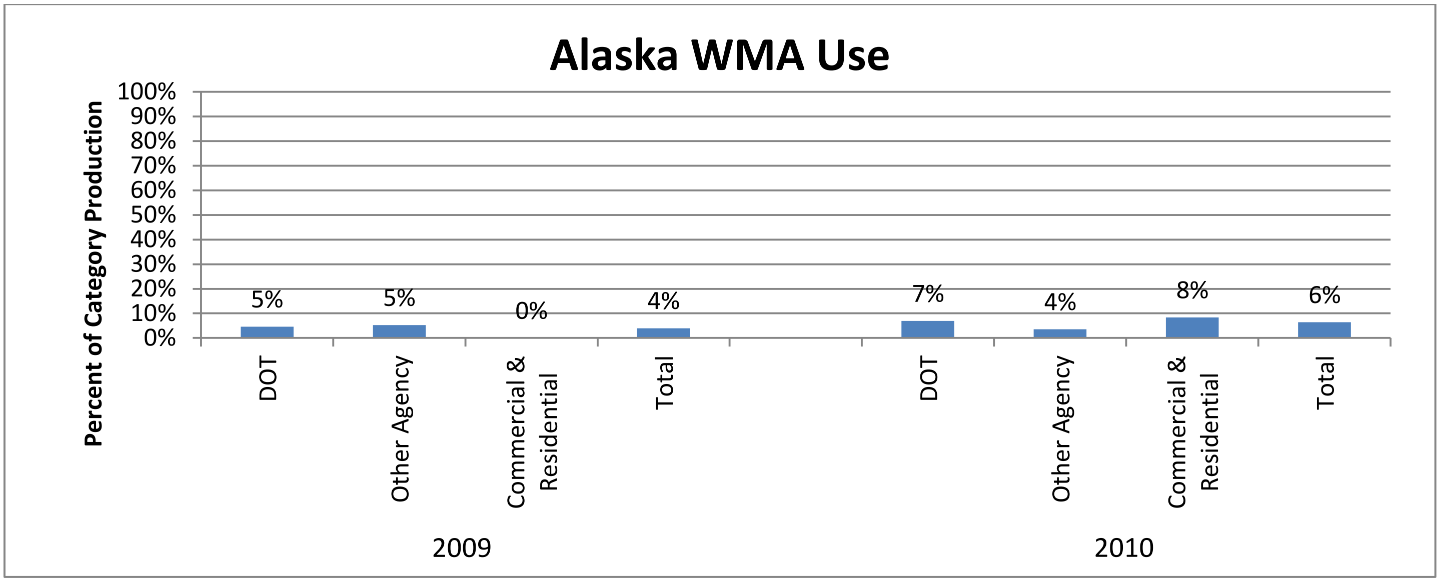
RAP Use



RAS Use

No companies reported using RAS.

WMA Use



Alaska WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
5%
5%
0%
4%
7%
4%
8%
6%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 2: Summary of Alaska Data

Companies Reporting 3

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	551,263	768,205	2,465,396	2,950,016
Total Other Agency Tonnage	142,140	232,269	635,686	891,944
Total Commercial & Residential Tonnage	128,014	147,537	572,512	566,564
Total Tonnage	821,417	1,148,011	3,673,595	4,408,524

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	67%	67%		
RAP Tons Received	151,519	56,517	677,633	217,033
RAP Tons used in HMA/WMA	38,167	34,598	170,693	132,861
RAP Tons used as Aggregate	48,557	38,261	217,160	146,928
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	10%	5%		
Average % RAP in Other Agency Mixes	6%	2%		
Average % RAP in Commercial & Residential Mixes	9%	6%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	67%	33%		
WMA DOT Tonnage	25,487	53,105	113,983	203,930
WMA Other Agency Tonnage	7,460	8,294	33,361	31,849
WMA Commercial & Residential Tonnage	-	12,362	-	47,472
Total WMA Tonnage	32,946	73,760	147,345	283,251
Percent WMA Tons using Chemical Additives	18.6%	0.0%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	81.4%	100.0%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

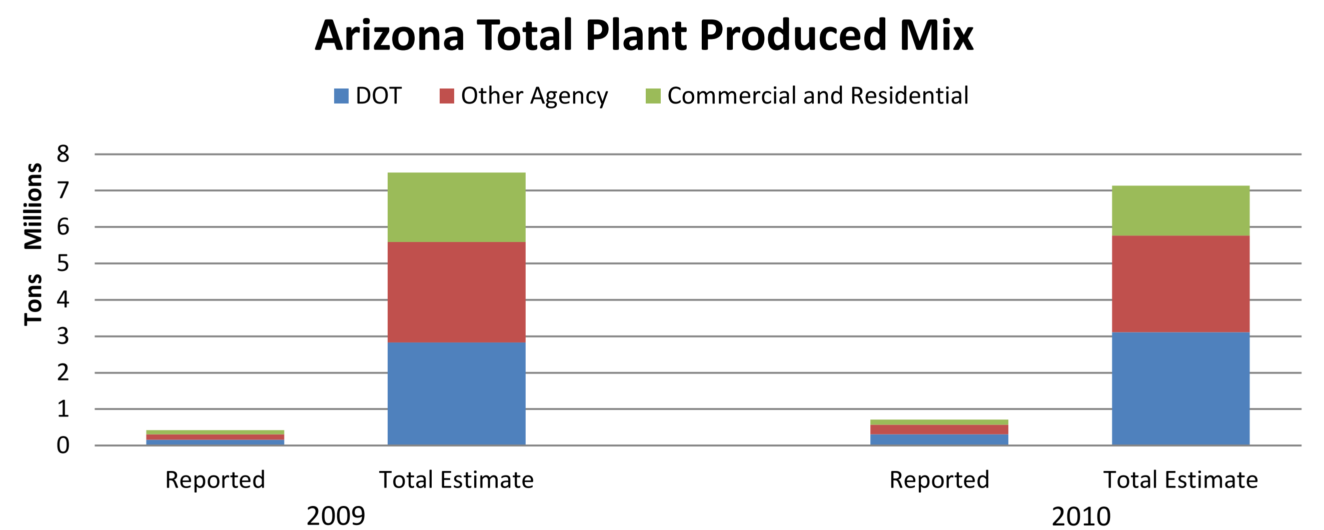
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

Arizona

Table B3 summarizes the results received from asphalt mix producers in Arizona.

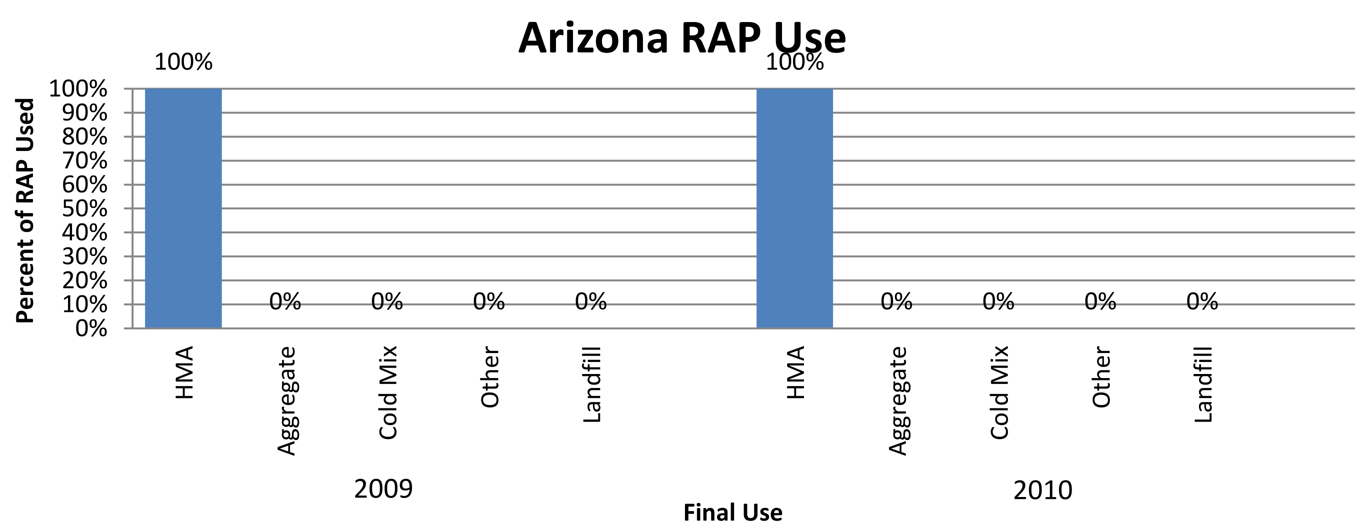
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

RAP Use



RAS Use

No companies reported using RAS in 2009 or 2010.

WMA Use

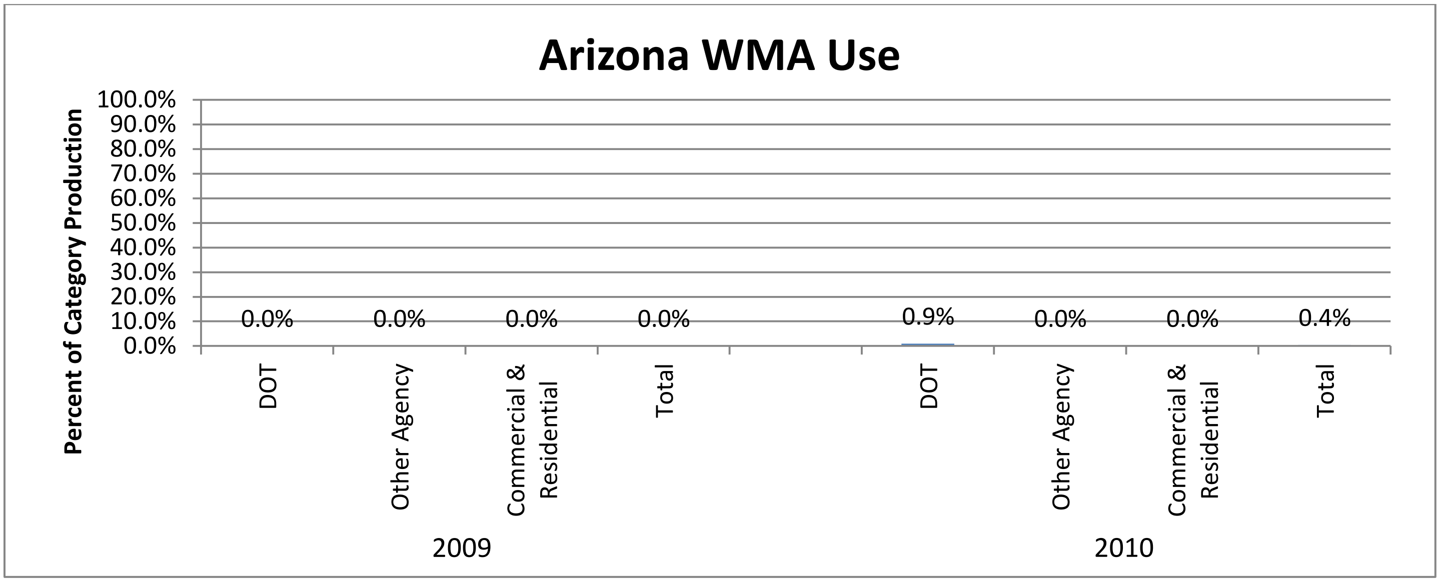

Arizona WMA Use
Percent of Category Production
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.9%
0.0%
0.0%
0.4%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 3: Summary of Arizona Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	158,523	309,595	2,832,459	3,107,020
Total Other Agency Tonnage	154,262	264,797	2,756,312	2,657,445
Total Commercial & Residential Tonnage	106,754	136,599	1,907,454	1,370,877
Total Tonnage	419,539	710,991	7,496,224	7,135,341
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	20,000	20,000	357,355	200,715
RAP Tons used in HMA/WMA	54,266	37,000	969,612	371,323
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	0%	9%		
Average % RAP in Other Agency Mixes	8%	10%		
Average % RAP in Commercial & Residential Mixes	19%	20%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	50%		
WMA DOT Tonnage	-	2,796	-	28,059
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	2,796	-	28,059
Percent WMA Tons using Chemical Additives	0.0%	0.0%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	0.0%	100.0%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

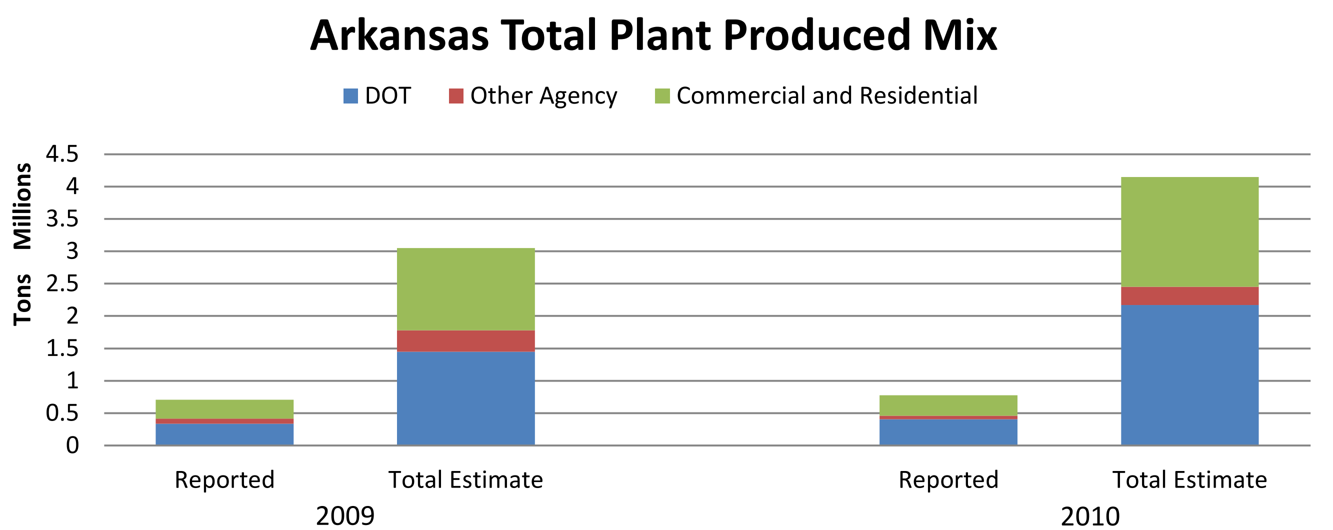
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

Arkansas

Table B4 summarizes the results received from asphalt mix producers in Arkansas.

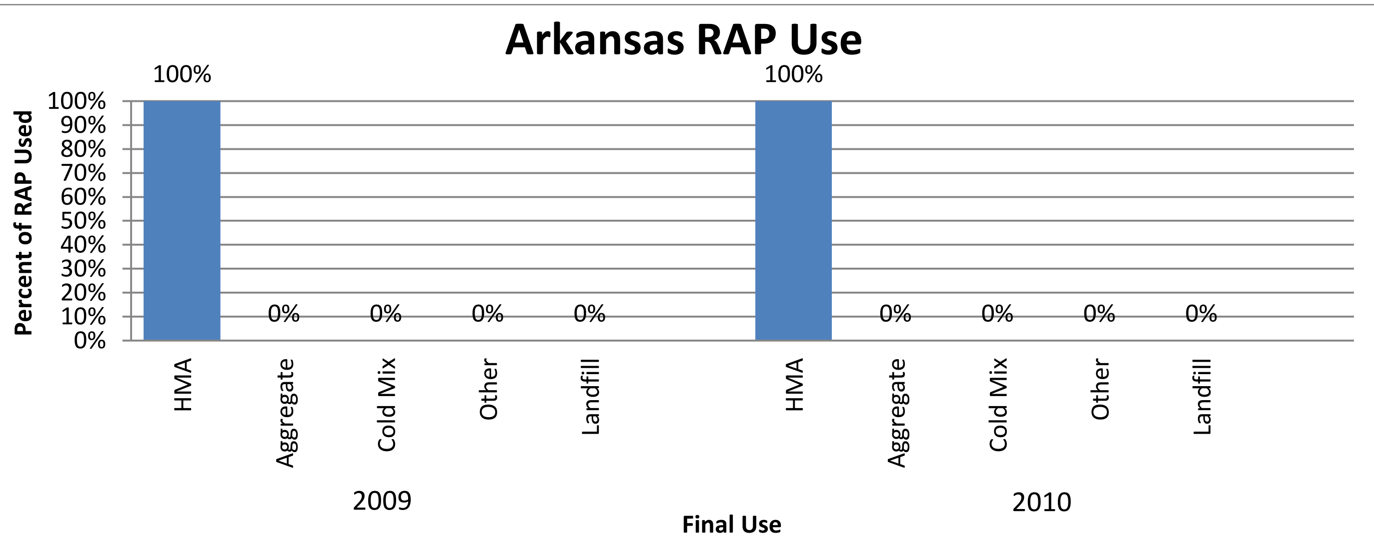
Total Asphalt Mix Tonnage

Companies responding: 3



Total tonnage provided by Arkansas Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

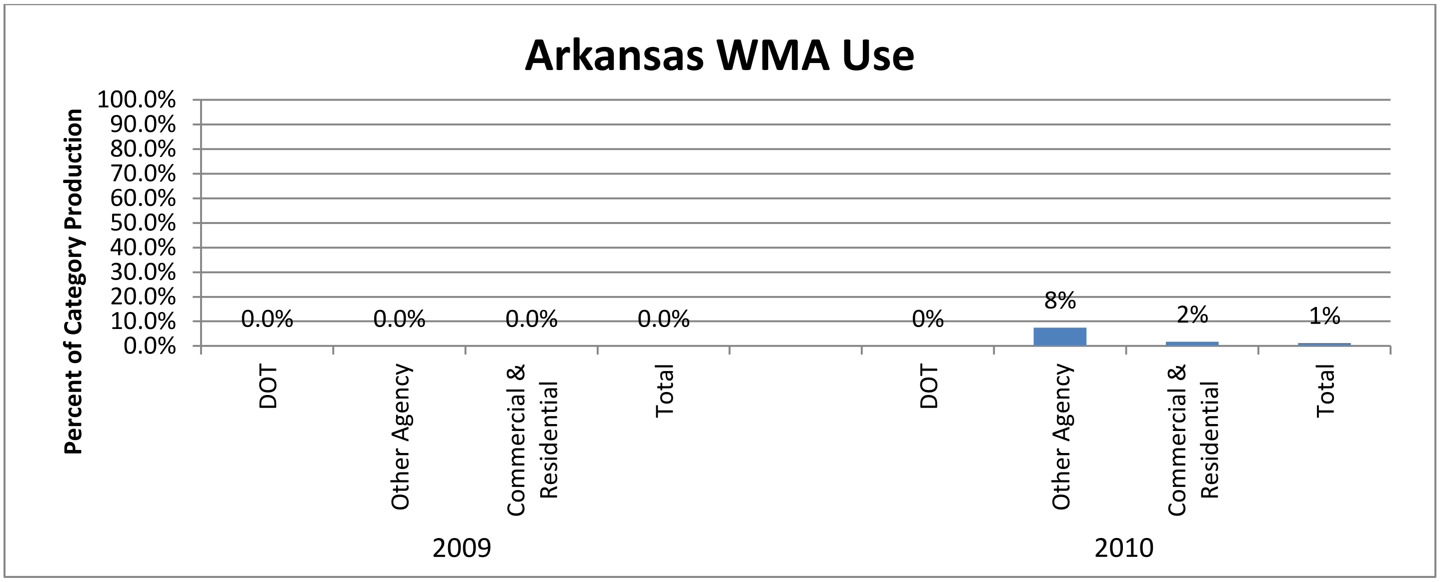
RAP Use



RAS Use

One company reported receiving RAS in 2010; however, no RAS was used in any mixes

WMA Use



Arkansas WMA Use
Percent of Category Production
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0%
8%
2%
1%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 4: Arkansas Summary

Companies Reporting 3

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	337,000	407,000	1,448,926	2,172,063
Total Other Agency Tonnage	77,000	52,000	331,060	277,512
Total Commercial & Residential Tonnage	295,000	318,000	1,268,347	1,697,091
Total Tonnage	709,000	777,000	3,048,333	4,146,667
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	98,000	100,000	421,349	533,677
RAP Tons used in HMA/WMA	71,085	81,623	305,628	435,604
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	22	23	96	124
Average % RAP in DOT Mixes	11%	12%		
Average % RAP in Other Agency Mixes	6%	9%		
Average % RAP in Commercial & Residential Mixes	9%	8%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	33%		
RAS Tons Received	-	200	-	1,067
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	33%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	3,900	-	20,813
WMA Commercial & Residential Tonnage	-	5,450	-	29,085
Total WMA Tonnage	-	9,350	-	49,899
Percent WMA Tons using Chemical Additives	0.0%	41.8%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	0.0%	58.2%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

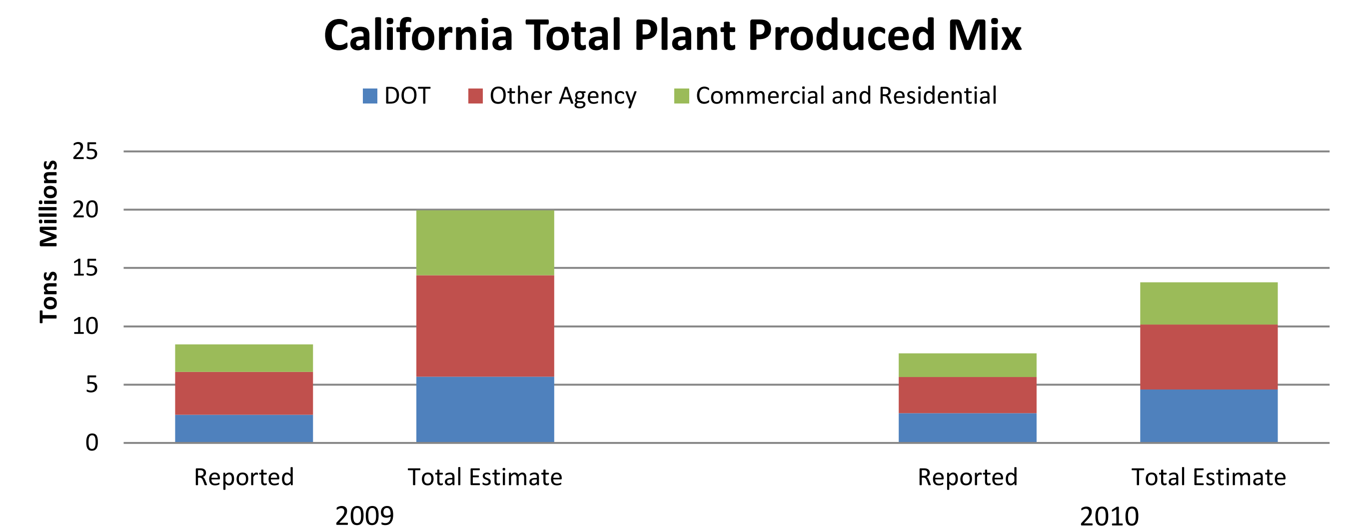
1. Total tonnage provided by Arkansas Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

California

Table B5 summarizes the results received from asphalt mix producers in California. The charts are used to summarize information calculated from information provided by the survey respondents.

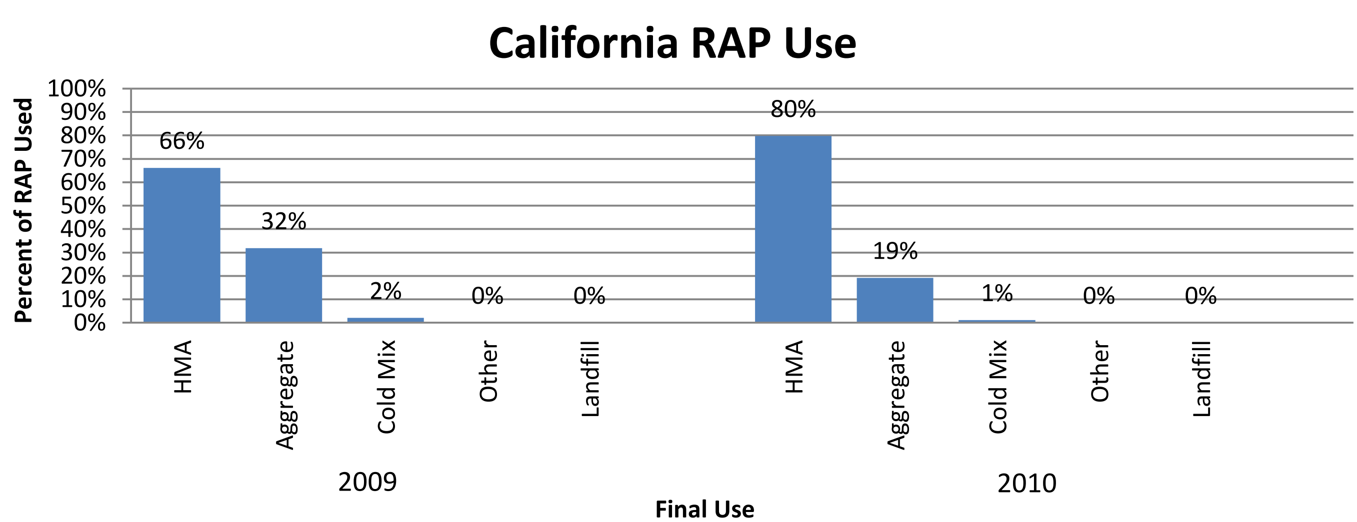
Total Asphalt Mix Tonnage

Companies responding: 6

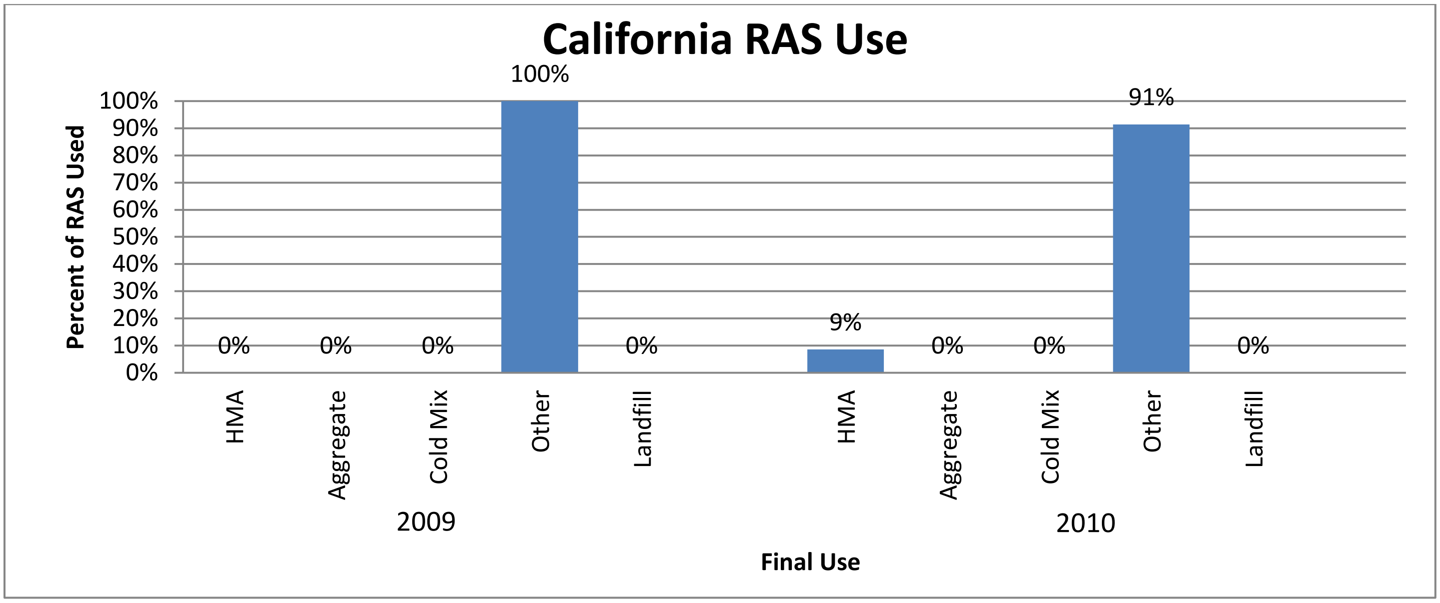


Total DOT tonnage provided by California Asphalt Pavement Association and ratio of reported total tons to reported total tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential ratios from reported tons.

RAP Use



RAS Use



WMA Use

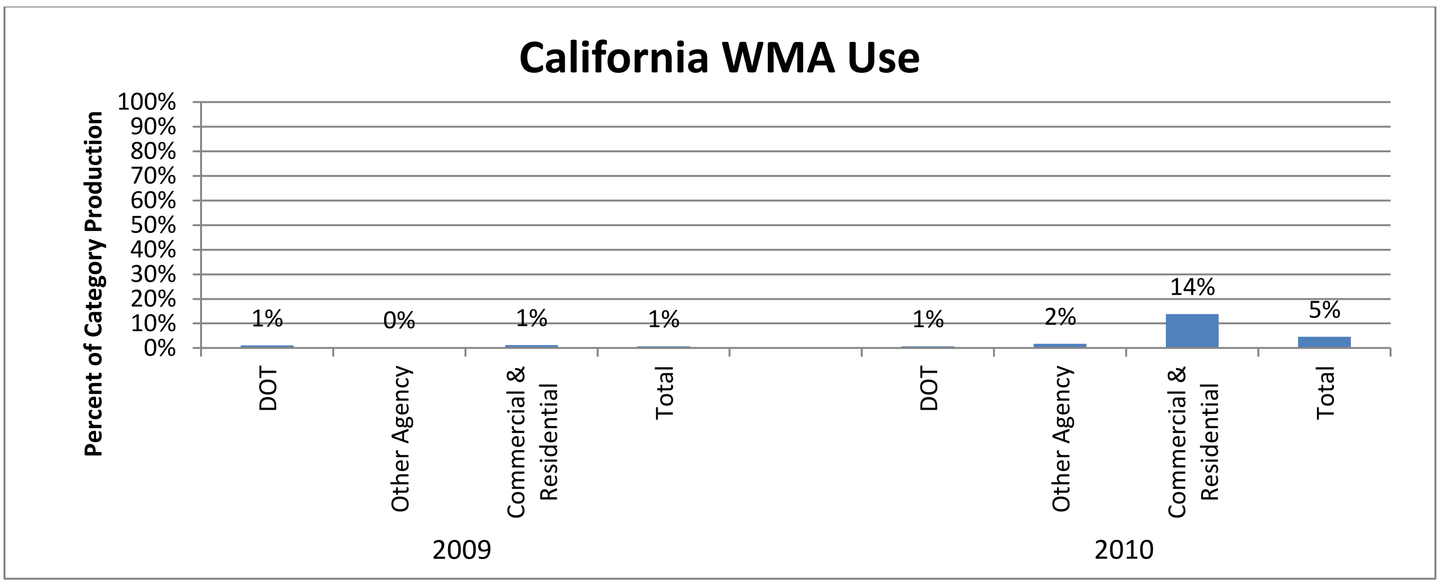


Table B 5: Summary of California Data

Companies Reporting 6

HMA/WMA	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,405,000	2,550,000	5,687,328	4,576,937
Total Other Agency Tonnage	3,672,146	3,106,825	8,683,866	5,576,369
Total Commercial & Residential Tonnage	2,366,205	2,025,000	5,595,585	3,634,626
Total Tonnage	8,443,351	7,681,825	19,966,779	13,787,932
Reclaimed Asphalt Pavement (RAP)	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	1,020,902	895,514	2,414,222	1,607,338
RAP Tons used in HMA/WMA	826,529	1,440,514	1,954,570	2,585,546
RAP Tons used as Aggregate	397,900	345,630	940,951	620,363
RAP Tons used in Cold Mix	25,000	20,000	59,120	35,898
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	12%	12%		
Average % RAP in Other Agency Mixes	11%	13%		
Average % RAP in Commercial & Residential Mixes	17%	15%		
Reclaimed Asphalt Shingles (RAS)	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	17%	33%		
RAS Tons Received	12,000	12,050	28,378	21,628
RAS Tons used in HMA/WMA	-	1,030	-	1,849
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	12,000	11,000	28,378	19,744
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	1%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	83%		
WMA DOT Tonnage	25,200	18,500	59,593	33,205
WMA Other Agency Tonnage	10,450	53,341	24,712	95,741
WMA Commercial & Residential Tonnage	27,632	279,900	65,344	502,386
Total WMA Tonnage	63,282	351,741	149,649	631,332
Percent WMA Tons using Chemical Additives	8.3%	2.4%		
Percent WMA Tons using Additive Foaming	3.2%	1.5%		
Percent WMA Tons using Plant Foaming	88.4%	96.1%		
Percent WMA Tons using Organic Additive	0.1%	0.0%		

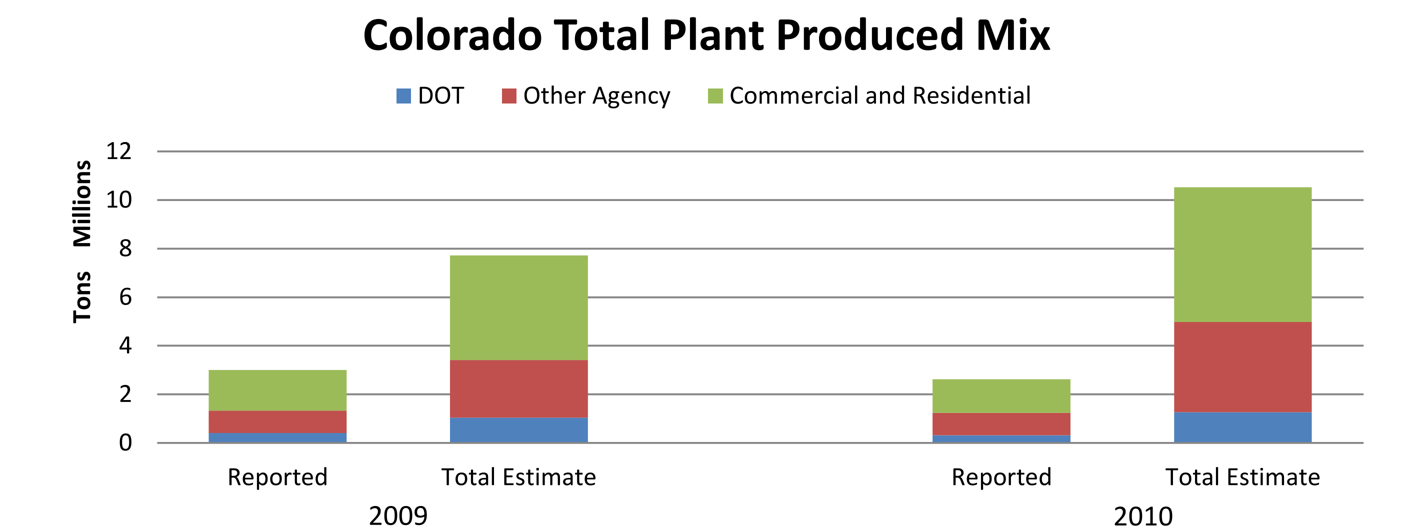
1. Total DOT tonnage provided by California Asphalt Pavement Association and ratio of reported total tons to reported DOT tons was used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

Colorado

Table B6 summarizes the results received from asphalt mix producers in Colorado. The charts are used to summarize information calculated from information provided by the survey respondents.

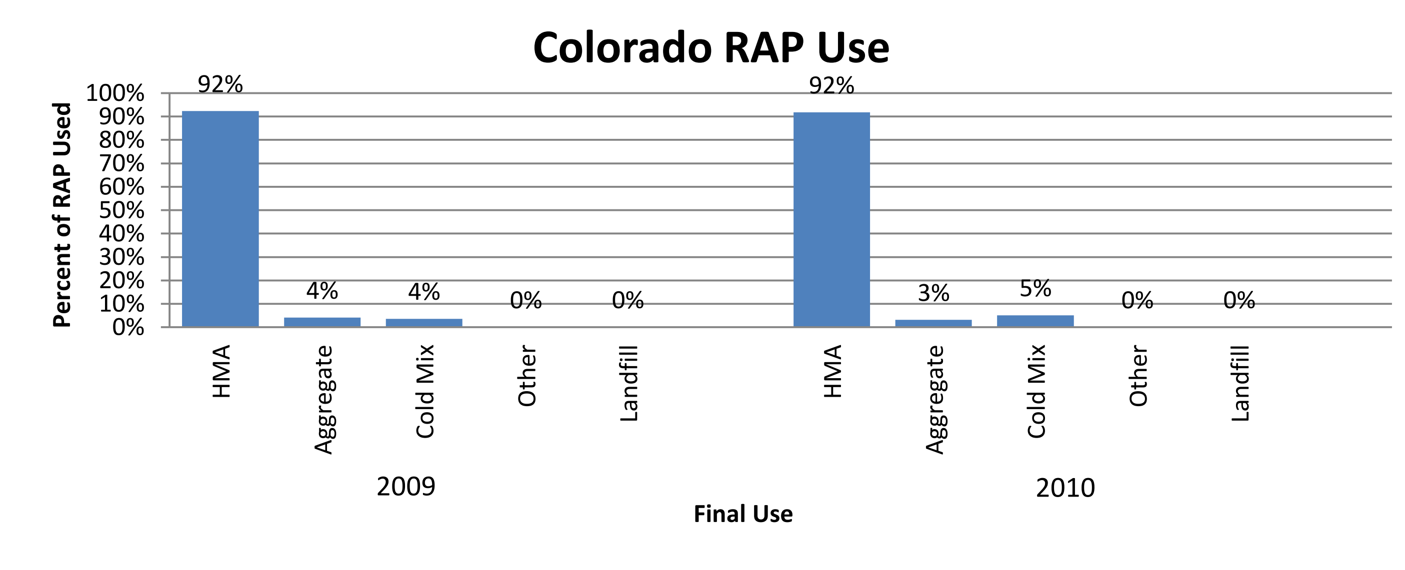
Total Asphalt Mix Tonnage

Companies responding: 8

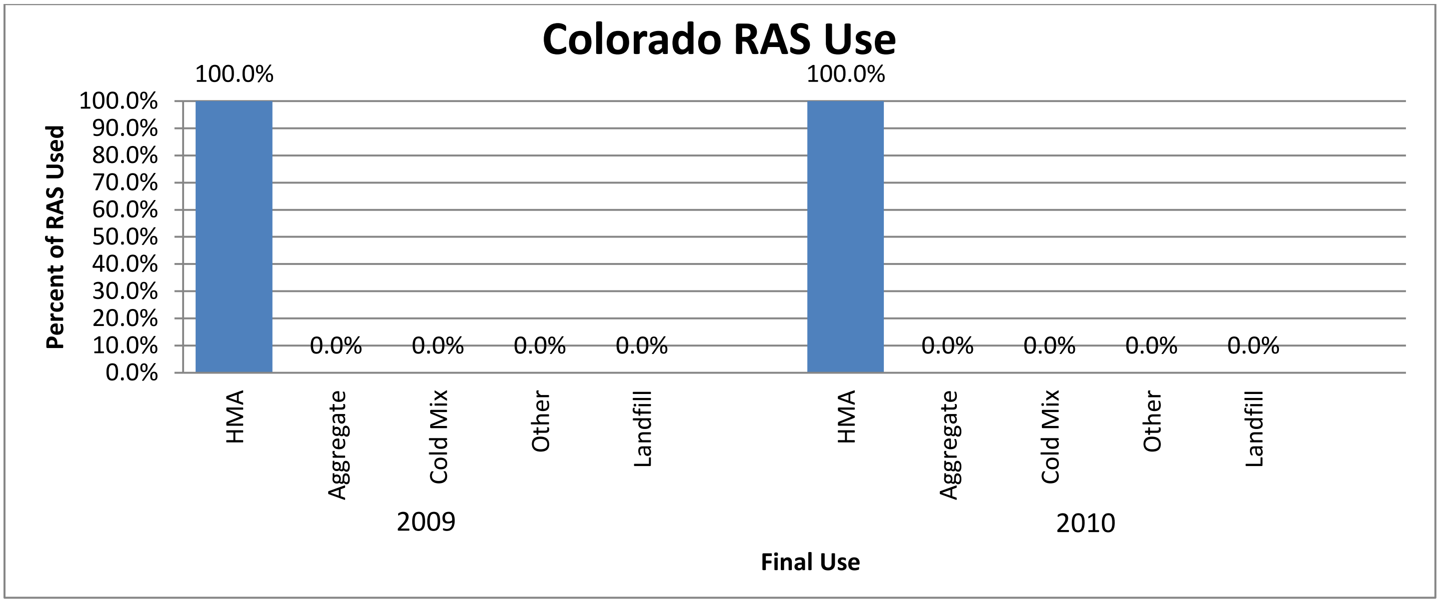


Total DOT tonnage provided by Colorado Asphalt Pavement Association and ratio of reported total tons to reported DOT tons was used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential ratios from reported tons.

RAP Use



RAS Use



WMA Use

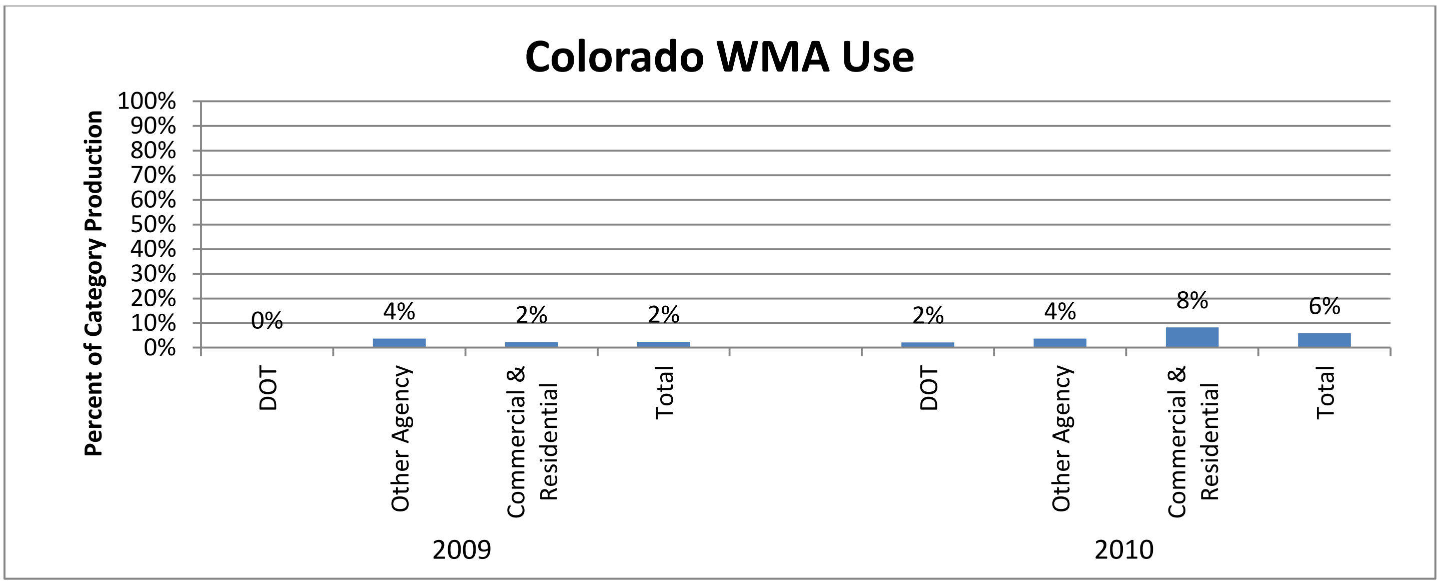


Table B 6: Summary of Colorado Data

Companies Reporting 8

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	401,944	314,268	1,035,394	1,262,143
Total Other Agency Tonnage	922,950	925,580	2,377,488	3,717,256
Total Commercial & Residential Tonnage	1,672,120	1,380,240	4,307,325	5,543,233
Total Tonnage	2,997,014	2,620,088	7,720,208	10,522,633
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	676,000	619,000	1,741,353	2,485,989
RAP Tons used in HMA/WMA	567,330	502,160	1,461,424	2,016,745
RAP Tons used as Aggregate	25,000	17,000	64,399	68,274
RAP Tons used in Cold Mix	22,180	28,000	57,135	112,452
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	42	48	107	191
Average % RAP in DOT Mixes	15%	15%		
Average % RAP in Other Agency Mixes	19%	19%		
Average % RAP in Commercial & Residential Mixes	24%	24%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	25%	25%		
RAS Tons Received	28,000	70,000	72,127	281,130
RAS Tons used in HMA/WMA	5,000	17,000	12,880	68,274
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	3%		
Average % RAS in Commercial & Residential Mixes	0%	2%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	38%	50%		
WMA DOT Tonnage	-	6,524	-	26,200
WMA Other Agency Tonnage	34,370	34,538	88,536	138,708
WMA Commercial & Residential Tonnage	38,035	113,468	97,977	455,703
Total WMA Tonnage	72,405	154,529	186,513	620,611
Percent WMA Tons using Chemical Additives	0.0%	0.0%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	100.0%	100.0%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

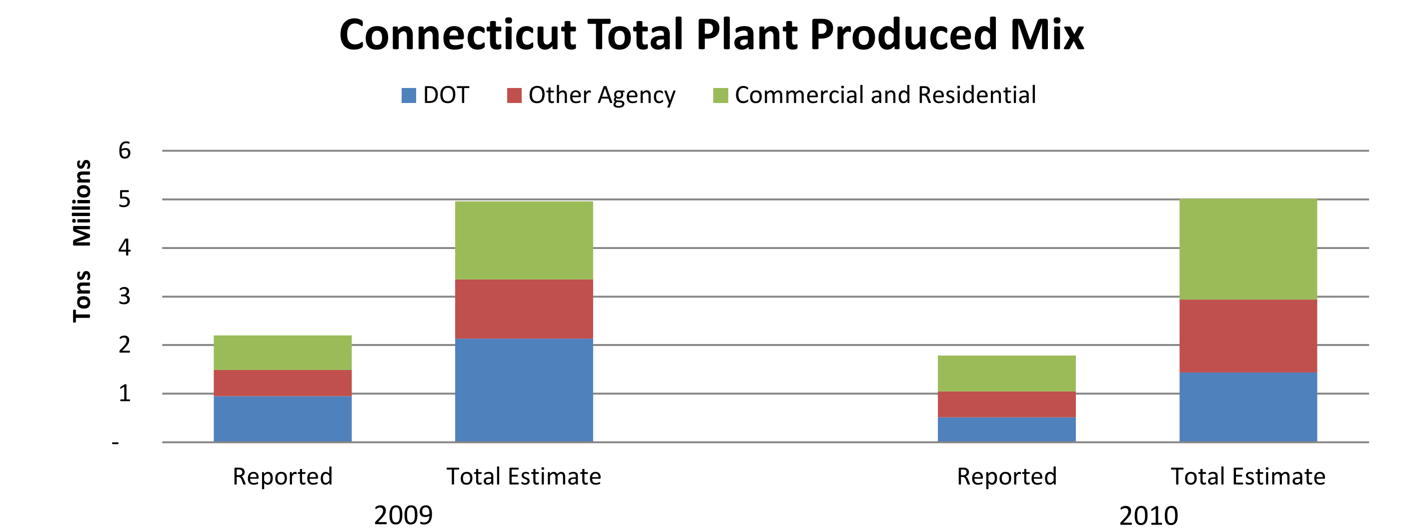
1. Total DOT tonnage provided by Colorado Asphalt Pavement Association and ratio of reported total tons to reported DOT tons was used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential ratios based on ratios from reported tons.

Connecticut

Table B7 summarizes the results received from asphalt mix producers in Connecticut. The charts are used to summarize information calculated from information provided by the survey respondents.

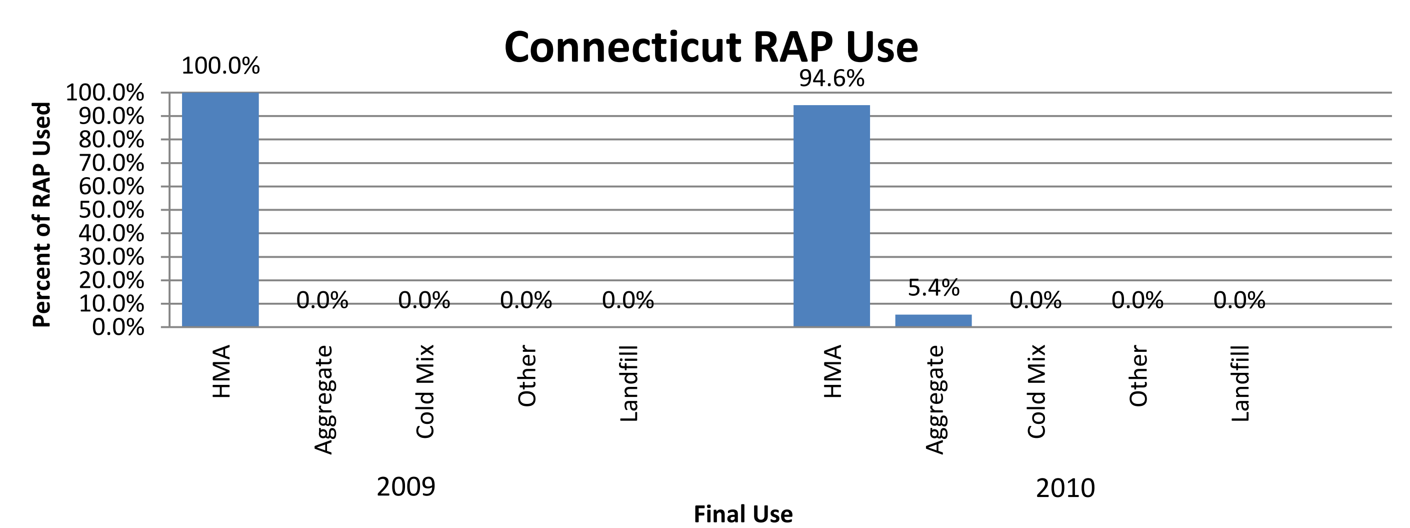
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

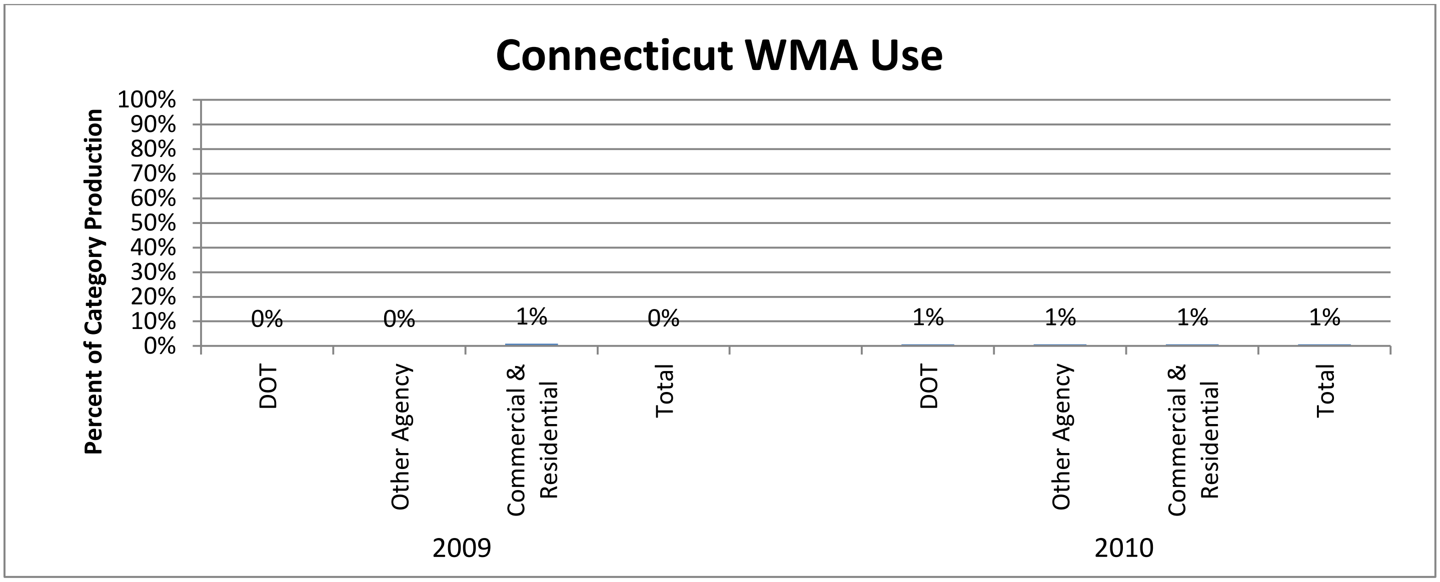
RAP Use



RAS Use

No contractors reported using RAS in 2009 or 2010.

WMA Use



Connecticut WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
0%
1%
0%
1%
1%
1%
1%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 7: Summary of Connecticut Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	946,000	511,000	2,134,920	1,434,638
Total Other Agency Tonnage	540,000	535,000	1,218,664	1,502,018
Total Commercial & Residential Tonnage	712,000	740,000	1,606,832	2,077,558
Total Tonnage	2,198,000	1,786,000	4,960,416	5,014,214
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	50%	100%		
RAP Tons Received	350,000	349,000	789,875	979,821
RAP Tons used in HMA/WMA	327,364	300,000	738,791	842,253
RAP Tons used as Aggregate	-	17,000	-	47,728
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	16	18	36	49
Average % RAP in DOT Mixes	13%	14%		
Average % RAP in Other Agency Mixes	16%	17%		
Average % RAP in Commercial & Residential Mixes	17%	19%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	0%		
WMA DOT Tonnage	-	3,507	-	9,846
WMA Other Agency Tonnage	-	3,500	-	9,826
WMA Commercial & Residential Tonnage	6,620	4,900	14,940	13,757
Total WMA Tonnage	6,620	11,907	14,940	33,429
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	90%		
Percent WMA Tons using Organic Additive	0%	10%		

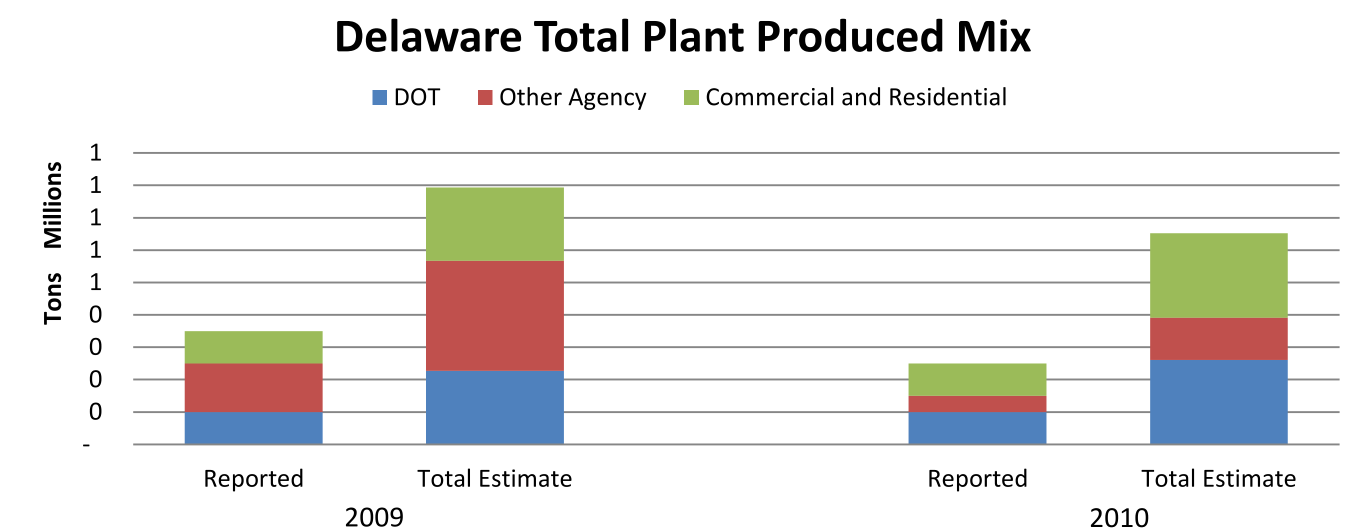
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Delaware

Table B8 summarizes the results received from asphalt mix producers in Delaware. The charts are used to summarize information calculated from information provided by the survey respondents.

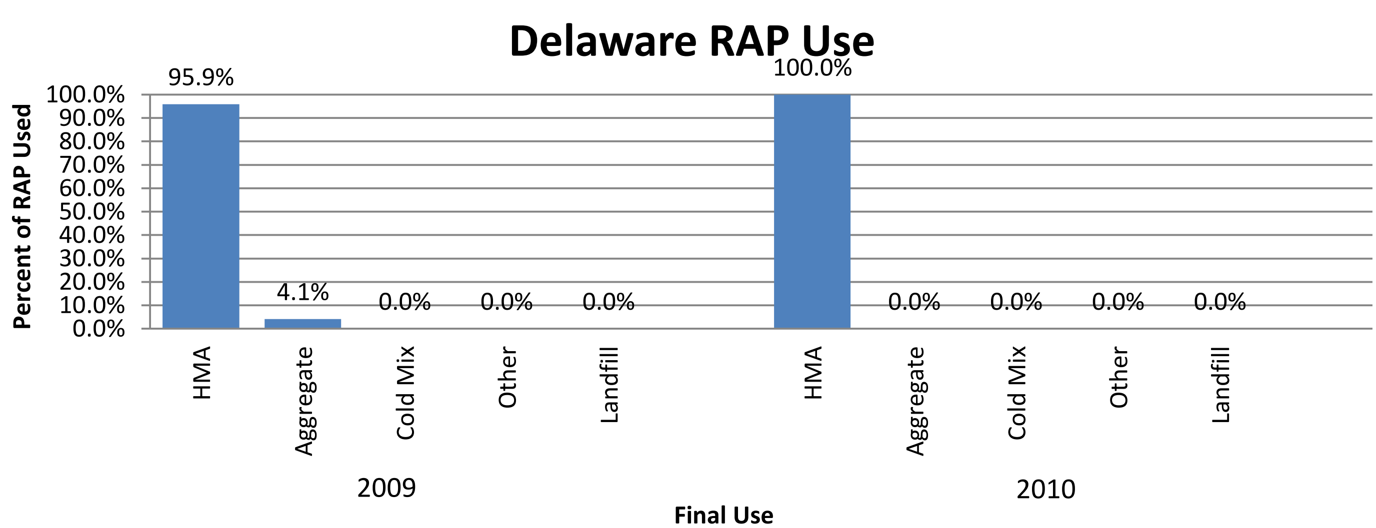
Total Asphalt Mix Tonnage

Companies responding: 1

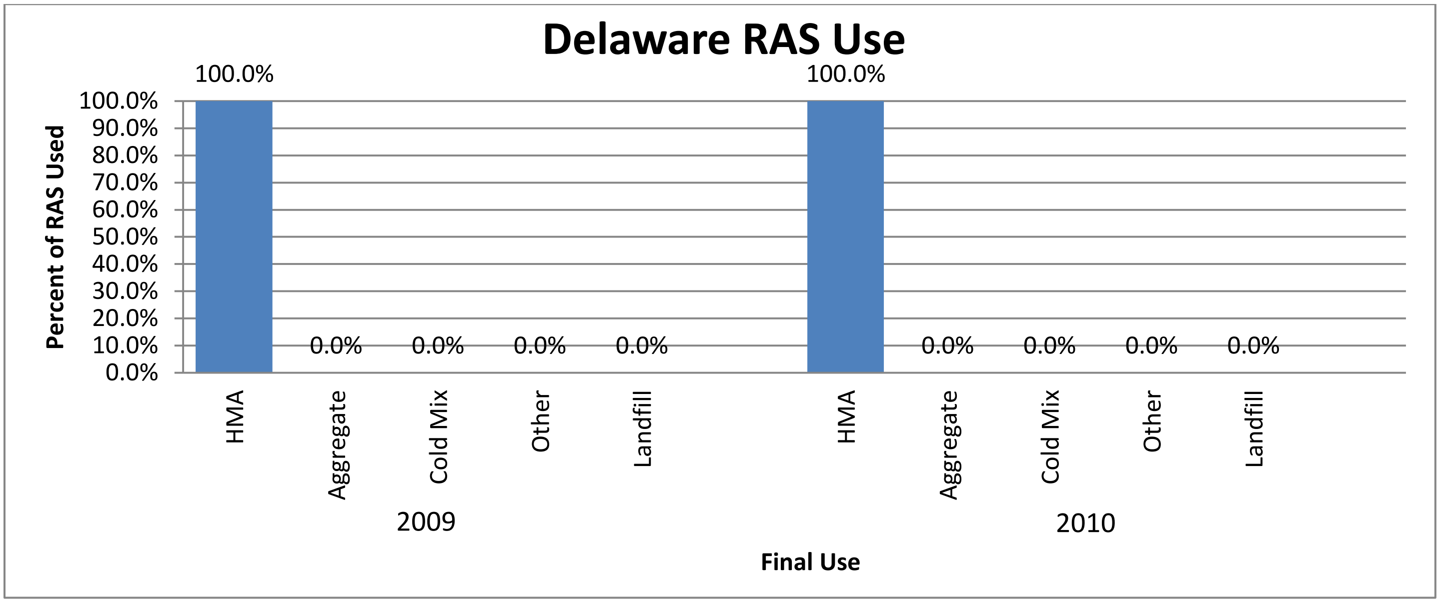


Total tonnage provided by Delaware Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

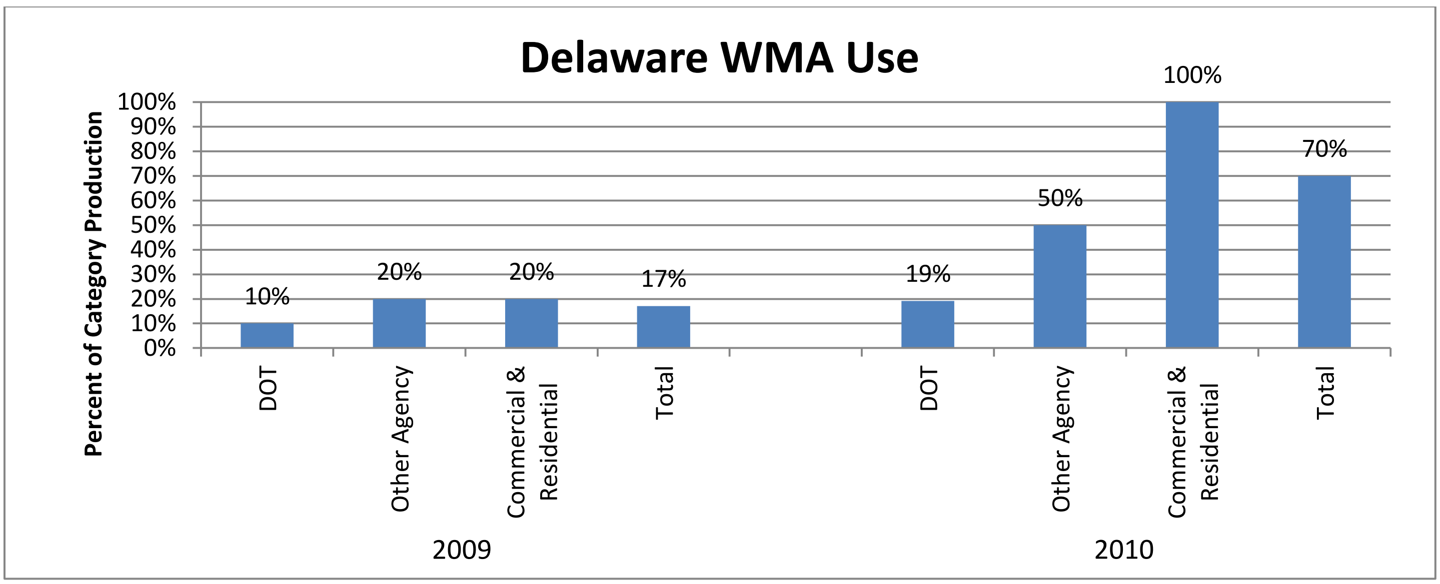


Table B 8: Summary of Delaware Data

Companies Reporting 1

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	100,000	100,000	226,753	260,664
Total Other Agency Tonnage	150,000	50,000	340,129	130,332
Total Commercial & Residential Tonnage	100,000	100,000	226,753	260,664
Total Tonnage	350,000	250,000	793,634	651,660

Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	70,000	50,000	158,727	130,332
RAP Tons used in HMA/WMA	70,000	50,000	158,727	130,332
RAP Tons used as Aggregate	3,000	-	6,803	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	20%	20%		
Average % RAP in Other Agency Mixes	20%	20%		
Average % RAP in Commercial & Residential Mixes	30%	30%		

Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	100%	100%		
RAS Tons Received	12,000	9,000	27,210	23,460
RAS Tons used in HMA/WMA	12,000	9,000	27,210	23,460
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	3%	10%		
Average % RAS in Other Agency Mixes	2%	3%		
Average % RAS in Commercial & Residential Mixes	5%	5%		

Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	100%		
WMA DOT Tonnage	10,000	50,000	22,675	50,000
WMA Other Agency Tonnage	30,000	25,000	68,026	65,166
WMA Commercial & Residential Tonnage	20,000	100,000	45,351	260,664
Total WMA Tonnage	60,000	175,000	136,052	375,830
Percent WMA Tons using Chemical Additives	0.0%	0.0%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	100.0%	100.0%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

1. Total tonnage provided by Delaware Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

District of Columbia

No contractors submitted data for the District of Columbia. Total tons were estimated based on a relationship tons to federal apportionment. Because RAP use is prevalent in all areas of the US it was estimated that RAP use in the District followed a national average. Table B9 summarizes this data.

Table B 9: Summary of District of Columbia Data

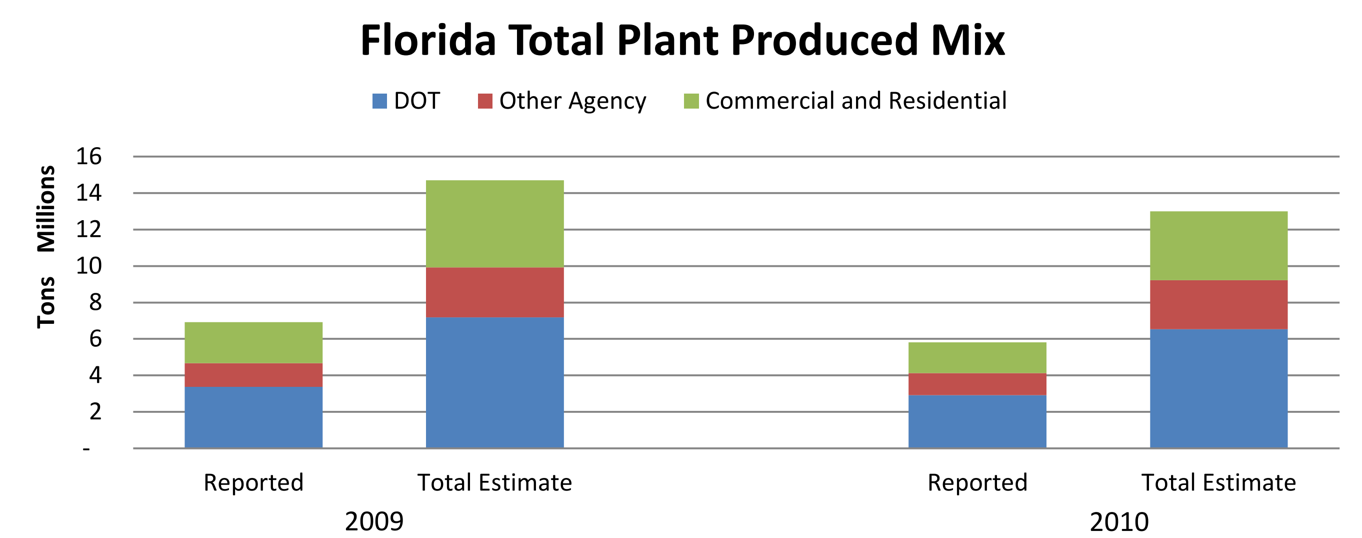
HMA/WMA		
	Total Estimated[1]	
	2009	2010
Total DOT Tonnage	-	-
Total Other Agency Tonnage	-	-
Total Commercial & Residential Tonnage	-	-
Total Tonnage	1,623,511	1,807,690
Reclaimed Asphalt Pavement (RAP)		
	Total Estimated	
	2009	2010
Percent Companies using RAP		
RAP Tons Received	304,216	368,017
RAP Tons used in HMA/WMA	253,788	310,816
RAP Tons used as Aggregate	28,186	36,736
RAP Tons used in Cold Mix	6,712	7,877
RAP Tons used as Other	3,336	4,003
RAP Tons Landfilled	652	23

Florida

Table B10 summarizes the results received from asphalt mix producers in Florida. The charts are used to summarize information calculated from information provided by the survey respondents.

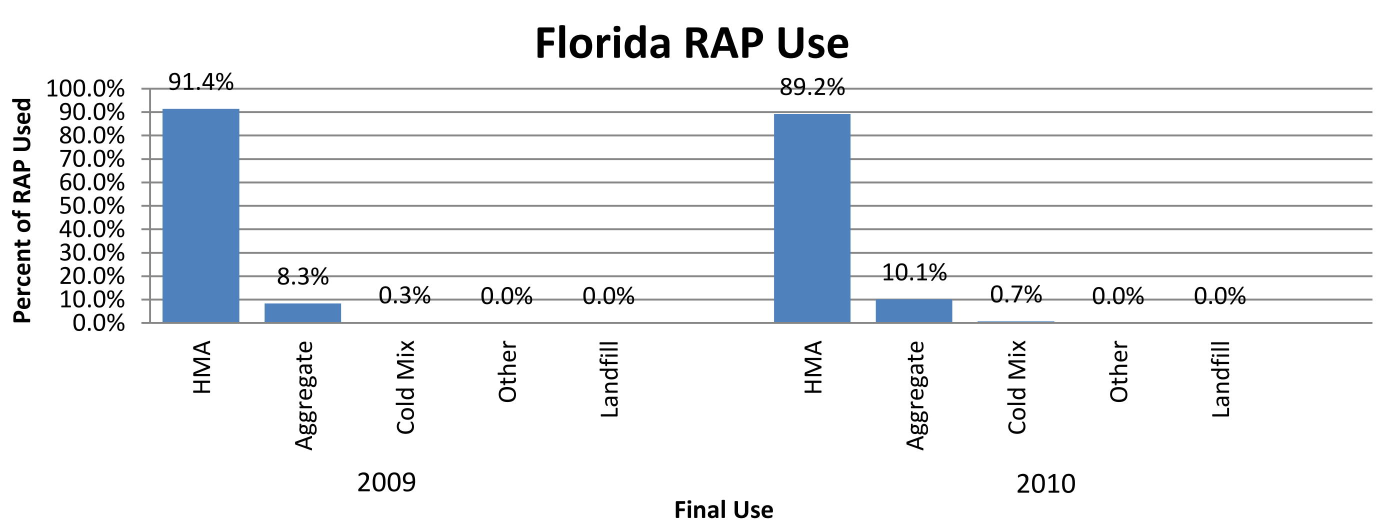
Total Asphalt Mix Tonnage

Companies responding: 6

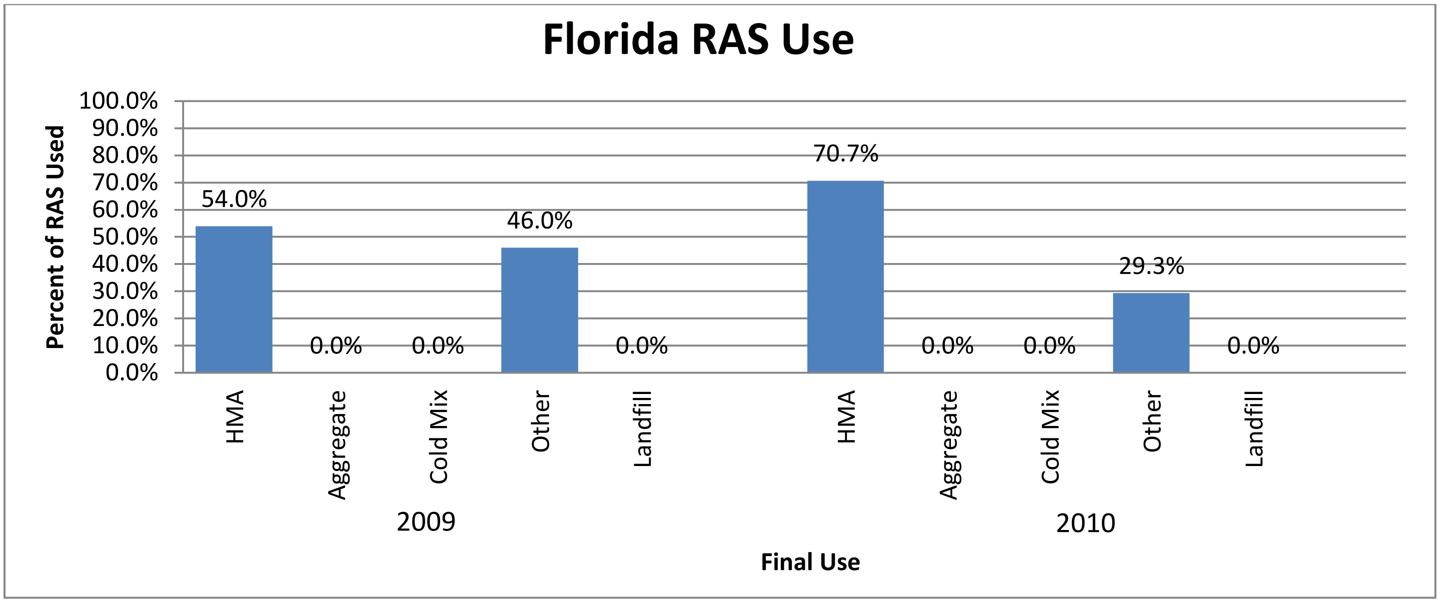


Total tonnage provided by Asphalt Contractors Association of Florida. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

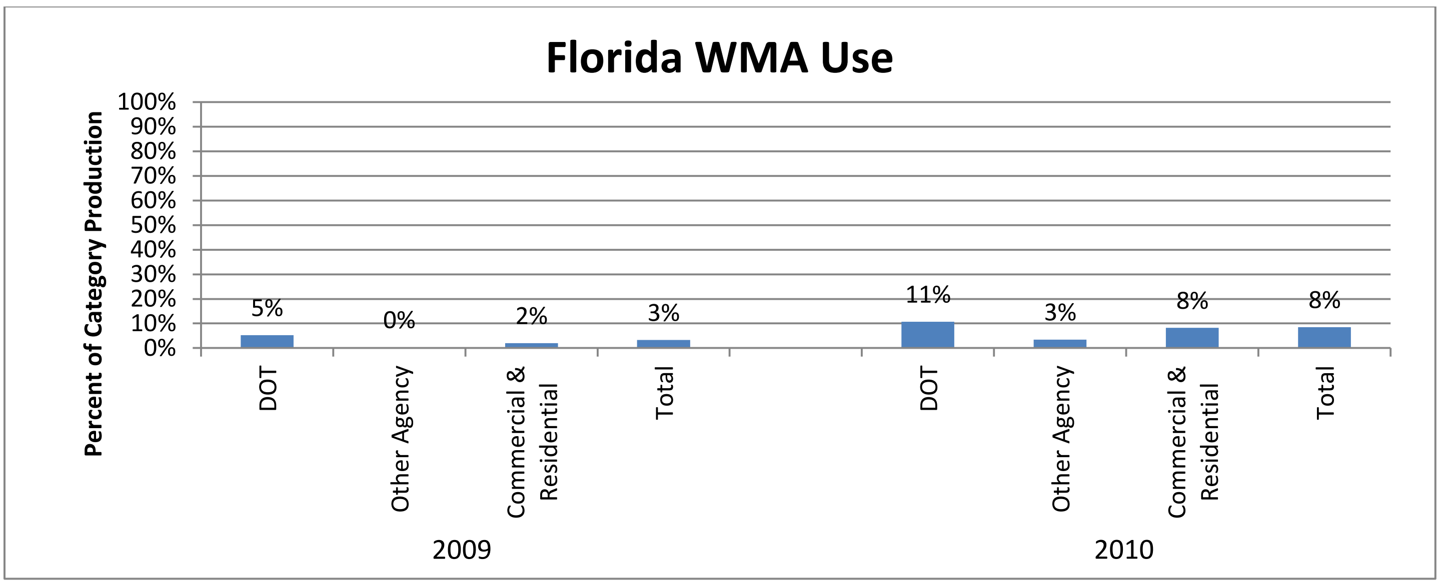


Table B 10: Summary Florida Data

Companies Reporting 6

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	3,378,702	2,919,247	7,184,378	6,533,888
Total Other Agency Tonnage	1,285,682	1,201,295	2,733,838	2,688,750
Total Commercial & Residential Tonnage	2,248,799	1,687,671	4,781,784	3,777,362
Total Tonnage	6,913,183	5,808,213	14,700,000	13,000,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	1,803,479	1,635,850	3,834,868	3,661,376
RAP Tons used in HMA/WMA	1,666,030	1,368,930	3,542,599	3,063,952
RAP Tons used as Aggregate	151,800	155,000	322,783	346,923
RAP Tons used in Cold Mix	5,200	10,500	11,057	23,501
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	42	44	88	99
Average % RAP in DOT Mixes	21%	21%		
Average % RAP in Other Agency Mixes	27%	26%		
Average % RAP in Commercial & Residential Mixes	31%	31%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	17%	17%		
RAS Tons Received	2,000	1,000	4,253	2,238
RAS Tons used in HMA/WMA	7,030	4,829	14,949	10,809
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	6,000	2,000	12,758	4,476
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	3%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	83%	83%		
WMA DOT Tonnage	177,125	312,662	376,634	699,804
WMA Other Agency Tonnage	4,220	41,850	8,973	93,669
WMA Commercial & Residential Tonnage	44,970	138,620	95,623	310,261
Total WMA Tonnage	226,315	493,132	481,230	1,103,734
Percent WMA Tons using Chemical Additives	0.9%	0.0%		
Percent WMA Tons using Additive Foaming	0.0%	0.0%		
Percent WMA Tons using Plant Foaming	99.1%	100.0%		
Percent WMA Tons using Organic Additive	0.0%	0.0%		

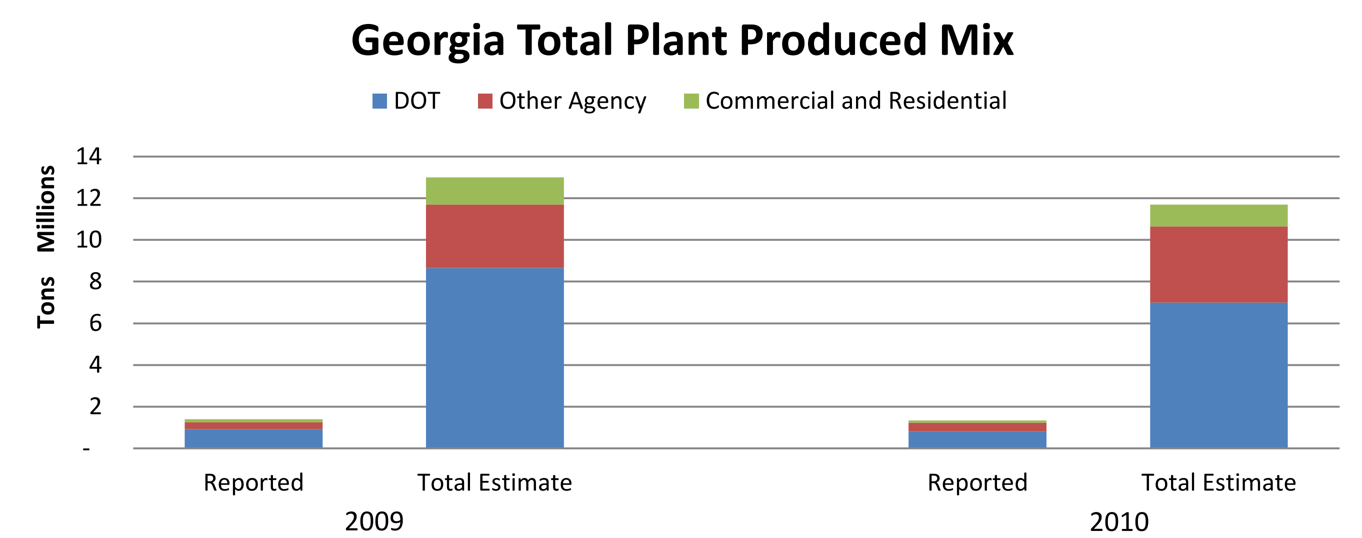
1. Total tonnage provided by Asphalt Contractors Association of Florida. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Georgia

Table B11 summarizes the results received from asphalt mix producers in Georgia. The charts are used to summarize information calculated from information provided by the survey respondents.

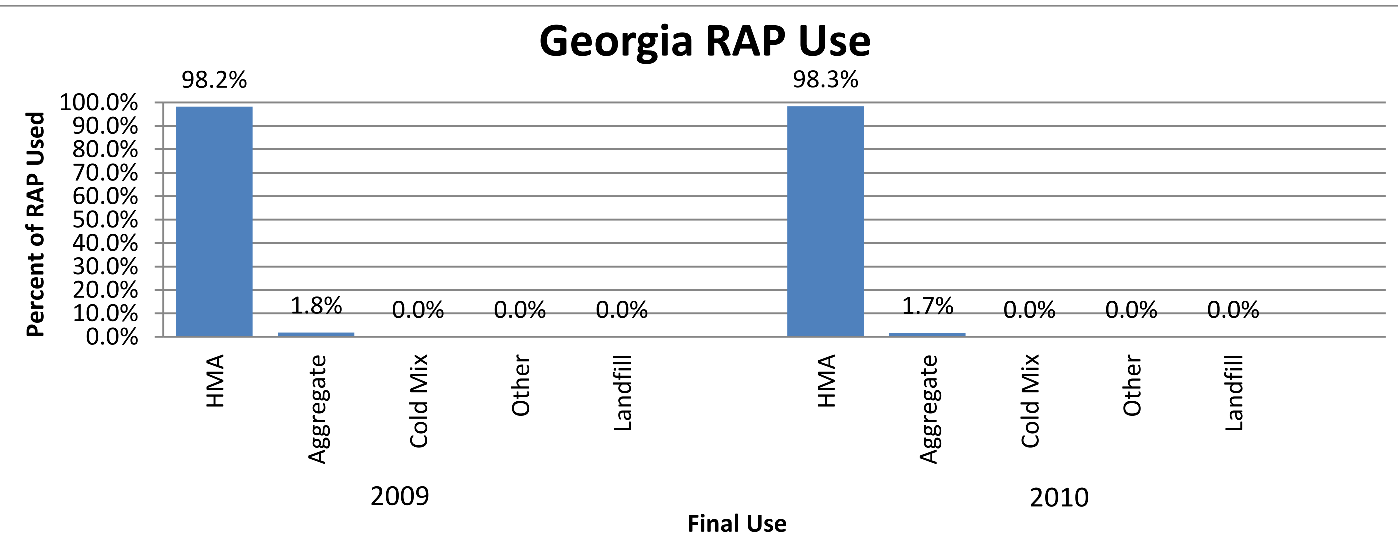
Total Asphalt Mix Tonnage

Companies responding: 2



Total tonnage provided by Georgia Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

RAP Use



RAS Use

No contractor reported using RAS in Georgia in 2009 and 2010. The Georgia DOT does allow RAS in mixes.

WMA Use

No contractos reported using WMA in Georgia in 2009 and 2010. The Georgia Asphalt Pavement Association reports there are 3 companies that have installed foaming systems in Georgia, and two are actively using theirs to produce WMA. They estimate about 50,000 tons were placed on DOT work last year, and expect to meet that same amount this in 2011. They do not have any information on WMA use for other purposes.

Table B 11: Summary of Georgia Data

Companies Reporting 2

HMA/WMA	Reported		Total Estimated	
	2009	2010	2009	2010
Total DOT Tonnage	925,000	800,000	8,651,079	6,985,075
Total Other Agency Tonnage	325,000	420,000	3,039,568	3,667,164
Total Commercial & Residential Tonnage	140,000	120,000	1,309,353	1,047,761
Total Tonnage	1,390,000	1,340,000	13,000,000	11,700,000

Reclaimed Asphalt Pavement (RAP)	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	250,000	300,000	2,338,129	2,619,403
RAP Tons used in HMA/WMA	270,000	295,000	2,525,180	2,575,746
RAP Tons used as Aggregate	5,000	5,000	46,763	43,657
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	18%	18%		
Average % RAP in Other Agency Mixes	24%	25%		
Average % RAP in Commercial & Residential Mixes	27%	28%		

Reclaimed Asphalt Shingles (RAS)	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

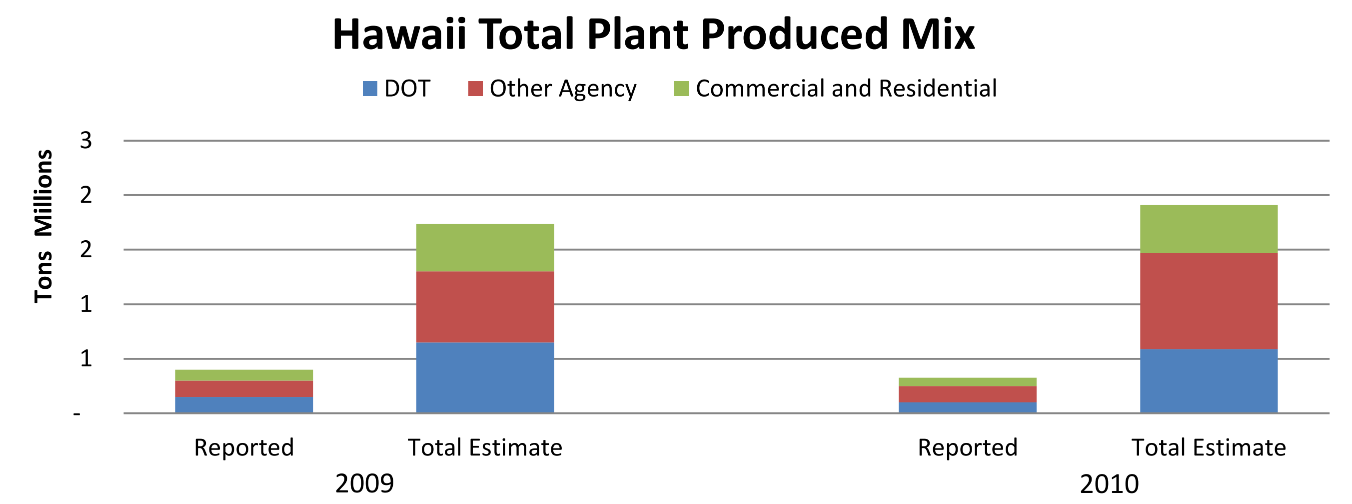
1. Total tonnage provided by Georgia Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

Hawaii

Table B12 summarizes the results received from asphalt mix producers in Hawaii. The charts are used to summarize information calculated from information provided by the survey respondents.

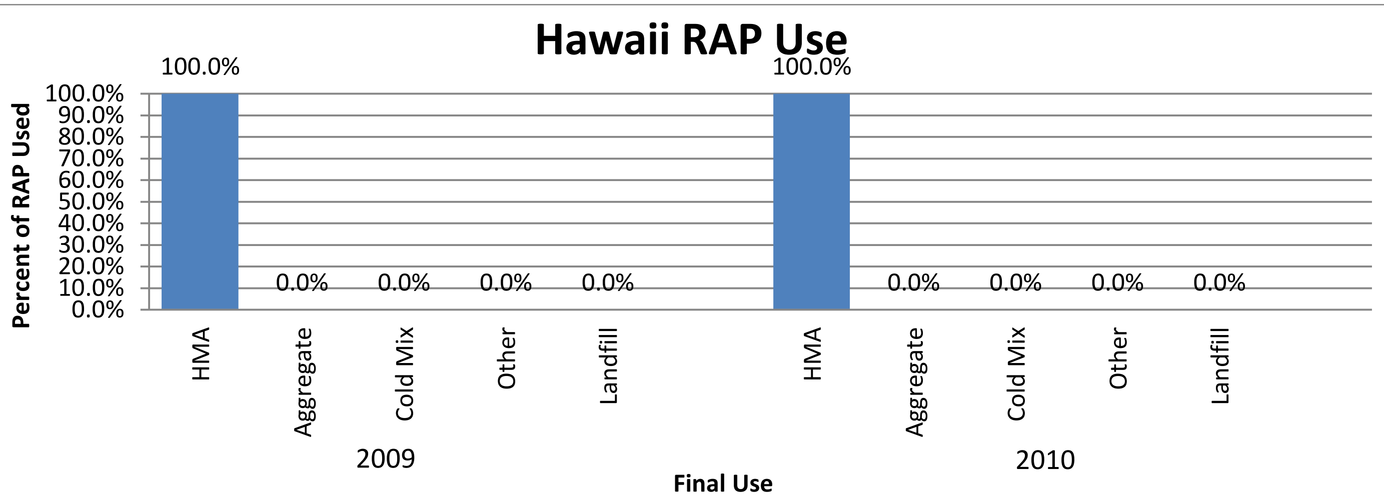
Total Asphalt Mix Tonnage

Companies responding: 1



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use

The contractor did not report accepting or using RAS in 2009 and 2010.

WMA Use

The contractor did not report using WMA in 2009 and 2010.

Table B 12: Summary of Hawaii Data

Companies Reporting 1

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	150,000	100,000	650,490	587,730
Total Other Agency Tonnage	150,000	150,000	650,490	881,596
Total Commercial & Residential Tonnage	100,000	75,000	433,660	440,798
Total Tonnage	400,000	325,000	1,734,640	1,910,124

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	40,000	30,000	173,464	176,319
RAP Tons used in HMA/WMA	40,000	30,000	173,464	176,319
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	10%	10%		
Average % RAP in Other Agency Mixes	7%	7%		
Average % RAP in Commercial & Residential Mixes	15%	15%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

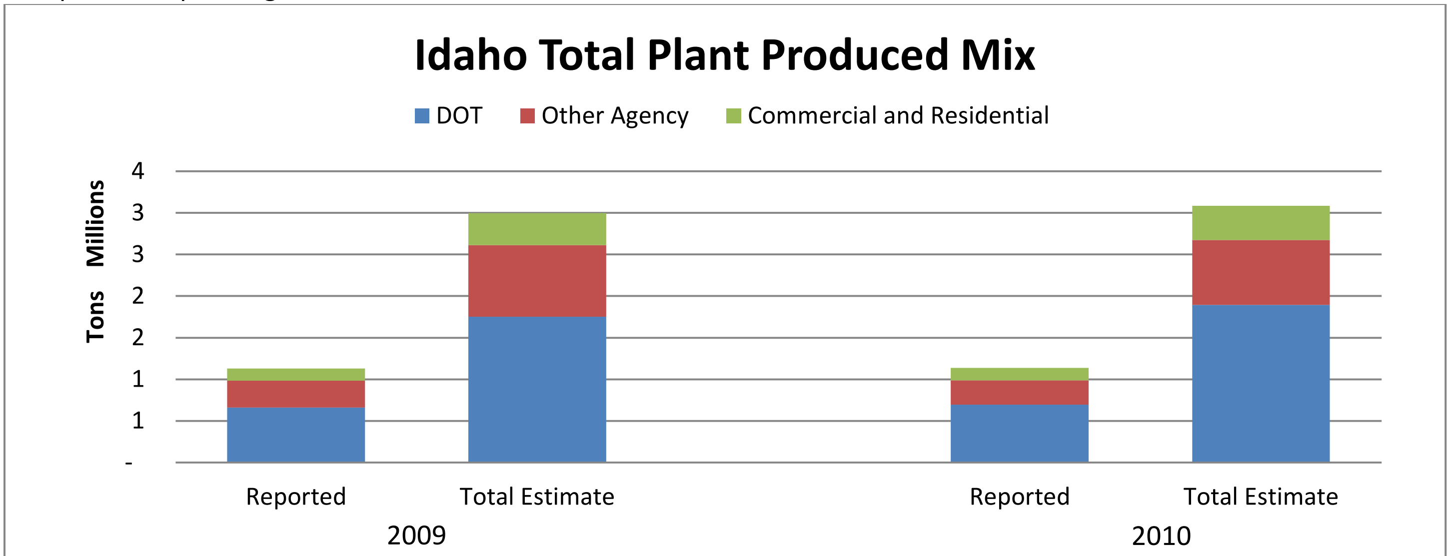
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Idaho

Table B13 summarizes the results received from asphalt mix producers in Idaho. The charts are used to summarize information calculated from information provided by the survey respondents.

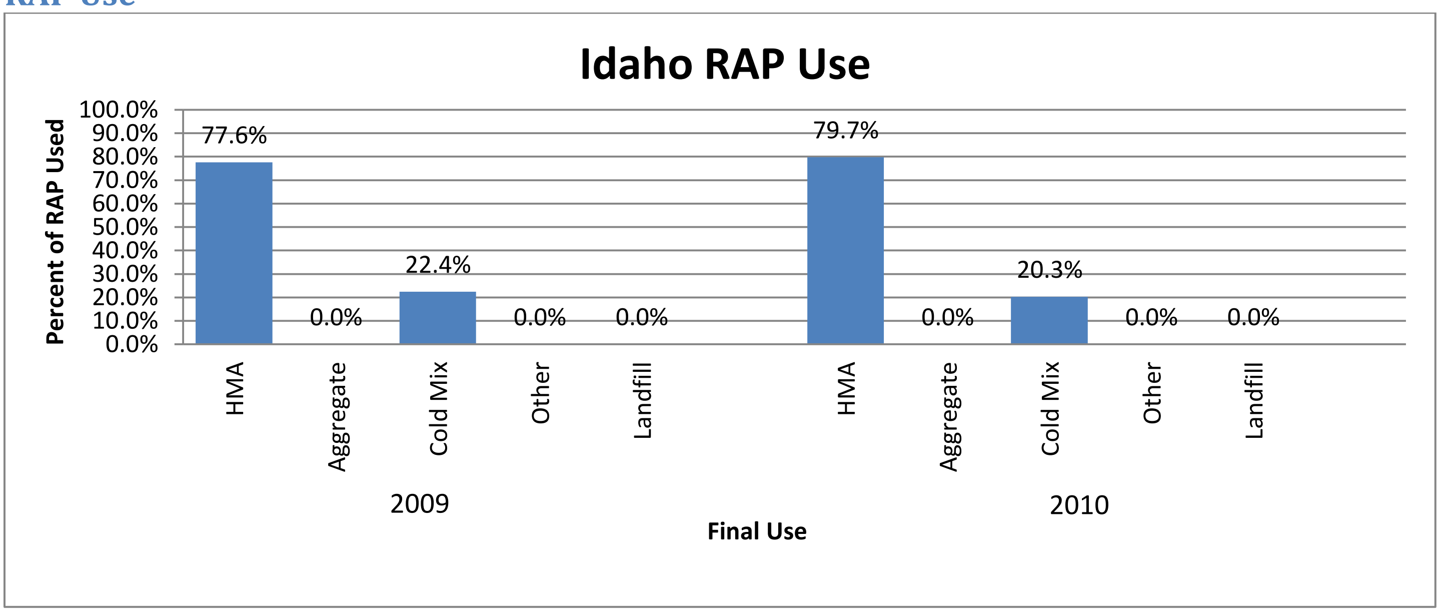
Total Asphalt Mix Tonnage

Companies responding: 5



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons

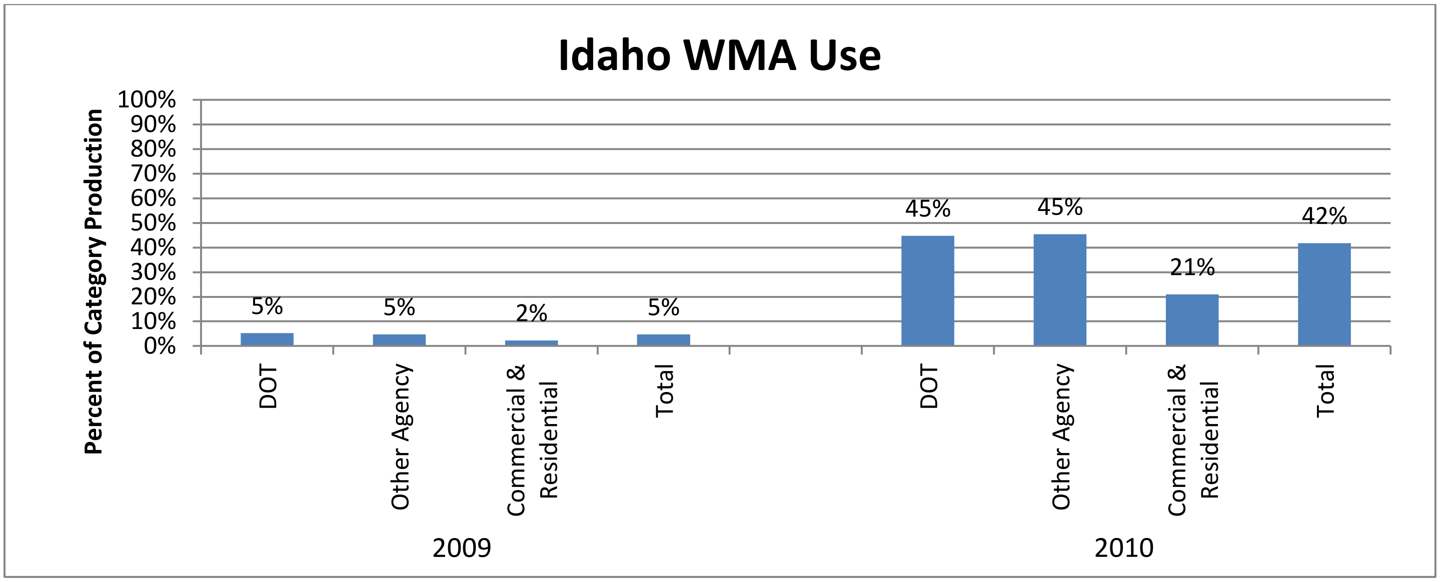
RAP Use



RAS Use

No contractors reported using RAS in 2009 and 2010.

WMA Use



Idaho WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
5%
5%
2%
5%
45%
45%
21%
42%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 13: Summary of Idaho Data

Companies Reporting 5

HMA/WMA	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	660,000	696,917	1,751,597	1,892,602
Total Other Agency Tonnage	323,857	288,484	859,495	783,430
Total Commercial & Residential Tonnage	145,200	151,520	385,351	411,480
Total Tonnage	1,129,057	1,136,921	2,996,444	3,087,512

Reclaimed Asphalt Pavement (RAP)	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	80%	80%		
RAP Tons Received	60,000	104,200	159,236	282,974
RAP Tons used in HMA/WMA	72,775	118,095	193,140	320,707
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	21,000	30,000	55,733	81,470
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	38	47	101	128
Average % RAP in DOT Mixes	5%	9%		
Average % RAP in Other Agency Mixes	10%	11%		
Average % RAP in Commercial & Residential Mixes	16%	17%		

Reclaimed Asphalt Shingles (RAS)	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	20%	60%		
WMA DOT Tonnage	34,300	312,138	91,030	847,666
WMA Other Agency Tonnage	15,430	131,175	40,950	356,229
WMA Commercial & Residential Tonnage	3,360	31,838	8,917	86,462
Total WMA Tonnage	53,090	475,151	140,897	1,290,357
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

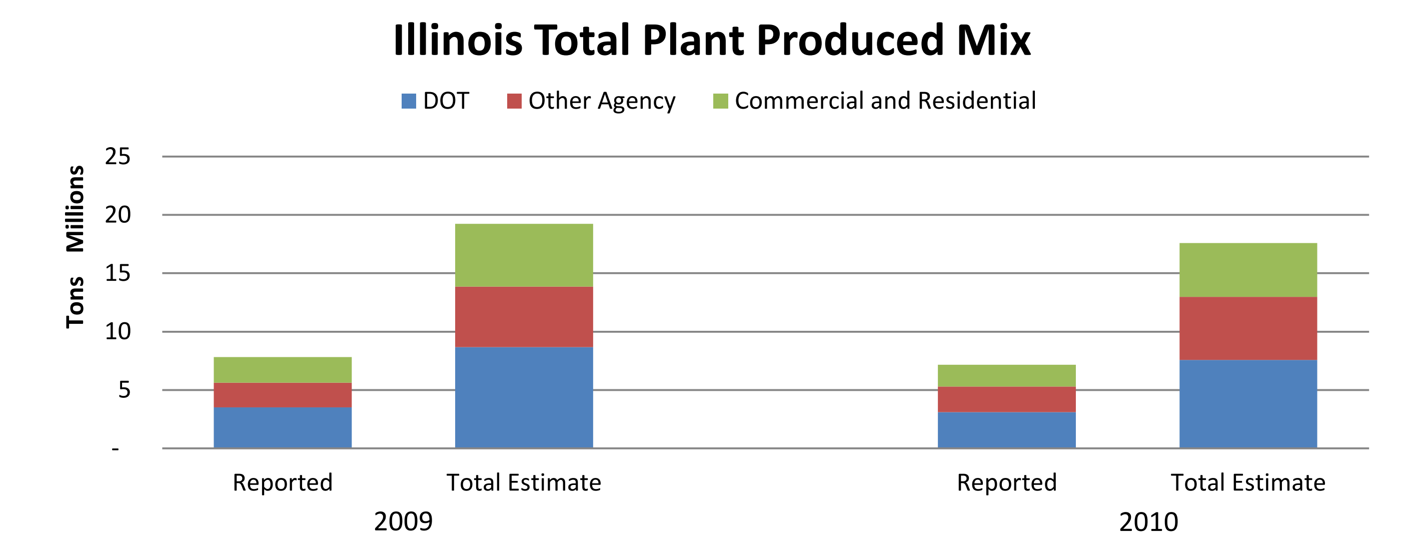
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Illinois

Table B14 summarizes the results received from asphalt mix producers in Illinois. The charts are used to summarize information calculated from information provided by the survey respondents.

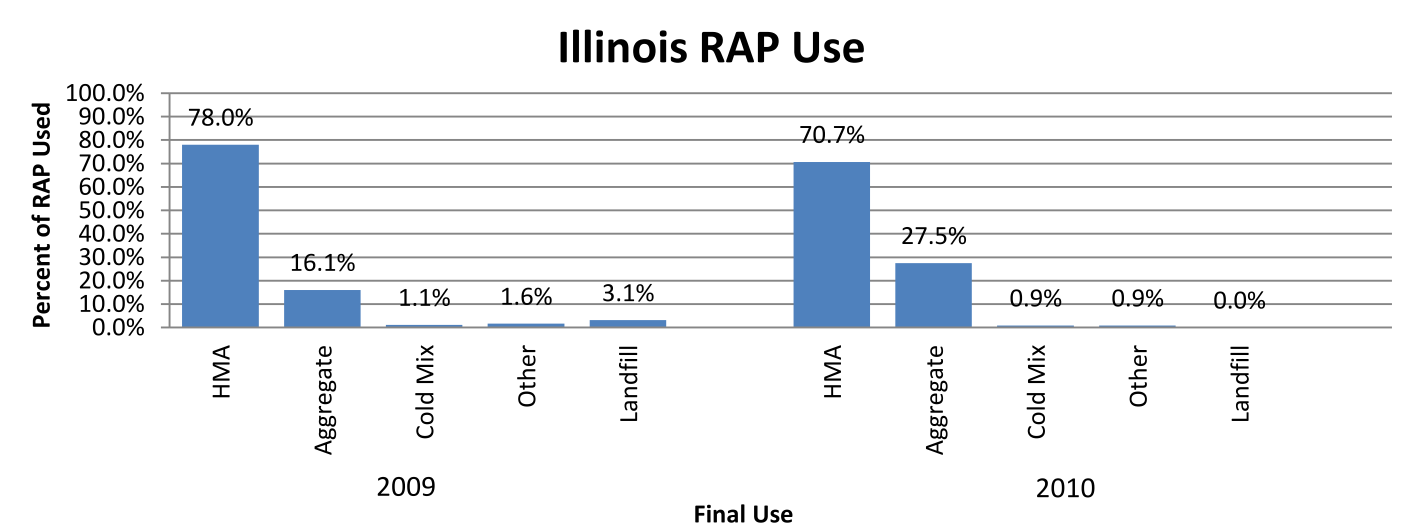
Total Asphalt Mix Tonnage

Companies responding: 16

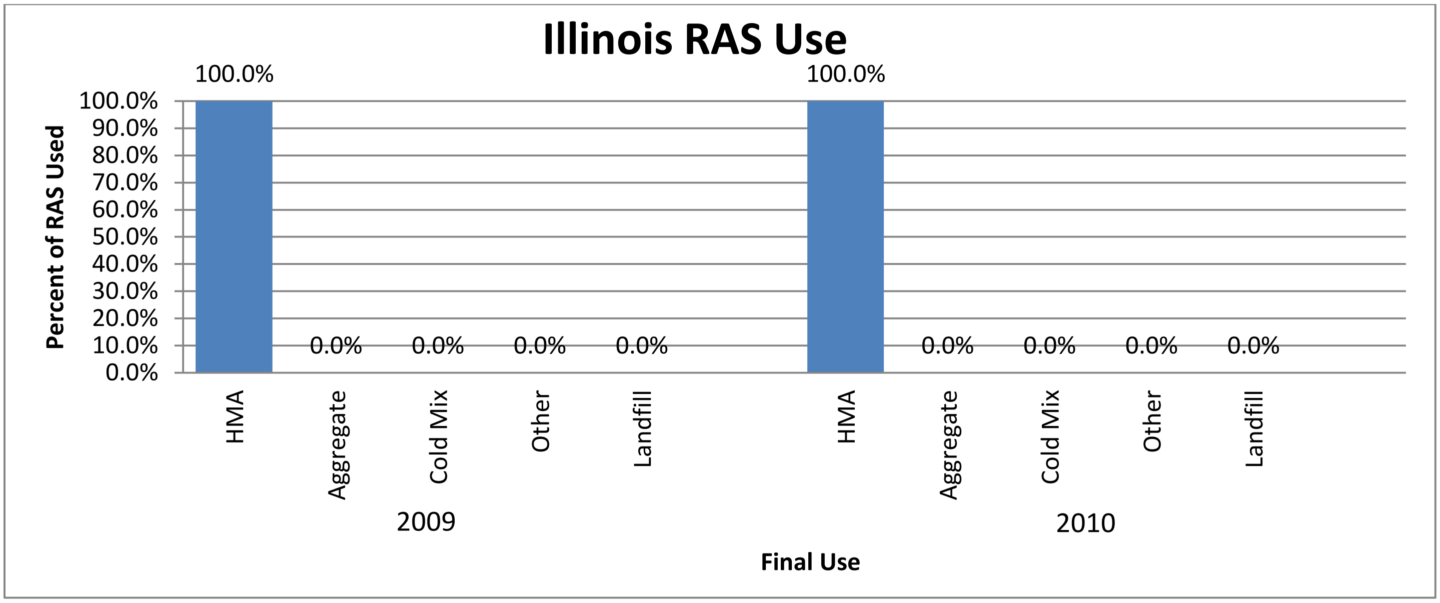


Total tonnage provided by Illinois Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

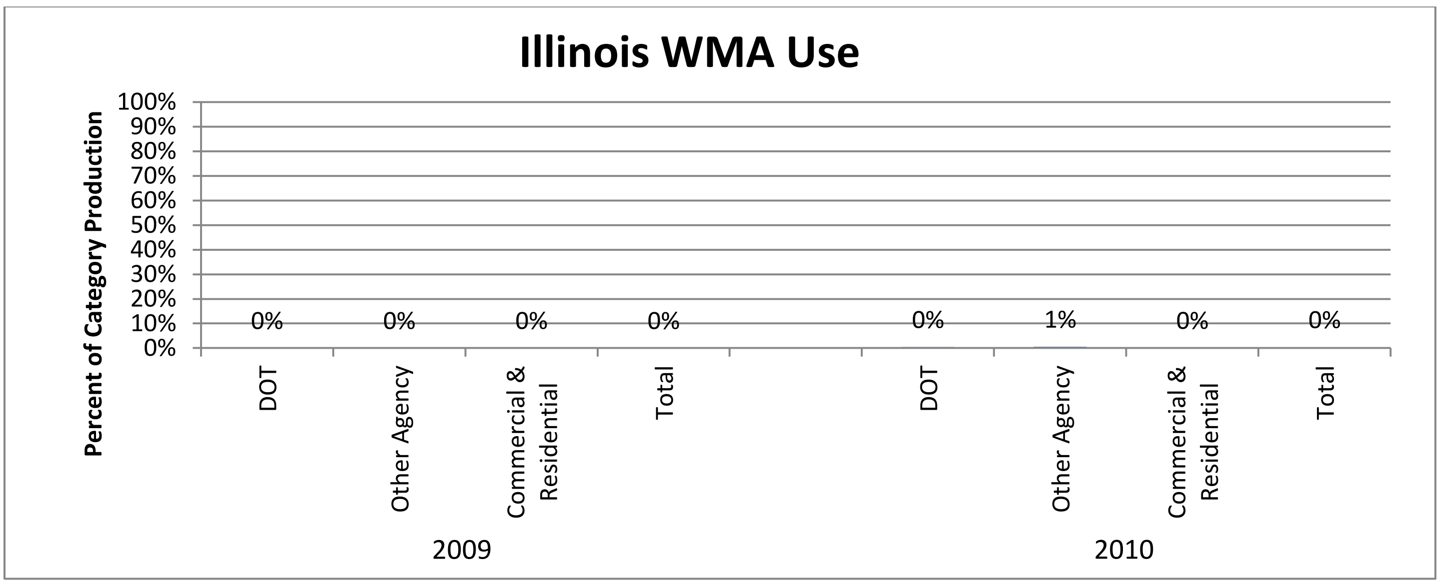


Table B 14: Summary of Illinois Data — Companies Reporting 16

HMA/WMA	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	3,512,816	3,086,094	8,660,332	7,578,622
Total Other Agency Tonnage	2,110,029	2,204,674	5,201,967	5,414,090
Total Commercial & Residential Tonnage	2,185,367	1,876,136	5,387,701	4,607,288
Total Tonnage	7,808,212	7,166,904	19,250,000	17,600,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	2,519,275	2,234,925	6,210,903	5,488,378
RAP Tons used in HMA/WMA	1,374,700	1,416,650	3,389,121	3,478,914
RAP Tons used as Aggregate	283,000	551,500	697,695	1,354,337
RAP Tons used in Cold Mix	20,000	18,000	49,307	44,203
RAP Tons used as Other	28,800	17,800	71,002	43,712
RAP Tons Landfilled	55,000	-	135,594	-
Average % RAP in DOT Mixes	17%	16%		
Average % RAP in Other Agency Mixes	20%	21%		
Average % RAP in Commercial & Residential Mixes	31%	32%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	19%	38%		
RAS Tons Received	2,000	8,750	4,931	21,488
RAS Tons used in HMA/WMA	1,740	14,250	4,290	34,994
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	4%		
Average % RAS in Other Agency Mixes	0%	1%		
Average % RAS in Commercial & Residential Mixes	0%	2%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	13%	38%		
WMA DOT Tonnage	-	12,650	-	31,065
WMA Other Agency Tonnage	-	11,895	-	29,211
WMA Commercial & Residential Tonnage	362	961	892	2,361
Total WMA Tonnage	362	25,506	892	62,637
Percent WMA Tons using Chemical Additives	0%	28.1%		
Percent WMA Tons using Additive Foaming	0%	0.0%		
Percent WMA Tons using Plant Foaming	100%	48.9%		
Percent WMA Tons using Organic Additive	0%	23.1%		

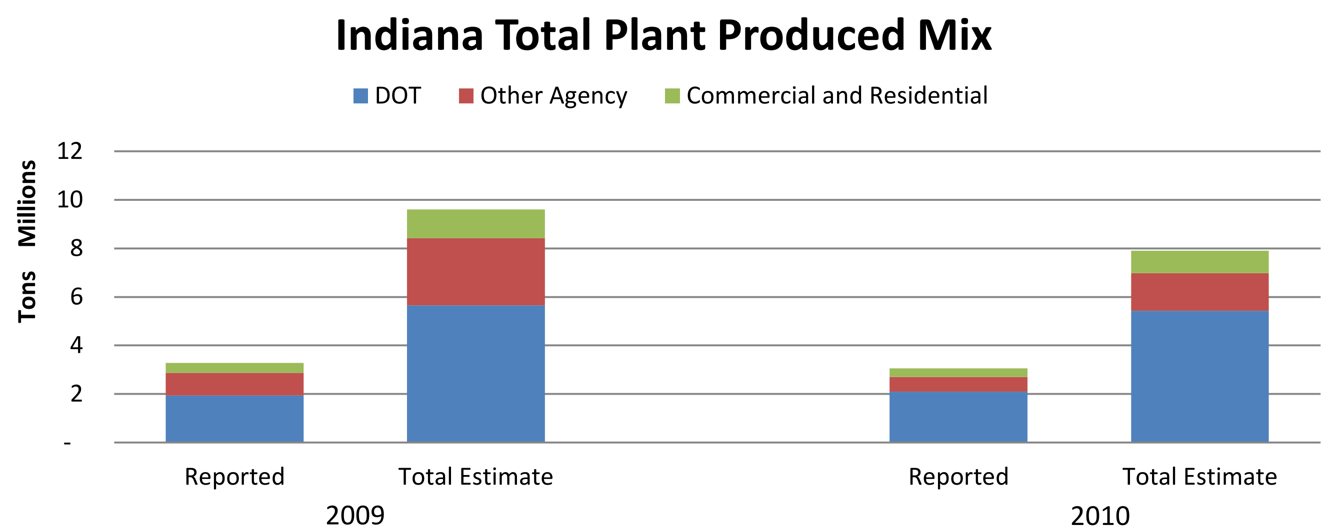
1. Total tonnage provided by Illinois Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Indiana

Table B15 summarizes the results received from asphalt mix producers in Indiana. The charts are used to summarize information calculated from information provided by the survey respondents.

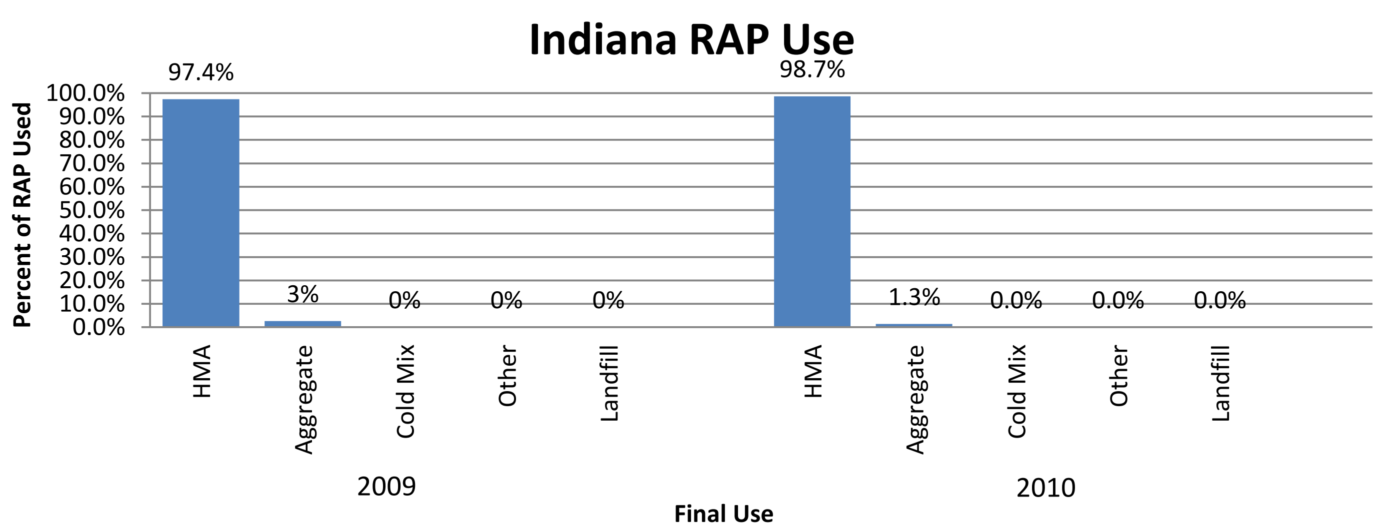
Total Asphalt Mix Tonnage

Companies responding: 3

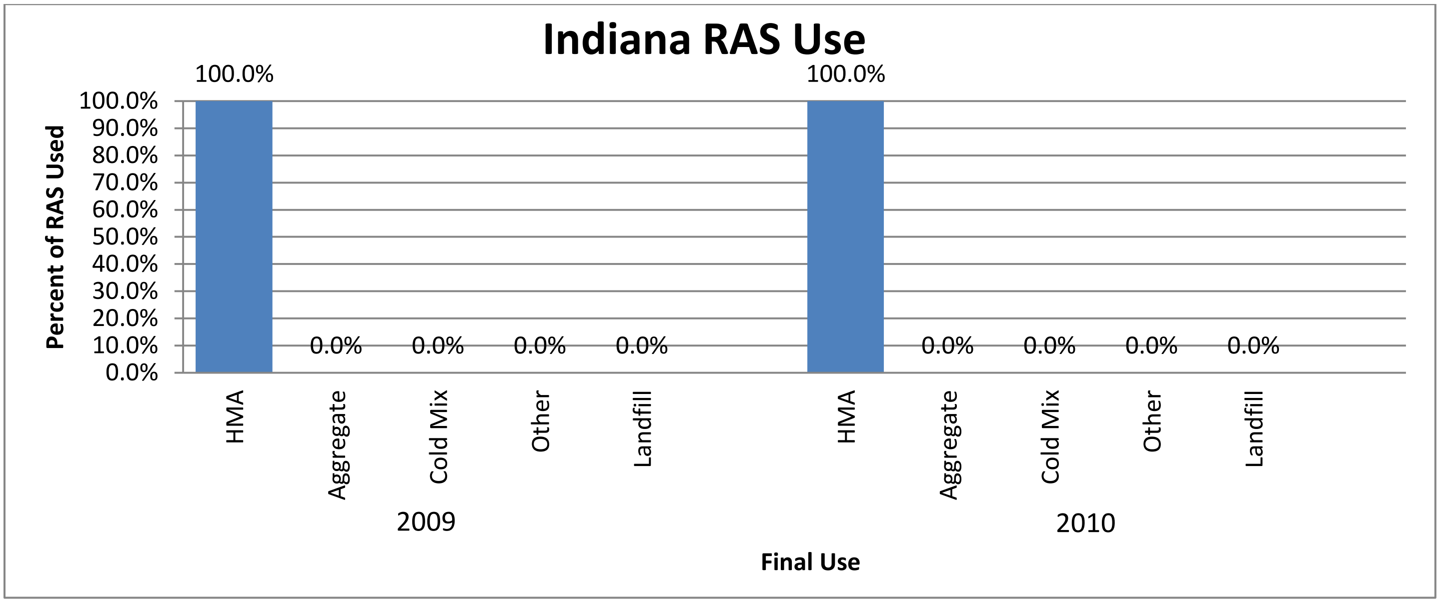


Total tonnage provided by Indiana Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

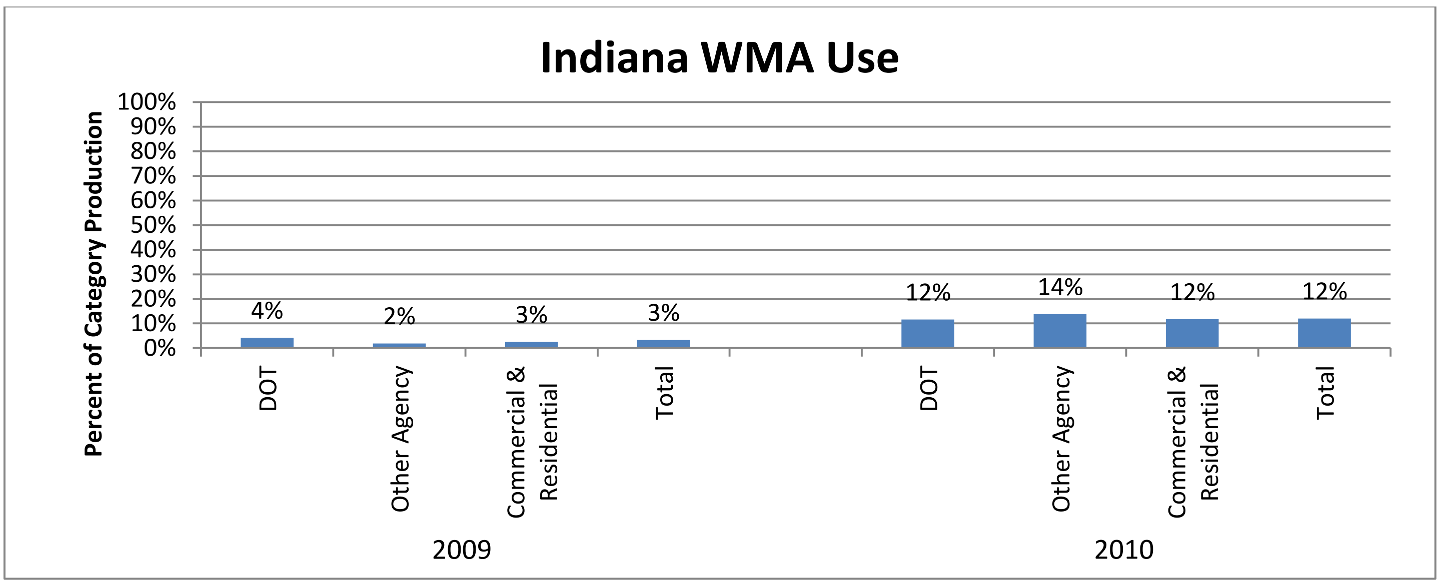


Table B 15: Summary of Indiana Data

Companies Reporting 3

HMA/WMA	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,931,000	2,097,000	5,654,293	5,422,684
Total Other Agency Tonnage	943,000	602,000	2,761,263	1,556,727
Total Commercial & Residential Tonnage	404,500	356,000	1,184,444	920,589
Total Tonnage	3,278,500	3,055,000	9,600,000	7,900,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	780,000	665,000	2,283,971	1,719,640
RAP Tons used in HMA/WMA	756,000	734,000	2,213,695	1,898,069
RAP Tons used as Aggregate	20,000	10,000	58,563	25,859
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	24%	26%		
Average % RAP in Other Agency Mixes	27%	26%		
Average % RAP in Commercial & Residential Mixes	31%	30%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	33%	100%		
RAS Tons Received	2,900	11,000	8,492	28,445
RAS Tons used in HMA/WMA	8,000	8,700	23,425	22,498
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	4%	9%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	4%	6%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	67%	100%		
WMA DOT Tonnage	81,000	242,820	237,182	627,914
WMA Other Agency Tonnage	18,000	82,885	52,707	214,334
WMA Commercial & Residential Tonnage	10,164	41,665	29,760	107,743
Total WMA Tonnage	109,164	367,370	319,649	949,991
Percent WMA Tons using Chemical Additives	0%	1%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	99%		
Percent WMA Tons using Organic Additive	0%	0%		

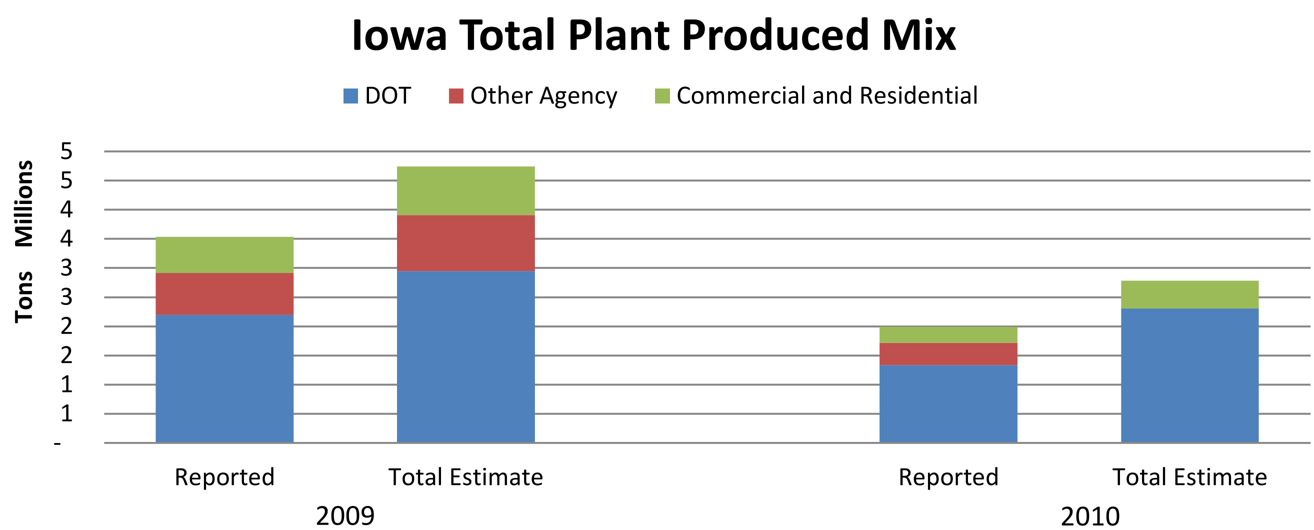
1. Total tonnage provided by Indiana Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Iowa

Table B16 summarizes the results received from asphalt mix producers in Iowa. The charts are used to summarize information calculated from information provided by the survey respondents.

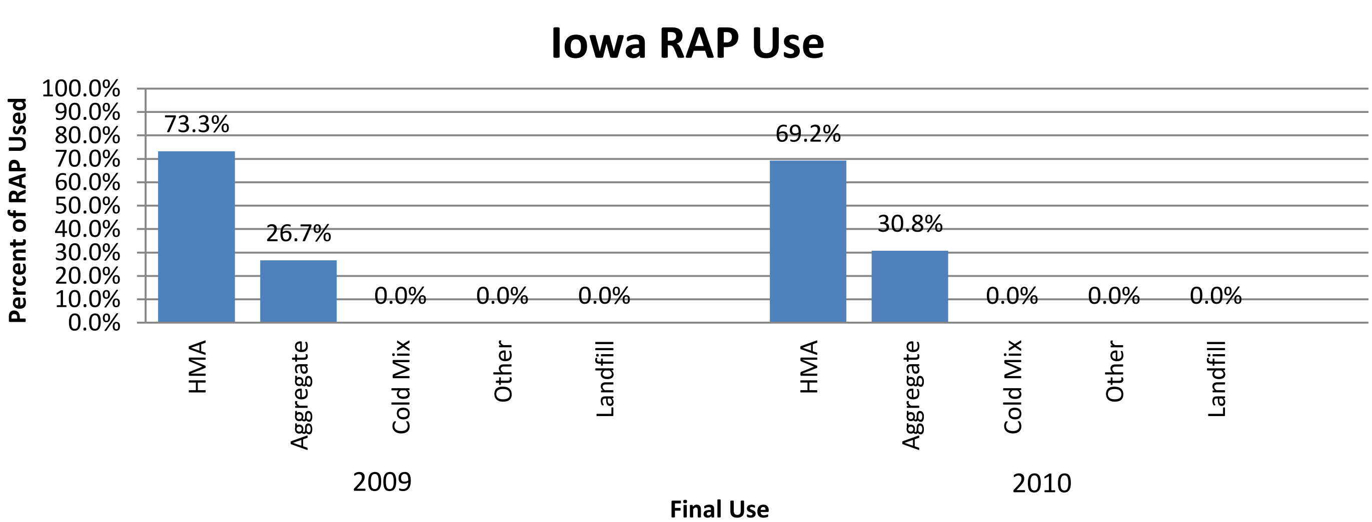
Total Asphalt Mix Tonnage

Companies responding: 7

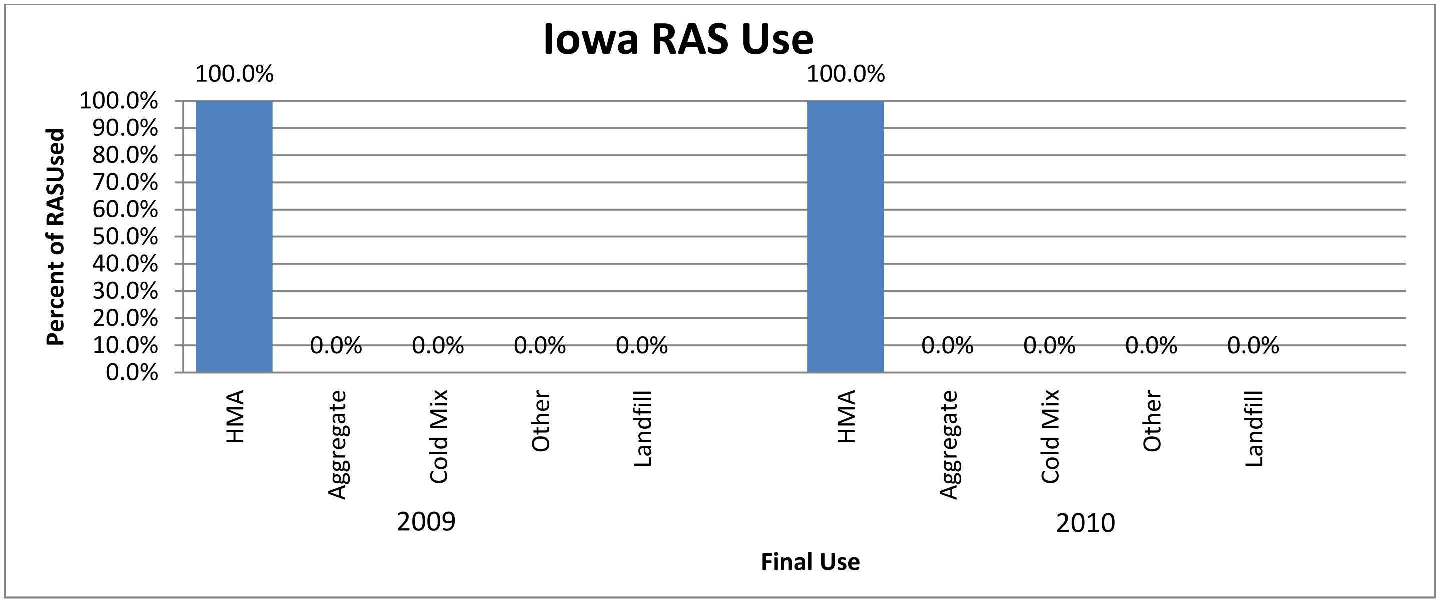


Total tonnage provided by Iowa Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based ratios from reported tons.

RAP Use



RAS Use



WMA Use

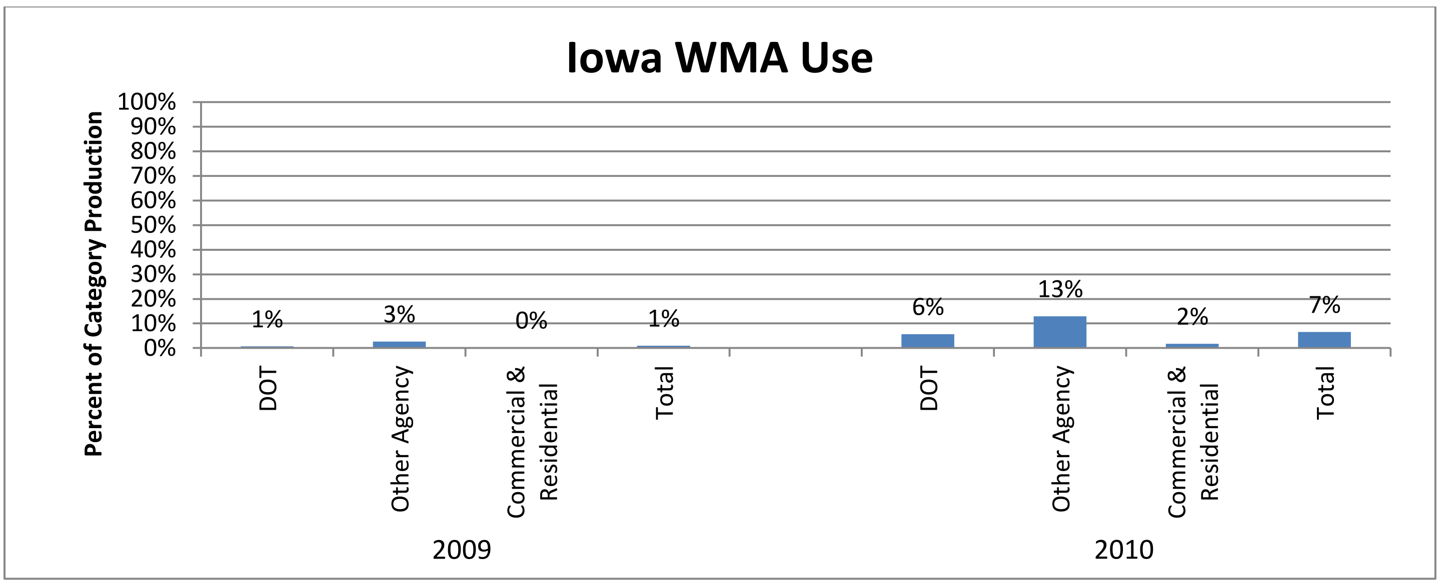


Table B 16: Summary of Iowa Data

Companies Reporting 7

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,197,527	1,333,000	2,948,284	2,307,501
Total Other Agency Tonnage	716,512	384,000	961,299	664,727
Total Commercial & Residential Tonnage	621,939	276,000	834,417	477,772
Total Tonnage	3,535,978	1,993,000	4,744,000	3,450,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	606,000	533,000	813,032	922,654
RAP Tons used in HMA/WMA	417,183	341,923	559,708	591,889
RAP Tons used as Aggregate	152,000	152,000	203,929	263,121
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	55	50	74	87
Average % RAP in DOT Mixes	10%	11%		
Average % RAP in Other Agency Mixes	8%	15%		
Average % RAP in Commercial & Residential Mixes	10%	13%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	43%	86%		
RAS Tons Received	6,900	22,000	9,257	38,083
RAS Tons used in HMA/WMA	6,700	12,734	8,989	22,043
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	1%	1%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	1%	1%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	43%	86%		
WMA DOT Tonnage	15,005	76,000	20,131	131,560
WMA Other Agency Tonnage	19,080	49,720	25,598	86,068
WMA Commercial & Residential Tonnage	1,100	4,850	1,476	8,396
Total WMA Tonnage	35,185	130,570	47,206	226,024
Percent WMA Tons using Chemical Additives	73%	22%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	18%	78%		
Percent WMA Tons using Organic Additive	8%	0%		

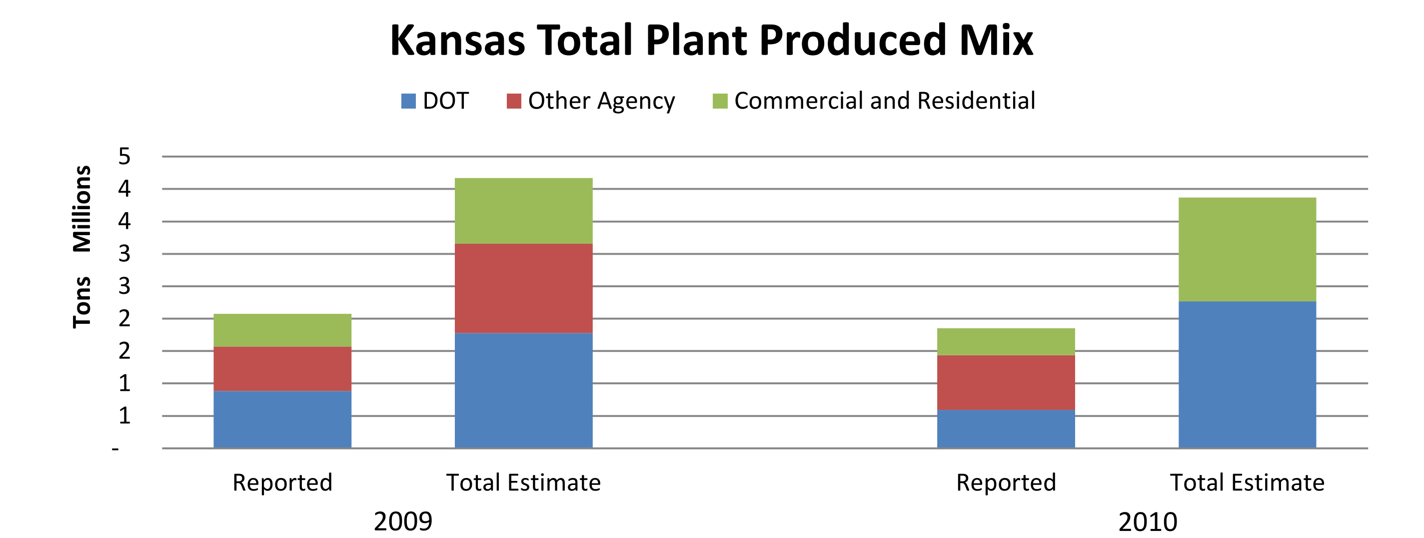
1. Total tonnage provided by Iowa Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Kansas

Table B17 summarizes the results received from asphalt mix producers in Kansas. The charts are used to summarize information calculated from information provided by the survey respondents.

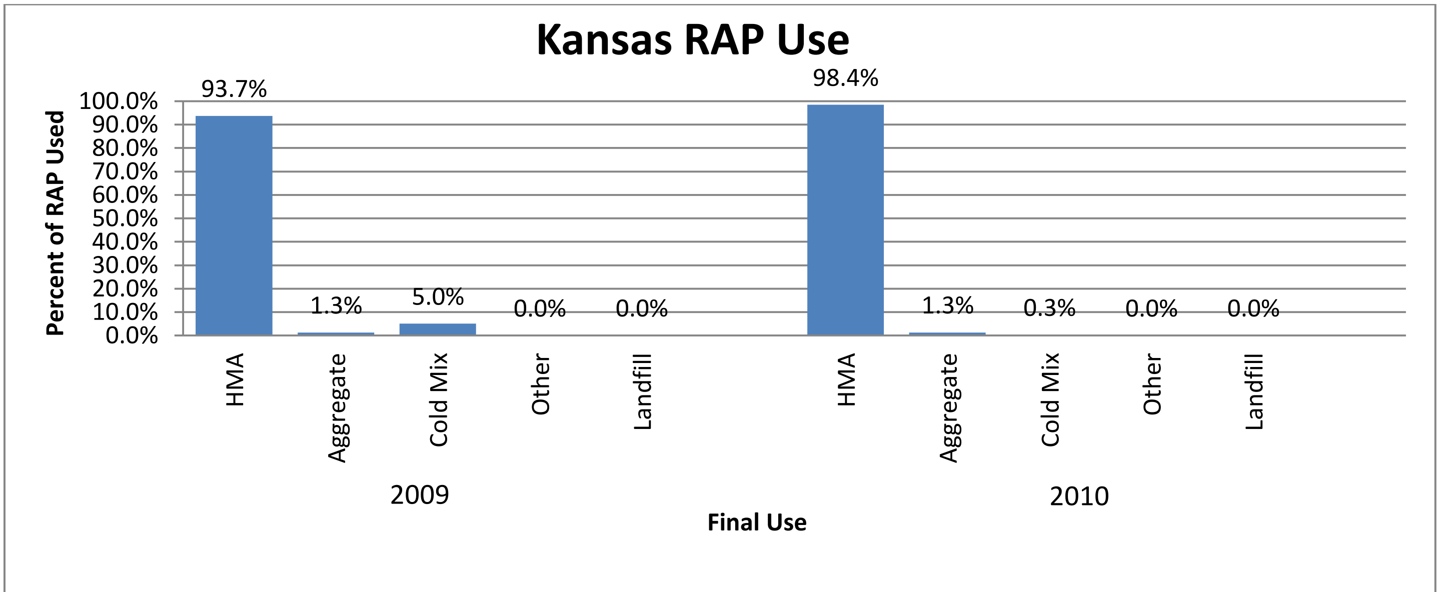
Total Asphalt Mix Tonnage

Companies responding: 6

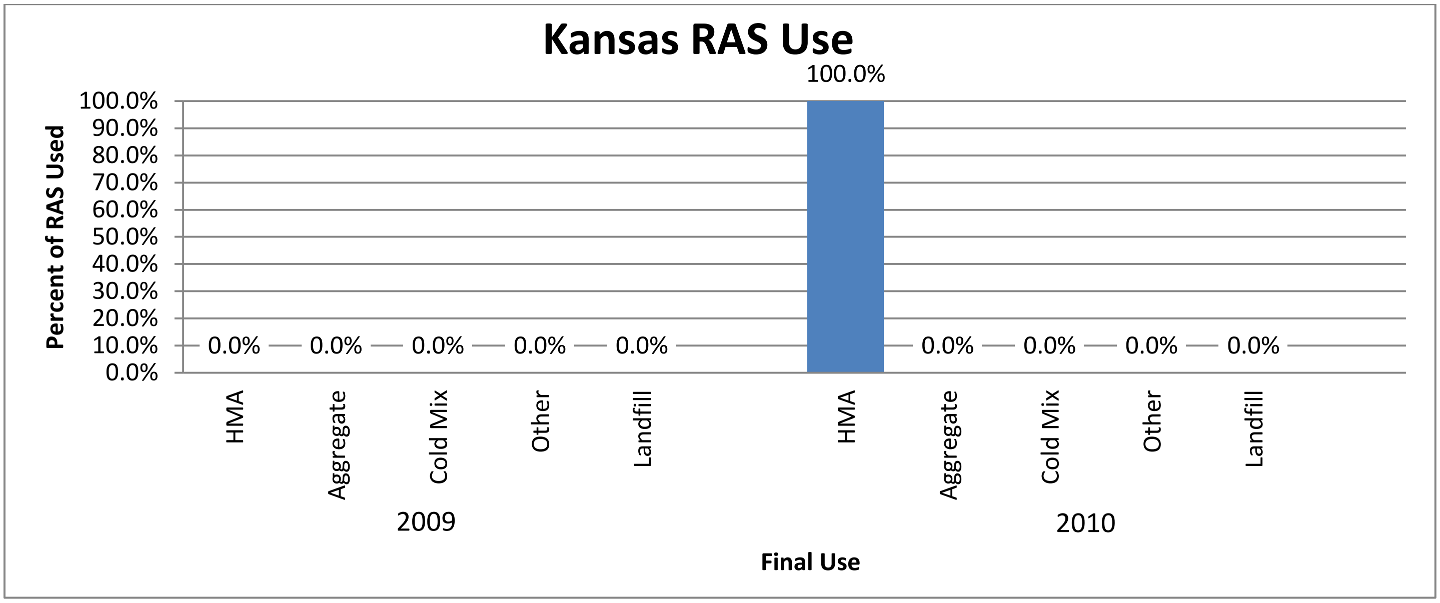


Total DOT tonnage provided by Kansas Asphalt Pavement Association and ratio of reported total tons to reported total DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

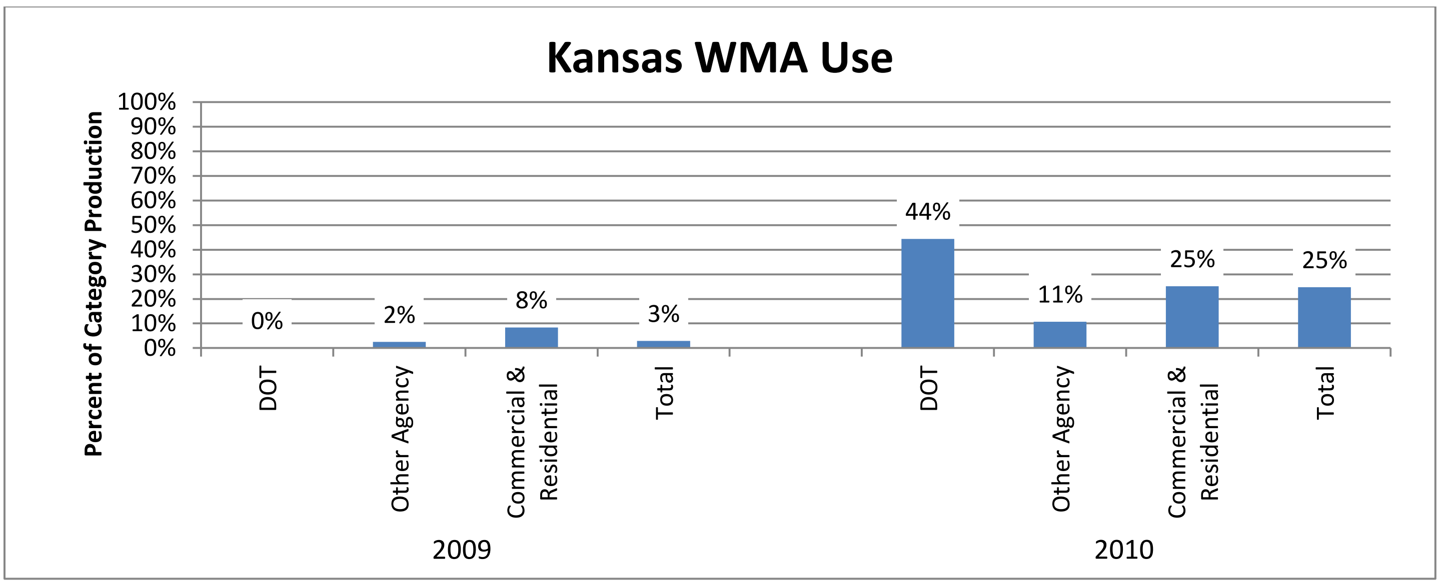


Table B 17: Summary of Kansas Data

Companies Reporting 6

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	885,000	590,000	1,778,559	2,268,554
Total Other Agency Tonnage	686,000	847,000	1,378,634	3,256,721
Total Commercial & Residential Tonnage	505,000	416,000	1,014,884	1,599,523
Total Tonnage	2,076,000	1,853,000	4,172,077	7,124,799
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	359,250	382,000	721,974	1,468,793
RAP Tons used in HMA/WMA	373,133	379,838	749,875	1,460,479
RAP Tons used as Aggregate	5,000	5,000	10,048	19,225
RAP Tons used in Cold Mix	20,000	1,000	40,193	3,845
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	29	41	58	156
Average % RAP in DOT Mixes	14%	15%		
Average % RAP in Other Agency Mixes	23%	20%		
Average % RAP in Commercial & Residential Mixes	22%	26%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	33%		
RAS Tons Received	-	4,000	-	15,380
RAS Tons used in HMA/WMA	-	1,500	-	5,768
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	50%		
WMA DOT Tonnage	-	262,150	-	1,007,969
WMA Other Agency Tonnage	17,000	91,150	34,164	350,472
WMA Commercial & Residential Tonnage	42,500	104,500	85,411	401,803
Total WMA Tonnage	59,500	457,800	119,575	1,760,244
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	99%		
Percent WMA Tons using Organic Additive	0%	1%		

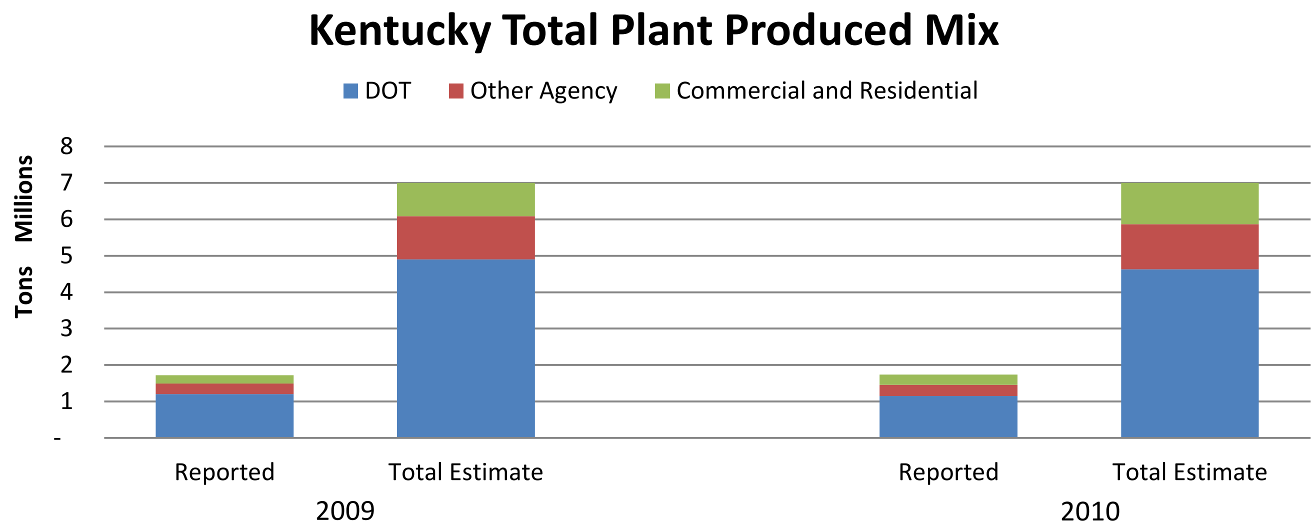
1. Total DOT tonnage provided by Kansas Asphalt Pavement Association and the ratio of reported total tons to reported total DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

Kentucky

Table B18 summarizes the results received from asphalt mix producers in Kentucky. The charts are used to summarize information calculated from information provided by the survey respondents.

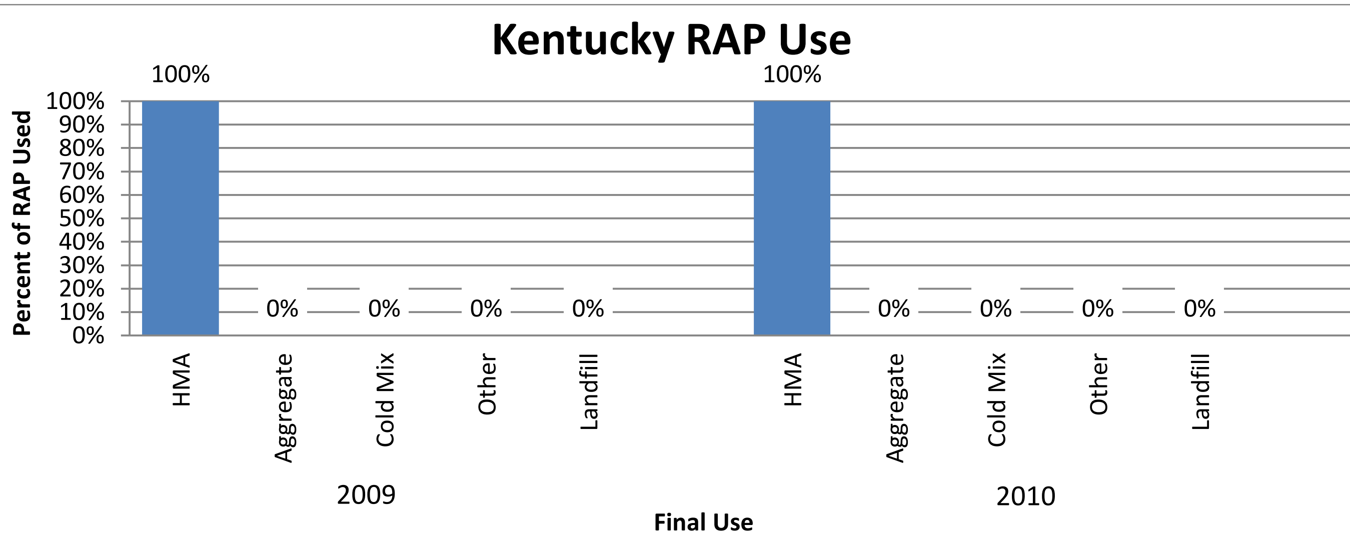
Total Asphalt Mix Tonnage

Companies responding: 3

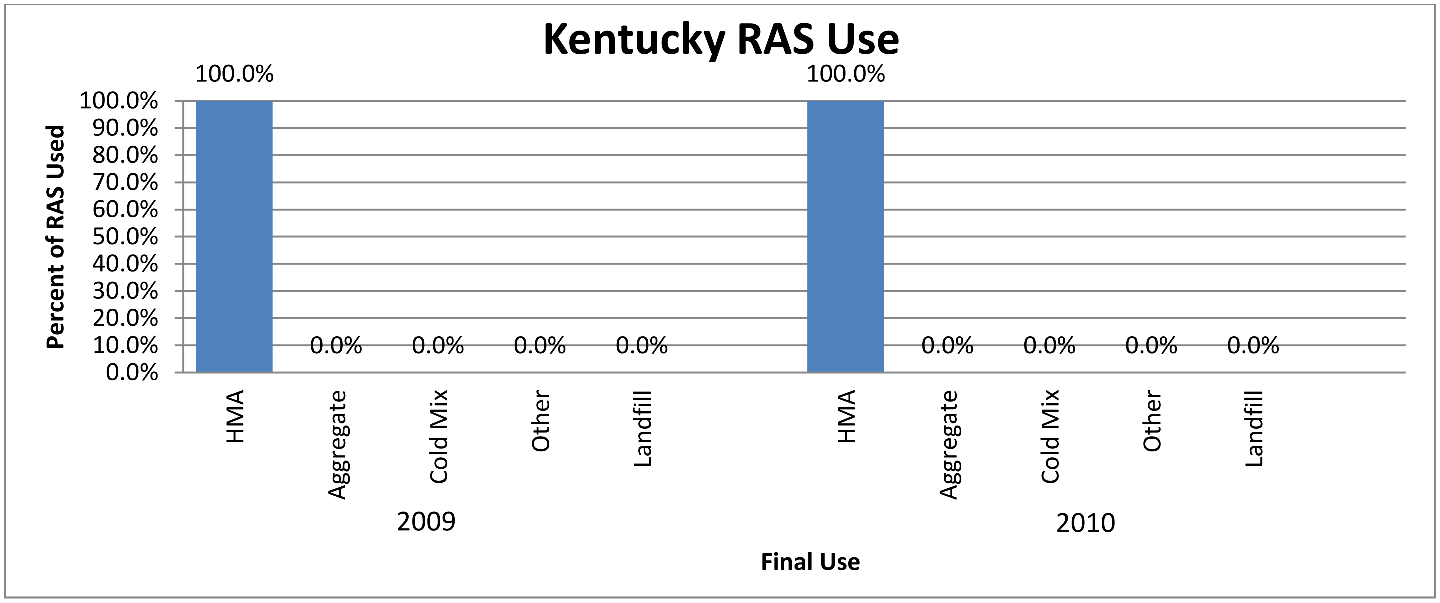


Total tonnage provided by Plantmix Asphalt Industry of Kentucky. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

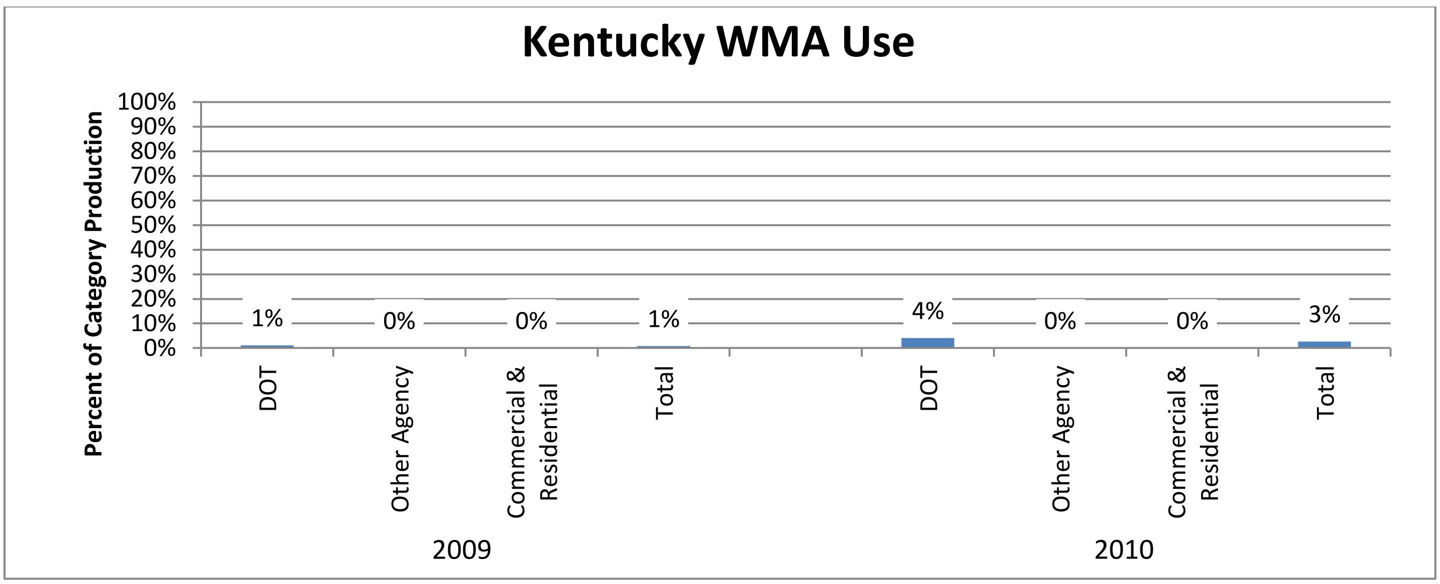


Table B 18: Summary of Kentucky Data — Companies Reporting 3

HMA/WMA	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,200,996	1,148,067	4,896,565	4,626,443
Total Other Agency Tonnage	291,380	308,817	1,187,982	1,244,461
Total Commercial & Residential Tonnage	224,536	280,189	915,453	1,129,096
Total Tonnage	1,716,912	1,737,073	7,000,000	7,000,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	195,000	165,000	795,032	664,912
RAP Tons used in HMA/WMA	155,000	158,000	631,949	636,703
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	11	11	44	46
Average % RAP in DOT Mixes	11%	12%		
Average % RAP in Other Agency Mixes	11%	14%		
Average % RAP in Commercial & Residential Mixes	15%	14%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	33%	33%		
RAS Tons Received	3,000	3,000	12,231	12,089
RAS Tons used in HMA/WMA	3,000	3,000	12,231	12,089
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	1%		
Average % RAS in Other Agency Mixes	3%	1%		
Average % RAS in Commercial & Residential Mixes	1%	1%		
Warm-Mix Asphalt				
	Reported		Total Estimated[2]	
	2009	2010	2009	2010
Percent Companies using WMA	67%	100%		
WMA DOT Tonnage	13,435	46,901	54,776	188,999
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	13,435	46,901	54,776	188,999
Percent WMA Tons using Chemical Additives	0%	18%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	76%	64%		
Percent WMA Tons using Organic Additive	24%	18%		

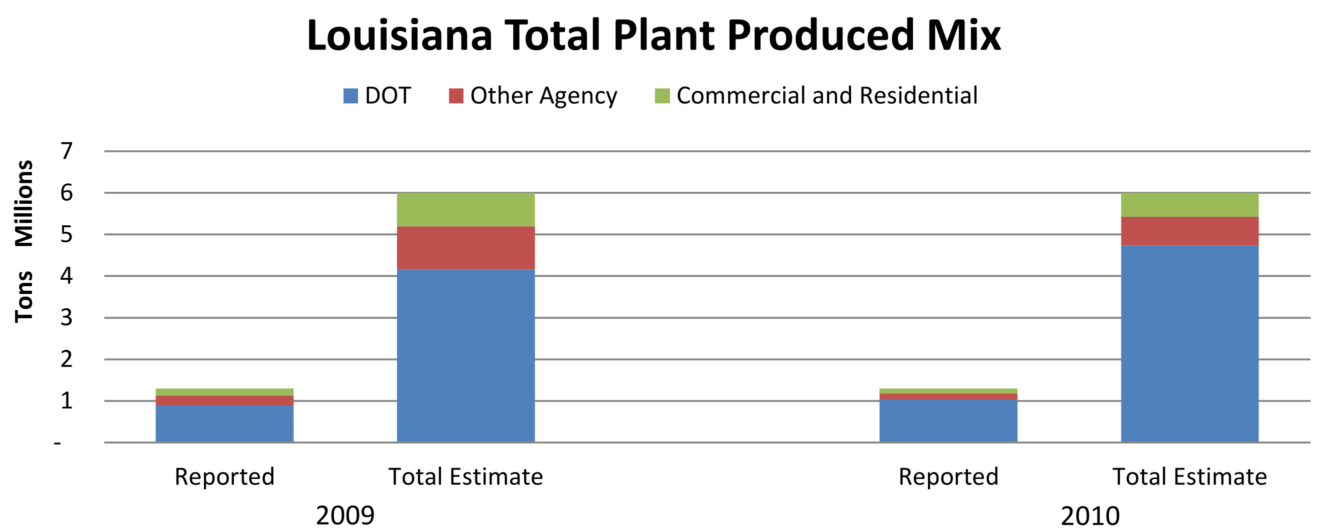
1. Total tonnage provided by Plantmix Asphalt Industry of Kentucky. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.
2. The Kentucky DOT reports in 2009 they placed about 930,000 tons of WMA (6300 tons by wax additive; the rest by water injection). In 2010, the Department purchased approximately 980,000 tons of WMA

Louisiana

Table B19 summarizes the results received from asphalt mix producers in Louisiana. The charts are used to summarize information calculated from information provided by the survey respondents.

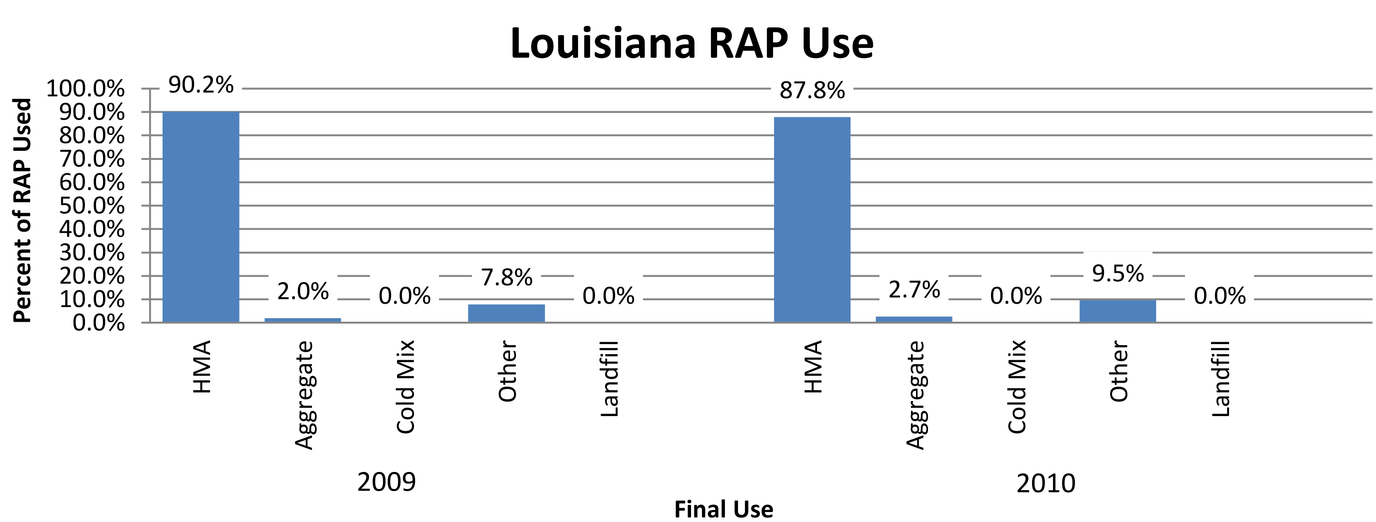
Total Asphalt Mix Tonnage

Companies responding: 2



Total tonnage provided by the Louisiana Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

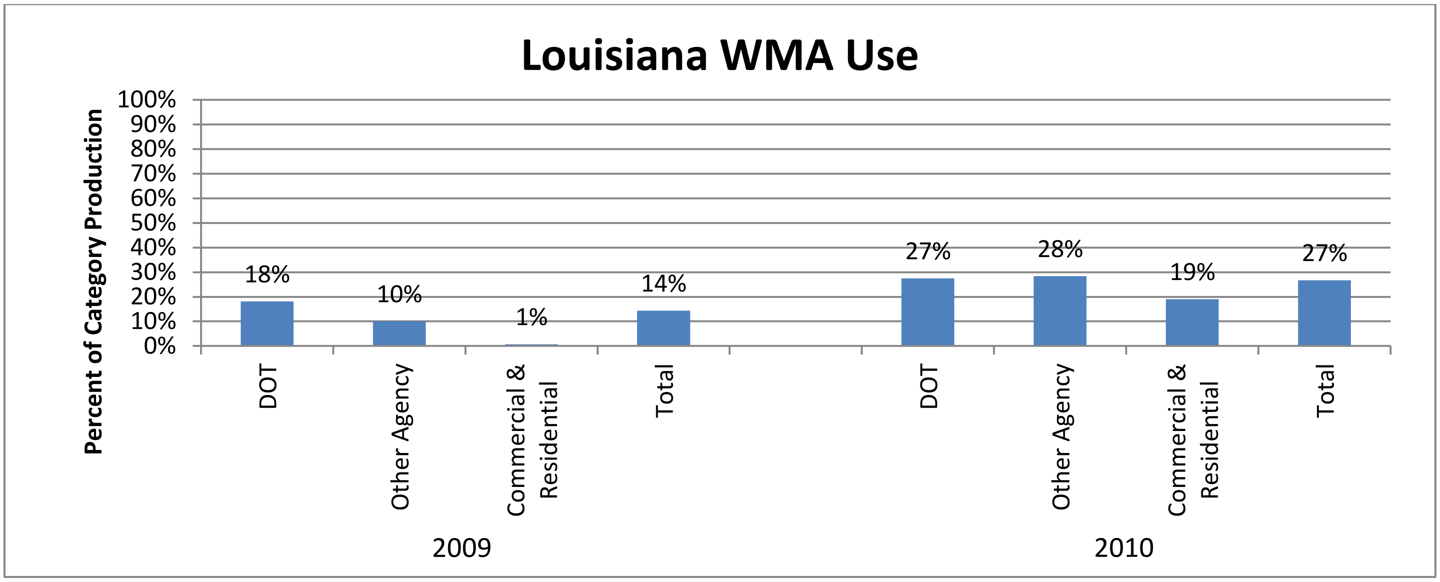
RAP Use



RAS Use

No contractors reported using RAS in 2009 and 2010.

WMA Use



Louisiana WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
18%
10%
1%
14%
27%
28%
19%
27%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 19: Summary of Louisiana Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	900,000	1,025,000	4,153,846	4,730,769
Total Other Agency Tonnage	225,000	150,000	1,038,462	692,308
Total Commercial & Residential Tonnage	175,000	125,000	807,692	576,923
Total Tonnage	1,300,000	1,300,000	6,000,000	6,000,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	300,000	400,000	1,384,615	1,846,154
RAP Tons used in HMA/WMA	230,000	230,000	1,061,538	1,061,538
RAP Tons used as Aggregate	5,000	7,000	23,077	32,308
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	20,000	25,000	92,308	115,385
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	19%	19%		
Average % RAP in Other Agency Mixes	20%	20%		
Average % RAP in Commercial & Residential Mixes	29%	28%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	100%		
WMA DOT Tonnage	162,500	281,250	750,000	1,298,077
WMA Other Agency Tonnage	22,500	42,500	103,846	196,154
WMA Commercial & Residential Tonnage	1,250	23,750	5,769	109,615
Total WMA Tonnage	186,250	347,500	859,615	1,603,846
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

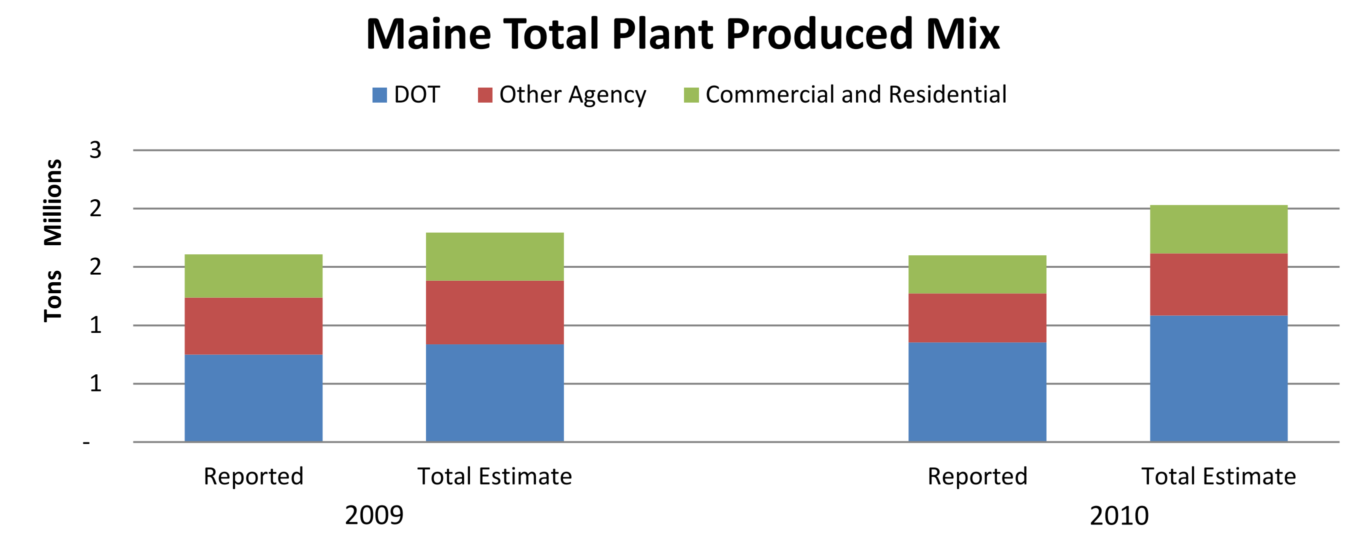
1. Total tonnage provided by the Louisiana Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Maine

Table B20 summarizes the results received from asphalt mix producers in Maine. The charts are used to summarize information calculated from information provided by the survey respondents.

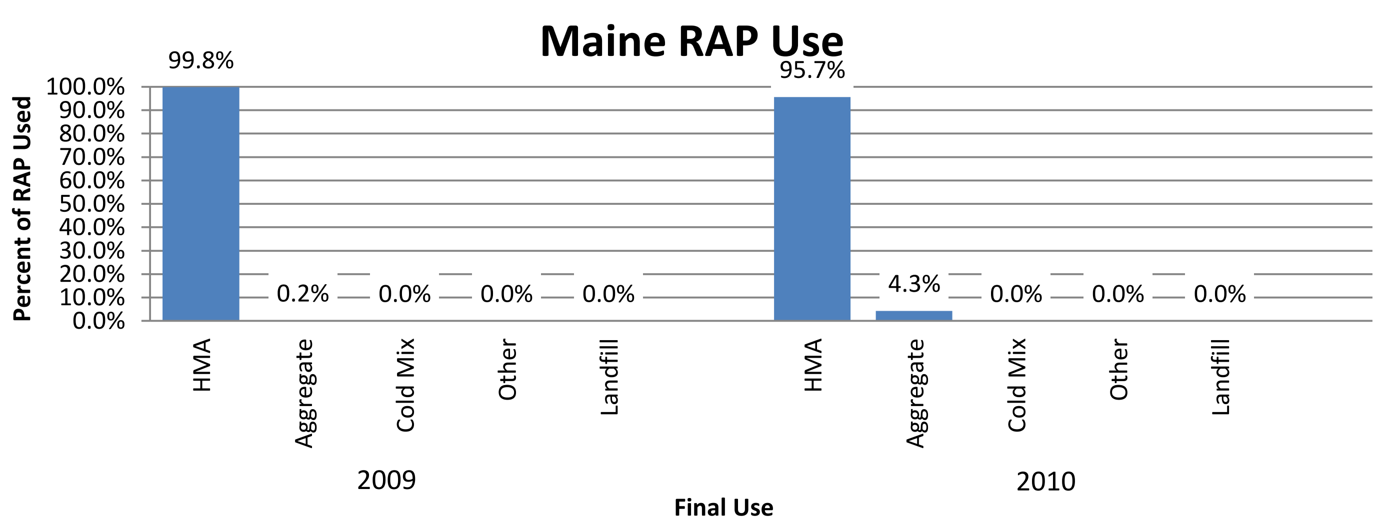
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons extimated based on relationship of tons to Federal Apportionment.   Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

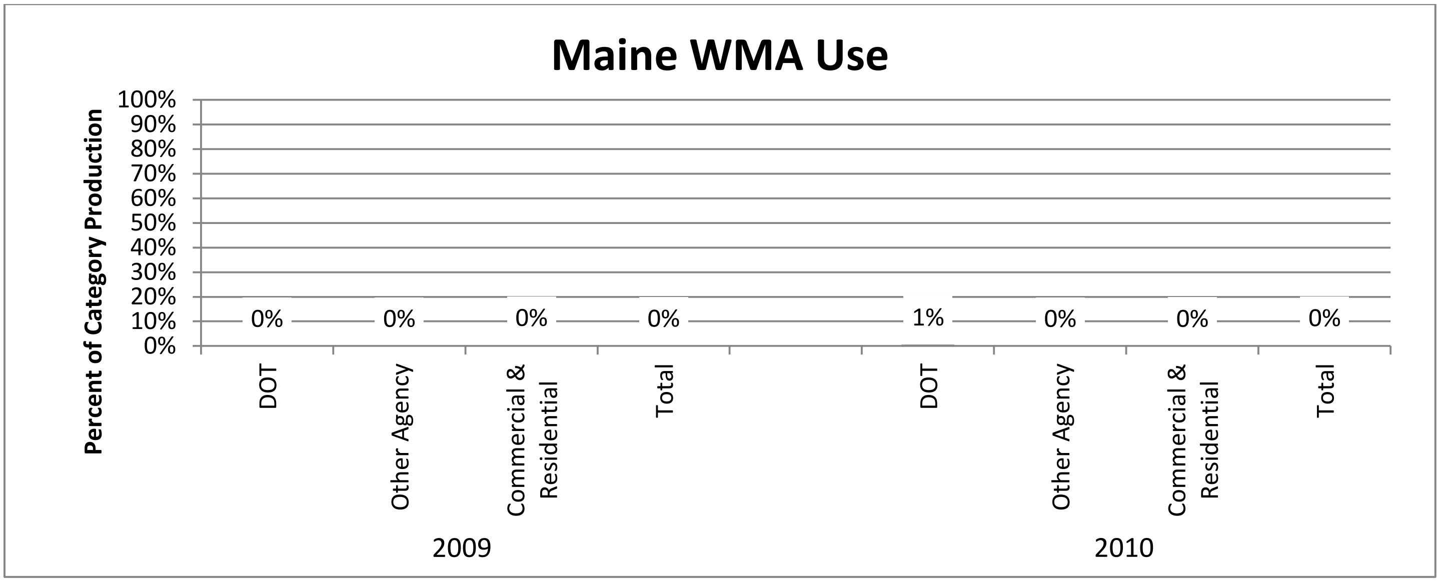
RAP Use



RAS Use

No contractors reported using RAS in 2009 and 2010.

WMA Use



Maine WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
0%
0%
0%
1%
0%
0%
0%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 20: Summary of Maine Data

	Companies Reporting	2		
HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	748,000	853,000	835,701	1,083,249
Total Other Agency Tonnage	490,000	419,000	547,451	532,100
Total Commercial & Residential Tonnage	369,000	327,000	412,264	415,267
Total Tonnage	1,607,000	1,599,000	1,795,416	2,030,616
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	147,000	240,000	164,235	304,783
RAP Tons used in HMA/WMA	210,000	222,000	234,622	281,924
RAP Tons used as Aggregate	400	10,000	447	12,699
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	15	15	16	18
Average % RAP in DOT Mixes	14%	13%		
Average % RAP in Other Agency Mixes	16%	17%		
Average % RAP in Commercial & Residential Mixes	16%	17%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	100%		
WMA DOT Tonnage	-	4,750	-	6,032
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	1,400	48	1,564	60
Total WMA Tonnage	1,400	4,798	1,564	6,093
Percent WMA Tons using Chemical Additives	100%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	1%		
Percent WMA Tons using Organic Additive	0%	99%		

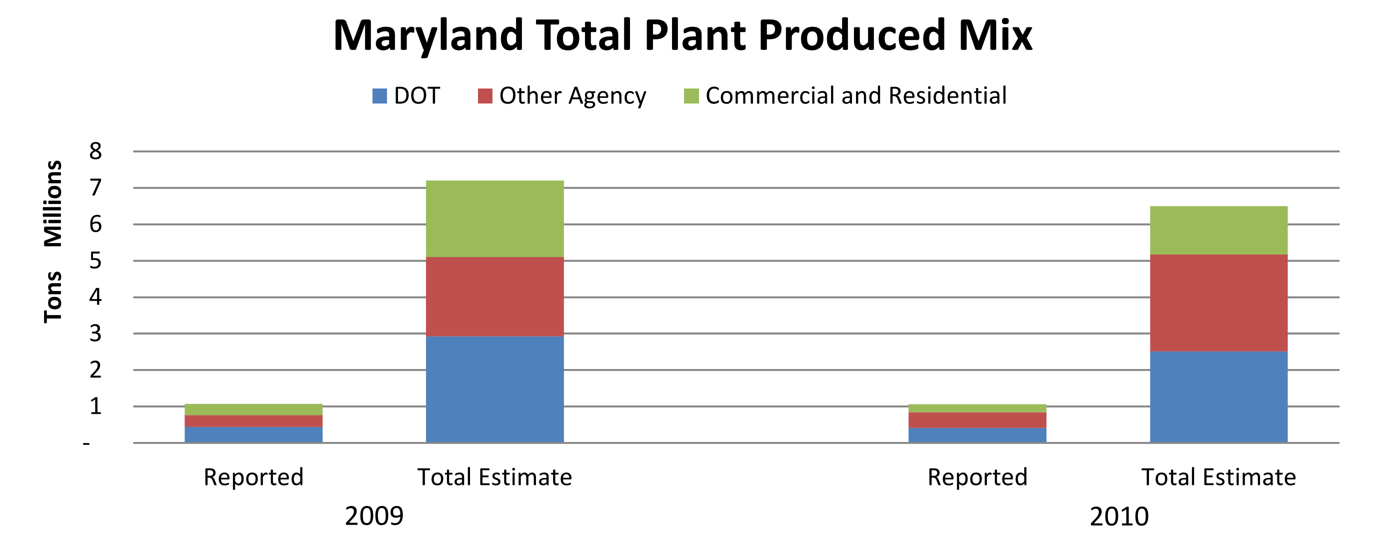
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Maryland

Table B21 summarizes the results received from asphalt mix producers in Maryland. The charts are used to summarize information calculated from information provided by the survey respondents.

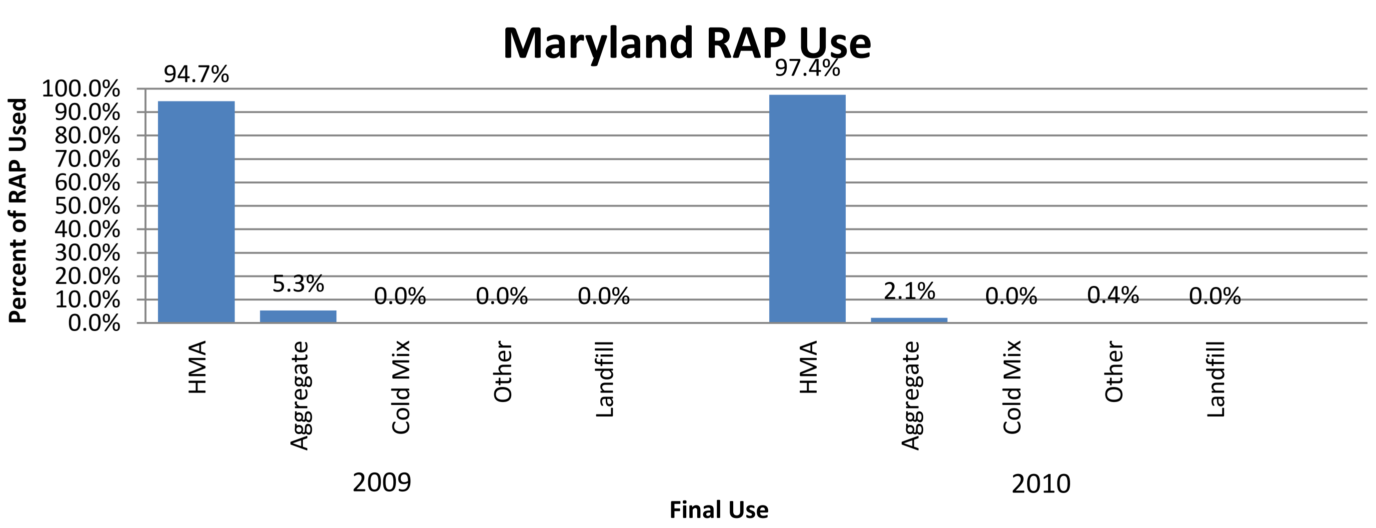
Total Asphalt Mix Tonnage

Companies responding: 4

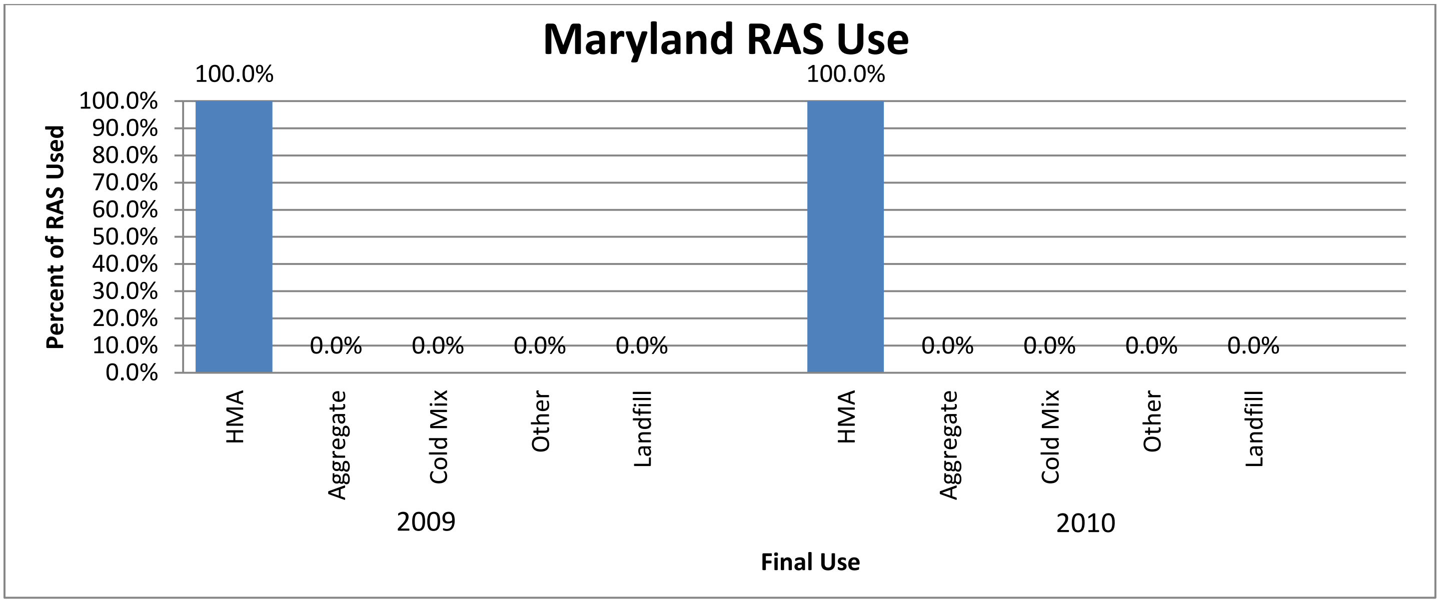


Total tonnage provided by the Maryland Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

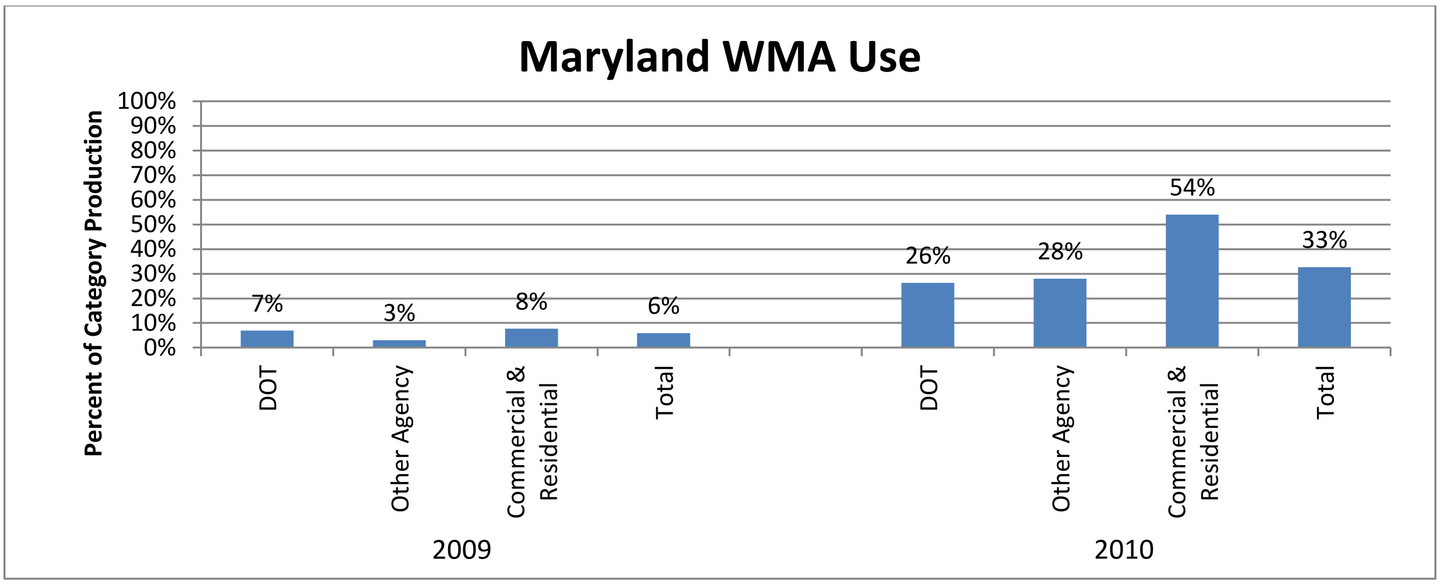


Table B 21: Summary of Maryland Data

Companies Reporting 4

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	435,100	410,086	2,921,441	2,510,746
Total Other Agency Tonnage	325,000	434,445	2,182,184	2,659,884
Total Commercial & Residential Tonnage	312,220	217,129	2,096,374	1,329,370
Total Tonnage	1,072,320	1,061,660	7,200,000	6,500,000

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	307,608	211,000	2,065,407	1,291,845
RAP Tons used in HMA/WMA	205,608	227,000	1,380,537	1,389,805
RAP Tons used as Aggregate	11,500	5,000	77,216	30,612
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	1,000	-	6,122
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	20%	20%		
Average % RAP in Other Agency Mixes	19%	21%		
Average % RAP in Commercial & Residential Mixes	25%	26%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	50%	50%		
RAS Tons Received	12,000	28,000	80,573	171,430
RAS Tons used in HMA/WMA	15,400	17,500	103,402	107,144
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	2%	6%		
Average % RAS in Other Agency Mixes	1%	2%		
Average % RAS in Commercial & Residential Mixes	2%	2%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	75%	100%		
WMA DOT Tonnage	30,000	108,086	201,432	661,755
WMA Other Agency Tonnage	10,000	121,885	67,144	746,239
WMA Commercial & Residential Tonnage	24,000	117,249	161,146	717,856
Total WMA Tonnage	64,000	347,220	429,722	2,125,850
Percent WMA Tons using Chemical Additives	0%	2%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	98%		
Percent WMA Tons using Organic Additive	0%	0%		

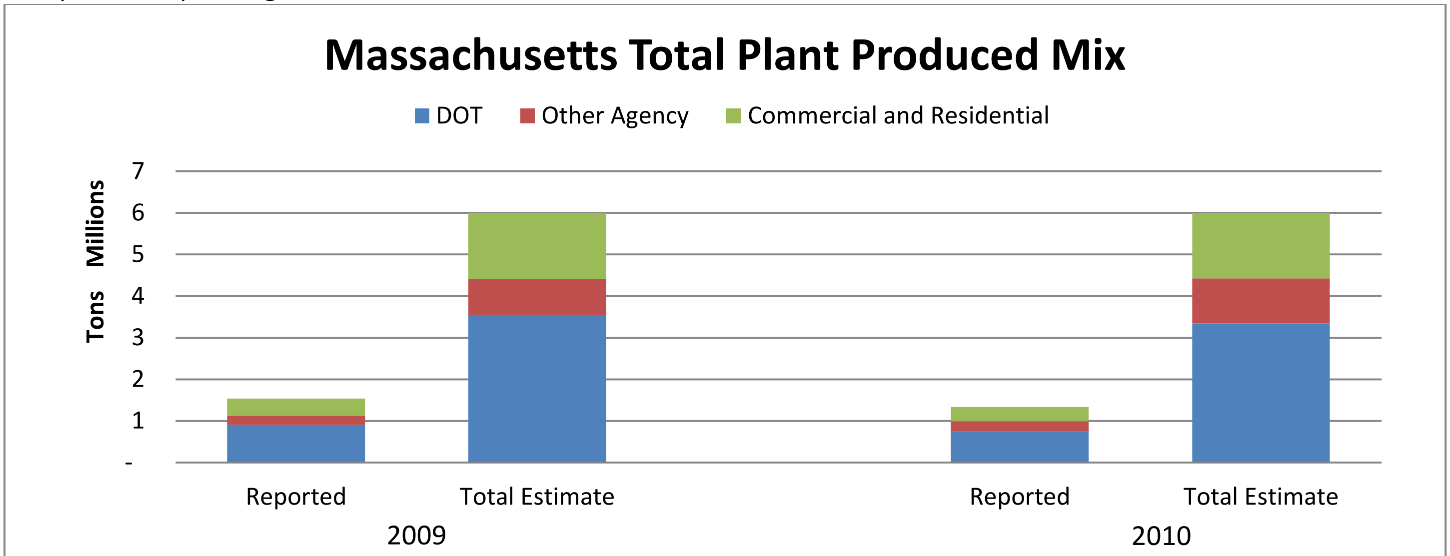
1. Total tonnage provided by the Maryland Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Massachusetts

Table B22 summarizes the results received from asphalt mix producers in Massachusetts. The charts are used to summarize information calculated from information provided by the survey respondents.

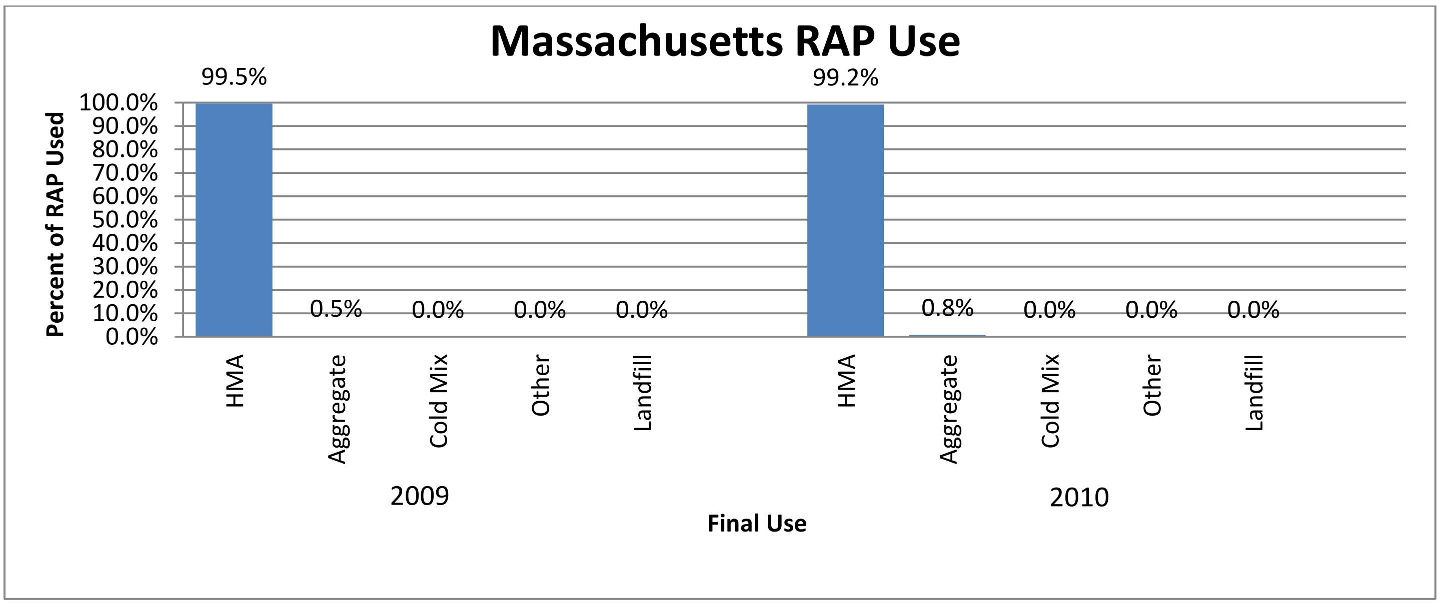
Total Asphalt Mix Tonnage

Companies responding: 2

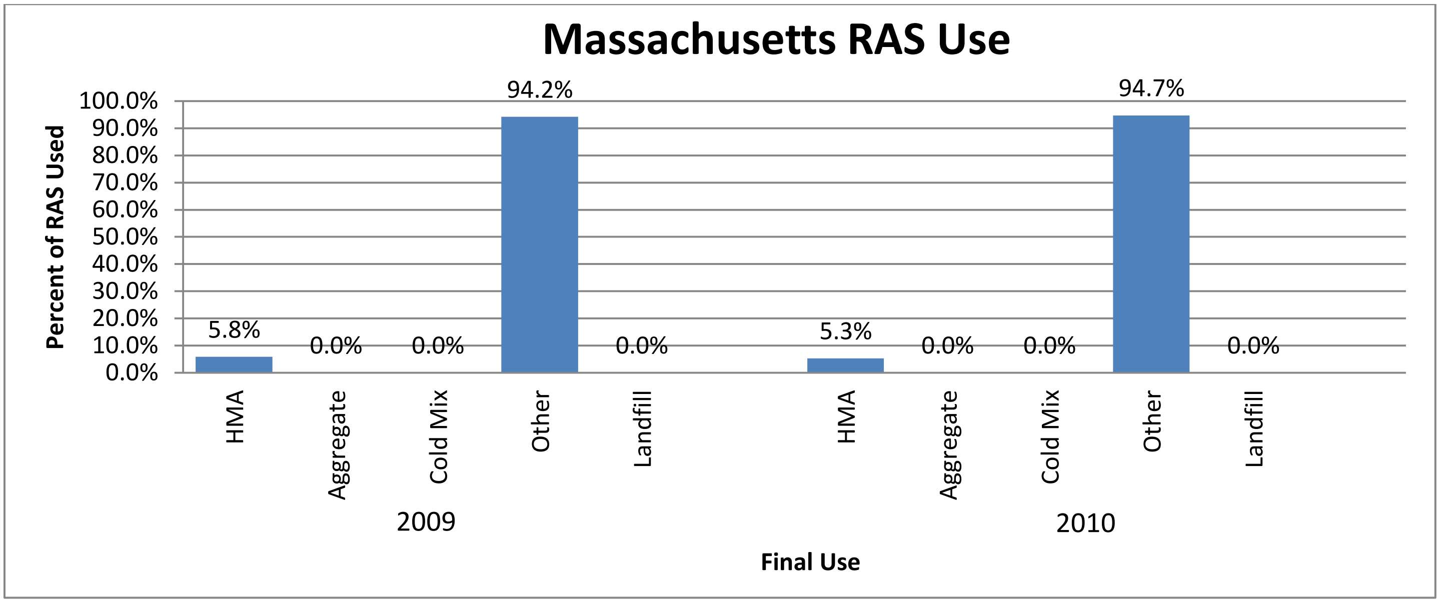


Total tonnage provided by the Massachusetts Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

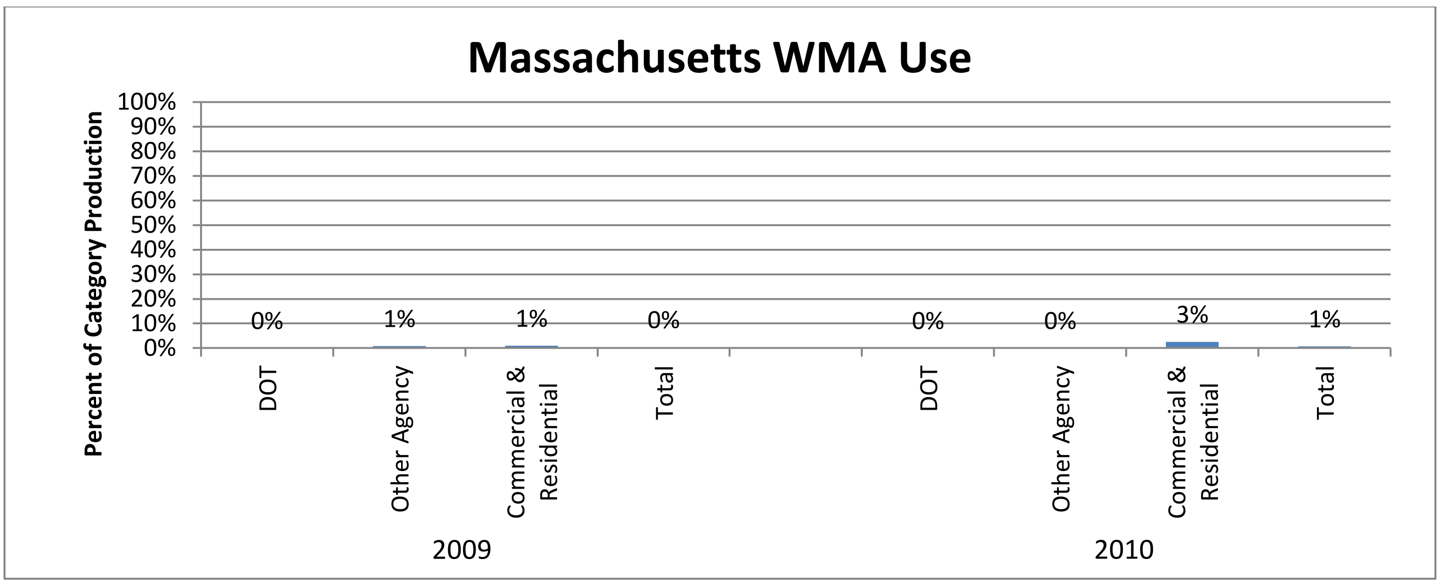


Table B 22: Summary of Massachusetts Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	907,358	744,491	3,546,568	3,339,388
Total Other Agency Tonnage	220,933	242,950	863,555	1,089,744
Total Commercial & Residential Tonnage	406,756	350,213	1,589,877	1,570,868
Total Tonnage	1,535,047	1,337,654	6,000,000	6,000,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	216,000	105,900	844,274	475,011
RAP Tons used in HMA/WMA	218,100	185,500	852,482	832,054
RAP Tons used as Aggregate	1,000	1,500	3,909	6,728
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	0	0	1	0
Average % RAP in DOT Mixes	1%	1%		
Average % RAP in Other Agency Mixes	22%	23%		
Average % RAP in Commercial & Residential Mixes	2%	4%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	50%	50%		
RAS Tons Received	41,000	36,000	160,256	161,477
RAS Tons used in HMA/WMA	1,300	1,000	5,081	4,485
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	21,000	18,000	82,082	80,738
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	50%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	1,769	-	6,916	-
WMA Commercial & Residential Tonnage	3,720	9,030	14,540	40,504
Total WMA Tonnage	5,489	9,030	21,456	40,504
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	68%	33%		
Percent WMA Tons using Organic Additive	32%	67%		

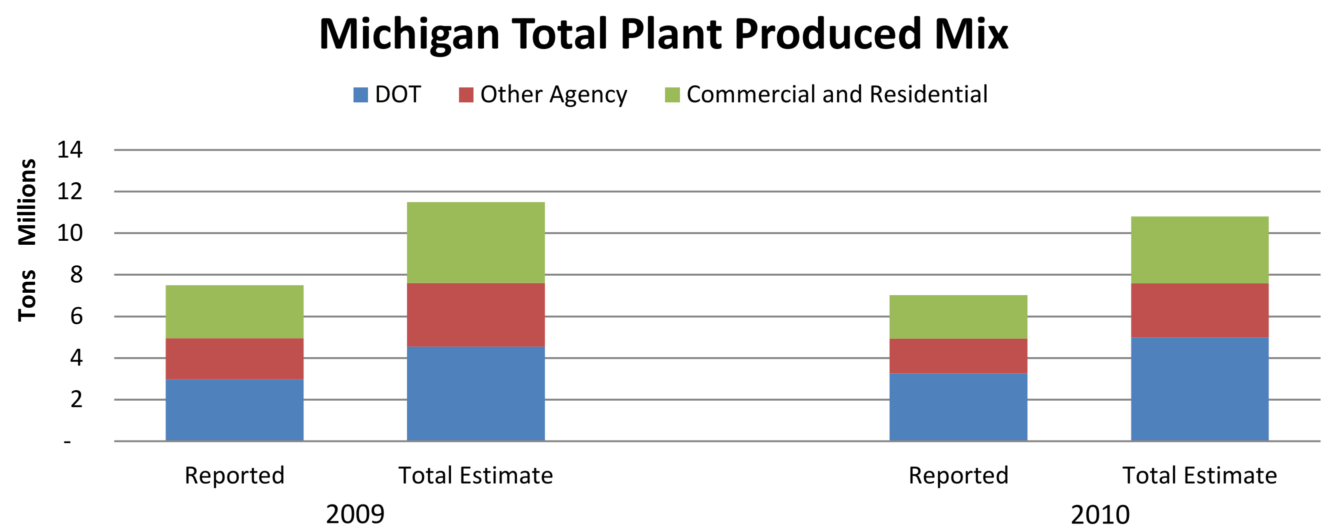
1. Total tonnage provided by the Massachusetts Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Michigan

Table B23 summarizes the results received from asphalt mix producers in Michigan. The charts are used to summarize information calculated from information provided by the survey respondents.

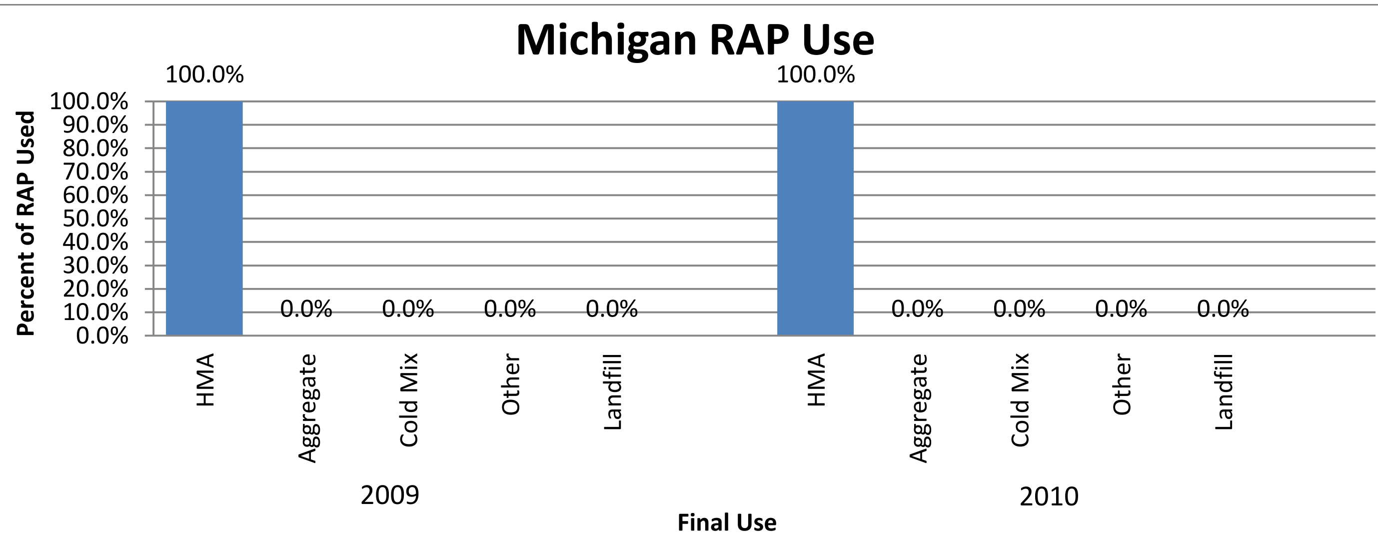
Total Asphalt Mix Tonnage

Companies responding: 8

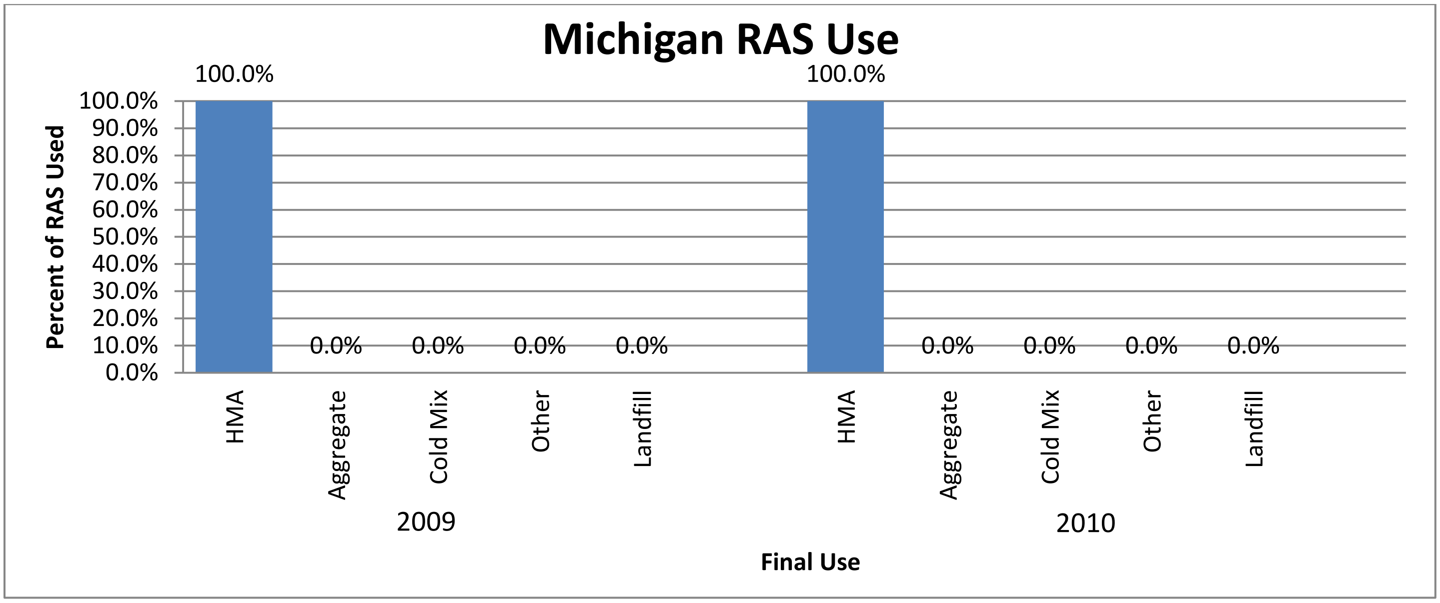


Total tonnage provided by the Michigan Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

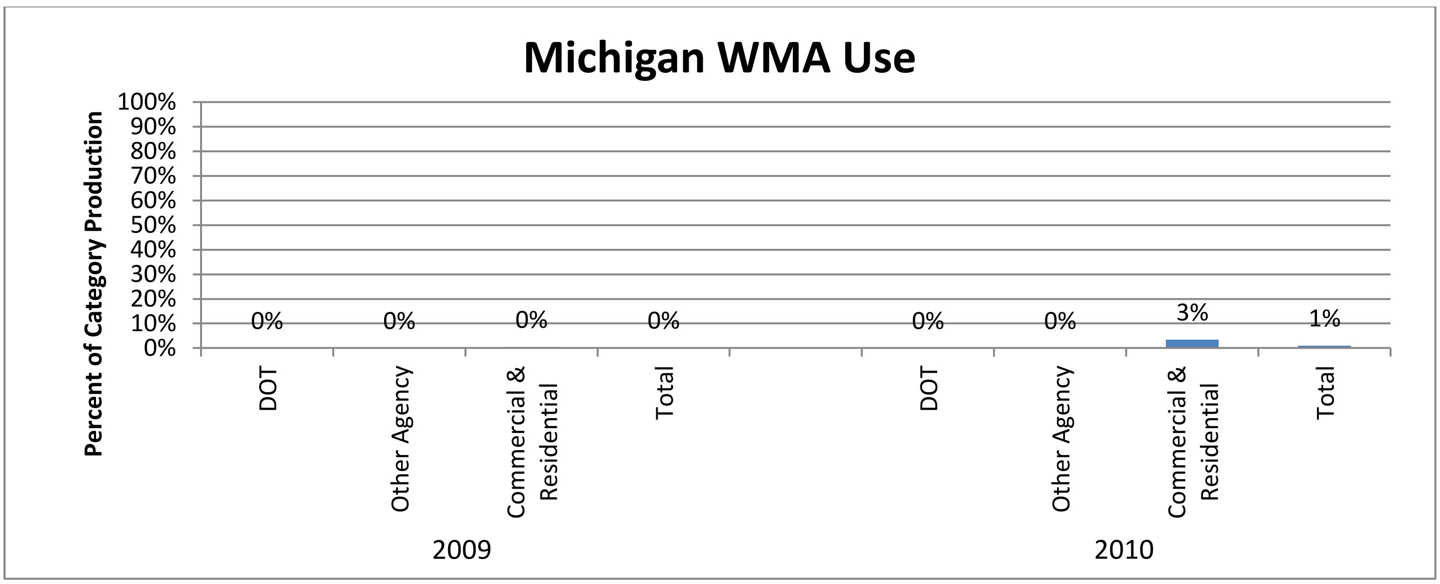


Table B 23: Summary of Michigan Data — Companies Reporting 4

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,964,000	3,252,000	4,549,046[2]	4,996,671[2]
Total Other Agency Tonnage	1,990,000	1,688,000	3,054,184	2,593,598
Total Commercial & Residential Tonnage	2,539,000	2,089,000	3,896,770	3,209,731
Total Tonnage	7,493,000	7,029,000	11,500,000	10,800,000

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	2,305,000	2,185,000	3,537,635	3,357,234
RAP Tons used in HMA/WMA	2,024,000	2,107,000	3,106,366	3,237,388
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	27	31	42	47
Average % RAP in DOT Mixes	17%	17%		
Average % RAP in Other Agency Mixes	23%	24%		
Average % RAP in Commercial & Residential Mixes	38%	38%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	100%[3]	50%[3]		
RAS Tons Received	5,000	8,000	7,674	12,292
RAS Tons used in HMA/WMA	5,636	11,017	8,650	16,928
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	1%	1%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	25%	25%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	12,000	72,000	18,417	110,627
Total WMA Tonnage	12,000	72,000	18,417	110,627
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

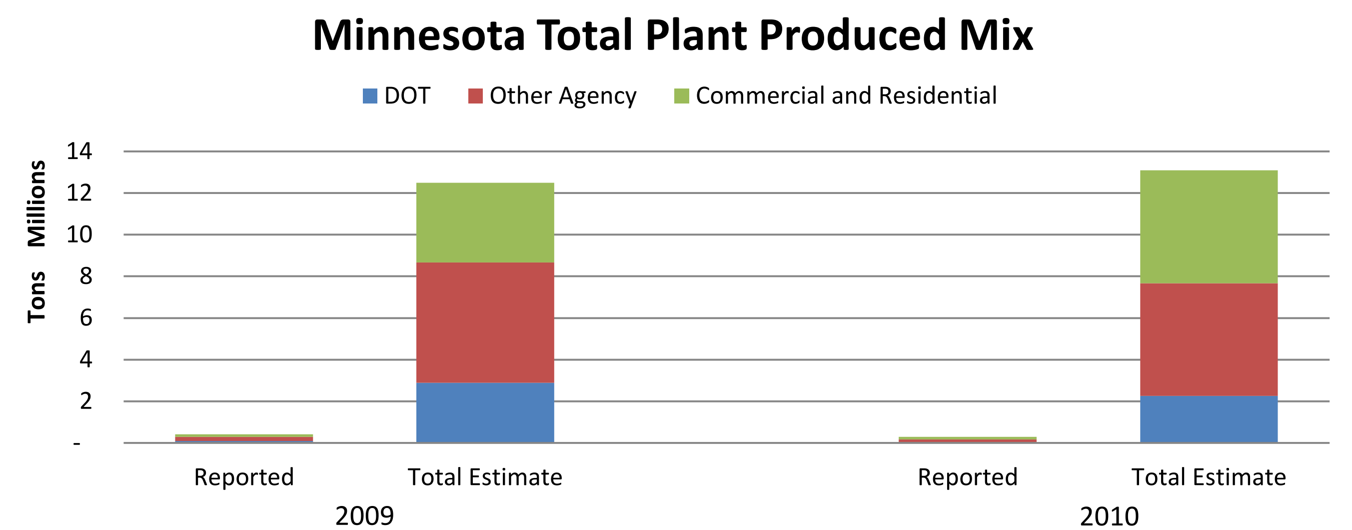
1. Total tonnage provided by the Asphalt Pavement Association of Michigan (APAM). Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.
2. APAM reports Total DOT Tonnage: 2009 = 3.2 M tons, 2010 =2.5 M tons. Some differences likely due to local aid projects bid through DOT that are not part of the DOT system.
3. APAM estimates 50% of companies used RAS in 2009 with fewer in 2010 due to excess RAP.

Minnesota

Table B6 summarizes the results received from asphalt mix producers in Minnesota. The charts are used to summarize information calculated from information provided by the survey respondents.

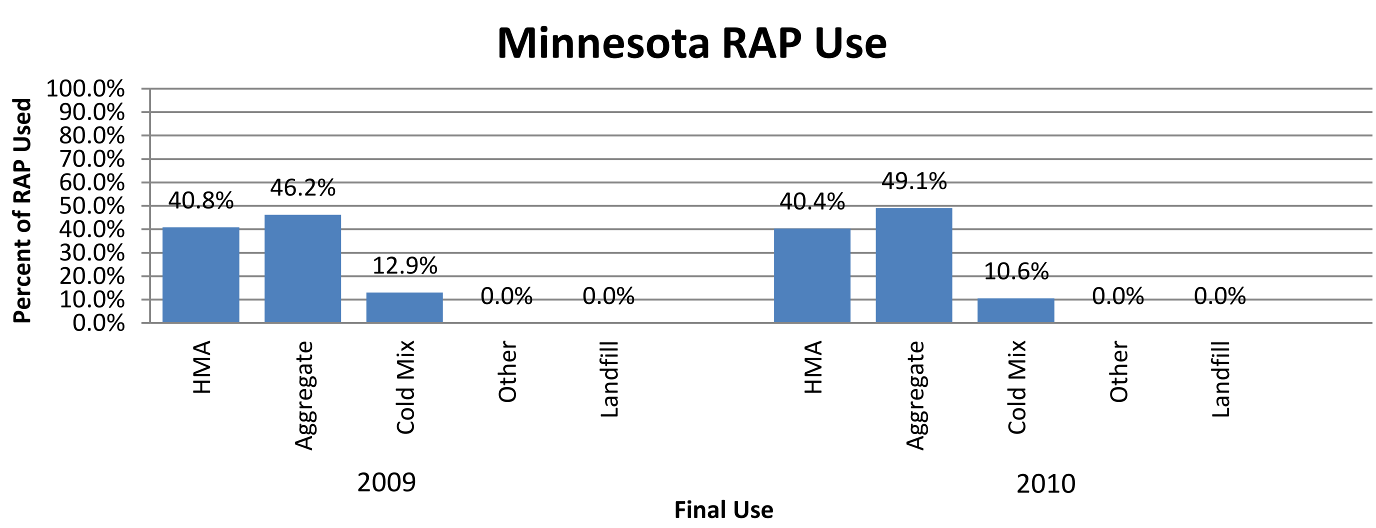
Total Asphalt Mix Tonnage

Companies responding: 8

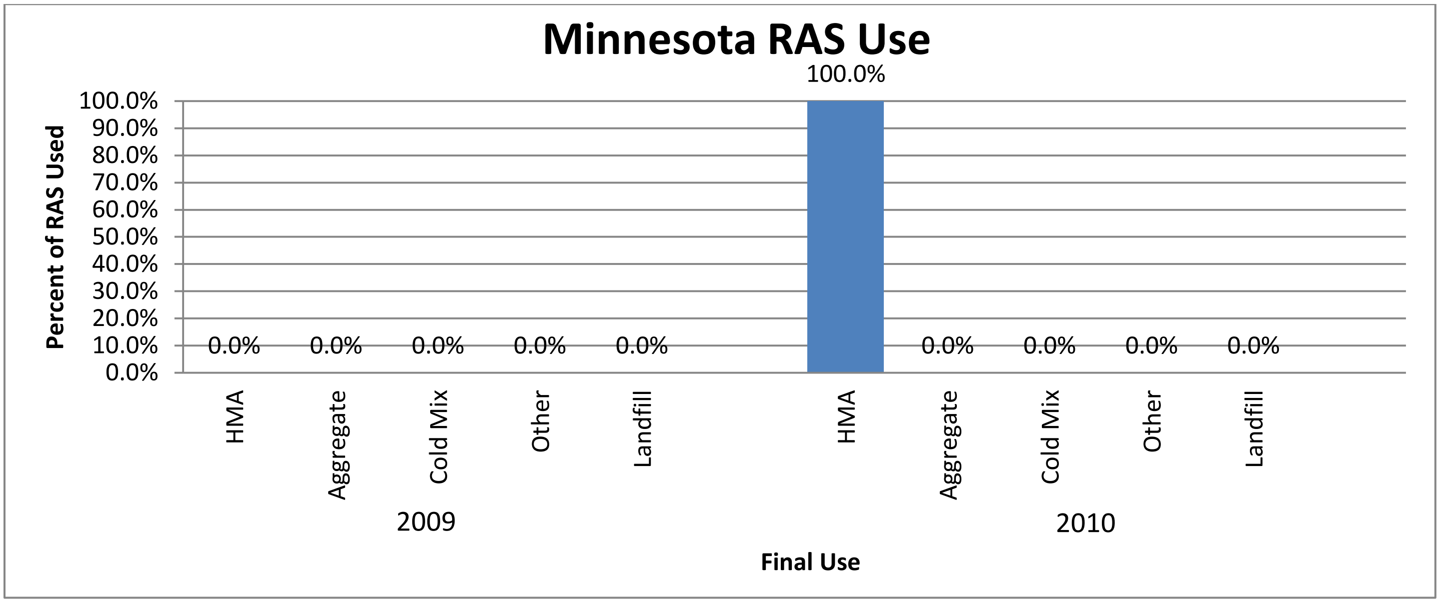


Total tonnage provided by the Minnesota Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

No contractors reported using WMA in 2009 or 2010.

Table B 24: Summary of Minnesota Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	96,000	49,000	2,891,566	2,252,281
Total Other Agency Tonnage	192,000	118,000	5,783,133	5,423,860
Total Commercial & Residential Tonnage	127,000	118,000	3,825,301	5,423,860
Total Tonnage	415,000	285,000	12,500,000	13,100,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	135,000	130,000	4,066,265	5,975,439
RAP Tons used in HMA/WMA	66,166	53,463	1,992,955	2,457,424
RAP Tons used as Aggregate	75,000	65,000	2,259,036	2,987,719
RAP Tons used in Cold Mix	21,000	14,000	632,530	643,509
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	16	14	486	627
Average % RAP in DOT Mixes	22%	28%		
Average % RAP in Other Agency Mixes	10%	13%		
Average % RAP in Commercial & Residential Mixes	11%	16%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	50%		
RAS Tons Received	-	2,000	-	91,930
RAS Tons used in HMA/WMA	-	558	-	25,642
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	4%		
Average % RAS in Other Agency Mixes	0%	2%		
Average % RAS in Commercial & Residential Mixes	0%	1%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

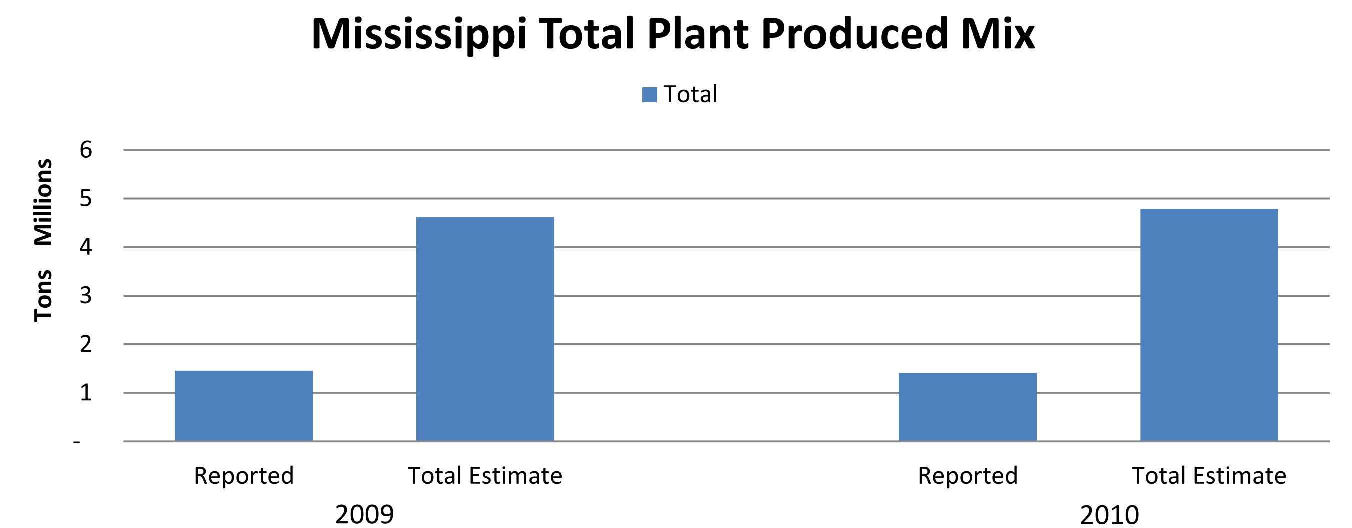
1. Total tonnage provided by the Minnesota Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Mississippi

Table B25 summarizes the results received from asphalt mix producers in Mississippi. The charts are used to summarize information calculated from information provided by the survey respondents.

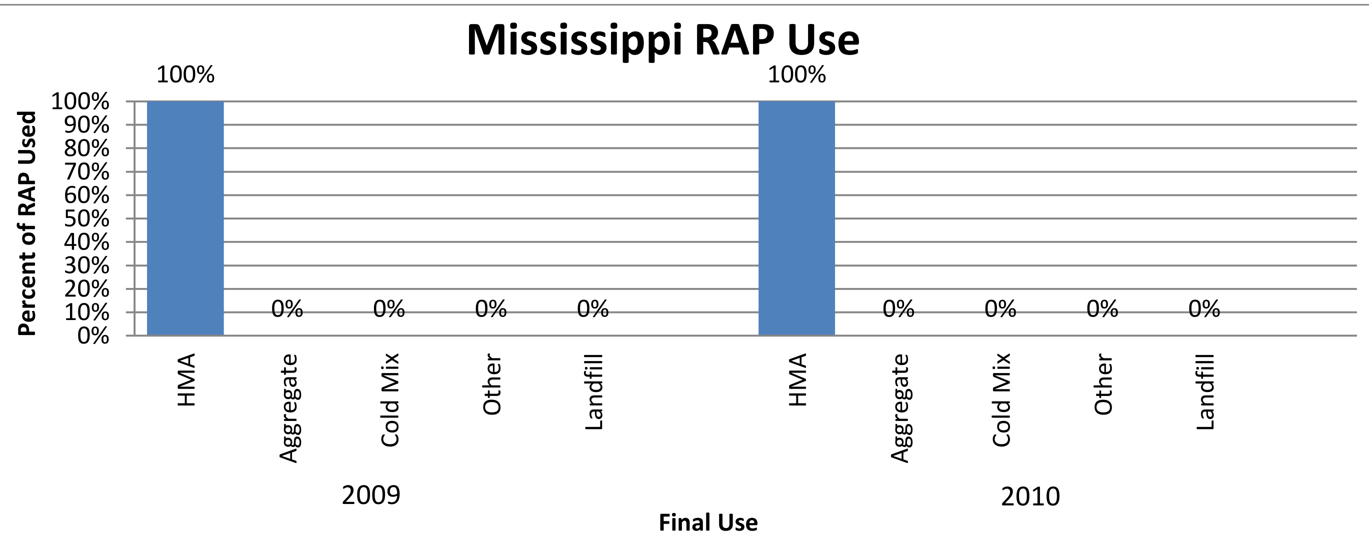
Total Asphalt Mix Tonnage

Companies responding: 1



Total tons extimated based on relationship of tons to Federal Apportionment. Tonnage could not be broken down by use since contractor did not submit this data.

RAP Use



RAS Use

The contractor did not report any RAS use in 2009 or 2010.

WMA Use

The contractor did not report an WMA use in 2009 or 2010.

Table B 25: Summary of Mississippi Data

Companies Reporting 1

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	-	-	-	-
Total Other Agency Tonnage	-	-	-	-
Total Commercial & Residential Tonnage	-	-	-	-
Total Tonnage	1,454,000	1,411,000	4,615,667	4,786,725

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	-	-	-	-
RAP Tons used in HMA/WMA	236,493	238,632	750,738	809,543
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	16	17	52	57
Average % RAP in DOT Mixes	0%	0%		
Average % RAP in Other Agency Mixes	0%	0%		
Average % RAP in Commercial & Residential Mixes	0%	0%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

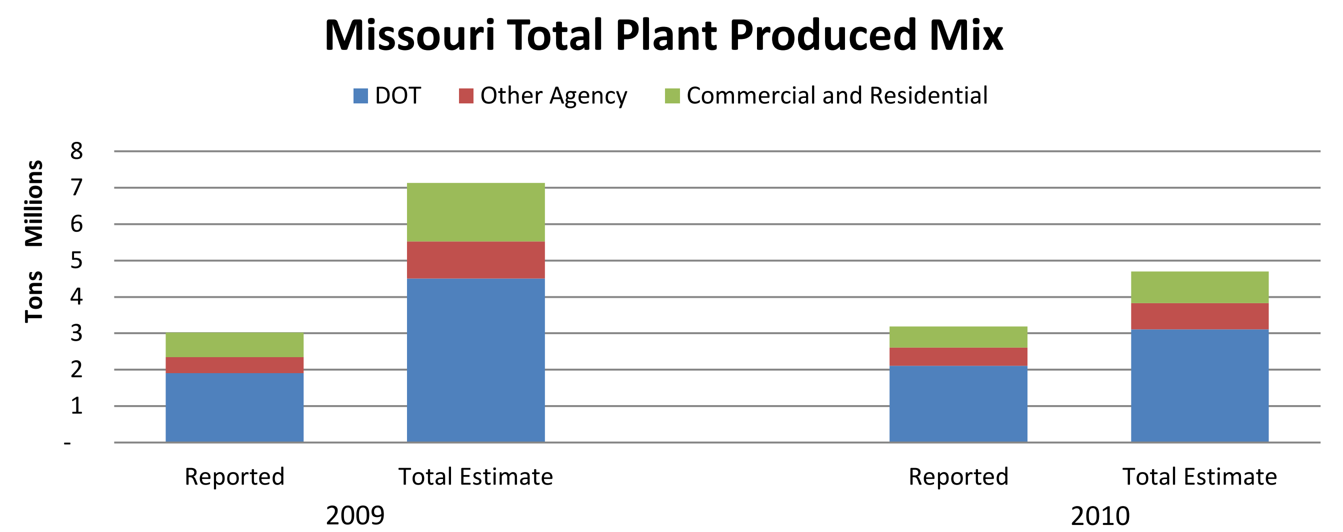
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

Missouri

Table B26 summarizes the results received from asphalt mix producers in Missouri. The charts are used to summarize information calculated from information provided by the survey respondents.

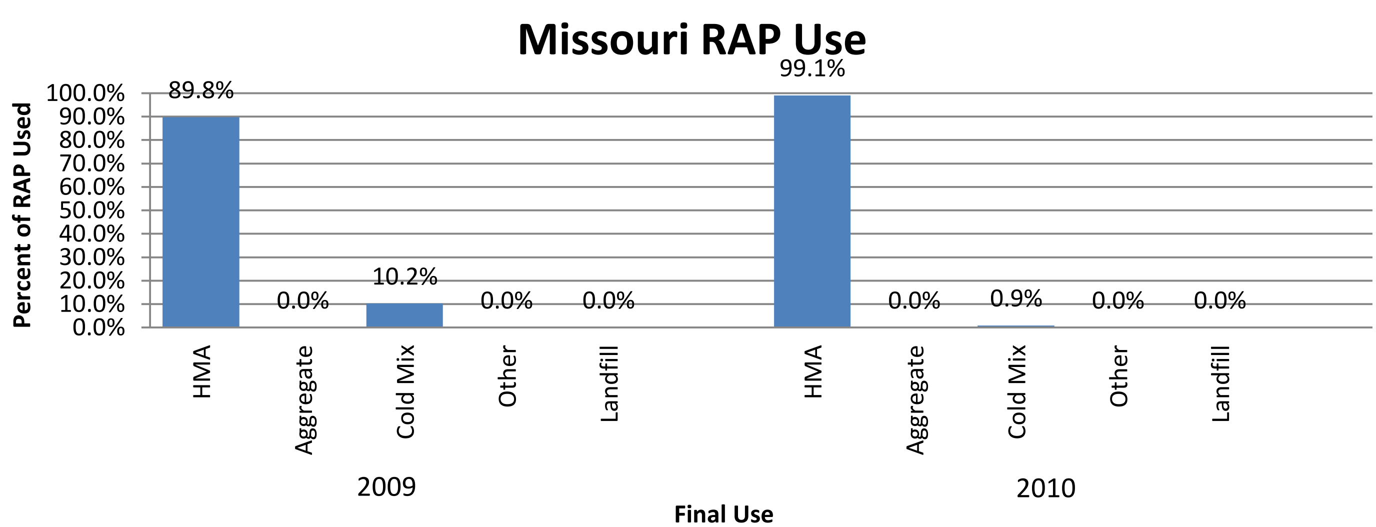
Total Asphalt Mix Tonnage

Companies responding: 6

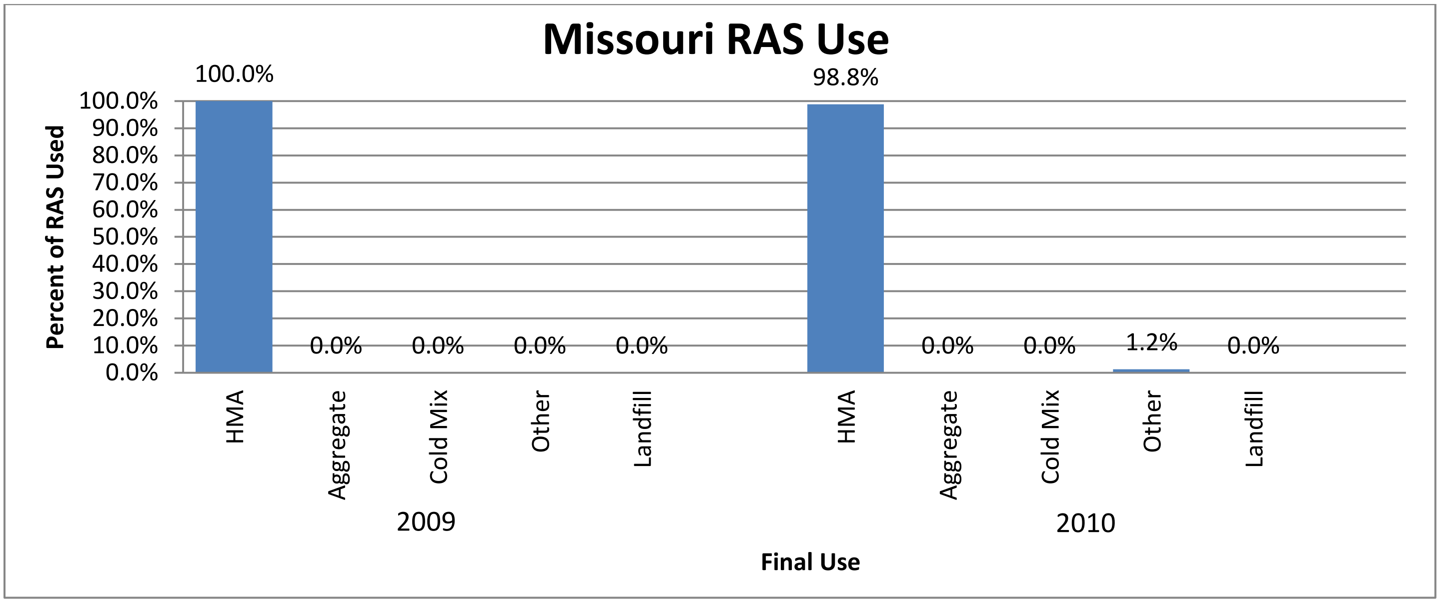


Total DOT tonnage provided by Missouri Asphalt Pavement Association and ratio of reported total tons to reported DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

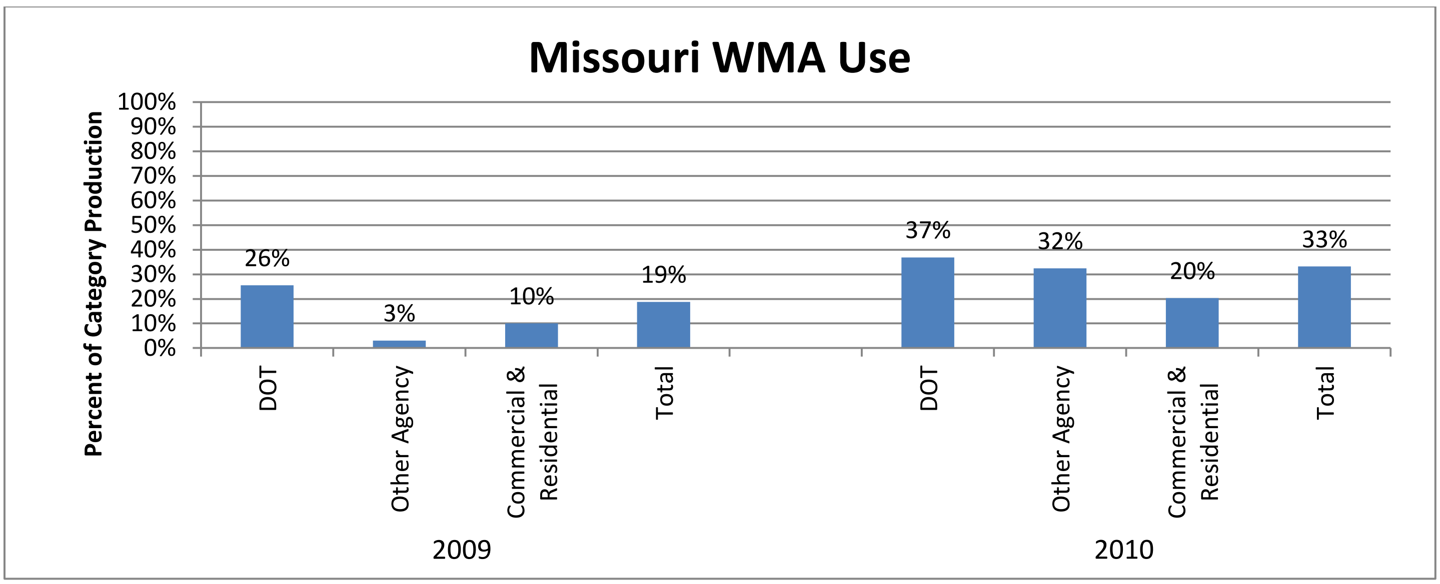


Table B 26: Summary of Missouri Data

Companies Reporting 6

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,906,900	2,109,800	4,502,775	3,104,824
Total Other Agency Tonnage	433,500	493,900	1,023,626	726,833
Total Commercial & Residential Tonnage	679,766	588,000	1,605,136	865,313
Total Tonnage	3,020,166	3,191,700	7,131,537	4,696,970
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	83%		
RAP Tons Received	379,000	411,000	894,935	604,836
RAP Tons used in HMA/WMA	359,345	386,014	848,523	568,066
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	41,000	3,500	96,814	5,151
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	11	13	26	19
Average % RAP in DOT Mixes	12%	27%		
Average % RAP in Other Agency Mixes	8%	15%		
Average % RAP in Commercial & Residential Mixes	8%	14%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	83%	83%		
RAS Tons Received	56,500	67,500	133,414	99,334
RAS Tons used in HMA/WMA	70,566	80,424	166,628	118,354
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	1,000	-	1,472
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	2%	6%		
Average % RAS in Other Agency Mixes	2%	1%		
Average % RAS in Commercial & Residential Mixes	2%	4%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	83%	83%		
WMA DOT Tonnage	486,602	778,186	1,149,016	1,145,194
WMA Other Agency Tonnage	13,355	160,160	31,535	235,695
WMA Commercial & Residential Tonnage	68,165	119,260	160,958	175,505
Total WMA Tonnage	568,122	1,057,606	1,341,510	1,556,394
Percent WMA Tons using Chemical Additives	14%	9%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	86%	71%		
Percent WMA Tons using Organic Additive	0%	20%		

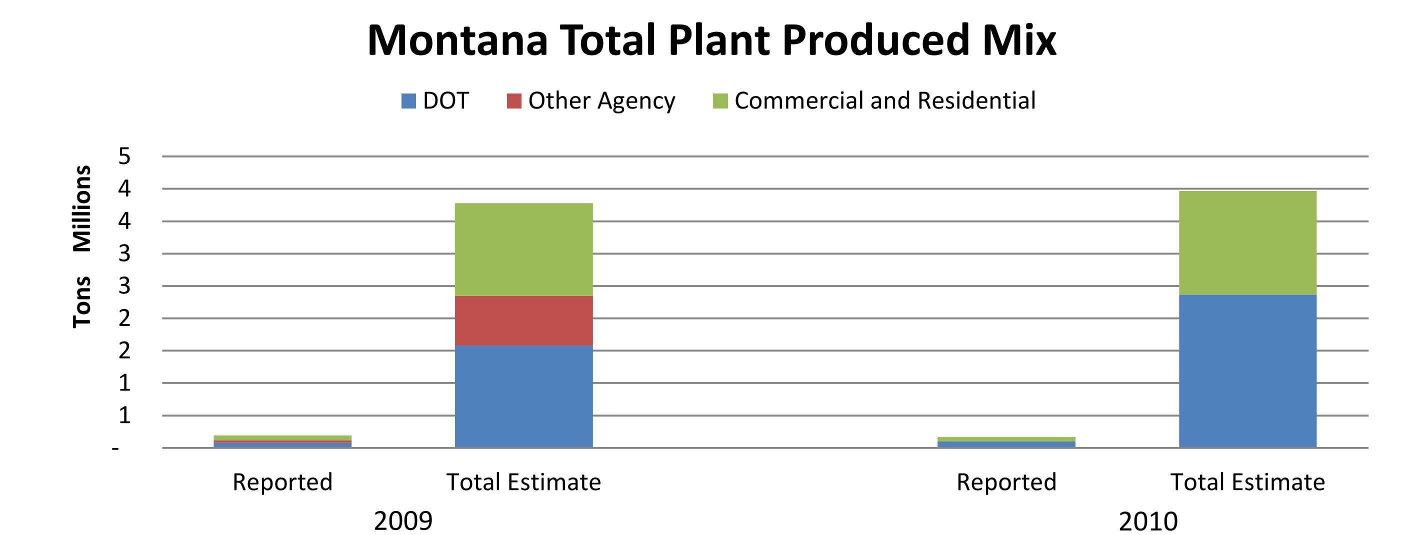
1. Total DOT tonnage provided by Missouri Asphalt Pavement Association and ratio of reported total tons to reported total DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

Montana

Table B27 summarizes the results received from asphalt mix producers in Montana. The charts are used to summarize information calculated from information provided by the survey respondents.

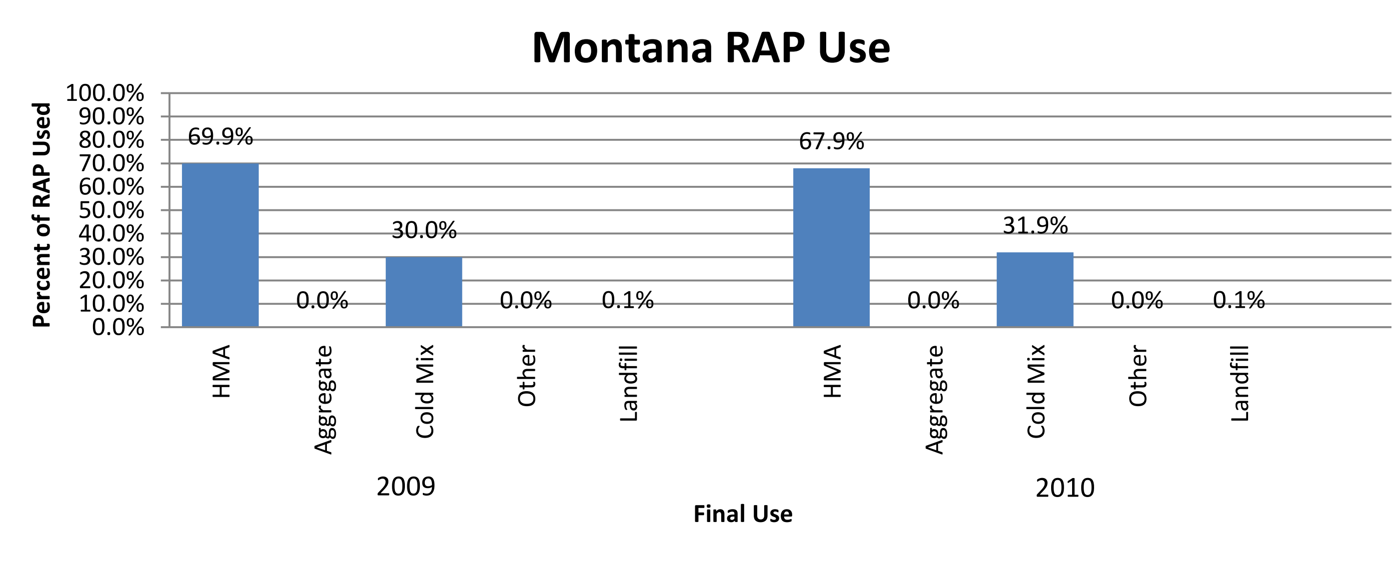
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use

No contractors reported usin RAS in 2009 or 2010.

WMA Use

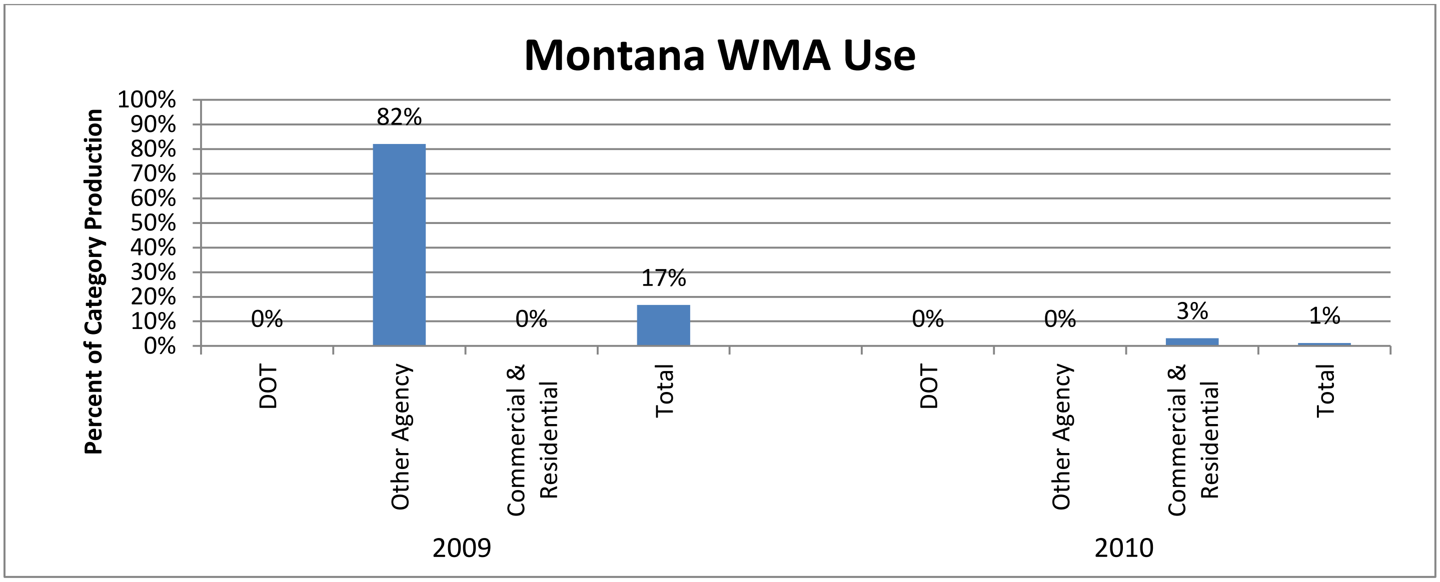

Montana WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
82%
0%
17%
0%
0%
3%
1%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 27: Summary of Montana Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	80,265	98,153	1,578,063	2,368,118
Total Other Agency Tonnage	39,000	1,000	766,766	24,127
Total Commercial & Residential Tonnage	73,003	66,222	1,435,287	1,597,725
Total Tonnage	192,268	165,375	3,780,115	3,989,969
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	76,000	53,700	1,494,210	1,295,609
RAP Tons used in HMA/WMA	13,993	12,761	275,113	307,889
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	6,000	6,000	117,964	144,761
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	16	21	317	501
Average % RAP in DOT Mixes	4%	5%		
Average % RAP in Other Agency Mixes	9%	20%		
Average % RAP in Commercial & Residential Mixes	12%	13%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	100%		
WMA DOT Tonnage	-	21	-	502
WMA Other Agency Tonnage	32,000	-	629,141	-
WMA Commercial & Residential Tonnage	-	2,112	-	50,961
Total WMA Tonnage	32,000	2,133	629,141	51,463
Percent WMA Tons using Chemical Additives	100%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Nebraska

No contractors submitted data for the Nebraska. Total tons were estimated based on a relationship tons to federal apportionment. Because RAP use is prevalent in all areas of the US it was estimated that RAP use in the District followed a national average. Table B28 summarizes this data.

Table B 28: Summary of Nebraska Data

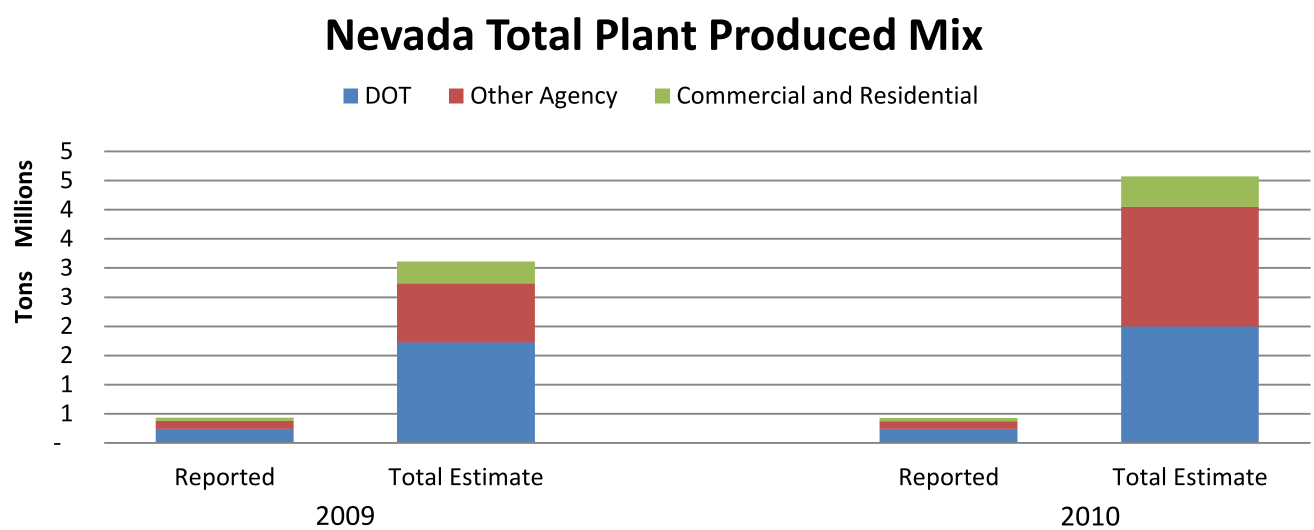
HMA/WMA		
	Total Estimated[1]	
	2009	2010
Total DOT Tonnage	-	-
Total Other Agency Tonnage	-	-
Total Commercial & Residential Tonnage	-	-
Total Tonnage	2,961,613	3,091,465
Reclaimed Asphalt Pavement		
	Total Estimated	
	2009	2010
Percent Companies using RAP		
RAP Tons Received	554,952	629,373
RAP Tons used in HMA/WMA	462,962	531,550
RAP Tons used as Aggregate	51,416	62,824
RAP Tons used in Cold Mix	12,244	13,471
RAP Tons used as Other	6,086	6,847
RAP Tons Landfilled	1,189	39

Nevada

Table B29 summarizes the results received from asphalt mix producers in Nevada. The charts are used to summarize information calculated from information provided by the survey respondents.

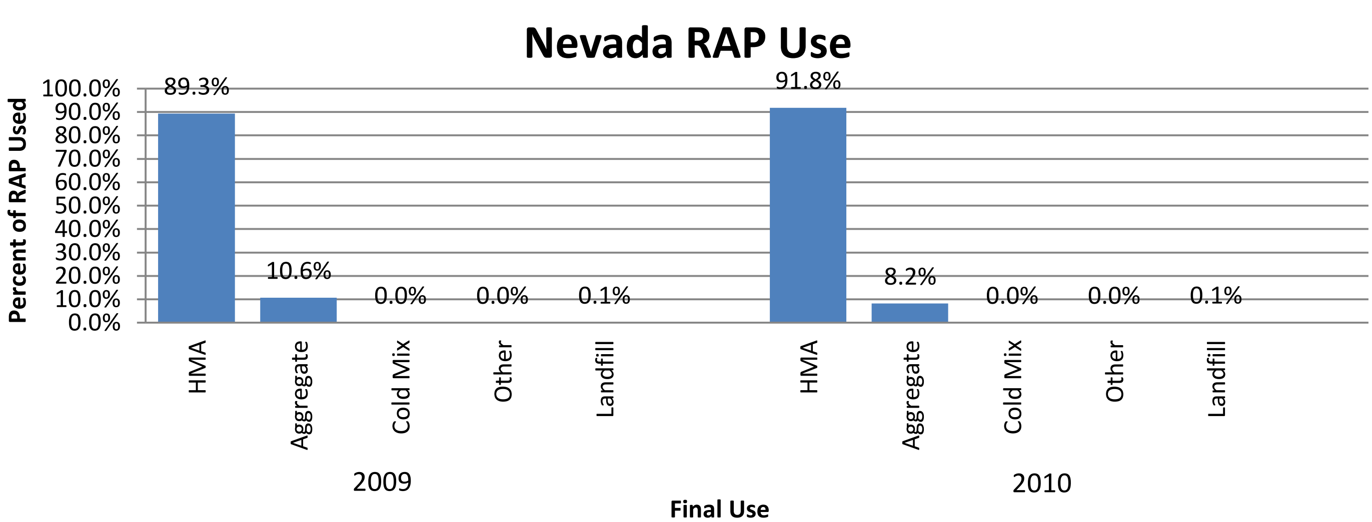
Total Asphalt Mix Tonnage

Companies responding: 2

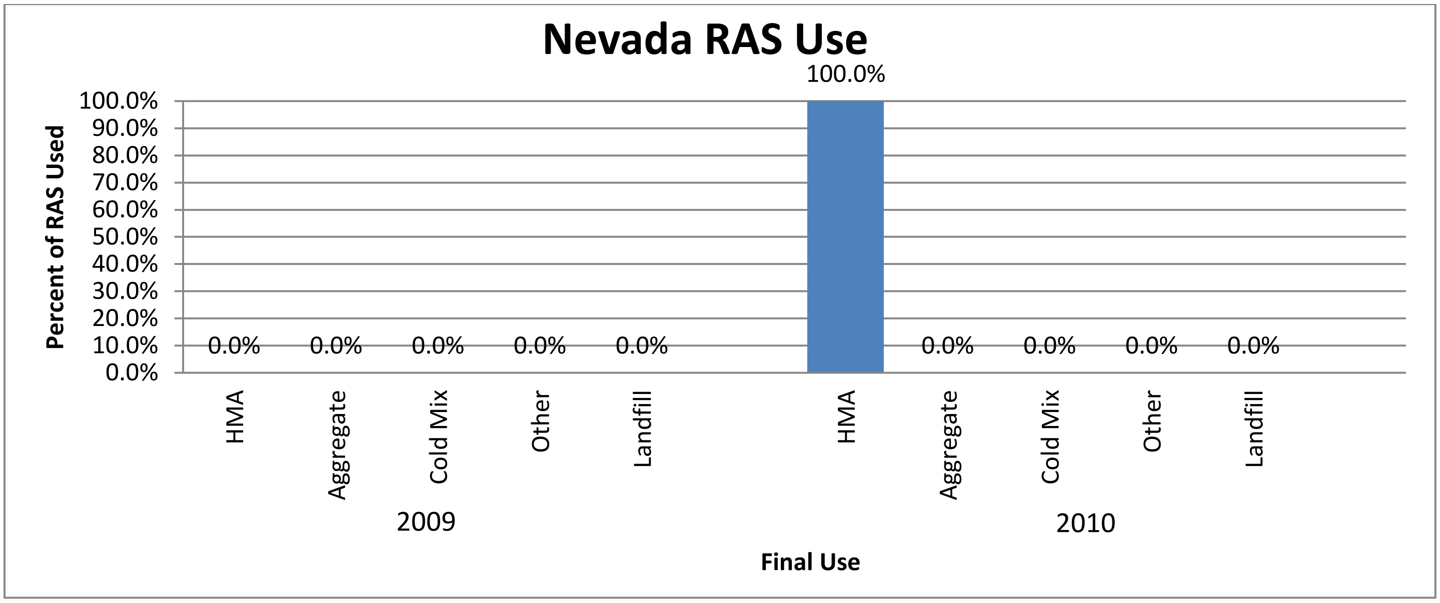


Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

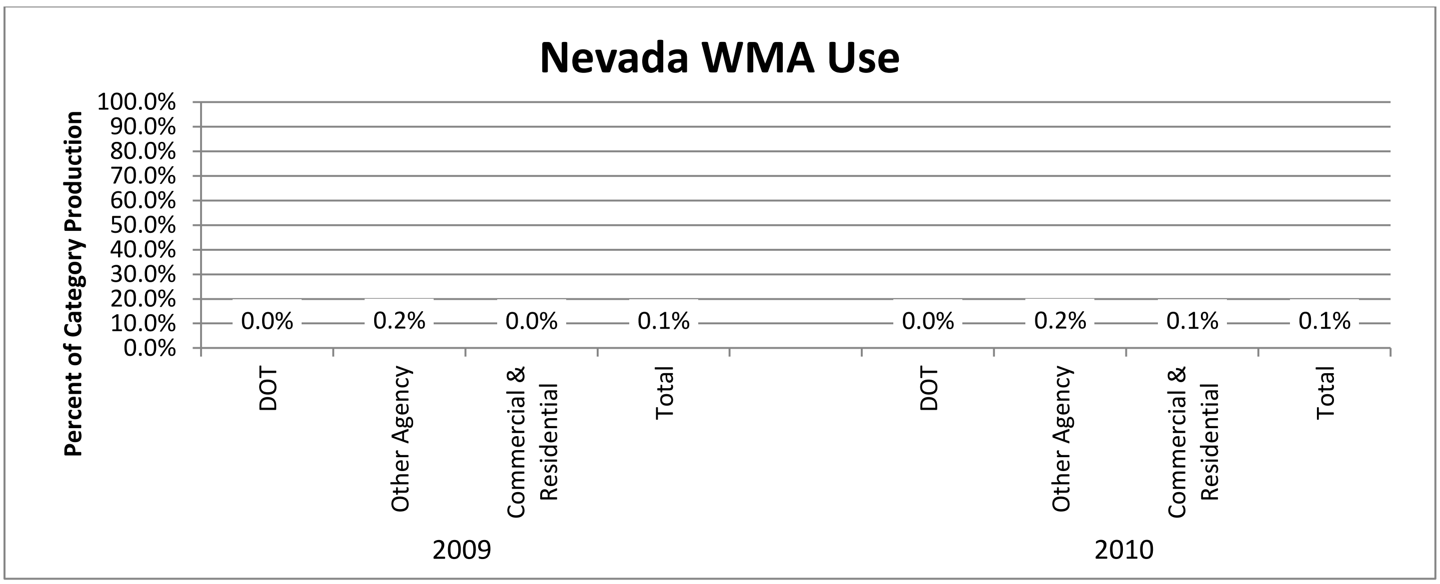


Table B 29: Summary of Nevada Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	239,283	239,966	1,724,595	1,996,379
Total Other Agency Tonnage	139,642	125,822	1,006,444	2,052,325
Total Commercial & Residential Tonnage	52,881	62,941	381,128	523,629
Total Tonnage	431,805	428,728	3,112,166	3,566,770

Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	32,595	33,839	234,923	281,521
RAP Tons used in HMA/WMA	25,255	31,305	182,020	260,437
RAP Tons used as Aggregate	3,000	2,784	21,622	23,160
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	14	21	102	175
Average % RAP in DOT Mixes	0%	2%		
Average % RAP in Other Agency Mixes	14%	11%		
Average % RAP in Commercial & Residential Mixes	19%	14%		

Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	50%		
RAS Tons Received	-	5,000	-	41,597
RAS Tons used in HMA/WMA	-	5,000	-	41,597
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	1%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	50%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	239	240	1,725	3,909
WMA Commercial & Residential Tonnage	-	40	-	332
Total WMA Tonnage	239	280	1,725	4,241
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

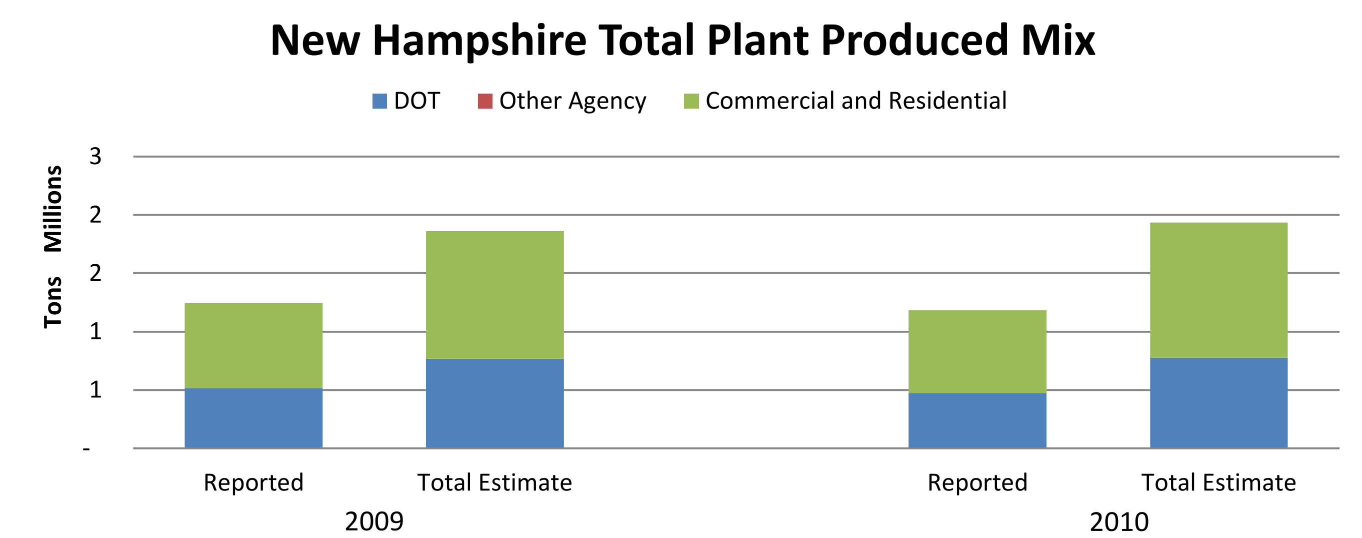
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

New Hampshire

Table B30 summarizes the results received from asphalt mix producers in New Hampshire. The charts are used to summarize information calculated from information provided by the survey respondents.

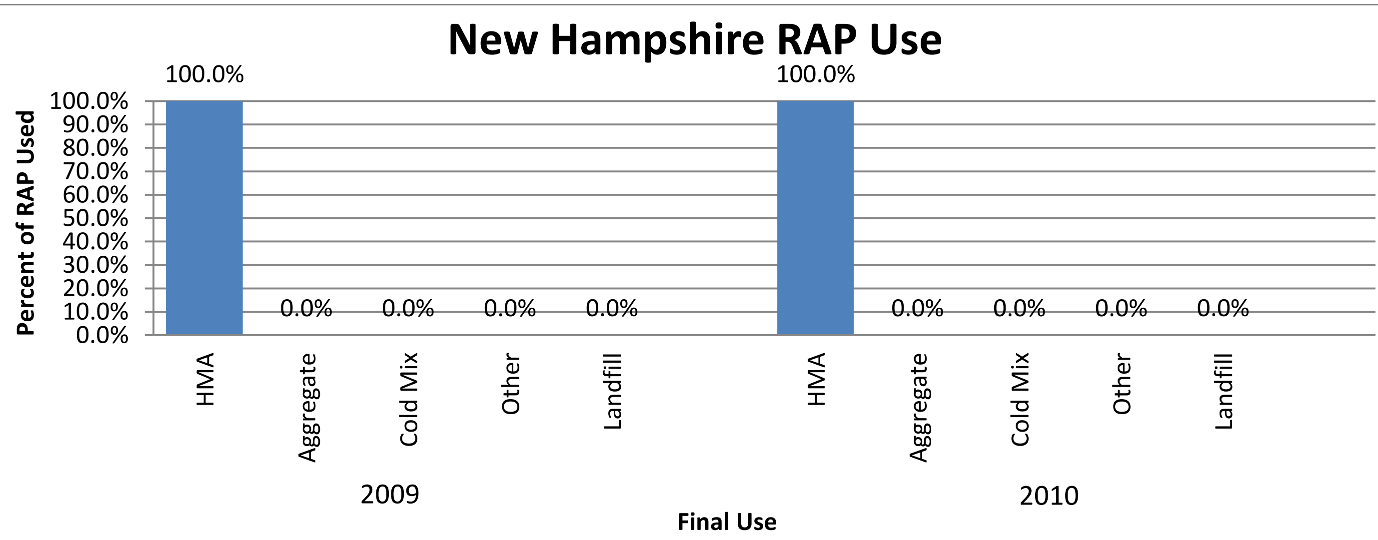
Total Asphalt Mix Tonnage

Companies responding: 1



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

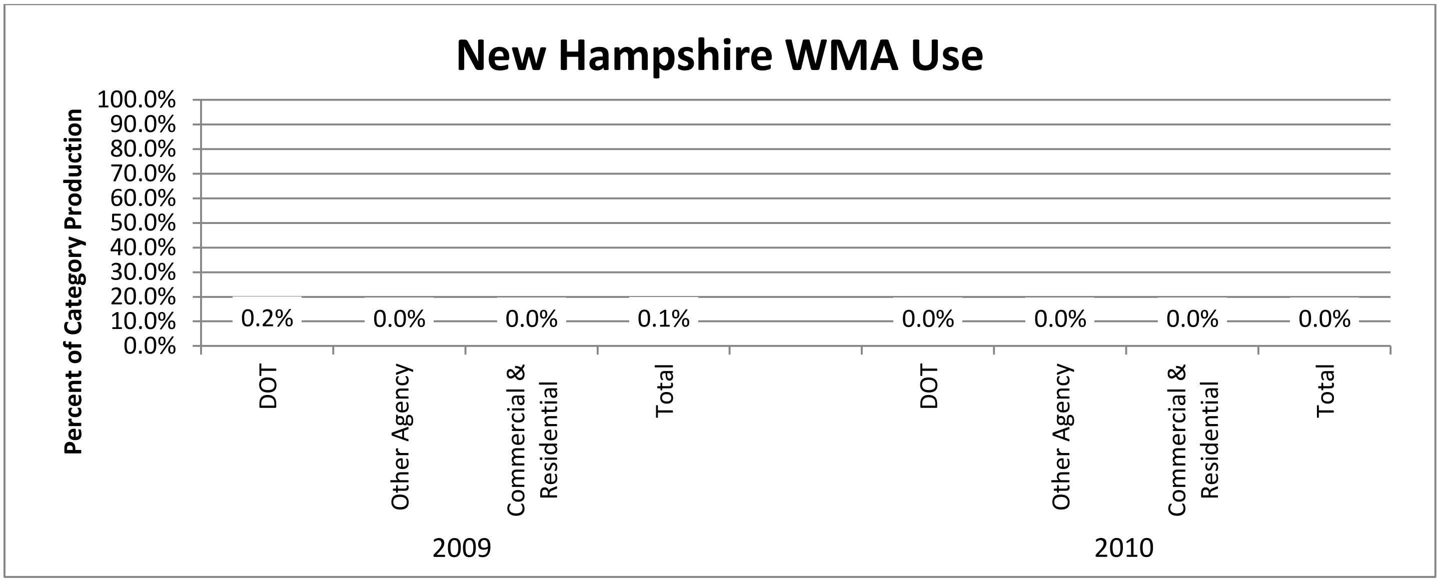
RAP Use



RAS Use

No contractors reported using RAS in 2009 or 2010.

WMA Use



New Hampshire WMA Use
Percent of Category Production
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.2%
0.0%
0.0%
0.1%
0.0%
0.0%
0.0%
0.0%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 30: Summary of New Hampshire Data

Companies Reporting 1

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	515,000	474,000	769,264	776,146
Total Other Agency Tonnage	-	-	-	-
Total Commercial & Residential Tonnage	731,000	708,000	1,091,907	1,159,306
Total Tonnage	1,246,000	1,182,000	1,861,171	1,935,452
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	171,000	246,000	255,426	402,810
RAP Tons used in HMA/WMA	183,000	212,005	273,350	347,145
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	15	18	22	30
Average % RAP in DOT Mixes	15%	20%		
Average % RAP in Other Agency Mixes	0%	0%		
Average % RAP in Commercial & Residential Mixes	15%	15%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	0%		
WMA DOT Tonnage	1,185	-	1,769	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	1,185	-	1,769	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

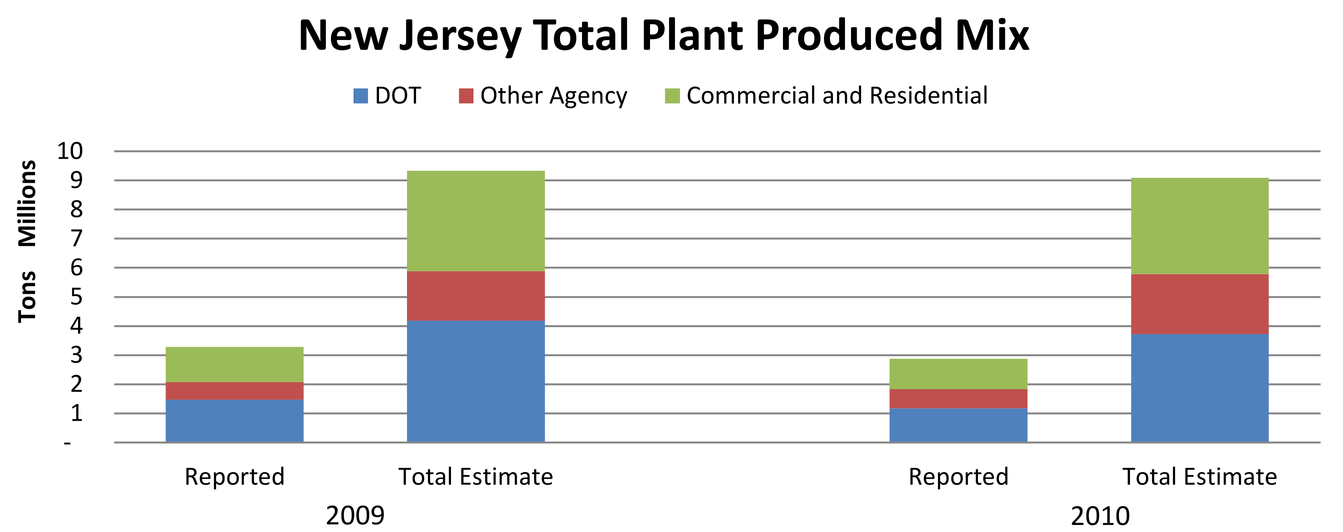
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

New Jersey

Table B31 summarizes the results received from asphalt mix producers in New Jersey. The charts are used to summarize information calculated from information provided by the survey respondents.

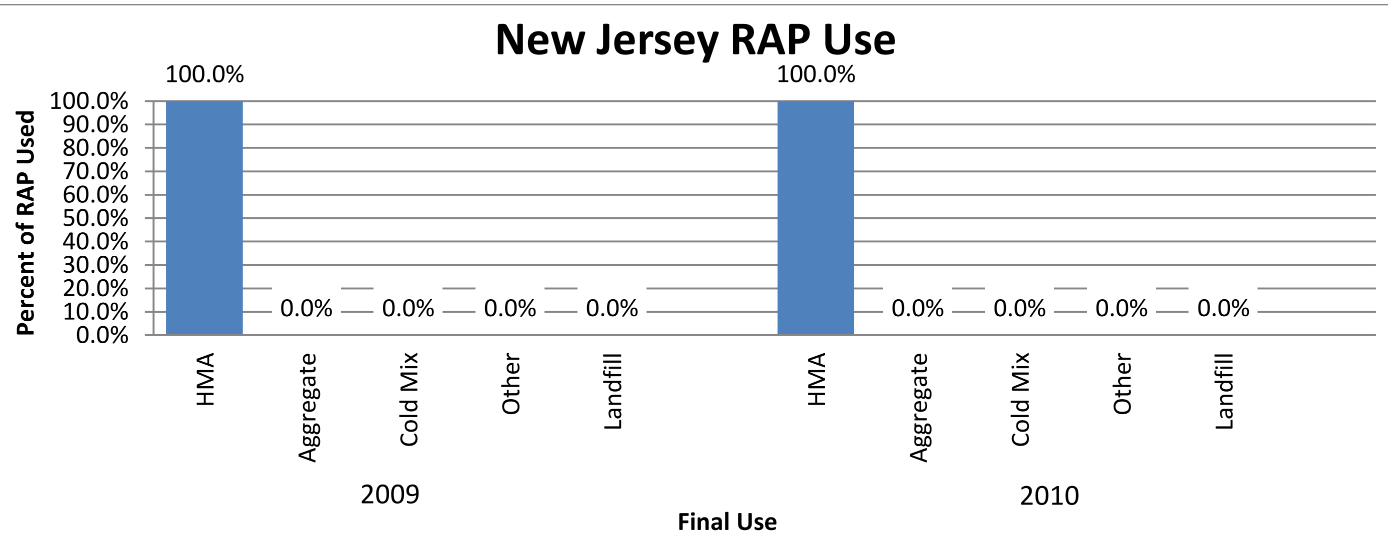
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons extimated based on relationship of tons to Federal Apportionment.   Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

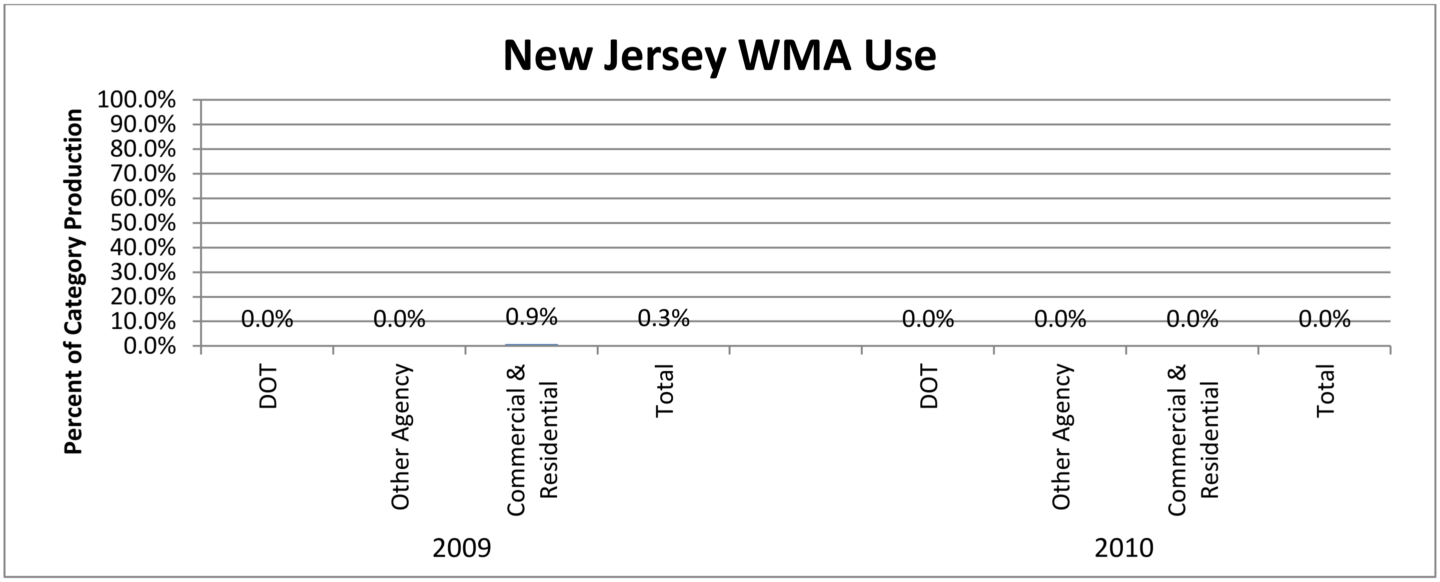
RAP Use



RAS Use

No contractors reporte using RAS in 2009 or 2010.

WMA Use



New Jersey WMA Use
Percent of Category Production
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.0%
0.0%
0.9%
0.3%
0.0%
0.0%
0.0%
0.0%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 31: Summary of New Jersey Data Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,471,000	1,176,700	4,179,781[2]	3,723,531[2]
Total Other Agency Tonnage	599,500	653,100	1,703,453	2,066,659
Total Commercial & Residential Tonnage	1,212,600	1,044,100	3,445,549	3,303,934
Total Tonnage	3,283,100	2,873,900	9,328,783	9,094,124

Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	190,000	655,000	539,877	2,072,672
RAP Tons used in HMA/WMA	141,000	474,980	400,645	1,503,018
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	17	18	48	56
Average % RAP in DOT Mixes	15%	15%		
Average % RAP in Other Agency Mixes	6%	7%		
Average % RAP in Commercial & Residential Mixes	22%	22%		

Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	10,606	-	30,136	-
Total WMA Tonnage	10,606	-	30,136	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.
2. The NJDOT reports 2009 FY HMA tonnage was 2,069,891 and 2010 FY HMA tonnage was 2,101,755
3. The NJDOT reported RAP usage in HMA was 0.33 M tons in 2009 and 0.31 tons in 2010.

New Mexico

No contractors submitted data for the New Mexico. Total tons were estimated based on a relationship tons to federal apportionment. Because RAP use is prevalent in all areas of the US it was estimated that RAP use in New Mexico followed a national average. Table B32 summarizes this data.

Table B 32: Summary New Mexico Data

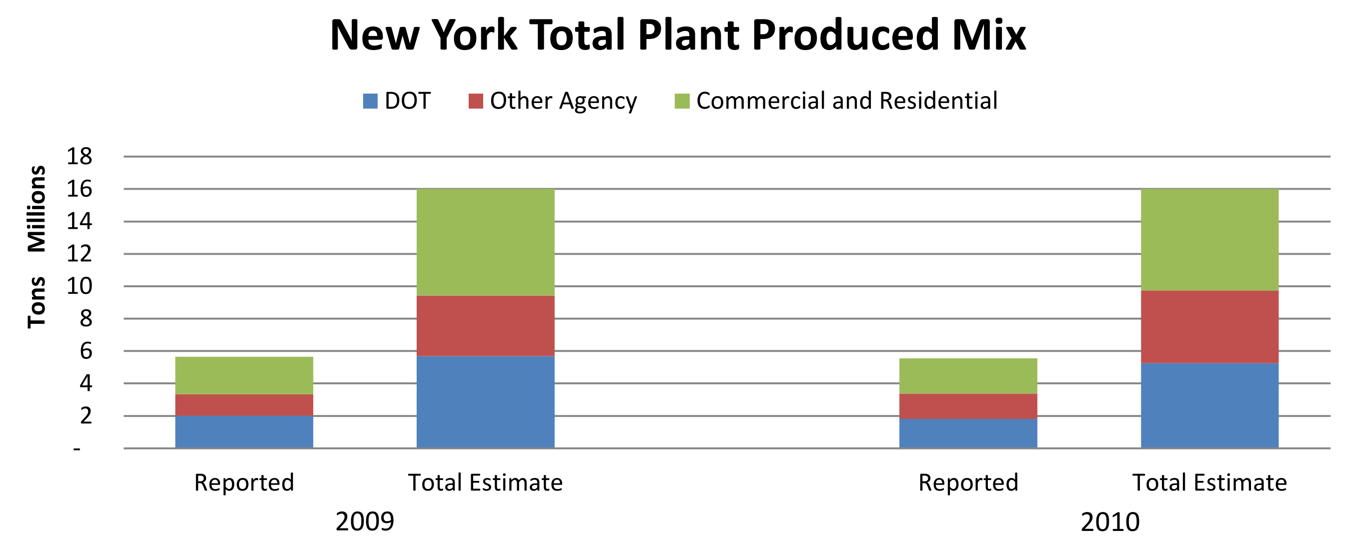
HMA/WMA		
	Total Estimated[1]	
	2009	2010
Total DOT Tonnage	-	-
Total Other Agency Tonnage	-	-
Total Commercial & Residential Tonnage	-	-
Total Tonnage	3,779,122	3,840,870
Reclaimed Asphalt Pavement (RAP)[2]		
	Total Estimated	
	2009	2010
Percent Companies using RAP		
RAP Tons Received	708,138	781,941
RAP Tons used in HMA/WMA	590,755	660,404
RAP Tons used as Aggregate	65,609	78,054
RAP Tons used in Cold Mix	15,624	16,737
RAP Tons used as Other	7,766	8,506
RAP Tons Landfilled	1,517	49

New York

Table B33 summarizes the results received from asphalt mix producers in New York. The charts are used to summarize information calculated from information provided by the survey respondents.

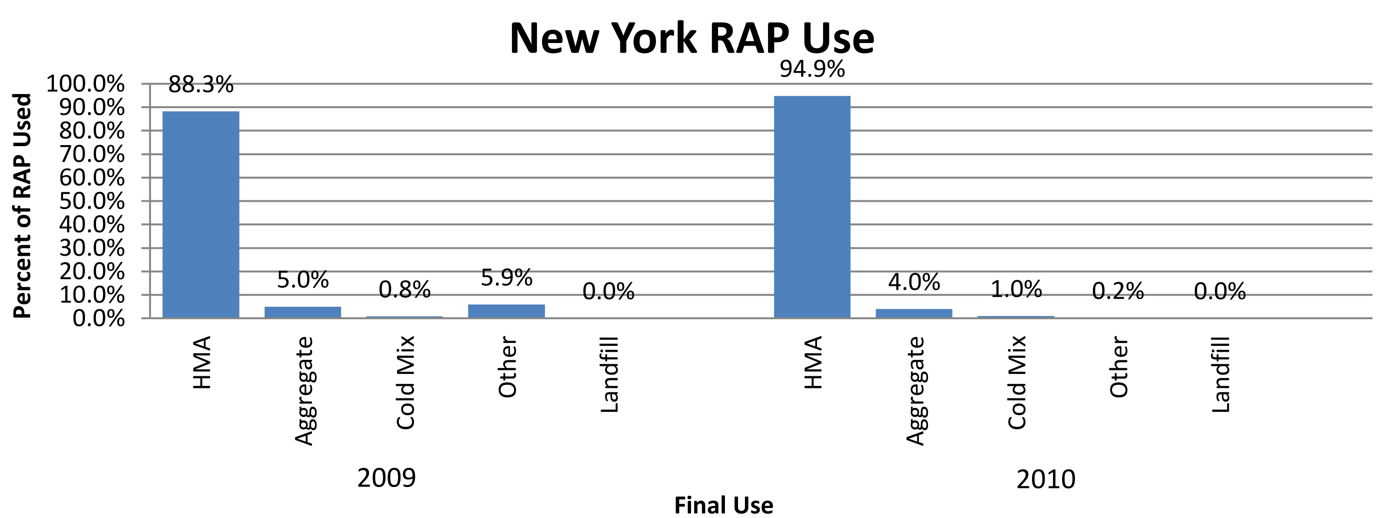
Total Asphalt Mix Tonnage

Companies responding: 13

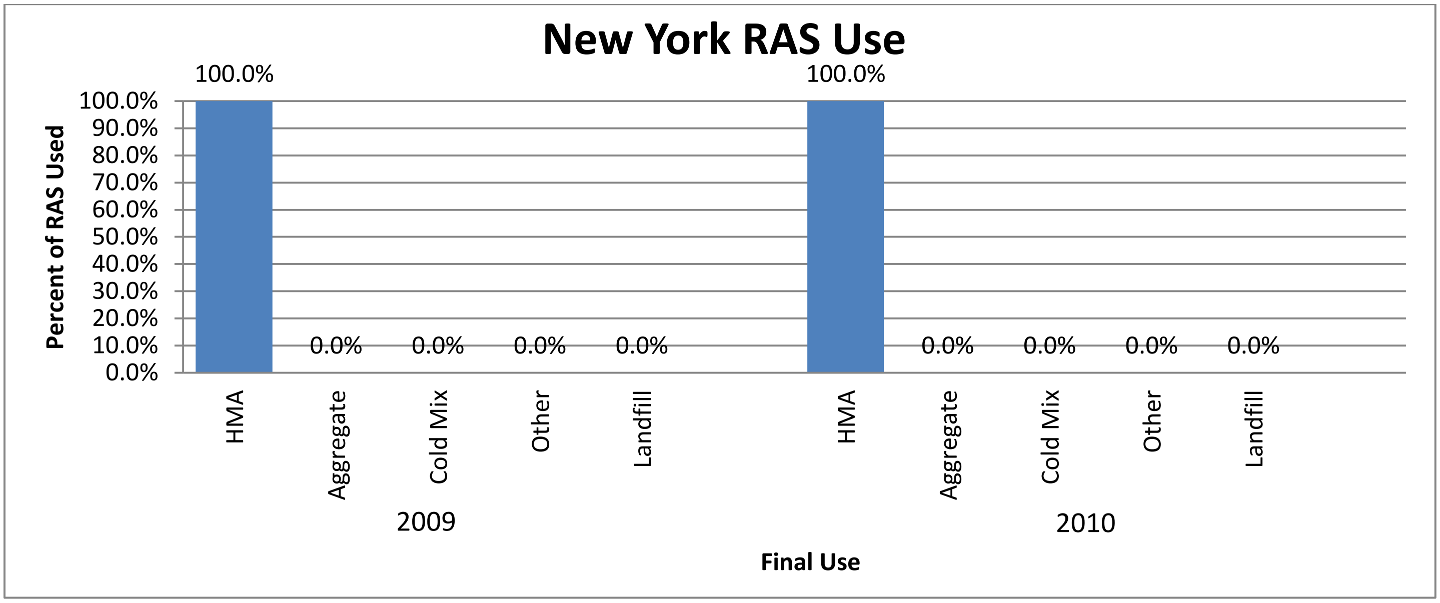


Total tonnage provided by the New York Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

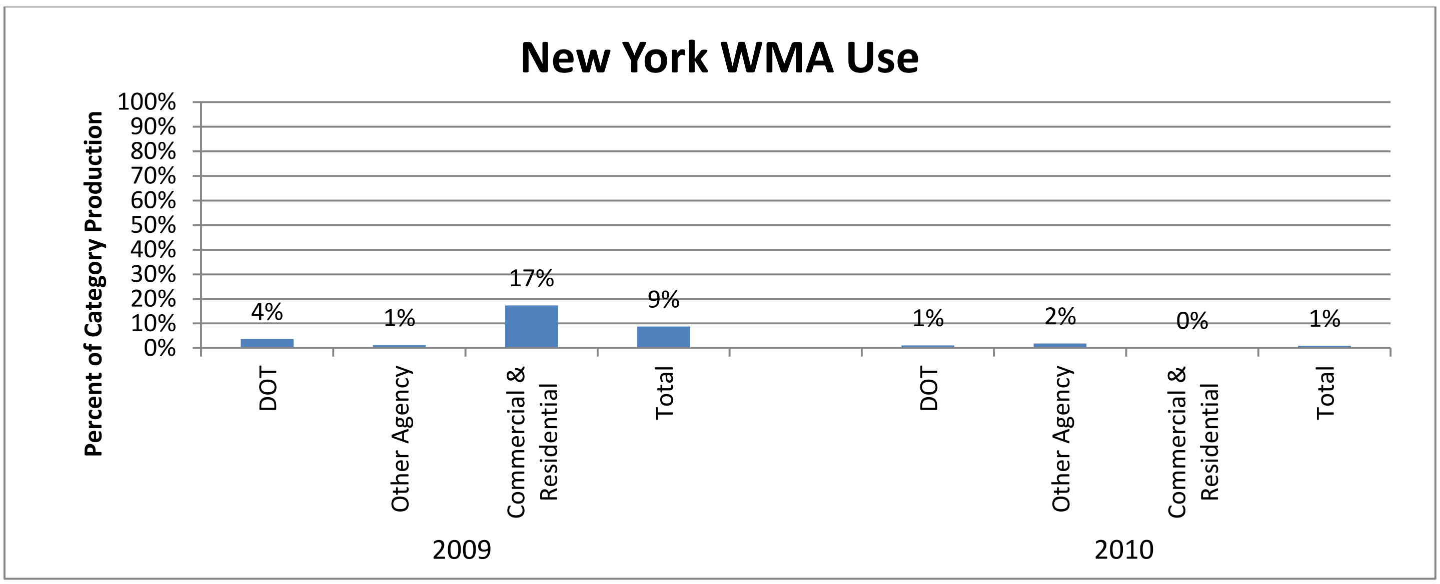


Table B 33: Summary of New York Data

Companies Reporting 13

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,009,374	1,820,500	5,687,243	5,255,864
Total Other Agency Tonnage	1,324,000	1,551,000	3,747,391	4,477,806
Total Commercial & Residential Tonnage	2,319,626	2,170,500	6,565,366	6,266,330
Total Tonnage	5,653,000	5,542,000	16,000,000	16,000,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	92%	92%		
RAP Tons Received	564,000	617,000	1,596,321	1,781,306
RAP Tons used in HMA/WMA	547,000	583,500	1,548,204	1,684,590
RAP Tons used as Aggregate	31,000	24,500	87,741	70,733
RAP Tons used in Cold Mix	5,000	6,000	14,152	17,322
RAP Tons used as Other	36,500	1,000	103,308	2,887
RAP Tons Landfilled	44	40	124	117
Average % RAP in DOT Mixes	10%	10%		
Average % RAP in Other Agency Mixes	14%	16%		
Average % RAP in Commercial & Residential Mixes	19%	20%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	15%	15%		
RAS Tons Received	20,000	10,000	56,607	28,870
RAS Tons used in HMA/WMA	2,600	43,300	7,359	125,009
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	31%	31%		
WMA DOT Tonnage	74,600	20,295	211,145	58,593
WMA Other Agency Tonnage	15,800	29,250	44,720	84,446
WMA Commercial & Residential Tonnage	402,300	1,699	1,138,652	4,905
Total WMA Tonnage	492,700	51,244	1,394,516	147,944
Percent WMA Tons using Chemical Additives	98%	50%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	48%		
Percent WMA Tons using Organic Additive	2%	2%		

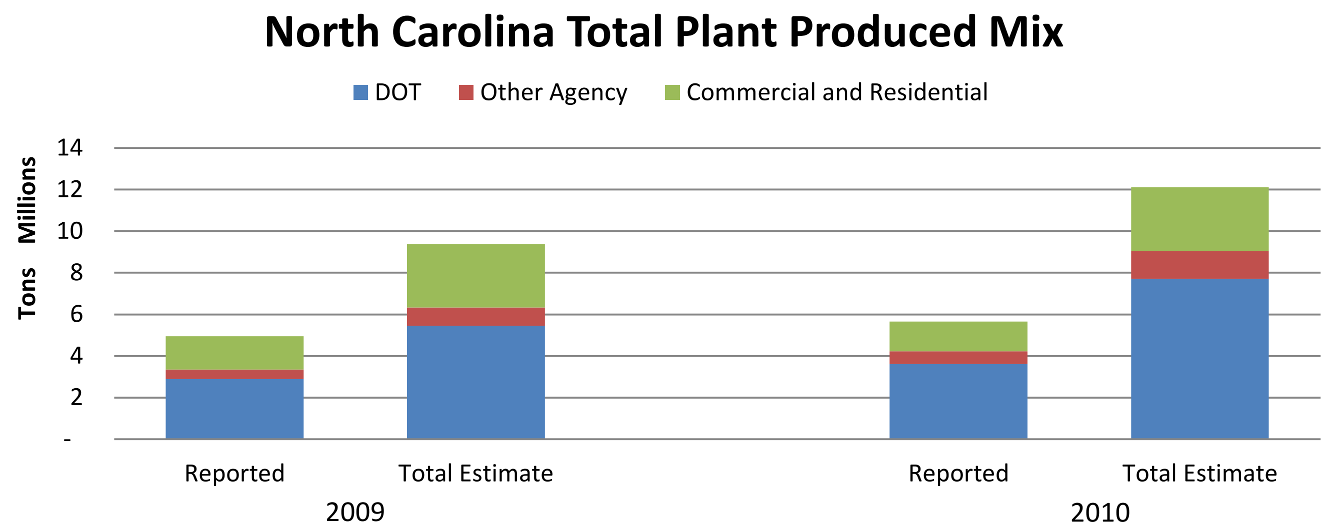
1. Total tonnage provided by the New York Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

North Carolina

Table B34 summarizes the results received from asphalt mix producers in North Carolina. The charts are used to summarize information calculated from information provided by the survey respondents.

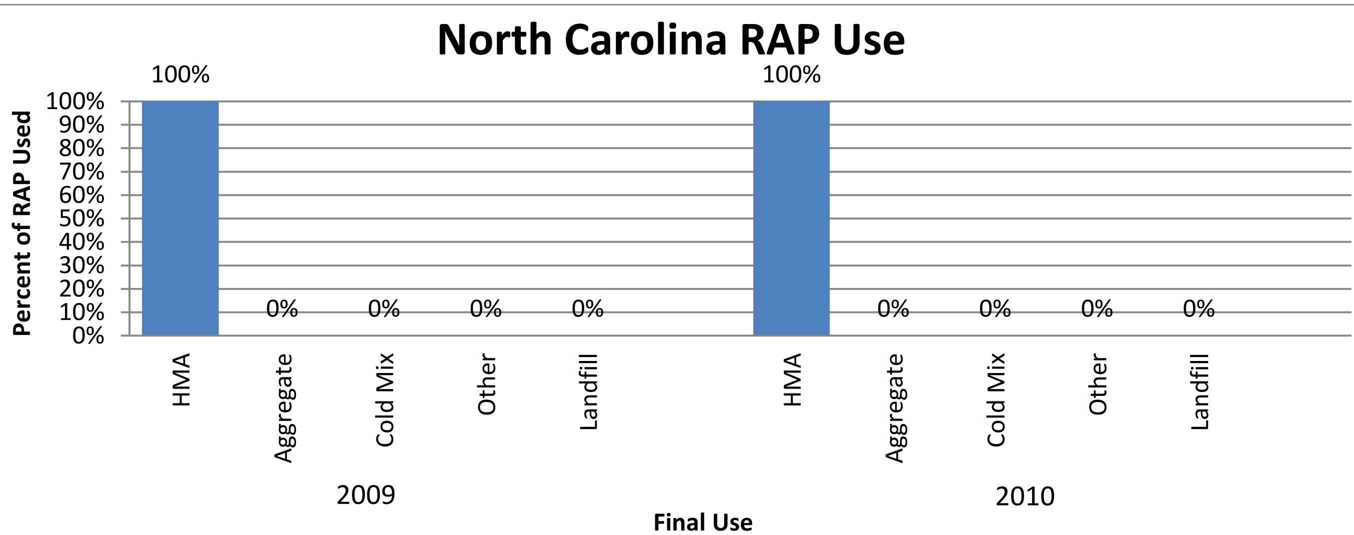
Total Asphalt Mix Tonnage

Companies responding: 6

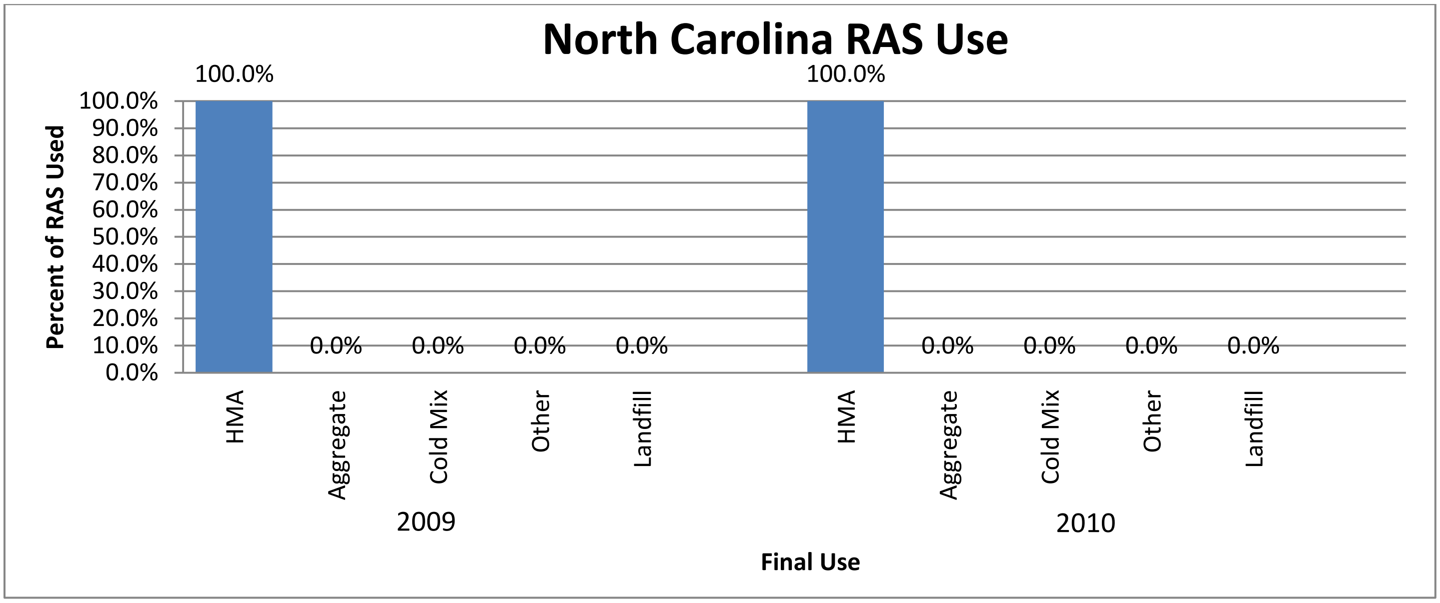


Total DOT tonnage provided by North Carolina Asphalt Pavement Association and the ratio of reported total tons to reported DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

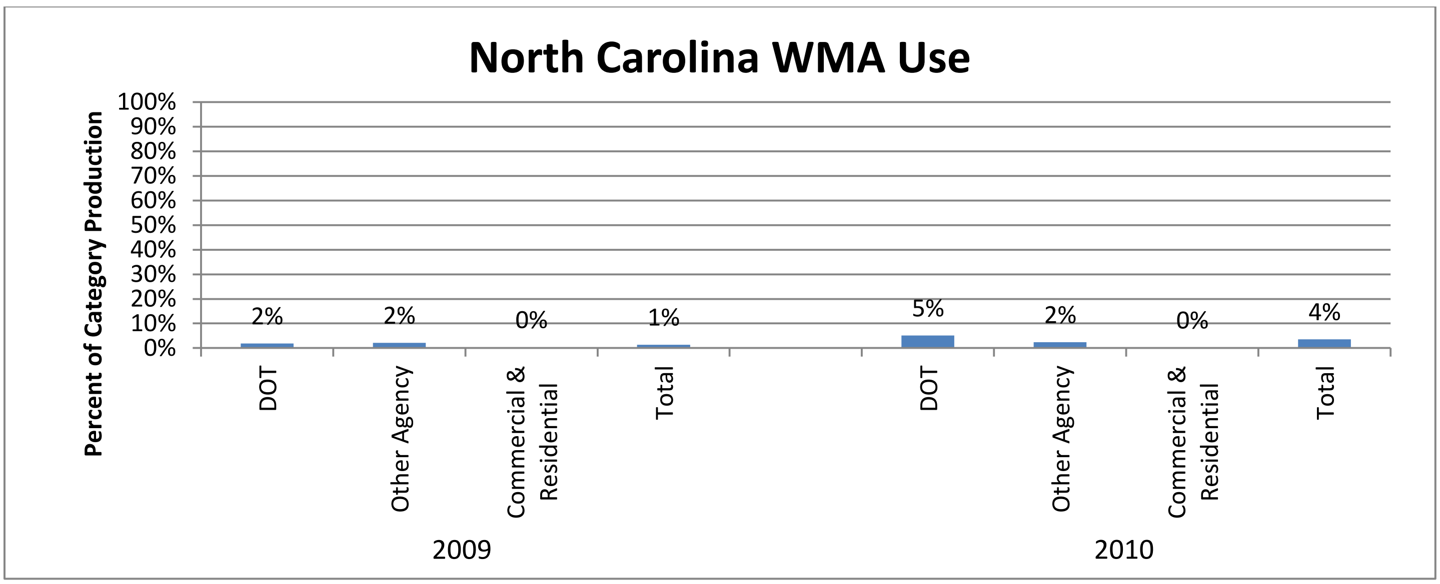
RAP Use



RAS Use



WMA Use



The North Carolina DOT reviewed Table B34 at the request of the Carolina Asphalt Pavement Association prior to publication and offered the following comments:

- Total DOT tons for 2009 and 2010 4,734,017 and 7,569,654, respectively.
- Percent companies using RAP 96% for 2009 and 2010
- Average percent RAP in DOT mixes 19 and 20 for 2009 and 2010, respectively.
- Average % RAS in DOT mixes 9.9% and 10% for 2009 and 2010, respectively.
- Percent companies using WMA 80 and 90 for 2009 and 2010, respectively.
- Percent WMA by additive for 2009 and 2010:
    - Chemical – 1.6 and 1
    - Additive foaming – 2 and 2
    - Plant Foaming   95 and 95
    - Organic Additive 1.2 and 0.

Table B 34: Summary of North Carolina Data — Companies Reporting 6

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,884,195	3,611,296	5,456,659	7,720,518
Total Other Agency Tonnage	462,457	615,047	874,930	1,314,897
Total Commercial & Residential Tonnage	1,605,161	1,435,931	3,036,832	3,069,848
Total Tonnage	4,951,813	5,662,274	9,368,421	12,105,263
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	1,189,324	1,303,917	2,250,103	2,787,618
RAP Tons used in HMA/WMA	997,713	1,223,063	1,887,591	2,614,762
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	31	40	59	86
Average % RAP in DOT Mixes	20%	22%		
Average % RAP in Other Agency Mixes	23%	23%		
Average % RAP in Commercial & Residential Mixes	22%	23%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	17%	50%		
RAS Tons Received	-	41,500	-	88,722
RAS Tons used in HMA/WMA	600	32,450	1,135	69,374
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	3%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	1%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	83%		
WMA DOT Tonnage	53,943	185,049	102,056	395,613
WMA Other Agency Tonnage	10,000	14,667	18,919	31,356
WMA Commercial & Residential Tonnage	5,692	2,860	10,768	6,114
Total WMA Tonnage	69,635	202,575	131,743	433,082
Percent WMA Tons using Chemical Additives	7%	1%		
Percent WMA Tons using Additive Foaming	3%	0%		
Percent WMA Tons using Plant Foaming	90%	99%		
Percent WMA Tons using Organic Additive	0%	0%		

1. Total DOT tonnage provided by North Carolina Asphalt Pavement Association and ratio of reported total tons to reported DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

North Dakota

No contractors submitted data for North Dakota. Total tons were estimated based on a relationship tons to federal apportionment. Because RAP use is prevalent in all areas of the US it was estimated that RAP use in New Mexico followed a national average. Table B35 summarizes this data.

Table B 35: Summary of North Dakota Data

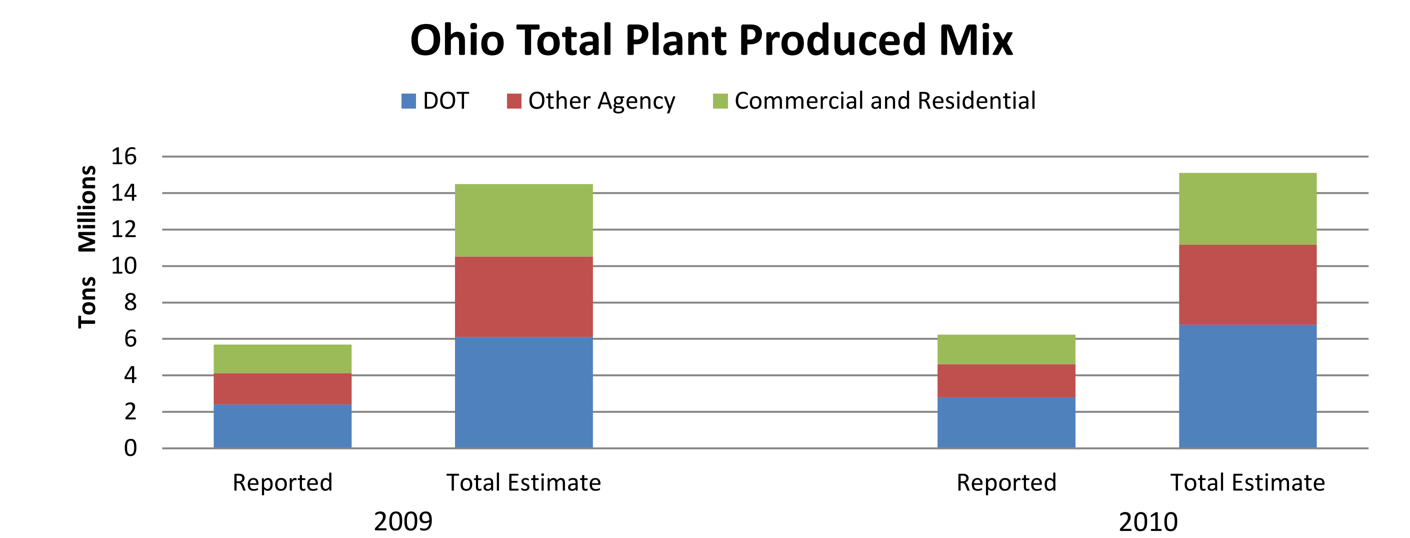
HMA/WMA		
	Total Estimated	
	2009	2010
Total DOT Tonnage	-	-
Total Other Agency Tonnage	-	-
Total Commercial & Residential Tonnage	-	-
Total Tonnage	2,549,882	2,698,591
Reclaimed Asphalt Pavement (RAP)		
	Total Estimated	
	2009	2010
Percent Companies using RAP		
RAP Tons Received	477,801	549,391
RAP Tons used in HMA/WMA	398,600	463,999
RAP Tons used as Aggregate	44,268	54,840
RAP Tons used in Cold Mix	10,542	11,759
RAP Tons used as Other	5,240	5,976
RAP Tons Landfilled	1,024	34

Ohio

Table B36 summarizes the results received from asphalt mix producers in Ohio. The charts are used to summarize information calculated from information provided by the survey respondents.

Total Asphalt Mix Tonnage

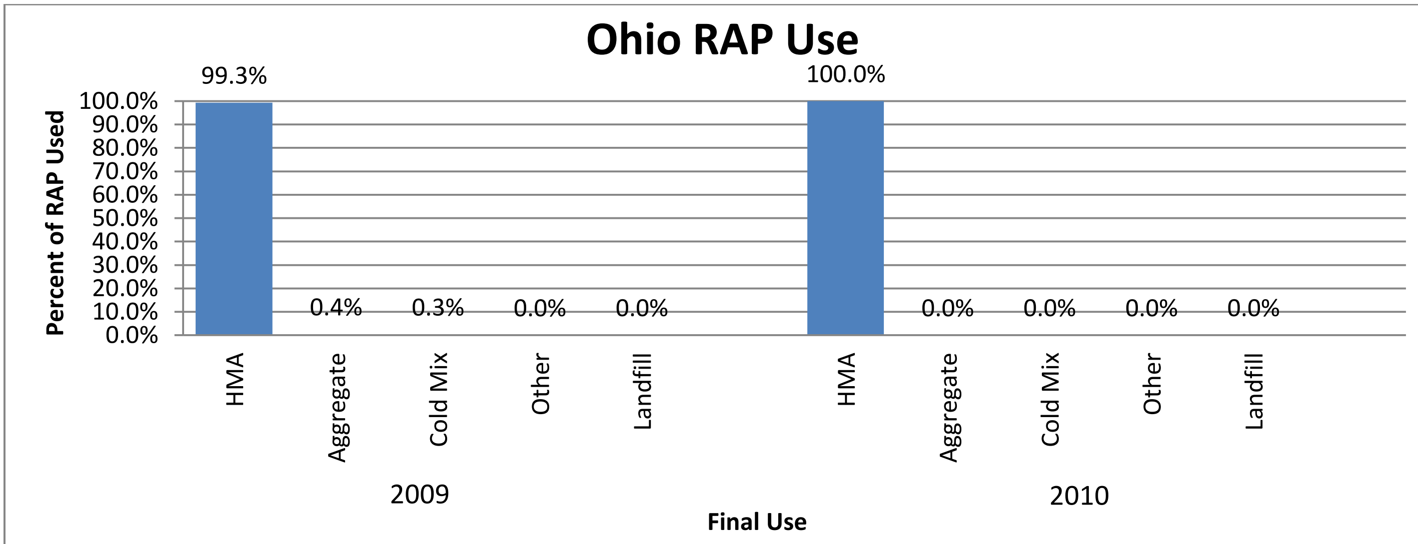
Companies responding: 5



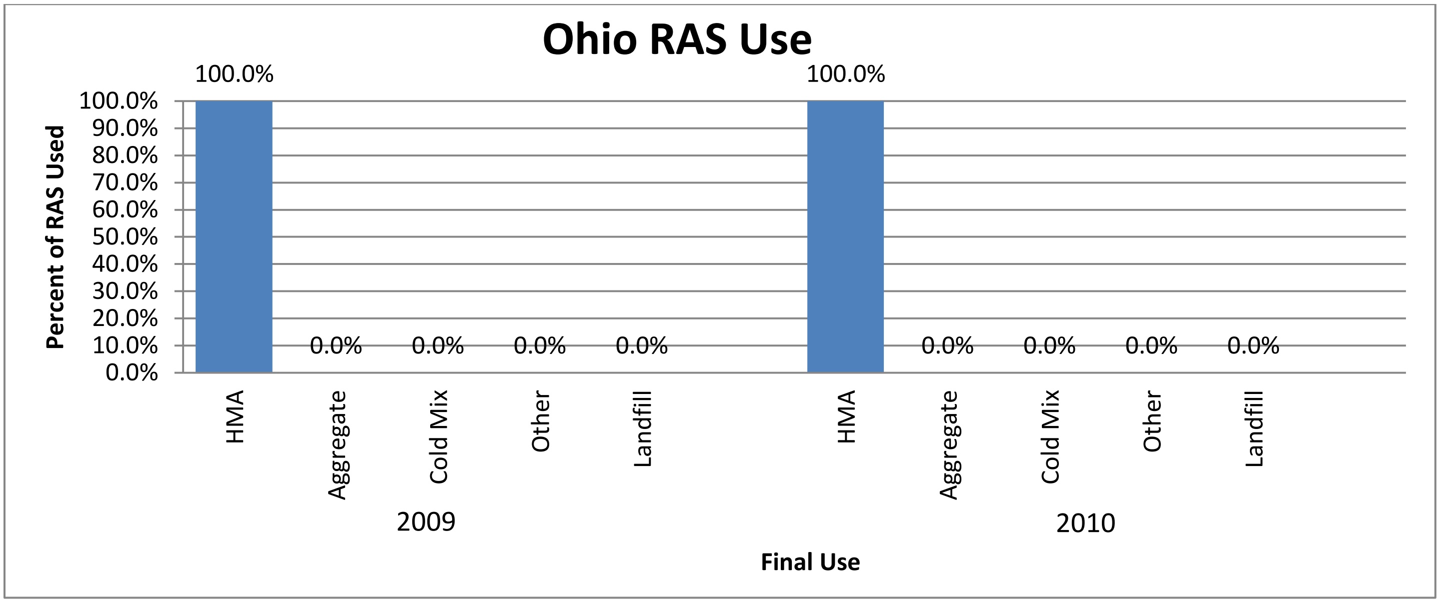
Total tonnage provided by Flexible Pavements of Ohio. Total tonnage for DOT, Other Agency and Commercial & Residential are based on ratios from reported tons.

Flexible Pavements of Ohio reports Total DOT Tons for 2009 and 2010 of 6,104,867 and 4,953,472, respectively

RAP Use



RAS Use



WMA Use

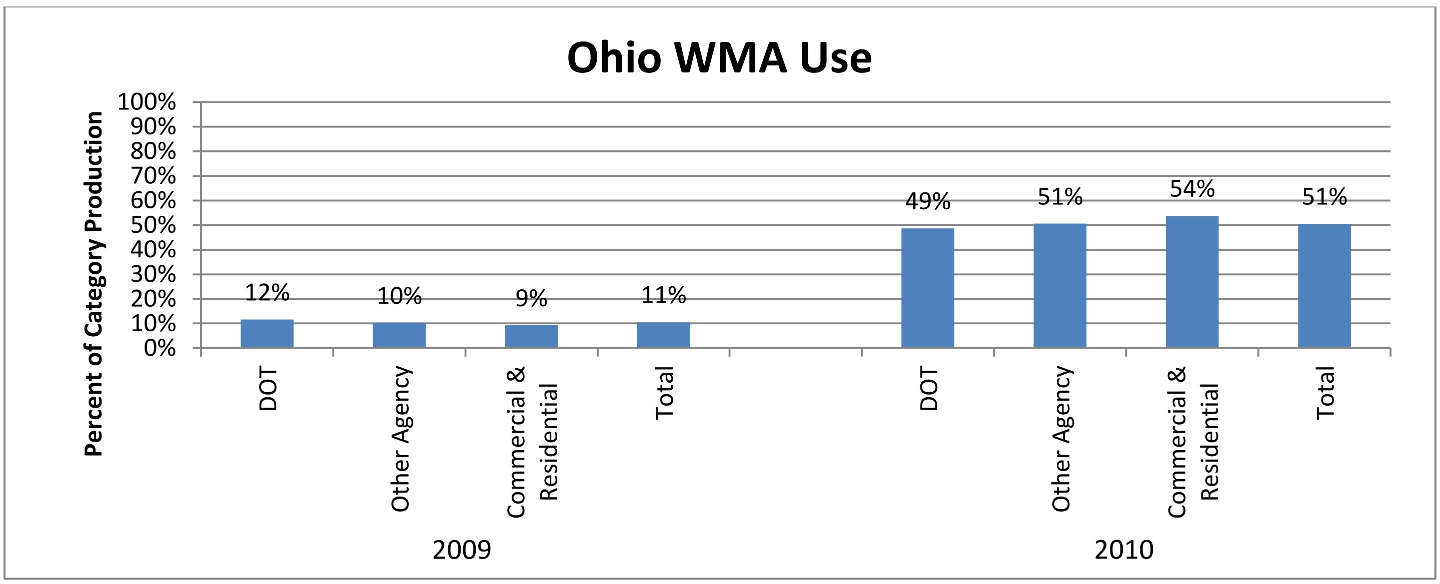


Table B 36: Summary of Ohio Data — Companies Reporting: 5

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,399,500	2,797,000	6,112,033[2]	6,775,983[2]
Total Other Agency Tonnage	1,732,000	1,816,000	4,411,770	4,399,422
Total Commercial & Residential Tonnage	1,561,000	1,620,000	3,976,197	3,924,595
Total Tonnage	5,692,500	6,233,000	14,500,000	15,100,000

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	1,568,000	1,257,000	3,994,027	3,045,195
RAP Tons used in HMA/WMA	1,317,000	1,474,000	3,354,677	3,570,897
RAP Tons used as Aggregate	5,000	-	12,736	-
RAP Tons used in Cold Mix	4,000	200	10,189	485
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	82	89	210	216
Average % RAP in DOT Mixes	22%	23%		
Average % RAP in Other Agency Mixes	22%	26%		
Average % RAP in Commercial & Residential Mixes	21%	23%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	60%	60%		
RAS Tons Received	38,000	10,300	96,794	24,953
RAS Tons used in HMA/WMA	22,000	11,000	56,039	26,648
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	4%		
Average % RAS in Other Agency Mixes	4%	2%		
Average % RAS in Commercial & Residential Mixes	3%	2%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	100%		
WMA DOT Tonnage	277,720	1,361,110	707,412[3]	3,297,411[3]
WMA Other Agency Tonnage	176,680	917,970	450,041	2,223,864
WMA Commercial & Residential Tonnage	144,090	870,780	367,028	2,109,542
Total WMA Tonnage	598,490	3,149,860	1,524,480	7,630,818
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

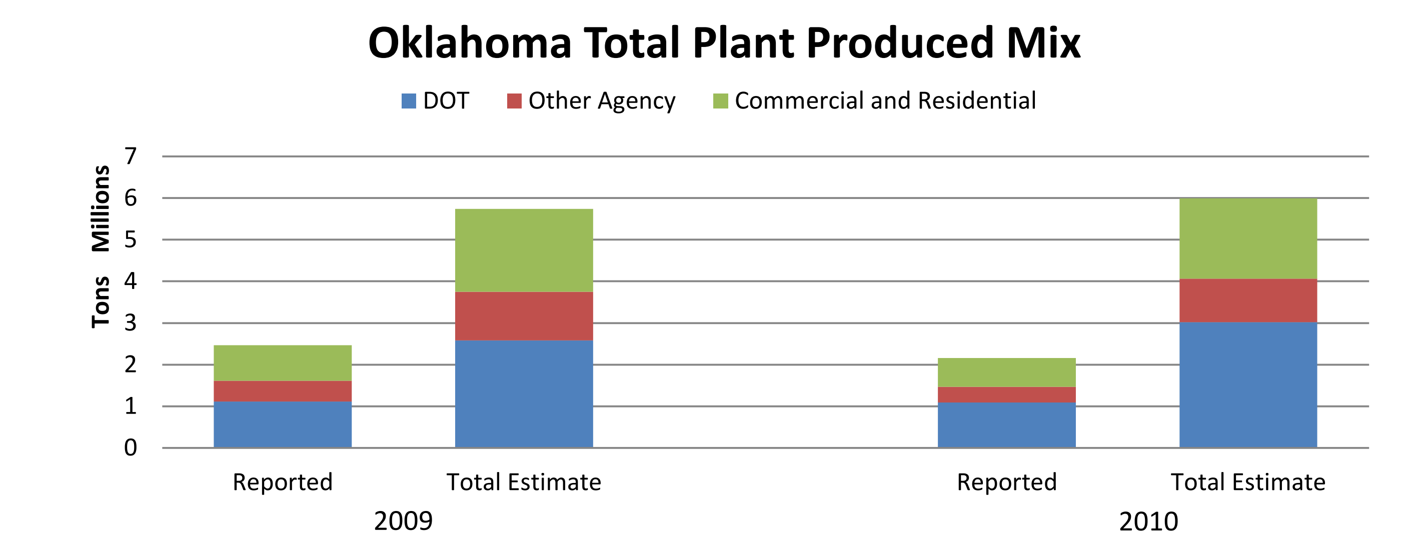
1. Total tonnage provided by Flexible Pavements of Ohio. Total tonnage for DOT, Other Agency and Commercial & Residential are based on ratios from reported tons.
2. Flexible Pavements of Ohio reports Total DOT Tons for 2009 and 2010 of 6,104,867 and 4,953,472, respectively
3. Flexible Pavements of Ohio reports Total DOT Tons for 2009 and 2010 of 148,576 and 1,948,162, respectively.

Oklahoma

Table B37 summarizes the results received from asphalt mix producers in Oklahoma. The charts are used to summarize information calculated from information provided by the survey respondents.

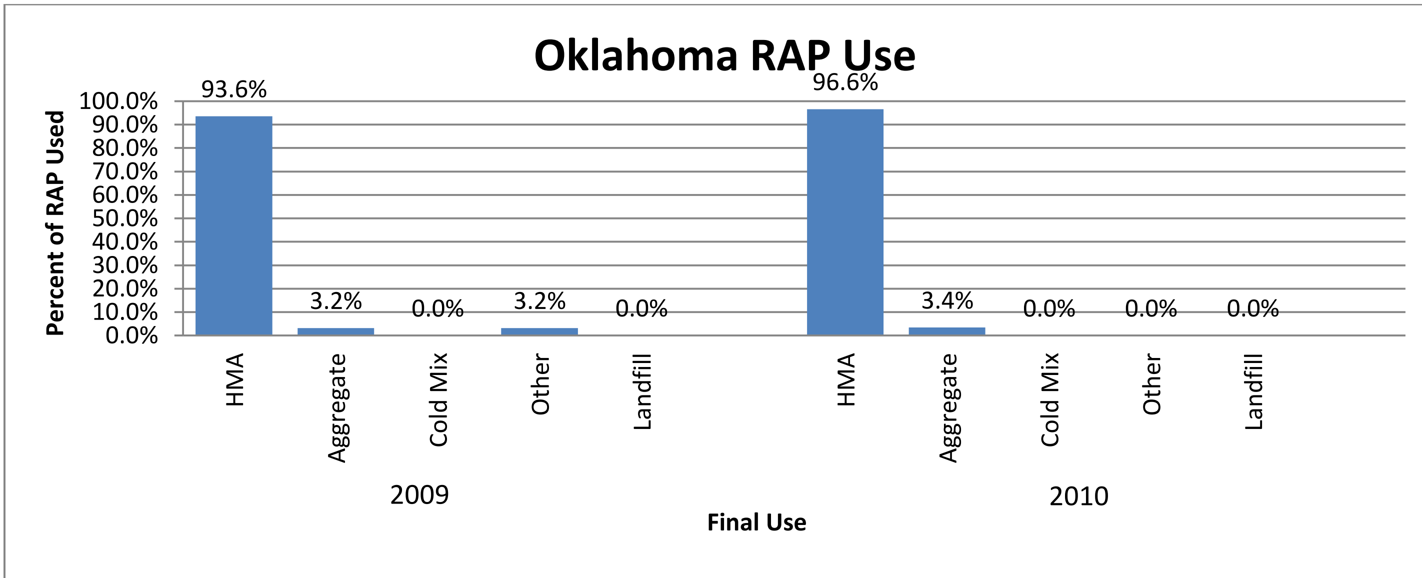
Total Asphalt Mix Tonnage

Companies responding: 4

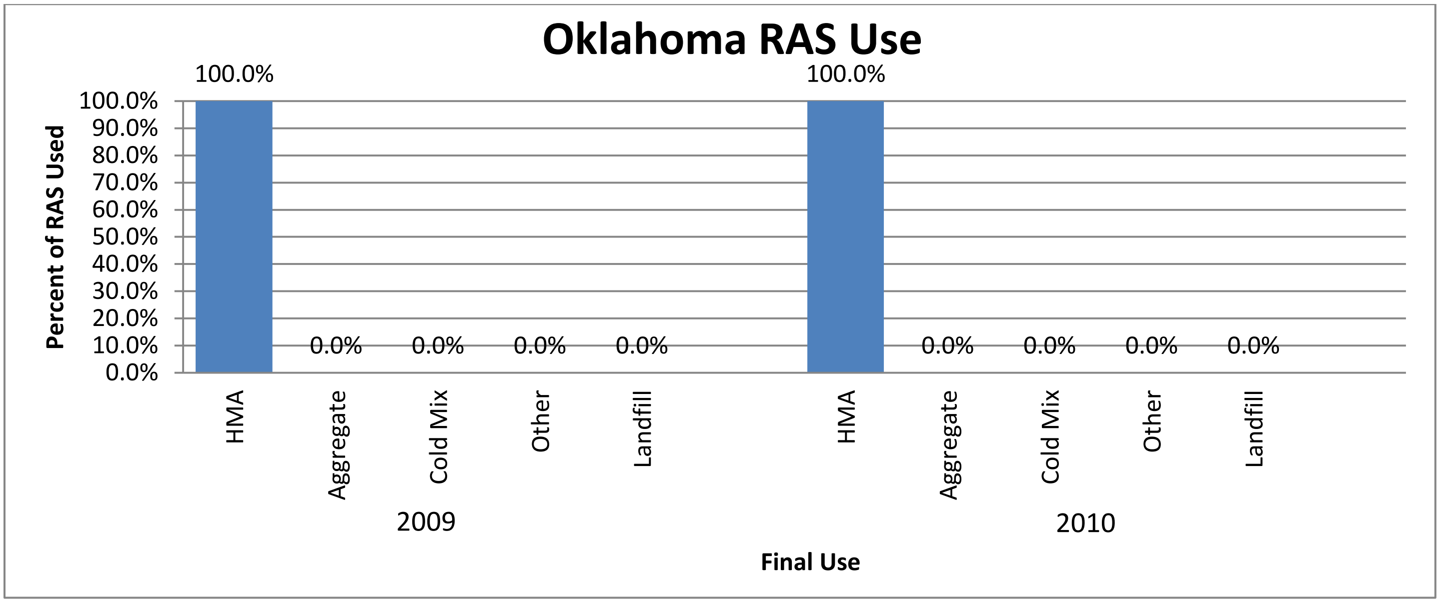


Total tons extimated based on relationship of tons to Federal Apportionment.   Total tonnage for DOT, Other Agency and Commercial & Residential based ratios from reported tons.

RAP Use



RAS Use



WMA Use

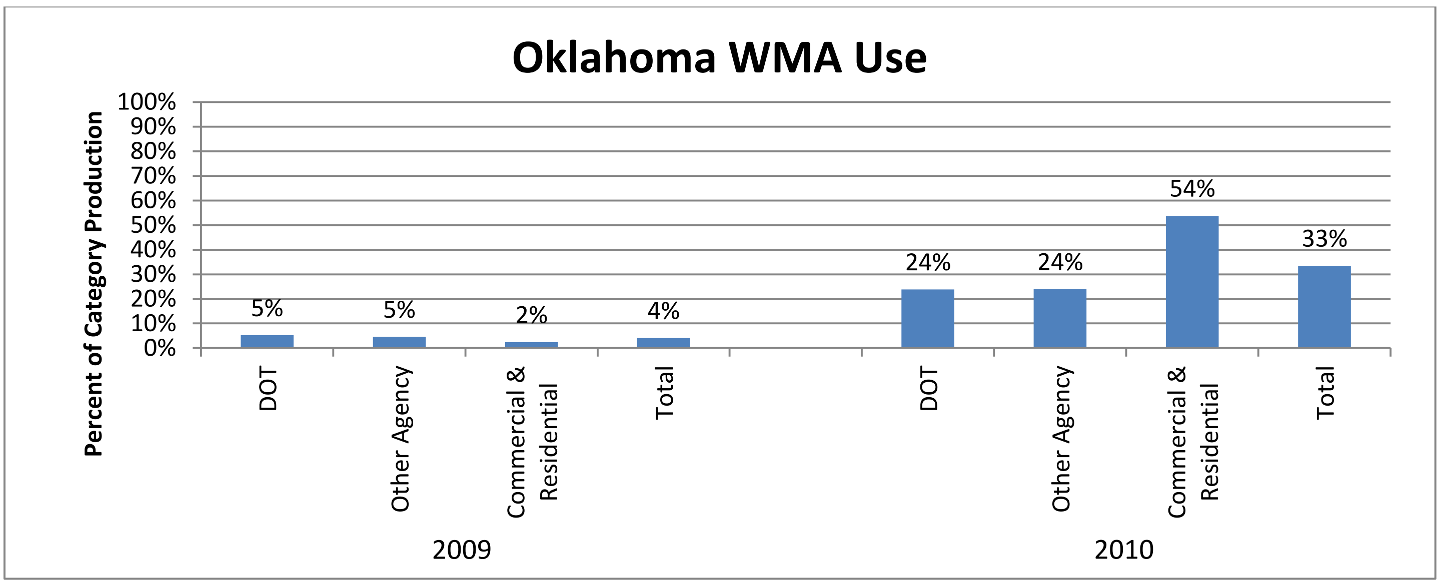


Table B 37: Summary of Oklahoma Data

Companies Reporting 4

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,110,900	1,089,000	2,582,202	3,020,841
Total Other Agency Tonnage	502,000	376,000	1,166,861	1,043,009
Total Commercial & Residential Tonnage	855,400	695,000	1,988,312	1,927,901
Total Tonnage	2,468,300	2,160,000	5,737,374	5,991,751
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	354,400	542,000	823,776	1,503,486
RAP Tons used in HMA/WMA	290,920	285,870	676,221	792,992
RAP Tons used as Aggregate	10,000	10,000	23,244	27,740
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	10,000	-	23,244	-
RAP Tons Landfilled	6	6	14	18
Average % RAP in DOT Mixes	11%	11%		
Average % RAP in Other Agency Mixes	16%	16%		
Average % RAP in Commercial & Residential Mixes	14%	13%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	50%	50%		
RAS Tons Received	17,200	45,200	39,980	125,383
RAS Tons used in HMA/WMA	983	8,000	2,285	22,192
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	1%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	1%	2%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	75%		
WMA DOT Tonnage	57,790	259,400	134,328	719,565
WMA Other Agency Tonnage	23,000	89,930	53,462	249,462
WMA Commercial & Residential Tonnage	20,720	373,790	48,162	1,036,878
Total WMA Tonnage	101,510	723,120	235,952	2,005,905
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

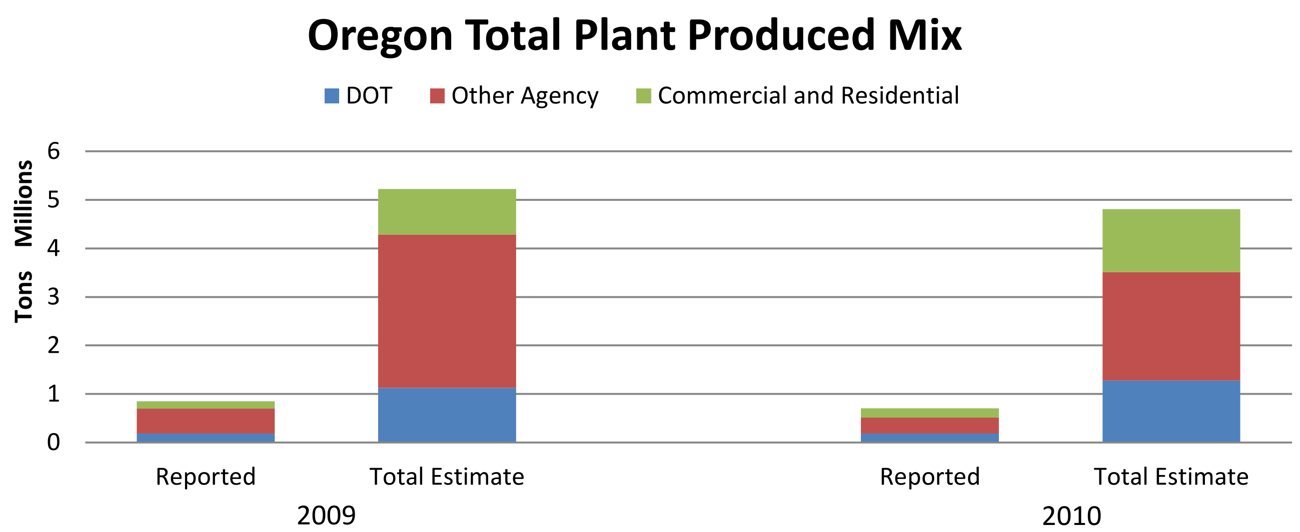
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Oregon

Table B38 summarizes the results received from asphalt mix producers in Oregon. The charts are used to summarize information calculated from information provided by the survey respondents.

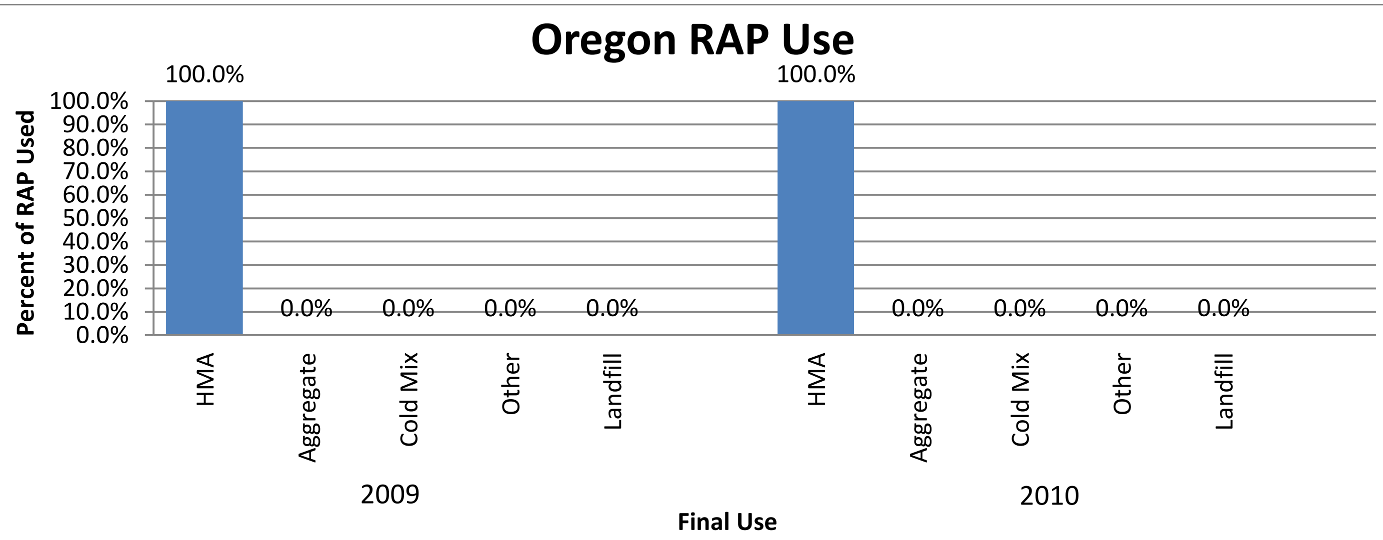
Total Asphalt Mix Tonnage

Companies responding: 8

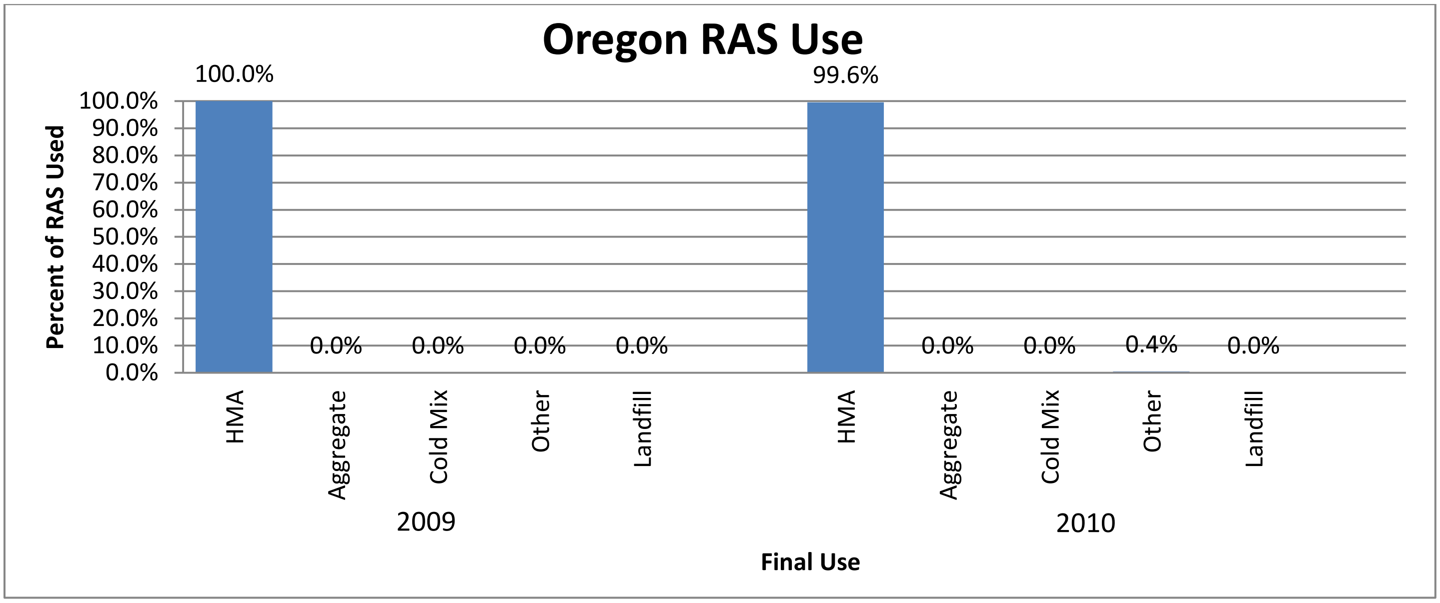


Total tonnage provided by the Asphalt Pavement Association of Oregon. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons. Total reported tonnage includes three companys/branchs that did not break out tonnages by different uses.

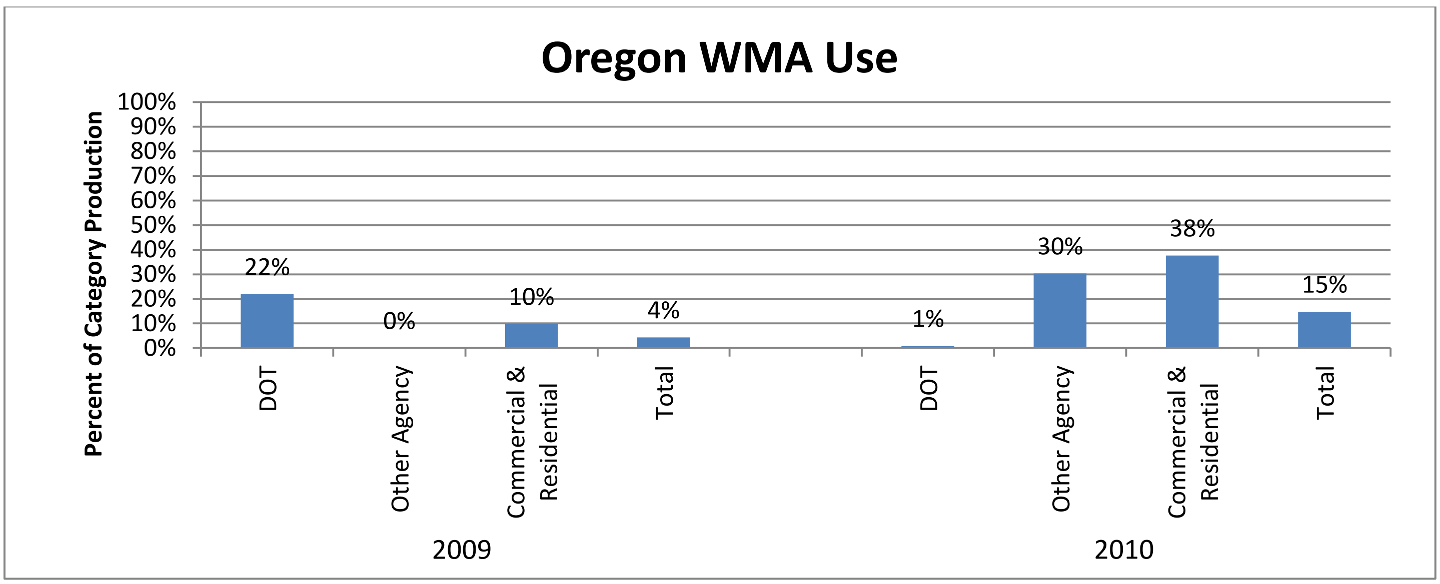
RAP Use



RAS Use



WMA Use



The Asphalt Pavement Association of Oregon estimates fewer WMA tons than the survey indicates. The APAO estimates are shown in the following table:

	2009	2010
WMA DOT Tonnage	150,000	0
WMA Other Agency Tonnage	80,000	80,000
WMA Commercial & Residential Tonnage	90,000	90,000
Total WMA Tonnage	320,000	170,000

Table B 38: Summary of Oregon Data

Companies Reporting 6

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	182,870	186,234	1,124,858	1,277,036
Total Other Agency Tonnage	512,823	326,210	3,154,444	2,236,874
Total Commercial & Residential Tonnage	153,280	188,899	942,846	1,295,310
Total Tonnage[2]	1,269,973	1,159,343	5,222,148	4,809,220
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	228,500	228,100	939,595	946,211
RAP Tons used in HMA/WMA	325,273	295,112	1,337,527	1,224,193
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	120	88	495	366
Average % RAP in DOT Mixes	24%	21%		
Average % RAP in Other Agency Mixes	20%	22%		
Average % RAP in Commercial & Residential Mixes	24%	23%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	33%	33%		
RAS Tons Received	6,500	36,000	26,728	149,336
RAS Tons used in HMA/WMA	2,362	4,070	9,711	16,883
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	17	-	71
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	4%		
Average % RAS in Other Agency Mixes	0%	5%		
Average % RAS in Commercial & Residential Mixes	2%	3%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	17%	50%		
WMA DOT Tonnage	40,000	1,610	246,045	11,040
WMA Other Agency Tonnage	-	98,837	-	677,740
WMA Commercial & Residential Tonnage	15,000	71,000	92,267	486,858
Total WMA Tonnage	55,000	171,447	338,312	1,175,638
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

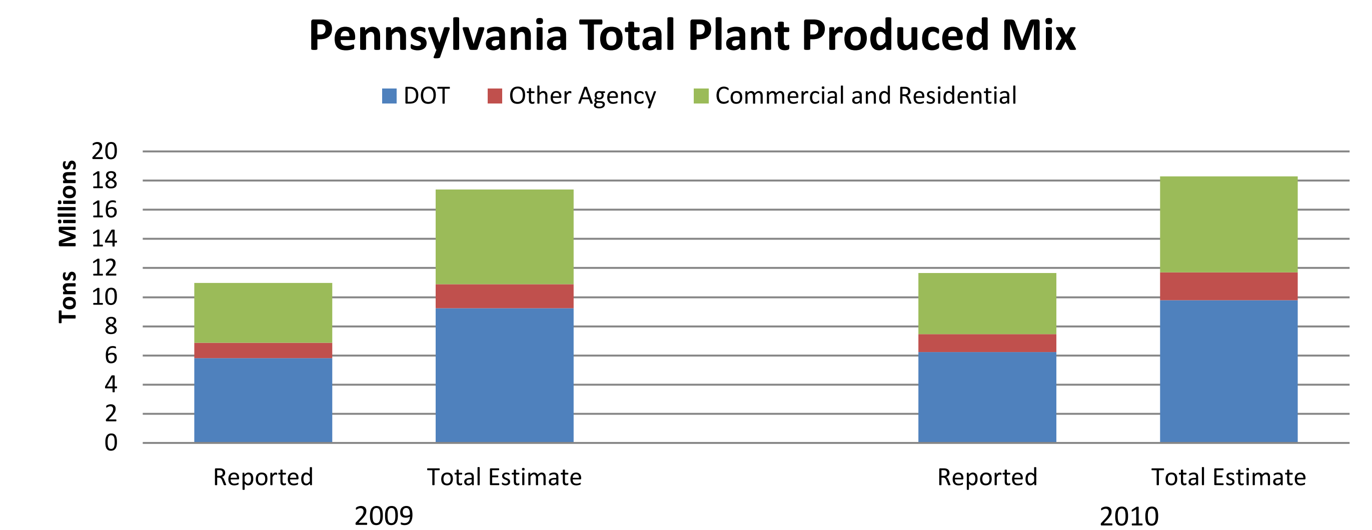
1. Total tonnage provided by the Asphalt Pavement Association of Oregon. Total tonnage for DOT, Other Agency and Commercial & Residential based ratios from reported tons.
2. Total reported tonnage includes three companys/branchs that did not break out tonnages by different uses.

Pennsylvania

Table B38 summarizes the results received from asphalt mix producers in Pennsylvania. The charts are used to summarize information calculated from information provided by the survey respondents.

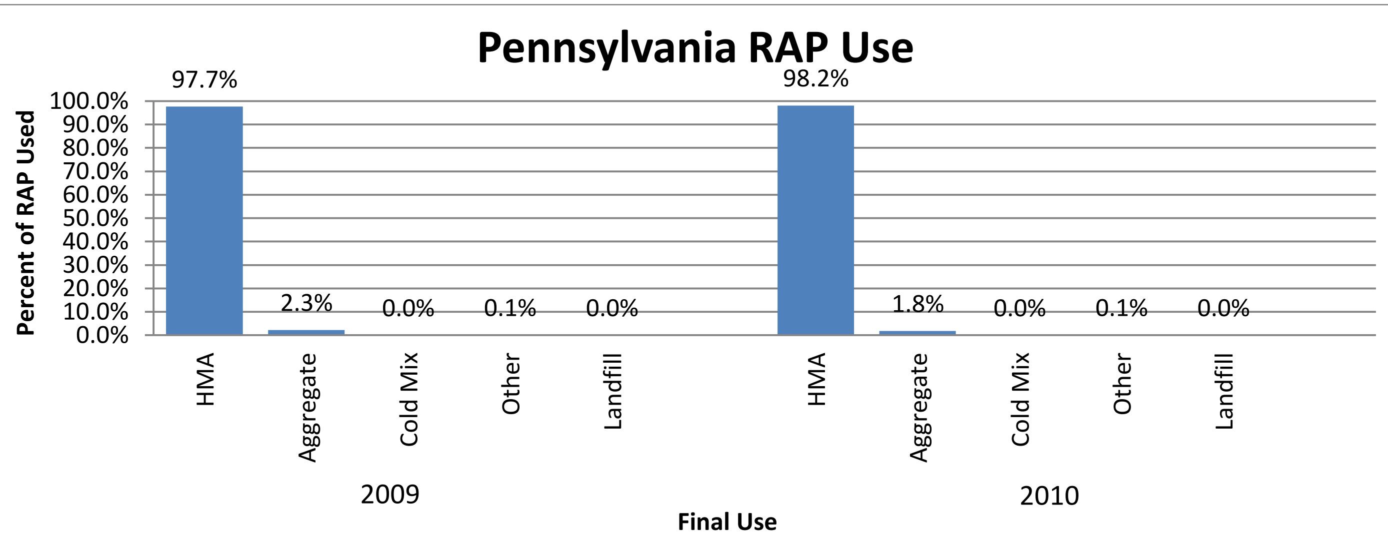
Total Asphalt Mix Tonnage

Companies responding: 17

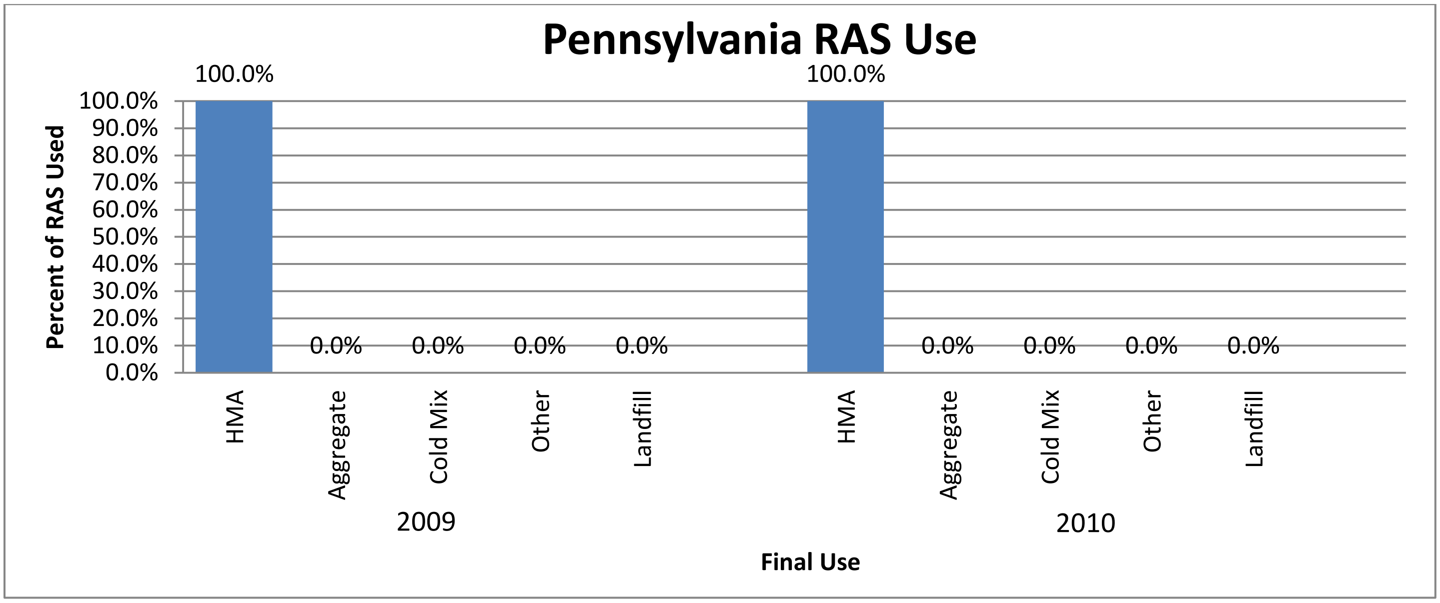


Total tonnage provided by the Pennsylvania Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

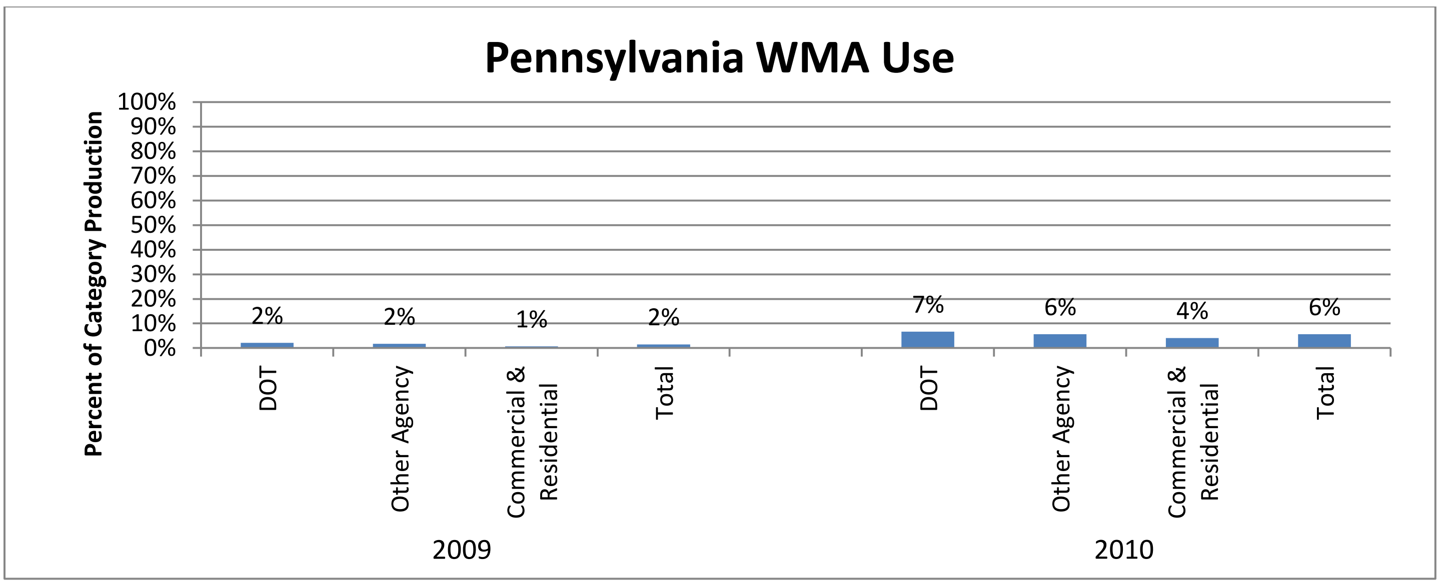


Table B 39: Summary of Pennsylvania Data

Companies Reporting 17

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	5,823,385	6,241,392	9,238,587	9,799,555
Total Other Agency Tonnage	1,037,664	1,217,886	1,646,216	1,912,192
Total Commercial & Residential Tonnage	4,106,743	4,196,096	6,515,197	6,588,253
Total Tonnage	10,967,792	11,655,374	17,400,000	18,300,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	94%	94%		
RAP Tons Received	1,255,680	1,341,322	1,992,090	2,105,998
RAP Tons used in HMA/WMA	1,379,675	1,567,121	2,188,803	2,460,523
RAP Tons used as Aggregate	32,000	28,500	50,767	44,748
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	1,000	1,000	1,586	1,570
RAP Tons Landfilled	30	36	47	57
Average % RAP in DOT Mixes	14%	15%		
Average % RAP in Other Agency Mixes	15%	15%		
Average % RAP in Commercial & Residential Mixes	17%	18%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	18%	24%		
RAS Tons Received	16,439	25,234	26,080	39,620
RAS Tons used in HMA/WMA	23,167	20,456	36,754	32,117
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	1%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	1%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	29%	71%		
WMA DOT Tonnage	120,850	415,348	191,724	652,134
WMA Other Agency Tonnage	17,855	68,239	28,326	107,141
WMA Commercial & Residential Tonnage	27,000	171,211	42,835	268,817
Total WMA Tonnage	165,704	654,798	262,884	1,028,092
Percent WMA Tons using Chemical Additives	13%	9%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	86%	91%		
Percent WMA Tons using Organic Additive	0%	0%		

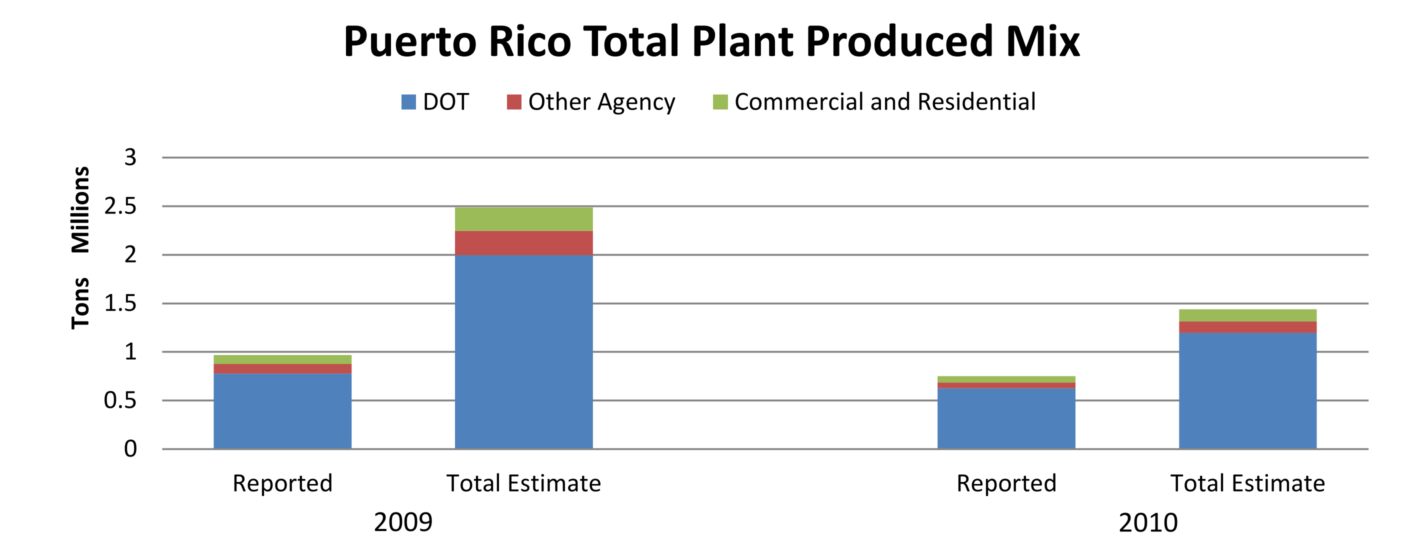
1. Total tonnage provided by the Pennsylvania Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Puerto Rico

Table B40 summarizes the results received from asphalt mix producers in Puerto Rico. The charts are used to summarize information calculated from information provided by the survey respondents.

Total Asphalt Mix Tonnage

Companies responding: 1



Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use

No contractors reported using RAP in Puerto Rico.

RAS Use

No contractors reporte using RAS in Puerto Rico.

WMA Use

No contractors reported using WMA in Puerto Rico.

Table B 40: Summary of Puerto Rico Data

Companies Reporting 1

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	777,800	623,777	1,996,884	1,194,513
Total Other Agency Tonnage	96,951	61,700	248,907	118,154
Total Commercial & Residential Tonnage	93,671	65,320	240,486	125,086
Total Tonnage	968,422	750,797	2,486,277	1,437,752

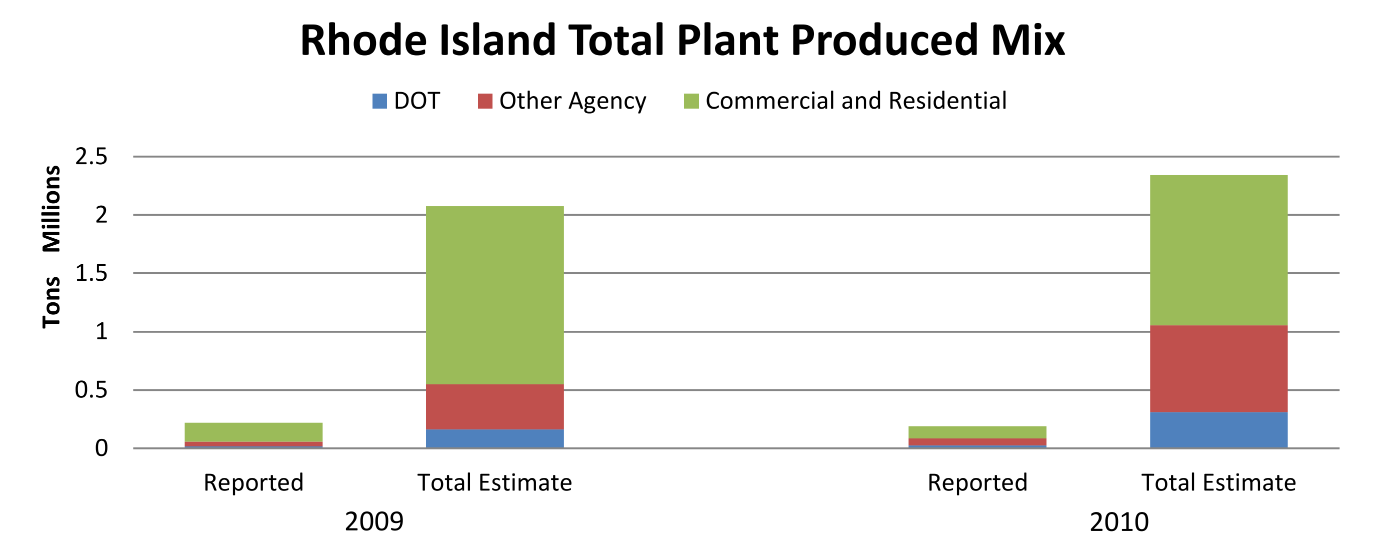
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Rhode Island

Table B41 summarizes the results received from asphalt mix producers in Rhode Island. The charts are used to summarize information calculated from information provided by the survey respondents.

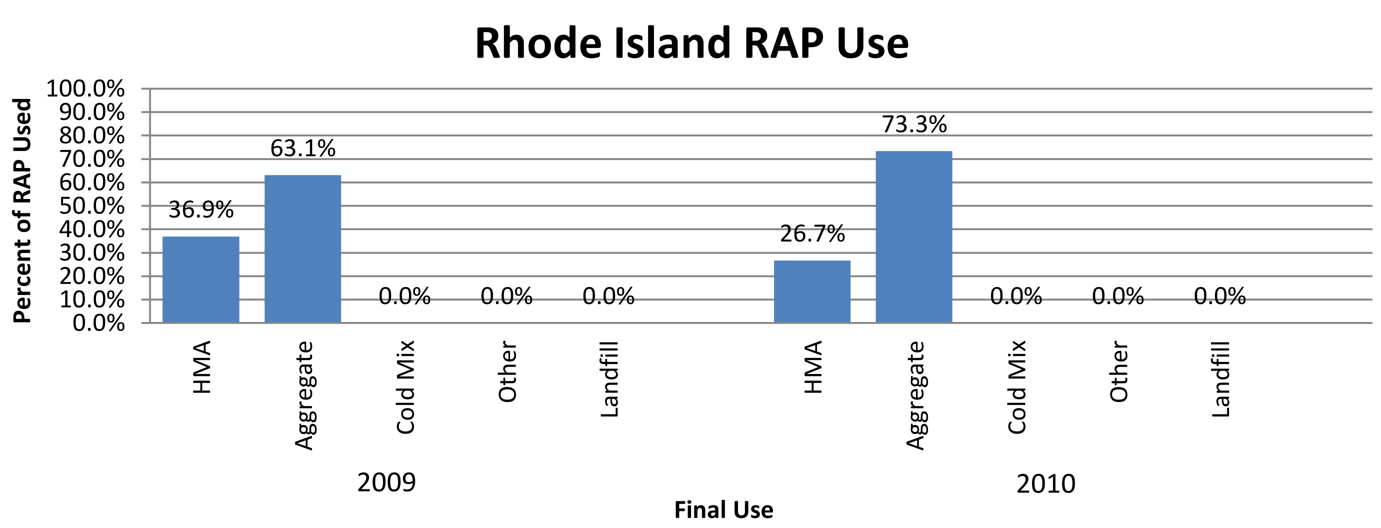
Total Asphalt Mix Tonnage

Companies responding: 2



1Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

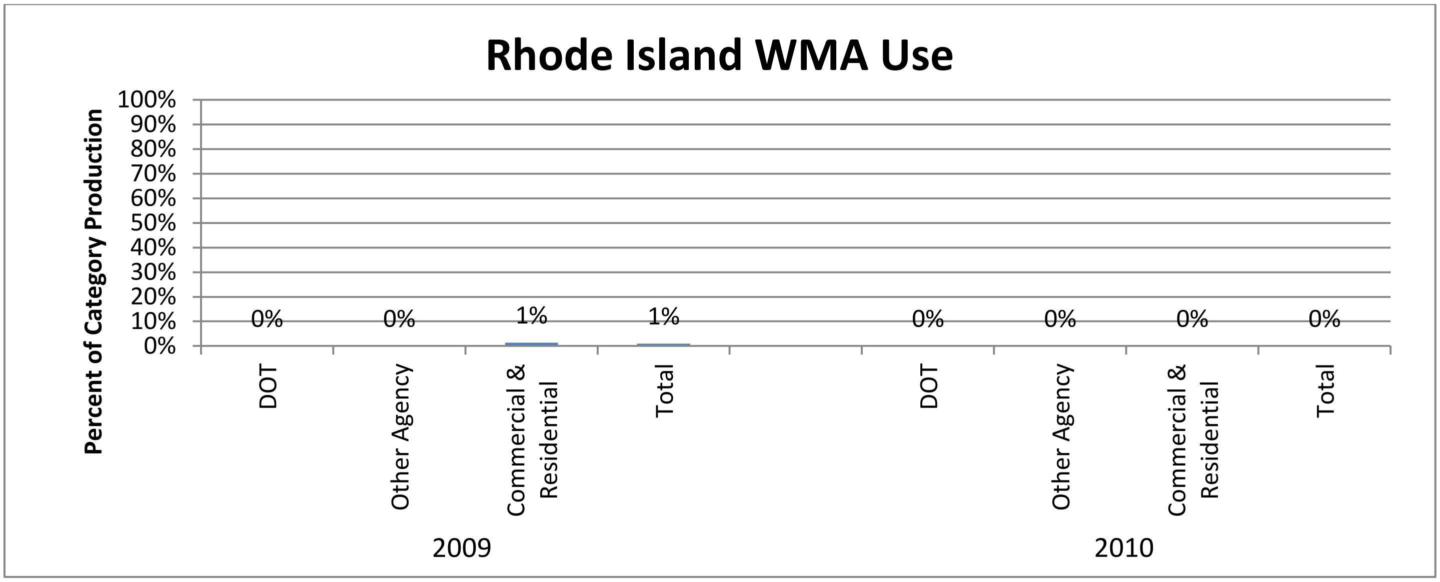
RAP Use



RAS Use

No contractors reported using RAS in Rhode Isand.

WMA Use



Rhode Island WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
0%
1%
1%
0%
0%
0%
0%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 41: Summary of Rhode Island Data

Companies Reporting 2

	Reported		Total Estimated[1]	
HMA/WMA				
	2009	2010	2009	2010
Total DOT Tonnage	17,000	25,000	161,007	309,400
Total Other Agency Tonnage	41,000	60,200	388,311	745,035
Total Commercial & Residential Tonnage	161,000	104,000	1,524,831	1,287,104
Total Tonnage	219,000	189,200	2,074,149	2,341,539
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	65,000	75,000	615,615	928,200
RAP Tons used in HMA/WMA	24,000	20,000	227,304	247,520
RAP Tons used as Aggregate	41,000	55,000	388,311	680,680
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	0%	0%		
Average % RAP in Other Agency Mixes	13%	10%		
Average % RAP in Commercial & Residential Mixes	10%	6%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	50%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	2,200	-	20,836	-
Total WMA Tonnage	2,200	-	20,836	-
Percent WMA Tons using Chemical Additives	100%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

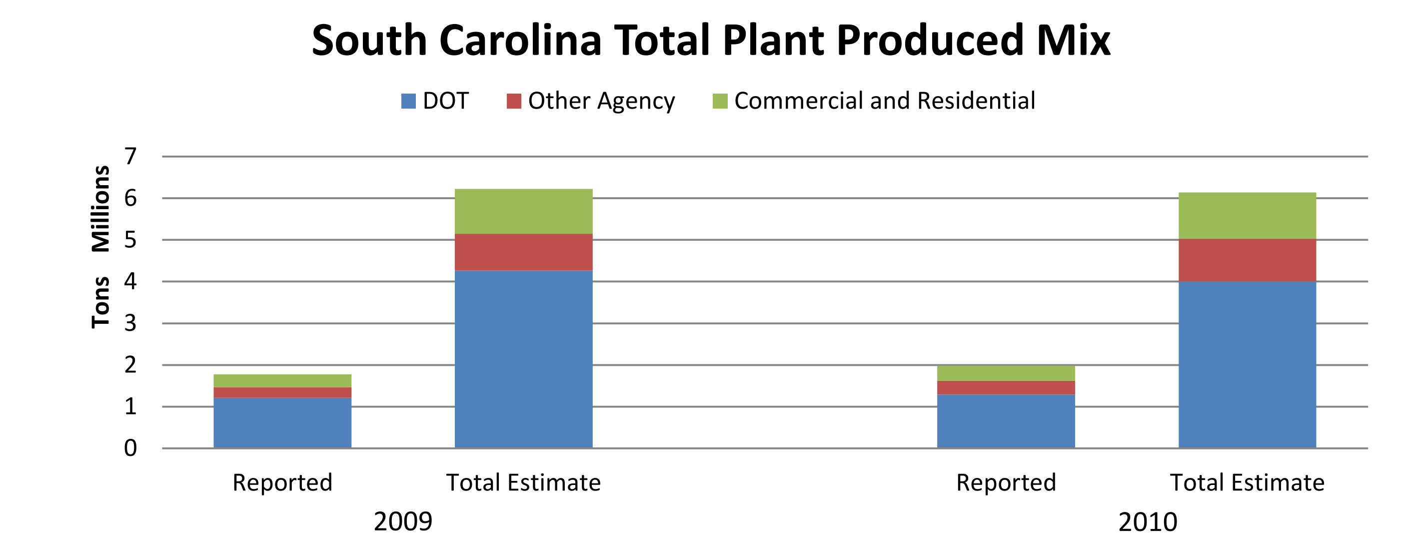
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

South Carolina

Table B42 summarizes the results received from asphalt mix producers in South Carolina. The charts are used to summarize information calculated from information provided by the survey respondents.

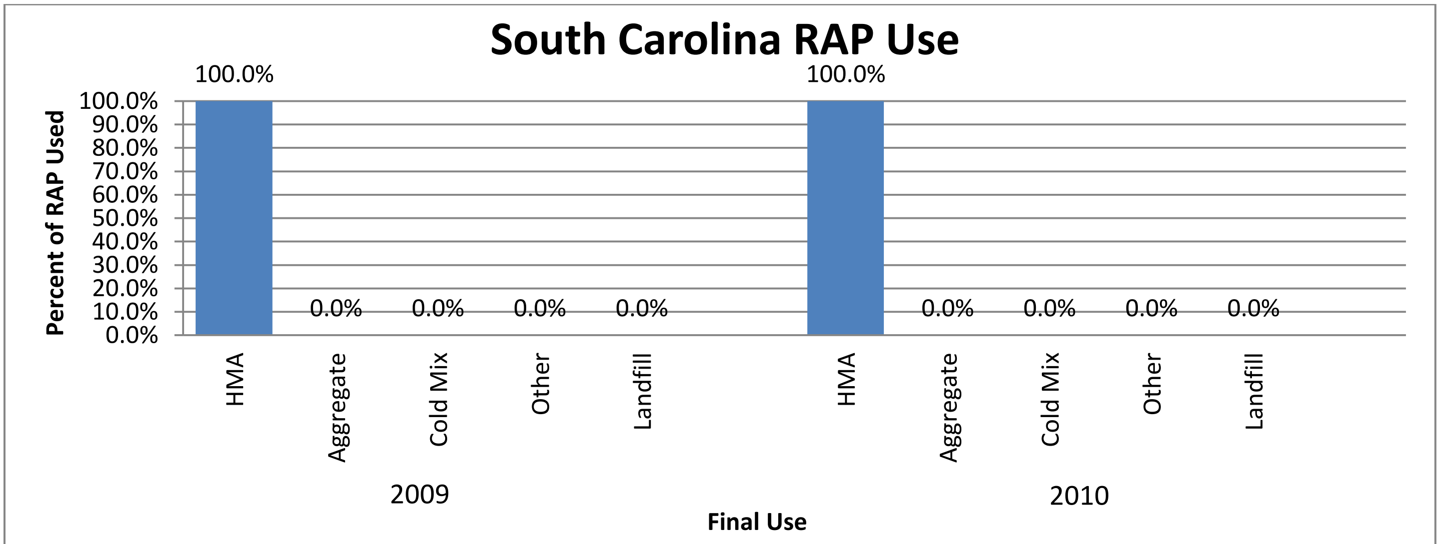
Total Asphalt Mix Tonnage

Companies responding: 4



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use

No contractos reported using RAS in South Carolina.

WMA Use

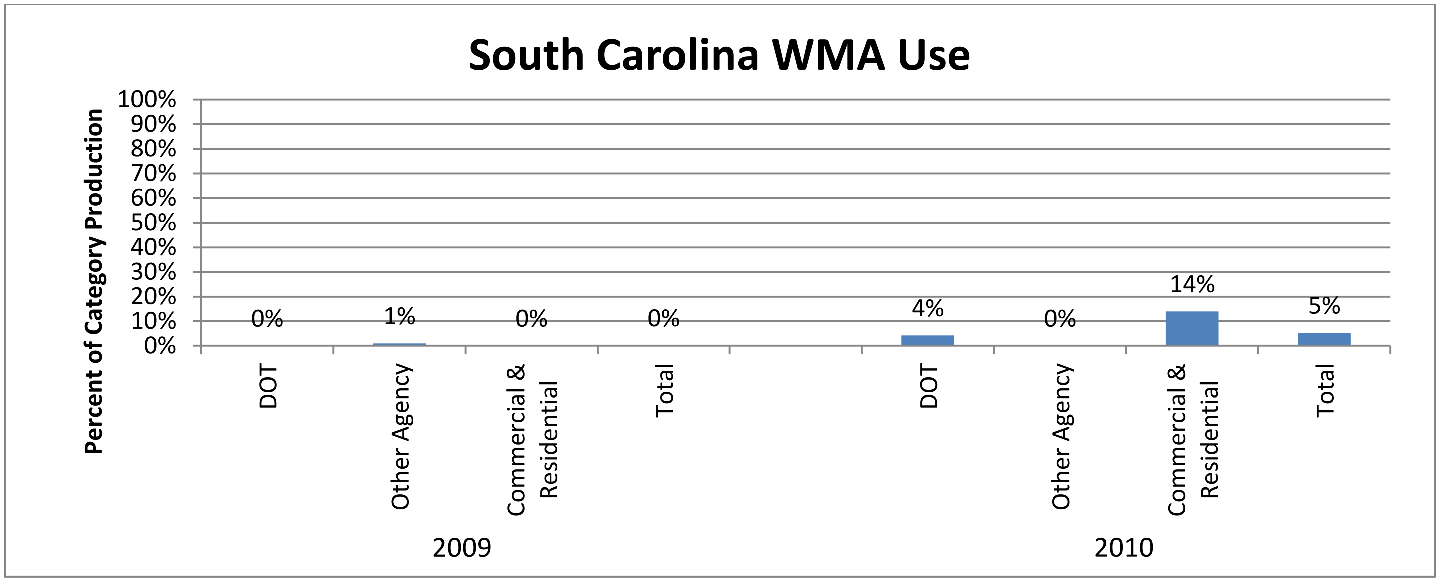

South Carolina WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
1%
0%
0%
4%
0%
14%
5%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 42: Summary of South Carolina Data

Companies Reporting 4

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,214,252	1,290,000	4,262,452	4,000,308
Total Other Agency Tonnage	251,700	332,250	883,556	1,030,312
Total Commercial & Residential Tonnage	308,200	357,750	1,081,891	1,109,388
Total Tonnage	1,774,152	1,980,000	6,227,898	6,140,008
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	405,000	500,000	1,421,693	1,550,507
RAP Tons used in HMA/WMA	294,000	395,000	1,032,044	1,224,901
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	17%	19%		
Average % RAP in Other Agency Mixes	17%	24%		
Average % RAP in Commercial & Residential Mixes	20%	24%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	100%		
WMA DOT Tonnage	-	54,500	-	169,005
WMA Other Agency Tonnage	2,475	-	8,688	-
WMA Commercial & Residential Tonnage	-	50,000	-	155,051
Total WMA Tonnage	2,475	104,500	8,688	324,056
Percent WMA Tons using Chemical Additives	100%	50%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	50%		
Percent WMA Tons using Organic Additive	0%	0%		

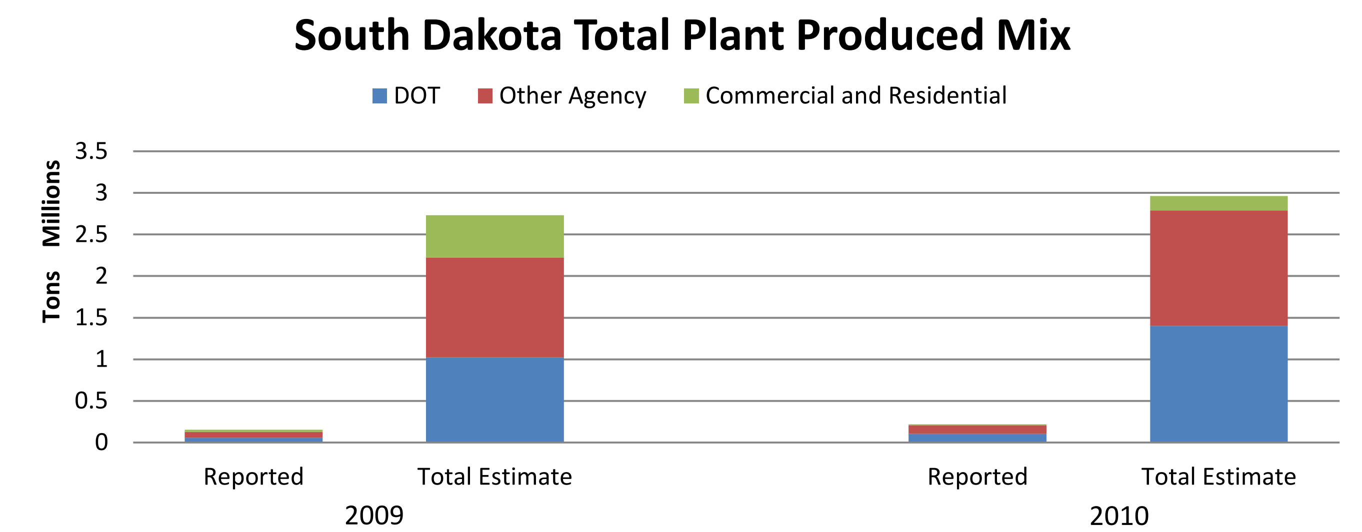
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

South Dakota

Table B43 summarizes the results received from asphalt mix producers in South Dakota. The charts are used to summarize information calculated from information provided by the survey respondents.

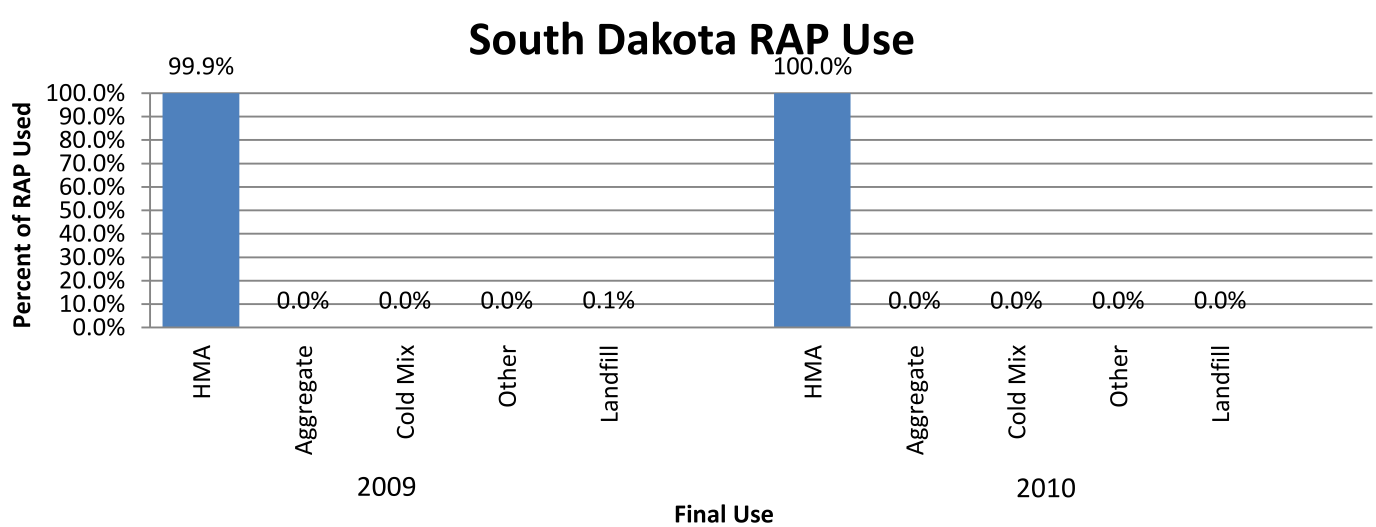
Total Asphalt Mix Tonnage

Companies responding: 1



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use

No contractors reported using RAS in South Dakota.

WMA Use

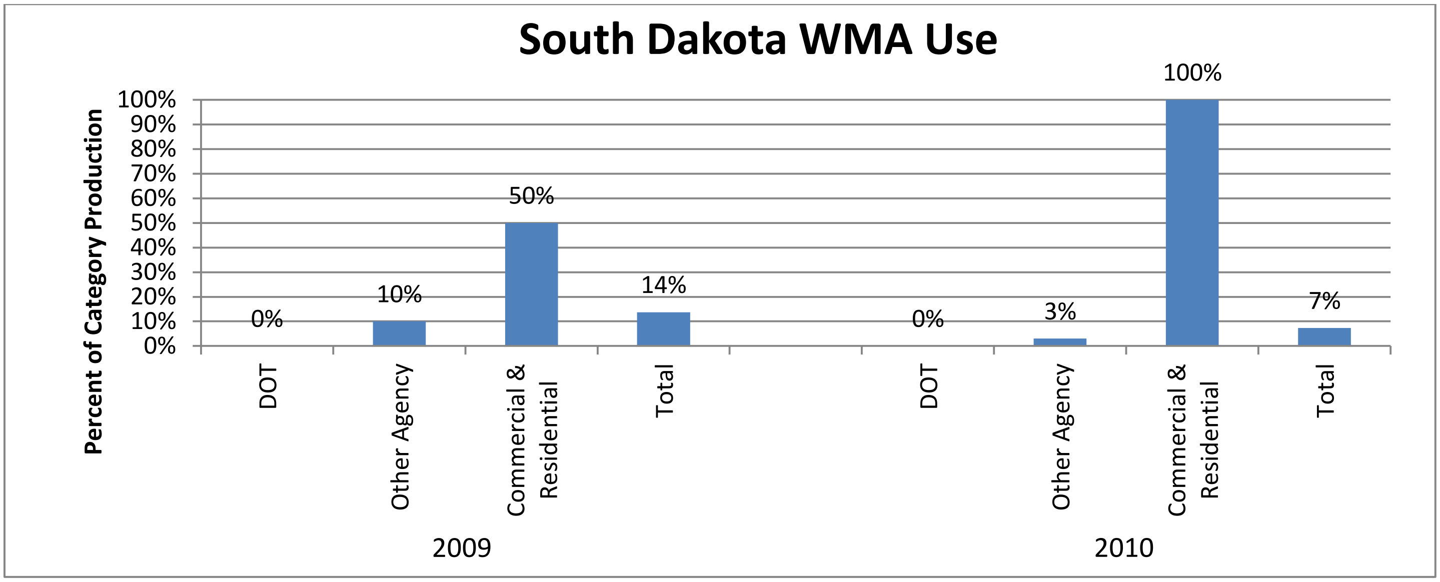

South Dakota WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
10%
50%
14%
0%
3%
100%
7%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 43: Summary of South Dakota Data

Companies Reporting 1

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	58,000	104,000	1,022,507	1,401,092
Total Other Agency Tonnage	68,000	103,000	1,198,801	1,387,620
Total Commercial & Residential Tonnage	29,000	13,000	511,253	175,137
Total Tonnage	155,000	220,000	2,732,561	2,963,849
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	26,000	13,000	458,365	175,137
RAP Tons used in HMA/WMA	18,692	13,600	329,523	183,213
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	12	6	213	88
Average % RAP in DOT Mixes	20%	5%		
Average % RAP in Other Agency Mixes	0%	5%		
Average % RAP in Commercial & Residential Mixes	20%	25%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	1,000	-	13,472
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	500	-	6,736
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	100%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	6,800	3,090	119,880	41,629
WMA Commercial & Residential Tonnage	14,500	13,000	255,627	175,137
Total WMA Tonnage	21,300	16,090	375,507	216,765
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

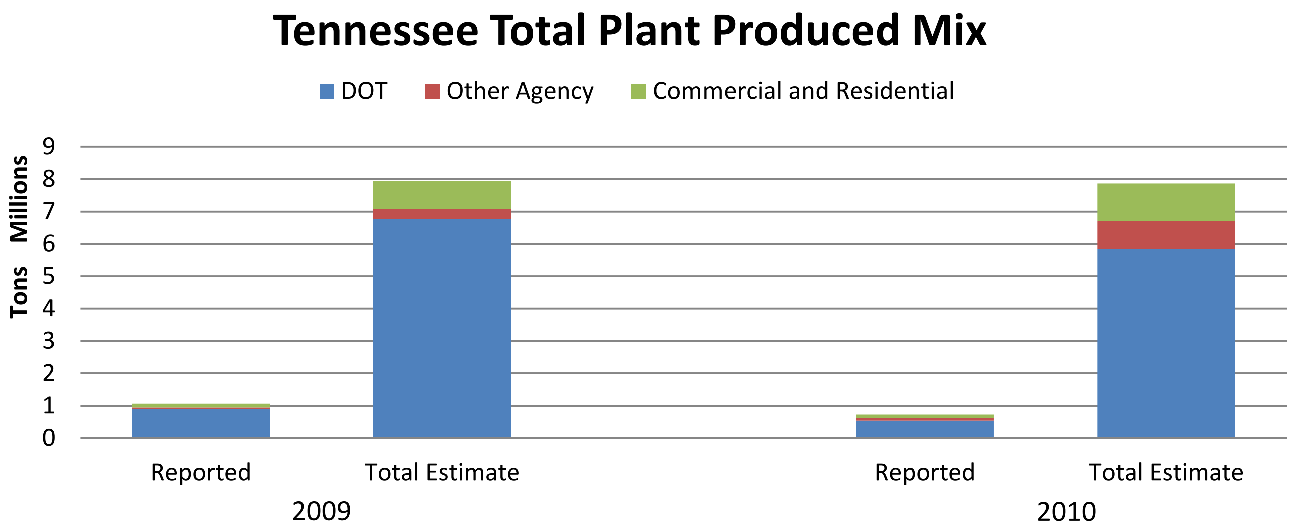
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Tennessee

Table B44 summarizes the results received from asphalt mix producers in Tennessee. The charts are used to summarize information calculated from information provided by the survey respondents.

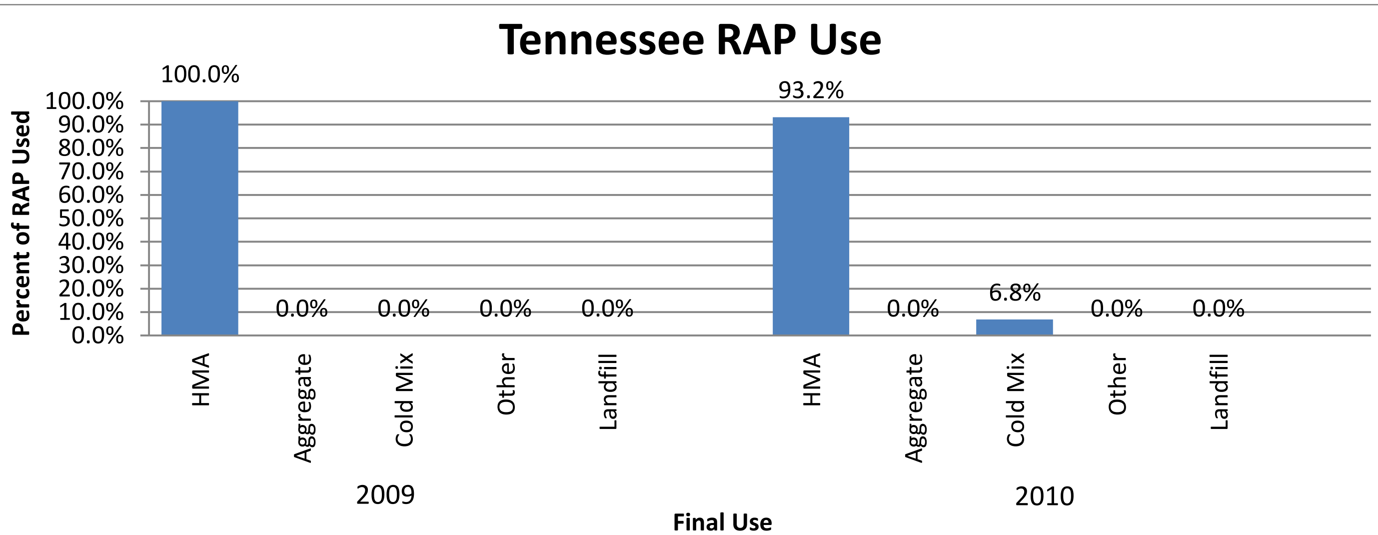
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

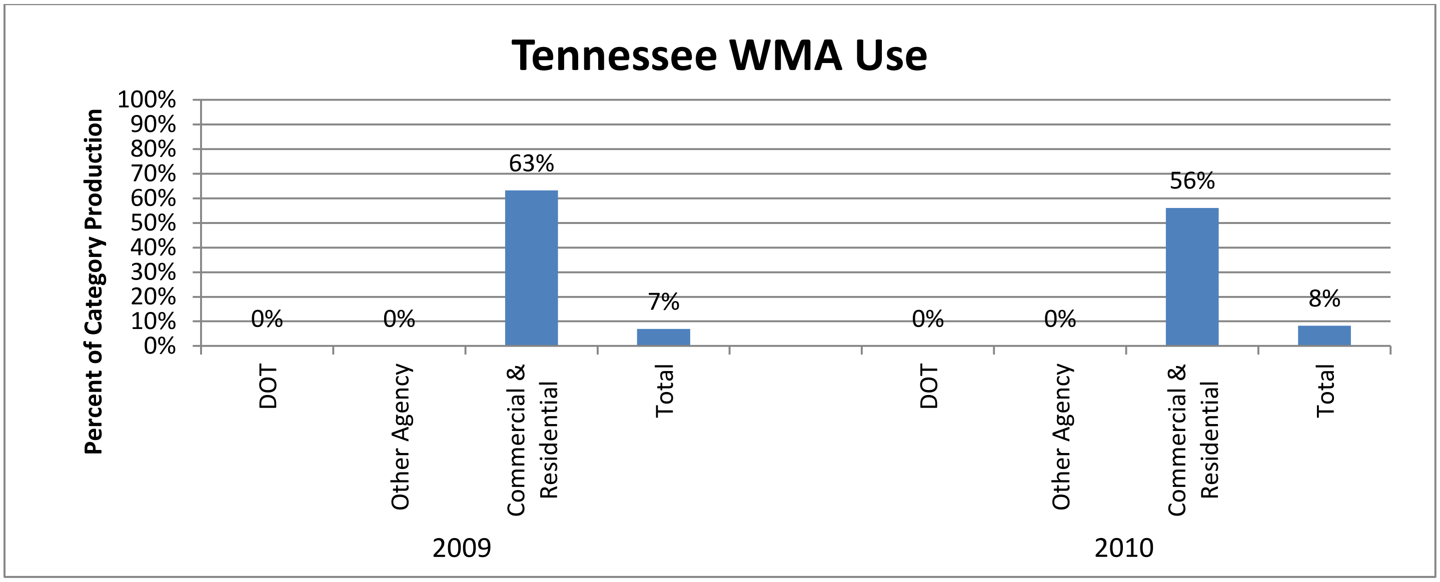
RAP Use



RAS Use

No contractors reported using RAS in 2009 or 2010.

WMA Use



Tennessee WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
0%
63%
7%
0%
0%
56%
8%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 44: Summary of Tennessee Data

Companies Reporting 2

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	911,000	544,000	6,766,170	5,838,444
Total Other Agency Tonnage	41,000	81,000	304,515	869,327
Total Commercial & Residential Tonnage	118,000	108,000	876,408	1,159,103
Total Tonnage	1,070,000	733,000	7,947,093	7,866,873
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	117,000	89,000	868,981	955,187
RAP Tons used in HMA/WMA	210,639	123,409	1,564,453	1,324,476
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	9,000	-	96,592
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	38	35	280	375
Average % RAP in DOT Mixes	17%	18%		
Average % RAP in Other Agency Mixes	0%	11%		
Average % RAP in Commercial & Residential Mixes	25%	25%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	50%	100%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	74,520	60,614	553,474	650,536
Total WMA Tonnage	74,520	60,614	553,474	650,536
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

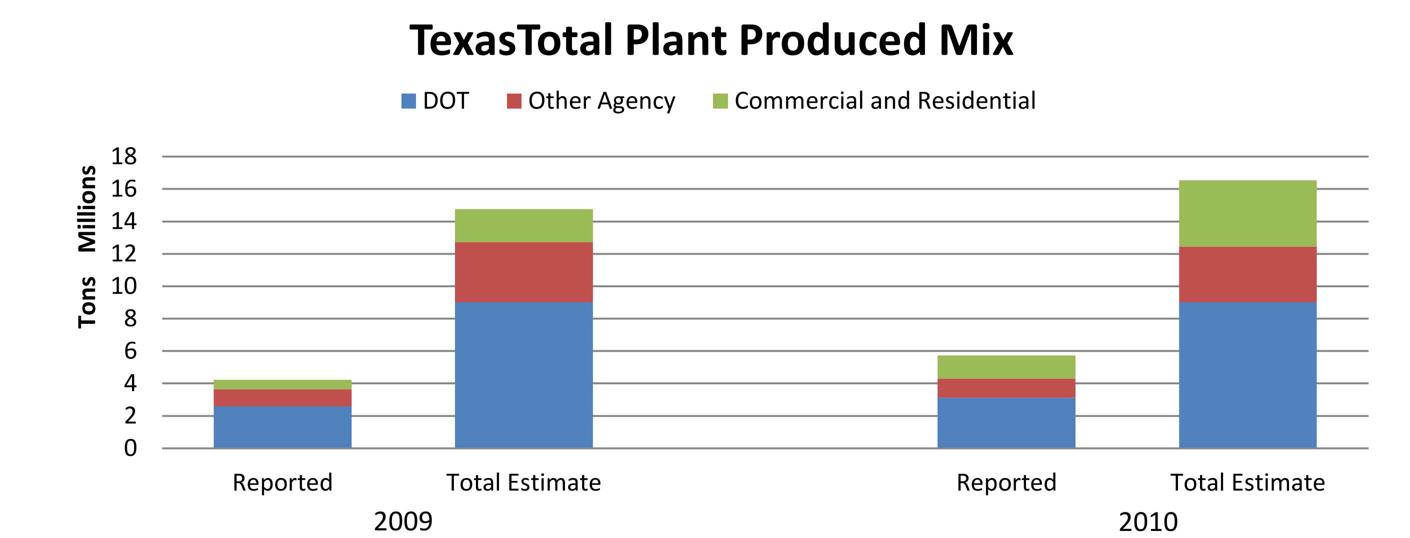
Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Texas

Table B45 summarizes the results received from asphalt mix producers in Texas. The charts are used to summarize information calculated from information provided by the survey respondents.

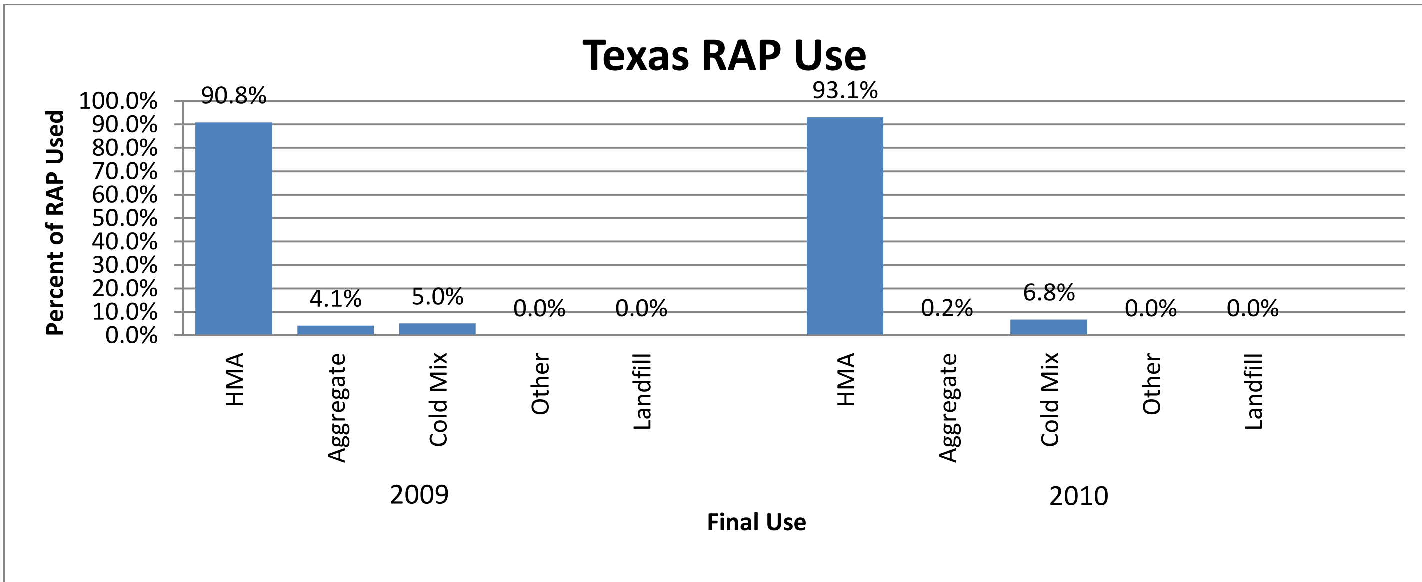
Total Asphalt Mix Tonnage

Companies responding: 7

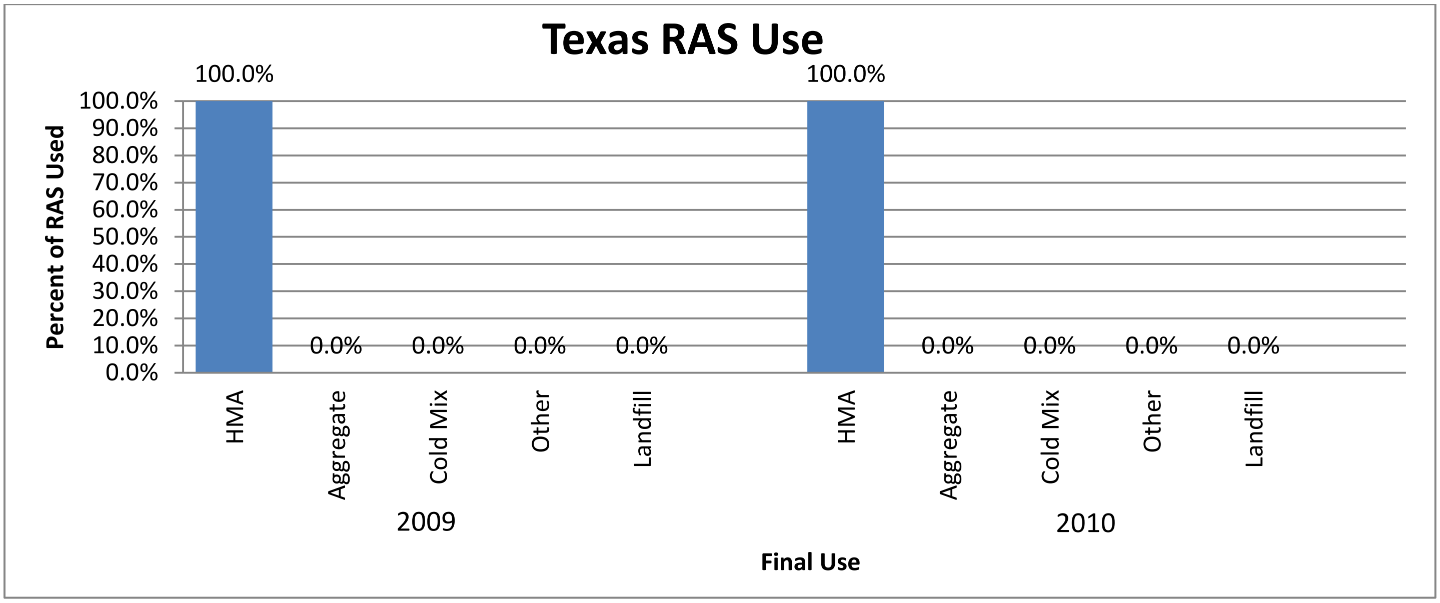


Total DOT tonnage provided by Texas Asphalt Pavement Association and ratio of reported total tons to reported DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

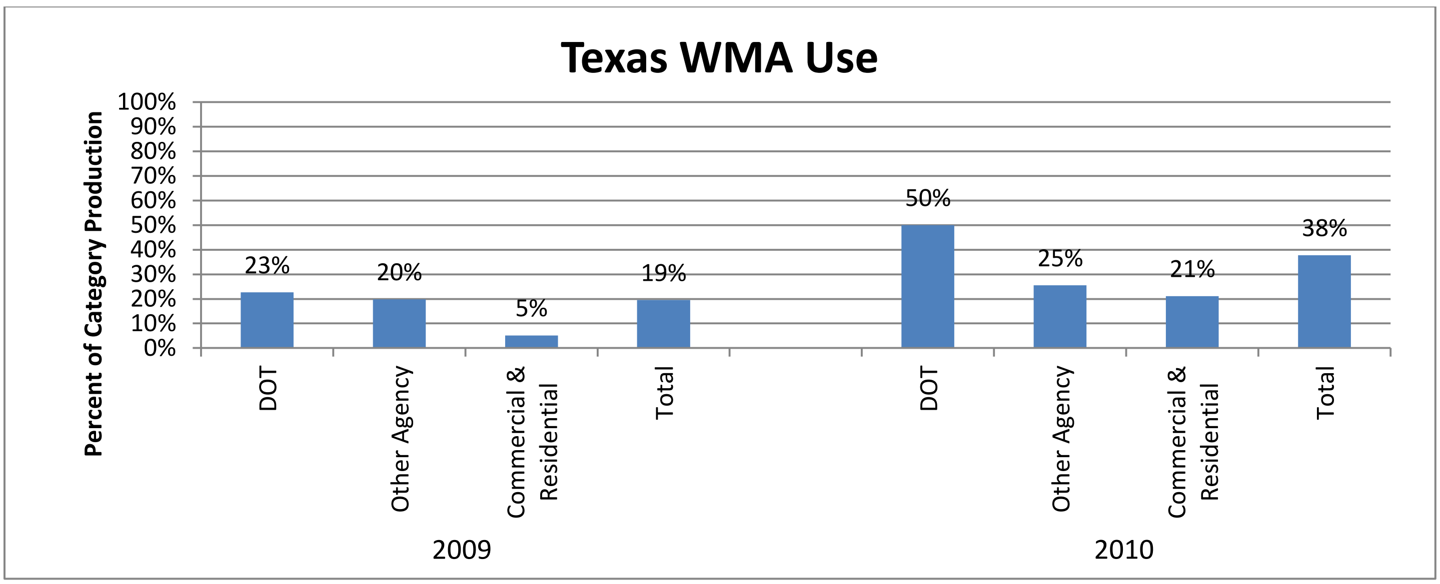


Table B 45: Summary of Texas Data

Companies Reporting 7

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,579,899	3,119,074	9,001,949	9,000,645
Total Other Agency Tonnage	1,065,851	1,192,805	3,719,036	3,442,052
Total Commercial & Residential Tonnage	586,103	1,419,612	2,045,068	4,096,544
Total Tonnage	4,231,853	5,731,491	14,766,053	16,539,242
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	86%		
RAP Tons Received	631,984	801,000	2,205,159	2,311,429
RAP Tons used in HMA/WMA	485,848	564,369	1,695,254	1,628,586
RAP Tons used as Aggregate	22,000	1,000	76,764	2,886
RAP Tons used in Cold Mix	27,000	41,000	94,210	118,313
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	32	35	110	102
Average % RAP in DOT Mixes	16%	15%		
Average % RAP in Other Agency Mixes	17%	18%		
Average % RAP in Commercial & Residential Mixes	21%	19%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	29%	57%		
RAS Tons Received	20,180	81,000	70,413	233,740
RAS Tons used in HMA/WMA	37,801	72,349	131,896	208,775
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	2%	5%		
Average % RAS in Other Agency Mixes	2%	1%		
Average % RAS in Commercial & Residential Mixes	4%	4%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	71%	71%		
WMA DOT Tonnage	583,431	1,558,444	2,035,745	4,497,170
WMA Other Agency Tonnage	211,090	303,774	736,549	876,593
WMA Commercial & Residential Tonnage	30,219	299,536	105,442	864,363
Total WMA Tonnage	824,740	2,161,754	2,877,736	6,238,127
Percent WMA Tons using Chemical Additives	2%	28%		
Percent WMA Tons using Additive Foaming	8%	5%		
Percent WMA Tons using Plant Foaming	90%	67%		
Percent WMA Tons using Organic Additive	0%	0%		

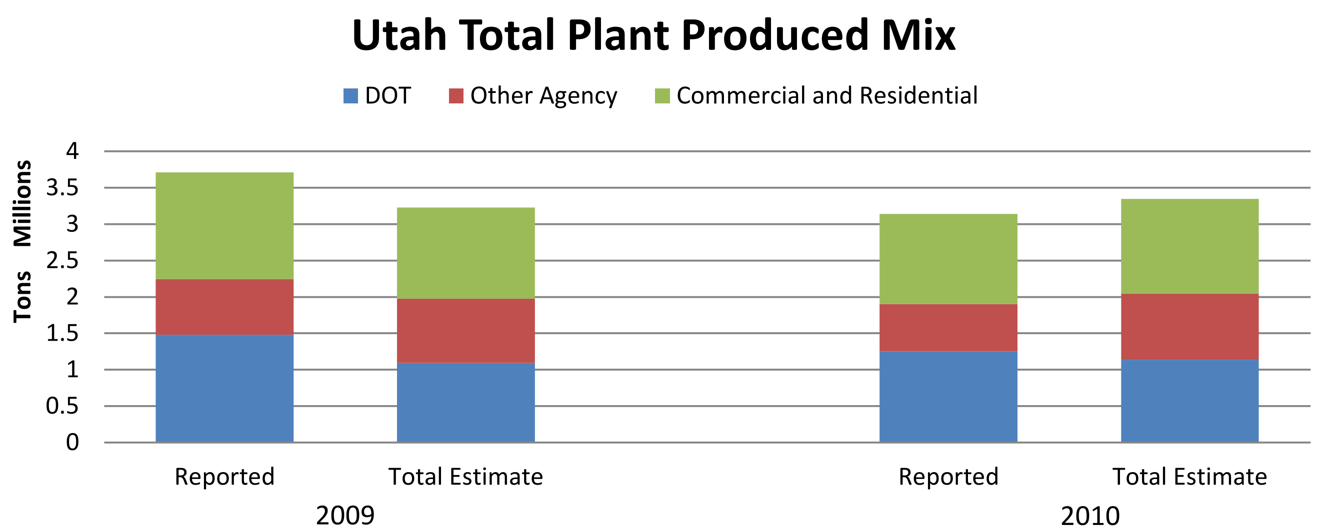
1. Total DOT tonnage provided by Texas Asphalt Pavement Association and ratio of reported total tons to reported DOT tons used to compute estimated total tons. Total tonnage for Other Agency and Commercial & Residential based on ratios from reported tons.

Utah

Table B46 summarizes the results received from asphalt mix producers in Utah. The charts are used to summarize information calculated from information provided by the survey respondents.

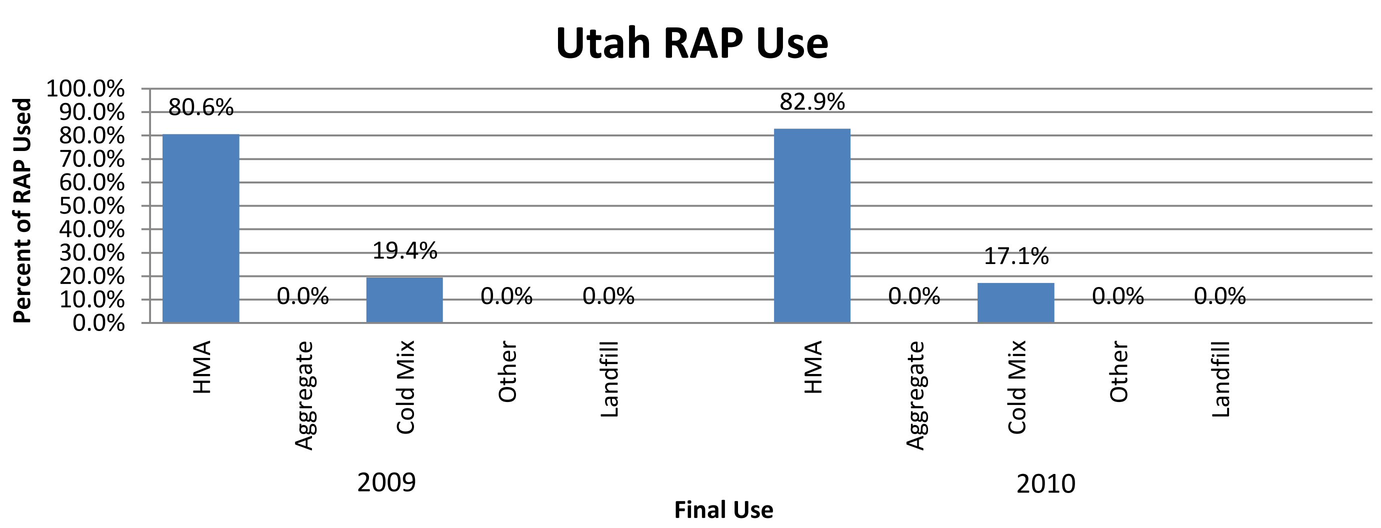
Total Asphalt Mix Tonnage

Companies responding: 5



Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based ratios from reported tons.

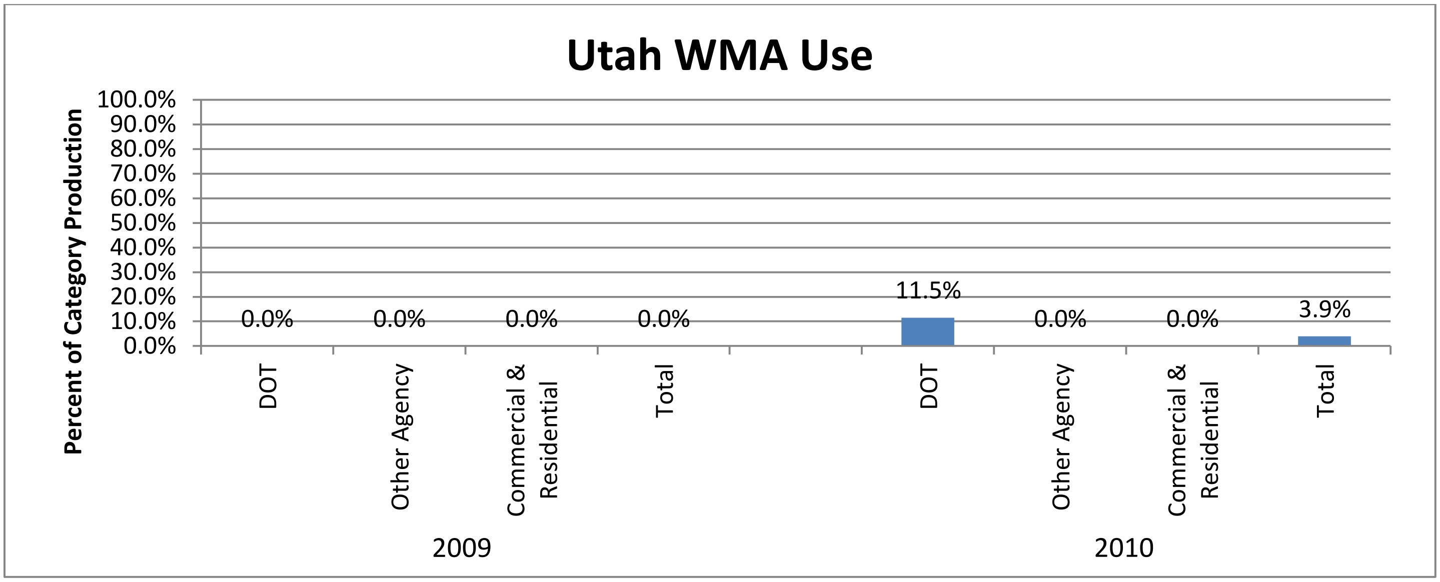
RAP Use



RAS Use

No contractors reported using RAS in 2009 or 2010.

WMA Use



Utah WMA Use
Percent of Category Production
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.0%
0.0%
0.0%
0.0%
11.5%
0.0%
0.0%
3.9%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 46: Summary of Utah Data

Companies Reporting 5

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,478,000	1,094,323	1,250,953	1,135,154
Total Other Agency Tonnage	766,000	880,000	648,329	912,835
Total Commercial & Residential Tonnage	1,467,000	1,253,000	1,241,643	1,299,752
Total Tonnage	3,711,000	3,227,323	3,140,924	3,347,741
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	80%	100%		
RAP Tons Received	947,000	1,806,000	801,524	1,873,385
RAP Tons used in HMA/WMA	715,427	671,165	605,525	696,208
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	172,000	138,000	145,578	143,149
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	57	60	49	62
Average % RAP in DOT Mixes	14%	10%		
Average % RAP in Other Agency Mixes	13%	12%		
Average % RAP in Commercial & Residential Mixes	22%	22%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	80%		
WMA DOT Tonnage	-	126,292	-	131,004
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	62	-	65
Total WMA Tonnage	-	126,354	-	131,069
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

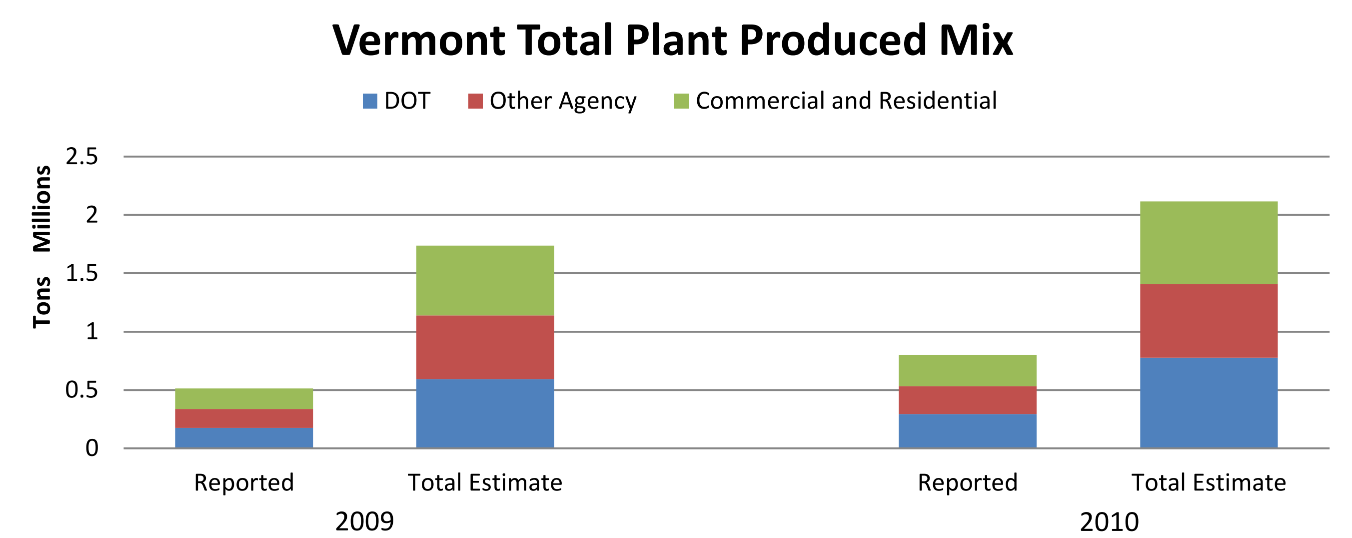
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Vermont

Table B47 summarizes the results received from asphalt mix producers in Vermont. The charts are used to summarize information calculated from information provided by the survey respondents.

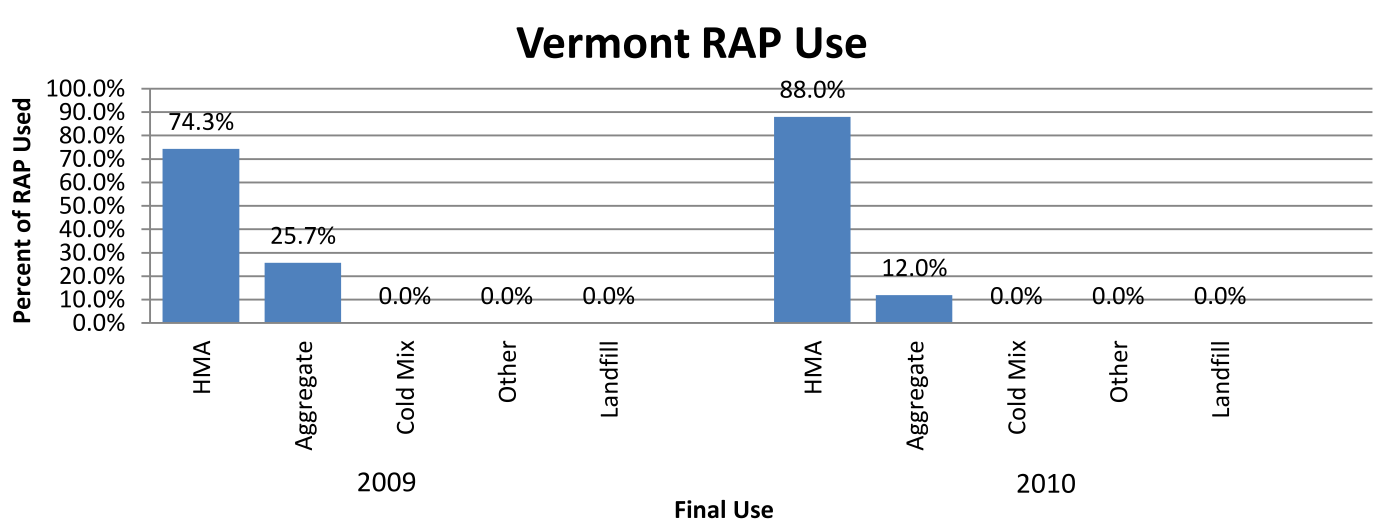
Total Asphalt Mix Tonnage

Companies responding: 1



Total tons extimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based ratios from reported tons.

RAP Use



RAS Use

No contractor reported using RAS in 2009 or 2010.

WMA Use

No contractor reported using WMA in 2009 or 2010.

Table B 47: Summary of Vermont Data

Companies Reporting 1

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	175,000	293,000	593,505	775,483
Total Other Agency Tonnage	161,000	239,000	546,024	632,561
Total Commercial & Residential Tonnage	176,000	268,000	596,896	709,315
Total Tonnage	512,000	800,000	1,736,425	2,117,360
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	91,000	157,000	308,622	415,532
RAP Tons used in HMA/WMA	107,000	162,000	362,886	428,765
RAP Tons used as Aggregate	37,000	22,000	125,484	58,227
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	21	20	71	54
Average % RAP in DOT Mixes	15%	15%		
Average % RAP in Other Agency Mixes	25%	25%		
Average % RAP in Commercial & Residential Mixes	25%	25%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

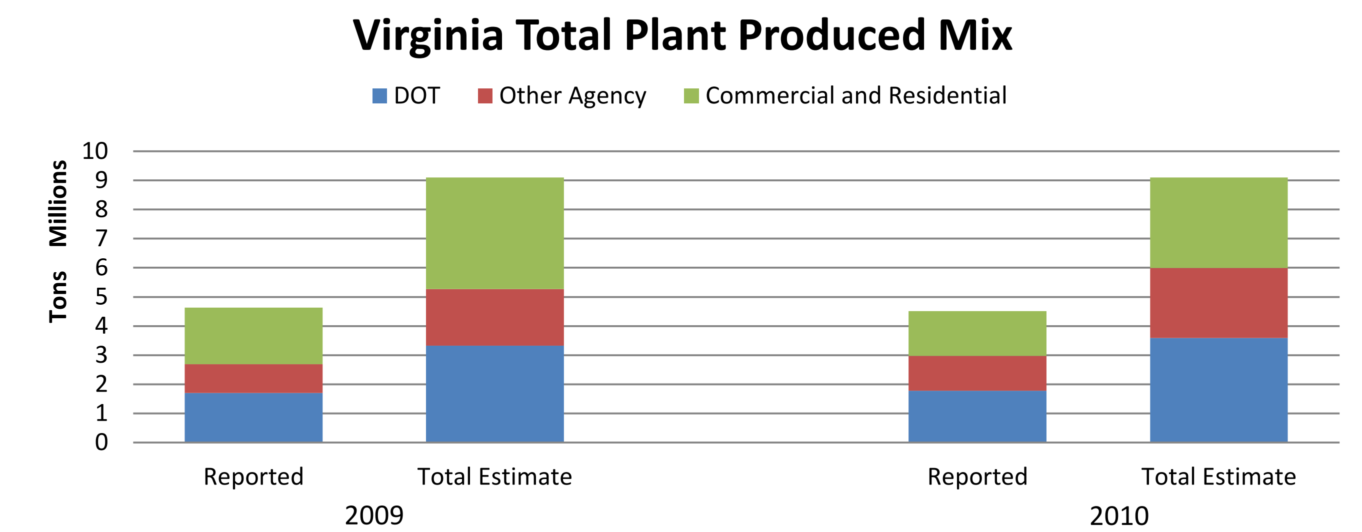
1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Virginia

Table B48 summarizes the results received from asphalt mix producers in Virginia. The charts are used to summarize information calculated from information provided by the survey respondents.

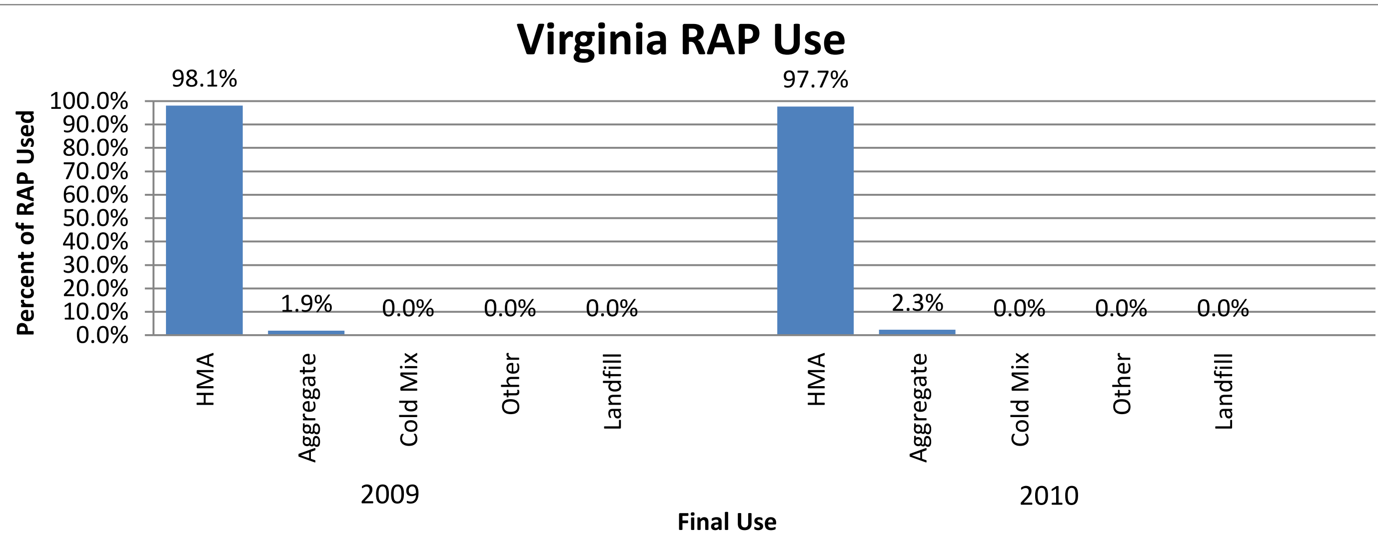
Total Asphalt Mix Tonnage

Companies responding: 5

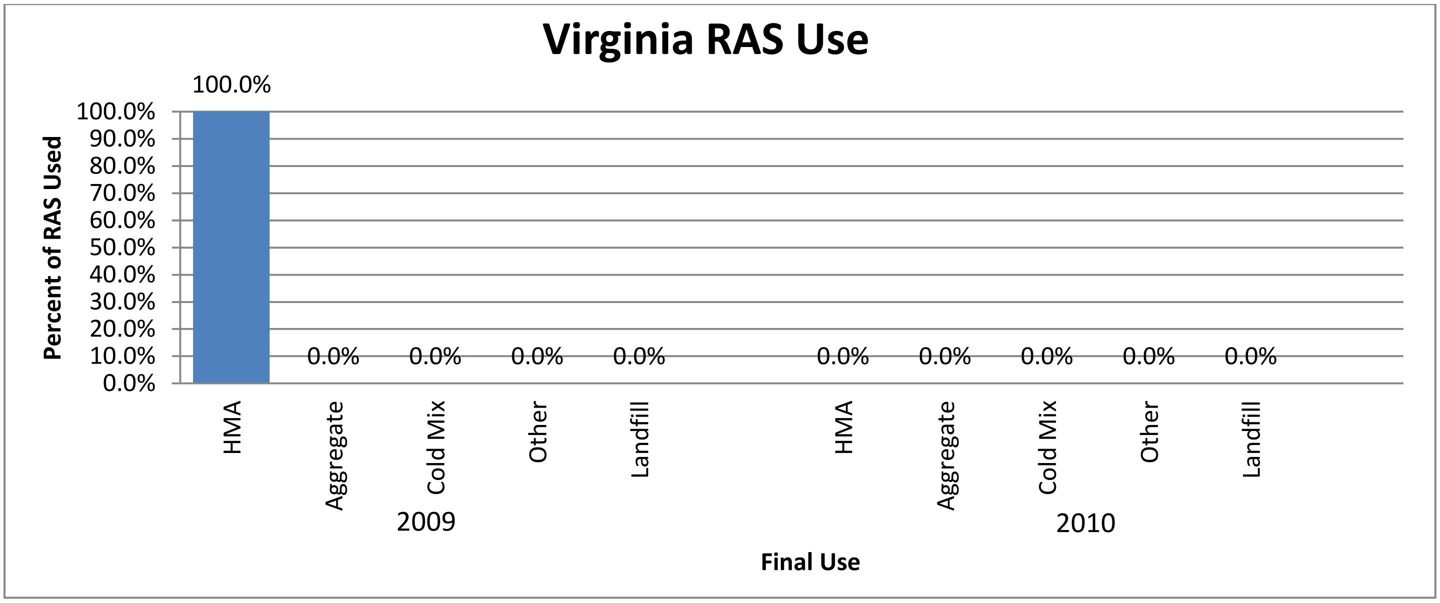


Total tonnage provided by the Virginia Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

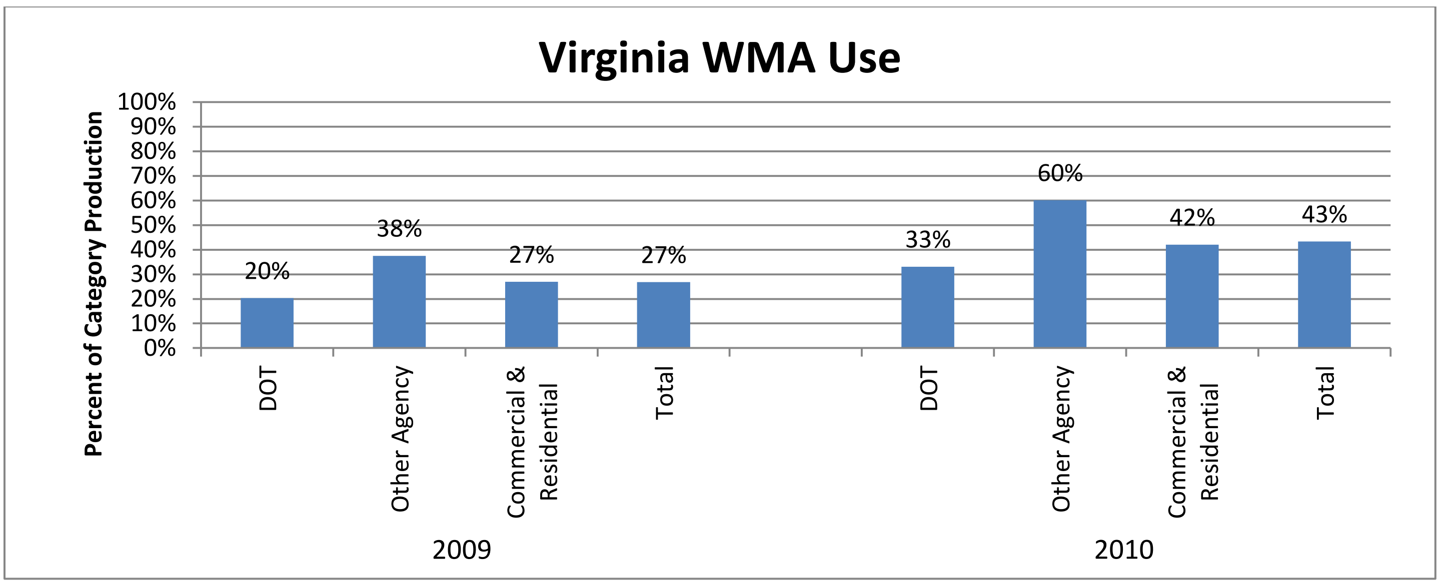


Table B 48: Summary of Virginia Data — Companies Reporting 5

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	1,695,958	1,776,316	3,327,984	4,296,582
Total Other Agency Tonnage	990,983	1,194,602	1,944,609	2,889,522
Total Commercial & Residential Tonnage	1,950,467	1,535,419	3,827,407	3,713,896
Total Tonnage	4,637,408	4,506,337	9,100,000	10,900,000

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	1,087,424	1,493,766	2,133,855	3,016,479
RAP Tons used in HMA/WMA	990,653	1,255,837	1,943,962	2,536,010
RAP Tons used as Aggregate	19,200	29,530	37,676	59,632
RAP Tons used in Cold Mix	1	-	2	-
RAP Tons used as Other	1	-	2	-
RAP Tons Landfilled	11	15	21	30
Average % RAP in DOT Mixes	22%	25%		
Average % RAP in Other Agency Mixes	27%	28%		
Average % RAP in Commercial & Residential Mixes	25%	28%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	20%	0%		
RAS Tons Received	2,003	-	3,930	-
RAS Tons used in HMA/WMA	1,503	-	2,949	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	2%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	100%		
WMA DOT Tonnage	344,500	588,138	676,013	1,187,673
WMA Other Agency Tonnage	372,000	718,341	729,977	1,450,602
WMA Commercial & Residential Tonnage	525,178	645,110	1,030,558	1,302,722
Total WMA Tonnage	1,241,678	1,951,589	2,436,548	3,940,997
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	100%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

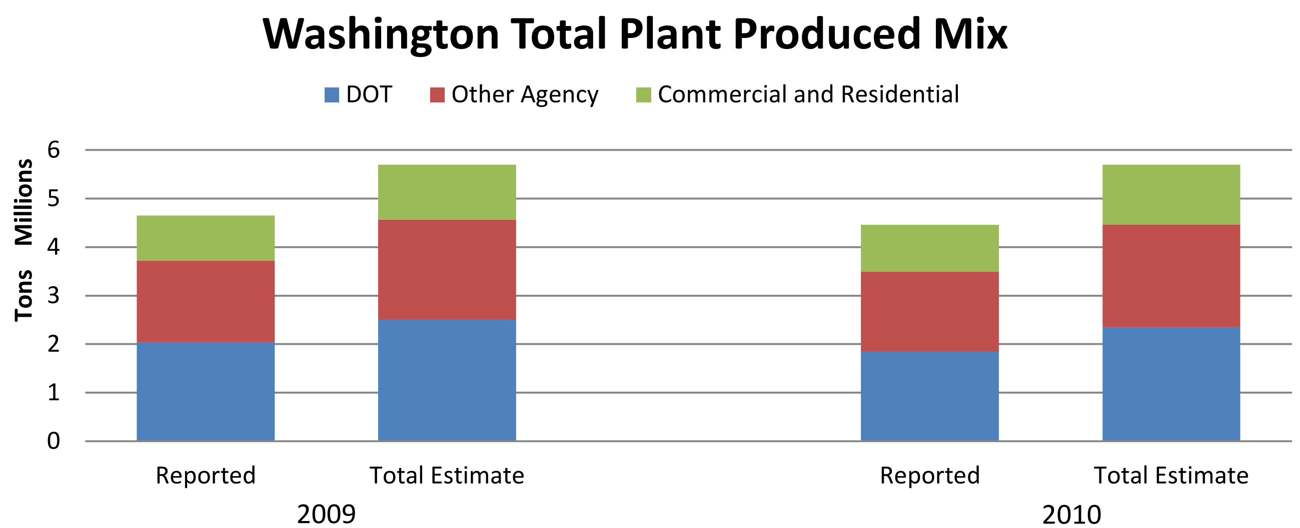
1. Total tonnage provided by the Virginia Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

Washington

Table B49 summarizes the results received from asphalt mix producers in Washington. The charts are used to summarize information calculated from information provided by the survey respondents.

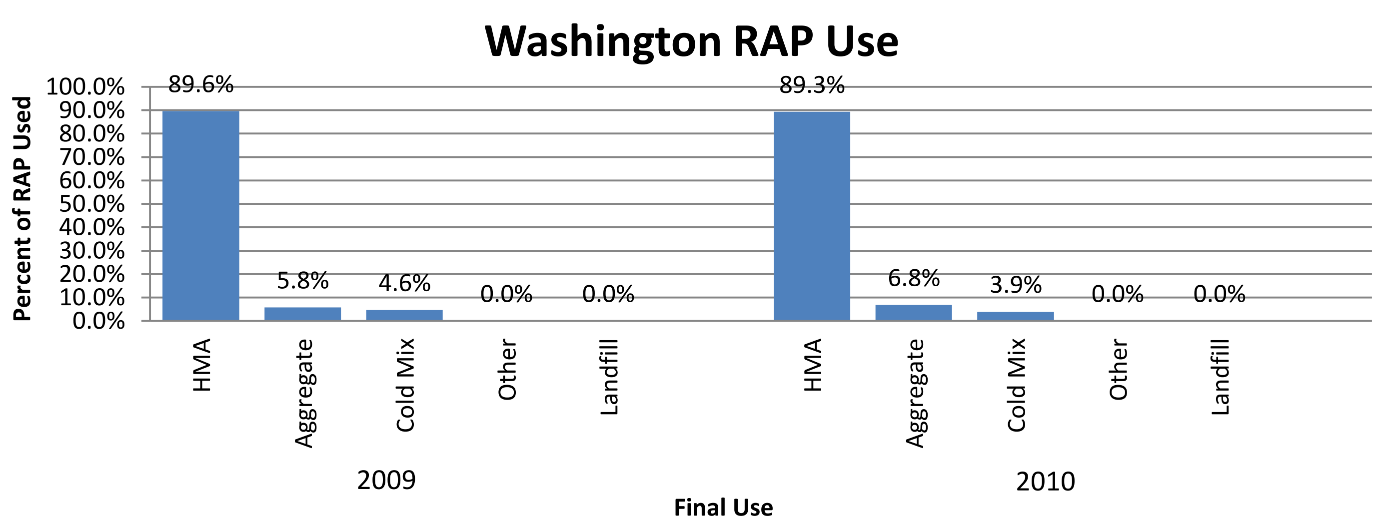
Total Asphalt Mix Tonnage

Companies responding: 6

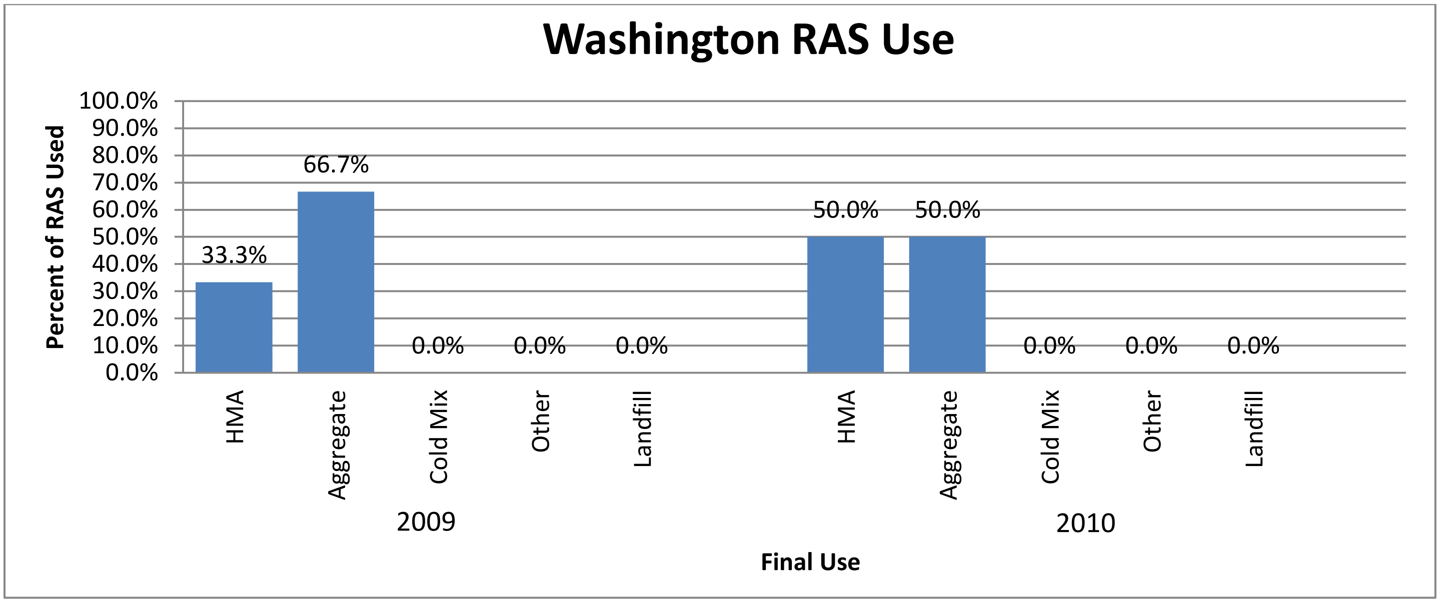


Total tonnage provided by the Washington Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

RAP Use



RAS Use



WMA Use

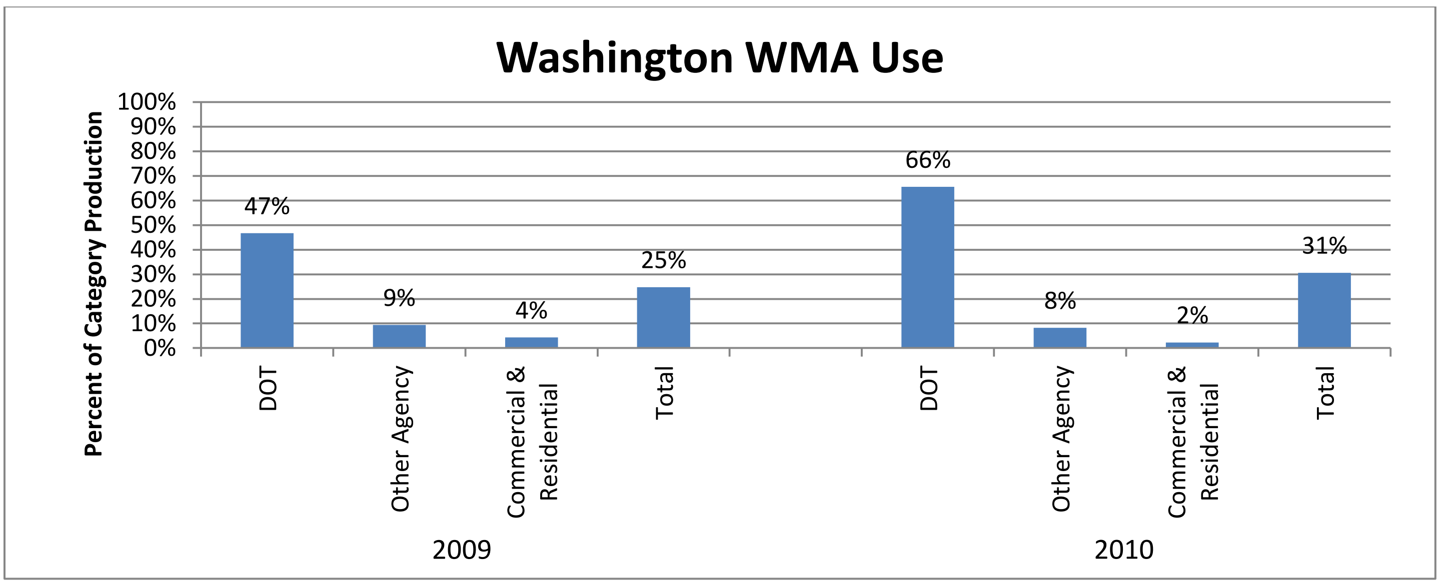


Table B 49: Summary of Washington Data Companies Reporting 6

HMA/WMA				
	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	2,042,031	1,841,321	2,503,675	2,354,053
Total Other Agency Tonnage	1,681,673	1,652,877	2,061,851	2,113,135
Total Commercial & Residential Tonnage	925,293	964,295	1,134,475	1,232,812
Total Tonnage	4,648,996	4,458,493	5,700,000	5,700,000
Reclaimed Asphalt Pavement (RAP)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	837,500	435,900	1,026,835	557,280
RAP Tons used in HMA/WMA	832,841	710,026	1,021,123	907,739
RAP Tons used as Aggregate	53,516	54,000	65,614	69,037
RAP Tons used in Cold Mix	43,000	31,000	52,721	39,632
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	31	34	38	43
Average % RAP in DOT Mixes	16%	18%		
Average % RAP in Other Agency Mixes	16%	15%		
Average % RAP in Commercial & Residential Mixes	16%	18%		
Reclaimed Asphalt Shingles (RAS)				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	17%	17%		
RAS Tons Received	7,500	5,000	9,196	6,392
RAS Tons used in HMA/WMA	2,500	2,500	3,065	3,196
RAS Tons used as Aggregate	5,000	2,500	6,130	3,196
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	1%	0%		
Warm-Mix Asphalt				
	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	33%	67%		
WMA DOT Tonnage	953,115	1,206,108	1,168,587	1,541,959
WMA Other Agency Tonnage	157,697	136,188	193,348	174,111
WMA Commercial & Residential Tonnage	39,713	22,153	48,691	28,322
Total WMA Tonnage	1,150,525	1,364,449	1,410,626	1,744,391
Percent WMA Tons using Chemical Additives	3%	0%		
Percent WMA Tons using Additive Foaming	1%	0%		
Percent WMA Tons using Plant Foaming	97%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

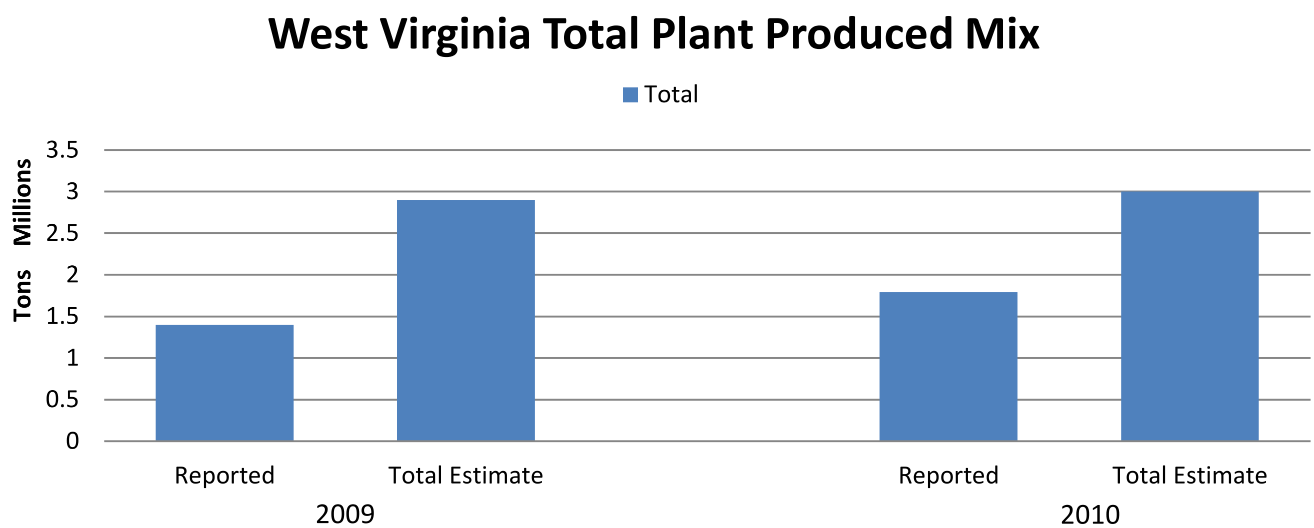
1. Total tonnage provided by the Washington Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based on ratios from reported tons.

West Virginia

Table B50 summarizes the results received from asphalt mix producers in West Virginia. The charts are used to summarize information calculated from information provided by the survey respondents.

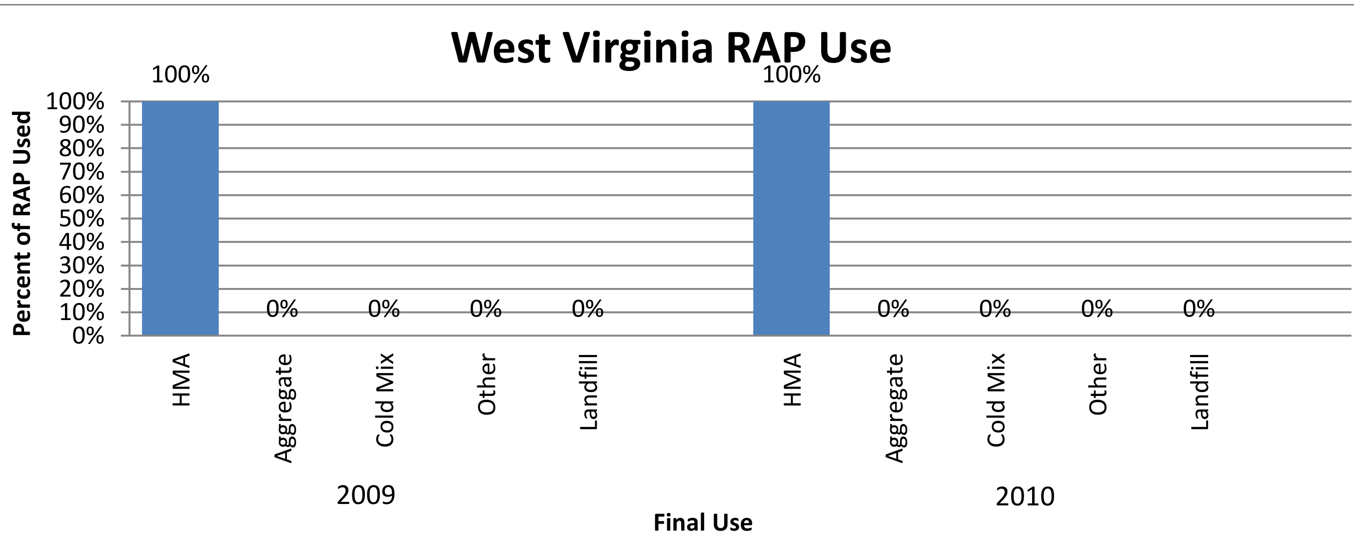
Total Asphalt Mix Tonnage

Companies responding: 8

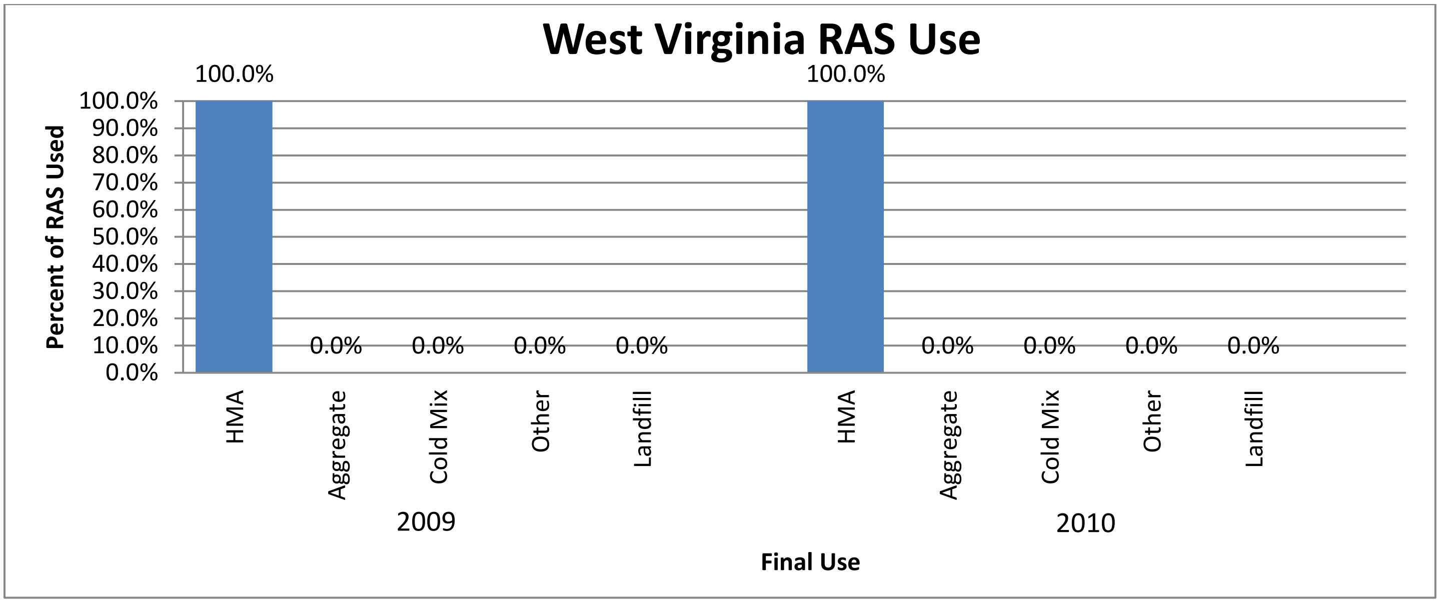


Total tonnage provided by the West Virginia Asphalt Pavement Association. No data is available on the split in tonnage between DOT, Other Agency, and Commercial and Residential

RAP Use



RAS Use



WMA Use

No contractor reported usin WMA in 2009 or 2010.

Table B 50: Summary of West Virginia Data — Companies Reporting 1

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	-	-	-	-
Total Other Agency Tonnage	-	-	-	-
Total Commercial & Residential Tonnage	-	-	-	-
Total Tonnage	1,399,092	1,789,000	2,900,000	3,000,000

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	-	-	-	-
RAP Tons used in HMA/WMA	140,265	193,549	290,738	324,566
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	10	11	21	18
Average % RAP in DOT Mixes	0%	0%		
Average % RAP in Other Agency Mixes	0%	0%		
Average % RAP in Commercial & Residential Mixes	0%	0%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	100%	0%		
RAS Tons Received	5,000	-	10,364	-
RAS Tons used in HMA/WMA	2,447	219	5,072	367
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	100%	100%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

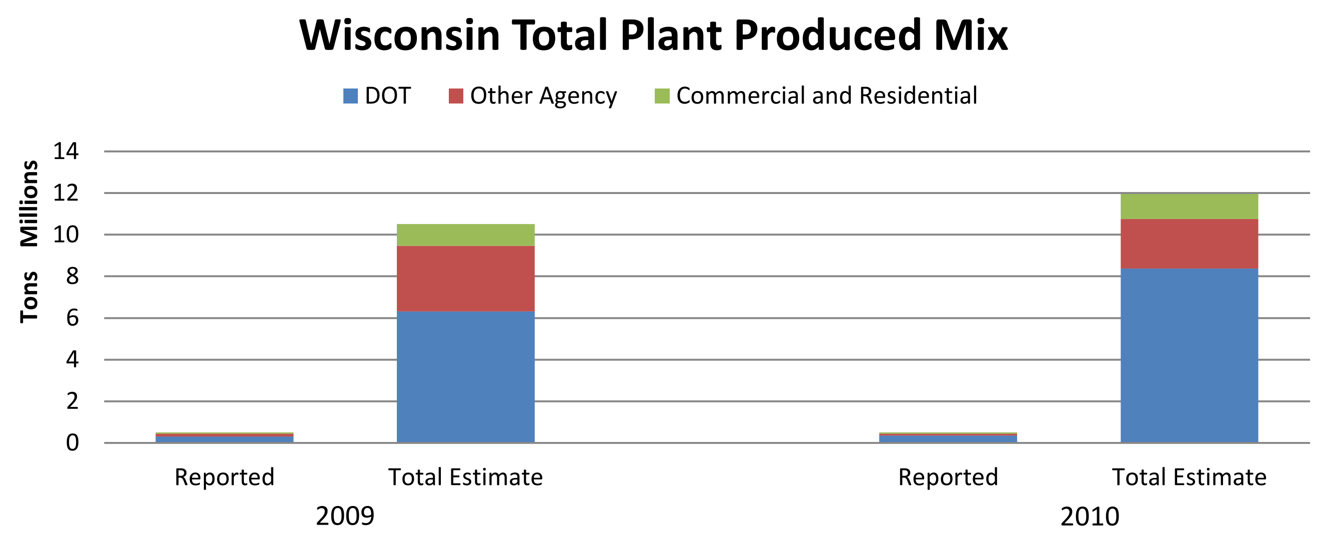
1. Total tonnage provided by the West Virginia Asphalt Pavement Association.

Wisconsin

Table B51 summarizes the results received from asphalt mix producers in Wisconsin. The charts are used to summarize information calculated from information provided by the survey respondents.

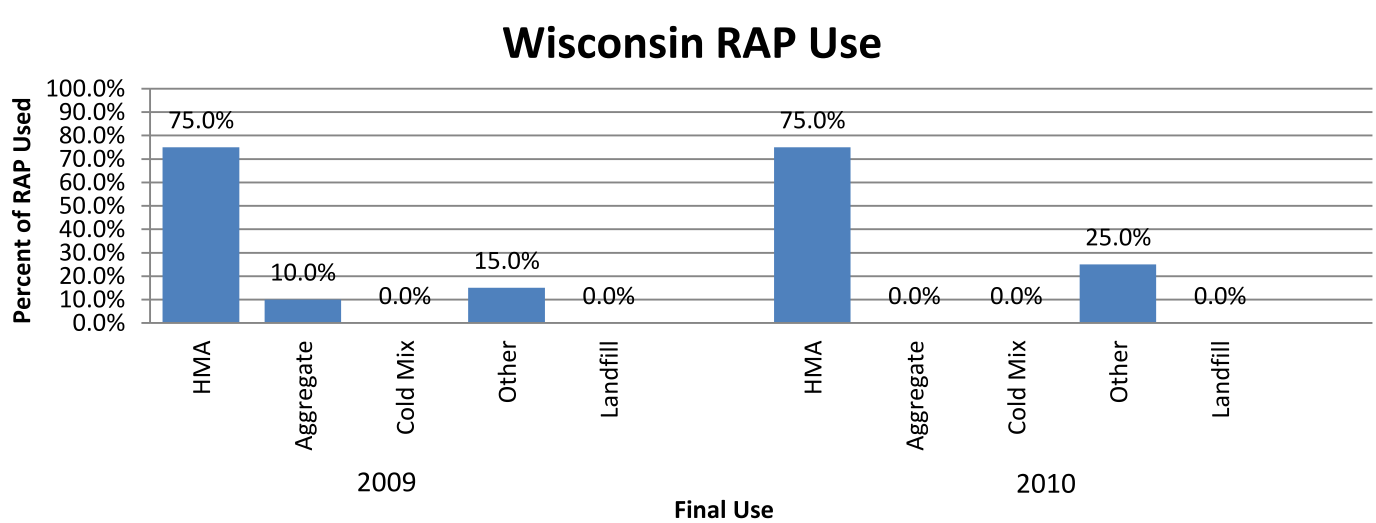
Total Asphalt Mix Tonnage

Companies responding: 1



Total tonnage provided by the Wisconsin Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential based ratios from reported tons.

RAP Use



RAS Use

The contractor did not report any RAS use in 2009 or 2010.

WMA Use

The contractor did not report any WMA use in 2009 0r 2010.

Table B 51: Summary of Wisconsin Data — Companies Reporting 1

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	300,000	350,000	6,310,800	8,370,541
Total Other Agency Tonnage	150,000	100,000	3,155,400	2,391,583
Total Commercial & Residential Tonnage	50,000	50,000	1,051,800	1,195,792
Total Tonnage	500,000	500,000	10,518,000	11,957,915

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	100,000	100,000	2,103,600	2,391,583
RAP Tons used in HMA/WMA	75,000	75,000	1,577,700	1,793,687
RAP Tons used as Aggregate	10,000	-	210,360	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	15,000	25,000	315,540	597,896
RAP Tons Landfilled	-	-	-	-
Average % RAP in DOT Mixes	20%	20%		
Average % RAP in Other Agency Mixes	20%	20%		
Average % RAP in Commercial & Residential Mixes	15%	15%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	0%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	-	-	-
WMA Commercial & Residential Tonnage	-	-	-	-
Total WMA Tonnage	-	-	-	-
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	0%		
Percent WMA Tons using Organic Additive	0%	0%		

1. Total tonnage provided by the Wisconsin Asphalt Pavement Association. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.

The Wisconsin Asphalt Pavement Association also estimated tonnage based on information available to them which is included in the Alternate Table 1 below:

Alternate Table 1: Wisconsin APA Estimate of Survey Data

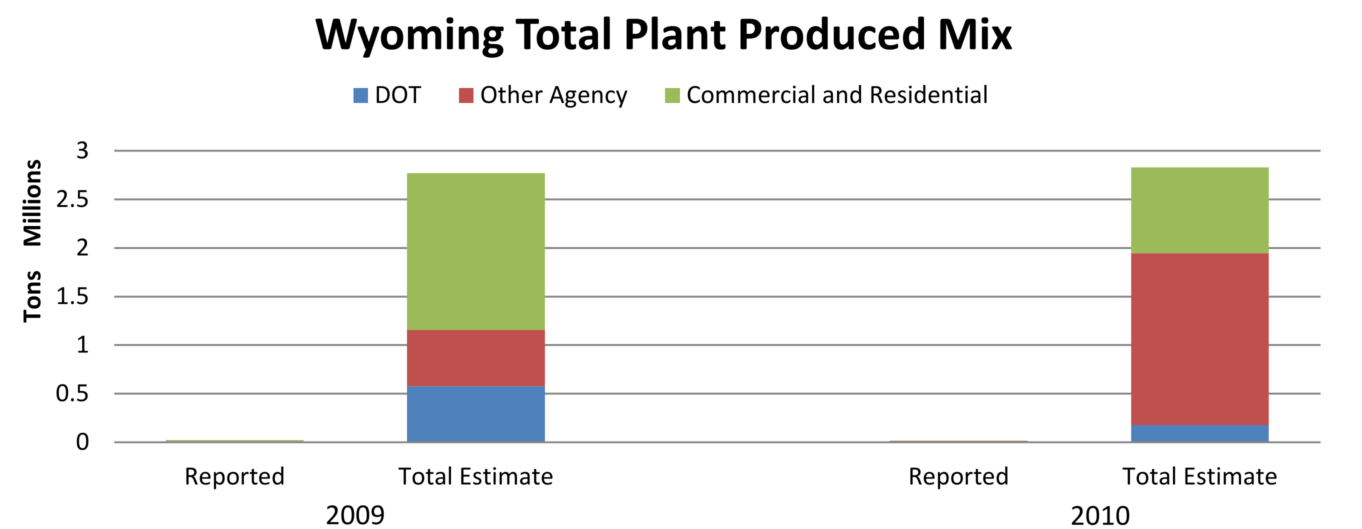
HMA/WMA		
	Total Estimated	
	2009	2010
Total DOT Tonnage	2,924,764	4,792,389
Total Other Agency Tonnage	6,521,476	7,387,611
Total Commercial & Residential Tonnage	1,072,270	1,820,000
Total Tonnage	10,518,510	14,000,000
Reclaimed Asphalt Pavement (RAP)		
	Total Estimated	
	2009	2010
Percent Companies using RAP	98%	98%
RAP Tons Received	2,629,628	3,500,000
RAP Tons used in HMA/WMA	2,103,370	3,095,505
RAP Tons used as Aggregate	52,592	35,000
RAP Tons used in Cold Mix	78,888	105,000
RAP Tons used as Other	5,000	6,000
RAP Tons Landfilled	1,000	1,500
Average % RAP in DOT Mixes	18%	20%
Average % RAP in Other Agency Mixes	23%	24%
Average % RAP in Commercial & Residential Mixes	20%	20%
Reclaimed Asphalt Shingles (RAS)		
	Total Estimated	
	2009	2010
Percent Companies using RAS	79%	80%
RAS Tons Received	368,148	490,000
RAS Tons used in HMA/WMA	198,879	279,259
RAS Tons used as Aggregate	-	-
RAS Tons used in Cold Mix	-	-
RAS Tons used as Other	-	-
RAS Tons Landfilled	-	-
Average % RAS in DOT Mixes	3.5%	3.5%
Average % RAS in Other Agency Mixes	3.5%	3.5%
Average % RAS in Commercial & Residential Mixes	3.5%	3.5%
Warm-Mix Asphalt		
	Total Estimated	
	2009	2010
Percent Companies using WMA	65%	77%
WMA DOT Tonnage	350,971	797,453
WMA Other Agency Tonnage	1,173,866	1,920,779
WMA Commercial & Residential Tonnage	128,672	364,000
Total WMA Tonnage	1,653,509	3,082,232
Percent WMA Tons using Chemical Additives	0%	0%
Percent WMA Tons using Additive Foaming	20%	35%
Percent WMA Tons using Plant Foaming	5%	10%
Percent WMA Tons using Organic Additive	75%	55%

Wyoming

Table B52 summarizes the results received from asphalt mix producers in Wymoming. The charts are used to summarize information calculated from information provided by the survey respondents.

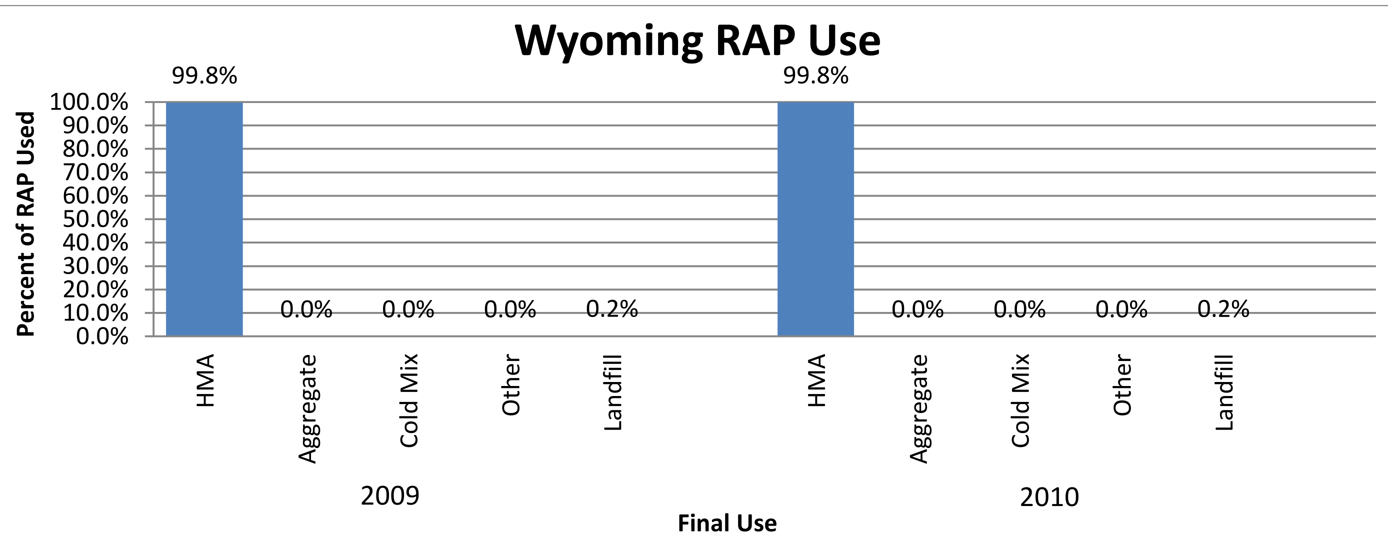
Total Asphalt Mix Tonnage

Companies responding: 2



Total tons extimated based on relationship of tons to Federal Apportionment.   Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons. Total reported tonnage includes one company/branch that did not break out tonnages by different uses.

RAP Use



RAS Use

No contractor reported using RAS in 2009 or 2010.

WMA Use

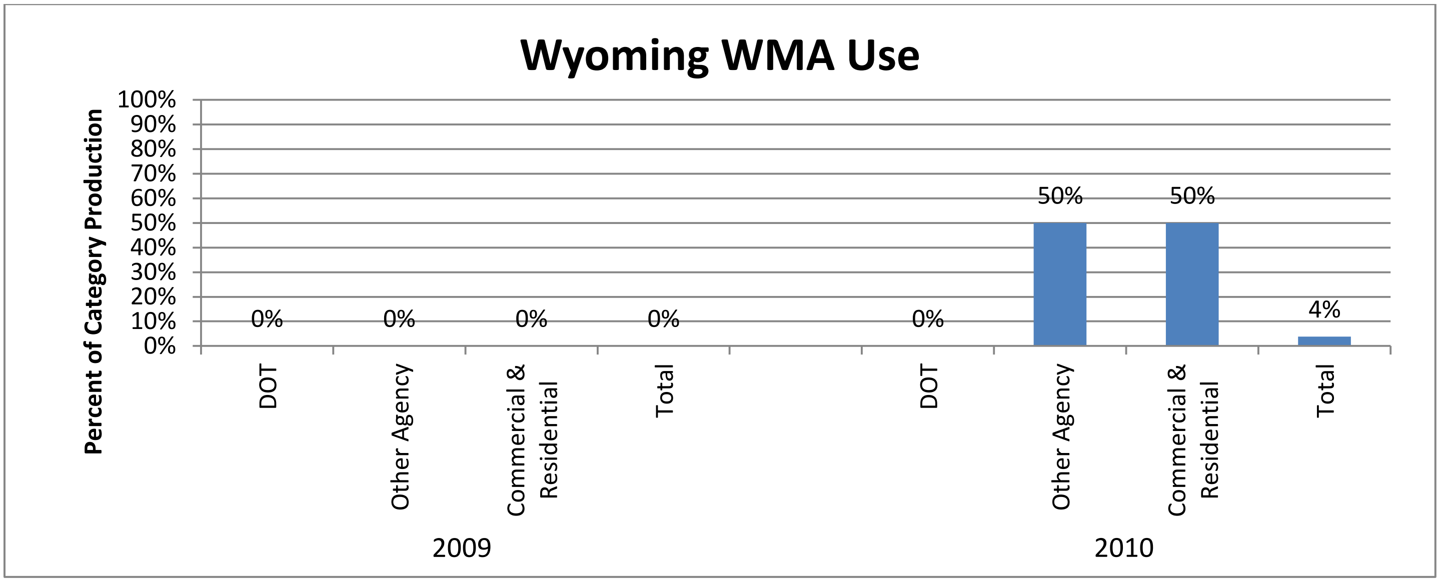

Wyoming WMA Use
Percent of Category Production
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
0%
0%
0%
0%
50%
50%
4%
DOT
Other Agency
Commercial & Residential
Total
DOT
Other Agency
Commercial & Residential
Total
2009
2010

Table B 52: Summary of Wyoming Data — Companies Reporting 2

HMA/WMA

	Reported		Total Estimated[1]	
	2009	2010	2009	2010
Total DOT Tonnage	5,000	1,000	577,221	176,836
Total Other Agency Tonnage	5,000	10,000	577,221	1,768,362
Total Commercial & Residential Tonnage	14,000	5,000	1,616,219	884,181
Total Tonnage[2]	151,000	197,000	2,770,661	2,829,380

Reclaimed Asphalt Pavement (RAP)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAP	100%	100%		
RAP Tons Received	3,000	4,000	55,046	57,449
RAP Tons used in HMA/WMA	8,694	9,646	159,525	138,537
RAP Tons used as Aggregate	-	-	-	-
RAP Tons used in Cold Mix	-	-	-	-
RAP Tons used as Other	-	-	-	-
RAP Tons Landfilled	20	16	362	224
Average % RAP in DOT Mixes	0%	0%		
Average % RAP in Other Agency Mixes	15%	11%		
Average % RAP in Commercial & Residential Mixes	15%	11%		

Reclaimed Asphalt Shingles (RAS)

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using RAS	0%	0%		
RAS Tons Received	-	-	-	-
RAS Tons used in HMA/WMA	-	-	-	-
RAS Tons used as Aggregate	-	-	-	-
RAS Tons used in Cold Mix	-	-	-	-
RAS Tons used as Other	-	-	-	-
RAS Tons Landfilled	-	-	-	-
Average % RAS in DOT Mixes	0%	0%		
Average % RAS in Other Agency Mixes	0%	0%		
Average % RAS in Commercial & Residential Mixes	0%	0%		

Warm-Mix Asphalt

	Reported		Total Estimated	
	2009	2010	2009	2010
Percent Companies using WMA	0%	50%		
WMA DOT Tonnage	-	-	-	-
WMA Other Agency Tonnage	-	5,000	-	884,181
WMA Commercial & Residential Tonnage	-	2,500	-	442,091
Total WMA Tonnage	-	7,500	-	1,326,272
Percent WMA Tons using Chemical Additives	0%	0%		
Percent WMA Tons using Additive Foaming	0%	0%		
Percent WMA Tons using Plant Foaming	0%	100%		
Percent WMA Tons using Organic Additive	0%	0%		

1. Total tons estimated based on relationship of tons to Federal Apportionment. Total tonnage for DOT, Other Agency and Commercial & Residential ratios from reported tons.
2. Total reported tonnage includes one company/branch that did not break out tonnages by different uses.