Increasing the Use of Reclaimed Asphalt Pavement (RAP) in United States Highway Pavements: A National Effort

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ABSTRACT: The Federal Highway Administration (FHWA), along with industry partners, support use of recycled highway materials in pavement construction in an effort to preserve the natural environment, reduce waste, and provide a cost effective material for constructing highways. FHWA's policy is recycling and reuse of existing highway materials can offer engineering, economic and environmental benefits and recycled materials should get first consideration in materials selection.

One of the greatest value added measures available to highway agencies is increasing the use of Reclaimed Asphalt Pavement (RAP) in the construction and rehabilitation of asphalt pavements. However, many highway agencies in the United States (US) have specifications that limit the amount of RAP used in certain asphalt pavement layers or mixture types. An objective established by FHWA is to encourage the use of RAP in the construction of flexible pavement highways to the maximum economical and practical extent possible with equal or improved performance.

This paper will discuss FHWA's research and implementation programs to increase the successful use of RAP in the United States. The purpose is to provide information to the international community and stimulate synchronization for the proper testing, evaluation, and use of RAP materials. Specific topics include contributing factors for increased RAP use, the level of RAP use in the US and information on FHWA-sponsored research and activities to improve testing, mixture design, analysis of RAP materials and performance of recycled asphalt pavements.

KEY WORDS: United States Federal Highway Administration (FHWA), Reclaimed Asphalt Pavement (RAP), recycled pavements, recycled asphalt technology

1 INTRODUCTION

In 2006 and again in 2008 sharp rises in asphalt costs coupled with diminishing supplies of quality aggregate stimulated increased use of Reclaimed Asphalt Pavement (RAP) in the United States (US) asphalt paving industry. The most economical use of RAP is as a binder and aggregate source in new HMA. State and local highway agencies are seriously considering the economic and environmental benefits of allowing high percentages of RAP in

asphalt mixtures for flexible pavements. FHWA has defined high RAP asphalt mixtures as mixtures that contain percentages of RAP over 25% by weight of the mix.

The urgency towards "Green" technology and sustainable pavements, including the use of recycled materials, is driven by stricter environmental regulations. One of the primary challenges facing highway agencies is ensuring proper use of high RAP while maintaining a quality, well-performing pavement infrastructure. Despite over thirty years of RAP use in HMA, questions remain on the correct approach for designing HMA with high percentages of RAP. This paper will discuss the factors contributing to the increased interest in RAP use, previous efforts, the current level of RAP use, and current nationally coordinated efforts to increase RAP use.

2 FACTORS CONTRIBUTING TO INCREASED RAP USE IN THE UNITED STATES

The cost of highway construction has outpaced all other forms of construction in the US since 2004 and has risen about fifty-one percent from 2003 to 2009. The US highway network is mature and there is little additional capacity being built. Funds are currently spent mostly on replacement and rehabilitation of existing pavements. In addition, high quality new materials are becoming scarcer. Due to these factors, there is a significant economic drive to incorporate recycled materials in the construction of HMA pavements.

2.1 Impact of Rising Material and Fuel Costs

Approximately 93% of the US highway system is built with HMA. The cost for construction and rehabilitation of asphalt pavements is dependent on the volatile prices for petroleum products. Diesel fuel and asphalt both come from crude oil. According to the US domestic Producer Price Index (PPI), a measure of the change in average cost for materials, crude oil has experienced average annual changes from -57.7% to +60.6% for the years 2002 to 2008. This indicates the highly variable prices in the market. From 2003 to 2009 the price of crude oil increased from $100 per unit to $240.1 per unit (Simonson 2009(a)). Figure 1 shows the percentage change in the PPI for 2002 to 2008.

There was a large reduction in crude oil prices at the end of 2008, but the extent of this reduction did not carry over to asphalt prices as seen in Figure 2, which shows the PPI for asphalt paving mixtures and blocks from 2007 through October 2009. It is not expected that the price will decline to 2007 levels. In fact, asphalt production has decreased due to the increased price for higher-value products such as gasoline, diesel, and jet fuel, improvements in the refining process, and the installation of cokers.

2.2 Binder Supply Issues

The number of refineries continues to decline and existing refineries are producing less asphalt as improvements to the refining process allows the production of more profit yielding products such as fuel oil. As the supply has decreased, the global demand for asphalt has risen.

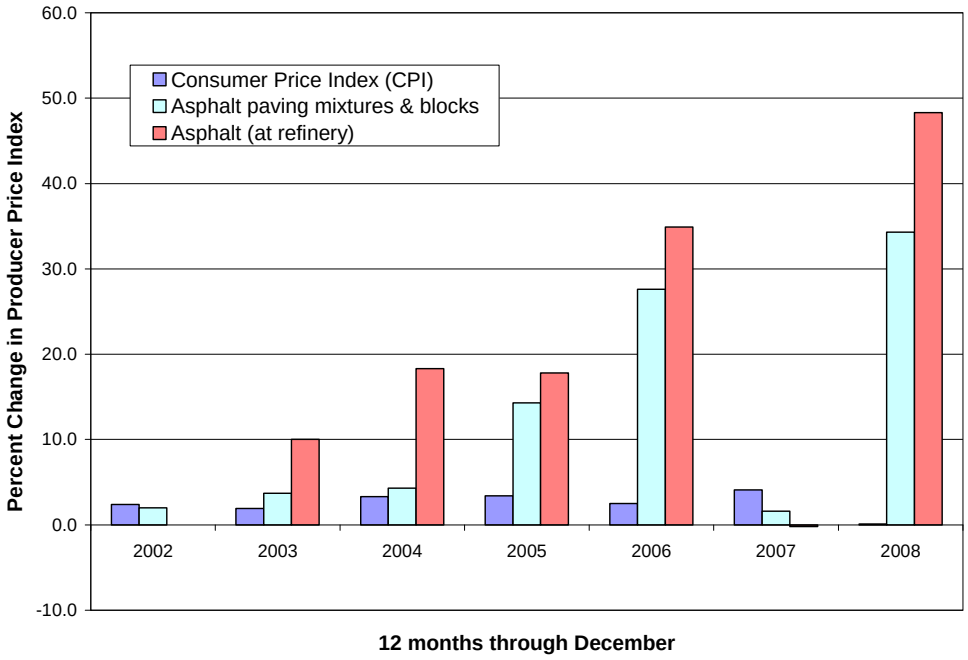


Figure 1: Percent Change in Producer Price Index (PPI) from 2002 to 2008

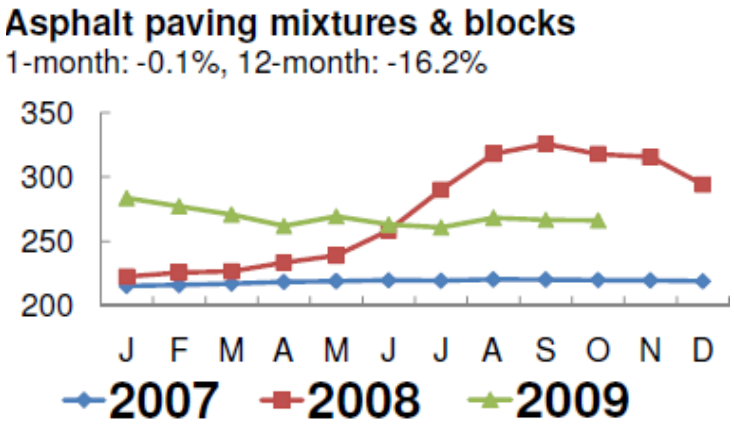


Figure 2: Producer Price Index (PPI) Values from January 2007 to October 2009 (Simonson 2009(b))

2.3 Aggregate Shortages

The demand for high quality aggregates has increased while sources are limited due to urban growth and environmental regulations. Due to availability issues, the aggregate in RAP is a cost-effective alternative to using all virgin aggregate. In addition, RAP aggregate is coated with asphalt binder allowing a lesser amount of virgin binder to be used. Fortunately, the existing highway system that is in need of rehabilitation and reconstruction is also a source of quality materials such as asphalt binder and aggregates that can be re-used

3 INCORPORATION OF RECLAIMED ASPHALT PAVEMENTS IN THE SUPERPAVE SYSTEM

RAP has been successfully used by highway agencies for many years until implementation of the Superpave mixture design method in the late 1990s. At the time Superpave was implemented, the Strategic Highway Research Program (SHRP) did not provide guidance for the use of RAP in HMA. Further, the Superpave mix design system included gradation requirements that encouraged the use of coarse-graded mixtures, which in many cases restricted the amount of RAP that could be used in the mix. Many highway agencies stopped allowing the use of high amounts of RAP in order to minimize variability during implementation of the Superpave system with virgin materials. Thus, the use of RAP dramatically declined. In addition, the cost to handle large amounts of RAP outweighed the cost of virgin materials providing marginal economic incentive for using RAP.

Since 2005, Superpave has become standard practice for binder performance grading and volumetric mixture design in the US. Guidelines for using RAP in Superpave mix designs were developed and validated under National Cooperative Highway Research Program (NCHRP) Project 9-12 *Incorporation of Reclaimed Asphalt Pavement in the Superpave System* (McDaniel and Anderson 2001). The current guidelines used in Superpave mix design are given in Table 1.

Recently, with increased RAP use, there has been increased scrutiny of these guidelines. First, the guidelines are based on the assumption that significant blending occurs between the virgin and RAP binder and the effects of plant production and RAP processing (e.g. fractionation) is unknown. Second, the binder grade change requires softer binders for amounts of RAP over 15% which may be more expensive and/or more difficult to obtain than the highway agency's standard binder. Finally, for high RAP use, blending charts are required to determine the virgin binder PG. Blending charts require extraction and recovery procedures that are time-consuming and require the use of hazardous solvents. Many highway agencies are reluctant to specify amounts of RAP that require this additional testing and, further, many contractors may not be equipped to perform binder extraction and recovery tests that involve hazardous solvents.

Table 1: Binder Selection Guidelines for Reclaimed Asphalt Pavement (RAP) Mixtures (AASHTO 2007)

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	< 15
Select virgin binder one grade softer than normal (e.g., select a PG58-28 if a PG64-22 would normally be used)	15-25
Follow recommendations from blending charts*	>25

* Procedure for developing a blending chart is provided in the appendix of AASHTO M 323.

4 LEVEL OF ASPHALT RECYCLING IN THE US

One of the greatest value-added measures available to highway agencies today is increasing the RAP in the construction and rehabilitation of asphalt pavements. However, many highway agencies in the US have specifications that limit the amount of RAP used in certain asphalt pavement layers or mixture types. A 2007 survey sponsored by the American Association of State Highway and Transportation Officials (AASHTO) and FHWA was conducted among all fifty states and Ontario, Canada (Jones 2008). The following questions were posed:

1) How much RAP is allowed or permitted in HMA mixtures?
2) How much RAP is actually used in HMA?
3) What are the main roadblocks to greater usage of RAP?

The majority of State highway agency specifications allow the use of RAP in HMA mixtures, with the average rate of use estimated at twelve percent. Moreover, RAP is typically permitted in subsurface, base and shoulder mixtures, but is restricted in surface/wearing courses. Very few States have restrictions of little or no RAP due to concerns regarding performance.

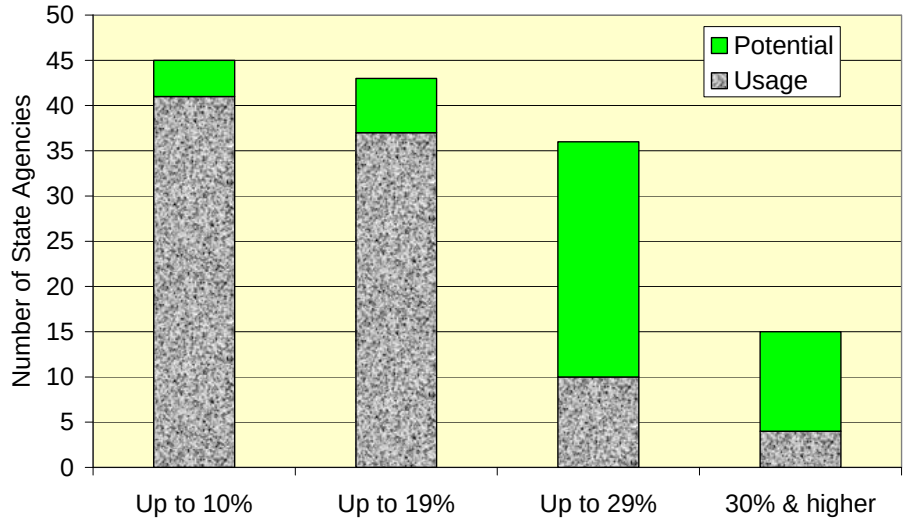
Figure 3 shows that the majority of State highway agencies are comfortable using up to 19% RAP in HMA. For RAP amounts over twenty percent, the survey results show a stark contrast between what State highway agencies permit (the potential amount of RAP that can be used) and how much RAP is actually being used. Less than ten State highway agencies regularly use between 20% and 29% RAP and less than five State highway agencies use more than 30% RAP even though more than thirty-five State highway agencies allow up to 29% RAP in the intermediate layer and twenty State highway agencies allow up to 29% RAP in the surface layer. Essentially, over 60% of State highway agencies permit high RAP in the intermediate and surface layers; however about 25% actually use high RAP in the intermediate and surface layers.

The most common barriers to using more RAP according to the 2007 survey were lack of specifications, lack of processing or high variability of RAP, poor past experiences, and concerns about RAP availability. US State highway agencies use AASHTO M 323 *Standard Specification for Superpave™ Volumetric Mix Design* for guidelines on using RAP in asphalt mix design; however there is currently no specification solely dedicated to incorporating RAP, especially in higher percentages, in the design of asphalt mixtures.

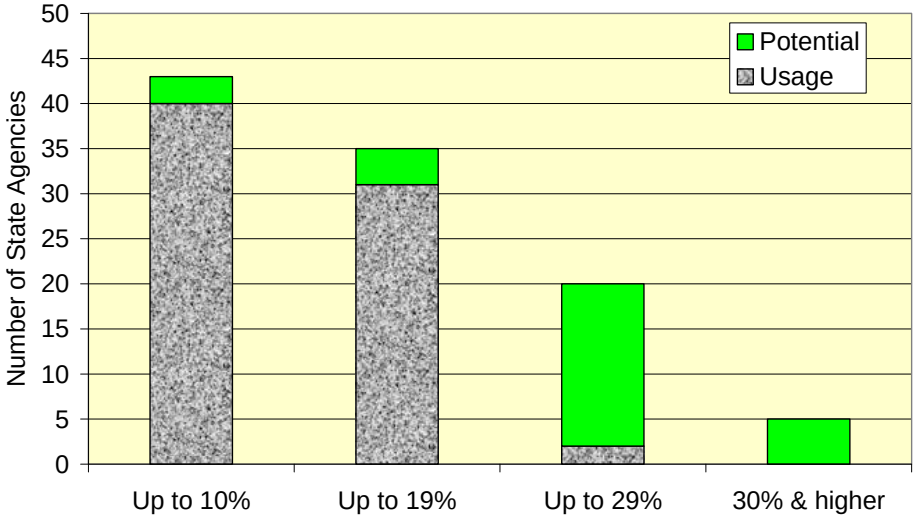
Another primary concern when using RAP is the perceived inherent variability in the material. Without proper processing or production techniques, this variability is compounded when high amounts of RAP are used. This may have led to a few isolated experiences with poor performing pavements that used RAP. Finally, there is concern that with an increase in the amount of RAP (e.g. over forty percent) used in HMA that supply of RAP may become an issue, particularly in rural areas.

4.1 Remaining Challenges

There are two primary obstacles that limit or preclude the use of RAP in HMA, especially in higher percentages. First, several State highway agencies are concerned that the use of RAP with polymer modified binders may reduce the qualities of the polymer-modified virgin binder. Second, high amounts of RAP may affect binder properties resulting in an “overly stiff” mix that may experience low-temperature cracking. There is also concern that for pavements experiencing high deflections, an “overly stiff” mix may not be as resilient and crack prematurely. A softer virgin binder may be required in order to account for additional stiffness due to the aged RAP binder, but State highway agencies want guidance on when and how to select a softer virgin binder.



(a)



(b)

Figure 3: Survey Results Indicating the Number of State Highway Agencies Using a Given Percentage of RAP and Permitting a Given Percentage of RAP in the (a) Intermediate Layer and (b) Surface Layer

Along with concerns about the cracking performance of high RAP mixes, on-going concerns include the durability of higher percentage RAP mixes used in the surface layer, especially in regards to raveling. Other concerns include the presence of dust in RAP making it difficult to meet the fine aggregate to binder ratio, the consistency/variability of RAP, and lack of Quality Control (QC) by the contractor.

5 NATIONAL EFFORTS TO INCREASE RAP USE

There are three key requirements that must be satisfied for acceptance of and to further increase asphalt pavement recycling. Recycled asphalt pavements must i.) be cost effective, ii.) perform well, and iii.) be environmentally responsible. In order to satisfy these requirements, the FHWA has identified the following specific objectives to encourage asphalt pavement recycling:

- Encourage the use of recycled material in the construction of highways to the maximum economical and practical extent possible with equal or improved performance;
- Promote the use of RAP because the utilization of RAP can have the greatest economic, environmental, and engineering impact in HMA pavements.

Specific goals include increasing the amount of highway construction and rehabilitation projects that use RAP and to increase the amount of RAP used in specific projects. In order to meet these objectives, three overarching tasks were identified:

i.) establishment of a public and industry working group;
ii) funded, coordinated research and demonstration projects; and
iii) research deployment and technology transfer for information dissemination and education.

A brief description of each task and progress follows.

5.1 Organization and Facilitation of Recycled Asphalt Pavements Expert Task Group

In order to promote best practices for increased RAP use, FHWA initiated an Asphalt Pavement Recycling Expert Task Group (ETG) referred to as the RAP ETG. The purpose of the RAP ETG is to provide the needed technical input to advance the use of reclaimed or recycled asphalt materials in asphalt paving applications by providing highway agencies with critical information regarding the use of RAP, technical guidance on research and high-RAP projects, and monitoring the implementation of findings. The ETG is comprised of experts on the use of RAP in asphalt paving mixtures from FHWA and other federal highway agencies, State highway agencies, industry, and academia and has a dedicated website at www.moreRAP.us.

The RAP ETG's first goal was to identify the most critical needs related to increasing RAP usage. The RAP ETG formulated the top 10 needs, shown in Figure 4. The RAP ETG has formed task groups to target each need and meets twice a year to discuss progress. For example, one task group has developed information for highway agencies and contractors interested in increasing their RAP use. A joint publication of FHWA, AASHTO and National Asphalt Pavement Association (NAPA) is available for designing and producing high RAP mixtures. The guide provides guidance for materials evaluation, mix design, plant verification, and QC when using high RAP (NAPA 2007). Another task group has developed a best practices document summarizing the state-of-the-practice for RAP use which will provide in-depth guidelines for incorporating RAP in asphalt mixtures. The document is in the final draft and will be published as an FHWA report. Another task group is documenting field performance of RAP mixtures by analyzing the Long Term Pavement Performance (LTPP) database and mining State highway agency Pavement Management Systems for performance information comparing pavements with RAP to pavements with little or no

RAP. So far, unpublished results indicate that performance is not a function of RAP content and, the majority of times, RAP mixtures perform as well or better than the virgin mixtures.

The Top 10 Needs for Increased RAP Use

1. Performance test(s) for evaluating RAP mixtures
2. Best practices for mix design and construction, including advantages of RAP and guidelines for producing a quality mix with varying levels of RAP
3. Ability to characterize RAP without hazardous solvents
4. Determining necessary binder grade changes
5. Determining amount of co-mingling between binders (RAP/virgin) in plants
6. Field performance data on high RAP mixtures
7. Ability to replicate plant heating in laboratory
8. Assist States with no or low percent RAP specifications with current practices
9. Improved understanding of variability of RAP – (aggregate, binder content, modification, binder characterization)
10. Better understanding of RAP processing including fractionation

Figure 4: The Top 10 Needs for Increased RAP Use

5.2 Funded, Nationally-Coordinated Research and Demonstration Projects

Improving Mix Design for HMA with High RAP An on-going NCHRP project titled *Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content* has as its goals; to evaluate and propose necessary changes to the existing specifications, such as AASHTO M 323 and AASHTO R 35, to account for HMA containing high RAP content and develop a mix design and analysis procedure for HMA containing high RAP content that provides satisfactory long-term performance. The expected mix analysis procedure will include performance-related tests and key criteria to address permanent deformation, fatigue cracking, low-temperature cracking, and moisture susceptibility (NCHRP 2009). Further, the procedure will identify any promising method(s) to assess the durability of HMA. The principal investigator for this project is the National Center for Asphalt Technology (NCAT).

In conjunction with the Asphalt Research Consortium (a cooperative agreement between FHWA and five organizations), NCAT has partnered with the University of Wisconsin, Madison and the University of Nevada, Reno to conduct research to develop methods for evaluating RAP binder characteristics without the use of hazardous solvents and determine the most appropriate methods for characterizing RAP aggregates. Work plans and quarterly progress reports are available on the ARC website at: http://www.arc.unr.edu/Publications.html. The results of this research are expected to be incorporated into the mix design and analysis procedure from NCHRP.

Evaluating Performance As a result of the RAP ETG's technical discussions, several demonstration projects have been initiated throughout the US using high percentages of RAP. The objectives of the field projects are to document the mixture design process, production, construction, performance testing, and best practices learned. FHWA along with NCAT and other industry partners work with the State highway agencies and provide assistance to establish an experimental plan for the design, production, placement, and

evaluation of high-percentage RAP mixes on a high volume roadway. Similar to virgin mixtures, it is important to consider aggregate characteristics, effective binder content (i.e. volume of effective binder), asphalt binder properties, in-place mix density, and conditions during placement.

The FHWA Mobile Asphalt Material Testing Laboratory (MAMTL) provides mixture design replication and performance testing of the RAP and control mix including dynamic modulus, fatigue, and low-temperature testing. The MAMTL is able to provide mix performance information and evaluate binder blending based on mixture properties using the Asphalt Mixture Performance Tester (AMPT). So far, the FHWA MAMTL has participated in four high RAP field projects. In each case the State highway agency approved higher RAP percentages than their specification allows. As RAP content is increased, best practices for Quality Control (QC) are essential. The field demonstration projects highlighted some of the best practices when using high RAP such as proper milling of the existing roadway, RAP processing and fractionating for uniformity and final blend consistency, and flexibility in plant operations. The field projects have also generated additional research projects to further explore if virgin and RAP binder blending is occurring, if blending is even necessary to achieve the required performance, and the need for proper performance testing protocols for high RAP mixes (Copeland et al. 2010).

5.3 Deployment and Technology Transfer of Findings

To encourage pavement recycling, technology transfer and training is necessary to assist field personnel in correctly utilizing recycling technologies and addressing construction problems with current state-of-the-practice solutions. Cosponsoring events with industry partners is another way to promote technology as well as receive feedback and input from stakeholders. FHWA cosponsors a series of workshops with NAPA that is solely focused on increasing the use of RAP and sustainable practices in asphalt mix production. The workshops have been held in each region of the US and the audience included designers (public agency and private consultant), construction engineers, construction inspectors, highway contractors as well as the diverse industry of asphalt binder suppliers, asphalt concrete mix producers, bituminous modifier, aggregate production, construction equipment and testing instrumentation suppliers.

Finally, the Transportation Research Board (TRB) held a webinar to explore the latest research and examine best practices for the processing, design, and production of high RAP mixes (Copeland and Kvasnak 2009). Successful high RAP use requires good materials management practices, complete characterization of the reclaimed asphalt pavement sources, and additional testing of the blended materials.

6 CONCLUSIONS

The use of RAP in recycled asphalt pavements plays a critical role in creating sustainable highways. Many US highway agencies are interested in using more RAP for cost savings and the majority of State highway agency projects have the potential to use more RAP. FHWA, along with AASHTO, NAPA, and NCAT, is leading the national effort to increase RAP use responsibly and provide answers to remaining issues that have prevented increased RAP use, especially for mix design and performance. Since 2007, there has been a concerted effort to increase the awareness and understanding for RAP use in HMA. As of 2009, twenty-one State highway agencies, out of fifty-one, increased the amount of RAP permitted and twenty-three State highway agencies now have experience with high RAP mixes (Jones 2009). While many State highway agencies increased the amount of RAP used in HMA, high amounts of RAP (i.e. greater than 25%) are still not common in State projects. Many State DOTs *permit*

more than 25% RAP in HMA layers; however less than half of the States actually *use* more than 20% RAP in HMA layers. Through current and future efforts of the RAP ETG, the long-term performance of RAP projects will be well documented to illustrate the success and lessons learned for using high RAP. In the future, expect improved test methods for analyzing blending between the virgin and RAP binder and evaluating the performance of high RAP mixtures.

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