Further Study

Warm Mix Asphalt

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Project Team

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San Joaquin Valley
AIR POLLUTION CONTROL DISTRICT

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I. EXECUTIVE SUMMARY

The San Joaquin Valley Air Basin (Valley) faces unique and unprecedented air quality challenges in attaining National Ambient Air Quality Standards (NAAQS). The San Joaquin Valley Air Pollution Control District (District) must explore all available emission reduction opportunities in order to demonstrate attainment for multiple federal ozone and PM2.5 standards in the coming years. In an effort to "leave no stone unturned," the District conducted a study to assess whether warm mix asphalt (WMA) use would result in significant emission reductions throughout the District and identify and address any barriers to adoption. Using WMA instead of hot mix asphalt (HMA) results in lower temperatures required for production, storage, and transport. This can lead to less fuel consumption, resulting in potential cost savings and emissions reductions. The District collaborated with asphalt industry stakeholders and policy makers in developing this further study in order to gain an understanding of the use of warm mix technologies in the Valley and identify potential opportunities and barriers for adoption of this technology. As a result of this effort, the District found the following:

1. WMA is a Potential Alternative to HMA

WMA has been used in Europe since 1997 and the United States (U.S.) since 2002. Several iterations of the technology have been developed for a variety of road applications. Case study results suggest that WMA performance can be equal to or better than that of HMA in certain instances, although more evidence will be required to demonstrate its reliability in climates like the Valley.

2. WMA Offers Benefits Compared to HMA

Although switching from HMA to WMA may require plant modifications, more precise moisture control in some cases, and an overall higher cost, WMA offers benefits over HMA including:

- Potential Reduced Fuel Consumption
- Improved Performance During Paving in Cooler Climates
- Extended Transportation and Compaction Window
- Safer Working Conditions

3. Potential Emissions Reductions Can be Negated

Using WMA instead of HMA shows promise for reducing emissions associated with the production of asphalt. Lower temperatures required for production, storage, transport, and application translates to potentially lower fuel consumption, which could lower criteria pollutant emissions associated with the fuel consumed. However, the emissions reductions from fuel savings could potentially be negated in certain long haul transport cases. In order to extend the hauling benefit, WMA could be heated to HMA temperatures in order to keep the material workable for *even longer* periods of time, thus reducing the fuel savings and eliminating potential emissions reductions.

4. WMA has Several Challenges in the Valley

While the WMA markets are developed and growing in other states, there are still several uncertainties that may limit the adoption of WMA technologies in the Valley. Some of these barriers include:

- Uncertainties in performance with WMA in the Valley
    - Insufficient number of pilot projects to demonstrate viability in the Valley
    - Durability demonstration
    - Longevity demonstration
- Poor curing in the Valley's hot summer climate
    - More time required to cool in Summer heat
    - Longer periods of road closures due to increased cooling time
    - Increased costs due to longer periods of road closures
- Lack of accepted WMA specifications and guidelines in California
    - Lack of awareness of WMA
- Lack of confidence in WMA
- Higher cost associated with WMA
    - Retrofit or new equipment required
    - Additional cost of chemical additives
- Low demand

Based on the above findings and in order to continue evaluating and promoting the use of WMA in the Valley, the District recommends the following:

1. **Encourage additional pilot projects to assess viability and life cycle of WMA in the Valley.**

2. **Encourage Caltrans to further develop WMA specification.**

3. **If found to be feasible in the Valley, work with stakeholders to educate and encourage WMA usage as a means of implementing additional pilot projects.**

4. **Meet with stakeholders as necessary.**

5. **If found to actually reduce emissions and be feasible, consider including WMA as an ISR mitigation measure.**

II. COMMITMENT FROM THE 2012 AND 2015 PM2.5 PLANS

Liquid asphalt production and paving in the Valley contributes 0.160 tons per day (tpd) of oxides of nitrogen (NOx) emissions across the entire Valley. While these emissions are low and do not significantly contribute to elevated PM2.5 levels in the Valley, the District has adopted a “no stone left unturned” policy when identifying potential emission reduction opportunities. As such, the District made a commitment in the *2012 PM2.5 Plan* and *2015 Plan for the 1997 PM2.5 Standard (2015 PM2.5 Plan)* to evaluate the feasibility of WMA as an alternative to HMA to reduce NOx emissions from this source category. In the *2015 PM2.5 Plan*, the District committed to:

1. Evaluate opportunities to further encourage transportation and county agencies to continue transitioning from HMA to WMA as feasible. As part of this evaluation, the District will explore the potential feasibility of additional control measures and granting mitigation credits for WMA usage through the District’s Indirect Source Review (ISR) program.
2. Evaluate potential outreach and education opportunities for encouraging project developers/construction managers to increase their adoption and implementation of WMA.

This study was conducted with significant interaction and input from stakeholders, including asphalt pavement plant operators, road construction companies and contractors, county and city planning departments, pavement plant consultants, and state and federal policy makers.

On October 8, 2015, District staff held a kick-off meeting with several members of the local California Department of Transport (Caltrans) district, a representative from a local pavement production facility, and an experienced local public works engineer. This initial meeting gave insight into the regional issues that affect the adoption of WMA technologies here in the Valley and shed light on WMA barriers that were not addressed in the District’s extensive literature review. Meeting attendees were also helpful in providing the District with additional contacts for further investigation. On October 28, 2015, the District conducted a larger and more comprehensive meeting with members from public works departments, local pavement plants, California Asphalt Pavement Association (Cal APA), Caltrans, Federal Highway Administration (FHWA), California Air Resources Board (CARB), and the Environmental Protection Agency (EPA). Following a presentation by District staff, attendees were asked a number of questions regarding their experiences with WMA. Through extensive stakeholder input during and following these meetings, the District was able to assess the challenges that still must be overcome before promoting WMA in the Valley. This report discusses the technological, economical, and practical efficacy of WMA use throughout the Valley.

III. WARM MIX ASPHALT

Asphaltic concrete is used worldwide for road construction. An asphaltic concrete mix consists of aggregate and liquid asphalt. The aggregate is comprised of rocks of varying size, angularity, and hardness. Liquid asphalt is a natural hydrocarbon substance primarily derived from the heaviest part of petroleum crude oil and is used to bind the aggregate to create a strong, durable material for an assortment of road conditions. The final mixture is brought to the construction site, poured, and compacted to become highways, roads, and parking lots.

The durability and longevity of the final pavement product depends on the asphalt mixture components and the quality of compaction during the final paving stages. In the end, all asphaltic concrete must meet a host of construction specifications (specs), which can vary depending on the type of road. These specs can include a certain temperature, density, and smoothness of the road required by state or local regulations. To achieve these specs, contractors must ensure a high level of control when pouring and compacting the asphaltic concrete. This control is reliant on the quality and workability of the asphalt mixture.

Conventional road asphaltic concrete is unworkable at ambient temperatures. Heating the asphalt mixture to temperatures greater than 300°F (>150°C) temporarily reduces the viscosity (the "thickness" of the liquid) and allows for mixing, pouring, and compacting of the material. This mixture is appropriately deemed hot mix asphalt (HMA) due to the hot temperatures needed during production and paving. The primary emissions source from asphaltic concrete production comes from the combustion of the diesel or natural gas fuel used to heat the dryers, hot bins, and mixers to these extreme temperatures.

In order to reduce fuel costs, European and American companies developed several techniques, collectively known as warm mix asphalt (WMA), to increase the workability of asphalt by lowering the viscosity at temperatures as much as 100°F below that of HMA. The lower temperatures require less fuel and therefore can decrease emissions from asphalt production. The use of WMA in the U.S. has been growing steadily since the first test section was completed in 2004 at Auburn University's National Center for Asphalt Technology (NCAT)[1]. Since then, an increasing number of U.S. roads have been paved with WMA, including extensive runway and taxiway projects at Boston's Logan International Airport and Chicago O'Hare International Airport[2]. By 2012, WMA represented an estimated 30% of the total asphalt market in the U.S. FHWA has chosen WMA for rapid deployment under its Every Day Counts (EDC) initiative. The EDC initiative is, "designed to identify and deploy innovation aimed at reducing the time it takes to deliver highway projects, enhance safety, and protect the environment."

WMA Techniques

WMA is defined as an asphalt mixture that is produced at a temperature of 270˚F or below. In order for WMA to be workable at these lower temperatures, the viscosity of the mixture is lowered using one of two different techniques. The first technique is mechanical alteration of the asphalt properties. Mechanical methods include, but are not limited to, adding water-containing products or water-based foaming processes to the mixing step of asphalt production to lubricate the mixture and decrease viscosity.

[1] "Public Roads" FHWA. Retrieved from: https://www.fhwa.dot.gov/publications/publicroads/10julaug/05.cfm
[2] Retrieved from: http://www.forconstructionpros.com/

Water foaming is the most common of the mechanical techniques and has been used in various WMA applications throughout the nation. All mechanical methods require some plant modifications, including adding new equipment and changing production practices. Mechanical methods for WMA have been shown to reduce the production temperature by 0-35°F.[3]

The other technique for WMA production is the addition of chemicals that alter the asphalt properties. Chemical additives include, but are not limited to, organic wax, cationic surfactants, surface-active agents, processing aids, and polymers. Additive dosages range from 0.2% to 3% by mass or weight. Chemical additives for WMA have been shown to reduce the production temperature by 10-100°F.[2] While the transition to the mechanical WMA methods requires change to the production facility, requiring additional investments, the use of chemical additives can be accommodated with minimal alteration to existing asphalt plant and production technology. However, with this technique, additives would be used in every batch and would still result in increased production costs.

In addition, both WMA technologies generally require an additional step in moisture or chemical additive dosage as well as additional process control strategies such as tuning of the burner to run efficiently at lower temperatures. These changes require training and education of operators and engineers before transition to WMA production at any HMA facility.

IV. WMA BENEFITS

WMA has been used in the U.S. for over a decade primarily for fuel cost savings and reasons other than air pollution control. Ongoing lab studies, accelerated pavement testing, and field testing have guided the implementation of WMA in California. Since 2010, Caltrans and the University of California Pavement Research Center have been evaluating WMA technology and its performance by testing the rutting and cracking performance, moisture sensitivity, durability, aging, and stability of multiple WMA products.[4] In the controlled testing environment, WMA has been shown to have equal or better overall performance, increased workability, potential energy savings, and safer working conditions compared to HMA.

Improved Performance in Cooler Climates

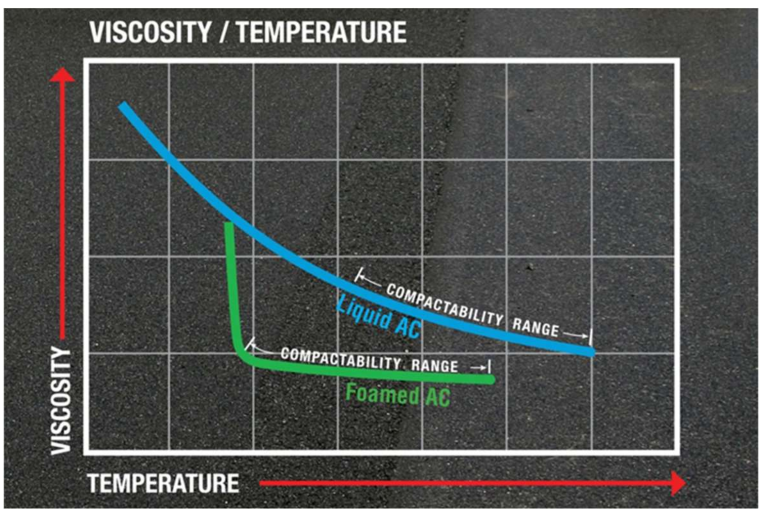
With HMA, asphalt binder becomes stiff and unworkable in cooler temperatures, which can make paving during the cold seasons difficult or impossible. WMA provides improved workability and easier pavement compaction, especially in cooler climates, which is critical to long-term performance of the road.[5] The slow curing time and improved viscosity of WMA allow for a longer compacting window, which provides

[3] Asphalt Pavement Association of Michigan Presentation. Retrieved from: http://www.apa-mi.org/docs/2013LRW-WarmMixAsphalt.pdf
[4] Jones et al. *Research Findings on the Use of Warm-Mix.* Retrieved from: http://ra-foundation.org/wp-content/uploads/2013/02/040-PAP_060.pdf
[5] MyAsphaltPavingProject.Com. (2011). "What are the Specifications?" Retrieved from http://www.myasphaltpavingproject.com/whatisasphalt/what-are-the-specifications

superior in-place density, one of the most important metrics of a successful pavement project. This longer compaction window in cold weather is due to decreased binder stiffness, which decreases the viscosity of the asphalt mixture at lower temperatures. In some locations, where the fall and winter months are extremely cold, the ability to pave in cooler temperatures with WMA can extend the paving season later into the fall.

Figure 1 is a plot of viscosity as related to temperature for two different asphalt mixtures. Asphalt becomes more workable as the viscosity decreases. The compatibility range of an asphalt mixture is a measure of the range of temperatures during which the material is able to be rolled to the final density and smoothness specs prior to cooling and opening for traffic operations. Conventional HMA, labeled in the figure as “Liquid AC,” is compactible only at higher temperatures. The WMA, labeled as “Foamed AC” because it was created using a mechanical foaming technique, has a larger compatibility range.

Figure 1. Viscosity of Two Asphaltic Concrete (AC) Mixtures Plotted Over a Range of Production Temperatures [6]



Safer Working Conditions

The lower mixing and paving temperatures of WMA have the potential to minimize visible blue smoke and odor emissions. These emissions consist of particulate matter, CO_2, and VOCs and can be harmful to the environment and workers at the paving site. One study indicates that fumes released at the paving site are reduced at a rate of 50% for each 10˚C. [7] Less odor and fumes reduces the public nuisance of placing asphalt and improves worksite safety for the construction team. The lower temperatures also create cooler working conditions for the asphalt workers.

[6] Astec Products Brochure (2015). Retrieved from: http://www.astecinc.com/products/liquid-additives/warm-mix-systems.html
[7] EAPA (2010). Retrieved from: http://www.eapa.org/usr_img/position_paper/the_use_of_warm_mix_asphalt_january_2010.pdf

Extended Transport Time

WMA allows for longer (slower) cooling periods than HMA. Slower cooling and lower viscosity at lower temperatures means the material can be hauled longer distances or compacted during a longer window of opportunity before the material begins to become too viscous and unworkable. Improved hauling time allows the material to be transported to more remote locations and introduces more flexibility in transportation schedules. Additionally, a longer cooling window and decreased binder stiffness allow the material to be compacted at safer, lower temperatures for a longer period of time.

Potential Energy and Cost Savings

By lowering the production, storage, transport, and placement temperatures, manufacturers require less fuel to heat aggregate and liquid asphalt. These energy savings can potentially offset the cost of additives or needed modifications to plants, especially where energy costs are high. Reduced plant temperatures may also cause less wear on plant equipment, thus reducing plant maintenance costs. [8]

Assessments outside of the Valley have shown potential for reduced costs. Although production facilities must modify some aspects of their plant by installing additional equipment in order to accommodate WMA technologies, the hauling, laydown, and compaction equipment do not need to change. The initial incremental cost of WMA over HMA is primarily due to the foaming equipment or additive chemicals used at the time of production. Over time, as WMA demand increases, the cost and fuel savings associated with WMA has the potential to outweigh the cost to purchase the WMA technology.

Additionally, the low temperatures used in WMA production allows for higher percentages of recycled highway materials to be used in the mixture with no effect on ultimate pavement performance. This type of mixture is called reclaimed asphaltic pavement (RAP).[9] The low temperatures of WMA result in less aging of the old recycled material, so a larger ratio of reclaimed aggregate can be used to meet the same aging properties as HMA with recycled aggregate. The use of RAP is less expensive than producing an asphalt mixture completely from raw materials, and additional savings can be generated from avoiding landfill disposal or recycling fees. The cost savings gained from using RAP could potentially further offset costs for additives or required plant modifications needed for WMA production. Fuel savings, an increase in reclaimed asphalt pavement content, and reductions in fuel and labor during the process of installing WMA could translate to reduced costs for WMA projects over time.

[8] Caltrans. (2013, April). Caltrans Activities to Address Climate Change: Reducing Greenhouse Gas Emissions and Adapting to Impacts. Retrieved from: http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/Caltrans_ClimateChangeRprt-Final_April_2013.pdf
[9] Canadian Asphalt Institute Presentation (2009). Retrieved from: http://www.captg.ca/docs/pdf/09presentations/Wednesday%20PM/Warm%20Mix%20Asphalt_Sandy%20Brown.pdf

Potential Emissions Reductions

Table 1 shows an estimate of the maximum potential NOx emissions reductions as a result of the complete transition from HMA to WMA at all asphalt production sites in the Valley. This estimate is not intended to reflect an estimate of realistic potential emissions reductions given the lack of information and potential implementation issues associated with converting from HMA to WMA. The District's 2017 emissions inventory from the *2015 PM2.5 Plan* estimates 0.160 tpd of NOx emissions from asphalt production at all 19 asphalt production facilities in the Valley. While fuel savings for WMA at production facilities have been reported to be from 20% to over 50% for some WMA technologies, U.S. studies have reported actual burner fuel savings of zero (0%) to 40%, with the average typically around 30%.[10] If every plant changed completely from HMA to WMA, there would be an estimated 0.048 tpd in NOx emissions reductions Valley-wide. This is a small potential emission reduction opportunity, especially considering the investments asphalt plants would have to incur to begin producing WMA. For example, a pavement plant unequipped for water-foaming based WMA production would typically need to invest $60,000-80,000.

Table 1. Potential NOx Emissions Reductions if all Valley Plants Changed all HMA to WMA

Estimated Reductions	
Hot Mix Asphalt (Production only) projected 2017	0.160 tpd NOx
Possible Average Fuel Savings	30%
Maximum Reductions	0.048 tpd NOx

Potential GHG Reductions

In response to climate change objectives, Caltrans included WMA in an April 2013 report as an activity to reduce GHG emissions and adapt the state's transportation system to prepare for the impacts of climate change. As stated in this report, Caltrans identified that WMA can reduce production temperatures by 35–100°F compared to conventional HMA, potentially yielding 30% fuel savings and an 18% reduction in the overall GHG emissions associated with manufacturing, mixing, and laying the asphalt.

V. POTENTIAL EMISSIONS REDUCTIONS CAN BE NEGATED

While emissions reductions are possible due to the fuel savings benefits of WMA, these reductions could be negated if standard WMA production temperatures are exceeded. During the District's research, asphalt production and paving experts stated that

[10]Retrieved from: http://www.warmmixasphalt.com/submissions/may2009/08_Marks_wmatwgprovidence.pdf

contractors around the state have requested WMA be heated to high temperatures for the purpose of extending transport time. WMA is already ideal for long transport due to the longer cooling period, so contractors ordering asphalt for remote locations take advantage of this property and attempt to further extend the hauling benefit. In this case, the WMA would be produced at HMA temperatures in order to keep the material workable for longer periods of time. This practice eliminates the fuel savings and leads to no difference in emissions from HMA. Any fuel or emissions savings will not be realized if there is no consistency in practice in keeping the temperatures lowered.

While transportation emissions should be the same regardless of material properties, the use of WMA for longer hauling distances may actually produce more emissions overall compared to HMA from the additional truck miles generated. With the initial limited number of Valley asphalt facilities producing WMA, contractors intending to use the material may need to travel further for WMA than HMA. The probability of longer hauling distances combined with the possibility of heating WMA to hotter temperatures may negate or actually increase emissions associated with the use of WMA compared to HMA.

VI. CHALLENGES FOR IMPLEMENTING WMA IN THE VALLEY

There are several advantages of WMA over HMA, as demonstrated by successful WMA installation in many parts of the U.S. However, the District has identified a number of barriers for the adoption of WMA technology in the Valley based on extensive input from asphalt producers and road paving experts.

Uncertainties in Performance with WMA in the Valley

Caltrans has been involved in a number of WMA performance studies since 2012, leading to a steady increase in adoption of WMA technology in some parts of the state. However, there are still a number of uncertainties in construction operations and pavement performance that limit WMA use here in the Valley. The ability of WMA to decrease fuel consumption and improve worksite conditions has been demonstrated in controlled environments and cooler climates, but there have been an insufficient number of studies to demonstrate viability in the Valley.

There have only been two Caltrans pilot projects for WMA in the Valley. One such project was a 5 mile stretch of highway laid on a hot day in 2014 in Kings County. After rolling out the material, the asphalt took much longer to cool and resulted in difficult compaction and extended lane closures, which significantly increased project costs. While a second project (on Highway 33) resulted in better paving conditions and is functioning as well as other HMA-paved lanes, more pilot projects like these are critical to identifying temperature concerns other Valley-specific problems.

These uncertainties in paving operations and durability performance in the Valley extend to long-term concerns. Because WMA is relatively new, a full life cycle analysis has not yet been assessed here in California. While there are experiments that have simulated long-term erosion of WMA, the longevity and durability of WMA in the Valley's unique climate is unknown. If longevity of the WMA product is not known, the cost and emissions benefits cannot be assessed properly. For example, if a road paved with WMA has to be repaved earlier than it would have with HMA due to accelerated aging or poor durability, the emissions associated with that additional round of paving would offset any reductions achieved with WMA production. Depending on the difference in lifecycle, the WMA could actually have more lifetime emissions than HMA. While experiments indicate that this is not likely, Valley contractors and public works agencies will not transition to WMA until more is known about performance in the Valley.

Poor Curing in the Valley's Hot Summer Climate

Laying WMA in high heat can lead to poor compaction and delayed curing time. The difference in temperature between the ambient air and the asphalt mixture affects the rate of cooling. Reducing that temperature difference allows for longer (slower) curing periods and is part of what makes WMA a superior material to HMA in most uses. However, if that temperature difference is too small due to hot ambient temperatures, the material may take too long to cool to the temperature approved for traffic use (typically below 130 ˚F for both WMA and HMA). Unfortunately, Valley summers are some of the hottest in the state, often reaching temperatures well above 100°F. Waiting for the asphalt to cool during typical Valley summer days can cause significant project delays resulting in increased costs and longer periods of road closures. Pavement plant operators who participated in the WMA study session indicated that almost all of the WMA orders their company receives are for Central Coast or Bay Area construction projects, places with cooler climates. Until clear WMA specs are written and the use of WMA is more widely implemented by Caltrans in the Valley, public works and other local agencies will not readily adopt WMA technologies.

Lack of Accepted WMA Specifications and Guidelines in California

One necessary step to reducing uncertainties in WMA is to identify safe and effective WMA practices and ensure the materials are suitable for a variety of conditions. This process to identify universal specs is commonly done through Caltrans conducting iterative pilot projects throughout various climates and conditions. While it takes years to complete each of these state-funded Caltrans projects, these are necessary in order to write new specs and promote the safe, easy use of a new material.

Most public and private agencies follow the Caltrans specs when constructing or maintaining roads. These agencies, including city and county public works departments, rely heavily on the Caltrans specs for operational guidance. Since 2012, Caltrans has tested and approved a growing list of WMA techniques and materials listed as available options for contractors. While the Caltrans paving specs identify WMA materials as an option, they do not contain the detailed procedures necessary for implementing WMA projects.[11] There is no differentiation in the specs between certain HMA and WMA practices; the section in which one can find any WMA information is titled "HMA Specifications." Unclear specs can be confusing and misleading. Without

[11] Caltrans Section 39 HMA Specifications. Retrieved from: http://calapa.net/section_39.html

WMA-specific procedures, contractors ultimately decide to pave with HMA, a familiar product that has been tested and handled in a variety of situations. Since proper handling of WMA can make a significant difference in the fuel and emissions reductions realized during a project, it is critical to have unified WMA specs in order to achieve the economic and environmental benefits.

Lack of Confidence in WMA

The District found that one of the largest barriers to adoption of WMA in the Valley is the lack of confidence in the technology and its potential benefits, especially when used with other technologies.

As an example, the District learned from stakeholders involved in this study that WMA use could clash with the state mandate that Caltrans use rubberized asphalt. This mandate is derived from a provision in Assembly Bill 338 (Levine) which requires Caltrans to use a minimum of 35% Crum Rubber Asphalt (CRA)[12] as paving material. CRA is a HMA mixture in which recycled rubber is added as an aggregate in order to reduce sound (when driving) and increase stability. This technique is cost effective and environmentally friendly due to rubberized asphalt's better aging properties and greater durability.[13] The rubber used in the mixture typically equals 3 recycled tires per ton, which can mean approximately 2,000 recycled tires per lane mile for a road overlay project.[14] While CRA is a green technology, stakeholders attending the District's WMA study meetings voiced concerns over the use of rubber in the WMA mixture until rubberized asphalt is fully understood or exhaustively tested.

Interestingly, these concerns were raised even though Caltrans conducted a large, multi-year study in conjunction with the UC Pavement Research Center that tested the performance of WMA made with rubberized aggregate. This study reported that there was not a significant difference in performance between rubberized WMA and HMA. However, these studies took place in Caltrans District 1 and 3, places with more temperate, cooler temperatures. Therefore, the regional Caltrans staff and local contractors may lack the confidence in WMA performance in part because none of the projects in the UC Pavement study took place in the Valley.[15] Education and outreach regarding these WMA studies may assist in increased use of WMA in the Valley, but ultimately additional pilot tests in Valley locations are necessary in developing WMA specs and instilling confidence in the pavement contractors and regional Caltrans staff.

Higher Cost Associated with WMA in the Valley

The incremental cost of producing WMA is a barrier to production facilities and end users. Mechanical methods for WMA production, like water foaming, require some

[12] AB 338 (Levine) (2005) Retrieved from: http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0301-0350/ab_338_cfa_20050427_134930_asm_comm.html
[13] Alameda County COG Presentation (2013). Retrieved from: http://www.acgov.org/sustain/documents/roundtable_rubberasphalt_gci.pdf
[14] Alameda County COG Presentation (2013). Retrieved from: http://www.acgov.org/sustain/documents/roundtable_rubberasphalt_gci.pdf
[15] Retrieved from: http://www.dot.ca.gov/newtech/researchreports/reports/2013/final_report_task_2385c.pdf

plant modifications, including adding new equipment and changing production practices, which can lead to high up-front costs associated with WMA production. Similarly, while the use of chemical additives can be accommodated with minimal alteration to existing asphalt plant production technology, the chemicals or materials can be costly and are used in every batch, nonetheless increasing the overall cost of WMA. Additionally, each facility must incur the cost of transition training and education of operators and engineers in order to successfully expand their operation to incorporate WMA. Finally, pavement plants must pay to obtain new permits for any new tanks.

The added costs of WMA production are incorporated in the final cost of the material to the end user.[16] With most Valley agencies operating on a tight budget in low-income communities, it could be difficult for these public entities to choose WMA over conventional HMA when the cost difference could be $0.50-5.00 more per ton. While most Valley operators who participated in this study indicated that they may be able to overcome these incremental costs, they could not do so without an increase in demand.

Low Demand

Due to uncertainties about the performance, longevity, operational procedures, and associated costs, WMA is not yet widely requested or ordered by asphalt plants. As such, very few Valley asphalt plants produce WMA. Until there is widespread request of the material, pavement plants have very little incentive to begin large-scale WMA production. As long as the demand for WMA remains low, the cost to purchase could be $0.50-5.00 more per ton than HMA (at an overall $60-80 per ton)[17], not including the potential for fuel cost savings. Since contracts for road construction projects go to the lowest bidder, it is difficult for production facilities and contractors to promote WMA use when the competition is selling cheaper material, no matter the other benefits WMA has to offer. Without an increase in demand, WMA may not provide any overall cost savings.

VII. FURTHER STUDY FINDINGS

This study has found that WMA has the potential to reduce emissions by using less fuel and the potential to provide safer conditions by producing less odor and fumes. However, this potential reduction in emissions must be further evaluated given that a number of other factors with respect to implementation may negate or actually increase emissions associated with WMA.

In other states and countries, WMA has shown to be a feasible alternative to HMA and continues to grow steadily due to performance and cost-savings advantages. However, in the Valley, many barriers still remain. Poor paving performance in the Valley's high summer heat, lack of confidence in WMA technology, an insufficient number of pilot projects to support feasibility in the Valley, lack of Caltrans WMA specifications to support proper WMA usage, and not enough demand to provide the needed economies

[16] Asphalt Pavement Association of Michigan Presentation. Retrieved from: http://www.apa-mi.org/docs/2013LRW-WarmMixAsphalt.pdf
[17] Retrieved from: http://www.cement.org/docs/default-source/about-pca-pdfs/paving_cost_comparisons_flash.pdf

of scale to achieve the identified cost benefits have all hindered widespread adoption of WMA throughout the Valley.

In order to continue evaluating and consider promoting the use of WMA in the Valley, the District recommends the following:

1. **Encourage additional pilot projects to assess viability and life cycle of WMA in the Valley**. Promote and support additional WMA pilot projects in the valley to reduce uncertainty and improve confidence in the performance and benefits (including emissions reductions) of WMA.

2. **Encourage Caltrans to further develop WMA specifications**. Encourage Caltrans to develop WMA specs to provide the appropriate guidance to contractors and public work agencies.

3. **If found to be feasible in the Valley, work with stakeholders to educate and encourage WMA usage as a means of implementing additional pilot projects**. Continue to meet with public works agencies, including Caltrans, to help educate and encourage WMA use. The District could also provide WMA literature and information during the permitting process at various pavement plants or through the ISR process for construction projects that require paving as a means of implementing additional pilot projects.

4. **Meet with stakeholders as necessary.** Continue to meet with Caltrans, Cal APA, plant operators, and other pavement industry leaders to assess feasibility and emission reductions. If found to be feasible and to result in actual emission reductions, identify challenges and look for solutions for adoption of WMA technology.

5. **If found to actually reduce emissions and be feasible, consider including WMA as an ISR mitigation measure.** District Rule 9510, Indirect Source Review (ISR), requires developers of larger residential, commercial and industrial projects to mitigate smog-forming and particulate emissions generated by their projects. If WMA is found to actually reduce emissions and be feasible, the District could consider allowing the use of the emission reductions achieved by using WMA in place of HMA to mitigate project emissions.

VIII. PUBLIC COMMENTS AND RESPONSES

1. **COMMENT:** Consider mentioning that WMA has been used to pave a runway at Logan International Airport and a taxiway at O'Hare International Airport as examples of the confidence other jurisdictions have in WMA. **(EPA)**

   RESPONSE: This comment will be addressed in the final draft.

2. **COMMENT:** State that fuel savings from lower WMA production temperatures may help offset the cost of the chemical additive in some cases. **(EPA)**

   RESPONSE: Under the section *Potential Energy and Cost Savings*, the District already addresses the cost savings associated with the lowered temperatures. "These energy savings can potentially offset the cost of additives or needed modifications to plants, especially where energy costs are high."

3. **COMMENT:** Under the "WMA Techniques" section, the District states that WMA requires more finesse in controlling the moisture in the aggregate and the overall system operation. Consider appending this section with input from the asphalt industry as to how significant this issue is (e.g., is it something that facilities should be aware of when they first produce WMA, or is it a potential barrier to expanding WMA usage?) **(EPA)**

   RESPONSE: Through the meetings with various WMA stakeholders, including those from production facilities in the Valley, the District learned that there is an operational learning curve for new WMA technologies. The District met with a variety of stakeholders with a wide range of experience with WMA technologies, so it is difficult to classify this specific issue as a barrier when some asphalt producers are more familiar with the product than others. For this reason, it is instead mentioned in the technology description section. While controlling production specifications is not listed as a barrier alone, the District does address unfamiliarity with WMA later in the document as a potential barrier to widespread adoption.

4. **COMMENT:** Address the fact that WMA's paving season is extended since it is able to be paved at lower temperatures compared to hot mix asphalt. **(EPA)**

   RESPONSE: While this is true in most cases, this is more of a factor in cooler climates like Chicago and Boston where the fall and winter ambient temperatures are dramatically lower than that of the summer and therefore the HMA paving season is shorter. The District will include a statement that the paving season could be extended in cooler climates in the final draft.

5. **COMMENT:** Add a note that the blue smoke seen with HMA loading and paving operations is particulate matter, and is generally not seen with WMA. **(EPA)**

   RESPONSE: This will be addressed in the final draft under the section titled *Safer Working Conditions*.

6. **COMMENT:** Consider adding the PM and VOC reductions when assessing potential emissions reductions as well as the potential costs associated with water-foaming technology. **(EPA)**

RESPONSE: PM and VOC emissions reductions achieved when using WMA are typically realized at the paving site and not during production. When assessing the valley-wide emissions reduction potential of WMA, it is difficult to assess the site-specific practices that may influence the VOC or PM emissions (how much asphalt is laid, to what temperature was the mixture cooled or heated, what were the environmental conditions). The NOx analysis performed in this report is based on an established emissions inventory of asphalt production plants throughout the Valley. It is therefore more straightforward to estimate the possible NOx reductions with WMA based on average burner fuel savings reported in literature.

7. **COMMENT:** The report indicates some contractors have requested WMA be heated to high temperatures to extend the distance WMA can be transported. We agree it's important to consider emissions holistically and heating WMA to a higher temperature and trucking it to longer distances can negate potential emissions reductions. Explain how common it is that a contractor requests WMA be heated to higher temperatures in order to haul longer distances. **(EPA)**

   RESPONSE: The District appreciates that EPA recognizes that emissions should be looked at holistically. Based on multiple discussions with stakeholders, due to the lack of WMA-only specifications and the sporadic use of WMA throughout the region, it is impossible to quantify exactly how often this is requested. As described in the section titled *Potential Emissions Reductions Can be Negated,* there are a limited number of Valley asphalt facilities producing WMA, so most contractors intending to use the material would need to travel further for WMA than HMA. It is therefore possible that this is a common practice in the region.

8. **COMMENT:** Include a note about the second pilot project in the valley (Highway 33). **(EPA)**

   RESPONSE: This will be addressed in the final draft.

9. **COMMENT:** Add more information about the difference between HMA and WMA technology in regards to the ambient temperature difference and temperature necessary for reopening of newly-paved roads. **(EPA)**

   RESPONSE: The Caltrans specs list 130˚F as the threshold temperature for roads to reopen regardless of WMA or HMA technology is used.

10. **COMMENT:** Consider compiling a WMA Best Practices document to address a variety of potential challenges (including ambient temperature and WMA type, lack of specs, etc.). This could be done by consulting with the Department of Transportation in states like Texas and Arizona. **(EPA)**

    RESPONSE: The responsibility to write new specs and/or compile a BPS document falls on the DOT and therefore, this comment should be deferred to the DOT.

11. **COMMENT:** Reference more instances in which Caltrans uses WMA with rubberized asphalt outside of the Valley. The experience gained from paving projects in Caltrans Districts 1 and 3 may be useful for spring or fall paving in the Valley. **(EPA)**

RESPONSE: The lack of confidence in WMA's performance with rubberized asphalt was listed as a potential challenge after discussions with Caltrans officials and pavement plant operators. This report already references the successful Caltrans WMA pilot projects in association with the large UC Pavement Research Center study. The District will specifically reference Caltrans District 1 and 3 projects in the final draft.

12. **COMMENT:** Append the section *Low Demand* to refer to the earlier discussion of potential fuel cost savings of producing WMA at lower temperatures. Also, include that cost information presented at the April 16, 2015 California Asphalt Conference estimates WMA to be approximately $0.25/ton for water-injection and $2-$3.50/ton using additives. **(EPA)**

    RESPONSE: This section will state that the low demand for WMA inhibits any overall cost savings that could be possible when using WMA. Additionally, according to the source[18] cited by the District, the cost of organic additives is $2-3.50/ton, but chemical additives could cost up to $5.00/ton more than HMA. Therefore it is more accurate to use the $0.50 to $5.00 per ton cost estimate.

13. **COMMENT:** A blanket statement saying that all warm-mix processes are equal would not be a fair assessment. There are several technologies used to achieve WMA, and not all of them guarantee lower temperatures. It is important to use the right technology. **(Asphalt Institute)**

    RESPONSE: The District does not conclude that all WMA technologies guarantee lower temperatures. Under the section *WMA Techniques*, the District outlines the vast differences between mechanical and chemical WMA techniques, including their varying temperatures reductions relative to HMA. As indicated in this section, there is a wide range of temperature benefits from zero all the way up to 100 ºF, depending on the technology. Additionally, not only does the warm-mix technology determine the temperature reduction (and therefore fuel savings), but the ways in which the mixture is handled from production to compaction can have a great effect on associated emissions. For clearer analysis and discussion, the District uses an average fuel savings of 30%. Regardless of the different WMA techniques, the District encourages Caltrans to work with stakeholders to document clear specifications such that the burner fuel savings and emissions benefits can be realized from a variety of WMA mixtures.

14. **COMMENT:** The draft document refers to HMA as a significant contributor to VOCs. The report also recognizes that NOx reductions are low. The report indicated that emissions reductions are variable and uncertain when comparing HMA to WMA. Therefore, WMA should not be promoted to reduce VOCs. **(Asphalt Institute)**

    RESPONSE: The purpose of this further study is to assess the potential emission reductions that can be achieved through the use of WMA and has found that WMA does not significantly reduce emissions, including VOC.

15. **COMMENT:** The document has confused the longer window of compaction with a slower rate of cooling. This longer compaction window is due to the lubricating effects of additives (including water) to create WMA. Therefore, while the rate of cooling is slower for WMA, this is just due to the temperature at which the product is placed compared to HMA (and the

[18] http://www.cement.org/docs/default-source/about-pca-pdfs/paving_cost_comparisons_flash.pdf

difference between this temperature and the ambient temperature). The compaction benefit actually comes from the binder stiffness. **(Asphalt Institute)**

RESPONSE: The lower temperatures also affect the binder stiffness, which can affect the compaction window; however, the District has clarified that the viscosity/surface tension of the binder is what truly aids in compaction and not the cooling period.