# Project Summary Page

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<th>Evaluation of Rubberized Asphalt Terminal Blends and a Preliminary Study on Warm Mix Technologies with Asphalt Rubber</th>
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<td>Authors:</td>
<td>R. Gary Hicks, Ding Cheng, Tyler Duffy, and Tyson Teesdale</td>
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<td>Prepared For:</td>
<td>California Integrated Waste Management Board</td>
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<tr>
<td>Prepared by:</td>
<td>CP2 Center</td>
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## Abstract:

This report presents a summary of work on two separate topics. The first was to evaluate whether terminal blend rubberized asphalt is an effective product and is eligible for the CIWMB grant program. Terminal Blends (TB) are binder materials that use finely ground (less than 40 mesh) crumb rubber modifier (CRM) and blended at the asphalt refinery. Historically, the primary differences between TB and asphalt rubber (AR) binders were the amount of CRM used in the binder (TB less than 10%; AR 15-20%) and the use of specialized mixing equipment for AR. However, in recent years the rubber content in Terminal Blends has been increased to 15-20 % or more. CIWMB now supports the use of terminal blends for chip seals, but does not yet support the use of Terminal Blends (TB) in hot mixes. Through this preliminary study, the overall current field testing and research results showed that TB hot mix is a promising paving material for preventing reflective and fatigue cracking. It performs better than conventional hot mix and, in many of the tests, proved equal to or superior to the performance of asphalt rubber. However, more research needs to be done on determining the amount of rubber in TB, moisture susceptibility of TB binder, and evaluating the long term performance of existing Terminal Blend projects in California or in other states.

The second portion of this study dealt with evaluating the use of warm mix technologies with AR mixes and chip seals. Warm mix asphalt (WMA) is the name given to certain technologies that reduce the production and placement temperatures of asphalt mixes. Generally, the placement temperatures should be between 185°F and 275°F for an asphalt to be considered warm mix asphalt. In the United States, WMA is a relatively new technology; however, it has been used in Europe since the mid 1990’s. This study evaluates whether there are any benefits of using warm mix technologies with Asphalt Rubber (AR) chip seals and hot mixes. The potential savings in energy and reduction in Green House Gas emissions could be great. This report includes a literature review and a survey of users of Warm Mix in the United States. It concentrates the research on the use of warm mix technologies with asphalt rubber in California. The overall field testing and research results demonstrate that there are a wide range of benefits which can be attained by using warm mix technology in rubberized asphalt mixes. These may include reduced fuel usage and emissions, compaction aid, longer paving season, night paving, long hauling distances, and improved working conditions. In the future, additional study needs to be done on warm mix technologies with asphalt rubber and terminal blend chip seals, moisture susceptibility of rubberized warm mix asphalts, and evaluation of new warm mix innovations used in rubberized asphalt concrete.

## Keywords:

Terminal blend, Asphalt Rubber, chip seals, hot mixes, and warm mixes
Acknowledgements

We appreciate the financial support of the CIWMB for providing the funding for this important and meaningful project. We would like to extend our gratitude to Nate Gauff and Bob Fujii, who provided continuous support to this project.

We also appreciate the support of Paramount Petroleum and Valero Oil in helping to identify a number of projects in California that have included terminal blend rubberized asphalt. We also appreciate the assistance provided by the states of Arizona, Florida, Nevada, Texas, Oregon, Louisiana, and Kansas.

The authors also appreciate the support from Caltrans engineers Michael Stapleton, Al Ochoa, Joe Peterson, and Cathrina Barrios as well as resident engineers Ben Hargrove and Cameron Knudson. Brandon Milar and Kee Foo, co-chairs of the Caltrans Industry WMATG, also provided useful input on the warm mix study.

Disclaimer

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The content does not necessarily reflect the official views or policies of the California Department of Resource Recovering and Recycling or the State of California.
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1.0 INTRODUCTION

1.1 Background

1.1.1 Terminal blends

Terminal blend asphalt rubber binder is a form of the wet process where Crumb Rubber Modifier (CRM) is blended with hot asphalt binder, at the refinery or at an asphalt binder storage and distribution terminal, and then transported to the asphalt concrete mixing plant or job site for use. The particle size of CRM used in the terminal blends is finer than that of the field blend currently used by Caltrans. The terminal blend does not require subsequent agitation to keep the CRM particles evenly dispersed in the modified binder. In the past, such blends manufactured in California contained 5-10 percent of ground CRM by mass (which does not satisfy the ASTM D 8 definition of asphalt rubber) and other additives to eliminate the need for agitation. However, new formulations have been developed that contain from 15 -22% CRM by total binder mass. Currently the terminal blend with minimum 15% tire rubber content qualifies for the CIWMB chip seal grants, but does not yet qualify for the hot mix grants. Initially the CIWMB grant requirements weren’t clear about including the use of terminal blends primarily for the reasons listed below:

- They are not certain of the performance benefits of this product and how it compares with the field blended asphalt rubber process.
- There may be gaps in the technical knowledge that have to be addressed before the product can be used statewide. However, Caltrans has just begun to use terminal blends as a PG-TR products in both HMA and chip seal applications.
- The need to be assured that CRM is being used in the product. A rapid, economical and simple test or monitoring system needs to be developed to ensure that the CRM usage is properly tracked or how they can be assured the rubber is in the product.
- A full range of potential pavement maintenance applications for which terminal blends can be used as a paving material has not been completely identified.

This study is addressing these questions. A series of actions have been proposed in this study to assess the performance of terminal blends and compare this with the performance of the field blended process.

1.1.2 Warm mixes

The CIWMB also requested a preliminary study on whether there is any benefit of using warm mix technologies for AR chip seals and mixes. The potential savings in energy and reduction in emissions could be great. Further, by reducing the temperatures of application, environmental controls presently used for chip seals may not be required.
This will potentially increase the usage of asphalt rubber chip seals by making the product more cost effective.

At present, there are several warm mix technologies that are being used in the United States, which include forms of emulsion technology, addition of wax, addition of a clay substance, or a foaming process. Other products are also emerging. The products most evaluated to date in California include SASOBIT, Aspha-min® zeolite, and Evotherm. These additives allow the mixes to be placed at lower temperatures, up to 100°F. As of the beginning of this study, the warm mix additives have not been widely used with hot mixes or spray binders containing hot applied asphalt rubber. Use of the additives in these applications could result in energy savings and reduce emissions because the additives could allow the construction to be taken at lower temperatures without the limitations by the current environmental controls.

1.2 Project objectives

This project will attempt to answer the questions posed in the background section about the terminal blend. The study will include a literature review, a survey of users of terminal blends in Arizona, California, Florida, Nevada and Texas as a minimum, and a review of test projects placed in California including the District 6 Firebaugh project, the District 1 project in Mendocino County, HVS test sections placed at the Richmond Field Station, and a new test section placed in the Antelope Valley of unincorporated Los Angeles County in July 2009.

The objectives of the preliminary study on warm mix are to evaluate the use of warm mix technologies for AR hot mixes and determine whether these technologies will allow operations at lower temperatures without harming the performance of the mix, and to evaluate the use of warm mix technologies for use in asphalt rubber spray binders. This could result in significant energy savings and a reduction on the emissions.

1.3 Work tasks and Organization of the report

The work tasks included in this study are as follows:

- Task 1. Identify existing Caltrans and local agency projects placed containing terminal blends, including the percentage of CRM used for each of the projects.
- Task 2. Identify and evaluate the use of terminal blends in the states of Arizona, Florida, Nevada, and Texas to see how they perform and in which applications they are used.
- Task 3. Identify any challenges or gaps in the knowledge when using terminal blends of rubberized asphalts.
- Task 4. Identify other pavement maintenance applications for which terminal blends could be used including chip seals and thin HMA overlays.
- Task 5. Contact the warm mix technology industries to determine whether these applications have been tried anywhere in the world.
- Task 6. Brainstorming meeting with warm mix suppliers
• Task 7. Prepare a report summarizing the findings of the study and make a presentation to the Board on the findings and the recommendations

Chapter 1 presents the background and objectives for the study. Chapter 2 presents the accomplishments from the study. Chapter 3 presents the major findings while chapter 4 presents the conclusions and recommendations. Technical memorandums were developed which provide a more completed description of the findings for both the terminal blends and the warms mixes. These can be found on the Center website at www.cp2info.org
2.0 SUMMARY OF ACCOMPLISHMENTS

This chapter presents a summary of the major accomplishments for each work task. More information can be found in the detailed technical memos posted on the Center website:

- Evaluation of terminal blends
- Evaluation of use of warm mix technologies for use with asphalt rubber HMA and spray applications

2.1 Task 1. Identify existing Caltrans and local agency projects placed containing terminal blends, including the percentage of CRM used for each of the projects.

This task consisted of contacting state and local agencies as well as suppliers of terminal blends. The results of this task included the following:

- Local agencies have used terminal blends for hot mix and chip seals since the 1990’s. The major suppliers (Paramount and Valero) provided us with a list of the projects. We have summarized projects in a tech memo on this subject documenting these projects.
- Caltrans has evaluated terminal blends in several projects including:
  - 10 pilot projects placed in the late 90’s
  - Test sections including the D6 Firebaugh and D1 Mendocino projects placed in the early 2000’s
  - HVS test sections at the Richmond field station, and
  - 5 year warrantee job on 395 between Reno and Susanville.
  Preliminary data collected so far would suggest the terminal blends with 15 % CRM will perform as well as the AR wet process field blends.
- Working with LA County and Paramount Petroleum, a test plan for a terminal blend test section was developed. LA County provided the pre-construction data on the project and the Center worked with them and others to finalize the test plan for the project. The Center also participated in the construction of the terminal blend chip seal project in Los Angeles County the week of July 5, 2009. The construction was completed in 3 days and on the 4th day the pavement was striped. The work went well, however there were some problems with the chip seal over fabric section. The site visit, conducted on October 29, 2009, indicated the pavement to be performing well. No major problems have been reported from the project. A final report summarizing all this information will be submitted in May 2010.
- The Center also toured the Paramount facility in Long Beach with CIWMB staff on May 13, 2009 to review their quality control (QC) process. The CIWMB staff felt comfortable with the QC process. The process used is included in the terminal blend tech memo. In addition, we have contacted several manufacturers of binder test equipment to be used in the determination of CRM content in the asphalt rubber binders. However, at this time, we feel the best solution is to document the batch quantities used by the producers. We will continue to work on the identification of tests to measure rubber content.
The Center is continuing to work with the suppliers of terminal blends to identify projects used in the state of California. This will involve the inclusion of all these projects into the Center’s Pavement Preservation Database located on the Center’s website at [www.cp2info.org/center](http://www.cp2info.org/center).

Center staff continues to monitor terminal blend projects in California. These are included in the tech memo along with photos of the current condition.

2.2 Task 2. Identify and evaluate the use of terminal blends in the states of Arizona, Florida, Nevada, and Texas to see how they perform and in which applications they are used.

A survey of all states in the United States was completed in January 2009 to identify the use of terminal blends. A total of 30 states responded and a summary of the responses on the use of terminal blends is given in Table 2.1.

### Table 2.1. Agency use of terminal blends

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The Center followed-up with the states responding ‘yes’ to address the following questions:
- Who are the producers of terminal blends in the states?
- In what applications are terminal blends used and how do the products perform?
- What tests are used to ensure that CRM is present in the binder?
- Who are the contacts in these states?

This data is included in the tech memo along with follow-up information collected through phone calls. The major users of terminal blends in the United States include the states of Arizona, California, Florida, Nevada, Oregon and Texas. All of them are pleased with the results of terminal blends for chips seals and HMA.

2.3 Task 3. Identify any challenges or gaps in the knowledge when using terminal blends.

The major challenges or gaps in knowledge identified to date are as follows:

- *How can an agency ensure that the CRM contents can be tested to quantify the number of tires being used by this process?* Currently, it would be easy to use polymers as a substitute for CRM. We are evaluating tests that can be used to quickly and easily determine the CRM content in the mix, but have not found a simple one to be suitable yet. Also, we have met with the terminal blend providers to review the QC process and allow agencies to tour their facility to see how they control the CRM input. Since the producers used a batch process, we feel that they can provide the user with a certificate of compliance (COC) that certifies the components of the batch as well that the CRM is from California.

- *What are the production issues that need to be addressed?* Even though the suppliers can provide the terminal blend materials, it may still be difficult for Hot Mix producers to stop production of the “work horse” mixes and use only terminal blends. The size of jobs will impact how much hot mix asphalt (HMA) producers will want to provide these materials. The terminal blends suppliers have indicated that they will work with their customers to provide a plan to minimize this problem. They have indicated that they can provide extra tankage in some cases. Because this is a new product and different from conventional chip seals, training may be required to make a smooth transition.

- *Additional challenges in the use of terminal blends.* We continue to contact users to identify additional challenges. So far there seem to be little other problems that have been identified.

2.4 Task 4. Identify other pavement maintenance applications for which terminal blends could be used including chip seals and thin HMA overlays. Indicate how many tires might be consumed using these new maintenance treatments.

The Center has discussed this issue with users and producers of terminal blends. Based on our work to date, the terminal blend asphalt can be used for the following applications:
• **Hot mix** - They can be used any place where an AR field blended hot mix can be used. The initial findings from a review of Caltrans research and field projects suggest that they are equivalent in performance to the field blends.

• **Chip seals** - They can be used anywhere an AR chip seal be used. Because of the lower production temperatures, smoke is not a major issue.

• **Slurry seals** - In this application, the slurry seals are different than the product REAS in that the rubber is an integral part of the asphalt and not just a filler. The rubber modified slurry seal product is produced by CPM and Roy Allen. We visited a test site of the CPM process in Yuba City and have identified numerous projects that have been constructed in the recent past.

2.5 Task 5. **Contact the warm mix technology industries to determine whether these applications have been tried anywhere in the world.**

2.5.1 **Use in California**

The Center has meet with Caltrans and producers of warm mix technologies for use for hot mix. Here are our findings to date:

- SASOBIT has been used with RHMA-G in the San Jose area with no problems.
- Evotherm and Green Drum technologies have been used on shoulders along I-5 near Fresno with RHMA-G. Ding Cheng visited this site during April 2010. The warm mix RHMA-G performed well during the visit.
- District 3 constructed a project using Evotherm and RHMA-O on Interstate 5 near Orland in May, 2009. The Center staff visited the site and the project went down very well.
- District 11 constructed a project using EVMA-G and RHMA-O on US 99 north of Sacramento. The Center has collected information on this project and has visited it. It is also performing very well.
- District 1 constructed a project using RAC-G and Evotherm on SR 101 in September, 2009. The Center has collected information on this project and has visited it. It is also performing very well.

In April 2010, the Center staff discussed the uses of warm mix technology the potential use of their technologies with asphalt rubber chip seals. Our preliminary findings would suggest that SASOBIT might be the most applicable for use with hot applied chip seals. The Center is working with applicators to see if we could get a test section in the Sacramento area during the Spring or Summer of 2010.
Caltrans is planning a number of asphalt rubber projects in 2010. Most of them will be in Districts 1 and 3. All will make use of warm mix technologies. Some terminal blend HMA with warm mix technologies will be constructed in the summer of 2010 in District 9.

2.5.2 Survey of other states

A survey of the states using warm mix technologies is given in Table 2.2. The states using warm mix have been contacted to determine if they have used warm mix technologies with asphalt rubber products. The major users include the following states: California, Florida, and Massachusetts.

Table 2.2 Agency use with warm mix technologies

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Center staff participated in a national asphalt pavement association (NAPA) meeting on recycled pavements and warm mixes in Sacramento on June 8-10, 2009. This provided more information on the use of warm mixes with asphalt rubber products. It was demonstrated that California is the leader in this effort.

Center staff will continue to participate in the Caltrans ETG on warm mixes. One WMAETG meeting was held on October 14, 2009 at UC Davis where Caltrans has scheduled some HVS testing using various warm mix technologies with asphalt rubber
mixes. Ding Cheng attended a WMA task group meeting at Teichert Aggregate facility in Sacramento on February 23, 2010. During the meeting, Caltrans engineers discussed that about 8 warm mix projects are planned for 2010 which include asphalt rubber.

The last Caltrans WMATWG meeting was held at UC Davis (April 6, 2010) along with HVS study on warm mix asphalt with asphalt rubber. The CP2C will work closely with Caltrans, industry, and UCPRC to monitor this important study.

2.6 Task 6. Brainstorming Meeting with Warm Mix Suppliers

Based on the findings in Task 4, it appears warm mix technologies can be used with asphalt rubber hot mixes. We feel it can also be used in hot spray applications. As a result, we met with the major warm mix suppliers in Sacramento to discuss the use with spray applications. This was done in conjunction with the NAPA meeting on warm mixes on June 8-10, 2009 to be held in Sacramento. The outcome of this effort was that the suppliers (Evotherm and Sasobit) will begin to look at possible projects to try this application. We continue to participate in the California warm mix ETG to discuss use of both terminal blends and asphalt rubber with the various warm mix technologies.

2.7 Task 7. Prepare a report summarizing the findings of the study and make a presentation to the Board on the findings and the recommendations

The Center has completed the technical memos on warm mixes and terminal blends. Dr. Ding Cheng of the Department of Civil Engineering is helping with this effort along with the help of 2 students, Tyler Duffy and Tyson Teesdale. Both tech memos were submitted to the CIWMB on April 1, 2010 for review. The revised versions will be submitted to CIWMB on May 15, 2010 as attachments to this summary report.
3.0 MAJOR FINDINGS

3.1 Terminal Blends

Major findings from this study include:

- Terminal blend products have been used since the mid 1980’s starting with Florida and Texas.
- California, Oregon, Arizona, Louisiana, Colorado, and Nevada also have used Terminal blend products.
- Application of products includes HMA, chips seals, and slurry seals.
- HMA mixes have been placed using dense, open and gap graded aggregates.
- Caltrans and others have completed a number of projects and lab tests to compare Terminal blends to other projects. These tests have increased awareness of the product as a viable alternative.
- Increased use is attributed to lower cost and better performance.
- Terminal blends have performed as well or better than comparable asphalt rubber products.
- Arizona and Nevada use similar specifications as California. Kansas, Texas, and Florida use a lower content of asphalt rubber than California.
- Issues with Terminal blend are mostly due to lack of experience with the product during the construction process.
- Terminal blend products have also shown to reduce noise and improve driving safety.

3.2 Warm mixes

Major findings from this study include:

- The use of warm mix additives with RHMA lowers production temperatures and visibly eliminates the “haze” associated with paving at hot temperatures. It has also been able to lower the emissions from the plant and allow the plant to save money by consuming less burner fuel.
- Even though the RWMA projects are in their early stages, they have been performing equally well or superior to conventional RHMA mixes.
- RWMA mixes were initially used for shoulder projects because of the unknown performance of the RWMA mixture. Lately, more districts of Caltrans are installing the RWMA mixes on the mainline of major thoroughfares.
- Many states are using the WMA technologies; however, only three are using RWMA. Those states are California, Massachusetts, and Florida.
- Caltrans is becoming more active with WMA and RWMA projects.
3.3 LA County Terminal Blend project

In January 2008, the California Integrated Waste Management Board (CIWMB) offered the Los Angeles County Department of Public Works (County) a grant to construct a chip seal using performance graded paving asphalt containing tire rubber, commonly referred to as a “terminal blend.” The Director of Public Works recommended to the County Board of Supervisors (Board) that the grant be accepted. On July 18, 2008 the Board accepted a grant in the amount of $400,000 from the CIWMB. The agreement states, “This contract will help build the knowledge base for terminal blend materials in pavement strategies such as chip seals by creating in-field test sections that will be monitored for material performance. … and should yield valuable empirical results that can be used by Caltrans, local governments and industry as to how the performance of terminal blend chip seals compares to conventional and asphalt rubber chip seals.”

The Lake Los Angeles/Hi Vista unincorporated areas of the Antelope Valley region of Los Angeles County were selected due to the suitability of many roads in these areas for chip sealing and the chip sealing experience and capability of Larry Dunlop, Road Maintenance Superintendent and his Road Division 555 staff. Erik Updyke and Imelda Diaz, P.E., Civil Engineer, Pavement Management Unit Head, reviewed pavement management data and field reviewed numerous roadways to identify potential roadway sections. The project roadway sections selected, after discussion with Larry Dunlop, were Avenue O between 120th Street East and 170th Street East and Avenue J between 150th Street East and 170th Street East.

Avenue O serves as an arterial route between the community of Lake Los Angeles and the City of Palmdale. Avenue J serves as an arterial route between the City of Lancaster to the west and western San Bernardino County to the east. Both routes have a posted speed limit of 55 mph and traffic appears to routinely exceed this limit. The sections were selected in order to contrast roadway conditions and the level of pavement preparation performed.

Findings from the test section included the following:

- The chip seal has performed well.
- The laboratory portion of the QAP was not closely adhered to.
- There is no evidence of rock loss. The occasional bare areas adjacent to an outside edge appear to be the result of the chip seal not being placed wide enough to cover the area in question.
- Distress in the underlying pavement is still evident, but has been sealed.
- There is no evidence of underlying cracks reflecting through the chip seal.
- The isolated areas of flushing are in locations where binder application overlapped.
- There is minor flushing in the wheel paths of several study sections. This flushing appears attributable to excessive overlap of spray bar nozzles.
- The chip seal over pavement fabric study section has the best appearance and texture among all the study sections. The best portion of this study section is where a double chip seal was applied as a corrective action during construction.
• The chip seal has the ability to fill transverse cracks approximately 3/4 inch in width or less, but not to fill ruts at typical chip application rates.
• The Avenue O segment appears suitable for a double chip seal application. This indicates that roads with more severe distress and limited preparation work should be considered for a double chip seal application.
• The deficiencies identified to date are attributable to workmanship, not to the performance of any material.
• Cost. Based on the data summarized in the “RINV Report” produced by the County’s eCaps accounting system, the total project cost was approximately $254,000, or $2.81/square yard assuming a pavement width of 22 feet. This cost includes labor, equipment, materials, material testing, and construction observation.
4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

4.1.1 Terminal blends

Conclusions on the terminal blend portion of the study include:

- Terminal blends have been used in asphalt pavements since the 1980’s and have performed as well or better than conventional products. They have been used in dense, gap and open graded mixes, but work best in dense and open graded mixes.
- Terminal blend projects should continue to be used throughout the state of California. They are another tool in the pavement preservation toolbox.
- Terminal blends can contain at least 15% asphalt rubber for use in chip seals and in hot mixes. These products should be eligible for the CIWMB grant program.
- Terminal blends and asphalt rubber perform in a comparable manner. However, they are not the same product and cannot be interchanges.

4.1.2 Warm mixes

Conclusions regarding the warm mix portion of the study include:

- Asphalt Rubber (AR) has shown that it can reduce noise levels of the roads and reduce fatigue cracking. This is of interest to California because the state’s roadways experience high distress levels and many urban thoroughfares are near residences.
- Producing AR mixes requires higher temperatures for both production and compaction. With the addition of warm mix additives, RHMA temperatures have been reduced significantly, allowing for better working conditions and an extension of the paving season. With the use of the lower production temperatures, emissions are reduced and more RWMA are able to be produced.
- California is an ideal state to have pilot projects of RWMA. This is because California has four different types of climate (coastal, mountain, valley, and desert). Along with the climates, California has roads that are ranked close to the poorest in the nation. If these pilot projects prove to be successful, then it will be known that RWMA works in various climates and can fix roads in poor condition.

Only time will tell whether or not RWMA is able to outperform RHMA mixes. If it does, then California will easily be able to adhere, and perhaps surpass the mandated AR usage by 2013.

4.1.3 LA County project

Preliminary conclusions resulting for the LA County project include the following:
• Terminal blends containing over 15% crumb rubber are another tool in the pavement preservation tool kit.
• This project demonstrated that PG 76-22TR could be successfully used in a chip seal application on roadways with low traffic volumes and traffic indexes and moderate to severe distress levels.
• Terminal blends can be applied without the need of a sniffer since they do not smoke excessively compared to asphalt rubber spray applications.
• The pavement condition (PCI 30-40) on which the terminal blend was applied was considered less than desirable: however the initial performance has been better than expected.

4.2 Recommendations

4.2.1 Terminal blends

Recommendations for this portion of the study include at least the following:
• Terminal blends are recommend for the grant program of the CIWMB as long as they contain at least 15% crumb rubber
• Terminal blends should be evaluated for use with warm mix technologies

4.2.2 Warm mixes

Based on the findings to date, the following recommendations are appropriate:
• More agencies should consider to use of warm mixes with asphalt rubber for night time construction and for cool climates
• We need to develop trials for using warm mix technologies in trials for spray applications with asphalt rubber and terminal blends.

4.2.3 LA County project

Recommendations resulting from the study included:
• Material temperatures (binder and pre-coated chips) require close monitoring during placement.
• Chip spreaders must be properly equipped to handle hot, pre-coated chips.
• Chip seal placement on roadway segments with moderate to steep grades (greater than 2%) should be placed downhill.

LA County will continue to monitor the performance of this section for another 5 years to establish the long term performance of the product applied to pavements in poor condition.
5.0 REFERENCES

