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Paving Cost Comparisons: Warm-Mix Asphalt Versus Concrete

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PCA Market Intelligence

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Key Findings

- ***Concrete pavement*** enjoys both an initial and life cycle cost advantage over HMA as well as the most cost effective WMA case for many roadways.

- ***WMA production uses less fuel than hot-mix asphalt (HMA):*** With temperature reductions of up to 100°F, burner fuel consumption can be reduced by up to 50 percent of HMA production levels; however, typical savings run between 11 and 35 percent.

- ***Estimates that reliance on warm mix asphalt could save the Department of Transportation $3.6 billion are incomplete:*** When looking at just fuel cost savings, PCA was able to closely match that figure with $3.4 billion. What that number does not account for are admixture costs, which can negate a large portion of the fuel cost savings.

- ***Most WMA is produced using water-based foaming methods:*** According to the National Asphalt Pavement Association (NAPA), in 2012, 88 percent of all WMA produced was through water-based foaming at the plant. The remaining 12 percent used additives.

- ***Water-based foaming methods may require other additives:*** Water-based foaming production carries the largest concern for moisture related problems. To counter increased moisture susceptibility, anti-stripping agents (ASA) may be required.

- ***There may be durability concerns with WMA:*** Moisture susceptibility from incomplete aggregate drying and insufficient binder stiffness can lead to pavement deformation such as rutting and fracturing. Multiple studies have addressed concerns that WMA is less resistant to such moisture problems than HMA. Results are mixed. More research is required for moisture susceptibility as well as long-term analysis, as it is still a relatively new technology.

- ***WMA pavements can perform on par with HMA***: To achieve the same level of quality as HMA, WMA mixes require additional measures – in the form of chemicals, waxes, and to varying extents, anti-stripping agents. These add to asphalt paving costs.

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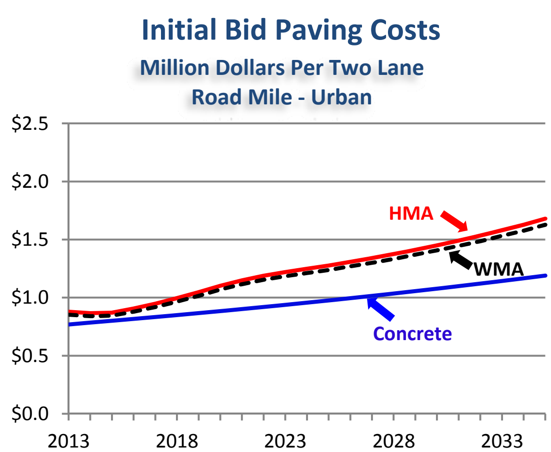
Overview

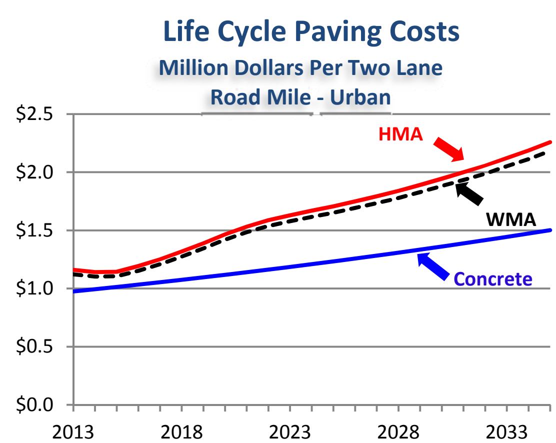
The U.S. Department of Transportation's (DOT) current initiatives involve adopting best practices for the sake of efficiency and ultimately cost savings. The program *Everyday Counts* is one initiative. In this forum, warm-mix asphalt (WMA) has been featured as an innovative technology that will play a big role in cost saving endeavors. Concerning this relatively new technology, the DOT suggests WMA could save "\$3.6 billion by 2020." [1] Research suggests that DOT estimates do not represent the net effect of fuel savings versus additional costs of additives and stripping agents. The savings estimates attached to WMA, therefore, may be exaggerated.

In terms of cost saving initiatives, amidst even the strongest fuel saving case for warm-mix asphalt, concrete remains the most cost effective pavement material for many roadways. Concrete pavement not only costs less over the life cycle of a roadway, but since 2008, also outperforms asphalt on initial cost for many roadways.

The purpose of this report was to investigate the proposed energy cost savings associated with producing WMA instead of traditional hot-mix asphalt (HMA), discuss the different production methods used and how they affect asphalt costs; and demonstrate that concrete pavement is still the most cost effective choice and should be included in the infrastructure recovery dialogue.

The real cost saver is not warm-mix asphalt....it's concrete.





Source: WisPAVE, PCA

[1] At the Transportation Research Board's Annual Meeting in Washington, D.C. on January 15, 2014, Transportation Secretary Anthony Foxx outlined his vision for tackling the infrastructure deficit.

Warm-mix asphalt may be a cheaper alternative to hot-mix asphalt. Concrete, however, remains the most cost effective option for many roadway systems. Using DOT initial bid and life cycle cost software, analyses were performed to compare hot-mix to warm-mix asphalt. An equivalent concrete pavement road was also analyzed. For the warm-mix asphalt representative, the strongest fuel savings case of 50 percent was used. The only difference from the hot-mix equivalent was the savings due to burner fuel reductions – admixture and stripping agent costs were not included for this scenario. The warm-mix alternative clearly saves on cost compared to hot-mix, both on initial and life cycle costs.

Compared to both the hot-mix case and the most favorable fuel savings case for warm-mix, concrete remains the least expensive option both for initial road construction and life cycle costs for many roadways. For an urban two-lane road in 2013, warm-mix asphalt paving costs were estimated at $852,238 per two-lane mile compared to $878,513 per two-lane mile for a hot-mix asphalt roadway – or a savings of roughly $26,000.

Even with the WMA improvement in asphalt paving process, a concrete road was cheaper – requiring only $769,269 per two-lane mile, or roughly $83,000 dollars cheaper than the lowest cost asphalt paving process. By 2020, these savings are expected to grow[2]. The warm-mix roadway is estimated to save roughly $32,000 per two-lane mile over hot-mix. The concrete roadway is estimated to save almost $186,000 over the best warm-mix case[3].

What is Warm-Mix Asphalt?

Warm-mix asphalt is defined by the Federal Highway Administration (FHWA) as "a general term for technologies that reduce the temperature needed to produce and compact asphalt mixtures for the construction of pavements. WMA temperatures generally start 30° - 70°F lower during mixing and remain lower during trucking, placement, and compaction."

This equates to lower energy costs, specifically the amount of burner fuel used in asphalt production. Because lower temperatures are required to dry the aggregate and heat the final asphalt mix for pavement use, less fuel is burned in the process – resulting in the implied savings.

While warm-mix asphalt can lead to lower production costs initially, the net effect of the additional measures required to perform as well as HMA can offset a large portion of these savings. For several production methods, slightly colder asphalt mix temperatures require additives to provide adequate coating of the liquid asphalt binder – at extra cost. These come in the form of chemicals and organic waxes. Other production methods use special equipment that injects water directly into the mix, creating a foaming effect that aids in coating the aggregate with the asphalt binder.

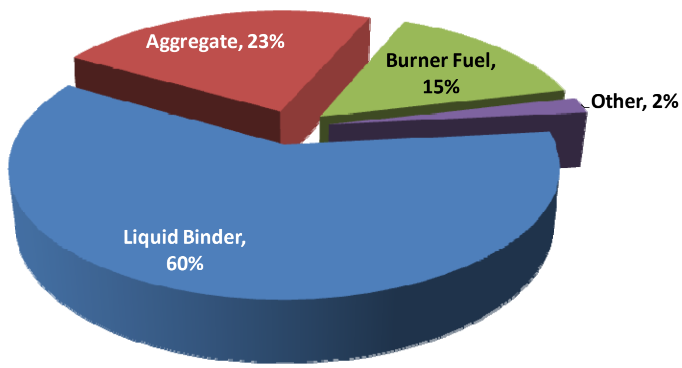
To combat potential moisture problems, other materials called anti-stripping agents can be introduced as well. The technical details and associated costs are discussed in a later section.

[2] Based on EIA oil price projections.

[3] Using WisPAVE Life Cycle Cost Analysis software from WisDOT, these are the total initial costs for HMA, WMA and concrete equivalents.

Concrete pavement remains the least expensive choice for roadway pavement. Since 2008, concrete outperforms asphalt on initial bid costs for an equivalent, urban roadway – even with the proposed energy cost savings associated with warm-mix asphalt. Because less frequent maintenance is required and the life span is much longer than with an asphalt roadway, concrete also exhibits a life cycle cost advantage for the same urban road. Admixture and anti-stripping agent costs further augment concrete's cost advantages.

HMA Cost Composition



Source: PCA Analysis

Burner fuel reduction – WMA versus HMA.

There are numerous reports describing a wide range of burner fuel savings associated with warm-mix asphalt processes. The majority of research suggests that WMA production can save from 11 to 50 percent in burner fuel consumption[4]. In a report performed by the National Cooperative Highway Research Program (NCHRP) in 2013 entitled: *Fuel Usage Factors in Highway and Bridge Construction,* the total fuel consumption was measured for several categories of items used in highway and bridge construction, ranging from grading/excavating to the hauling and placing of asphalt pavement.

The report also provided a comparison of the fuel consumption between the production of HMA and WMA. While the initial fuel consumption for HMA production – 2.0 gallons of diesel fuel per ton – was provided by a FHWA technical document from 1980, the WMA fuel consumption number was not physically measured, but rather assigned as 20 percent less than that of HMA production. This assumption translates into a reduction of 0.4 gallons of diesel fuel per ton of asphalt mix.

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[4] In a February 2008 report, *Warm-mix Asphalt: European Practice*, performed by the International Technology Scanning Program, and sponsored in part by the Federal Highway Administration (FHWA), the "burner fuel savings with WMA typically range from 20 to 35 percent."

In actuality, the amount of burner fuel consumed for HMA and WMA depends on the production method used. There are three types of methods: organic additives, chemical additives, and water or plant foaming, each with several different sub variations and brands. Altogether there are 22 different WMA technologies in practice in the U.S. The technical details of these methods are summarized in a later section.

According to NAPA in 2012, "plant foaming was used most often in producing WMA, with more than 88 percent of the market; additives accounted for about 12 percent of the market." PCA investigated the fuel savings for each of the three methods and found that chemical additives save up to 50 percent (1.0 gallon), organic additive technologies save up to 35 percent (0.7 gallon), and water-based foaming up to 20 percent (0.4 gallon). Most water-based foaming technologies save between 11 and 14 percent. Only ***the strongest*** cases put forth for each method were considered in the analysis – in other words, asphalt's best foot forward in cost reduction. Three popular WMA processes were assessed, each representing one of the three method categories: Double-Barrel Green® for water-based, Sasobit® for organic additives, and Advera® for the chemical additive technologies.

Method	Example Product	Burner Fuel Savings
Chemical Additives	Advera®	1.0 gal/ton (50%)
Organic Additives	Sasobit®	0.7 gal/ton (35%)
Water-Based Foaming	Double-Barrel Green®	0.4 gal/ton (20%)

Source: FHWA, PCA

Net warm-mix asphalt paving cost savings from burner fuel reduction WITHOUT additives.

It has been stated that warm-mix asphalt could save $3.6 billion by 2020. To assess this possibility requires future projections regarding both hot-mix and warm-mix asphalt costs as well as paving activity. Because asphalt prices are sensitive to movements in oil prices, expected changes for both burner fuel and asphalt bid prices must be considered. For this, PCA relies on oil and energy costs projections provided by the Energy Information Administration (EIA). According to the EIA, oil prices are expected to increase by 8.6 percent from 2013 levels by 2020.

Three fuel savings scenarios were considered: chemical additives with 50 percent savings, organic additives with 35 percent, and water-based foaming with 20 percent. The benchmark for hot-mix asphalt burner fuel consumption was set at 2.0 gallons of diesel fuel per ton. This translates to the following fuel gallon savings: 1.0 gal/ton for chemical additives, 0.7 gal/ton for organic additives, and 0.4 gal/ton for water-based foaming.

Ratios of fuel cost reductions to hot-mix asphalt bid price projections were used to find the asphalt cost savings percentages for each of the three scenarios. Diesel price projections from the EIA were used for the burner fuel prices. As an example, in 2014, the price of a gallon of diesel is expected to be $3.48 and the price of a ton of hot-mix asphalt is expected to bid at $46.02. Therefore, with a 50 percent reduction in fuel usage, or 1.0 gallon, the savings are $3.48 per ton (7.6 percent) in 2014. For a 35 percent fuel reduction, or 0.7 gallon, the savings are $2.44 per ton (5.3 percent). For 20 percent fuel reduction, or 0.4 gallon, the savings are $1.39 per ton (3.0 percent). The table below is a summary of the fuel cost savings projected out to 2020.

Price Inputs			Fuel Cost Savings			Asphalt Bid Price Savings		
Year	*Diesel Price ($/gal)*	*HMA Bid Price ($/ton)*	*Chemical 1.0 gal/ton*	*Organic 0.7 gal/ton*	*Water-Based 0.4 gal/ton*	*Chemical*	*Organic*	*Water-Based*
2014	$3.48	$46.02	$3.48	$2.44	$1.39	7.6%	5.3%	3.0%
2015	$3.56	$45.89	$3.56	$2.49	$1.42	7.8%	5.4%	3.1%
2016	$3.68	$48.19	$3.68	$2.57	$1.47	7.6%	5.3%	3.1%
2017	$3.81	$51.01	$3.81	$2.67	$1.52	7.5%	5.2%	3.0%
2018	$3.94	$54.28	$3.94	$2.76	$1.58	7.3%	5.1%	2.9%
2019	$4.08	$57.80	$4.08	$2.86	$1.63	7.1%	4.9%	2.8%
2020	$4.20	$61.61	$4.20	$2.94	$1.68	6.8%	4.8%	2.7%

Source: EIA, PCA

The cost savings per lane mile were then calculated in an effort to duplicate the $3.6 billion figure. Admixture costs were excluded at first, thus illustrating warm-mix's effect on energy costs alone. Initial and life cycle cost analyses were performed for one hot-mix asphalt and the three warm-mix asphalt scenarios. From the initial cost findings, the cost for one lane mile of road was calculated for each scenario from 2014 to 2035.

In terms of paving activity, only state DOT jurisdictions were considered. Interstates, arterials, and collectors were included while local roads were excluded. The amount of lane miles that are paved each year was measured at 4.7 percent. Using the latest PCA analysis of Oman Systems bid tabulation data, asphalt's market share of state DOT roads was estimated at 86%. Applying the stock of roads that are likely to be repaved annually, with the portion that are asphalt yields a rough approximation of lane miles under state DOT jurisdiction paved with asphalt. This translates into an average of 74,391 lane miles.

Applying the lane mile savings for each warm-mix scenario from 2014 to 2020, the total cost savings were calculated. A weighted average, using NAPA's share of 88 percent water-foamed and 12 percent additives was applied to find a final savings of approximately $3.4 billion, closely matching the original claim of $3.6 billion. The following table illustrates the lane mile savings for the weighted average of the warm-mix scenarios as compared to the lane mile cost of a hot-mix asphalt road, projected to 2020.

Cumulative Savings - Before Additive and ASA Costs			
	Asphalt Paved Lane Miles	*Average Savings*	*Total Savings*
2014	74,391	$5,959	$443,279,439
2015	74,391	$6,078	$452,153,780
2016	74,391	$6,302	$468,779,365
2017	74,391	$6,551	$487,315,088
2018	74,391	$6,733	$500,907,900
2019	74,391	$6,987	$519,780,287
2020	74,391	$7,203	$535,844,369
Total	**520,737**	**-**	**$3,408,060,228**

Source: Oman Systems, Inc., FHWA, PCA

Admixture requirements for warm-mix asphalt.

The lower temperatures of warm-mix asphalt result in lower energy costs in the process of asphalt production. PCA calculates the cost savings at $3.4 billion compared to estimates that warm mix asphalt could save the DOT $3.6 billion. Unfortunately, slightly colder asphalt mix temperatures require additives to provide adequate coating of the liquid binder. These admixtures drive up asphalt paving costs and can negate a large portion of the fuel cost savings. Research suggests that these estimates do not include the admixture costs and the savings estimates attached to WMA may be exaggerated.

There are 22 WMA production technologies currently used in the U.S. These technologies fall under three broader categories: organic additives, chemical additives, and water-based foaming technologies. Water-based methods do not use additives and therefore require no additional cost for production once initial plant equipment upgrades are performed.

Chemical additives to warm-mix asphalt and costs: The role of the chemical additive is to provide adequate aggregate coating by the liquid binder at lower production temperatures. There are two major types of chemical additive processes. One is called "dispersed asphalt technology," which replaces a portion of the liquid binder with an asphalt emulsion product combined with a chemical additive. The other method uses synthetic zeolites, which are typically used in water softeners[5]. Burner fuel savings for chemical additives can reach 50 percent of HMA levels. This translates to a reduction of 1.0 gallon of diesel fuel per ton. Although they have the greatest reduction in fuel usage, chemical additives can add between $3.50 and $4.50 to the cost of a ton of asphalt mix[6].

Organic additives to warm-mix asphalt and costs: Similar to the chemical additives, organic additives lower the viscosity of the liquid binder, allowing for aggregate coating at lower-than-normal temperatures. The difference is the material used. Instead of a chemical interacting with the binder, an organic wax is added. The wax melts and helps bond the binder to the aggregate, reducing the amount of heat that is normally needed for this bonding to occur. Burner fuel savings with organic additives typically range between 20 and 35 percent. For the purposes of this analysis, the higher end of 35 percent was chosen. This equates to a 0.7 gallon per ton fuel savings. Organic additives can add between $2.00 and $3.50 for each ton of asphalt mix produced[6].

Water-based foaming additives to warm-mix asphalt and costs: Water or plant foaming is the most commonly used group of WMA technologies (88 percent of 2012 WMA production). Water is pumped into the asphalt mix via a spraying mechanism and interacts with the heated liquid binder creating a foaming effect, which then coats the aggregate. Burner fuel savings for water-based foaming

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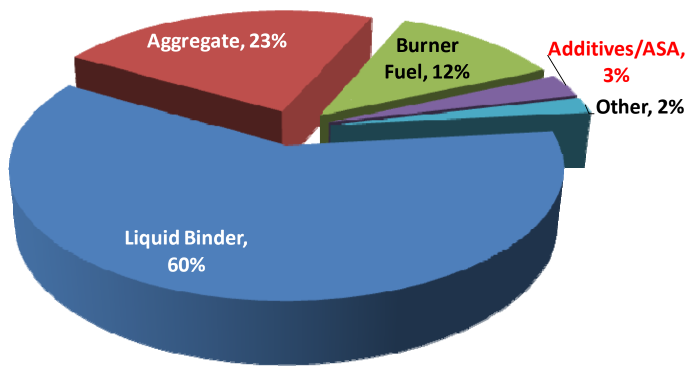
[5] At the molecular level, a zeolite is a chemical whose mass is about 20 percent water that is trapped within its crystalline structure. This water gets released at temperatures close to the boiling point of water. When it comes in contact with the heated asphalt binder in the production process, it creates a foaming effect, which helps coat the aggregate at lower temperatures. Ultimately, the temperature needed to complete the asphalt mix is lowered significantly.

[6] *Warm Mix Asphalt Performance. Potential Benefits And Other Parameters*. Ryerson University, Ontario, Canada. Winter 2010.
http://www.academia.edu/3042215/Warm_Mix_Asphalt_Performance_Potential_Benefits_and_other_Parameters_-_Course_Report

methods range between 11 and 14 percent, with a few claims of up to 20 percent. The higher end of 20 percent was chosen for this analysis. Because these techniques do not use additives, there is no added cost per ton, excluding the initial equipment installation costs.



Source: PCA Analysis

Moisture susceptibility and preventative costs.

Moisture susceptibility: One reason hot-mix asphalt production requires temperatures upwards of 340°F is because of the moisture content in the aggregate. A major role of the burner in asphalt production is to dry the aggregate enough to allow adequate bonding with the liquid asphalt binder, as too much moisture in the mix can adversely affect this bonding. Incomplete drying of the aggregate can lead to a phenomenon called "stripping," in which the aggregate and binder separate. This can cause the pavement to fail structurally, causing rutting and fracturing. Lowering the temperature during production increases the risk for incomplete drying. Warm-mix asphalt production uses lower temperatures. Further still, the most common form of WMA production is **water**-based foaming.

Anti-stripping countermeasures: Anti-stripping agents help strengthen bonds between the aggregate and asphalt binder. Hydrated lime is one of the most common examples and has been used in hot-mix asphalt for decades. Other examples are tallow diamine (TDA) and bis-hexamethylene triamine (BHMT), both liquid agents. ASAs can add between $1.32 and $7.50 per ton of asphalt mix, thus driving up pavement costs[7].

Asphalt binders can vary greatly, with or without additives. Work performed by the FHWA has demonstrated that a binder's stiffness is crude source dependent. The choice of anti-stripping agent can depend heavily on the physical nature of the binder. Some work well with one type of binder, while others may not. Modified binders further complicate the situation as they can also affect the physical nature of the binder.

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[7] Prices for hydrated lime from USGS: http://minerals.usgs.gov/minerals/pubs/commodity/lime/mcs-2013-lime.pdf. TDA, BHMT prices and mix percentages taken from http://www.alibaba.com/ and http://www.asphaltmagazine.com/archives/2005/Spring/Effect_Antistripping_Additives_On_PG_Grades_Asphalt_781778887_7202005152935.pdf

WMA can contain more Reclaimed Asphalt Pavement (RAP) than HMA. This could save on costs in that less virgin materials would be needed; however, the reason for higher levels of RAP is to add to the pavement's structural durability. Another consequence of moisture susceptibility is decreased binder stiffness, which can lead to structural problems. RAP can increase this stiffness. Typically, RAP content in an asphalt mix falls between 10 and 25 percent. Warm-mix asphalt may require higher RAP content to ensure the adequate binder stiffness is maintained.

While increased RAP can reduce the need for virgin materials, it comes at a price too – structural integrity of the pavement. Increased binder stiffness can lead to reduced resistance to thermal cracking. The right combination of production methods, binders, and virgin/reclaimed aggregates must be reached to avoid these issues.

Research on moisture susceptibility: The severity of moisture concerns can vary significantly, and multiple studies have provided mixed conclusions. After reviewing previous research on the subject, the National Cooperative Highway Research Program (NCHRP) states, "the conclusion of several laboratory studies is that WMA has increased moisture susceptibility as compared to HMA…"[8]

As part of their own research, the NCHRP tested samples from the three groups of WMA technologies: chemical additives, organic wax additives, and water foaming. Most of the WMA pavement samples performed well over the specified times. Anti-stripping agents improved performance metrics that were used to gauge moisture susceptibility, especially for the water foaming samples.

WMA production uses less burner fuel; however, chemical and organic wax additives cost money. Depending on the extent of moisture susceptibility, anti-stripping agents may also be required, further adding to paving costs. While many of the WMA field samples performed well in the study, the NCHRP concluded in reference to moisture susceptibility, "several issues regarding WMA remain unclear, and future research is suggested."

Net warm-mix paving cost savings from burner fuel reduction INCLUDING additives.

When accounting for additives and anti-stripping costs, the initial savings of warm-mix asphalt could shrink to as little as $300 million. This suggests the savings estimate could be exaggerated more than ten-fold. To estimate the net warm-mix savings from burner fuel reduction including additives, PCA used the lowest possible admix costs for both the chemical and organic additive groups while excluding the anti-stripping agent (ASA) costs from the water-based foaming group. In doing so, the greatest cost savings accrued to warm-mix asphalt over hot-mix asphalt can be estimated. Including additive costs ***while excluding ASA costs*** yields a potential net savings of approximately $2.7 billion by 2020.

[8] *Evaluation of the Moisture Susceptibility of WMA Technologies,* National Cooperative Highway Research Program 2014 http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_763.pdf

Cumulative Savings - With Additive Costs			
	Asphalt Paved Lane Miles	*Average Savings*	*Total Savings*
2014	74,391	$4,713	$350,601,941
2015	74,391	$4,853	$360,992,832
2016	74,391	$5,004	$372,226,289
2017	74,391	$5,230	$389,076,922
2018	74,391	$5,383	$400,479,202
2019	74,391	$5,612	$417,498,026
2020	74,391	$5,799	$431,371,531
Total	**520,737**	**-**	**$2,722,246,742**

Source: Oman Systems, Inc., FHWA, PCA

If the costs for anti-stripping agents are considered, the savings drop to under $300 million. The reason for such a significant difference is that the large majority of WMA is produced using water-based foaming (88 percent). If we consider the lowest end of the ASA cost range, $1.32 per ton (hydrated lime), the resulting savings are as follows[9]:

Cumulative Savings - With Additive and ASA Costs			
	Asphalt Paved Lane Miles	*Average Savings*	*Total Savings*
2014	74,391	$328	$24,377,410
2015	74,391	$368	$27,353,839
2016	74,391	$452	$33,644,758
2017	74,391	$579	$43,080,929
2018	74,391	$627	$46,653,706
2019	74,391	$795	$59,145,033
2020	74,391	$882	$65,604,404
Total	**520,737**	**-**	**$299,860,078**

Source: Oman Systems, Inc., FHWA, PCA

Conclusions

Warm-mix asphalt is a growing technology in Europe and the United States. Since its adoption on U.S. soil in the 2000s, production of WMA has grown to 87 million tons in 2012, roughly 24 percent of total U.S. asphalt production.

WMA production requires less fuel than HMA. Fuel is consumed by burners, which dry the aggregate and heat the mix once the liquid binder is added. Diesel fuel is the most common burner fuel. Typical asphalt plant production consumes approximately 2 gallons of diesel fuel for every ton of mix.

[9] The severity of moisture susceptibility with warm-mix asphalt pavements will dictate the need for ASAs. Depending on the extent of use with these ASAs, the savings could be considerably less.

Estimates that reliance on warm mix asphalt could save the Department of Transportation $3.6 billion by 2020 appear to be incomplete: These savings refer to the reduction of burner fuel that warm-mix provides. PCA investigated these claims and matched fairly close to this number at $3.4 billion when looking at fuel reductions only. These estimates were found to be incomplete, as they do not appear to take into account any admixture costs that are associated with these new technologies.

There are currently 22 WMA production technologies in practice in the U.S. These technologies fall under three broader categories: chemical additives, organic additives, and water-based foaming.

Depending on the method used, the amount of fuel consumed during warm-mix production can be reduced by 11 to 50 percent of hot-mix asphalt levels. Chemical additives result in the greatest burner fuel reductions at up to 50 percent of HMA levels. Organic additives can reduce burner fuel consumption by up to 35 percent and water-based foaming can save between 11 and 20 percent. In 2012, 88 percent of all WMA produced in the U.S. was performed via water-based foaming.

Because temperatures are lower than normal hot-mix production levels, the risk for incomplete aggregate drying is increased. Incomplete aggregate drying can lead to increased moisture susceptibility. Excessive moisture in asphalt pavements can cause a phenomenon called "stripping," in which the aggregate separates from the binder. This can cause the pavement to fail structurally. Anti-stripping agents, typically liquid additives, can alleviate moisture susceptibility in WMA – at a cost.

Studies have produced various conclusions regarding moisture susceptibility in WMA pavements. In a recent report by the NCHRP, several WMA samples performed on par with HMA. Chemical and organic additive technologies were represented in the majority of the samples. Anti-stripping agents were also found to reduce moisture related risks, particularly with water-foamed samples. Further research on moisture susceptibility was suggested.

Using the strongest fuel savings case provided, PCA was able to reach a projected fuel cost savings of $3.4 billion by 2020. The next step was to incorporate the additive costs in order to reach a net savings figure. Accounting for conservative chemical and organic wax additive costs, the net savings falls to $2.7 billion. With the most conservative ASA costs included, the net savings by 2020 falls below $300 million, a difference of over ten-fold.

When discussing transportation and infrastructure recovery, concrete pavement should also be included in the dialogue. Even with the advent of warm-mix asphalt and the savings it provides, concrete pavements remain the most cost effective alternative. For an urban road, concrete costs less than both the hot-mix and most fuel reducing warm-mix equivalents, initially and throughout the life of the road. ***Yes, warm-mix asphalt is more cost effective than hot-mix but still does not compare to concrete pavement.***