FEASIBILITY OF USING CRUMB RUBBER MODIFIER IN HOT-MIX ASPHALT PAVEMENT APPLICATIONS IN PUERTO RICO

Final Report

Submitted to

Puerto Rico Highway and Transportation Authority
Minillas South Building, Santurce, P.R. 00940

Submitted by

Dr. Benjamín Colucci
Dr. José A. Colucci
Principal Investigators

Eng. Jorge Velar Prieto
Research Assistant

in collaboration with

David Dayton
Technical Editor
Civil Infrastructure Research Center

March 1994
NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its content or use thereof. The contents of this report reflect the views of the contractor, who is responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the Department of Transportation. This report does not constitute a standard, specification or regulation.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Summary</td>
<td>1</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>4</td>
</tr>
<tr>
<td>Glossary of Acronyms</td>
<td>5</td>
</tr>
<tr>
<td><strong>Introduction</strong></td>
<td>6</td>
</tr>
<tr>
<td>Background</td>
<td>6</td>
</tr>
<tr>
<td>1991: ISTEA Establishes Minimum Usage Requirements</td>
<td>6</td>
</tr>
<tr>
<td>1993: Congress Delays Enforcement of CRM Provisions</td>
<td>7</td>
</tr>
<tr>
<td>1993: FHWA Implementation Guidelines</td>
<td>8</td>
</tr>
<tr>
<td>The Rationale: Recycling Scrap Tires</td>
<td>11</td>
</tr>
<tr>
<td>Possible Technical Benefits and Legitimate Concerns</td>
<td>12</td>
</tr>
<tr>
<td>Objective and Scope of This Study</td>
<td>14</td>
</tr>
<tr>
<td>Organization of the Report</td>
<td>15</td>
</tr>
<tr>
<td>1. Use of Crumb Rubber in Hot-Mix Asphalt: Feasibility Issues</td>
<td>16</td>
</tr>
<tr>
<td>1.1 Definition</td>
<td>16</td>
</tr>
<tr>
<td>1.2 CRM Production Process</td>
<td>16</td>
</tr>
<tr>
<td>1.3 Shipping Considerations</td>
<td>18</td>
</tr>
<tr>
<td>1.4 Factors Affecting Price</td>
<td>18</td>
</tr>
<tr>
<td>1.5 CRM Technologies</td>
<td>19</td>
</tr>
<tr>
<td>1.5.1 Wet Process: General Description</td>
<td>19</td>
</tr>
<tr>
<td>1.5.2 Dry Process: General Description</td>
<td>20</td>
</tr>
<tr>
<td>1.5.3 Other CRM Terminology</td>
<td>21</td>
</tr>
<tr>
<td>1.5.4 CRM State-of-the-Technology</td>
<td>21</td>
</tr>
<tr>
<td>1.6 Wet Process: Technical Discussion</td>
<td>24</td>
</tr>
<tr>
<td>1.6.1 Description of Reaction</td>
<td>24</td>
</tr>
<tr>
<td>1.6.2 Equipment and Methodology</td>
<td>24</td>
</tr>
<tr>
<td>1.6.3 Factors Affecting Reaction</td>
<td>25</td>
</tr>
<tr>
<td>1.6.4 Modified Binder Tests</td>
<td>26</td>
</tr>
<tr>
<td>1.6.5 Rehabilitation and Construction Techniques</td>
<td>29</td>
</tr>
<tr>
<td>1.6.6 Advantages of Modified Binder</td>
<td>30</td>
</tr>
<tr>
<td>1.6.7 Disadvantages of Modified Binder</td>
<td>31</td>
</tr>
<tr>
<td>1.7 Dry Process: Technical Discussion</td>
<td>33</td>
</tr>
<tr>
<td>1.7.1 Process Description</td>
<td>33</td>
</tr>
<tr>
<td>1.7.2 Advantages of CRM HMA Pavements</td>
<td>34</td>
</tr>
<tr>
<td>1.7.3 Disadvantages of CRM HMA Pavements</td>
<td>34</td>
</tr>
<tr>
<td>1.8 CRM Construction Experience</td>
<td>35</td>
</tr>
</tbody>
</table>
3. Known CRM technologies at different levels of development ........................................ 22
4. Experience with CRM technologies among the states ............................................... 23
5. Allowable contents of deleterious particles in CRM ................................................... 26
6. Allowable contents of the chemical components of CRM ........................................... 27
7. Estimated Costs of RUMAC Compared to Unmodified HMA ....................................... 44
8. Estimated Cost of HMA Conventional Binder versus Asphalt Rubber Binder ............... 45
9. CRM Minimum Utilization Requirements Applied to Puerto Rico ................................. 78
10. Summary of scrap tire legislation among the States ................................................... 80
11. Cabo Rojo Municipal Tire Sales Tax Schedule ............................................................ 85

FIGURES
1. Schematic of the basic CRM processes and products .................................................. 21
2. Schematic of the wet process ....................................................................................... 24
3. The effect of CRM on the binder temperature-viscosity curve ...................................... 31
4. Numbers of registered motor vehicles in Puerto Rico .................................................. 56
5. Territorial distribution of the municipalities that responded to the questionnaire ......... 65
6. Characterization of the scrap tire disposal problem by municipalities responding to the questionnaire ............................................................... 66
7. Methods currently used by municipalities to dispose of scrap tires ............................... 66
8. Municipalities with a designated area for storage of scrap tires .................................. 67
9. Municipalities reporting that storage of scrap tires is a problem .................................. 67
10. Municipalities reporting alternative uses for scrap tires .......................................... 68
11. Municipalities that envision using a tire shredder in the near future ............................ 68
12. Municipalities that are in the process of purchasing a tire shredder, alone or in cooperation with other municipalities .......................... 69
13. Municipalities with legislation related to scrap tire disposal ...................................... 69

PHOTOGRAPHS
1. Unsheltered storage of discarded tires ........................................................................ 57
2. Illegal dumping of scrap tires ..................................................................................... 59
3. Illegal dumping of scrap tires ..................................................................................... 60
4. Storage of Scrap Tires in Landfills ............................................................................. 71
5. Whole tire shredder owned by municipality of Bayamón ........................................... 73
6. Strips produced by municipality of Bayamón tire shredder ......................................... 74
7. A typical roadside used tire business ........................................................................ 84

EXHIBITS
1. Survey of Municipalities .............................................................................................. 61
Executive Summary

This report presents the findings of a study to assess the feasibility of using crumb rubber modifier (CRM) in hot-mix asphalt (HMA) pavement applications in Puerto Rico, as required by Section 1038(d) of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). The study was undertaken at the request of the Department of Transportation and Public Works (DTPW), with the joint support of the Puerto Rico Transportation Technology Transfer Center and the Civil Infrastructure Research Center in the Department of Civil Engineering at the University of Puerto Rico, Mayagüez Campus.

Early in the course of this study, the investigators found that CRM utilization in HMA pavement applications is inextricably linked to the problem of scrap tire recycling. It was decided, therefore, to deal with both subjects in an integrated fashion, giving more detailed emphasis to CRM HMA technology, but also providing an overview of the tire recycling issue as it pertains to Puerto Rico. The goal was to provide the Island's policy makers with a complete and coherent understanding of the challenges presented by the Section 1038(d) minimum utilization requirements for CRM in HMA pavement applications.

For this reason, the detailed findings of this study are reported in two sections.

- Section 1 reviews the basics of CRM HMA technology and summarizes the potential benefits, problems, and unanswered questions related to its use in pavement applications.

- Section 2 provides an overview of the solid waste management problem created by discarded scrap tires in Puerto Rico.

The information reported in Section 1 derives from an extensive review of the pertinent research literature and interviews with experts in CRM production and CRM HMA applications. The latest guidelines for compliance with Section 1038(d) issued in 1993 by the Federal Highway Administra-
tion (FHWA) are summarized, and concerns about crumb-rubber modified asphalt production and performance raised by the National Asphalt Pavement Association (NAPA) and representatives of Puerto Rico's asphalt producers are discussed.

Section 2 is based primarily on a survey of the Island's municipal governments. The legislation that has been enacted or proposed at various levels of government to address the problem of scrap tires is also reviewed, and various non-pavement recycling/reuse alternatives are discussed.

Each section concludes with the key findings reviewed in condensed form, followed by pertinent recommendations for action by the DTPW and other Commonwealth agencies to prepare Puerto Rico to meet the ISTEAA Section 1038(d) requirements for utilization of CRM and other recycled materials in hot-mix asphalt pavement applications.

The major conclusions of this study are:

1. In Puerto Rico, as in most areas of the mainland U.S., discarded motor vehicle tires present a serious solid waste management problem.

2. Using CRM in asphalt paving applications offers, at best, a partial solution to the Island's scrap tire problem, and there appear to be other ways of reusing and recycling tires that are more cost-effective.

3. The engineering benefits of asphalt rubber pavements are uncertain, and it is not known whether their higher costs are justified by better performance and durability.

4. In comparison with most of the states, Puerto Rico will have to do more and spend more, in relative terms, to meet ISTEAA CRM requirements, because the Island's current waste management and asphalt production and paving practices present greater obstacles.

5. Though there is considerable disagreement in the U.S. over the desirability of utilizing CRM in HMA applications, the current minimum utilization requirements are scheduled to go into effect beginning in Federal Fiscal Year 1995 (October 1, 1994-September 30, 1995). The first State certification for meeting the CRM requirements will be due on January 1, 1996. If Puerto Rico does not meet the 10% utilization requirement, it will face the loss of 10% of its Highway Trust Fund apportionment in FY 1996.
The major recommendations of this report are:

1. The DTPW should establish a task force to coordinate the implementation of a comprehensive plan for satisfying ISTEA utilization requirements for CRM in HMA pavement applications. The task force should include the Governor's Advisor on the Infrastructure and representatives from the DTPW, the Puerto Rico Highway and Transportation Authority (PRHTA), the Solid Waste Authority (SWA), the municipalities, the tire importers association, the local asphalt production industry, and the FHWA.

2. The DTPW should work closely with the Island's asphalt producers and contractors to identify the best course of action to overcome the obstacles to incorporating CRM and other recycled materials in HMA pavements.

3. The DTPW should fund and coordinate a pilot project to test one or more of the newer CRM technologies.

4. The Commonwealth should enact a new tire sales tax to defray the costs incurred in tire shredding, storage operations, and to subsidize the research and development necessary to test and implement a variety of environmentally benign methods for the disposal of scrap tires.
Acknowledgments

The authors wish to extend their sincere appreciation to the Puerto Rico Highway and Transportation Authority for funding this research project.

This report was prepared as part of a special project of the Transportation Technology Transfer Center (TT3 Center) in conjunction with the Civil Infrastructure Research Center of the Department of Civil Engineering of the University of Puerto Rico, Mayagüez Campus. Acknowledgment is also made to the University Transportation Research Center, which awarded funds to the University of Puerto Rico for Eng. Jorge Velar's research assistantship.

The contents of this report reflect only the views of the authors and do not necessarily reflect those of the officials of the PRHTA, the DTPW, the FHWA, or the University of Puerto Rico.
# Glossary of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>Average Annual Daily Traffic</td>
</tr>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>AC</td>
<td>Asphalt Cement</td>
</tr>
<tr>
<td>AR</td>
<td>Asphalt Rubber</td>
</tr>
<tr>
<td>ARHM</td>
<td>Asphalt Rubber Hot Mix</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>CALTRANS</td>
<td>California Department of Transportation</td>
</tr>
<tr>
<td>CRM</td>
<td>Crumb Rubber Modifier</td>
</tr>
<tr>
<td>DTPW</td>
<td>Department of Transportation and Public Works</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation (Federal)</td>
</tr>
<tr>
<td>FDOT</td>
<td>Florida Department of Transportation</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>HMA</td>
<td>Hot Mix Asphalt</td>
</tr>
<tr>
<td>ISTEA</td>
<td>Intermodal Surface Transportation Efficiency Act</td>
</tr>
<tr>
<td>IVHS</td>
<td>Intelligent Vehicle-Highway System</td>
</tr>
<tr>
<td>MUR</td>
<td>Minimum Utilization Requirement</td>
</tr>
<tr>
<td>NAPA</td>
<td>National Asphalt Pavement Association</td>
</tr>
<tr>
<td>NCAT</td>
<td>National Center for Asphalt Technology</td>
</tr>
<tr>
<td>NJDOT</td>
<td>New Jersey Department of Transportation</td>
</tr>
<tr>
<td>PCCP</td>
<td>Portland Cement Concrete Pavement</td>
</tr>
<tr>
<td>PRHTA</td>
<td>Puerto Rico Highway and Transportation Authority</td>
</tr>
<tr>
<td>RAP</td>
<td>Recycled Asphalt Pavement</td>
</tr>
<tr>
<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
</tr>
<tr>
<td>RUMAC</td>
<td>Rubber Modified Hot Mix Asphalt</td>
</tr>
<tr>
<td>SAM</td>
<td>Stress Absorbing Membrane</td>
</tr>
<tr>
<td>SAMI</td>
<td>Stress Absorbing Membrane Interlayer</td>
</tr>
<tr>
<td>SHRP</td>
<td>Strategic Highway Research Program</td>
</tr>
<tr>
<td>SWA</td>
<td>Solid Waste Authority (Puerto Rico)</td>
</tr>
<tr>
<td>TDF</td>
<td>Tire Derived Fuel</td>
</tr>
<tr>
<td>TDOT</td>
<td>Texas Department of Transportation</td>
</tr>
<tr>
<td>T³</td>
<td>Transportation Technology Transfer Center</td>
</tr>
<tr>
<td>UPR</td>
<td>University of Puerto Rico</td>
</tr>
<tr>
<td>UPRM</td>
<td>University of Puerto Rico at Mayagüez</td>
</tr>
<tr>
<td>WPLC</td>
<td>Wisconsin Power &amp; Light Company</td>
</tr>
</tbody>
</table>
Introduction

Background

Puerto Rico’s highway pavement infrastructure, representing billions of dollars in public funds invested over several decades, constitutes a remarkable engineering achievement which has made an invaluable contribution to the Island's socio-economic growth. Today, now that most of the Island’s planned highway network has been constructed, emphasis is being shifted to development of innovative maintenance techniques and rehabilitation procedures, along with the identification of new paving materials.

Recently, the search for improved paving materials in the United States has coincided with a growing effort to recycle solid waste materials. A wide variety of waste materials have been suggested as viable, or even beneficial, additives to HMA pavements. Legislation has been enacted in many states, though not yet in Puerto Rico, to either mandate the use of industrial waste (cellulose, wood lignin bottom ash, and fly ash), municipal and/or domestic waste (incinerator residue, scrap rubber, and glass), and mining wastes (coal mine refuse) in HMA pavements, or to examine the feasibility of such usage. Rubber from scrap tires has become the principal focus of federal government’s efforts to encourage the use of recycled materials in the reconstruction and rehabilitation of deteriorated pavements.

Rubber from scrap tires is used in HMA paving in the form of crumb rubber modifier (CRM), which is simply the term for crumb rubber derived from scrap tire rubber that has been reduced to particle sizes of less than 1/4", making it suitable for use in the asphalt paving process. CRM can be used in asphaltic concrete mix design either as part of the aggregate or as part of the asphalt binding material.

1991: ISTEA Establishes Minimum Usage Requirements

In December of 1991, President Bush signed into law the Intermodal Surface Transportation Efficiency Act (ISTEA). The use of recycled rubber from scrap tires in HMA pavements mandated by Section 1038 of ISTEA is a Federal requirement applicable to Puerto Rico. Section
1038(d) of ISTEA established minimum utilization requirements (MURs) for asphalt pavement containing recycled rubber, which were to go into effect beginning in Fiscal Year 1994. The law stipulated that a percentage of the total tons of HMA laid in any given State to pave roadways partially financed with Federal funds would be required to contain recycled rubber. The percentages were 5% for 1994, 10% for 1995, 15% for 1996, and 20% for 1997. The 20% minimum utilization requirement would remain in effect each year after 1997. The law required that any State failing to fully achieve the required percentage in any year would lose the same full percentage of their highway funds as the missed mandated percentage for the year in question; i.e., a State failing to meet the 10% MUR in 1995 would lose 10% of its formula funds under Title 23 in FY1996, unless granted a waiver by the U.S. Secretary of Transportation. (See Appendix A for the text of Section 1038, "Use of Recycled Paving Material," and Section 2.5.1 of this report, "Federal Legislation.")


Concerns about the high costs of asphalt pavements containing recycled rubber and the possible environmental and health risks associated with CRM HMA production processes have fueled opposition to the widespread implementation of CRM technology as mandated by Section 1038 of ISTEA. The National Asphalt Pavement Association is spearheading an effort in Washington to get Congress to postpone, indefinitely, the minimum utilization requirements for asphalt pavements containing recycled rubber. This effort may be gaining ground. In July of this year U.S. Department of Transportation (DOT) Secretary Federico Peña sent a letter to the Speaker of the U.S. House of Representatives in which he indicated that while the DOT appreciated the importance of addressing the scrap tire problem, it lacked sufficient test data to conclude that scrap rubber was an acceptable additive to asphalt.¹

In late September, after conducting hearings on the recycled rubber provision of ISTEA, the House Transportation Appropriations Subcommittee included a provision in its version of the FY 1994 DOT appropriations bill (H.R. 2750) that prohibits any Federal efforts to enforce the requirements for recycled rubber in asphalt pavements during 1994.² The full House
adopted and the Senate later passed the appropriations bill with Section 325, the anti-CRM provision, intact; the Senate added $750,000 for the FHWA to conduct more studies on the health and environmental issues related to the use of CRM in asphalt paving.³

1993: FHWA Implementation Guidelines

The FHWA issued three important memoranda in 1993 setting forth the agency's policy regarding fulfillment of the Section 1038 requirements by the States. The most important points in these memoranda are summarized below; the full texts are included in Appendix B.

Memorandum of June 28, 1993. This memorandum from the FHWA Associate Administrator for Program Development provides detailed information needed to ensure compliance with each subsection of Section 1038 of ISTEA. Regarding subsection (d), the memorandum reiterates the MUR percentages described above and then makes the following important points regarding implementation of the MURs:

1. The MURs will be based on "percentages of the contract bid quantities of asphalt pavement awarded in the State during the fiscal year and financed in whole or part by any assistance pursuant to Title 23, United States Code. Compliance with the minimum utilization requirement shall be based on the total number of kilograms of recycled rubber required by awarded contract bid quantities of asphalt pavement containing recycled rubber."

2. "Both Federal-aid and non-Federal-aid quantities of asphalt pavement containing recycled rubber shall be eligible for satisfying the minimum utilization requirement."

3. The formula $R = U \times (10M + 150S)$ will be used to compute the MUR, where $R$ is the kilograms of recycled rubber needed to satisfy the MUR; $U$ is the required MUR percentage expressed as a decimal; $M$ is the total contract metric tons of Federal-aid hot mix awarded during a given fiscal year; and $S$ is the total contract metric tons of Federal-aid hot spray applied binder awarded during the fiscal year. The formula is based on 10 kg (22 pounds) of recycled rubber per metric ton (1.1 tons) of hot mix and 150 kg (330 pounds) of recycled rubber per metric ton of spray applied binder.
4. "Any application of recycled rubber in hot mix or spray-applied binder used to construct or maintain an asphalt pavement base, interlayer, or surface on any highway project is eligible for satisfying the minimum utilization requirement. Other highway related uses of asphalt pavement containing recycled rubber shall also be eligible."

5. ISTEA Section 1038(d)(2), "Other Materials," stipulates that any other recycled material or materials designated by the FHWA can be substituted for recycled rubber in meeting up to 5% of the MUR in any given year. In the memorandum of June 28, 1993, the FHWA identifies the following materials as being acceptable substitutes for CRM and sets the equivalency amounts indicated below for each type of material:

- **Reclaimed Asphalt Pavement (RAP):** 1 metric ton will be considered equal to 10 kg of recycled rubber.
- **Recycled Glass:** 1 metric ton will equal 70 kg of recycled rubber.
- **Reclaimed Concrete Pavement:** 1 metric ton will equal 10 kg of recycled rubber.
- **Coal Fly Ash:** 1 metric ton will equal 170 kg of recycled rubber.
- **Mining Waste Rock:** 1 metric ton will equal 10 kg of recycled rubber.
- **Blast Furnace Slag** (non-metallic by-product of iron production): 1 metric ton will equal 10 kg of recycled rubber.

**Memorandum of September 17, 1993.** Also from the FHWA Associate Administrator for Program Development, this follow-up to the June 28 memorandum consists of a series of questions and answers regarding Section 1038. The most noteworthy clarifications offered in this memorandum are:

1. States will not be given a "running account" for the purpose of fulfilling the MURs; i.e., exceeding the MUR in one year will not affect the State's obligation to fully meet the MUR for the next year.

2. The penalty applied to a State that does not meet the MUR in a given year will be assessed for the full percentage of the MUR, even if the State fails to meet the MUR by a fraction of a percentage point. In other words, if the MUR is 10% and the State manages only
9.5% utilization, the penalty assessed will still be 10% of its formula funding for the subsequent fiscal year.

3. States cannot request a reduction in the MUR based on insufficient supply of CRM.

4. Rubber asphalt sealants and other materials eligible for satisfying the MURs may be used by State maintenance crews. For these materials, purchase orders or contracts for the purchase of these materials will be considered the same as awarded contract quantities and counted toward the MUR for the Federal fiscal year in which they are purchased.

5. A State may use less than 10 kg/ton of recycled rubber in hot mix pavement applications and less than 150 kg/ton of spray-applied binder so long as the total amount of recycled rubber for the fiscal year is equal to or greater than the amount computed by the equation specified in the June 28 memorandum and explained on the previous page of this document.

6. Hot-mixed, cold-laid mixture containing RAP is not allowable for satisfying MURs; only hot-mix applications are allowed. Thus, in-place recycling and RAP mixed with emulsion and placed as a treated base are also ineligible applications.

7. For every metric ton of RAP used in an eligible application, credit will be given for 10 kg of recycled rubber, regardless of what percentage of RAP is used in the mixture. Thus, one ton of a mixture containing 50 percent RAP would earn the State credit for 5 kg of recycled rubber.

Memorandum of November 2, 1993. This memorandum from the Executive Director of the FHWA clarifies the ramifications of Section 325 of H.R. 2750, the Department of Transportation Appropriations Act for FY 1994, which prohibited use of the appropriated funds "to implement, administer, or enforce the provisions of Section 1038(d)" of ISTEA. The memorandum makes three points:

1. Section 325 does not prohibit a State's use of asphalt pavement containing recycled rubber.

2. Section 325 will not result in a State's being assessed a penalty in subsequent years for not meeting the Section 1038(d) FY 1994 5% MUR.
The effect of Section 325 is to nullify the FY 1994 MUR under Section 1038(d); the other MURs remain in effect and, unless Congress legis­lates a continuation of the moratorium on enforcement of Section 1038(d), States will be required to meet the 10% MUR for CRM and allowable substitute materials (up to 5%) applicable for Federal FY 1995.

**The Rationale: Recycling Scrap Tires**

The Environmental Protection Agency (EPA) has estimated that 285 million tires are discarded annually in the United States, and only 34% (97 million) are currently being reused or recycled. The remaining 66% (188 million) contribute to the already alarming environmental solid waste problem. Table 1 presents a statistical overview of the scrap tire problem nationwide.

**Table 1. Description of scrap tire usage in the United States**

<table>
<thead>
<tr>
<th>Scrap Tire Usage</th>
<th>Quantity (millions)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retreaded</td>
<td>33</td>
<td>11.6%</td>
</tr>
<tr>
<td>Reused/resold</td>
<td>22</td>
<td>7.7%</td>
</tr>
<tr>
<td>Tire-derived fuel (TDF)</td>
<td>26</td>
<td>9.1%</td>
</tr>
<tr>
<td>Crumb Rubber Modifier (CRM)</td>
<td>2</td>
<td>0.7%</td>
</tr>
<tr>
<td>Other Uses (i.e., retaining walls, sub-base, etc.)</td>
<td>14</td>
<td>4.9%</td>
</tr>
<tr>
<td>Solid waste (i.e., landfills, illegal dumps, etc.)</td>
<td>188</td>
<td>66%</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>285</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

In Puerto Rico, as in most areas of the mainland U.S., discarded motor vehicle tires present a serious solid waste management problem. The Puerto Rico Solid Waste Authority (SWA) estimates that 2-3 million tires end up in landfills and illegal dumps each year. The unregulated importation of used tires from the U.S. mainland makes the Island's scrap tire problem even worse. In 1992, 806,270 used tires were brought to Puerto Rico, according to the Chamber of Commerce's Maritime Register.
The Executive Director of the SWA has estimated that the true figure is closer to 1.5 million used tires imported annually.\textsuperscript{8}

In Puerto Rico, a very small percentage of the tires discarded each year are reused or recycled. A survey of current waste management practices in Puerto Rico, conducted as part of this study, found that less than 7\% (2 out of 31) of the municipalities on the Island recycle used tires in any way. **Incorporating scrap tire rubber in HMA paving, then, would represent an even greater environmental benefit here in Puerto Rico than in most of the mainland U.S.** When CRM is used as an aggregate, a typical three-inch overlay construction of two-lane road could use up to 12,000 discarded tires per mile as part of its job mix design. Seal coats containing CRM could use an additional 1,600 tires per mile on a typical two-lane road.\textsuperscript{9,10}

**Possible Technical Benefits and Legitimate Concerns**

In addition to the environmental benefits to be gained from using CRM in HMA applications, there are a number of possible performance benefits associated with the engineering qualities of CRM asphalt pavements, namely:\textsuperscript{11}

- Thinner lift
- Retarded reflection and thermal cracking
- Increased pavement life
- Reduced maintenance costs
- Decreased traffic noise

Balanced against the possible advantages of adopting this technology, however, are a number of legitimate concerns, which may be summarized as follows:\textsuperscript{12}

- **Engineering concerns** regarding factors affecting the engineering properties of the resulting asphalt (i.e. strength, durability, ductility,
etc.), quality assurance testing procedures, and required modifications to conventional production processes.

- **Countervailing environmental concerns** regarding the recyclability of CRM pavements and the possible pollution and worker health hazards associated with the processing and application of CRM asphalt products.

- **Basic economic concerns** about the costs versus benefits of CRM asphalt products.

It should be stressed, at the outset of this report, that there is considerable disagreement over the desirability of utilizing CRM in HMA pavements. NAPA is opposed to implementation of ISTEA's minimum utilization requirements for CRM in HMA pavements. NAPA has stated in several forums that it will continue to pursue deferment of the minimum utilization requirements for rubber in asphalt pavement contained in the 1991 ISTEA bill. In December of 1992, NAPA sent a letter to then U.S. Secretary of Transportation Andrew Card and EPA administrator William K. Reilly, recommending that implementation of the CRM mandates be waived until studies verify that its use in HMA poses no threat to worker health during production or placement of the material.13

A report published by NAPA in February 1993 argues that several promising uses for scrap tires, principally as an energy resource and as lightweight fills and drainage layers in civil engineering applications, are much more cost-effective solutions to this solid waste problem than using CRM in HMA pavements.14 In addition to highlighting concern that worker health risks and environmental damage may be exacerbated by the addition of CRM to asphalt, the NAPA report claims that the cost to dispose of tires in asphalt pavements works out to between $5 and $10 per tire, whereas alternative uses (which are discussed later in this report) could cost as little as 15 cents per tire. While those numbers appear to overstate the cost-benefit advantage presented by the alternative uses, they underscore the possible desirability of adopting a scrap tire management plan that puts equal or greater emphasis on non-
pavement-related uses of scrap tire rubber as it does on CRM pavement applications.

Objective and Scope of This Study

The original objective of this study was to make a preliminary assessment as to the feasibility of using CRM asphalt pavement mixtures in Puerto Rico, as required by Section 1038(d) of the 1991 Intermodal Surface Transportation Efficiency Act. The study was undertaken at the request of the Department of Transportation and Public Works (DTPW), with the joint support of the Puerto Rico Technology Transfer Center and the Civil Infrastructure Research Center in the Department of Civil Engineering at the University of Puerto Rico Mayagüez Campus.

In accordance with the objective stated above, the following tasks were carried out:

1. An extensive review of the pertinent research literature.

2. A questionnaire survey of the Island's municipal governments regarding the uses and management of discarded tires.

3. Interviews with (a) experts in the construction of CRM asphalt pavements, (b) a CRM producer, (c) new tire dealers, and (d) representatives of the Island's asphalt producers.

Organization of the Report

In the course of this study, the investigators found that CRM utilization in HMA pavement applications cannot logically be separated from the issue of scrap tire recycling. It was decided, therefore, to deal with both subjects in an integrated fashion, going beyond the original intent of the study to give a more complete and coherent understanding of the challenges presented by the Section 1038(d) minimum utilization requirements for CRM in HMA pavement applications. The body of this report, therefore, is divided into two broad areas, which are followed by a section that summa-
rizes the major findings and a brief concluding section that presents a recommended action plan.

**Section I** summarizes the asphalt technology issues involved in assessing the feasibility of using CRM in HMA pavement applications; it is based on an extensive review of the research literature and interviews with experts in CRM production and CRM HMA paving applications. The 1993 guidelines for compliance with Section 1038(d) issued by the FHWA are summarized, and concerns about crumb-rubber modified asphalt production and performance are discussed. The main purpose of this section is to identify the technology options, estimated costs, and the engineering and environmental uncertainties involved in implementing CRM HMA pavement applications in Puerto Rico. The section ends with a summary analysis followed by specific recommendations corresponding to short-, medium-, and long-term horizons.

**Section 2** provides an overview of the magnitude and significance of the solid waste management problem created by discarded scrap tires in Puerto Rico. The results of a survey taken of the Island's municipal governments regarding their current procedures and plans for handling scrap tires are reported, along with the general attitudes and concerns of new tire vendors. The legislation that has been enacted or proposed at various levels of government to address the problem of scrap tires is reviewed, and various recycling/reuse alternatives, other than using recycled rubber in pavements, are discussed. The purpose of this section is to make a preliminary determination of legislative action that needs to be taken and waste management practices that need to be implemented in order to limit the numbers of tires discarded each year and to establish procedures for dealing with them that would be compatible with the requirements of CRM processing. The section ends with a summary analysis followed by specific recommendations corresponding to short-, medium-, and long-term horizons.
Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico

SECTION 1

Use of Crumb Rubber in Hot-Mix Asphalt: Feasibility Issues
1. Use of Crumb Rubber in Hot-Mix Asphalt: Feasibility Issues

1.1 Definition

Crumb rubber is recycled rubber reduced to crumb-size by mechanical shearing and grinding. The term crumb rubber modifier (CRM) refers to crumb rubber derived from scrap tire rubber that has been reduced to particle sizes of less than 1/4", making it suitable for use in asphalt paving. Though considerable variation in tire rubber exists, between distinct sections of the same tire as well as between different kinds of tires, the composition of a CRM bulk final sample—percent of natural rubber, synthetic rubber, carbon black, fibers, and steel belting—is reasonably uniform.

1.2 CRM Production Process

Scrap tire rubber can be delivered to CRM processing plants as whole tires, cut tires, and/or shredded tires, depending of the capability of the processing plant. Whole tires are the least expensive option, but they are more difficult to handle and take more space than either cut or shredded tires. Cut tires represent an unsatisfactory middle option from the standpoint of either cost or handling ease. Shredded tire rubber is the most preferred, logical, and cost-effective raw material for producing CRM. Most tire shredding equipment is mobile and can easily be moved from one scrap tire stockpile or landfill to another. The shredding process reduces the tire to pieces that are 6 inches square or smaller. Though tire shredding is usually a mobile operation, CRM processing is not, and requires, at the very least, a small industrial facility with $5-10 million worth of equipment.¹⁵

Tire recyclers in the U.S. use four different methods to produce crumb rubber; one of them, cryogenic grading, uses liquid nitrogen to freeze the rubber before crushing it. Cryogenic-produced CRM has shown unsatisfactory asphalt reaction and is not recommended for production of CRM. The final product of any grading process performed at below ambi-
ent temperatures are angular smooth-faced particles which give the asphalt rubber poor elastic properties.\textsuperscript{16,17,18}

There are, then, three currently accepted methods of processing scrap tire rubber into crumb rubber suitable for use as an asphalt pavement modifier:\textsuperscript{19}

- **crackermill** (or "ambient grinding") 1/4" to 40 mesh,
- **granulator** (or "ambient granulating") 1/4" to 40 mesh, and
- **micro-mill** (or "wet grinding") 40 to 100 mesh.

The **crackermill process** produces crumb rubber from *shredded scrap tires only* by passing the pieces between rotating corrugated steel drums. A tearing action is achieved by the close spacing between the steel drums and their differential speeds. **This is by far the most common and productive method of producing crumb rubber.** It renders irregularly shaped particles with a large surface area.

The **granulator process** cuts the scrap tire rubber apart with revolving steel plates that pass very close to each another. An advantage of this process is that it may be carried out with any scrap tire rubber size, including whole tires. The granulator produces uniform, roughly cubical particles that have a low surface area.

The **micro-mill process** takes crumb rubber produced by one of the other two processes and mixes it with water to make a rubber slurry. The slurry is pressured between rotating abrasive discs which reduce the crumb rubber to very finely ground particles, which are dried to become the final crumb rubber product.

It should be noted that the crackermill and granulator processes include a series of fiber and steel separators; because the micro-mill process begins with crumb rubber, it doesn't require such separators.

The specifications for a given CRM project should include the required gradation of the CRM and the type of particle, whether ground (crackermill process), granulated (granulator process), or very fine ground (micro-
mill process). The desired surface area, size, and shape of the CRM for a particular project determine which processing method is required.

1.3 Shipping Considerations

Talc or other inert mineral powder is often added to CRM to reduce the rubber particles' tendency to stick together and to improve the material's ability to be handled and flow from its shipping container. Generally, the amount of talc or other powder used should not exceed 4 percent by weight of the rubber.

Packaging of CRM can be accomplished in many ways depending on the user's need. The four most widely used packaging methods are:

a. 50-lb. paper bags stretch-wrapped on 2750-lb. pallets.

b. 25-50 lb. poly bags stretch-wrapped on 2200-lb. pallets. The bags are made of low-melt materials (near 220°F) so that they blend easily in the mixing process.


d. 2200-lb. super-pallets (either returnable or recyclable).

In bulk shipment of CRM, separation of smaller particle sizes to the bottom of the container is a major problem. If blends of CRM specify a broad gradation range, bulk shipment may not be an appropriate method of transporting the CRM.

1.4 Factors Affecting Price

The price of CRM can vary considerably, depending on the customer's particular specification, the quantities ordered, total volume, packaging requirements, and other services required by the CRM buyer. Packaging in bulk is less expensive than the use of smaller poly or paper bags. Typical
prices for volume purchases of CRM based on the gradation are summarized in Table 2.22

<table>
<thead>
<tr>
<th>Gradation Material</th>
<th>Price per Pound in U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4&quot;</td>
<td>$0.10 - 0.22</td>
</tr>
<tr>
<td>10 mesh</td>
<td>$0.10 - 0.24</td>
</tr>
<tr>
<td>30/40 mesh</td>
<td>$0.17 - 0.30</td>
</tr>
<tr>
<td>80 mesh</td>
<td>$0.30 - 0.45</td>
</tr>
</tbody>
</table>

A typical ton of a modified Hot Mix Asphalt paving material requires an average of 4 scrap tires; an average tire reduces to about 11 pounds (55% recovery) of CRM. Therefore, the use of CRM will represent an additional cost, for the material alone, in the range of $13.20 to $19.80 for 80-mesh material per ton of HMA and $7.48 to $13.20 for the 30-40 mesh gradation.

See Section 1.10 for a more complete discussion of estimated costs of CRM HMA pavement applications.

1.5 CRM Technologies

There are two basic technologies currently used to incorporate crumb rubber in pavement applications of asphaltic concrete. The term wet process covers any method that blends the crumb rubber with the asphalt cement (AC) before incorporating the binder into the project. The term dry process applies to those technologies that mix the crumb rubber with the aggregate before the mixture is charged with the asphalt binder.23,24

1.5.1 Wet Process: General Description

In the wet process, the crumb rubber is blended with the asphaltic cement, thus becoming a modifier to the binder. For this reason the wet process is also known as the modified binder method. The wet process has been used
to produce crack and joint sealants and thin surface treatments as well as hot mix asphalt.

Wet process technologies are classified by the method used to blend CRM into the asphalt cement. There are three blending-method categories:

- **Batch Blending**: technologies that mix batches of CRM and asphalt in production.

- **Continuous Blending**: technologies that have a continuous production system.

- **Terminal Blending**: technologies implemented at an asphalt cement supply terminal, whose products have extended storage characteristics.

### 1.5.2 Dry Process: General Description

In the dry process, the CRM is blended into HMA under conditions which are similar to the process of adding dry aggregate. For this reason, the dry process is also called the *rubber aggregate method*. The dry process is limited, by its very concept, to the production of HMA mixtures.

### 1.5.3 Other CRM Terminology

The term *asphalt rubber* (AR) refers to an asphalt cement binder modified with CRM and usable in a number of asphalt paving products. An AR can be produced by either a wet process or a dry process, though it is most commonly produced by a wet process. There is considerable variation in the properties and performance of ARs produced by different processes.

The term **rubber modified hot mix asphalt** (RUMAC) refers to a HMA containing CRM added using a dry process. In RUMAC mixtures, a dominant portion of the CRM particles retain their tire rubber characteristics, which implies that most of the CRM particles are relatively coarse. Variations in RUMAC mixtures can be achieved by designing the gradation of the stone aggregate and CRM "aggregate" to achieve particular final mixture properties. RUMAC mixtures are classified as dense-graded, gap-graded, and open-graded.
A schematic of the basic processes and products associated with CRM is shown in Figure 1.

![Figure 1. Schematic of the basic CRM processes and products](image)

1.5.4 CRM State-of-the-Technology

There are 9 known CRM technologies at different levels of development in the United States. Table 3 lists these technologies and one from Europe by their commercial and generic names and gives their most important distinguishing characteristics. The wet process technologies are classified by blending method; the dry process technologies, by type of paving product.27

The FHWA, in its June 1993 Report to Congress on the use of recycled paving material, classified the experience of states using specific CRM technologies as either "extensive" or "limited," based on the documented research available. Table 4 summarizes the FHWA’s findings regarding the extent of experience with CRM technologies among the states.
Table 3. Known CRM technologies at different levels of development

<table>
<thead>
<tr>
<th>Technology</th>
<th>Development Date and Location</th>
<th>Process/Product</th>
<th>Patented?</th>
<th>Marketing Firm</th>
<th>Field Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>McDonald (1)</td>
<td>1960s, Arizona</td>
<td>wet/batch/AR</td>
<td>yes (2)</td>
<td>(3)</td>
<td>extensive since 1970s</td>
</tr>
<tr>
<td>pressure</td>
<td>1990, Missouri</td>
<td>wet/batch/AR</td>
<td>no</td>
<td>Dan Truax</td>
<td>none</td>
</tr>
<tr>
<td>continuous blending</td>
<td>1989, Florida</td>
<td>wet/continuous</td>
<td>no</td>
<td>Rouse Rubber (4)</td>
<td>limited since 1969</td>
</tr>
<tr>
<td>Ecoflex™</td>
<td>1992, Canada</td>
<td>wet/terminal/AR</td>
<td>yes</td>
<td>Blumar</td>
<td>limited since 1992</td>
</tr>
<tr>
<td>Flexochape™</td>
<td>1986, France</td>
<td>wet/terminal/AR</td>
<td>yes</td>
<td>BAS Recycling (Beugnet)</td>
<td>none in U.S.</td>
</tr>
<tr>
<td>PlusRide™</td>
<td>1960s, Sweden</td>
<td>dry/RUMAC-gap</td>
<td>yes</td>
<td>EnviRotre</td>
<td>extensive since 1978</td>
</tr>
<tr>
<td>generic dry (RUMAC)</td>
<td>1989, New York</td>
<td>dry/RUMAC-gap, dense</td>
<td>no</td>
<td>TAK (4)</td>
<td>limited since 1989</td>
</tr>
<tr>
<td>chunk rubber*</td>
<td>1990, SHRP</td>
<td>dry/RUMAC-gap, dense</td>
<td>no</td>
<td>CRREL</td>
<td>none</td>
</tr>
<tr>
<td>generic dry (AR)</td>
<td>1992, Kansas</td>
<td>dry/AR-open, gap, dense</td>
<td>no</td>
<td>(4)</td>
<td>limited since 1992</td>
</tr>
</tbody>
</table>

(1) McDonald Technology includes both Overflex™ and Arm-R-Shield™ products.
(2) There are numerous patents related to this technology. Some have expired; others have not.
(3) Prior to 1983, this technology was marketed through the Asphalt Rubber Producers Group and the licensed applicators. Presently, the technology is marketed by individual applicators.
(4) Individual highway agencies are developing their own products with this technology.

* Chunk rubber was developed by the Army Corps of Engineers Cold Regions Research and Engineering Laboratory as part of a project funded by the Strategic Highway Research Program. The research was confined to laboratory experimentation; no experimental field applications were carried out. CRREL is seeking research funding to continue the development of its chunk rubber mixes, which modify the standard (PlusRide™) dry process design by increasing maximum size of the crumb and percent of CRM.
Table 4. Experience with CRM technologies among the states

<table>
<thead>
<tr>
<th>CRM TECHNOLOGY</th>
<th>STATE EXPERIENCE</th>
<th>EXTENSIVE</th>
<th>LIMITED</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>McDonald</td>
<td>AZ, CA</td>
<td>AL, AR, CO, CT, DE, FL, GA, ID, IA, KS, ME, MD, MA, MI, MS, MO, NC, NE, OH, OK, OR, PA, TN, TX, VA, WA, WI, WY</td>
<td>Most of the 1970s and early 1980s experience was with SAM and SAMI applications. Most of the research in the last 10 years has focused on HMA applications. Some routine use in the Southwest.</td>
<td></td>
</tr>
<tr>
<td>pressure reaction</td>
<td></td>
<td></td>
<td></td>
<td>Has not been field-evaluated</td>
</tr>
<tr>
<td>continuous blending</td>
<td></td>
<td>FL, IA, KS, MS, NJ, PA, VA, WA</td>
<td>Designed to meet local binder specifications.</td>
<td></td>
</tr>
<tr>
<td>terminal blend</td>
<td></td>
<td>AZ, FL, OR, WA</td>
<td>Designed to meet local binder specifications.</td>
<td></td>
</tr>
<tr>
<td>Ecoflex™</td>
<td></td>
<td>NC</td>
<td>Very limited experience.</td>
<td></td>
</tr>
<tr>
<td>Flexochape™</td>
<td></td>
<td>AK</td>
<td>Has not been field-evaluated in U.S.</td>
<td></td>
</tr>
<tr>
<td>PlusRide™</td>
<td></td>
<td>AZ, CA, IA, MN, MT, NJ, NM, NY, NV, OK, OR, SC, UT, WA</td>
<td>Project constructed prior to 1985 do not represent existing Plus Ride™ design guidelines.</td>
<td></td>
</tr>
<tr>
<td>generic dry-RUMAC</td>
<td></td>
<td>AZ, CA, IA, MN, MT, NJ, NM, NY, NV, OK, OR, SC, UT, WA</td>
<td>Projects represent early technology development.</td>
<td></td>
</tr>
<tr>
<td>Chunk rubber</td>
<td></td>
<td></td>
<td></td>
<td>Has not been field-evaluated.</td>
</tr>
<tr>
<td>generic dry-AR</td>
<td></td>
<td>FL, KS</td>
<td>Very limited experience.</td>
<td></td>
</tr>
</tbody>
</table>

This table does not reflect the use of crack/joint sealant and does not distinguish between various types of applications for each technology.
1.6 Wet Process: Technical Discussion

1.6.1 Description of Reaction

The interaction between CRM and asphalt cement that occurs during the blending process is defined as non-chemical polymer swell. During this process the aromatic oils in the asphalt cement are absorbed by the polymer chains of the CRM. It is analogous to a compressed, hard dry sponge being placed in a water bath: when it absorbs water, it swells and softens. In a similar fashion, the CRM reacts with the asphalt cement, swelling 3 to 5 times its original volume. This does not result in a melting of the CRM into the asphalt cement. A fully reacted particle becomes tacky and develops adhesive properties desirable in paving applications.

1.6.2 Equipment and Methodology

Figure 2 shows a schematic of the wet process, which requires three components: (1) CRM and AC feeding lines (2) a blending unit, and (3) a reaction tank.

![Figure 2. Schematic of the wet process](image)
CRM and AC feeding lines. These must be provided with a metering system and supply pump, respectively, to control the relative amounts of AC and CRM introduced into the blending unit.

Blending unit. This unit should be able to mix the CRM and the asphalt binder in a predetermined proportion at a constant temperature ranging from 300–400°F. The blend has to be conducted by low shear mixers in a continuous and homogeneous fashion.

Reaction tank. After the materials are combined, they are immediately discharged into the reaction tank. This tank must have the same properties as the blending tank (i.e., uniform blend, constant temperature, and low shear mixers) except that it has to hold the mixture for a longer period of time. The holding time is usually 30 minutes to 2 hours, depending on the time required to obtain the required stable viscosity. The viscosity is the key indicator that the modified binder is ready for use.

The modified binder goes from the reaction tank into a transfer unit. These mobile units can transfer the modified binder from one project to another. The final application of the modified binder will dictate the method that will be used to transfer the binder. Most applications require systems to measure and/or control the flow of the modified binder. Studies and the experiences of previous contractors have shown that modified binder with CRM is very abrasive; consequently, it is best to use special pumps and to calibrate them frequently to ensure an accurate application of the binder.

1.6.3 Factors Affecting Reaction

The reaction which occurs between the CRM and the asphaltic binder may be affected by the following factors:

1. The physical and chemical characteristics of the asphaltic binder.

2. The physical and chemical characteristics of the CRM.

3. The duration and temperature of the reaction between the CRM and the binder.

4. The mechanical energy applied in the mixing process.
These factors are discussed in more detail below.

**Characteristics of the asphaltic binder.** The physical and chemical characteristics of the asphaltic binder influence, in great measure, the properties of the asphalt rubber. The binder's grade and susceptibility to temperature will influence the performance of the pavement at low temperatures (say, 39° F), a concern that can be disregarded in Puerto Rico.

Asphalt is composed of asphaltenes, resins, and oils, which vary with the crude source. The grade of asphalt selected will depend in great measure on the desired final properties of the asphalt rubber and will determine the amount of extender oils added during the process, if any. An asphalt binder which has a high content of aromatic oils will react with the rubber to a greater extent than binder which has a lower level.

**Characteristics of the CRM.** The physical characteristics of the CRM, including the particle sizes (gradation), form (angular or elongated), and the level of deleterious particles (see Table 5) affect the properties of a mixture of an asphaltic binder with CRM. By increasing the surface area of the CRM, the rate of reaction between CRM and the AC can be increased, which will be associated with an increase in viscosity.

<table>
<thead>
<tr>
<th>Deleterious Substances</th>
<th>Allowable Contents (by weight of CRM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>0.75% maximum</td>
</tr>
<tr>
<td>Fiber</td>
<td>0.1% minimum</td>
</tr>
<tr>
<td>Mineral Contaminant</td>
<td>0.25% maximum</td>
</tr>
</tbody>
</table>

Table 5. Allowable contents of deleterious particles in CRM

The chemical characteristics of the CRM also influence the properties of such a mixture (see Table 6). The proportions of natural rubber and synthetic rubber, which may alter the elastic qualities of the mixture and thermal properties (susceptibility), respectively, are key determinants of the CRM chemistry. Carbon black plays a vital role in the mixture, since it delays the tendency towards oxidation of the asphaltic binder and thus retards the aging process and its associated problems.
Generally speaking, there is not too much flexibility regarding changing the overall CRM composition. Some CRM producers, however, can make some minor adjustments to the composition of their final product by changing the usual mix of rubber sources. This service implies additional costs.

Table 6. Allowable contents of the chemical components of CRM

<table>
<thead>
<tr>
<th>Chemical Analysis</th>
<th>Allowable Contents (by weight of CRM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Rubber</td>
<td>15% - 30%</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>25% - 38%</td>
</tr>
<tr>
<td>Rubber Hydrocarbon</td>
<td>40% - 50%</td>
</tr>
<tr>
<td>Acetone Extract</td>
<td>10% - 18%</td>
</tr>
<tr>
<td>Ash</td>
<td>8% minimum</td>
</tr>
</tbody>
</table>

Reaction time and temperature. Studies have demonstrated that the reaction time between the rubber and the asphaltic binder changes the properties of the final product. The temperature at which the mixture is blended also influences the rate of reaction. To accelerate the reaction for a desire product, the blending temperature must be in the range of 300 to 400° F. Increasing the reaction temperature accelerates the interaction process, but this method of inducing a heightened level of interaction runs the risk of allowing the temperature to approach the flash point of the asphalt binder. In addition, high temperatures or long times could "break down" the mix. This is usually due to the devulcanization of the rubber. There is an optimum time-temperature combination which has to be determined in laboratory tests before production begins.

Mechanical mixing energy. The quantity and intensity of shear stress used in the blending process exercises considerable influence on the properties of the rubber binder. The use of mixers which apply a low shear stress to the rubber asphalt during the mixing process are recommended. Mixing conditions or shear could also accelerate the rubber devulcanization process.
1.6.4 Modified Binder Tests

Most of the binder tests currently used to measure the properties of asphalt cement can be applied to modified binders. Due to the ineffectiveness of the capillary viscometer tests, the method used to measure the viscosity of modified binders is rotational shear resistance using the Brookfield viscometer. The specifications developed as a result of the Strategic Highway Research Program (SHRP) require the Brookfield viscometer for characterizing conventional as well as modified binders. These new asphalt specifications, which apply to both modified and unmodified binders, were recently issued by the National Center for Asphalt Technology (NCAT) at Auburn University in Alabama. This development is discussed in Section 1.10 below.

One of the largest hot mix asphalt producers in Puerto Rico claims that the criteria for the standard test method for Marshall Stability and Flow (ASTM D 1559), required as part of DTPW Specification 401 for HMA pavements, cannot be met when crumb rubber is used as a modifier of the asphalt binder in the standard gradation for surface course (S-1). This assertion is based on a study conducted by the HMA producer. Samples with 9% crumb rubber content by total AC content were tested, resulting in permanent deformation or flow values on the order of 20, exceeding the upper limit of 16 established by the specification. In most of the samples tested, stripping could readily be noticed.

Some states such as Florida have managed to design AR pavement mixes that have met a specification similar to DTPW Specification 401. The difficulty presented by this specification has been discussed in a number of documented studies, some of which have suggested that the acceptable scale for Marshall Stability and Flow should be moved upward to accommodate the performance of modified binder. Due to the higher binder contents typically required when CRM is incorporated in the mix (6.5 to 7.5% by total mixture weight for dense-graded), it has been suggested that the maximum flow values can be raised to 24 for light traffic, 22 for medium traffic, and 20 for heavy traffic.
The uncertainty regarding the applicability of this specification is an issue that should be approached with caution in Puerto Rico. Adopting a higher acceptable flow rate when CRM is present in the mixture may be acceptable in other places; in Puerto Rico, however, it could contribute to the generation of functional failures such as rutting and ravelling due to the high percentage of overloaded trucks that exceed the axle and gross vehicle weight limits recommended by the DTPW Vehicle Weights and Measures Bill, which has been submitted to the Commonwealth Legislature.

1.6.5 Rehabilitation and Construction Techniques

There are several construction techniques that can incorporate rubber as part of its hot mix asphalt design, among those are:

- Crack and Joint Sealant
- Stress Absorbing Membrane (SAM)
- Stress Absorbing Membrane Interlayer (SAMI)

**Crack and Joint Sealant.** Modified binders have been widely used in crack and joint sealants in the United States, demonstrating excellent performance and cost-effectiveness. More than half of the state highway agencies currently include an asphalt rubber (AR) sealant in their pavement maintenance and rehabilitation programs. The usual application temperature of AR sealant is 350°F; it is very resistant to flow even at that temperature and does not level itself out when applied. To obtain optimum bond between the sealant and the pavement, it is recommended that the pavement area contiguous to the joint be heated to 40°F above the application temperature of the sealant. Also, the width of a crack to be filled with AR sealant must not be more than twice the depth.

**SAM.** The acronym for "Stress Absorbing Membrane," SAM is a rehabilitation technique in which the pavement surface is sprayed with modified binder at a rate of 0.5 to 0.7 gal/yd² followed by a layer of aggregate which has been precoated with asphaltic cement; the aggregate should have a uniform size of 1/4 to 3/8 of an inch. The modified binder, which
contains 20 to 30 percent CRM, may be diluted with a solvent if necessary to assure an adequate flow through the sprayers.

The application ratio of aggregate depends in great measure on the surface characteristics and the size of the aggregate used. If the surface of the pavement is extremely oxidized, a tack coat of an asphaltic emulsion should be used to assure the necessary adhesion between the surface and the membrane.

**SAMs are widely used to solve problems associated with low skid resistance and to extend the serviceability of asphaltic pavements which may be experiencing extensive cracking.** Nevertheless, this method does not increase the structural capacity of the pavement.

**SAMI.** The acronym for "Stress Absorbing Membrane Interlayer," SAMI is similar to SAM, differing only in that it is followed by the application of a concrete asphaltic layer approximately 3/4 to 3 inches thick. The construction may be carried out in stages over several years. In this kind of application the binder may be somewhat softer than for a SAM due to the fact it will not be exposed to traffic. This method generally provides an effective means to reduce and retard reflection cracking in thin layer applications over asphaltic pavement. One variation of this method is to first apply a leveling layer of HMA. The buildup of HMA layers in this rehabilitation technique may increase the structural capacity of the pavement.

**It should be noted that the FHWA has concluded that neither SAM nor SAMI applications appear to improve the performance of all rehabilitation strategies, and that both are especially susceptible to poor performance over pavements exhibiting dominant transverse crack or joint patterns.**

### 1.6.6 Advantages of Modified Binder

Modified binder exhibits enhanced binder properties when compared to non-modified binder. The addition of CRM reduces the binder's temperature susceptibility. Figure 3 shows the effect of CRM on the binder's temperature/viscosity curve. The CRM could make it feasible to select a lower grade asphalt for a particular application, without incurring prob-
lems associated with low viscosity at high temperature, as with conventional asphalt.

Figure 3. The effect of CRM on the binder temperature–viscosity curve
Modified binder may influence some characteristics associated with the performance of in-service pavements; among these are:

- **Aging.** CRM is composed of an average of 32% carbon black, which is known to improve the binder's durability.

- **Reduction of thermal cracking.** Although not applicable to conditions in Puerto Rico, it is worth mentioning that softer binders can be chosen which are more flexible at low temperatures, enhancing the mixture's ability to resist tensile stresses.

- **Rutting.** Adding CRM to the binder makes it possible to modify the high operating temperature properties of the binder, due to the higher viscosity at high temperatures compared to conventional asphalt.

- **Reduction in reflective cracking.** In laboratory tests CRM modified binder demonstrates a significant enhancement in elasticity and resilient modulus.

- **Chip retention.** The binder's ability to hold aggregate in place in surface treatment applications is greatly influenced by the adhesive properties of the natural rubber in CRM.

### 1.6.7 Disadvantages of Modified Binder

Modified binder requires an increase in asphaltic cement contents, and this may produce undesirable side effects, such as bleeding and excessive tire tracking during cooling of newly constructed surfaces. Blotter sand is recommended to reduce tire tracking until the pavement cools to normal operational temperature.

The increase in binder content, added to the cost of CRM by itself, raises the cost of the CRM pavement substantially compared to conventionally constructed pavements.

The short storage life of modified binder maintained at high temperature (375°F ±20) was, until recently, a major disadvantage associated with its use. Mobile units were employed to produce the asphalt rubber mixture...
at the project production site, and all costs incurred in the transportation, setup, and removal of the mobile equipment had to be recovered in the unit cost of the tonnage produced. In addition, using this method the binder had to be used no later than six to eight hours after mixing.

In 1987 a road contractor in France developed a novel formula for AR which gives it a shelf life of up to 8 days. The optimized storable AR formulation specifies a blending time of 2 hours at 356°F and storage at 320°F in hermetically sealed containers without agitation. In a personal communication to Eng. Jorge Velar, research assistant, a bituminous materials engineer with the Florida Department of Transportation (FDOT) reported that if the modified binder is maintained at close to 325°F it can be stored for up to one week without the mix breaking down to any significant degree.

1.7 Dry Process: Technical Discussion

1.7.1 Process Description

The dry process incorporates CRM into HMA products either as mineral filler or as aggregate. The CRM grading selected for any particular project in this process is highly affected by the aggregate grading used (i.e., dense-graded, gap-graded, and open-graded).

The limited reaction time with this method does not permit the asphalt cement to penetrate the entire rubber mass. The surface of the coarse rubber particle is the only part that reacts with the asphalt cement, which creates an asphalt/rubber interface which bonds the two materials together (asphalt and CRM). A mix design using this concept will include a percentage of finer ground CRM which produces a partially reacted modified binder and another percent of coarse aggregate. The fine CRM particles produce the "swelling" which occurs in the laboratory mix, while the coarse granulated CRM particles retain their shape and rigidity to function as aggregate.
Although the aromatics oils contained in the asphalt do not play a critical role in the dry process, the degree of binder modification desired in any particular project will govern the need to consider laboratory tests to assure compatibility between the CRM and asphalt cement.

The CRM feeding system has to be extremely sensitive and electronically synchronized with the aggregate cold feeding system to assure the proper proportioning of the CRM into HMA. The equipment used for introducing reclaimed asphalt product (RAP) into a drum mixer can be used to introduce CRM in the same way.

### 1.7.2 Advantages of CRM HMA Pavements

The dry process has more or less the same advantages as the wet process (i.e., slower aging, less rutting, more resistance to thermal cracking, etc.), but on a lower scale due to the reduced interaction between the CRM and the binder. The CRM that does not react with the asphalt, though, can help delay the advance and propagation of reflective cracking.

No equipment changes are needed for using the dry process if an asphalt production plant uses a conventional drum system with a hopper for adding reclaimed asphalt pavement; the CRM is simply added instead of RAP.

### 1.7.3 Disadvantages of CRM HMA Pavements

The two major potential disadvantages associated with CRM used as a rubber aggregate are:

- **Cost.** The dry process requires more CRM per ton of HMA than the wet process to achieve the desired change in properties. This could contribute to a higher total cost compared to the wet process; as the CRM is more expensive than conventional aggregates, of course, the dry process will be that much more costly. There is also an additional increase in cost due to the greater binder content needed in order to produce a sufficient degree of rubber/asphalt reaction on the surface of the CRM particles. See Section 1.10 for a detailed discussion of increased costs associated with CRM paving technologies.
**Ravelling.** The unreacted CRM acts as a spring when subjected to load. When a load is placed on a CRM particle, it will deform and then rebound when the load is removed. The excessive strain magnitude and/or repetition of strain between the aggregate and the binder weakens the ability of the binder to hold it in place. Therefore, surface ravelling may occur due to lack of bonding needed in order to retain the surface aggregate. Naturally, this will not be a problem if the PRHTA uses CRM HMA primarily as a black base rather than as a surface course.

### 1.8 CRM Construction Experience

This section summarizes experiences with CRM paving applications reported by several state highway agencies. Arizona, California, Florida, and Texas are included because their climatic conditions are comparable to Puerto Rico’s; New York and New Jersey are included because their experiences are very recent and involve generic CRM technologies whose potential cost savings over patented processes make them of special interest.

**Arizona.** The City of Phoenix pioneered the use of AR chip seal, more commonly referred to as a stress absorbing membrane (SAM), in the mid-1960s. Over a period of approximately two decades, the Phoenix Street and Transportation Department placed over 3,000 lane miles of AR SAMs. Arizona’s first use of AR HMA came in 1975 by the Arizona Department of Transportation (ADOT). The City of Phoenix began experimenting with asphalt rubber hot mix (ARHM) overlays in 1985 and began to use a gap-graded ARHM overlay as a substitute for AR chip seal treatments in 1989 after the Phoenix City Council banned the use of chip seals. Between 1985 and 1987, it is estimated that Phoenix used approximately 600,000 scrap tires to place 600 lane miles of ARHM. From 1971 to 1987, it is estimated that Phoenix used about 3.6 million scrap tires in all for asphalt paving applications.
In 1990, the ADOT carried out the largest AR project in the history of the industry on Interstates 40 and 17 near Flagstaff. The project rehabilitated an 8-inch Portland Cement Concrete Pavement (PCCP) built in 1969 and included placing edge drains, cracking and seating concrete, and resurfacing. The resurfacing of I-40 included a 3-inch conventional dense graded asphalt concrete leveling course and placement of a 2-inch AR gap-graded hot-mix surface course. For I-17, 1.5 inches of gap-graded ARHM was placed directly on the PCCP without cracking and seating. One-half inch of the gap-graded AR open-graded HM was also placed on I-40. Observations made a year later reported no reflective cracking.\textsuperscript{51}

Binder for the conventional mix in this project was 6 percent, 7 percent for the dense-graded AR, and 9 percent for the open-graded AR fiction course. FNF Construction of Tempe, Arizona, completed the project in three months at a total cost of $10.7 million, including 10- and 12-hour shifts on weekends. This project has been cited as the latest evidence reaffirming the cost-effectiveness of AR in rehabilitating pavements.\textsuperscript{52} A report on AR pavements co-authored by City of Phoenix engineers in 1989 concluded that a 1-inch ARHM overlay will resist cracks from reflecting through the existing worn out pavement.\textsuperscript{53} The report also observed that skid resistance of the surface is not reduced by the AR and that there are two significant performance improvements: an improved riding surface and a marked decrease in traffic noise.

**California.** Although many counties in California have pilot projects underway to evaluate CRM for pavement applications, Los Angeles County has the most experience in the state. The county is still monitoring a two-inch asphalt rubber pavement (HMA dense-graded) that was laid down on Olympic Boulevard back in 1978. The test section is still in good shape, according to Frank Lancaster, chief of the materials lab for L.A. County.\textsuperscript{54}

The county has placed about 15 AR SAMs. The preferred application at present is an overlay of gap-graded wet-process ARHM. They are now leaving the sand (N° 30 sieve) out of this mix, leaving voids that are filled with asphalt rubber. This allows an increase in binder content to 8.5 percent (originally 5 to 5.4 percent). So far they have done three resurfacing projects with this mix, including a 1.5 inch overlay on the access road to
the La Puete landfill, used by about 2,000 trucks daily (most of them overloaded). Though admitting that asphalt rubber may be cost-effective for certain projects, Joe Vicelija, a consultant retired from the Los Angeles County Materials Lab, has questioned whether the new mix will ever be cost-effective for low-volume residential streets.  

Contra Costa County also has considerable experience with CRM paving applications and has used more asphalt rubber chip seal than any other county in the state. They have used approximately 450 tons of asphalt rubber binder in chip seals application since 1976. After evaluation of all the test sections in Contra Costa County using the wet process in open-, dense- and gap-graded test projects, the gap-graded mix was chosen for widespread county application. (The gap-graded mix has more gaps, or voids, in comparison with the other mixtures. These gaps are easily filled with asphalt rubber binder.)

The California Department of Transportation (CALTRANS), Division of New Technology, Materials and Research, has published a formal guide on the use of CRM in gap-graded HMA mixtures using the wet process. The guide specifies that the modified binder should be in the range of 6.7 percent to 8.7 percent by dry weight of the aggregate. They also specify the amount of extender oils (2 to 6 percent by weight of the asphalt) and the amount of CRM used (17 to 23 percent by weight of the total combined mixture of asphalt, extender oil, and rubber).

Florida Experience. As a part of this study, Eng. Jorge Velar traveled to Gainesville, Florida, to learn more about the state-of-the-art in asphalt rubber technology. He interviewed Eng. James A. Musselman, Bituminous Materials Engineer at the Florida Department of Transportation (FDOT), and Dr. Mang Tia, Professor at the University of Florida at Gainesville.

The Florida Department of Transportation (FDOT) has decided that the most advantageous use of rubber would be as a binder modifier to improve the performance of friction course mixtures. They have determined that the optimum rubber content for dense-graded friction course
mixtures is 5% by weight of asphalt cement using a fine ground tire rubber (GTR) passing the No. 50 sieve (i.e., a maximum nominal 80-mesh).

The FDOT has used a range of CRM sizes (24, 40, and 80 mesh) and amounts (3% to 17% by weight of asphalt cement binder) and intends to specify nominal size and amount of CRM based on specific application: membrane interlayer (20 mesh, 20%), open-graded friction course (40 mesh, 12%), and dense-graded friction course (80 mesh, 5%). In comparison to the McDonald wet process, FDOT's approach requires smaller amounts of CRM, smaller particle size, and lower reaction temperature and time.60

A report on emissions, including emissions from hot-mix operations, was submitted by the FDOT to the Florida Department of Environment Regulation (FDER), Bureau of Air Regulation. Their response stated that the Bureau had no objections to the FDOT's uses of asphalt rubber membrane interlayer. This was based on the results obtained from the monitoring of asphalt cement with and without rubber and during hot-mix plant production of both conventional and asphalt-rubber mixtures. The toxicity levels in the manufacture of rubber asphalt were higher than in conventional manufacture of hot mix asphalt pavement; however, the levels of toxicity were below maximum level allowed by the EPA.61 Further information on emissions is expected from the monitoring of a test project scheduled for construction by the FDOT early in 1993.

Texas Experience. A cost-benefit analysis performed for the Texas Department of Transportation (TDOT) by the Texas Transportation Institute concluded that the major obstacles to widespread use of asphalt rubber are its high initial cost and great uncertainty about the effects of asphalt rubber applications on the life of pavement surfaces.62 In contrast to the experience reported in Arizona, the Texas study concluded that AR SAMs do not appear to be cost-effective. It estimated that an AR SAM would have to last three times longer than a conventional chip seal treatment to have the same annual cost. Stress-absorbing membrane interlayers (SAMIs), however, were found to be much more cost-effective. A 2-inch overlay with an AR SAMI would need to last about 50 percent longer than a 2-inch overlay alone to yield an equivalent annual cost. The study re-
ported only three experiences with ARHM concrete in Texas. In one 1989
test project, the hot mix was applied along a 1-mile section of a state high-
way in McAllen; the mix raveled severely and the district had to put a
chip sea over the mix within 3 months. The Tyler district had a successful
experience with ARHM that same year, using a dense-graded overlay at
the intersection of a local road and Loop 323 just outside Tyler. ARHM
concrete was chosen because of a severe rutting problem at that site; dis-
trict personnel were pleased with the results and expressed interest in us-
ing the product again on a standard hot-mix project. Finally, District 4 in
Amarillo constructed 10 lane miles of dense-graded ARHM in the fall of
1990; the study did not report any observations on the results of that pro-
ject, but noted that the in-place cost was $52/ton for the AR paving ma-
terial, as compared to the usual cost of $30-35/ton most Texas districts
were paying for conventional hot-mix AC.

The Texas study concluded that offering incentives to use scrap tire
rubber or mandating its use in asphalt pavements did not appear to
be in the best interest of the tax-paying public.

New Jersey Experience. In 1984 the New Jersey Department of Trans-
portation (NJDOT) constructed five test sections and a control section on
Route 41 in Cherry Hill to evaluate the performance of several additives
and construction processes. In one of the test sections the PlusRide™ Sys-
tem (patented dry process) was used; essentially, it consisted of incorpo-
rating a 1" maximum size ground rubber derived from waste tires into a
special-gap-graded mix design. The ground rubber was added directly into
the pugmill during mixing. The design asphalt content was 7.7%. The ex-
traction results from representative cores taken during a five-year cycle
(1984-1988) have been consistent, showing an asphalt content ranging be-
tween 7.2 and 7.6% by weight. The range in air voids varies from 2.1 to
4.7%. The Abson recovery results indicate a slow aging of the asphalt.
The average Marshall Stability was 1,000 lbs. with an average flow value
of 42. Performance data associated with the PlusRide™ system indicate an
increase in skid resistance and improvement in low temperature flexibil-
ity.
The NJDOT has also used the Rouse Rubber System in open-graded friction course on Route 195. The open-graded friction course consisted of 15% rubber blended by the Rouse rubber process into an AC-20 and added to the pugmill. The AC and rubber were blended at 360° F. The mix in the truck was 320-325° F and on the job site was between 290-310° F. There were no problems in the laydown of the mix. It was done using conventional paving equipment and compacted with two static rollers. The finished pavement has a good rideability with a reduction in noise as compared to conventional mixes.

**New York.** In the summer of 1989 the New York Department of Transportation (NYDOT) constructed two pilot projects using the generic dry process (generic RUMAC). One project was located on Route 17 (AADT 5,200 and 15 percent trucks) in the Town of Deposit, Delaware County, and the other was on Route 144 (AADT 5,200 and 16 percent trucks) in the Town of Bethlehem, Alabama County. Each project consists of five sections of 2,000 feet of rigid pavement that were in a need of rehabilitation. The rehabilitation technique consisted of a 2.5-inch HMA leveling course, followed by a 1.5-inch binder course, and finally a 1.5-inch dense-graded surface course of either RUMAC or conventional HMA. The five sections were as follows: three sections using a RUMAC mixture with different coarse-graded CRM contents (one, two and three percent by weight of mixture, respectively); the fourth section was a regular PlusRide™ mixture (three percent of a coarse-graded CRM); and the fifth section was the control section (conventional HMA).63

Examination of the pavements, after three years, led to the following observations:

- All pavements show comparable performance in terms of rut resistance and cracking between conventional and rubber mixture.

- The pavements with rubber show unacceptable levels of raveling, with the exception of the sections that had one percent of CRM.

- All of the test sections exhibit acceptable surface friction.
The conventional asphalt sections produced lower deflection based on the measurements taken by the falling-weight deflectometer (FWD).

Based on these observations, the New York researchers had the following recommendations:

- To continue to closely monitor and record the pavement behavior on the sections in the pilot projects.
- To begin new testing projects incorporating finer CRM in the dry process and to consider possible applications and testing of the wet process.
- To incorporate rubber for all types of pavement courses (surface, binder, and base) in future studies.

These preliminary results and the recommendations from the CRM pavement testing projects in New York will be of great help as a point of reference for other state highway agencies, especially those that, like the DTPW, have not yet conducted any CRM studies and are looking for the most effective way to address the CRM usage requirements of ISTEA.

**Documented construction experience of other states.** Construction and rehabilitation techniques using asphalt rubber have been documented for other states in several papers published in national conferences conducted in San Antonio, Texas, in October 1981 and in Kansas City, Missouri, in October 1989.

### 1.9 Patented versus Generic CRM Processes

The use of rubber as an additive to HMA is not a new technique. The use of natural rubber in asphalt cement was first introduced long ago, but a lack of economic techniques for mixing the rubber in AC delayed the development of the idea. In 1950's the concept of adding scrap tire rubber was developed and laboratory tests were performed in the 1960's. It wasn't until 1964, however, that a method to add small particles of ground scrap
rubber to asphalt cement was developed, by Charles McDonald, a materials engineer for the city of Phoenix, Arizona.  

McDonald's name later became associated with the first patented CRM technology, which is referred to variously as the **McDonald process**, the McDonald technology, or McDonald asphalt rubber. The early development of CRM technology during the 1960's and 1970's focused exclusively on the McDonald process. For many years, a number of companies on the U.S. mainland were licensed by the patent owners to apply the McDonald process. There are no current patents covering the wet process per se, and the patent covering the use of diluent recently expired. Only a patent covering the use of extender oils to prolong the life of the modified binder is still in effect; it will expire in 1995.  

The dry process was developed in the late 1960's in Sweden and patented for use in the U.S. in 1978 under the trade name **PlusRide™**. EnvirOtire, Inc., in Washington state retains all patent rights to this technology today and establishes licensing agreements with contractors on a project by project basis. Most research on CRM technology in the 1980's concentrated on improving McDonald's AR and the RUMAC marketed as PlusRide™.  

The general descriptions of the wet process and the dry process given in previous subsections basically refer to the McDonald technology and PlusRide™ respectively. There are a number of more recently developed technologies based on variations of the wet process and dry process, including the **generic dry process**, **chunk rubber asphalt concrete**, and **continuous blending asphalt rubber** (also known as the Rouse method because it was developed by Rouse Rubber Industries). One new technology even combines features of both processes and is called **generic dry process asphalt rubber**.  

The first experimental field applications of these new CRM technologies were placed in 1989. Thus, there is no field performance record to demonstrate that they can provide an acceptable level of service over a normal performance period.  

Because these new technologies are adaptations of the basic principles of the wet and dry processes, they may run the risk of patent infringe-
ment. The extent of this risk is unknown at this time; the FHWA ad-
vises that state and local highway agencies should be aware of the known
patented products and make their own determination as to whether any
conflict exists between a proposed new technology and its comparable
patented product.  

1.10 Unresolved Questions about CRM

A state highway agency required to use CRM in its pavements must give
special consideration to the following factors:  

- cost
- specifications
- expertise of the contractor with CRM
- type of equipment to be used
- potential recyclability of materials
- air quality control

Due to the limited use of CRM in asphalt concrete pavements in the
United States, information on performance of these materials and state-of-
the-art technology is fragmentary. There are many unresolved issues and
unknowns associated with the use of CRM in HMA pavements that should
be investigated before this technology is implemented nationwide. Some
of the unresolved issues are:

- **High initial costs.** In April of 1993, the American Association of
  State Highway and Transportation Officials (AASHTO) estimated that
  the cost of full implementation of the CRM requirements would be
  about $1 billion per year in 1997, a figure based on a survey of its
  member departments regarding the costs they experienced in 1992 for
  paving projects using CRM. In September, while the FY 1994
  Transportation Appropriations bill was being considered by the
  House and Senate, AASHTO conducted another survey of 1993
CRM costs which found that for 66 projects, the average cost of CRM HMA was about 67% higher than the average cost of conventional HMA. 72 Whether higher initial costs of asphalt rubber pavements are justified by better performance and durability is at the center of the controversy surrounding the ISTE A CRM requirements.

In July of 1993, an engineer and executive officer of Puerto Rico's largest asphalt producer, testifying before the Committee on Planning and Socioeconomic Development of the Puerto Rico House of Representatives, estimated that adding CRM to HMA would raise the cost 256%, from $32 to $82 per ton. 73

Some State highway agencies and mainland U.S. private asphalt rubber contractors claim increases of 25% to over 200% in the cost of asphalt rubber pavements as compared to the costs of conventional asphalt pavements. In a workshop on CRM sponsored by the FHWA, Stroup-Gardiner provided formulas for estimating the costs of RUMAC and ARHM versus conventional mixtures. Estimates for Puerto Rico based on those formulas are shown in Tables 7 and 8. It should be noted that the estimates for the cost of the rubber alone reflect an average price for medium-grade CRM; this cost could be as much as double the numbers shown if a very fine grade of CRM is used. The estimates below, then, should be considered in conjunction with the prices for volume purchases of CRM shown previously in Table 2.

Table 7. Estimated Costs of RUMAC Compared to Unmodified HMA*

<table>
<thead>
<tr>
<th>S/Ton HMA</th>
<th>S/Ton Asphalt</th>
<th>% AC, Unmod.</th>
<th>% AC, Mod.</th>
<th>$ Rubber/Ton HMA</th>
<th>S/Ton RUMAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmod.</td>
<td>40.00</td>
<td>184.00</td>
<td>5.5</td>
<td>6.5</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1%</td>
<td>59.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2%</td>
<td>59.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3%</td>
<td>59.84</td>
</tr>
</tbody>
</table>

*Based on formulas provided by Stroup-Gardiner* and average HMA prices for Puerto Rico estimated by personnel from Betteroads Asphalt, Inc., in personal communication to Eng. Jorge Velar, September 1993.
Table 8. Estimated Cost of HMA Conventional Binder versus Asphalt Rubber Binder*
(Using Supplier-Produced Asphalt Rubber Binder)

<table>
<thead>
<tr>
<th>S/Ton Unmodified Binder in the Mixture</th>
<th>% AC Unmodified Mixture</th>
<th>S/Ton Modified Mixture</th>
<th>% AC Modified Mixture</th>
<th>Total Estimated Cost of Rubber Hot Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$40</td>
<td>$184</td>
<td>5.5</td>
<td>$400</td>
<td>$55.88</td>
</tr>
</tbody>
</table>

*Based on formulas provided by Stroup-Gardiner and average HMA prices for Puerto Rico estimated by personnel from Betteroads Asphalt, Inc., in personal communication to Eng. Jorge Velar, September 1993.

- **Life-cycle costs.** Some contractors have stated that asphalt rubber could double the life of conventional pavements; however, due to the lack of long-term data, a cost-performance study cannot be carried out to determine if the high initial costs are truly justified. It is repeatedly pointed out in the literature that the cost-benefit picture for asphalt rubber pavement applications is extremely uncertain because of the lack of experience with AR and RUMAC pavements and because many factors affect the performance of flexible pavements in general.

- **Uncertainty about modified binder specifications.** The National Center for Asphalt Technology (NCAT) issued new specifications designed to apply to both modified and unmodified binders on March 31 of this year, as part of the completion of the five-year Strategic Highway Research Program (SHRP). The SHRP specifications replace empirical penetration and viscosity tests with a grading technique based on the lowest and highest pavement temperatures experienced at the project site. Consequently, these grades will vary from state to state. The SHRP specifications require new testing equipment and do not involve any field testing. State highway agencies will need only one set of testing equipment in the central laboratory for verifying suppliers' test results. The SHRP specifications are being validated against field test sections throughout the U.S. It is believed that the new specifications provide a more rational and reliable
procedure for evaluating new binder materials, such as the various grades of CRM, and will thus make the process of evaluating these new products faster and less costly. At the present time, however, there is considerable uncertainty about these specifications. The Montana DOT, for example, has reported that the use of CRM as required by ISTEA is forcing it to write specifications for patented processes, which could potentially increase costs without an increase in service life.76

Extraction test. There is concern about how to modify the "Standard Test Method for Quantitative Extraction of Bituminous Paving Mixtures," ASTM D 2172, used for hot mix asphalt paving applications. The solvents typically used for this test (i.e., trichloroethylene, trichloroethane, or methylene chloride) react with the modified asphalt binder.77 The standard procedure does not allow the solvent to remove all rubber particles, and the reaction between asphalt binder and CRM contents has not been studied. Thus, the present specification does not allow the exact CRM and AC contents to be determined separately; only a rough combined estimate can be achieved.

Plant and equipment modifications. The local asphalt concrete industry has concerns about the modifications to asphalt plants and/or equipment that will be needed to handle asphalt rubber, which is more viscous than conventional asphalt. The wet process requires that asphalt plants add another binder storage tank and a new binder pump that can handle the abrasive and more viscous modified binder. The wet process also requires additional equipment for the blending of CRM with the binder and a transferring unit for transporting the binder from point of production to job site.

The dry process will cost less than the wet process in the long-run, and for batch plant production the dry process requires little modification to the conventional HMA process: bags of CRM are charged directly into the mixing chamber. Of the 19 asphalt plants in Puerto Rico, however, only two are batch plants. The other 17 are drum plants. Unfortunately, none of the drum mix asphalt plants

uses RAP hoppers, which rules out convenient conversion to CRM production by using the dry process. In order to adopt CRM technology, the drum mix plants would first have to be modified with RAP hoppers. For that reason, the initial investment to add CRM capability will be higher for contractors with drum mix plants than for those with batch plants. A HMA local contractor has stated that the only possible way to incorporate the CRM in the dry process here without major equipment modifications is to add the CRM when the mix comes out of the drum, which is where mineral filler is currently added in the process.  

- **Toxic fumes.** There are concerns that the emissions from crumb rubber asphalt production may pose a more serious threat to human health than conventional asphalt mix production due to the higher mixing temperatures involved. The Florida Department of Transportation conducted a study which found that the toxicity levels in the manufacture of rubber asphalt were higher than in conventional manufacture of hot mix asphalt pavement; however, the levels of toxicity were below maximum level allowed by the EPA. The EPA has stated, in the June 1993 Report to Congress on the reuse of recycled paving material (which it issued jointly with the FHWA) that the limited data currently available indicate no obvious trends of significantly decreased or increased emissions attributable to the use of CRM in HMA pavement production. Only seven projects in the U.S. and Canada have carried out thorough air quality studies at asphalt plants, however, and three of those studies found the emission of methyl isobutyl ketone (MIBK) in CRM asphalt paving mixes but not in conventional mixes; that finding, concluded the EPA, warrants further study.  

- **Recyclability.** The recyclability of asphalt materials containing scrap tires has not been adequately investigated. In the June 1993 Report to Congress mentioned above, the FHWA concluded that there is no evidence suggesting that asphalt pavements containing recycled rubber cannot be recycled to substantially the same degree as conventional pavement, but it knew of only two projects in which CRM-
containing pavements were recycled; the performance results to date are comparable to existing HMA pavements. A national pooled-funds study has been initiated with the participation of 33 states, the FHWA, and the EPA to further evaluate recycling of CRM pavements.81

1.11 Summary Analysis

This subsection encapsulates the findings reviewed in Section 1 and specifically relates them to current highway construction practices in Puerto Rico. The series of general conclusions which forms the framework for this section are the basis for the recommendations in the final subsection.

1. The use of crumb rubber from scrap tires in HMA pavements is a federal requirement applicable to Puerto Rico.

Section 1038 of ISTEA establishes minimum utilization requirements for asphalt containing recycled rubber. Section 325 of H.R. 2750, the Department of Transportation Appropriations Act for FY 1994, prohibits use of the appropriated funds "to implement, administer, or enforce the provisions of Section 1038(d)" of ISTEA. The effect of Section 325 is to nullify the FY 1994 MUR under Section 1038(d); the other MURs remain in effect and, unless Congress legislates a continuation of the moratorium on enforcement of Section 1038(d), States will be required to meet the 10% MUR for CRM and allowable substitute materials (up to 5%) applicable for Federal FY 1995.

2. The use of CRM in asphalt paving offers indisputable environmental benefits and potential, but uncertain, engineering benefits.

The environmental benefits of using CRM in asphalt paving are obvious and undisputed. Disposing of scrap tires is a major waste management problem in Puerto Rico and CRM technologies represent a good recycling alternative, from a purely environmental perspective.
However, the engineering benefits of CRM asphalt paving products are still unproven and, thus, the ultimate costs versus benefits picture is on asphalt pavements modified with CRM is still unknown. Though the use of CRM in asphalt paving mixtures has been studied by various state highway agencies since the 1970's, the available information on engineering performance of asphalt pavements containing recycled rubber is too limited at present to support more than tentative, general conclusions. This is reflected in the most recent position taken by the FHWA in its Report to Congress on CRM technologies: "There is no reliable evidence that asphalt pavement containing recycled rubber does not perform adequately as a material for the construction or surfacing of highways and roads." §2

The report used the same formula to sum up its findings regarding the other two matters that ISTEA specifically required the FHWA and EPA to report on: the recyclability of CRM asphalt and possible increases to health and environmental risks from the manufacture and use of HMA modified with recycled rubber. It found "no reliable evidence" indicating that such pavements cannot be recycled and "no reliable evidence" that their manufacture and use created an increased threat to human health or the environment.

3. **Puerto Rico will have more to do and further to go in meeting ISTEA CRM requirements than most of the states, because the Island's current asphalt recycling practices are not up to the state-of-the-art.**

ISTEA Section 1038(d)(2), "Other Materials," stipulates that any other recycled material or materials designated by the FHWA can be substituted for recycled rubber in meeting up to 5% of the MUR in any given year. In the memorandum of June 28, 1993, the FHWA identifies the following materials as being acceptable substitutes for CRM: reclaimed asphalt pavement (RAP), recycled glass, reclaimed concrete pavement, coal fly ash, mining waste rock, and blast furnace slag.

**Forty-two states already recycle asphalt pavement.** Many of them may be able to meet half of the 1995 10% MUR without laying a single ton of HMA modified with CRM simply by reporting their RAP usage as a sub-
stitute for the CRM requirement. Because the asphalt producers in Puerto Rico are not set up to use RAP, the Island won't be able to take advantage of this mechanisms in the law that allows a 5% reduction in the MUR as applied to CRM.

4. The close and energetic cooperation of the Island's asphalt producers will be essential to meet ISTEA minimum utilization requirements.

Selecting the best CRM technologies for application in Puerto Rico will require intensive, systematic technical and planning analysis by the DTPW, in coordination with asphalt industry representatives.

Most of the states have drum mix plants with drums that have been modified with RAP hoppers, which can also be used for adding CRM to the mix. Seventeen of the Island's 19 asphalt plants are conventional drum mix plants but they do not have RAP hoppers that would make it a relatively easy matter to produce asphalt with CRM or RAP. The remaining two plants are older technology batch plants with limited production capacities. The local asphalt industry's current plant and equipment capabilities may tend to favor initial use of the wet process, which is the more established process and also would seem to require less modification to existing production and application equipment and procedures. The dry process, especially the generic dry process, would appear to offer a more cost-effective medium-term approach, assuming the industry makes the necessary investment in modified and new production equipment.

Conversations with representatives of the asphalt industry have given the investigators the impression that the industry is not prepared for the changes that will be required by the CRM minimum utilization requirements. It is our impression that the asphalt industry will need forceful direction and technical exchange and cooperation from the DTPW, as well as favorable financing terms and other incentives.

Designing rubber modified HMA that meets the DTPW's current specifications for HMA is a key industry concern, as discussed in Section 1.6.4 and 1.10. The DTPW should revise its specifications based on the new specifications recently issued by the National Center for Asphalt Technol-
ogy and in light of CRM state-of-the-practice. Working closely with industry on the new specifications is essential as they involve new procedures and testing equipment.

5. **The initial cost of CRM asphalt pavement, regardless of which technologies are used, will be substantially higher than the cost of conventional asphalt pavement, and the relative cost increase will be greater here than in most parts of the U.S. mainland.**

Rough preliminary estimates for Puerto Rico are that RUMAC will cost $8-20 more per ton than conventional HMA (a 20-50% increase), and ARHM will cost about $16 more per ton (a 40% increase). The actual cost increase may be substantially higher; a spokesman for the Island's leading asphalt producer has indicated that CRM HMA will raise the price of AC pavement from $32 to $82 per ton, an increase of 256%.

To meet the 10% MUR for CRM pavements in 1994, then, the DTPW could expect an increase in paving project costs of $337,120 to $853,120 (figuring 43,000 tons of asphalt rubber modified pavement and using the formulas shown in Tables 7 and 8, Section 1.10). These are very rough estimates and should be considered conservative; many factors could drive the price much higher. Using the $50 per ton increase (from $32/ton to $82/ton) estimated by the asphalt industry spokesman cited above, the projected costs to Puerto Rico of complying with Section 1038 rise dramatically, to between $2.15 million and $6.45 million per year, depending on the percentage of CRM used in the HMA mix.

### 1.12 Recommendations

The recommendations for action in this subsection follow directly from the conclusions set forth in the previous subsection. The recommendations are grouped according to short-term, medium-term, and long-term perspectives. A recommendation whose rationale has already been well-established by information and explanations in previous sections of this report will not be followed by further comment.
Short-Term Horizon: Fiscal Year 1994

1. The DTPW should establish a task force to coordinate the implementation of a comprehensive plan for satisfying ISTEA usage requirements for CRM and other recycled materials in HMA pavements.

The task force should include the Governor's Advisor on the Infrastructure and representatives from the DTPW, PRHTA, the Solid Waste Authority, the municipalities, the tire importers association, the local asphalt production industry, and the Federal Highway Administration.

2. The DTPW should work closely with the Island's asphalt producers and contractors to identify the current obstacles to incorporating CRM and other recycled materials in HMA pavements; viable options for overcoming those obstacles should then be sought.

Special immediate attention should be given to getting the Island's asphalt producers to make the changes necessary in their drum mix plants so that RAP can be added to asphalt mixes. Forty-two states currently use reclaimed asphalt pavement in HMA asphalt pavement applications. Using RAP in HMA is recognized worldwide as an effective, economical method for rehabilitating existing flexible pavement. RAP reduces the amount of virgin aggregate needed for HMA, and also requires less binder than conventional HMA, which can translate into considerable cost savings.

The use of RAP can pave the way for the use of CRM. Drum mix plants with RAP hoppers can easily incorporate CRM into HMA via the dry process.

3. The DTPW should designate a CRM projects coordinator to supervise a follow-up study of CRM technologies aimed at identifying:
   (a) the proven CRM technologies that will best enable the agency to fulfill ISTEA usage requirements in the short-term, and
   (b) the most promising new generic technologies that could offer long-term cost-benefit advantages if tested locally and adapted for implementation in 3-5 years.
Target dates for CRM usage requirements will probably be a prime initial consideration in choosing among the available CRM technologies. Wet process CRM technologies have been around the longest and for rapid incorporation of CRM into the local asphalt production process, they appear to represent the best alternative; however, they are more expensive than newer generic dry processes, which appear to be the most promising recent development in CRM technology. Incorporating a generic dry process within a short-term timeframe, however, implies greater risks in terms of engineering performance.

4. The DTPW should fund and coordinate a pilot project to test one or more of the newer CRM technologies.

The project should include laboratory tests of the chemical and physical properties of the pavements produced, as well as the construction and long-term testing of field evaluation sections.

5. The DTPW's CRM projects coordinator and his team should establish a cooperative effort with a State highway authority that has a CRM research and development program already underway.

Eng. Jorge Velar, research assistant, visited Florida during the course of this study and consulted with FDOT personnel involved in the CRM pavement testing program. He found that the FDOT engineers dealing with the asphalt rubber implementation effort believe that the wet process in a friction course using a very fine grade of CRM will produce the optimal cost-benefit results. One advantage of working with the FDOT in this area is that they have already developed a comprehensive set of specifications governing CRM paving projects. (See Appendix C).

6. Based on its own internal study, on consultations with outside experts, and on asphalt industry input, the DTPW should issue a set of revised specifications and procedures governing the use of CRM and other recycled materials in asphalt paving projects.
Medium-Term Horizon: Fiscal Years 1995 - 1997

1. The DTPW, working with the CRM producer and asphalt contractors, should establish quality assurance specifications for both the CRM producer and the tire recycling companies or government-run recycling centers that provide the CRM producer with shredded rubber.

2. Based on the results of pilot projects, the DTPW should select a preferred CRM technology for widespread use in Puerto Rico and work with the CRM producer, asphalt producers, and asphalt contractors to assure quality control in the implementation of this technology.

3. The DTPW should develop special training programs and monitoring, assessment, and repair procedures for CRM pavements and incorporate them into its Pavement Management System.

Long-Term Horizon: Fiscal Year 1998 and Beyond

1. The DTPW should institute a systematic program to carefully monitor the performance of CRM pavements so that it can respond quickly to any unexpected signs of pavement failure that may indicate problems with the CRM process used.

2. The DTPW should take initiatives to transfer CRM HMA technology to other countries in Latin America and the Caribbean.
Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico

SECTION 2

Overview of Solid Waste Management Problems Created by Discarded Tires in Puerto Rico
2. Overview of Solid Waste Management Problems Created by Discarded Tires in Puerto Rico

2.1 The Scrap Tire Problem in Puerto Rico

In Puerto Rico, as in most areas of the mainland U.S., discarded motor vehicle tires present a serious solid waste problem. The Puerto Rico Solid Waste Authority (SWA) estimates that 2-3 million tires end up in landfills and illegal dumps each year. The higher figure is consistent with documented motor vehicle statistics and known tire-usage rates. According to the Puerto Rico Planning Board, there are more than 1,750,000 motor officially registered vehicles on the Island (see Figure 4). Based on an average annual motor vehicle tire replacement rate of 1.7, we estimate that 3 million tires are scrapped in Puerto Rico each year. As an average tire weighs approximately 20 pounds, this amounts to about 30,000 tons of tires discarded annually, which, according to statistics of the SWA, is about 1.7 percent of the Island's annual industrial-plus-residential solid waste stream.

The unregulated importation of used tires makes the Island's scrap tire problem even worse. In 1992, 806,270 used tires were brought to Puerto Rico, according to the Chamber of Commerce's Maritime Register. The Executive Director of the SWA has estimated that the true figure is closer to 1.5 million tires imported annually. Whereas new tires may last 2-3 years, used tires typically last only 6-18 months. Our estimate of the number of tires discarded each year is conservative; the widespread practice of buying used tires rather than new ones probably warrants a higher tire-turnover rate. We would expect that the number of tires discarded on the Island each year may actually be somewhat higher than 3 million.

On the U.S. mainland scrap tires began to be seen as a problem in the mid-1980s, after a series of major scrap tire stockpiles burned out of control. Similar fires have recently occurred in Puerto Rico. Because stockpiled tires hold rainwater, they can easily become a breeding ground for mosquitoes; they are also a haven for vermin. Photograph 1 illustrates the...
Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico

Figure 4. Numbers of registered motor vehicles in Puerto Rico

Registered motor vehicles (*1000)

1,870,000 Vehicles for 1994 (expected value)

Years

Acceptable storage of discarded tires

Because stockpiled tires hold rainwater, they can easily become a breeding ground for mosquitoes; they are also a haven for vermin.
inherent health and environmental problems associated with the unsheltered storage of discarded tires. Illegal stockpiles of scrap tires are a growing problem in Puerto Rico. When tires are illegally dumped on roadsides, they soon attract other dumping; the unsightly and unsanitary situation that results constitutes an environmental hazard and gives a negative impression of the Island to passing tourists (see Photographs 2 and 3). For a more thorough description of the scrap tire problem on the Island, see Appendix D, which contains copies of recent newspaper articles.

2.2 Survey of Municipalities

A questionnaire was developed to assess how the Island's municipalities are currently handling the disposal of scrap tires and what their plans may be for the future. The questionnaire was mailed in early March 1993 to all 78 municipalities on the Island. Appendix E contains a copy of the original questionnaire in Spanish. The translated English version, shown in Exhibit 1, summarizes the descriptive statistics.

Figure 5 presents a map of the Island showing the distribution of the municipalities that responded to the survey. The municipalities that responded are well distributed throughout the Island with the exception of the southeast quadrant. Forty percent of the municipalities returned the questionnaire (31 out of 78).

2.3 Discussion of Survey Findings

Figures 6 to 13 were generated based on the 40 percent of the municipalities that answered the questionnaire.

Figure 6 shows that almost 94 percent of the municipalities responding reported that they had a substantial tire disposal problem: 74.2% rated it critical and 19.4% rated it moderate.
Photograph 2. Illegal dumping of scrap tires

When tires are illegally dumped on roadsides, they soon attract other dumping; the unsightly and unsanitary situation that results constitutes an environmental hazard and gives a negative impression of the Island to passing tourists. This dump was found along the roadside in Trujillo Alto.
Photograph 3. Illegal dumping of scrap tires

This dump was found along the roadside in Bayamón.
Exhibit 1

UNIVERSITY OF PUERTO RICO
MAYAGÜEZ CAMPUS
CIVIL ENGINEERING DEPARTMENT

Questionnaire Regarding
The Uses and Management of Discarded Tires in Puerto Rico

Municipality Summary of Questionnaire Responses
Mayor ____________________________
Date _____________________________

Name of the person who will answer this questionnaire:

Occupation ______________________
Telephone ________________________

1. Classify the magnitude of the problem of management and disposal of discarded tires in your municipality:

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2%</td>
<td>None</td>
</tr>
<tr>
<td>3.2%</td>
<td>Little</td>
</tr>
<tr>
<td>19.4%</td>
<td>Moderate</td>
</tr>
<tr>
<td>74.2%</td>
<td>Critical</td>
</tr>
</tbody>
</table>

2. How many tires do you estimate are discarded in your municipality per year?

906,360 (accumulated response of the 31 municipalities)

3. What is your municipality doing at present to solve/mitigate this problem?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>Selling</td>
</tr>
<tr>
<td>66.7%</td>
<td>Storing</td>
</tr>
<tr>
<td>6.5%</td>
<td>Burning</td>
</tr>
<tr>
<td>12.9%</td>
<td>Shredding</td>
</tr>
<tr>
<td>12.9%</td>
<td>Other (Please specify)</td>
</tr>
</tbody>
</table>

[Remarks: The other action not mentioned above was depositing the scrap tires in landfills.]
4. Do you have a designated location for discarded tires?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>77.4%</td>
<td>Yes (Please specify the location.)</td>
</tr>
<tr>
<td>22.6%</td>
<td>No</td>
</tr>
</tbody>
</table>

5. At the present time do you have problems with discarded tire storage in illegal dumps?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>71.0%</td>
<td>Yes</td>
</tr>
<tr>
<td>29.0%</td>
<td>No</td>
</tr>
</tbody>
</table>

6. Alternative uses found by your municipality for discarded tires. (Please specify the number of tires used for each purpose.)

<table>
<thead>
<tr>
<th>Alternative Use</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>None at the present time</td>
<td>N/A</td>
</tr>
<tr>
<td>Construction of artificial reefs</td>
<td>N/A</td>
</tr>
<tr>
<td>Safety wall on highways</td>
<td>N/A</td>
</tr>
<tr>
<td>Stuffing material for highways sub-bases</td>
<td>N/A</td>
</tr>
<tr>
<td>Bulking agent in the fertilizer production</td>
<td>N/A</td>
</tr>
<tr>
<td>Tire Derived Fuel (TDF)</td>
<td>N/A</td>
</tr>
<tr>
<td>Others (Please specify.)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

[Remarks: The only alternative use mentioned under "Others" above was tree protection.]

7. Would you be able to participate in a hot mix rubber-asphalt pavement pilot project that incorporates crumb rubber to paving mixtures?

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0%</td>
<td>Yes</td>
</tr>
<tr>
<td>0.0%</td>
<td>No</td>
</tr>
</tbody>
</table>

8. Is there any municipal law, in effect or in the process of being considered for approval, regarding the uses, management and/or disposal of discarded tires? (If yes, please mail a copy to the address shown below.)

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.7%</td>
<td>Yes</td>
</tr>
<tr>
<td>90.3%</td>
<td>No</td>
</tr>
</tbody>
</table>
9. Is your municipality planning to use a tire shredding machine in the near future?

| 61.3% | Yes |
| 38.7% | No  |

If the answers to question N° 9 were "Yes," continue with question N° 10; otherwise, proceed with the final part of the questionnaire.

[The response percentages given in questions N° 10 to N° 17 are based only on the number of municipalities that answered "Yes" in question N° 9.]

10. Is your municipality planning and/or currently making arrangements to purchase a tire shredding machine?

| 31.6% | Yes |
| 68.4% | No  |

11. Is your municipality planning to take the discarded tires produced by your municipality to another municipality that has purchased or will purchase a tire shredding machine (i.e., Bayamón, Cabo Rojo)? (If your answer is yes please name the municipality that has been contacted.)

| 57.9% | Yes |
| 42.1% | No  |

[Remarks: The municipalities named were: Bayamón, Cabo Rojo, Fajardo, and Río Grande.]

12. Is your municipality planning to purchase a tire shredding machine in conjunction with another municipality or municipalities? (If your answer is yes please name the contacted municipality/ies.)

| 36.9% | Yes |
| 63.2% | No  |

13. Model(s) considered(s) for the purchase N/A

14. Cost of the machine (with or without transportation charges) N/A
15. Information on the company that represents the tire shredding machine in Puerto Rico.

Name: N/A
Address: N/A
Telephone: (809) - Fax (809) -

16. Information concerning the company that distributes the tire shredding machine outside the Island.

Name: N/A
Address: N/A
Telephone: ( ) - Fax ( ) -

17. Are you interested in participating in the development and/or production of educational seminars on the safe operation and use of these shredding machines?

96.8% Yes
3.2% No

18. Would you like to obtain a copy of this study when it is finished?

100.0% Yes
0.0% No
Figure 5. Territorial distribution of the municipalities that responded to the questionnaire.
Figure 6. Characterization of the scrap tire disposal problem by municipalities responding to the questionnaire

Figure 7. Methods currently used by municipalities to dispose of scrap tires
Figure 8. Municipalities with a designated area for storage of scrap tires

Figure 9. Municipalities reporting that storage of scrap tires is a problem

continues, next page
Figure 10. Municipalities reporting alternative uses for scrap tires

Figure 11. Municipalities that envision using a tire shredder in the near future
Figure 12. Municipalities that are in the process of purchasing a tire shredder, alone or in cooperation with other municipalities.

Figure 13. Municipalities with legislation related to scrap tire disposal.
Figure 7 shows that the overwhelming majority of the municipalities have adopted a traditional, passive approach to handling the scrap tire problem. At the present time two-thirds of the municipalities are simply stockpiling discarded tires, usually in an area set aside for this purpose within the municipal landfill. (Photograph 4 shows such an area in the Mayagüez landfill and the difficulties encountered in handling the large piles of tires.) The remaining third of the municipalities use disposal methods other than stockpiles, i.e., burning (6.5%), shredding (12.9%), and mixing them with general refuse in landfills (12.9%). Figure 8 shows that 77.4 percent of the municipalities have a designated area for discarded tires; Figure 9 shows that 71 percent reported that they are facing storage problems.

There are a number of alternative, non-asphalt pavement uses for scrap tires, and several of them seem suitable for adoption in Puerto Rico. Scrap tires could be used in the construction of breakers and artificial reefs, as safety walls on highways, as fill material for civil engineering projects, and as bulking agent in fertilizer production. An important demonstrated use of scrap tires is Tire Derived Fuel (TDF), which is used in industrial processes and/or to generate electrical energy. (See Section 2.6 for a discussion of TDF and other alternatives for reusing scrap tire rubber.)

The municipalities responding to the survey did not indicate that they use any of these options, which were explicitly provided as possible answers in question number 6 (see Figure 10). On the other hand, the investigators have personal knowledge, some of it first-hand and some gathered from informal interviews, of the following instances of alternative uses of discarded tires on the Island:

- in the construction of artificial reefs at Lajas
- in safety walls on highway PR 2 in Mayagüez
- as bulking agent in the fertilizer production at the secondary water treatment plant in Mayagüez.
Photograph 4. Storage of Scrap Tires in Landfills

Two-thirds of the municipalities are simply stockpiling discarded tires, usually in an area set aside for this purpose within the municipal landfill. This photograph shows such an area in the Mayagüez landfill and the difficulties encountered in handling the large piles of tires.
It is clear from this survey and the investigators' informal discussions with municipal officials that the tire disposal problem on the Island is increasing at a very alarming rate. Figure 11 shows that 61.3% (19) of the reporting municipalities envision using a tire shredding machine in the near future to help them deal with the problem of scrap tires. Figure 12 shows that of those 19 municipalities planning to use a tire shredder, 31.6% (6) have already made arrangements to acquire a tire shredding machine, either alone or in cooperation with another municipality.

At present, however, only one municipality has acquired a tire shredder, a mobile unit owned by the Municipality of Bayamón. Photograph 5 shows this whole tire shredder, which does not have a classifier device installed. A classifier device, which is sold separately, shreds material to a predetermined size by letting only pieces that are the specified size or smaller pass through, returning larger size material to the main hopper for further shredding. Because it lacks a classifier device, the equipment owned by Bayamón is limited to producing strips approximately 2-4" wide (see Photograph 6).

Figure 13 shows that only 9.7% of the municipalities responding (3 of 31) have taken legislative action toward solving the problem of scrap tire disposal. The problem of tire disposal is so complex and difficult that all the municipalities answering the questionnaire (100%) indicated that they would be willing to look for alternative scrap tire management solutions. All of them (100%) demonstrated a willingness to participate in pilot projects related to asphalt rubber pavements, and 96.8% would like to participate in a seminar on this topic. All of them (100%) also expressed the desire to receive a copy of the findings of this study.

### 2.4 Involvement of Private Industry

Though responses to the questionnaire did not indicate any involvement of private industry in the scrap tire disposal practices or plans of the municipalities, newspaper reports have indicated that three waste management firms on the Island have plans to at least investigate the possibility of becoming involved in tire shredding operations.
Photograph 5. Whole tire shredder owned by Municipality of Bayamón

This machine does not have the classifier device installed. The function of the classifier device, which is sold separately, is to select materials of a predetermined size by letting them pass through, returning the larger size material to the main hopper for further shredding.
Photograph 6. Strips produced by Municipality of Bayamón tire shredder

Because it lacks the classifier device, the equipment used in Bayamón is limited to producing strips approximately 2-4" wide.
The waste management firms are:

- **Commercial Incineration Corp.**, reportedly the first private firm on the Island to obtain a multi-use shredder, capable of shredding tires, carton, glass, wood, plastic, and metal. Carlos E. Rodríguez Pardo, president of the firm, indicated that he planned to acquire a second, larger-capacity shredder and hoped to obtain contracts with various municipalities on the Island; shredding scrap tires, presumably, would be among the services his company plans to offer.  

- **End Tire Recycling**, which incorporated in Puerto Rico in 1993. Donald Schiavetta, the company's president, is reportedly waiting for Commonwealth legislation to establish a uniform scrap disposal policy before getting into the tire recycling market here.  

- **The American Tire Systems International-Puerto Rico**, which established an operation at the Aguirre sugar refining plant in Salinas, in December of 1993. ATSI-PR is reportedly seeking contracts with Municipalities to haul scrap tires from their landfills. The company owns a stationary tire shredder and is currently studying the potential markets for crumb rubber to decide various production parameters, such as the optimal range of particle sizes.  

### 2.5 Legislation Dealing with Scrap Tires

#### 2.5.1 Federal Legislation

In 1990 and 1991, when the U.S. Congress began to consider the reauthorization of the Resource Conservation and Recovery Act (RCRA), the following bills were introduced to amend the RCRA by adding provisions that specifically address the scrap tire problem:

- **Tire Recycling Incentives Act**: would have required tire manufacturers to recycle tires or use a recycling credit system. Tire Recycling and
Recovery Act: would have established a scrap tire trust fund to assist state-developed recycling programs.

- **Waste Tire Recycling, Abatement, and Disposal Act:** would have mandated a market for CRM on Federally funded asphalt paving projects.

None of these proposed amendments became law because the 1990-1992 Congress did not pass the reauthorization of the RCRA. (The last bill listed above, however, bears some resemblance to the provisions of Section 1038 of ISTEA.) It is expected that the new Congress will reconsider the scrap tire issue when it takes up the RCRA reauthorization sometime later this year.

Currently, the 1991 ISTEA is the only Federal law relating to the disposal of scrap tires. Section 1038(d) of ISTEA establishes a minimum utilization requirement for "asphalt pavement containing recycled rubber" that was set to take effect beginning in 1994 but was postponed by Congress to 1995. Subsection (e) defines "asphalt pavement containing recycled rubber" as any hot mix or spray applied binder in asphalt paving mixture that contains rubber from whole scrap tires or shredded tire material; i.e., what has been referred to generally in this report as "CRM HMA paving applications." (See Appendix A for the complete text of ISTEA Section 1038, "Use of Recycled Paving Material.")

Section 1038 states that a percentage of the total tons of HMA laid on the Island to pave roadways partially financed with Federal-aid funds will be required to contain crumb rubber modifier, or an acceptable substitute recycled material. The percentages stipulated are 5% for 1994, 10% for 1995, 15% for 1996, and 20% for 1997 and each year thereafter. As previously explained in the Introduction, the FY 1994 DOT appropriations bill contains a provision, Section 325, prohibiting any Federal efforts to enforce the requirements for recycled rubber in asphalt pavements during 1994. In November 1993, the FHWA issued a memorandum on this matter stating that the effect of Section 325 is to nullify the FY 1994 MUR under Section 1038(d); however, the other scheduled MURs remain in effect and, unless Congress legislates a continuation of
the moratorium on enforcement of Section 1038(d), States will be required to meet the 10% MUR for CRM and allowable substitute materials (up to 5%) applicable for Federal FY 1995.

The FHWA issued two other memoranda in 1993 containing detailed information on its policy for eventually enforcing Section 1038(d). The memorandum of June 28, 1993, changes the accounting method for enforcing the law. Rather than use a percentage of total tons of HMA laid in a State during a given year, the FHWA will assess compliance with the MUR based on "the total number of kilograms of recycled rubber required by awarded contract bid quantities of asphalt pavement containing recycled rubber."

ISTEA Section 1038(d)(2), "Other Materials," stipulates that any other recycled material or materials designated by the FHWA can be substituted for recycled rubber in meeting up to 5% of the MUR in any given year. In the memorandum of June 28, 1993, the FHWA identifies the following materials as being acceptable substitutes for CRM: reclaimed asphalt pavement (RAP), recycled glass, reclaimed concrete pavement, coal fly ash, mining waste rock, and blast furnace slag. Other key points contained in the FHWA memoranda are summarized in the Introduction. The complete memoranda are reproduced in Appendix B.

The average quantity of HMA laid on Federal-assisted roads in Puerto Rico during Federal Fiscal Years 1991, 1992, and 1993 was approximately 430,000 tons.\(^9\) Table 9 shows estimates of how many scrap tires would be consumed by HMA asphalt applications if Puerto Rico meets ISTEA's CRM minimum utilization requirements at the levels designated for 1995-1997 using AR or RUMAC with 1%, 2%, and 3% CRM.

Based on a maximum-tire-usage scenario, then, to comply with the 20% usage level scheduled to take effect in 1997, Puerto Rico would only consume about half a million tires per year (6 tires per ton of HMA x 20% of 430,000); in other words, it would not appear that CRM usage at even the maximum levels mandated by ISTEA, in and of itself, will solve the Island's scrap tire use/disposal problem.
Table 9. CRM Minimum Utilization Requirements Applied to Puerto Rico

<table>
<thead>
<tr>
<th>Year / % Tons HMA</th>
<th>Estimated tires consumed at these levels of %CRM in HMA, using 430,000 tons HMA as baseline number for annual tons of HMA laid on Federal-aid roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1% (2 tires/ton)*</td>
</tr>
<tr>
<td>1995 / 10%</td>
<td>66,000</td>
</tr>
<tr>
<td>1996 / 15%</td>
<td>129,000</td>
</tr>
<tr>
<td>1997 / 20%</td>
<td>172,000</td>
</tr>
</tbody>
</table>

*approximate minimum stipulated by ISTEA

It should be noted that Section 1038 authorizes the U.S. Secretary of Transportation to waive or reduce the above requirements for individual states. Subsection (d) paragraph (6) of Section 1038 provides that a separate determination that asphalt pavement containing recycled rubber does not perform adequately may be made for individual states or regions based on "climate, geography, and other factors that may be unique to the State or region and that would prevent the adequate performance of asphalt pavement containing recycled rubber." It is conceivable that Puerto Rico could make a case for postponing implementation of the CRM minimum utilization requirements based on the lack of experience with CRM pavements in tropical climates.

It is also worth investigating the implications of subsection (e) paragraph (1) subparagraph (B), which allows a state to use an asphalt paving mixture containing less recycled rubber than specified as the minimum in (e)(1)(A): "a mixture of not less than 20 pounds of recycled rubber per ton of hot mix or 300 pounds of recycled rubber per ton of spray applied binder." The mixture specified as the minimum here is a 1% CRM RUMAC or AR; the asphalt paving literature documents many experiences with mixtures containing 2% and 3% CRM.

RUMACs and ARs with less than 1% CRM have not been studied because the effects of CRM at levels of less than 1% are not considered significant. However, for the sake of fulfilling the CRM mandate, it might be ad-
vantageous for a state that uses a large portion of its scrap tire supply in other ways to implement the use of RUMACs and/or ARs with less than 1% CRM. The state is authorized to do this if the total scrap tires consumed by the other recycling uses and its CRM paving applications is equivalent to the number of scrap tires that would be consumed if the state fulfilled the minimum utilization requirements using asphalt containing at least 1% CRM.

2.5.2 State Scrap Tire Legislation

Forty-seven states have passed laws or regulations to control their scrap tire problems.91 Table 10 summarizes these diverse efforts. Only three states—Alaska, Delaware, and New Mexico—do not have laws or regulations specifically targeted at scrap tires. Of the 47 states that do, 14 regulate either the collection, transporting, processing, or storage of scrap tires and impose landfill restrictions, including bans or requirements related to size-reductions (cutting and/or shredding).

Two-thirds of the states that have laws or regulations to control scrap tire disposal have enacted either a disposal fee or new tire tax to generate funds for managing the scrap tire problem. In many states, scrap tire provisions are part of a comprehensive recycling or solid waste management law which requires local communities to develop recycling management plans for tires.

2.5.3 Commonwealth Waste Management Legislation

2.5.3.1 Commonwealth Bill N° 70

On September 18, 1992, Commonwealth Bill N° 70 was signed by the Governor of Puerto Rico. The bill provided for the establishment of a Municipal Waste Management Program designed to reduce the current total municipal waste production by 35 percent by 1994. The bill also specifies that the municipalities shall continue to reduce their waste production in order to achieve a 50 percent waste reduction from the current level by the year 2000. The bill allows the municipalities to hire all the personnel and institutions (including private firms) needed in order to achieve the stipulated waste disposal goals.
<table>
<thead>
<tr>
<th>State</th>
<th>Funding Source</th>
<th>Regulation</th>
<th>Landfill Restrictions</th>
<th>Market Incentives</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td></td>
<td>S P</td>
<td>cut and monotilled</td>
<td>grant/tax credits</td>
</tr>
<tr>
<td>AR</td>
<td>$1.50/tire retail sales</td>
<td>S P H</td>
<td>bans whole tires -1/92</td>
<td></td>
</tr>
<tr>
<td>AZ</td>
<td>2% sales tax on retail sale</td>
<td>S P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>$0.25/tire disposal fee</td>
<td>S P</td>
<td>bans whole tires -1/93</td>
<td>grant/loans 5% PP</td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td>S P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td></td>
<td>S</td>
<td>10% PP</td>
<td></td>
</tr>
<tr>
<td>FL</td>
<td>$1.00/tire retail sales</td>
<td>S P H</td>
<td>tire must be cut</td>
<td>DOT required use, R&amp;D grants, 10% PP</td>
</tr>
<tr>
<td>GA</td>
<td>$1.00/tire mgt. fee</td>
<td>to be written</td>
<td>bans whole tires -1/95</td>
<td></td>
</tr>
<tr>
<td>HI</td>
<td></td>
<td>(Honolulu only)</td>
<td>bans whole tires -7/92</td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>$1.00/tire retail sales</td>
<td>S P H</td>
<td></td>
<td>$20/ton-$1/retr.-grants</td>
</tr>
<tr>
<td>IL</td>
<td>$1.00/tire retail sales, $0.50/vehicle tire</td>
<td>S P H</td>
<td>bans whole tires -7/94</td>
<td>grants/loans, proc. required</td>
</tr>
<tr>
<td>IN</td>
<td>permit fee tire storage sites</td>
<td>S P H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IA</td>
<td></td>
<td>H</td>
<td>bans whole tires</td>
<td>recycled cont. required</td>
</tr>
<tr>
<td>KS</td>
<td>$0.50/tire retail sales</td>
<td>S P H</td>
<td>tire must be cut</td>
<td>municipal grants</td>
</tr>
<tr>
<td>KY</td>
<td>$1.00/tire retail sales</td>
<td>S P H</td>
<td>tire must be cut</td>
<td>loans/RC preference</td>
</tr>
<tr>
<td>LA</td>
<td>$2.00/tire retail sales-2/92</td>
<td>S P H</td>
<td>tire must be cut</td>
<td>st. should buy recycled</td>
</tr>
<tr>
<td>ME</td>
<td>$1.00/tire disposal fee</td>
<td>S P H</td>
<td></td>
<td>st. should buy recycled loans/grants</td>
</tr>
<tr>
<td>MD</td>
<td>$1.00/tire first sale 2/92</td>
<td>S P H</td>
<td>bans tires -1/94</td>
<td>5% PP</td>
</tr>
<tr>
<td>MA</td>
<td></td>
<td>S P H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI</td>
<td>$0.50/vehicle title fee</td>
<td>S P H</td>
<td></td>
<td>grants</td>
</tr>
<tr>
<td>MN</td>
<td>$4.00/vehicle title transfer</td>
<td>S P H</td>
<td>shredded tires only</td>
<td>grants</td>
</tr>
<tr>
<td>MS</td>
<td>$1.00/tire retail sales</td>
<td>S P H draft</td>
<td>to be written</td>
<td>grants</td>
</tr>
<tr>
<td>MO</td>
<td>$0.50/tire retail sales</td>
<td>S P H</td>
<td></td>
<td>10% PP</td>
</tr>
<tr>
<td>MT</td>
<td></td>
<td>S H</td>
<td>bans whole tires</td>
<td></td>
</tr>
<tr>
<td>NE</td>
<td>business assessment fee</td>
<td>S P H</td>
<td></td>
<td>st. req. to buy recycled</td>
</tr>
<tr>
<td>NV</td>
<td>$1.00/tire fee new tires</td>
<td>S P H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH</td>
<td>town graduated vehicle registration fee</td>
<td>S P H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>Funding Source</td>
<td>Regulation</td>
<td>Landfill Restrictions</td>
<td>Market Incentives</td>
</tr>
<tr>
<td>-------</td>
<td>----------------</td>
<td>------------</td>
<td>-----------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>NJ</td>
<td></td>
<td>S P</td>
<td></td>
<td>st. should buy recycled loans/grants</td>
</tr>
<tr>
<td>NY</td>
<td></td>
<td>S H</td>
<td></td>
<td>grants/DOT use</td>
</tr>
<tr>
<td>NC</td>
<td>1% sales tax on new tires</td>
<td>S P H</td>
<td>tires must be cut</td>
<td>funds city, tire collect.</td>
</tr>
<tr>
<td>ND</td>
<td></td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OH</td>
<td></td>
<td>S</td>
<td>tires must be cut-1/93</td>
<td></td>
</tr>
<tr>
<td>OK</td>
<td>$1.00 sales tax new tires</td>
<td>S P</td>
<td>tires must be cut</td>
<td>grants/processor credits</td>
</tr>
<tr>
<td>OR</td>
<td>$1.00/tire disposal tax new tire sales-ends 10/1/92</td>
<td>S P H</td>
<td>tires must be cut</td>
<td>st. should buy recycled loans</td>
</tr>
<tr>
<td>PA</td>
<td></td>
<td>S</td>
<td></td>
<td>EPA proc. guidelines</td>
</tr>
<tr>
<td>RI</td>
<td>$0.50 sales tax on new tires</td>
<td>S P</td>
<td></td>
<td>promotes use of recycled products</td>
</tr>
<tr>
<td>SC</td>
<td>$2/tires new sales</td>
<td>S P H</td>
<td>bans whole tires</td>
<td>st. req. to buy recycled grants to counties</td>
</tr>
<tr>
<td>SD</td>
<td>$0.25/tire vehicle registration</td>
<td>S P H</td>
<td></td>
<td>grant fund to be developed</td>
</tr>
<tr>
<td>TN</td>
<td>$1.00/tire retail sale</td>
<td>S P H</td>
<td></td>
<td>grant/equipment credits</td>
</tr>
<tr>
<td>TX</td>
<td>$2.00/tire retail sales-1/92</td>
<td>S</td>
<td>bans whole tire</td>
<td>processor credit 15% pref. A/R</td>
</tr>
<tr>
<td>UT</td>
<td>grad. tax per tire size</td>
<td>S P H</td>
<td></td>
<td>$20.00/ton</td>
</tr>
<tr>
<td>VT</td>
<td></td>
<td>S</td>
<td>bans whole tire</td>
<td>stated req. to buy recycled 5% PP</td>
</tr>
<tr>
<td>VA</td>
<td>$0.50/tire disposal fee on new tires</td>
<td>S P</td>
<td>bans whole tire</td>
<td>processor credit/subsidy</td>
</tr>
<tr>
<td>WA</td>
<td>$1.00 fee on new tires</td>
<td>S P</td>
<td></td>
<td>grants</td>
</tr>
<tr>
<td>WV</td>
<td></td>
<td>S</td>
<td></td>
<td>state req. to buy recycled</td>
</tr>
<tr>
<td>WI</td>
<td>$2/tire per vehicle title fee</td>
<td>S P H</td>
<td>tires must be cut-12/31/94</td>
<td>$20.00/ton/grant</td>
</tr>
<tr>
<td>WY</td>
<td></td>
<td>S</td>
<td></td>
<td>state shall buy recycled</td>
</tr>
</tbody>
</table>

**Legend**

S = Storage  
P = Processor  
H = Hauler  
PP = Price preferences for products with recycled content
Commonwealth Bill N° 70 provided the municipalities with a framework for considering new ways to meet the mandated waste reduction. At present, many local municipalities are conducting feasibility studies of procedures and programs that might help them manage the solid waste problem. Recycling is the technique most commonly considered by the municipalities to address this issue. Several municipalities, including San Juan and Bayamón, have already started pilot recycling projects in small urbanized areas of their jurisdiction to evaluate public response and participation levels. Currently, these pilot projects are only recycling glass, paper, and aluminum. The local municipal agencies which have implemented the pilot recycling projects have indicated that they plan to expand the program as time goes on.

2.5.3.2 Rosselló Administration’s Solid Waste Master Plan

Recently, the Rosselló Administration enacted a new Solid Waste Master Plan calling for a complete restructuring of the old municipal landfill system in order to comply with stricter Federal environmental regulations which go into effect on October 9 of this year. The plan mandates that 31 of the Island’s 60 landfills will stop accepting garbage by that date and begin the long process of closing in an environmentally acceptable manner; meanwhile, the affected municipalities will have to truck their garbage to one of the 29 landfills that will remain in operation. The Master Plan calls for rehabilitating the landfills that will remain open during a transition period in which 10 regional landfills will be constructed at strategic locations around the Island.

The Master Plan also calls for the construction of 17 recyclable materials recovery stations and two garbage incinerators ("waste-to-energy plants"); finally, the plan envisions the possibility of converting five of the Island’s sugar plants into energy producing facilities that would burn compost and other organic materials.

It is highly relevant to the scope of this study to note that the Solid Waste Master Plan, as explained in press reports at least, does not specifically address the management of scrap tires. Undoubtedly, however, the SWA has studied the scrap tire problem, as evidenced by a recent
newspaper article reporting that the SWA will propose an environmental
tax on every imported tire as part of the recycling legislation which it will
send to the Commonwealth Legislature in January of 1994.95

The Puerto Rico Association of Tire Importers, which speaks for most
of the Island's new tire retailers, maintains that the scrap tire problem
is much worse here than in the mainland U.S. due to the uncontrolled
sale of used tires. Photograph 7 shows a used tire business typical of
those often found operating on roadsides in Puerto Rico. The association
points out that many of these tires have already exceeded their useful
life and have been taken out of service by their original owners; they fur­
ther claim that the majority of these tires have defects and do not meet
DOT minimum thread depth requirements.

The association would favor a new tire sales tax if the Commonwealth
Legislature passes a law forbidding the importation of used tires. Such a
law was proposed in 1992; it would have imposed an "environmental tax" of $4 per new tire for passenger vehicle tires and $8 per tire for truck tires.
The association does not support such a high tax; it favors a tax of $2 per
passenger vehicle tire.96 As Table 10 (above, Section 2.5.3.1) shows, the
tax on new tires imposed in the states ranges from a low of $0.25 to $2.00
per tire.

2.5.4 Municipal Legislation

Only three municipalities (representing 9.7% of the respondents) have
taken legislative action toward solving the problem of scrap tire disposal.
These municipalities are Bayamón, Cabo Rojo, and San Juan. The Cabo
Rojo bill merits consideration as a model for the entire Island. On
February 19, 1993, the Mayor of Cabo Rojo signed Municipal Ordinance
N°25 which mandates how discarded tires will be recycled, a new tire
sales tax to cover the recycling expenses, and tax incentives for private
corporations that participate in the tire recycling program.
Photograph 7. A typical roadside used tire business

The Puerto Rico Association of Tire Importers, which speaks for most of the Island's new tire retailers, maintains that the scrap tire problem is much worse here than in the mainland U.S. due to the uncontrolled sale of used tires.
The tire sales tax schedule is summarized in Table 11. This sales tax will be collected by tire retailers and represents an additional charge to the customer in any purchase of tires (new, used, and/or retreaded).

Table 11. Cabo Rojo Municipal Tire Sales Tax Schedule

<table>
<thead>
<tr>
<th>Tire Size</th>
<th>Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 16&quot; in diameter</td>
<td>$2.50</td>
</tr>
<tr>
<td>Greater than 16&quot; but less than 22&quot; in diameter</td>
<td>$7.50</td>
</tr>
<tr>
<td>For each pound of a tire greater than 22&quot; in diameter (in addition to the $7.50 fee)</td>
<td>$0.30</td>
</tr>
</tbody>
</table>

2.6 Other Uses of Scrap Tire Rubber

A synthesis report published by NAPA in February 1993 argues that several promising uses for scrap tires are much more cost-effective solutions to the problem of scrap tires than using CRM in HMA pavements. In addition to highlighting concern that worker health risks and environmental damage may be exacerbated by the addition of CRM to asphalt, the NAPA report claims that the cost to dispose of tires in asphalt pavements works out to between $5 and $10 per tire, whereas alternative uses (which are discussed later in this report) could cost as little as 15 cents per tire. While the report’s cost-estimates appear to overstate the cost-benefit advantage presented by the alternative uses, they underscore the possible desirability of adopting a scrap tire management plan that puts equal or greater emphasis on non-pavement-related uses of scrap tire rubber as it does on CRM pavement applications.

Appendix F contains an excerpt of the NAPA report, which identifies the following major uses of scrap tires as having technical and economic benefits when compared to rubber modified asphalt:

- As an energy resource. Tire-derived fuel (TDF) and dedicated tires-to-energy facilities have the greatest potential, according to the NAPA report, for consuming large quantities of scrap tires. A 1992 study by the Scrap Tire Management Council found that 11 cement kilns, 9
pulp and paper mills, and 9 electricity generating facilities were using TDF; another 12 cement kilns and 9 electric power plants had conducted test burns and were awaiting permits.98 The NAPA report noted that a cement kiln provides an environment conducive to the use of many types of fuel, including tires. Section 2.6.1 contains a technical overview of TDF as a possible use of scrap tires especially suitable for development in Puerto Rico.

- **Other Civil Engineering uses.** Shredded and whole tires have been used in a variety of non-AC highway applications in recent years, as lightweight fill for embankments, as subbase drainage layers in highway construction, and in slope and shoulder stabilization projects. Using shredded tires as lightweight fill has the potential to consume many more tires than adding crumb rubber to asphalt mixes. A two-lane AR overlay only uses up about 3,600 tires per mile, whereas a two-lane, 20-foot-high embankment could require more than 5 million shredded tires per mile.99

The NAPA report argues that though there is potential for using CRM in asphalt pavements, significant disadvantages exist, in addition to higher costs. **Compared to other potential uses of scrap tires as an energy resource and in other civil engineering applications, adding rubber from scrap tires to asphalt mixes seems an unnecessarily expensive, and possibly risky, way to deal with this waste management problem.** For this reason, NAPA is lobbying to defer the implementation of ISTEA's minimum utilization requirements and suggesting that these other uses be developed to solve the scrap tire problem.100

### 2.6.1 Tire-Derived Fuel

Of the possible markets for scrap tires, besides CRM, only the fuel for combustion alternatives have shown some growth potential. This application, known as tire-derived fuel (TDF), presently consumes 26 million tires annually in the United States. **Several studies have concluded that TDF represents a cost-effective method of utilizing scrap tires in large volumes.**101 The main reason is the high energy content of scrap tire rubber. A study performed by the Wisconsin Power & Light Company...
(WPLC) estimated the heating value of used tires at approximately 15,000 BTU/Lb versus 10,000 to 11,000 BTU/Lb for coal. Another advantage highlighted by the WPLC study was the 61% volatile matter content of used tires, which is almost twice as high as even the most volatile coals. This helps the relatively large tire chips volatilize rapidly in the cyclone furnace and complete combustion.

WPLC also performed a test in their coal powered facilities in which TDF either outperformed or matched coal in several operation requirements such as air emissions, particulates, etc. Such an application of TDF requires an initial investment to retrofit the facilities to handle the different raw material even though in a coal fired plant both fuels are solid.

In Puerto Rico, cement plants are the biggest users of coal (100,000 to 150,000 tons/year). These facilities are highly energy intensive due to the nature of the manufacturing process, which requires long oven residence times and high temperatures. In theory, then, cement plants are excellent candidates for using scrap tires. According to WPLC, 70 tires have the equivalent energy content of 1 ton of coal. This means that 1.0 million tires could provide 10% of the energy requirements of a cement plant.

Based on a conversation with engineers from Puerto Rico Cement, there are several problems that must be resolved before implementing this technology. The main problem is that scrap tires are not "drop in" replacements; modifications must be performed to the feeding system. According to the engineers at Puerto Rico Cement, a few cement plants on the U.S. mainland that attempted to use this technology had serious operational problems. These problems, however, could be overcome with the right tire pretreatment and feeding system, which would require a high capital investment. An economical analysis that addresses these issues must be performed for the local industry.

There are other tire derived fuel applications that are also being investigated. Recent emphasis has been to convert the tires into an easier to handle fuel such as gases or liquids. Pyrolysis is a good example of converting tires to gas fuel. Several systems have been studied, such as...
melting vessels, blast furnaces, autoclaves, tube reactors, rotary kilns, cooking chambers, and fluid-bed reactors. Rotary kilns, the most common method, have several disadvantages, including long residence times and large temperature gradients which lead to a diverse product. In theory, these deficiencies could be overcome by using a fluidized-bed reactor, a type of reactor characterized by excellent heat and mass transfer as well as constant temperature throughout, which should result in a largely uniform product. Professor Moses Bogere of the Chemical Engineering Department at UPR-Mayagüez has expressed interest in starting a research program in this area.

The liquefaction of tires into fuel is also under investigation. These studies are an extension of coal liquefaction. The Department of Energy, in particular, has a strong interest in this area, especially since the carbon black present in tires can serve as a catalyst for coal liquefaction. The strategy is to mix the used tires with the coal to take advantage of the high energy and carbon black content of tires.

Texaco contributed to another interesting development in this area by designing a pilot plant to convert used tires to either power or chemicals via a hybrid liquefaction/gassification process. A commercial-development unit, capable of handling 1,000–2,000 tires/day, went on line in December 1992.

All of the previous technologies are under evaluation. Besides the initial investment hurdle, other factors, such as meeting strict environmental regulations, must be studied. It should be emphasized, however, that the best evidence so far is that burning tires for their fuel energy poses no significant threat to air quality when proper emission controls are in place. That was the conclusion of a major study commissioned by the EPA to investigate the implications for air quality control of burning tires for fuel and tire pyrolysis. Furthermore, the same study found that when cement kilns change to burning TDF, the effect on emissions is generally minor, and in some cases the emission levels improve.
2.7 Summary Analysis

This section summarizes the findings reviewed in Section 2 and relates them to the current waste management practices in Puerto Rico. A series of general conclusions forms the framework for this section; these conclusions encapsulate the main considerations shaping the recommendations in the final section of this report.

1. The results of a survey of municipal governments underscore the need for uniformity and comprehensiveness in the Island's response to the scrap tire problem, which can only be achieved through action by the Legislature.

See the discussion of the survey's findings, Section 2.3.

2. The local market for CRM that would be created by the effort to meet ISTEA minimum utilization requirements may not be sufficient, by itself, to support a profitable CRM production plant on the Island.

The FHWA estimates that a CRM production plant can be built for an initial investment of $5-10 million. At current levels of annual asphalt tonnage laid on Federal-assisted roads in Puerto Rico, however, the 10% minimum utilization requirement for CRM would create the need for only 1 to 3 million pounds of CRM, depending on whether the final AR or RUMAC contained the minimum allowable or maximum feasible percentage of rubber (1 to 3%, or approximately 2 to 6 scrap tires per ton of HMA, with each tire representing 11 pounds of CRM).

Baker Rubber, Inc., of South Bend, Indiana, reported that its Indiana plant currently produces CRM at the rate of 5,000 pounds per hour. Operating with one shift (7 hours) for 250 days per year, such a plant would produce approximately 8.75 million pounds of CRM, from approximately 800,000 scrap tires. And this calculation probably underestimates the plant's production capability. It was reported recently that a new CRM production plant built for about $8 million in Mesa, Arizona, had the capability of processing 4 million scrap tires per year, which would render about 44 million pounds of CRM annually.
These figures suggest that the potential market in Puerto Rico for CRM created by implementing the ISTEA minimum utilization requirements will be on a much smaller scale than CRM producers are accustomed to working with on the U.S. mainland. To create a viable market for a CRM production plant on the Island, it may be necessary to help private industry develop other uses for crumb rubber and to export it to the U.S. Virgin Islands and other countries in the region. In addition to CRM, crumb rubber can also be used in road construction as a subbase material, and it is an ideal additive for running tracks, playgrounds, and tennis court surfaces. It is possible that some manufacturing plants on the Island already use crumb rubber in their operations, because it is an ingredient in the manufacture of plastics and compression molded materials.

Importing CRM, while it is obviously not a practical long-term alternative, given that the purpose of using the CRM in the first place is to use up scrap tires already on the Island, may be a viable short-term solution. According to the FHWA memorandum of September 17, 1993, importing CRM would be allowable so long as the tires used to produce the CRM are from the United States.

3. Using recycled rubber from scrap tires to modify HMA pavements only offers a partial solution to the Island's scrap tire problem; there are other beneficial uses for scrap tire rubber that merit serious consideration, especially tire derived fuel (TDF).

The NAPA report excerpted in Appendix F should be given careful consideration. Pilot projects in some of the TDF technologies discussed in that report, and summarized in Section 2.6.1 of this report, would seem to fit quite well into the search for viable waste-to-energy technologies being planned by the SWA as part of its Solid Waste Master Plan.

4. Local research and development is essential to the successful adaptation of CRM technologies and alternative uses for scrap tire rubber in Puerto Rico.

The many uncertainties regarding the performance of CRM pavements under conditions found in Puerto Rico make it imperative that the DTPW initiate a major research effort, including both laboratory and field tests.
and involving the participation of asphalt pavement experts and chemical engineers within the DTPW, the asphalt industry, and the University of Puerto Rico.

Alternate uses for scrap tire rubber must also be studied, especially the possible use of TDF by the Island's cement plants. The SWA should direct such an effort in coordination with the Science and Technology Board.

### 2.8 Recommendations

The recommendations for action in this subsection follow directly from the conclusions set forth in the previous subsection. The recommendations are grouped according to short-term, medium-term, and long-term perspectives. A recommendation whose rationale has already been well-established by information and explanations in previous sections of this report will not be followed by further comment.

#### Short-Term Horizon: Fiscal Year 1994

1. The Commonwealth should enact a new tire sales tax to defray the costs incurred in tire shredding, storage operations, and to subsidize the research and development necessary to test and implement a variety of environmentally benign methods for disposing of scrap tires.

2. The Commonwealth should study a possible ban on the importation and sale of used tires.

#### Medium-Term Horizon: Fiscal Years 1995 - 1997

1. The Science and Technology Board should fund research projects related to the development of products or processes using scrap tire rubber.
Even at the eventual 20% minimum utilization requirement mandated by ISTEA, using CRM in HMA pavement applications will only consume, at most, about 15-20% of the tires discarded each year on the Island. As discussed in Section 2.6, there are other uses for scrap tires that are not only technically feasible but more cost-effective than rubber modified asphalt.

On the U.S. mainland, 62 percent of the tires recycled (26 million tons out of 42 million tons, see Table 1) are consumed as Tire Derived Fuel (TDF). The high energy content of scrap tire rubber makes conversion to energy a cost-effective method for disposing of large volumes of scrap tires; this method can be designed to meet EPA emission standards. A study performed by the Wisconsin Power & Light Company (WPLC) estimated the heating value of used tires at approximately 15,000 BTU/Lb versus 10,000 to 11,000 BTU/Lb for coal. In Puerto Rico, cement plants are the biggest users of coal (100,000 to 150,000 tons/year), making them excellent candidates for using scrap tires. According to WPLC, 70 tires have the equivalent energy content of 1 ton of coal. This means that 1.0 million tires could provide 10% of the energy requirements of a cement plant.

Researchers in the Chemical Engineering Department of the UPR College of Engineering have the necessary expertise in this area and have already expressed interest in developing R&D proposals on TDF specifically geared to targeted end-users on the Island, such as the cement plants.

More and more uses are being suggested for shredded tire rubber. Recently published research documents the use of shredded tire rubber with geotextiles to construct embankments and retaining walls. Shredded tire rubber concrete is another idea for recycling scrap tires. A professor who recently joined the Civil Engineering Department at UPR Mayagüez has expressed great interest in developing a proposal to investigate the properties of shredded tire rubber concrete, which he says can be used for concrete utility poles, roadside barriers, and movable highway lane barriers such as those being contemplated for use in the DTPW's IVHS program.
2. The Solid Waste Authority should draw up and implement a Scrap Tire Management Plan as part of its Solid Waste Master Plan. The plan should include an efficient and logistically sensible tire collection, sorting, and shredding process, preferably one involving the private sector.

---

**Long-Term Horizon: Fiscal Year 1998 and Beyond**

1. The Solid Waste Authority should cooperate with the Puerto Rico Electric Power Authority to study the feasibility of constructing a power generation plant that burns whole tires.

2. FOMENTO should coordinate the export promotion of technologies for scrap tire recycling and reuse to other countries in the Caribbean and Latin America.
Appendix A

Text of Section 1038 of the 1991 Intermodal Surface Transportation Efficiency Act, "Use of Recycled Paving Material."
SEC. 1038. USE OF RECYCLED PAVING MATERIAL.

(a) Asphalt Pavement Containing Recycled Rubber Demonstration Program.—Notwithstanding any other provision of title 23, United States Code, or regulation or policy of the Department of Transportation, the Secretary (or a State acting as the Department's agent) may not disapprove a highway project under chapter 1 of title 23, United States Code, on the ground that the project includes the use of asphalt pavement containing recycled rubber. Under this subsection, a patented application process for recycled rubber shall be eligible for approval under the same conditions that an unpatented process is eligible for approval.

(b) Studies.—

(1) In General.—The Secretary and the Administrator of the Environmental Protection Agency shall coordinate and conduct in cooperation with the States, a study to determine—

(A) the threat to human health and the environment associated with the production and use of asphalt pavement containing recycled rubber;

(B) the degree to which asphalt pavement containing recycled rubber can be recycled, and;

(C) the performance of the asphalt pavement containing recycled rubber under various climate and use conditions.

(2) Division of Responsibilities.—The Administrator shall conduct the part of the study relating to paragraph (1)(A) and the Secretary shall conduct the part of the study relating to paragraph (1)(C). The Administrator and the Secretary shall jointly conduct the study relating to paragraph (1)(B).

(3) Additional Study.—The Secretary and the Administrator, in cooperation with the States, shall jointly conduct a study to determine the economic savings, technical performance qualities, threats to human health and the environment, and environmental benefits of using recycled materials in highway devices and appur-
tenances and highway projects, including asphalt containing over 80 percent reclaimed asphalt, asphalt containing recycled glass, and asphalt containing recycled plastic.

(4) ADDITIONAL ELEMENTS.—In conducting the study under paragraph (3), the Secretary and the Administrator shall examine utilization of various technologies by States and shall examine the current practices of all States relating to the reuse and disposal of materials used in federally assisted highway projects.

(5) REPORT.—Not later than 18 months after the date of the enactment of this Act, the Secretary and the Administrator shall transmit to Congress a report on the results of the studies conducted under this subsection, including a detailed analysis of the economic savings and technical performance qualities of using such recycled materials in federally assisted highway projects and the environmental benefits of using such recycled materials in such highway projects in terms of reducing air emissions, conserving natural resources, and reducing disposal of the materials in landfills.

(c) DOT GUIDANCE.—

(1) INFORMATION GATHERING AND DISTRIBUTION.—The Secretary shall gather information and recommendations concerning the use of asphalt containing recycled rubber in highway projects from those States that have extensively evaluated and experimented with the use of such asphalt and implemented such projects and shall make available such information and recommendations on the use of such asphalt to those States which indicate an interest in the use of such asphalt.

(2) ENCOURAGEMENT OF USE.—The Secretary should encourage the use of recycled materials determined to be appropriate by the studies pursuant to subsection (b) in federally assisted highway projects. Procuring agencies shall comply with all applicable guidelines or regulations issued by the Administrator of the Environmental Protection Agency.

(d) USE OF ASPHALT PAVEMENT CONTAINING RECYCLED RUBBER.—

(1) STATE CERTIFICATION.—Beginning on January 1, 1995, and annually thereafter, each State shall certify to the Secretary that such State has satisfied the minimum utilization requirement for asphalt pavement containing recycled rubber established by this section. The minimum utilization requirement for asphalt pave-
ment containing recycled rubber as a percentage of the total tons of asphalt laid in such State and financed in whole or part by any assistance pursuant to title 23, United States Code, shall be—

(A) 5 percent for the year 1994;

(B) 10 percent for the year 1995;

(C) 15 percent for the year 1996; and

(D) 20 percent for the year 1997 and each year thereafter.

(2) Other Materials.—Any recycled material or materials determined to be appropriate by the studies under subsection (b) may be substituted for recycled rubber under the minimum utilization requirement of paragraph (1) up to 5 percent.

(3) Increase.—The Secretary may increase the minimum utilization requirement of paragraph (1) for asphalt pavement containing recycled rubber to be used in federally assisted highway projects to the extent it is technologically and economically feasible to do so and if an increase is appropriate to assure markets for the reuse and recycling of scrap tires. The minimum utilization requirement for asphalt pavement containing recycled rubber may not be met by any use or technique found to be unsuitable for use in highway projects by the studies under subsection (b).

(4) Penalty.—The Secretary shall withhold from any State that fails to make a certification under paragraph (1) for any fiscal year, a percentage of the apportionments under section 104 (other than subsection (b)(5)(A)) of title 23, United States Code, that would otherwise be apportioned to such State for such fiscal year under such section equal to the percentage utilization requirement established by paragraph (1) for such fiscal Year.

(5) Secretarial Waiver.—The Secretary may set aside the provisions of this subsection for any 3-year period on a determination, made in concurrence with the Administrator of the Environmental Protection Agency with respect to subparagraphs (A) and (B) of this paragraph, that there is reliable evidence indicating—

(A) that manufacture, application, or use of asphalt pavement containing recycled rubber substantially increases the threat to human health or the environment as compared to the threats associated with conventional pavement.
(B) that asphalt pavement containing recycled rubber cannot be recycled to substantially the same degree as conventional pavement; or

(C) that asphalt pavement containing recycled rubber does not perform adequately as a material for the construction or surfacing of highways and roads.

The Secretary shall consider the results of the study under subsection (b)(1) in determining whether a 3-year set-aside is appropriate.

(6) **RENEWAL OF WAIVER.**—Any determination made to set aside the requirements of this section may be renewed for an additional 3-year period by the Secretary, with the concurrence of the Administrator with respect to the determinations made under paragraphs (5)(A) and (5)(B). Any determination made with respect to paragraph (5)(C) may be made for specific States or regions considering climate, geography, and other factors that may be unique to the State or region and that would prevent the adequate performance of asphalt pavement containing recycled rubber.

(7) **INDIVIDUAL STATE REDUCTION.**—The Secretary shall establish a minimum utilization requirement for asphalt pavement containing recycled rubber less than the minimum utilization requirement otherwise required by paragraph (1) in a particular State, upon the request of such State and if the Secretary, with the concurrence of the Administrator of the Environmental Protection Agency, determines that there is not a sufficient quantity of scrap tires available in the State prior to disposal to meet the minimum utilization requirement established under paragraph (1) as the result of recycling and processing uses (in that State or another State), including retreading or energy recovery.

(e) **DEFINITIONS.**—For purpose of this section—

(1) the term “asphalt pavement containing recycled rubber” means any hot mix or spray applied binder in asphalt paving mixture that contains rubber from whole scrap tires which is used for asphalt pavement base, surface course or interlayer, or other road and highway related uses and—

(A) is a mixture of not less than 20 pounds of recycled rubber per ton of hot mix or 300 pounds of recycled rubber per ton of spray applied binder; or
(B) is any mixture of asphalt pavement and recycled rubber that is certified by a State and is approved by the Secretary, provided that the total amount of recycled rubber from whole scrap tires utilized in any year in such State shall be not less than the amount that would be utilized if all asphalt pavement containing recycled rubber laid in such State met the specifications of subparagraph (A) and subsection (d)(I); and

(2) the term "recycled rubber" is any crumb rubber derived from processing whole scrap tires or shredded tire material taken from automobiles, trucks, or other equipment owned and operated in the United States.
Appendix B

Copies of three memoranda from the Federal Highway Administration regarding implementation guidelines for Section 1038 of ISTEA.
ACTION: Implementation of Section 1038 of the ISTEA of 1991

From
Associate Administrator
for Program Development

To
Regional Federal Highway Administrators

Section 1038 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requires the States to recycle rubber from whole scrap tires in asphalt pavements beginning in 1994. The purpose of this memorandum is to provide guidance for implementation of Section 1038.

Beginning on January 1, 1995, and each year thereafter, the States are required to certify that they have complied with the minimum utilization requirement for the previous Federal fiscal year for the use of recycled scrap tire rubber in asphalt pavements. Therefore, beginning on October 1, 1993, the States must begin implementation of the Section 1038 provisions. It is important that the States develop their programs to comply with Section 1038. The regional offices are asked to work with the division offices to ensure that each State understands fully the requirements of Section 1038.

This implementation guidance provides details and information needed to comply with each subsection of Section 1038 of the ISTEA.

Subsection (a) Asphalt Pavement Containing Recycled Rubber Demonstration Program.

The FHWA or any State acting pursuant to the Federal-aid highway program shall not disapprove a highway project under Chapter 1 of Title 23, United States Code, on the ground that the project includes the use of asphalt pavement containing recycled rubber. Also, patented processes and materials shall be eligible for approval under the same conditions as unpatented processes and materials. This subsection means that 23 CFR 635.411, prohibiting the use of Federal funds for patented or proprietary materials or processes, does not apply to asphalt pavement containing recycled rubber.

Subsection (b) Studies

This subsection requires no action by the States.

Subsection (c) DOT Guidance

This subsection requires no action by the States.
Subsection (d) Use of Asphalt Pavement Containing Recycled Rubber

This subsection contains the minimum utilization requirements for the use of asphalt pavement containing recycled rubber. Refer to Subsection (e)(2) for the definition of recycled rubber.

(1) State Certification

Beginning on January 1, 1995, and annually thereafter, each State highway agency (SHA) shall certify to the FHWA Division Administrator that the following minimum utilization requirement for asphalt pavement containing recycled rubber from scrap tires has been met for the previous year:

(A) 5 percent for the fiscal year 1994;
(B) 10 percent for the fiscal year 1995;
(C) 15 percent for the fiscal year 1996; and
(D) 20 percent for the fiscal year 1997 and each fiscal year thereafter.

These are percentages of the contract bid quantities of asphalt pavement awarded in the State during the fiscal year and financed in whole or part by any assistance pursuant to Title 23, United States Code.

Compliance with the minimum utilization requirement shall be based on the total number of kilograms of recycled rubber required by awarded contract bid quantities of asphalt pavement containing recycled rubber. Both Federal-aid and non-Federal-aid quantities of asphalt pavement containing recycled rubber shall be eligible for satisfying the minimum utilization requirement.

The quantity of recycled rubber required to satisfy the minimum utilization requirement shall be computed by the following equation, which is based on 10 kilograms (22 pounds) of recycled rubber per metric ton (1.1 tons) of hot mix and 150 kilograms (330 pounds) of recycled rubber per metric ton (1.1 tons) of spray applied binder. This is the metric equivalent of 20 pounds of recycled rubber per ton of hot mix and 300 pounds of recycled rubber per ton of spray applied binder as specified in Section 1038 of the ISTEA under the definition of asphalt pavement containing recycled rubber.

\[ R = U \times (10M + 150S) \]

Where:

\( R \) = The kilograms of recycled rubber required to satisfy the minimum utilization.
\( U \) = The required utilization percentage expressed as a decimal.
\( M \) = The total contract metric tons of Federal-aid Hot Mix awarded during the fiscal year.
\( S \) = The total contract metric tons of Federal-aid Hot Spray Applied Binder awarded during the fiscal year.
The State’s certification should contain, as a minimum:

1. The total metric tons of hot mix and spray applied binder awarded during the fiscal year and financed in whole or part by any assistance pursuant to Title 23, United States Code;

2. The total kilograms of recycled rubber required by contract bid quantities of asphalt pavement containing recycled rubber and awarded during the fiscal year; and

3. The total metric tons of each "other recycled material," to be used as a substitution for recycled rubber as provided for in Subsection (d)(2), required by contract bid quantities of asphalt pavement containing those materials and awarded during the fiscal year.

Any application of recycled rubber in hot mix or spray applied binder used to construct or maintain an asphalt pavement base, interlayer, or surface on any highway project is eligible for satisfying the minimum utilization requirement. Other highway related uses of asphalt pavement containing recycled rubber shall also be eligible. Hot applied asphalt based joint and crack sealants containing recycled rubber shall be considered spray applied binder for the purpose of satisfying the minimum utilization requirements.

Any use or technique found to be unsuitable for use in highway projects shall not be eligible for the purpose of satisfying the minimum utilization requirements. Unsuitable uses or techniques are those which do not perform equivalent to conventional asphalt paving materials. Any use of scrap tires, including lightweight embankment, that is not an application in asphalt pavement shall not be eligible for the purpose of satisfying the minimum utilization requirements.

(2) Other Materials

Other recycled materials determined acceptable by the FHWA may be substituted for the recycled rubber in asphalt pavements to meet the minimum utilization requirements up to 5 percent utilization. For example, a 20 percent minimum utilization requirement could be met by constructing 15 percent of the asphalt pavements with recycled rubber and 5 percent with other recycled materials. Acceptability of other materials will be based on the ability of asphalt pavement containing those other recycled materials to perform in a manner equivalent to conventional asphalt pavement.

Section 1038 of the ISTEA does not specify the kilograms of other recycled material required for each metric ton of asphalt pavement containing that material to qualify for substitution for recycled rubber. Therefore, in order to utilize the substitution option, the total metric tons of each eligible other recycled material required by awarded contract quantities of asphalt pavement containing that material must be converted to an equivalent number of kilograms of recycled rubber. Equivalencies for each of the eligible other recycled materials
have been established in a manner that is consistent with the overall objective of encouraging maximum utilization of recycled materials in asphalt pavement.

The equivalencies were developed by determining from past research and experience, the maximum feasible percentage of each other recycled material that has shown acceptable performance in asphalt pavements, and then equating the number of kilograms of the other recycled material contained by one metric ton (1.1 tons) of hot mix at that percentage to 10 kilograms (22 pounds) of recycled rubber. For example, past research has shown that the maximum percentage of recycled glass that can be used in hot mix and provide acceptable mix performance is 15 percent. At 15 percent, glass would represent 150 kilograms (330 pounds) of the total mix. Therefore, 150 kilograms (330 pounds) of recycled glass would equal 10 kilograms (22 pounds) of recycled rubber or 1 metric ton (1.1 tons) of recycled glass would equal 70 kilograms (154 pounds) (rounded up from 66.6 kilograms for convenience) of recycled rubber for the purpose of satisfying the minimum utilization for the use of recycled rubber in asphalt pavements. The total credit for use of recycled rubber by other materials substitution may not exceed 5 percent utilization as computed by the equation in Subsection (d)(1) of this guidance.

At present time, only the following materials will be eligible for substitution for recycled rubber in asphalt pavements.

- **Reclaimed Asphalt Pavement (RAP)** - RAP is asphalt pavement that has been milled or otherwise removed from existing pavements. There are processes available that can recycle RAP up to 100 percent under certain conditions and provide acceptable performance. Therefore, the equivalency for RAP shall be 1 metric ton (1.1 tons) of RAP equals 10 kilograms (22 pounds) of recycled rubber.

- **Recycled Glass** - Recycled glass is waste glass that has been crushed to produce aggregate for hot mix. Due to the stripping characteristics of recycled glass, it can only be recycled up to a maximum of 15 percent of the total mix. Therefore, the equivalency for recycled glass shall be 1 metric ton (1.1 tons) of recycled glass equals 70 kilograms (154 pounds) of recycled rubber.

- **Blast Furnace Slag** - Blast furnace slag is the non-metallic by-product of iron production. It has been used as an aggregate in hot mix and, if properly graded, mixtures using 100 percent blast furnace slag are possible. Therefore, the equivalency for blast furnace slag shall be 1 metric ton (1.1 tons) of blast furnace slag equals 10 kilograms (22 pounds) of recycled rubber.

- **Reclaimed Concrete Pavement (RCP)** - RCP is concrete pavement that has been removed and crushed to produce aggregate. The RCP has been used for up to 100 percent of the aggregate in hot mix. Therefore, the equivalency for RCP shall be 1 metric ton (1.1 tons) of RCP equals 10 kilograms (22 pounds) of recycled rubber.
- Mining Waste Rock - Waste rock is the coarse material removed during the mining process for ore which contains little or no mineral value. Waste rock can be crushed and sized to provide up to 100 percent of the aggregate for hot mix. Therefore, the equivalency for waste rock shall be 1 metric ton (1.1 tons) of waste rock equals 10 kilograms (22 pounds) of recycled rubber.

- Coal Fly Ash - Coal fly ash is a very fine light material that is collected from the stack gases from coal combustion. Research has shown that acceptable asphalt hot mix can be produced with up to 6 percent fly ash by weight of the total mix. Therefore, the equivalency for coal fly ash shall be 1 metric ton (1.1 tons) of coal fly ash equals 170 kilograms (375 pounds) of recycled rubber.

As more research is completed, other recycled materials may be identified as acceptable for substitution for recycled rubber in asphalt pavements. At such time other acceptable materials are identified, guidance will be issued on their use.

(3) Increase

This paragraph requires no action by the States.

(4) Penalty

Any State that fails to certify by January 1 that they have met the minimum utilization requirement for the use of asphalt pavement containing recycled rubber for the previous fiscal year, as described in Subsection (d)(l), shall have withheld a percentage of the apportionments under Section 104 (other than Subsection (b)(5)(A)) of Title 23, United States Code, equal to the total minimum utilization percentage for asphalt containing recycled rubber for the previous fiscal year. As an example, if the minimum utilization is 10 percent and the State's actual utilization is 8 percent, then the penalty would be a full 10 percent of the State's apportionments.

Any State found in non-compliance with the minimum utilization requirements will be notified in writing by the FHWA Division Administrator and be given 30 days to provide additional information or comment. A final decision will be issued in writing to the State within 30 days after the receipt of the State's response to the initial notice of non-compliance. Once the final decision is issued, if the State was found in non-compliance with the minimum utilization requirements, an amount, determined by multiplying the percent utilization requirement for the non-complying fiscal year by the apportionment for that fiscal year (other than Subsection (b)(5)(A) of Title 23, United States Code), will be withheld from the next apportionment made. Once apportioned funds are withheld, they cannot be restored.

(5) Secretarial Waiver

This paragraph requires no action by the States.
(6) Renewal of Waiver

This paragraph requires no action by the States.

(7) Individual State Reduction

Upon request by a particular State, FHWA, with the concurrence of the EPA, may reduce the minimum utilization requirement for that State for any fiscal year if it is determined that there is not a sufficient quantity of scrap tires available in that State for recycling in asphalt pavement as a result of other recycling or processing use. The quantity of scrap tires available for recycling in asphalt pavement shall include all existing stockpiles plus the number of tires expected to be discarded within the State during the year, based on historical data, minus the number of tires from that State committed to be recycled in other processes in that State or any other State. Waste tires proposed for disposal, without beneficial use, by placement in a landfill, monofill, or water will be considered as available for recycling in asphalt pavements for the purposes of evaluating the minimum utilization requirement of a particular State.

Requests for Individual State Reductions shall show that they have been coordinated with the appropriate State agency having jurisdiction over scrap tires and should be submitted through the FHWA Division Office for further processing to the FHWA Office of Engineering, which will seek the concurrence of the EPA. As a minimum, requests shall contain documentation which provides the following information:

1. The quantity of scrap tires currently contained in existing permitted or non-permitted stockpiles. Discuss the anticipated disposition of these scrap tires.

2. The quantity of scrap tires expected to be generated during the fiscal year. This is generally an estimate based on population, registered vehicles, or other surrogate data bases.

3. The quantity of scrap tires anticipated to be imported into or exported from the State during the next fiscal year.

4. The quantity of scrap tires committed to be recycled through other acceptable processes such as retreading, energy recovery, specialty products, etc. Discuss the end-product application and the quantities anticipated to be used for each application.

5. The estimated total metric tons of asphalt pavement financed with Federal funds pursuant to Title 23, United States Code to be let to contract during the fiscal year.
The determination for an Individual State Reduction will be based on an average of 5 kilograms (11 pounds) of recycled rubber per scrap tire. If scrap tires will not be available in sufficient quantity to meet the minimum utilization requirements, then the utilization percentage will be reduced such that the amount of recycled rubber required will be equivalent to that contained in the available scrap tires.

Individual State Reductions will be granted on a yearly basis. Therefore, a separate request must be made for each year for which a reduction in the minimum utilization requirement is requested. Requests for Individual State Reductions for any fiscal year may be submitted at anytime beginning 6 months prior to the beginning of that fiscal year until the end of that fiscal year.

Subsection (e) Definitions

The following are definitions contained in Section 1038, as well as others necessary for implementation.

(1) "asphalt pavement containing recycled rubber" Any hot mix or spray applied binder in asphalt paving mixture that contains rubber from whole scrap tires which is used for asphalt pavement base, surface course or interlayer, or other road and highway related uses and

(A) is a mixture of not less than 10 kilograms (22 pounds) of recycled rubber per metric ton (1.1 tons) of hot mix or 150 kilograms (330 pounds) of recycled rubber per metric ton (1.1 tons) of spray applied binder; or

(B) is any mixture of asphalt pavement and recycled rubber, provided that the total amount of recycled rubber from whole scrap tires utilized in any year in such State shall be not less than the amount that would be utilized if all asphalt pavement containing recycled rubber awarded in such State met the specifications of subparagraph (A) and subsection (d)(1).

(2) "recycled rubber" Any crumb rubber, derived from processing whole scrap tires or shredded tire materials taken from automobiles, trucks, or other equipment owned and operated in the United States, provided that such processing does not produce, as a waste, casings, or other round tire material that can hold water when stored or disposed above ground. Rubber tire buffings produced by the retreading process qualify as a source of crumb rubber for credit as "recycled rubber."

(3) "asphalt pavement" Any pavement layer or section which is constructed using hot asphalt cement.

(4) "hot mix" An asphalt paving mixture of aggregate and asphalt cement that is mixed, laid, and compacted while hot.
(5) "spray applied binder" Any asphalt cement, excluding cutback or
emulsified asphalt cement, that is applied while hot in the form of a
spray to a pavement layer.

The Pavement Division is available to answer questions regarding the
implementation of Section 1038 and is available to provide technical
assistance for the use of recycled rubber in asphalt pavements. Questions
should be directed to Mr. John Hallin at (202) 366-1323.

Anthony R. Kane
Implementation guidance for Section 1038 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was transmitted by my memorandum of June 28, 1993. After reviewing the guidance, a number of regions, divisions, and States requested clarification on a number of points. Attached are questions and answers addressing the points raised.

During our conference call on July 7, 1993, several regions pointed out that some States do not specify percentages of Reclaimed Asphalt Pavement, Crumb Rubber Modifier, or other eligible recycled materials in their contracts. Rather, they allow the contractor to determine the percentages during the mix design approval process. State certifications are to be based on awarded contract bid quantities, both in establishing the minimum utilization requirements and in determining compliance. The States will have to determine how they accomplish this within their contracting procedures.

Some materials eligible for satisfying the Section 1038 minimum utilization requirement may be used by State maintenance forces. In this case, purchase orders or contracts for the purchase of these materials will be considered the same as awarded contract quantities and may be counted toward the minimum utilization requirement for the year they are purchased.

Any further questions should be addressed to Mr. John Hallin at 202-366-1323.
Section 1038 Q's & A's

COST

Question: When performing Life-Cycle Cost Analysis for pavements when the CRM requirements are in effect, should a higher unit cost for HMA be used to reflect the higher unit cost of CRM?

Answer: Life-Cycle Cost Analysis should be done using estimates of performance and costs for the material being considered.

STATE CERTIFICATION

Question: If a State exceeds the minimum utilization requirements for asphalt pavement containing recycled rubber for a given year, can the surplus be credited to the following year?

Answer: No. Utilization can only be counted for the year the contract is awarded.

Question: What if there is insufficient ground rubber to meet the anticipated 1994 demand?

Answer: The availability of crumb rubber from scrap tires does not impact the minimum utilization requirement. However, if there is insufficient scrap tires available to produce the crumb rubber, the State may ask for an individual State reduction.

Question: Why not use actual quantities laid as opposed to contract quantities which are estimates anyway?

Answer: Awarded contract bid quantities were specified in lieu of actual quantities laid in order to minimize the bookkeeping requirements and to allow the States to program their projects to comply with Section 1038. By using awarded contract bid quantities, the States will be able to determine their required minimum utilization of recycled rubber when they plan their construction program for the year.

Question: Since the quantity of spray applied binder is small compared to hot mix asphalt, why must the quantity of spray applied binder awarded be used to compute the quantity of recycled rubber required?

Answer: By definition, asphalt pavement containing recycled rubber includes spray applied binder.
Question: What should be used as the rounding factor for the purposes of calculating the achievements in meeting the required use? Would 4.51 percent round to 5 percent or where would the break point be?

Answer: In order to satisfy the minimum utilization requirement, the quantity of recycled rubber must be computed by the equation provided in the June 28, 1993, guidance. This computed quantity of recycled rubber must be met by awarded contract bid quantities during each fiscal year. There is no tolerance for rounding.

Question: Would the State still get credit for the rubber for a specific fiscal year if a project that was awarded was later placed in default and not constructed?

Answer: Yes.

Question: Are BIA jobs, Public lands projects, "Parkways and Park Highways," included in the total tons of Federal-aid asphalt laid, and do these quantities contribute toward minimum utilization requirement for the State?

Answer: Only if the projects are partially or wholly funded using Title 23 funds and administered by the State.

Question: Is the "contract bid quantities of asphalt pavement awarded in the State during the fiscal year" the projects let in the fiscal year, or authorized in the fiscal year (or concurred in award in the fiscal year, or the award date by the Department)?

Answer: "Awarded" refers to the date the State awards the contract to the contractor.

Question: Should spray applied binder be counted any time that binder (AC-20) is used or just in direct application as a pavement material (i.e., as a tack coat for petromat)?

Answer: It is to be counted any time it is used for a hot applied pavement application.

Question: At what level is the State's certification to come from (i.e., the DOT Director, State Governor, etc.)?

Answer: This will be left up to the State to decide.

Question: Does the certification require both the awarded quantity of recycled rubber and the actual quantity of recycled rubber laid to be reported?

Answer: The certification must report the quantity of recycled rubber based on awarded contract bid quantities of asphalt pavement containing recycled rubber.
Question: Is it required to report utilization in metric terms for our first report, dated January 1, 1995?
Answer: Yes.

Question: Will credit for overrun of contract bid quantities be allowed for compliance with utilization requirements?
Answer: Credit for utilization of recycled rubber in asphalt pavement is based on awarded contract bid quantities. No adjustments will be made for overruns or underruns.

Question: May a State claim credit for recycled rubber used by cities, counties, and on reservations, on non-State projects if otherwise in accordance with guidelines?
Answer: Yes.

CRM ELIGIBILITY

Question: Rubber asphalt sealants are considered spray applied binder under implementation guidance. However, this material is mostly used in State maintenance force account operations. There is no contract bid quantity or awards for this work. How can this material be claimed?
Answer: Some materials eligible for satisfying the Section 1038 minimum utilization requirement may be used by State maintenance forces. In this case, purchase orders or materials contracts for the purchase of these materials will be considered the same as awarded contract quantities.

Question: Can a State utilize less than 20#/ton of hot mix or 300#/ton of spray applied binder “or mixtures provided additional quantities that are required resulting in the same or more use of recycled” rubber?
Answer: Yes. Any percentage of recycled rubber may be used in a mixture as long as the total amount of recycled rubber for the fiscal year is equal to or greater than the amount computed by the equation.

Question: The implementation guidance provides that rubber tire buffings from the retreading process qualifies as a source of crumb rubber. How will a State know whether the crumb rubber it is using is from a qualifying crumb rubber source?
Answer: It is the States’ responsibility to ensure their certification covers materials that meet the requirements of the law.
Question: Since maintenance work also can be counted, are fog seals (with rubber) eligible as spray applied binder?
Answer: No, since fog seals are emulsions or cutbacks.

Question: Does a spray applied asphalt rubber membrane applied on expansive subgrade soil qualify?
Answer: Yes.

Question: To determine the total Federal-aid work using the formula, does "total spray applied binder" include tack coat, prime coat, seal coats?
Answer: Yes. As long as it is hot asphalt cement and not an emulsion or cutback.

Question: By putting a token amount of CRM in every ton of asphalt used, is the State violating the intent of the regulation?
Answer: No. The States have flexibility in using CRM in asphalt pavement as long as the overall usage requirements are met.

Question: Is the recycled rubber used for railroad crossing improvements allowable for satisfying minimum utilization requirements?
Answer: Molded rubber crossings would not qualify, however, any asphalt hot mix containing recycled rubber would qualify.

Question: If a patented wet process is selected for a project instead of a patented dry process, will both patented processes have to be in the contract as alternates?
Answer: No. Regulations and restrictions on the use of patented processes do not apply to recycled rubber in asphalt pavement. Patented processes shall be treated the same as unpatented processes.

Question: Will Canadian scrap tires count towards the minimum utilization requirement.
Answer: Only tires taken from automobiles, trucks, or other equipment owned and operated in the United States are eligible.

Question: Does crack sealant used on concrete pavements count towards the minimum utilization requirement and, if so, in what amount?
Answer: Yes, the amount of rubber in the awarded contract bid quantity of sealant.
OTHER MATERIALS

Question: Concerning equivalencies for RAP (and also other substitutes); what if the State used, say, 70 percent RAP rather than 100 percent RAP. Would the equivalency factor still be: 1 ton RAP = 20 lbs. rubber?

Answer: It would still be 1 metric ton of RAP = 10 kilograms of rubber. One ton of hot mix containing 70 percent RAP would, therefore, equal 70 percent of 10 kilograms, or 7 kilograms of rubber.

Question: Will hot-mixed, cold-laid mixture containing RAP, be allowable for satisfying minimum utilization requirements?

Answer: No. It must be an application in hot mix, which is defined as "an asphalt paving mixture of aggregate and asphalt cement that is mixed, laid, and compacted while hot."

Question: Can we expect plastics to be added as an "other material" to satisfy utilization requirements?

Answer: If research and experience becomes available that shows that asphalt pavement containing recycled plastic performs in a manner equivalent to conventional mixes, then plastic could be added as an "other material."

Question: Will we be allowed to use our inventory system to document RAP quantity used in a fiscal year in lieu of some type of "as awarded" system?

Answer: State certifications are to be based on awarded contract bid quantities, both in establishing the minimum utilization requirements and in determining compliance. The States will have to determine how they accomplish this within their contracting procedures.

Question: Is RAP mixed with an emulsion and placed as a treated base eligible for substitution for recycled rubber?

Answer: No. This process would be classified as cold mix and is not eligible.

Question: Is use of RAP on projects other than those set up for recycled rubber eligible? How about county or city awarded projects using RAP from State or local projects?

Answer: RAP is eligible for satisfying the minimum utilization of recycled rubber in accordance with the implementation guidance for any project. The source of the RAP is not a consideration for determining eligibility.
Question: Must RAP be hot recycled, or are cold recycling methods which have proven acceptable eligible?
Answer: The RAP must be used in hot mix to be eligible.

Question: Why are the substitutions limited to use in asphalt pavements?
Answer: Other materials are allowed as a substitution for recycled rubber in asphalt pavement. Therefore, they must be used in asphalt pavement to be eligible for counting toward the minimum utilization requirement.

Question: Why is the formula for RAP computed using 100 percent recycled when the common practice of recycling is usually in the 50 percent range?
Answer: The formulas for other materials were derived from the maximum feasible amount that could be used and not the common practice.

Question: Does the 1.1 tons of RAP to 22 lbs of rubber refer to 100 percent RAP mixes or is it any percent RAP mixture. Also, if it is a 100 percent RAP = 22 lbs rubber, can we just prorate for a 40 percent, 50 percent, etc., RAP mix?
Answer: For every 1 metric ton of RAP to be used, credit is allowed for 10 kilograms of recycled rubber. It does not matter what percent RAP is used in the mixture. A mixture containing 50 percent RAP would get credit for 5 kilograms of rubber.

Question: The implementation guidance specifies the equivalency for RAP is 1 metric ton (1.1 tons) of RAP equals 10 kg (22 pounds) of recycled rubber. The ISTEA 1038(b)(3) lists other qualifying recycled materials "including asphalt containing at least 80 percent reclaimed asphalt." Therefore, the equivalency for RAP should be 0.8 metric tons (0.88 tons) of RAP equals 10 kg (22 pounds) of recycled rubber.
Answer: Section 1038 required the FHWA to study 80 percent RAP but does not establish eligibility. Since recycling 100 percent RAP is possible, the equivalency is based on 100 percent RAP.

Question: It is stated that the "acceptability of other materials will be based on the ability of asphalt pavement containing those other recycled materials to perform . . . ." Section 1038(d)(2) does not specify that "other recycled material" that is substituted has to be contained in asphalt pavement. As long as the "other recycled material" is utilized in a "highway related use," the intent of depleting the waste materials is accomplished and should be acceptable.
Answer: Section 1038 allows substitution of "other materials" for recycled rubber in "asphalt pavement." As a substitution, it must be used in asphalt pavement.

Question: Do the "other materials" identified in the implementation guidance have to be used in a hot asphalt pavement application to be eligible for substitution for recycled rubber?

Answer: Yes.

Question: The implementation guidance identifies blast furnace slag, which is defined as the non-metallic by-product of iron production, as eligible for substitution for recycled rubber in asphalt pavement. Can this definition be expanded to include slag from the production of other materials such as steel and chrome?

Answer: No. Blast furnace slag from the production of iron was the only slag material determined from the literature to produce asphalt mixtures that perform equivalent to conventional asphalt mixtures.

Question: Subsection (a) of the implementation guidance provides that 23 CFR 635.411 does not apply to asphalt pavement containing recycled rubber. Does this statement also apply to other recycled material? Can patented or proprietary material/processes be used for plastic, etc.?

Answer: Subsection (a) only applies to asphalt pavement containing recycled rubber.

Question: Is there an equivalent for recycled plastics? What is the conversion factor? Is it based upon the maximum percentage of plastic that can be used on the actual amount?

Answer: Recycled plastics have not yet been found acceptable for substitution for recycled rubber.

Question: The implementation guidance identifies mining waste rock as an acceptable substitute material. Would overburden material from mining operations be included as mining waste rock?

Answer: If this overburden is associated with mining for ore, then it would be acceptable as long as it meets specification.

Question: Can a State satisfy the 5 percent requirement for 1994 by using only "other materials" in lieu of ground rubber?

Answer: Yes.

Question: Does the use of RAP as a substitute include the tonnage that may be produced by in-place recycling?
Answer: No, in-place recycling is not an acceptable application for use of RAP as a substitute material.

Question: What percentage of the mix must be blast furnace slag or mining waste rock before it qualifies as other materials?

Answer: Any percentage of blast furnace slag or mining waste rock qualifies. The appropriate equivalency factor must be applied to convert the material to recycled rubber.

INDIVIDUAL STATE REDUCTION

Question: Is it the intent of ISTEA that tires used in a State come from tires discarded in that State?

Answer: No. Preference for in-State materials is still prohibitive on Federal-aid projects.

Question: The last sentence in the first full paragraph on page 6 says that tires disposed of in water (such as artificial reef formation) will be considered available for recycling in asphalt pavement.

Answer: Tires disposed of in water refers to an underwater stockpile that serves no beneficial use. The guidance says nothing about artificial reefs being a non-beneficial use. Artificial reefs that serve as a benefit to the underwater environment would not be considered available for recycling in asphalt pavement.

PENALTY

Question: The implementation guidance gives an example where a State, whose actual rubber utilization is 8 percent rather than the required 10 percent, is penalized the full 10 percent. This seems to be very harsh.

Answer: Section 103B requires the penalty to be equal to the minimum utilization percentage and does not provide any flexibility to reduce it to the difference between the actual and required utilization.

Question: The implementation guidance specifies that where a State fails to comply with the minimum utilization requirements, the funds will be withheld from the next apportionment. Provisions should be made to allow a State to double up on the succeeding year to make
up for a shortfall in the preceding year. This would allow a State who made a good faith effort but fell short to not be penalized and still get the used tires incorporated into asphalt mixes, albeit at a later date.

Answer: Section 1038 does not allow credit for previous or future years.
Questions have arisen concerning the effect of Section 325 of H.R. 2750, the Department of Transportation Appropriations Act for fiscal year (FY) 1994, which states:

"None of the funds made available in this act may be used to implement, administer, or enforce the provisions of Section 1038(d) of Public Law 102-240."

Attached is the Chief Counsel's discussion on this section, which responds to questions relative to the use of asphalt containing recycled rubber on Federal-aid projects and assessment of the penalty requirements contained in Section 1038(d). The Chief Counsel reached the following conclusions:

- Section 325 will not result in a State being assessed the Section 1038(d) FY 1994 penalty in a subsequent year; rather under the current law the first applicable penalty will be the 10 percent penalty with respect to FY 1995 provided in Section 1038(d).

- Section 325 does not contain any prohibitions against utilizing funds to carry out any other subsection of Section 1038. Therefore, Section 325 does not preclude a State from using asphalt pavement containing recycled rubber on Federal-aid projects.

It should also be noted that Section 325 precludes us from taking any action on waivers or on requests for individual State reductions during FY 1994. Any questions should be addressed to Mr. John Hallin at (202) 366-1323.

E. Dean Carlson
QUESTIONS:

A question has arisen as to the effect of Section 325 of H.R. 2750, the Department of Transportation Appropriations Act for FY 1994. Section 325 provides:

"None of the funds made available in this Act may be used to implement, administer, or enforce the provisions of section 1038(d) of Public Law 102-340."

Questions have been raised as to whether this section would: (i) preclude States from using in a federal-aid highway project asphalt pavement containing recycled rubber; or (ii) subject States to the FY 1994 penalty contained in section 1038(d) if they fail to meet the 5 percent requirement provided in that section.

ANSWERS:

(i) Section 325 does not preclude a State from using asphalt pavement containing recycled rubber.

(ii) Section 325 will not result in a State being assessed the section 1038(d) FY 1994 penalty in a subsequent year; rather under current law the first applicable penalty will be the 10 percent penalty with respect to FY 1995 provided in section 1038(d).

DISCUSSION:

Section 1038(d) relates to state certification as to the use of asphalt pavement containing recycled rubber; it requires beginning on January 1, 1995 , and annually thereafter, that each State certify to the Secretary of Transportation that such State has satisfied the minimum utilization requirements for asphalt pavement containing recycled rubber which are established by section 1039(d); the percentages are set forth for the years 1994 through 1997, and each year thereafter. The section further provides that other materials may be substituted for recycled rubber, that the Secretary may increase the percentages in certain circumstances, and a penalty is provided. The Secretary is required to withhold a certain percentage of a State’s apportionments under 23 U.S.C. 104 for failure to make a certification. Subsection (d) also gives the Secretary discretionary authority to waive the subsection under certain conditions and to renew that waiver.

Section 1038(a) of ISTEA states that notwithstanding any other provision of title 23, or regulation or policy of the Department of Transportation, the Secretary (or a State acting as the Department’s agent) may not disapprove a highway project under chapter 1 of title 23, U.S.C., on the ground that the project includes the use of asphalt pavement containing recycled rubber.
Section 325 prohibits use of any funds appropriated under the FY 1994 DOT Appropriations Act "to implement, administer, or enforce the provisions of section 1038(d) of Public Law 102-240." Thus, the Secretary may not take any actions under section 1038(d); those actions are the certification, the imposition of the penalty, and the granting of a waiver to a State from complying with the provisions of 1038(d), e.g. certifying as to minimum utilization. Section 325 does not contain any prohibitions against utilizing funds to carry out any other subsection of section 1038, such as section 1038(a) which clearly allows the Secretary to approve projects in States utilizing asphalt pavement containing recycled rubber.

Section 325 on its face is clearly intended to prohibit the Secretary of Transportation from requiring the certification and imposing a penalty for failure to make a certification as to minimum utilization for FY 1994. Accordingly, Section 325 will not have the effect of permitting a State to be subjected to the 5 percent FY 1994 penalty. The first applicable penalty under current law will be the 10 percent penalty provided for in section 1038 with respect to FY 1995.
Appendix C

Copy of the Florida Department of Transportation specifications relating to CRM paving applications.
DEVELOPMENTAL SPECIFICATION
for
ASPHALT-RUBBER BINDER

BBB-1 SCOPE

1.1 This specification controls the production of asphalt-rubber binder for use in asphaltic concrete friction courses and asphalt-rubber membrane interlayers.

1.2 This standard does not address any safety or environmental concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health and environmental practices and determine the applicability of regulatory limitations prior to use.

BBB-2 MATERIALS

2.1 Asphalt Cement - The particular grade of asphalt cement as specified in Table BBB-1 for the respective uses shall meet the requirements of Section 916. The asphalt cement shall be fully compatible with the proposed ground tire rubber as determined by the State Materials Office.

2.2 Ground Tire Rubber - The type of ground tire rubber as specified in Table AAA-I shall meet the requirements of Section AAA.

2.3 Asphalt-Rubber Binder - The asphalt cement and ground tire rubber shall be thoroughly mixed and reacted in accordance with the requirements of Table BBB-1. The rubber type shall be in accordance with the approved job mix formula. The blending unit may be a batch type or continuous type and shall be capable of sampling the blended and reacted asphalt-rubber binder material during normal production.

BBB-3 EQUIPMENT

The meter for the asphalt rubber binder shall meet the requirements for accuracy, condition, etc. of the Bureau of Weights and Measures of the Florida Department of Agriculture and such fact shall be recertified every 6 months either by the Bureau of Weights and Measures or by a registered scale technician.

BBB-4 METHOD OF MEASUREMENT

The ground tire rubber content in the asphalt-rubber binder shall be monitored based on the weight of ground rubber used vs. the gallons of asphalt-rubber binder used. The weight per gallon for the various types of asphalt-rubber binders included in Table BBB-1 are to be used for these calculations.

The quantity of asphalt-rubber binder material used shall be determined by a certified meter meeting requirements of BBB-3.
# TABLE BBS-1

**ASPHALT-RUBBER BINDER**

<table>
<thead>
<tr>
<th>USES</th>
<th>Dense-graded FC</th>
<th>Open-graded FC</th>
<th>Asphalt-Rubber Membrane Interlayer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber Type</td>
<td>TYPE I</td>
<td>TYPE II (or I)</td>
<td>TYPE III (or II or I)</td>
</tr>
<tr>
<td>% Gr. Tire Rubber (by wt. of asphalt cement)</td>
<td>5</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>AC Grade</td>
<td>AC-30</td>
<td>AC-30</td>
<td>AC-20</td>
</tr>
<tr>
<td>Minimum Blending Temp., °F</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Maximum Blending Temp., °F</td>
<td>335</td>
<td>350</td>
<td>375</td>
</tr>
<tr>
<td>Min. Reaction Time</td>
<td>10 min. (for Type II)</td>
<td>15 min. (for Type II)</td>
<td>30 min. (for Type III)</td>
</tr>
<tr>
<td>wt/gal. <em>(b)</em></td>
<td>8.6 lbs</td>
<td>8.7 lbs</td>
<td>8.8 lbs</td>
</tr>
</tbody>
</table>

*(a)* Use of finer rubber could result in the reduction of the minimum reaction time.

*(b)* Conversions to standard 60°F are not necessary.

**Note:** The minimum reaction time may be adjusted if approved by the State Materials Office depending upon the blending temperature, size of the ground tire rubber and viscosity measurement determined from the asphalt-rubber binder material prior to or during production. The addition of diluents or modifiers to obtain the desired viscosity shall be approved by the State Materials Office. Hold-over time of the asphalt-rubber binder material in excess of six hours will not be allowed without corrective action approved by the State Materials Office.
SECTION 337
ASPHALTIC CONCRETE FRICTION COURSES
(RUBBER MODIFIED ASPHALT BINDER)

337-1 Description.

This Section specifies the materials, composition, job mix formula and compensation for Asphaltic Concrete Friction Courses containing rubber modified asphalt binder. The plant and equipment requirements for this pavement are specified in Section 320. General construction requirements for all asphaltic concrete pavements as specified in Section 330 are applicable to this Section, subject to any exceptions contained herein.

The work will be accepted on a LOT by LOT basis in accordance with the applicable requirements of Sections 5, 6, and 9. The size of the LOT for the bituminous mix accepted at the plant will be as specified in 331-5, and for the material accepted on the roadway as stipulated in 330-10 and 330-12.

The mixes covered by this Section are designated as Friction Course 1 (FC-1), Friction Course 2 (FC-2), and Friction Course 4 (FC-4).

337-2 Materials.

337-2.1 General: The materials used shall conform with the requirements specified in Division III as modified herein.

337-2.2 Rubber Modified Asphalt Binder: The rubber modified asphalt binder shall meet the requirements of Section 336.

337-2.3 Coarse Aggregate: Except as modified herein, all coarse aggregate shall meet the requirements of Section 901.

337-2.4 Fine Aggregate:

337-2.4.1 General: Fine aggregates shall meet all applicable requirements of Section 902.

337-2.4.2 Special Requirements for FC-1:
(a) Local Materials: If clay is present in the fine aggregate, the quantity shall not exceed seven percent and it shall be of a type which will not produce clay balls in the mixture. The sand shall be nonplastic and shall be suitable for use in bituminous mixtures as determined by laboratory tests. If the sand deposits consist of stratified layers of varying characteristics and gradation, the Contractor shall employ such means as necessary
to secure uniform material. The fine aggregate will be sampled at the asphalt plant.

(b) Screenings: Slag, granite and gravel or any combination of these materials shall be crushed and meet the following gradation requirements in addition to the requirements in 902-5.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
<td>100</td>
</tr>
<tr>
<td>No. 10</td>
<td>40-75</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-13</td>
</tr>
</tbody>
</table>

337-2.4.3 Special Requirements for FC-4: Fine aggregate shall be composed of quartz grains and shall be reasonably free from lumps, clay, soft or flaky particles, salt, alkali, organic matter, loam or other extraneous substances. Only approved fine aggregate sources located above parallel 27 degrees, 30 minutes, in the State of Florida will be acceptable for use in FC-4 mixes. The weight of extraneous substances shall not exceed the following percentages:

<table>
<thead>
<tr>
<th>Material passing No. 200 Sieve</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>4.0</td>
</tr>
<tr>
<td>Coal and Lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>Clay Lumps</td>
<td>1.0</td>
</tr>
<tr>
<td>Cinders and Clinkers</td>
<td>0.5</td>
</tr>
</tbody>
</table>

In addition, the total amount of all the above materials in the fine aggregate shall not exceed five percent.

Fine aggregate, excluding crushed stone screenings, shall be subjected to the colorimetric test for organic impurities, and if the color produced is darker than the standard solution, the aggregate shall be rejected unless it can be shown by appropriate tests that the impurities causing the color are not of a type that would be detrimental to the pavement. Such tests shall be in accordance with FM 1-T 071 and AASHTO M-6.

Fine aggregate shall be reasonably well-graded, from coarse to fine and when tested by means of laboratory sieves, it shall meet the following requirements, in percent of total weight passing:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>95-100</td>
</tr>
<tr>
<td>No. 10</td>
<td>80-100</td>
</tr>
<tr>
<td>No. 40</td>
<td>10-40</td>
</tr>
<tr>
<td>No. 80</td>
<td>0-10</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-4</td>
</tr>
</tbody>
</table>

The above gradation for fine aggregate represents the extreme limits which will be used in determining the suitability.
for use of sand from all sources of supply. The gradation of fine aggregate from any one source shall be reasonably uniform and not subject to the extreme range specified above. For the purpose of determining the degree of uniformity of fine aggregate, fineness modulus determinations shall be made upon representative samples of fine aggregate submitted by the Contractor from such sources as they propose to use. Fine aggregate from any one source having a variation in fineness modulus greater than 0.20 either way from the fineness modulus of the representative sample submitted by the Contractor may be rejected.

337-2.5 Crushed Stone Screenings: Any screenings used in the combination of aggregates shall contain not more than 15 percent of material passing the No. 200 sieve. When two screenings are blended to produce the screenings component of the aggregate, one screening may contain up to 18 percent of material passing the No. 200 as long as the combination of the two does not contain over 15 percent material passing the No. 200 sieve. Screenings may be washed to meet these requirements. Crushed stone screenings used in friction course mixes shall meet the requirements of Section 902.

337-3 General Composition of Mixes.

337-3.1 General: The bituminous mix shall be composed of a combination of aggregate (coarse, fine, or a mixture thereof), mineral filler if required, and rubber modified asphalt binder. The several aggregate fractions shall be sized, uniformly graded and combined in such proportions that the resulting mix will meet the grading and physical properties of the approved mix design.

337-3.2 Aggregate Components: The aggregate components of the various mixes set out in this Section shall be as follows:

FC-1:
Either crushed slag, crushed gravel or crushed granite, any combination of these aggregates or a combination of one or more of these aggregates with fine aggregate. The coarse aggregate component (crushed slag, crushed gravel or crushed granite) shall comprise at least 60 percent of the aggregate combination.

FC-2:
Either crushed granite, crushed slag, crushed gravel or a combination of these. Crushed limestone from the Oolitic formation will also be permitted if the coarse aggregate contains a minimum of 12 percent non-carbonate material as determined by FM 5-510 and approval of the source is granted by the State Materials Office prior to its use. In addition, use of aggregates other than those listed above may be permitted if approved by the State Materials Office.

FC-4:
A blend of fine aggregate and crushed limestone screenings, with the fine aggregate comprising 50 to 70 percent of the

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico  Page 127
total aggregate in the mix. The combined aggregates in the mix shall contain a minimum of 50 percent acid insoluble materials as determined by the FM 5-510. All aggregate materials shall be furnished from DOT approved sources.

Continuing approval of all sources of material for use in FC-1, FC-2 and FC-4 will be based on field performance.

337-3.3 Grading Requirements: The mix design, as established by the Contractor and approved by the Department, shall be within the design range specified in Table 331-1 for all friction course mixes.

337-4 Mix Design.

The mix design shall conform to the requirements of 331-4.3 of these specifications except that Item No. 7 in 331-4.3.1 shall not apply to FC-2. For FC-1 and FC-4, data shall be submitted showing that the mix design meets the requirements of Table 331-2 using conventional AC-30. The rubber modified asphalt will then be substituted at the optimum conventional binder content for production and shall be shown as the optimum binder content on the approved mix design.

337-5 Contractor’s Quality Control.

The Contractor shall provide the necessary quality control of the friction course mix and construction in accordance with the applicable provisions of 6-8.4 and 331-4.4. After the mix design has been approved, the Contractor shall furnish the material to meet the approved mix design in accordance with the provisions of 331-4.4.2 and Table 331-3. Plant calibration shall comply with the provisions of 331-4.4.3 and Table 331-3.

337-6 Acceptance of Mix.

337-6.1 Acceptance at the Plant: The friction course mix shall be accepted at the plant with respect to gradation in accordance with the applicable requirements of 331-5. Acceptance determinations for rubber modified asphalt binder content for mixtures produced by automatic batch plants with printout will be based on the calculated binder content using the printouts of the weights of rubber modified asphalt binder actually used. In all other cases, acceptance determinations for rubber modified asphalt binder content will be based on calculated binder content using a reading from the certified meter meeting the requirements of 336-4 and the quantity of mix produced. Payment will be made based on the provisions of Table 331-6. In this table, the asphalt cement content (Printout) shall be used for rubber modified asphalt binder.

337-6.2 Acceptance on the Roadway: The friction course mix will be accepted on the roadway with respect to density and surface
tolerance in accordance with the applicable provisions of 330-10 and 330-12. There will be no density requirements for FC-2.

337-6.3 Additional Tests: The provisions of 331-5.5 shall apply to the friction courses FC-1, FC-2 and FC-4.

337-7 Special Construction Requirements.

337-7.1 Temperature Requirements for FC-2:

337-7.1.1 Air Temperature at Laydown: The mixture shall be spread only when the air temperature (the temperature in the shade away from artificial heat) is at or above 60°F.

337-7.1.2 Temperature of the Mix: The rubber modified asphalt binder and aggregates shall be heated and combined in such a manner as to produce a mix having a temperature, when discharged from the pugmill, within the range of 275°F and 310°F. The target temperature will be 290°F. All other requirements of 330-6.3 shall apply to FC-2.

337-7.2 Temperature Requirements for FC-1 and FC-4:

337-7.2.1 Air Temperature at Laydown: The mixture shall be spread only when the air temperature (the temperature in the shade away from artificial heat) is at or above 60°F.

337-7.2.2 Temperature of the Mix: The rubber modified asphalt binder and aggregates shall be heated and combined in such a manner as to produce a mix having a temperature, when discharged from the pugmill, within the range of 290°F and 325°F. The target temperature will be 310°F. All other requirements of 330-6.3 shall apply to FC-1 and FC-4.

337-7.3 Compaction of FC-2: Only seal rolling will be required; this rolling will be accomplished using a tandem steel-wheel roller. The weight of the steel-wheel roller shall not exceed 135 pounds per linear inch (PLI) of drum width.

\[
\text{PLI} = \frac{\text{Total Weight of Roller (pounds)}}{\text{Total Width of Drums (inches)}}
\]

A small amount of liquid detergent may be added to the water in the roller to reduce adhesion to the drum. Rolling shall be accomplished with a single coverage and with a nominal amount of overlap. In no case shall a roller be allowed on the mat after the seal rolling has been completed.

Where the lane being placed is adjacent to a previously laid mat, the longitudinal joint will not be pinched in a manner with the roller on the cold mat. The longitudinal joint will be pinched with the roller on the mat being rolled, overlapping onto
the cold mat by no more than three inches.

At intersections and in other areas where the pavement would be subjected to traffic before it has a chance to cool, the surface of the approaching pavement shall be sprayed with water so that the tires of the vehicles are wet prior to crossing over the compacted mat.

337-7.4 Compaction of FC-1 and FC-4: A small amount of liquid detergent may be added to the water in the roller to reduce adhesion to the drum.

At intersections and in other areas where the pavement would be subjected to traffic before it has a chance to cool, the surface of the approaching pavement shall be sprayed with water so that the tires of the vehicles are wet prior to crossing over the compacted mat.

337-7.5 Thickness of Friction Courses:

337-7.5.1 General: The thickness of the friction course shall be designated in the plans. This is the minimum desirable thickness for FC-1 and FC-4, and the maximum desirable thickness for FC-2. The minimum spread rate for FC-2 shall be 25 pounds per square yard when lightweight aggregates are used and 40 pounds per square yard when conventional aggregates are used.

337-7.5.2 Thickness Requirements - Square Yard Payment: The thickness shall be determined in accordance with 330-15.1 except that the average thickness will not be calculated. Cores will not be taken in areas where the friction course is being transitioned in thickness to tie into an existing surface. The maximum allowable deficiency from the thickness specified in the plans shall be 1/4 inch. If any area is deficient in thickness by more than the allowable tolerance, the Contractor shall correct the deficiency by removing and replacing the friction course at the proper thickness. The replacement friction course shall extend 50 feet either side of the deficient area and shall extend across the full width of the roadway.

As an exception to the foregoing, if the Engineer determines that the friction course will satisfactorily perform its intended function without corrective work, the friction course may be left in place without compensation. The area for which no payment will be made shall be the product of the total distance between cores indicating thickness within tolerances and the width of the lane which was laid in the particular pass in which the deficient thickness occurred. Additional cores will be taken as necessary to define the limits of a deficiency. Open-graded friction courses (FC-2) will not be cored for thickness determinations.

337-7.6 Hot Storage of FC-2 Mixes: When surge or storage bins
are used in the normal production of FC-2, as with the drum mixer plants, the maximum time the mix is allowed to remain in the surge or storage bin shall not exceed one hour.

337-7.7 Longitudinal Grade Controls for Open-Graded Friction Courses (FC-2): On open-graded friction courses (FC-2), the use of the longitudinal grade control (skid, ski, or traveling stringline) is prohibited. The use of the joint matcher is required.

337-7.8 Paving of Adjacent four-foot Wide Shoulders: When construction includes the paving of adjacent four-foot wide shoulders, the mainline pavement and the shoulder shall be paved in a single pass.

337-8 Method of Measurement.

The area to be paid for shall be plan quantity subject to 9-3.2. The pay area shall include entire areas of transitions to tie into existing pavement but excluding areas for which no payment is to be made due to deficient thickness as defined in 337-7.5. No adjustment to the area to be paid for will be made for extra thickness.

337-9 Basis of Payment.

337-9.1 Rubber Modified Asphalt Binder: The bid price for the friction course mix shall include the cost of the asphalt cement, ground tire rubber, anti-stripping agent and blending and handling of the rubber modified asphalt binder in the friction course mix. The bid price for the friction course shall be based on the following rubber modified asphalt binder contents:

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Rubber Modified Asphalt Binder Content (%) by weight of total mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC-1</td>
<td>6.0</td>
</tr>
<tr>
<td>FC-2</td>
<td>7.6*</td>
</tr>
<tr>
<td>FC-4</td>
<td>7.0</td>
</tr>
</tbody>
</table>

*14.6 for FC-2 with lightweight aggregate.

If the rubber modified asphalt binder content in the approved mix design increases or decreases from the foregoing percentages, the bid price of the mix will be adjusted based on the invoice price of the rubber modified asphalt binder material plus ten percent of the invoice price. When the rubber modified asphalt binder is blended at the asphalt plant, the invoice price will be a combination of the invoice price for the asphalt cement, the ground tire rubber and the blending of the rubber modified asphalt binder.
\[
\text{Adjustment} (\$/\text{sy}) = t \frac{(\text{RMABC}_{\text{Design}} - \text{RMABC}_{\text{Table}}) 100 \text{lb/sy-in}}{8.6 \text{lb/gal}} (IP) 1.10
\]

where

\[
\text{RMABC}_{\text{Table}} = \text{Rubber Modified Asphalt Binder Content (\%)} \text{ from above table,}
\]

\[
\text{RMABC}_{\text{Design}} = \text{Rubber Modified Asphalt Binder Content (\%)} \text{ in the mix design, as issued by the Materials Office,}
\]

\[
t = \text{Design Thickness (inches)},
\]

\[
\text{IP} = \text{Invoice Price}.
\]

As an example, when the rubber modified asphalt binder content for a FC-1 mix is determined to be 6.8 percent the adjustment shall be calculated as follows:

\[
\text{\$ Per square yard} = t \times \left(0.005 \times 100 \text{ lb/sy-in} / 8.6 \text{ lb/gal}\right) \times \text{Invoice Price} \times 1.10
\]

where \( \text{RMABC}_{\text{Design}} - \text{RMABC}_{\text{Table}} = 0.065 - 0.060 = 0.005 \), and other variables are defined above.

*For FC-2 the lb/sy-inch will be based on the average spread rate for the project, and the thickness will not be needed.

The contract unit price per square yard for Asphaltic Concrete Friction Course shall be full compensation for all the work specified under this Section.

Payment shall be made under:

Item No. 337-5 - Asphaltic Concrete Friction Course - per square yard.
SECTION 918

ASPHALTIC CONCRETE - LATEX ADDITIVE

918-1 Description.

This work involves the placing of asphaltic concrete mixtures using a latex modified asphalt binder in accordance with all applicable requirements of the Standard Specifications and the Special Provisions. Asphaltic concrete mixtures using a latex modified asphalt binder shall be placed in areas as shown on the plans. Use of an asphalt binder meeting the requirements of Section 336, may be substituted in lieu of the latex modified asphalt binder.

918-2 Materials.

Latex Additive: The Latex additive shall conform to the following specifications:

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic Character</td>
<td>Anionic</td>
</tr>
<tr>
<td>Total Solids (wt. percent)</td>
<td>69 ± 0.5</td>
</tr>
<tr>
<td>pH</td>
<td>10.5 ± 0.5</td>
</tr>
<tr>
<td>Viscosity (Brookfield RVT No. 3 Spindle, 20 rpm)cp</td>
<td>1000-2500</td>
</tr>
<tr>
<td>Pound/Gallon</td>
<td>7.95 ± 0.5</td>
</tr>
<tr>
<td>Monomer Ratio percent (Styrene/Butadiene)</td>
<td>24/76 ± 1.0</td>
</tr>
</tbody>
</table>

The Contractor shall furnish vendor’s certified test reports for each transport, or equivalent, of latex additive shipped to the project. The report shall be delivered to the Engineer before permission is granted for the use of the material. The furnishing of the vendor’s certified test report for the latex additive shall not be interpreted as a basis for final acceptance. All such reports shall be subject to verification by testing sample materials as received for use on the project.

Three percent Latex Solids (4.3 percent Latex Emulsion), by weight of asphalt cement binder material, shall be added to the asphaltic concrete mixture in accordance with the following:
Batch and continuous mix plants: The introduction of the latex shall begin within five seconds of the wet mix portion of the mixing cycle, and be continued simultaneously with the asphalt spray operation. The minimum wet mixing time shall be 50 seconds.

Drum mix plant: The latex shall be introduced into the drum mixer at a point approximately two feet downstream from the point where the asphalt cement is introduced.

The metering device for the latex additive must be accessible to the plant operator and the accuracy of the meter must be approved by the Engineer prior to the start of production.

The target temperature established for the latex modified asphaltic concrete mixture shall be 290 degrees F for FC-2 and 310 degrees F for FC-1, FC-4 and Type S Asphaltic Concrete mixtures. Any change in this target temperature must be approved by the District Bituminous Engineer.

NOTE: 1) Every effort shall be made to minimize hand work.

2) Rolling shall be completed before the mat has cooled to a temperature that will prevent proper compaction. A small amount of liquid detergent may be added to the water in the roller to reduce adhesion to the drum.

3) At intersections and in other areas where the pavement may be subjected to cross traffic before it has had a chance to cool, the pavement shall be cooled by spraying water onto the surface immediately after rolling is completed. The method of artificial cooling shall be done in the shortest possible time to minimize a disruption of traffic.

If a rubber modified asphalt binder is substituted in lieu of the latex modified asphalt binder, the requirements of Section 336 and all other relevant specifications shall apply.

918-3 Payment.

The quantity of latex material will not be paid for directly, but shall be included in the asphaltic items of the contract.

If an asphalt binder is substituted in lieu of the latex modified binder, the asphalt rubber binder will not be paid for directly, but included in the bid price of the friction course mix in accordance with Section 337.
SECTION 341
RUBBER MODIFIED ASPHALT MEMBRANE INTERLAYER

341-1 Description.

The work specified in this Section consists of the construction of a rubber modified asphalt membrane interlayer composed of a separate application of rubber modified asphalt binder covered with a single application of aggregate.

341-2 Materials.

341-2.1 Rubber Modified Asphalt Binder: The rubber modified asphalt binder shall conform to the requirements of Section 336.

341-2.2 Cover Material: The cover aggregate shall be Size No. 6 stone, slag or gravel meeting the requirements of Section 901, with the modification that 100 percent of the material shall pass the 3/4-inch sieve.

341-3 Equipment.

341-3.1 Power Broom: The power broom for cleaning the existing pavement shall be capable of removing all loose material from the surface. The power broom for cleaning loose aggregate from the finished surface shall be a rotary sweeper type.

341-3.2 Spreading Equipment: The aggregate spreader shall be a self-propelled unit that can be adjusted to accurately apply the cover material at the specified rate and will spread the material uniformly.

341-3.3 Rollers: The rollers used shall be self-propelled, pneumatic-tired traffic type rollers equipped with at least seven smooth-tread, low-pressure tires and capable of carrying a gross load of at least eight tons. The inflation of the tires shall be 90 psi minimum and shall be maintained such that in no two tires shall the air pressure vary more than five psi. The traffic roller shall be loaded as directed by the Engineer.

341-3.4 Mixing Equipment: The mixing equipment for rubber modified asphalt binder shall be designed for that purpose and shall be capable of producing and maintaining a homogeneous mixture of rubber and asphalt cement at the specified temperature.

341-3.5 Pressure Distributor: The distributor used to apply rubber modified asphalt binder shall be a pressure type capable of maintaining a homogeneous mixture of rubber and asphalt cement at
the specified temperature and consistently apply the material in a uniform manner.

341-4 Preparation of Rubber Modified Asphalt Binder.

The materials shall be combined as rapidly as possible for such a time and at such a temperature that the consistency of the binder approaches that of a semi-fluid material. The time and temperature for blending of the rubber modified asphalt binder shall be as specified in Table 336-1. The Engineer shall be the sole judge of when the material has reached application consistency, and will determine if an extender oil or dilutent is needed for that purpose. After reaching the proper consistency, application shall proceed immediately. In no case shall the mixture be held at temperatures over 325°F for more than six hours after reaching that point.

341-5 Construction Procedure.

341-5.1 Preparation of Surface: Prior to application of the rubber modified asphalt binder, the existing pavement shall be cleaned as specified in 300-4.

341-5.2 Application of Rubber Modified Asphalt Binder: The rubber modified asphalt binder shall be applied only under the following conditions:

a) The air temperature is above 60°F and rising.
b) The pavement is absolutely dry.
c) The wind conditions are such that cooling of the rubber modified asphalt binder will not be so rapid as to prevent good bonding of the aggregate.

The rubber modified asphalt binder shall be uniformly applied, using a pressure distributor meeting the requirements of this specification, at the rate of 0.6 ± 0.05 gallon per square yard. The Engineer may vary the rate of application. The application rate is based on pounds per hot gallon as shown in Table 336-1. Conversions to standard 60°F are not necessary.

341-5.3 Application of Cover Material: Immediately after application of the rubber modified asphalt binder, cover material meeting the requirements set out herein shall be uniformly spread at a rate of between 0.26 and 0.33 cubic feet per square yard. The exact rate will be set by the Engineer.

The application of the rubber modified asphalt binder and the application of the cover material shall not be separated by more than 150 feet.

341-5.4 Rolling: In order to ensure maximum embedment of the aggregate, it is imperative that the entire width of the mat be covered immediately by traffic rollers meeting the requirements of
this specification. For the first coverage, a minimum of three traffic rollers shall be provided in order to accomplish simultaneous rolling in echelon of the entire width of the spread. When spreading is stopped, the spreader shall be moved ahead to allow immediate rolling of all cover material.

Following the first coverage, a minimum of four coverages shall be made with additional traffic rollers.

341-5.5 Traffic Control: The normal sequence of construction operations shall require the first course of asphalt concrete overlay to be placed over the membrane prior to opening to traffic. When this is not possible due to circumstances outside the Contractor's control, he shall terminate placement of the membrane layer as soon as possible to minimize the amount of the layer that will be exposed to traffic. In no case shall traffic be permitted on the membrane layer for a period of at least two hours. Any exposed membrane layer that is left open to traffic shall be covered immediately when the Contractor resumes his normal paving operation. The intent of this specification is to minimize the amount of membrane interlayer material directly exposed to traffic.

341-6 Unacceptable Rubber Modified Asphalt Membrane Interlayer.

If the rubber modified asphalt membrane interlayer is unacceptable due to incorrect blending, application rate, or not meeting the requirements of this Section, or damaged prior to placement of the asphaltic concrete layer, it shall be removed and replaced as directed by the Engineer. In no case shall excessive amounts of rubber modified asphalt binder be allowed.

341-7 Method of Measurement.

The area of Rubber Modified Asphalt Membrane Interlayer shall be determined as provided in 9-1.3.1.

341-8 Basis of Payment.

The quantity of Rubber Modified Asphalt Membrane Interlayer shall be paid for at the contract unit price for this item. Such price and payment shall constitute full compensation for all work specified in this Section including furnishing cover materials, asphalt cement, ground tire rubber, and all processing, mixing, handling, spreading, rolling, and other incidental work necessary to complete this item.

Payment shall be made under:

Item No. 341-70- Asphalt-Rubber Membrane Interlayer
-per square yard
SECTION 919  
GROUND TIRE RUBBER  
FOR USE IN RUBBER MODIFIED ASPHALT BINDER

919-1 Description.

This specification governs ground tire rubber for use in rubber modified asphalt binders for use in a variety of paving applications.

919-2 General Requirements.

The ground tire rubber shall be produced by ambient grinding methods. The rubber shall be sufficiently dry so as to be free flowing and to prevent foaming when mixed with asphalt cement. The rubber shall be substantially free from contaminants including fabric, metal, mineral, and other non-rubber substances. Up to four percent (by weight of rubber) of talc (such as magnesium silicate or calcium carbonate) may be added to prevent sticking and caking of the particles.

919-3 Physical Requirements.

919-3.1 Gradation: The sample shall be tested in accordance with FM 1-T 027 (AASHTO T 27) with the following exceptions: a 100g sample size and up to 25% dusting agent (talc). (Rubber balls may also be used to aid in the sieving of finely ground rubber.) The resulting rubber gradation shall meet the gradation limits shown in Table 919-1 for the type of rubber specified.

919-3.2 Specific Gravity: The specific gravity of the rubber shall be 1.15 ± 0.05 when tested in accordance with ASTM D-297, pycnometer method.

919-3.3 Moisture Content: The moisture content shall be determined in accordance with AASHTO T 255 with the exception that the oven temperature shall be 140 ± 5 °F and the weight of the sample shall be 50 ± 0.1g. The moisture content shall not exceed 0.75% by weight.

919-3.4 Metal Contaminants: No more than 0.01% metal particles shall be detected when thoroughly passing a magnet through a 50g sample.

919-4 Chemical Requirements.

The chemical composition of the ground tire rubber shall be
determined in accordance with ASTM D 297 and shall meet the following requirements:

- Acetone Extract - Maximum 25 percent.
- Rubber Hydrocarbon Content - 40 to 55 percent.
- Ash Content - Maximum 8 percent.
- Carbon Black Content - 20 to 40 percent.
- Natural Rubber - 16 to 34 percent.
- 10 percent for Type A rubber.

919-5 Packaging and Identification Requirements.

The ground tire rubber shall be supplied in moisture resistant packaging such as either disposable bags or other appropriate bulk containers. Each container or bag of ground tire rubber shall be labeled with the manufacturer's designation for the rubber and the specific type, maximum nominal size, weight and manufacturer's batch or lot designation.

919-6 Certification Requirements.

The manufacturer of the ground rubber shall furnish the Engineer certified test results covering each shipment of material to each project. These reports shall indicate the results of tests required by this specification. They shall also include a certification that the material conforms with the specification, and shall be identified by manufacturer's batch or lot number.

Table 919-1
Gradations Of Ground Tire Rubber

<table>
<thead>
<tr>
<th>Sieve Size % Passing</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>--</td>
<td>--</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>--</td>
<td>100</td>
<td>85-100</td>
</tr>
<tr>
<td>30</td>
<td>--</td>
<td>95-100</td>
<td>40-65</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
<td>85-100</td>
<td>20-45</td>
</tr>
<tr>
<td>60</td>
<td>98-100</td>
<td>30-60</td>
<td>--</td>
</tr>
<tr>
<td>80</td>
<td>90-100</td>
<td>15-40</td>
<td>5-20</td>
</tr>
<tr>
<td>100</td>
<td>70-90</td>
<td>5-25</td>
<td>--</td>
</tr>
<tr>
<td>200</td>
<td>35-60</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Appendix D

Copies of newspapers articles on the scrap tire waste management problem in Puerto Rico.
Waste Authority proposes 1st legislation on disposal of tires

Recycling measure aims at taxation to cover handling

By ROBERT P. WALZER
Or the Star Staff

Scrap tire folklore has it that there are 22 million junked tires in Puerto Rico. Theoretically, it's possible to count each one, because tires don't break down. Some are in municipal landfills. Many more litter the roadsides. They are discarded in ravines, rivers and along Puerto Rico's countryside. Others are illegally buried, releasing jet black toxic smoke into the air.

By weight tires represent just 1 percent, or 45,000 tons, of Puerto Rico's annual solid waste, according to the Solid Waste Authority. But because of their bulk, durability and the lack of regulations for their disposal, they are a symbol for the other 99 percent of Puerto Rico's garbage headaches.

"At this moment there is nothing that regulates the handling of used tires," said Daniel Pagán, executive director of the Solid Waste Authority.

The government has not dealt with the ubiquitous rubber donuts. There are many uses for scrap tires, but, if nothing else, simply shredding would reduce their volume by 80 percent.

"That would make it a hell of a lot easier to deal with in landfills," said Fritz Kirsling, an environment consultant and representative of Shredding Systems Inc., a manufacturer of such equipment. Kirsling has been trying for two years to sell the government a shredder to no avail.

There is now for the first time an effort to confront the scrap-tire plague. The Solid Waste Authority has prepared legislation it will submit in January as part of an administrative recycling bill that would require the payment of an environmental tax on every imported tire. The money, which would help pay for its disposal afterwards, would go into a special Treasury Department account, said Pagán.

"We are trying to provide needed infrastructure to the industry to develop recycling techniques for tires," he said.

Under the plan, tire dealers, such as Western Auto, would be paid to carry scrap tires to a central location. Now the dealers pay tire collectors to pick them up but there is no guarantee of where they are dumped. Some of the money would also go to the Treasury Department to maintain stronger vigilance on the import of tires, and to the Environmental Quality Board to create a permit process for the disposal of tires.

Several companies are on the sidelines waiting for the legislation to pass. But one firm, the Pittsburgh-based American Tire System Inc., is already forging ahead with its own plan, one that will likely conflict with the government plan.

"I think it's the market place that must dominate, not the government," said Henry Boch, president of American Tire, which has an operation in Cabo Rojo. "This is a service job. If you don't respond, you get replaced. But just try firing the government if they don't perform."

He said that statewide disposal programs similar to Pagán's, such as in Maryland and Pennsylvania, plan have not worked.

American Tire has already forged a contract with the Cabo Rojo municipal government to buy used tires from tire dealers there starting in October.

The Cabo Rojo city council recently approved a scrap tire recycling pilot plan which grants it authority to charge its own "environmental tariff" of 25¢ on every used tire. It would be charged at the point of sale of new tires when customers deliver their old ones.

"It will be beneficial to the municipal coffer as well as alleviating existing problems related to tire disposal," said Kelley Escalón, an advisor to Cabo Rojo Mayor Santos Ortiz.

American Tire is working on contracts with other municipalities and hopes to have 50 signed up by next year, accordingly.

Please see TIRES, Page 9

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico Page 141
From Page 3

**Tires**

To both. Under the Municipal Reform Act of 1991, municipalities have the ability to enter into private contracts for waste management.

Another firm, End Tire Recycling System, has incorporated in Puerto Rico, but is waiting for new laws to proceed.

"Until somebody comes up with legislation there's not much we could do," said Donald Schiavetta, president of the company. "There's no way of knowing if your going to be paid, from who your going to get paid and if tires will be available."

Meanwhile, the old tire dilemma is worsening. There are about 12 million cars on the road, and according to the Solid Waste Authority, as many as 6.5 million tires thrown away each year. As tire problems become apparent, municipal landfills have increasingly shown them during the past five years, passing laws prohibiting their dumping.

You cannot burn a tire. Like floating glaciers, they eventually wiggle their way to the top of any landfill. Tires also make it difficult to compact the rest of garbage, acting as trampolines, bouncing right back up.

And once on top of the heap, they cause other problems. Rain water sits in tires and they become perfect mosquito breeding grounds. Mosquitoes carry dengue fever and other viral diseases. Rodents love abandoned tires, too.

Tires will take centuries to break down. Tire manufacturers make them so well that they last long after serving their original use. It is illegal to burn them. Nonetheless, thousands go up in smoke, every year, usually the result of arson. People attempting to burn off the rubber covering of copper wire to reclaim the copper set junk yard tires ablaze for use as kilns, for example. A tire fire in the Cabo Rojo municipal dump in January took more than two weeks to put out. But not before it blackened skies with toxic smoke.

Tires burn practically every week in an illegal makeshift dump alongside the San Juan municipal dump.

On Thursday there were five separate fires there spewing jet black smoke into the skies. Residents said it was the second set of fires that day. Aggravating the problem, there is a proliferation of used tires being imported to the island. U.S. federal regulations prohibit tires with treads of less than 1/16th of an inch to be driven on highways.

Thus, southern state entrepreneurs buy them for pennies, and ship them to Puerto Rico, where rules are more lax, selling them for about $4 or $10 apiece, according to Pagán. However, the used tires are normally jumbled in more mouths, a fraction of the average two or three years that new tires last.

In 1992 there were 80,276 such used tires imported to Puerto Rico, according to the Chamber of Commerce's Maritime Register. One company alone, Inter East Tire Inc., imported 171,707 used tires that year, states the register. Pagán said a number closer to the truth is 1.5 million used tires imported each year.

"Puerto Rico is being used as a dumping ground," he said.

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico
Old tires may find way back to the highways — as additives

By ROBERT P. WALZER
Of The STAR Staff

In volatile times, Italians have used them for “necklacing,” that is, forcing burning rubber tires around the necks of their victims. But there are also more civil uses for scrap tires which Puerto Rico has yet to explore.

One of them may become law in 1994. Under the Intermodal Surface Transportation Efficiency Act of 1991, recycled tires must be used to supply 5 percent of the mix of pavement in the construction of federally funded highways. The amount of recycled tires required in the mix will then rise each year until it reaches 20 percent in 1997.

Yet it is unclear if that law will remain unaltered. A letter last month from federal Department of Transportation Secretary Federico Peda to Thomas Foley, speaker of the U.S. House of Representatives, expresses doubt over the plan.

"The problem of scrap tire disposal is a serious one and it is important to address it," states Peda. "However, as a study makes clear, this material"

Please see RUBBER, Page 9

From Page 3

Rubber

has not been tested long enough over a broad enough range of conditions for the DOT to conclude, at this time, that it is an acceptable additive to asphalt.”

There may be other problems with the scrap tire requirement in road building. Better Roads and Asphalt, one of the island’s largest road contractors, says the cost of building roads would more than double with the use of crumb rubber. The company further claims that the technology is not approved by the Puerto Rico Environmental Quality Board and the process would expose workers to carcinogenic gases.

The Commonwealth Department of Transportation and Public Works said that the federal law allows the substitution of other recycled material for the asphalt mix such as glass, and is considering fulfilling the federal requirement that way. The agency said it hired the Civil Engineering school, part of the University of Puerto Rico in Mayaguez, to study possible substitutes for scrap tires.

Retreading used tires, something most often done with truck tires, has become less common as the cost of tires has dropped. But that option could be required by law to help reduce Puerto Rico’s annual 3.5 million scrap tire volume. In the United States 20 million tires are retired a year, according to the Scrap Tire Management Council.

Nonetheless, scrap tires have great potential. They can be burned in cement kilns and pulp and paper mills as a supplemental fuel in electricity generating facilities, even burned whole as a pure fuel source.

Each tire has 2.5 gallons of recoverable petroleum. The estimated 22 million scrap tires in Puerto Rico would yield 80 million gallons of petroleum.

An oppressive heat is emitted from any burning pile of tires. One burning tire will release about 250,000 British Thermal Units of heat, enough to heat fourteen hundred pounds of ice water to a boil. Tires burn more BTUs than an equivalent amount of coal. If burned with pollution controls they release less sulphur and nitrous oxides than coal, according to the Scrap Tire Management Council.

Puerto Rican Cement spokesman Jose Serra said the company is not considering using scrap tires as a fuel additive to its coal plant now. However Danny Pagán, executive director of the Solid Waste Authority, will propose to the island’s two cement companies to burn tires along with the coal.

Scrap tires can also be separated into their raw materials, char, oil and steal, and be resold and reused.

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico  Page 143
Reciclaje de neumáticos

Por MILDRED RIVERA MARRERO
Especial para El Nuevo Día

LA PRIMERA compañía de reciclaje de gomas de automóviles comenzó a operar en Salinas, y espera procesar gran parte de las millones de unidades que se generan anualmente.

American Tire Systems International-Puerto Rico (ATSI-PR) comenzó a operar desde el mes de diciembre, señalaron en una entrevista con este diario los dueños de la compañía, Henry Boch y Henry Wolfgang. La compañía pretende inicialmente recoger las gomas de los vertederos municipales, para lo cual ya tiene algunos contratos en el oeste, sur y centro del país, según los empresarios.

Uno de los problemas ocasionado por las gomas desechadas, tanto en los vertederos como fuera de éstos, es la propagación de plagas por la acumulación de agua, en la que se reproducen los mosquitos. Además, no son biodegradables y ocupan mucho espacio. Las gomas constituyen el 2% de los desperdicios sólidos en la isla. Anualmente se desechan alrededor de 45,000 toneladas de gomas.

"El problema (de gomas) ha existido por años y se volverá peor. Se podía pensar en quemar (gomas) pero esa no es la solución, la única solución real es reciclarlas", dijo el vicepresidente de la compañía, Henry Wolfgang. El equipo de ATSI-PR comprimirá la gomas sin quemarlas o usar otros métodos que despidan partículas al aire, según los empresarios.

EL PRODUCTO final puede ser utilizado junto con el asfalto en la construcción de carreteras, en alfombras y selladores de techos, entre otras cosas. Alegadamente, ATSI-PR ya tiene contratos con compañías locales que los utilizarán para hacer mejoras al ambiente, pero no quisieron dar más detalles.

Negaron, además, que vayan a exportar el material, aunque esa fue la información que le suministraron al Departamento de Agricultura cuando comenzaron las conversaciones para alquilar varios edificios de la Central Aguirre, en Salinas, según funcionarios de esa agencia.

La empresa, que tiene sus oficinas centrales en Delaware, tiene un contrato de renta por 10 años con la Corporación Azucarera. El acuerdo establece un pago de $20,400 el primer año, y seguirá aumentando hasta alcanzar los $48,000 en el quinto año. Luego de ese período, la renta será de $48,000 más un subsidio por inflación, según una fuente de Agricultura.
Appendix E

Copy of the original questionnaire in Spanish sent to Island municipalities in March 1993 seeking information on the uses and management of discarded Tires in Puerto Rico.
Hon. Alcalde Municipio de

Estimado señor Alcalde:

El Centro de Transferencia de Tecnología en Transportación del Recinto Universitario de Mayagüez actualmente tiene a su cargo un proyecto especial sobre la Viabilidad de Utilizar Gomas Descartadas Como Agente Modificador de Mezclas Asfálticas. El proyecto, presupuestado por la Autoridad de Carreteras y Transportación y la Administración Federal de Carreteras, surge como parte de las nuevas disposiciones de la ley ISTEA (Intermodal Surface Transportation Efficiency Act) para atender la problemática ambiental en cuanto a la reutilización de gomas descartadas, específicamente a su aplicabilidad en mezclas asfálticas.

Como parte inicial de este estudio hemos preparado el cuestionario adjunto para realizar una encuesta que nos permita conocer más a fondo la problemática de cada municipio con relación al uso, manejo y disposición de gomas descartadas.

Los resultados de esta encuesta ayudarán, además, a establecer un estimado del volumen total de gomas descartadas anualmente en Puerto Rico. Esta información se utilizará para determinar si los municipios cuentan con la suficiente materia prima en términos de gomas descartadas, para poder considerar viable implantar la ley propuesta en Puerto Rico. Esta ley exige que un porcentaje de los pavimentos que se construyan en el 1994 y años subsiguientes utilicen gomas descartadas como un constituyente de la mezcla.

Le solicitamos a estos efectos su cooperación identificando el personal idóneo de su Municipio para que cumplamente el cuestionario de epígrafe y cualquier otra información relacionada y nos la haga llegar a la siguiente dirección:

Universidad de Puerto Rico
Recinto Universitario de Mayagüez
Atención: Ing. Jorge Velar
Departamento de Ingeniería Civil
Mayagüez, Puerto Rico 00680
12 de marzo de 1993

Para agilizar esta fase de nuestro estudio, le agradeceremos que de tener acceso a un facsímil, nos envíe el cuestionario a través del mismo a nuestro número de fax 265-5695.

Una vez finalice este estudio, los resultados estarán disponibles a través de nuestra oficina y de la Autoridad de Carreteras y Transportación.

Gracias anticipadas por su colaboración en esta encuesta.

Cordialmente,

Benjamín Colucci, Ph.D
Co-Director
Encuesta Sobre

El Uso Y Manejo De Gomas Descartadas en Puerto Rico

Municipio :
Alcalde :
Fecha : / / 1993

Nombre de la persona que procederá a contestar el cuestionario
Ocupación: ____________________ Teléfono: ____________

1. Clasifique la magnitud del problema de manejo y disposición de gomas descartadas en su Municipio:
   [ ] Ninguno  [ ] Leve  [ ] Moderado  [ ] Crítico

2. Cuantas gomas usted estima que se descartan anualmente en su Municipio _______________________

3. Que gestiones realiza actualmente el Municipio para atender esta problemática: (marque todas las que apliquen).
   [ ] Venderlas  [ ] Almacenarlas  [ ] Quemarlas  [ ] Triturarlas  [ ] Otros ________________________________

4. Tienen un lugar en especial para depositar las gomas descartadas. [ ] Si  [ ] No (De tenerlo favor de indicar dirección):
   ________________________________

5. Actualmente tienen problemas de almacenamiento de gomas en vertederos clandestinos. [ ] Si  [ ] No

6. Usos alternos que le da su Municipio a las gomas descartadas (indique, además, un estimado de gomas para dichos usos)
   [ ] Ninguno al presente  [ ] Construcción de arrecifes artificiales CANTIDAD ____________
   [ ] Muros de retención en carreteras ____________
   [ ] Relleno para la sub-base de carreteras ____________
   [ ] Agente abultante en la producción de abono ____________
   [ ] Fuente alterna de combustible ____________
   [ ] Otros (mencione) ____________

7. Esta dispuesto a participar en un proyecto piloto que incorpore gomas pulverizadas en mezclas asfálticas para carpetas. [ ] Si  [ ] No
8. Existe alguna Ordenanza Municipal con relación al uso, manejo y/o disposición de gomas descartadas. [ ] Sí [ ] No (De existir favor de suministrar una copia.)

9. El Municipio contempla utilizar una máquina de triturar goma en un futuro cercano. [ ] Sí [ ] No

De ser afirmativa la respuesta en la pregunta N°9, proceda a contestar la N°10; de lo contrario proceda al final del cuestionario.

10. Han hecho gestiones para adquirir una máquina de triturar goma. [ ] Sí [ ] No

11. Planean llevar las gomas a municipios que han adquirido maquinaria para tales fines (p.e. Bayamón, Cabo Rojo). [ ] Sí [ ] No (De así hacerlo indique el Municipio) __________

12. Planean adquirir la máquina en conjunto con otro Municipio. [ ] Sí [ ] No (De existir contacto favor de mencionar el Municipio) __________

13. Modelo(s) considerado(s) para la compra. __________

14. Costo de la máquina (con o sin costo de transportación). __________

15. Información de la compañía que representa el equipo de triturar gomas en Puerto Rico.
   Nombre __________
   Dirección __________
   Teléfono (809) - Fax (809) -

16. Información de la compañía que distribuye el equipo de triturar fuera de la Isla.
   Nombre __________
   Dirección __________
   Teléfono ( ) - Fax ( ) -

17. Interesa participar en el desarrollo y/o producción de seminarios educativos sobre el uso y medidas de seguridad a los operadores de las máquinas trituradoras de goma. [ ] Sí [ ] No

18. Interesaría obtener copia de esta encuesta una vez finalizada. [ ] Sí [ ] No

Favor de enviar el Cuestionario vía Facsímil (265-695) a la atención del Dr. Benjamin Colucci. Gracias por su colaboración en esta encuesta.
Appendix F

Excerpt of the National Asphalt Pavement Association report on alternative uses of scrap tires.
Scrap Tire Utilization Technologies

Information Series 116

Sponsored by:
National Asphalt Pavement Association and
State Asphalt Pavement Association Executives
Introduction

Problem

Each year in the United States, approximately 285 million tires are discarded. Of that figure, 33 million are retreaded, 22 million are resold,* and 42 million are used in various alternative manners. The remaining 188 million tires, considered scrap, are added to stockpiles, landfills, or illegal dumps [Heitzman, 1991]. The U.S. Environmental Protection Agency (EPA) estimates that the present size of the scrap tire stockpiles is 2 to 3 billion tires [EPA, 1991].

Objective

The objective of this synthesis is twofold. One, to provide a State-of-the-Practice on various ways to use scrap tires; and two, to use engineering feasibility and economic analysis as a means of assessing the best uses of scrap tires while considering the potential environmental implications.

* The EPA does not count retreads and reused (resold) tires as scrap tires.

Scope

The scope of this synthesis has been limited to those uses of scrap tires that have the potential to make a substantial contribution to the reduction of the scrap tire problem. Relatively small markets exist for using scrap tires in such areas as rubber molded products, artificial reefs, playground gravel, etc. The development and expansion of these potential markets and others are fully encouraged. However, this document focuses only on the following areas: energy resource, civil engineering uses, and crumb rubber in Hot Mix Asphalt (HMA).

In order to compare the use of scrap tires among its many potential uses, an equivalent weight and volume for scrap tires must be used. For the purposes of this document, one passenger-size "scrap tire" is equal to 20 pounds for use as tire-derived fuel and in roadway fills and drainage layers or to 10 pounds when ground and used as crumb rubber. From the standpoint of volume, as often used in civil engineering applications, one cubic yard (cu yd) contains 40 scrap tires.
Scrap Tires
As an Energy Resource

Tire-derived fuel (TDF) and dedicated tires-to-energy facilities have the greatest potential for consuming large quantities of scrap tires. Several studies have concluded that a "cost-effective method of utilizing scrap tires in large volumes in the near term is to use scrap tires as fuel" [Burger, 1991; Getz and Ruffer, no date]. With a heating value of 15,000 Btu per pound (200,000 Btu's per tire), which is higher than that of most types of coal, tires are being burned as an inexpensive supplemental fuel with coal and wood [Pope, 1991]. In a report prepared for the Environmental Protection Agency, the potential energy source of 0.07 quadrillion Btu per year that would be furnished by the roughly 242 million waste tires per year "... is equivalent to 12 million barrels of crude oil and represents about 0.09 percent of the nation's energy needs" [EPA, 1991]. The economic feasibility of TDF depends strongly on the price of competing fuels and for dedicated tires-to-energy plants it depends on the buy-back rate of the electricity.

With the proper emission controls, burning tires for their fuel energy can be an environmentally sound method of disposing of a difficult waste. It can also be financially advantageous and can improve the operating characteristics of a number of processes [Clark, et al., 1991].

Controlled burning of TDF for fuel value occurs most frequently in kilns and boilers. Lime and, more commonly, cement kilns use TDF as supplemental fuel. Electric utility and pulp and paper boilers use TDF as supplemental fuel for either coal, gas, refuse-derived fuel (RDF) or wood waste [Clark, et al., 1991].

There are several factors that must be considered in burning TDF. The size and quantity of the TDF, the material handling capability of the facility, and the cleanliness of the TDF may be more important in some industries than others.

The uses of TDF and dedicated tires-to-energy are discussed in detail below as they are used in cement kilns, electric utilities, tire-to-energy facilities, and pulp/paper mills. Another potential use, pyrolysis, is also discussed, as well as the economic conditions that will have to prevail for it to become cost effective. A very thorough discussion of the technical implications of burning tires as well as pyrolysis is provided in a document entitled "Burning Tires for Fuel and Tire Pyrolysis: Air Implications" prepared for the Environmental Protection Agency [Clark, et al., 1991].

Current and Potential Uses

In the Scrap Tire Use/Disposal Study-1992 Update [Kearney, 1992], the list of facilities using TDF included: 11 cement kilns, with another 12 having concluded test burns and awaiting permits; nine pulp and paper mills; and nine electricity generating facilities with nine more having conducted test burns. This report has assessed the current and five-year potential usage by industry as shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Kilns</td>
<td>7†</td>
<td>60</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td>14</td>
<td>55</td>
</tr>
<tr>
<td>Electricity</td>
<td>21</td>
<td>75</td>
</tr>
<tr>
<td>Tires-to-Energy</td>
<td>15</td>
<td>40</td>
</tr>
</tbody>
</table>

Cement Kilns

The production of portland cement is extremely energy intensive (from four to six million Btu's are required to make a ton of product); therefore, alternative and cost-effective fuel options are of great interest. One source estimated that, theoretically, if all waste tires went to the cement industry, these could provide only about 11 percent of the fuel requirements for this industry [Clark, et al., 1991].

A cement kiln provides an environment conducive to the use of many types of fuel, including tires. The very hot, long inclined rotary kiln provides temperatures up to 2700°F, long residence time, and a scrubbing action on kiln materials that allows a kiln to accommo-

* In the cement industry, the 1992 Permitted Capacity is 14 million tires.

---

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico © Page 153
date and destroy many problem organic substances. The following advantages are attributable to using TDF in cement kilns.

1. The rock-like "clinker" formed in the kiln can often incorporate the resulting ash residue with no decrease in product quality.

2. Tires are a compact fuel with low moisture content and some iron and zinc content, both of the latter are desirable in the raw material mix for cement manufacturing.

3. The materials handling operations already in place at many cement plants, especially those with preheaters, require only minimal modification to accommodate TDF feed.

4. Nitrogen and sulphur oxides air emissions and ash quantities are lower than the emissions typical for coal.

For these reasons, cement kilns are one of the most common methods by which energy in waste tires is recovered.

Environmental Issues

The effect of a fuel change to TDF on emissions in cement kilns is minor, which is a positive factor supporting the use of TDF in the cement industry. According to an EPA report, the results of several air emission tests on cement kilns while burning scrap tires or TDF indicate the emissions are not adversely affected. In several cases the emission levels improve while utilizing the scrap tires for fuel [Clark, et al., 1991].

Economics

The costs of modifying the feed system to burn TDF in cement kilns is minor, and fuel savings can be 70 to 90 percent of the cost of the primary fuel depending on the plant location and governmental incentives.

Calaveras Cement Co. in California, which burns approximately 60 tons of TDF per day, purchases 2 inch TDF chips with the wire-in for approximately $30 per ton ($0.30/tire). On a dollar per Btu basis, this is about one-half the cost of coal. Calaveras will be installing a whole tire feed system which will cost $400,000. A tipping fee of between $0.50 and $1.00 per tire for whole tires will be charged by Calaveras. Once the whole tire system is in place, it is estimated that the tire fuel will cost less than one-tenth of coal on a Btu basis [Clark, et al., 1991].

At another cement manufacturer, Holnam/Ideal, TDF costs are 34 percent of their coal costs on a dollar per Btu basis.

In analyzing the economics of tire utilization, the following equation has been developed for determining the potential profit per tire [EPA, 1991]:

\[ P = F + R - C - T - D \]

where

- **P** is the profit per tire
- **F** is the tipping fee per tire
- **R** is the revenue received per tire
- **C** is the processing cost per tire for operating the facility
- **T** is the transportation cost for the tires
- **D** is the disposal cost for waste products

This equation has been used to analyze the profit per tire and the input in determining the payback period for using TDF in various industries.

For cement kilns, there is no increased operating cost in labor for feeding TDF instead of coal, and there is no disposal cost since the steel wire becomes iron oxide. If the TDF is delivered free, the terms F, C, T, and D in the equation become zero. Thus, for the cement kiln operator, the profit per tire equals the revenue, which in this case is the fuel cost savings. Assuming coal costs $50 per ton and the same Btu value can be provided with $20 per ton TDF, then the savings are $30 per ton ($0.30/tire) for using TDF.

The profit per tire becomes

\[ P = 0 + 0.30 - 0 - 0 - 0 \]

\[ = 0.30 \]

If the kiln burns 65 tons of TDF per day, the equivalent of about 2.4 million tires will be burned per year. The annual fuel savings from burning TDF will be $0.30 x 2.4 million = $700,000. If a capital investment of $1.5 million is necessary to set up the TDF feed system, the payback period is a very attractive 2.1 years.

Electric Utilities

Boilers at electric power plants use fuel to generate power for municipalities and industry. The heat generated by the burning of TDF rises into the radiation chamber, where the heat causes water to turn to high pressure steam. The steam is then forced through a turbine linked to a generator that creates the power.

Materials handling provides a challenge to burning TDF in a power plant boiler. TDF must be correctly sized so as to "fit" in fuel conveyors and must be well mixed to ensure proper combustion. Metal contained in tires can cause operational difficulties. If the TDF contains wire, it must be removed from the grate or bed because on becoming molten it plugs the grate, restricting the incoming air thereby decreasing efficiency. Also small pieces of radial mat-type wire can block conveyor joints, slag exit points, and augers [Clark, et al., 1991].

Environmental Issues

The effect of burning tires on emissions in coal-burning utilities varies by pollutant. For electric utility boilers,
The use of TDF has proven to often generate less emissions than coal.

In an Ohio test burn, the significant findings dealing with emissions are as follows:

1. The applicable compliance limits as stipulated by Ohio EPA for particulate and sulphur dioxide are 0.1 and 8.1 lbs./million Btu, respectively. For all runs performed, the particulate and sulphur dioxide emission rates were less than these compliance limits.

2. Emission rates for sulphur dioxide, nitrogen oxide, particulates, and lead generally decreased as the percent of TDF in the fuel increased. When 20 percent of the total Btu input to the boiler was provided by TDF, sulphur dioxide emission rates were equivalent to non-tire emission rates, lead emission rates were five percent lower, particulate emission rates were 28 percent lower, and nitrogen oxides emission rates were 36 percent lower.

3. Higher emission rates at lower feed rates are believed to be related to the non-uniform Btu supply associated with the slower whole tire feed rates.

**Economics**

Some companies have tested TDF in their fuel at the request of state agencies, but most are motivated by the possibility of lowering their operating costs. The savings resulting from replacing some of the primary fuel with TDF is very site specific. Factors that affect the potential savings include the availability of scrap tires, local processing costs to make TDF, transportation costs, inventory and handling costs, and government incentives. Other major factors are the availability and costs, including transportation, of the primary fuel as well as alternative fuels [Clark, et al., 1991].

One company, Wisconsin Power and Light (WP&L), purchases TDF at a cost of $20 to $30 per ton ($0.20 to $0.30/tire) delivered. On an average, this is $0.67 to $1.00 per million Btu's. The State of Wisconsin has an incentive program that reimburses WP&L for disposing of scrap tires originating in Wisconsin at the rate of about $20 per ton ($0.20/tire). With this incentive, WP&L's cost of the TDF ranges from zero to $0.33/million Btu's. The cost of coal, delivered to WP&L, is between $1.80 and $2/million Btu's.

**Dedicated Tires-to-Energy Facilities**

The Oxford Energy Co., founded in 1985, has pursued a strategy of developing an integrated waste tire utilization system. Their philosophy is to collect and sort the waste tires and utilize them for fuel or other cost-effective applications. This approach includes culling out the tires in the best condition, which can be sold as used tires or retreadable casings. Some tires are selected as raw material for manufacturing processes involving stamping, peeling, or buffing. Still other tires are used as TDF. However, to a large extent, the majority of the tires are used in the whole-tire-to-energy plants [EPA, 1991].

Two dedicated tires-to-energy facilities are currently operational in the U.S., both operated by the Oxford Energy Co.: the Modesto Energy Project in Westly, Calif. and the Exeter Energy Company in Sterling, Conn. The Modesto Energy Project was designed to burn whole scrap tires as its sole fuel. The location of this plant is directly adjacent to the country's largest scrap tire pile which, at its maximum, contained 30 to 40 million tires [Clark, et al., 1991]. This plant consumes approximately 4.9 million tires per year [EPA, 1991]. The technology used at the Modesto Energy Project was developed and licensed by the German company Gummi-Mayer in the late 1970's. The facility consists of two whole-tire boilers that provide steam to drive a 15.4 MW steam turbine generator.

The boilers and feed system can accommodate tires made of rubber, fiberglass, polyester, and nylon and as large as four feet in diameter. Tires are weighed by automatic scales, and the information is fed to a computer to maintain the proper feed to the boilers. The operation of this plant, as well as the way operational difficulties were overcome, is well-covered in the report entitled “Burning Tires for Fuel and Tire Pyrolysis: Air Implications” [Clark, et al., 1991]. All the by-products of this plant can be recycled. The steel slag from the incinerator, which contains the steel from the tire belts and beads, is being sold for use in cement production or road base. The zinc oxide from the baghouse can be used in zinc production. The gypsum generated by the scrubber can be used in wallboard production or as a soil conditioner. The power generated at the Modesto plant is sold to Pacific Gas & Electric Company under a long-term agreement to provide the utility electric power [EPA, 1991]. The tires for the Modesto Energy Project come from both the adjacent tire pile and the community. To facilitate the use of the community-produced tires, Modesto has created a subsidiary, Oxford Tire and Recycle, to collect and transport tires from tire dealers.

**Environmental Issues**

Based on Oxford Energy's experience, controlled emissions from their Modesto Energy Project compare extremely favorably to controlled emissions from electric utility plants powered by traditional fuels [Clark, et al., 1991].

**Economics**

An estimate has been made of the profitability of the Modesto Energy plant using the profit per tire equation, as discussed previously. The buy-back rate of 8.3 cents per kilowatt-hour means that each tire consumed will
generate revenue of $1.84 from the sale of electricity to the utility. For tires coming from the on-site tire pile, there is no tipping fee or transportation costs. The processing cost for operations, maintenance, labor, and materials has been estimated at $0.50 per tire. The disposal costs per tire for fly ash, gypsum, and bottom ash has been estimated at $0.08 per tire. Substituting these values in the tire profit equation yields the following results:

\[
P = F + R - C - T - D
\]

\[
= $0 + $1.84 - $0.50 - $0 - $0.08
\]

= $1.26 per tire

The annual gross profit from the Modesto Energy plant is $1.26 x 4.5 million tires = $5.7 million per year. Dividing the gross profit into the $38 million capital cost of the plant yields the favorable payback period of 6.7 years. A payback period of seven years or less is considered acceptable for a dedicated tires-to-energy facility [EPA, 1991]. Conclusions as to the profitability of the dedicated tires-to-energy plants are:

"The generation of electricity at dedicated tires-to-energy facilities appears to be very promising from both an air pollution and financial perspective" [Clark, et al., 1991].

"The success of the Modesto plant showed that whole-tire-to-energy plants can be built and run profitably in the U.S." [EPA, 1991].

In 1991, Oxford Energy brought on-line another tires-to-energy electric power plant in Sterling, Conn. called the Exeter Energy Company. It is about twice as large as the Modesto Energy Project and is designed to consume about 10 million tires per year. The payback period for the Sterling, Conn. plant is viewed as being as good or slightly better than the Modesto Project. Oxford Energy has plans to build two additional plants; one in Michigan and one in Nevada, with planned capacities of 10 and 15 million tires per year, respectively [Keamey, 1992].

According to the November 1992 issue of SCRAP TIRE NEWS, Oxford Energy is experiencing financial difficulties. They reportedly filed for Chapter 11 bankruptcy protection in August 1992 and are looking for a buyer.

Pulp and Paper Mills

Pulp/paper mills generate large amounts of waste wood products in the process of making wood chips for the pulp digester. Many mills burn this waste in boilers to obtain heat for process steam and to alleviate possible solid waste disposal problems. These waste wood boilers, known as "hog-fuel" boilers, require a supplementary fuel to maintain consistent boiler performance. Supplemental fuel facilitates uniform boiler combustion ensuring a sufficient amount of power is generated regardless of the fuel value of the wood waste at any time. The consistent Btu value and low moisture content of TDF in combination with its low cost, in comparison to other supplemental fuels, make TDF an especially attractive fuel in this industry. One TDF supplier has found pulp and paper mills tend to purchase the most expensive (cleanest) type of TDF partially because this process requires a high quality of shredded tire and because their fuel costs tend to be higher than industries such as utilities [Clark, et al., 1991].

Environmental issues

Burning TDF in pulp and paper mills may require modification to the emission control system because the emission control device used in this industry is generally a venturi wet scrubber in which the effectiveness decreases as the particle size in the emission decreases. To avoid this problem, one plant, Smurfit, replaced their venturi scrubber with an electrostatic precipitator (ESP) to improve particulate removal and to increase the amount of TDF they are permitted to burn [Clark, et al., 1991]. Fabric filters also appear to be an effective way to meet emission requirements.

However, with the consumption of 14 million tires for TDF in 1992 [Kearney, 1992], many pulp mills have apparently overcome the emission problem. In fact, the use of TDF can be environmentally positive, as indicated by a series of performance tests which concluded that the use of TDF supplementally in hog fuel boilers enhances combustion of wood waste, and enables disposal of biological sludge in conjunction with wood waste without necessitating use of other fossil fuels such as coal [Clark, et al., 1991].

Economics

Burning TDF is often economically attractive for pulp and paper mills. TDF supplies a consistent and dry Btu input which is an advantage because the hog fuel often has a high and variable moisture content.

Often the competing hog fuel is more expensive than TDF on a dollars per Btu basis. Using the profit per tire equation assuming wire-free TDF is $30 per ton ($0.30/tire) and hog fuel is $0.45 for the same Btu value as one tire, and handling, transportation, and ash disposal costs are the same for both fuels, the profit per tire equals the fuel cost savings:

\[
P = $0.15
\]

If the pulp/paper mill consumes 500,000 tires per year as TDF, then the annual fuel cost savings over hog fuel is $0.15 x 500,000 = $75,000.

If the cost of improving the emission control system is $150,000, the payback period is two years and TDF can be burned economically.

*The EPA report "Markets for Scrap Tires" uses both 4.5 and 4.9 million tires consumed by the Modesto Plant in 1991.
Pyrolysis

Pyrolysis is a destructive process of thermal degradation of tires which produces three principal products: pyrolytic gas, oil, and char (carbon black). These products are marketable to various degrees. The gas has a heat value on average of 635 Btu/cu ft (natural gas averages about 1,000 Btu/cu ft). The light oils can be sold for gasoline additives to enhance octane, and heavy oils can be used as a replacement for No. 6 fuel oil. Carbon black can meet some market needs, but if markets for char are not developed this by-product can become a solid waste problem [Clark, et al., 1991].

Conrad Industries operates a pyrolysis unit in Centralia, Wash. The unit is manufactured by Kleenair Products Company of Portland, Oreg. and licensed to Conrad. This unit converts 100 tires per hour to 600 pounds of carbon black, 90 gallons of oil, and 240,000 cu ft of vapor gas.

Environmental Issues

The environmental issues for this industry are minimal. As an example, the Conrad plant needs no pollution equipment except for an outside flare for burning excess gas. No continuous emissions monitoring systems are needed. An annual inspection is conducted on site by regulatory agencies, and plant personnel conduct weekly checks for gas leaks [Clark, et al., 1991].

Economics

During the past 10 years, no less than 34 major pyrolysis projects have been proposed, designed, patented, licensed, or built; only one or two are operational today. Technically, tire pyrolysis is feasible; financially it is questionable. The economics of the pyrolysis business are complex. For example:

1. An initial investment of over $10 million is required to construct a 100-ton-per-day plant.
2. The yield of pyrolytic oil can vary from 82 to 171 gallons per ton.
3. The value of pyrolytic oil can vary from 36 to 95 cents per gallon.

Two factors can have a very large impact on the profitability of pyrolysis. Naturally, the selling price of the products is a major one. But another important impact is the disposal costs or tipping fees. The report entitled "Burning Tires for Fuel and Tire Pyrolysis: Air Implications" [Clark, et al., 1991] contains a table that analyzes the influence of tipping fees and selling prices of pyrolytic products to produce a 20 percent return-on-equity for five pyrolysis plants. The tipping fees range from $0.04 to $1.03/tire. Tipping fees are constantly rising, and in the Northeast fees of $100 to $150 per ton ($1.00 to $1.50/tire) are not unusual for tires. As this cost continues to rise, pyrolysis may prove to be economically viable. Thus, although pyrolysis is marginally profitable at present, the economic picture may change with increased tipping fees and this method of helping solve the scrap tire problem should not be overlooked in the future.

Page 157
Shredded and whole tires have been used in a variety of highway applications over the last several years. Some of the advantages attributed to these applications are that they:
1. are a lightweight material,
2. are replacements for more expensive or scarce aggregate,
3. provide a material with high permeability characteristics,
4. are resistant to ultraviolet radiation,
5. are non-biodegradable (important as a stable fill),
6. provide a material with improved thermal characteristics relative to frost penetration,
7. are cost effective, and
8. are technically superior to land filling.

The uses discussed below consist of lightweight embankments, drainage layers, slope stability and retaining walls.

**Lightweight Embankment**

The use of scrap tire rubber as a lightweight fill has been studied by Oregon [Read, et al., 1991], Vermont [Winters, 1991] and Minnesota [MNDOT, 1992; Geisler, et al., 1989; Public Works, 1990], and an installation is planned by Washington DOT for 1993 [R. Finkle, personal communication, Sept. 15, 1992]. Two studies addressing leachate from scrap tires either used or capable of being used in embankments have been reported. One was done for the Minnesota Pollution Control Agency and the other for the Rubber Manufacturers Association [MPCA, 1990; Radian Corp, 1989; Zellor, 1991].

**Oregon**

Oregon used shredded rubber tires in a lightweight fill to repair landslide damage under a highway embankment in mountainous terrain on Highway U.S. 42 in 1990. The forces creating the slide were reduced by removing the soil embankment and replacing it with the lighter weight of tire chips. The tire embankment had a three foot thick compacted soil cap on the top and side slopes. It supported a conventional aggregate base and an asphalt pavement. Approximately 580,000 tires and 5,800 tons of shredded tires replaced approximately 12,800 tons of soil. The tire chips were placed and compacted in three foot lifts using a D-8 bulldozer. Density (unit weight) of the tire chips was approximately 30 pcf loose, 45 pcf in-place compacted, and 52 pcf when compressed under the soil cap and pavement [Read, et al., 1991].

This Oregon report contains some interesting information to potential users of this scrap tire technology. The loose unit weight of the tires from three different vendors varied from 24 to 33 pcf, probably because of the shredding and handling processes. If long hauls are necessary to bring the material to the job site, the unit weight of the material is important. In fact, as discussed under the Vermont embankment installation, haul cost can increase the cost of the scrap tires tremendously [Winters, 1991]. Also included in the Oregon report is a Lightweight Rubber Fill Specification (Appendix C) which was borrowed from the Minnesota Department of Natural Resources (MNDNR). The Oregon report also includes the Oregon Department of Environmental Quality (ODEQ) Administrative Rules Relating to Reimbursement to Users of Waste Tires and Cleanup Funds for Tire Storage Sites. This document shows how incentives can be used to encourage scrap tire usage—and is of paramount interest so it has been included as Appendix B [Read, et al., 1991]. Incentives such as those used in Oregon are vital to encourage the use of waste tires in any application.

**Economics** — Cost of the tires delivered to the site in Oregon was $30/ton ($0.30/tire), and reduced by $20/ton ($0.20/tire) reimbursement from the ODEQ, resulted in a net cost of $10/ton ($0.10/tire). Cost of placing and compacting the tires was $8.33/ton ($0.08/tire) bringing the total cost of the tire fill at final in-place density to $18.33/ton ($0.18/tire).

**Vermont**

This Vermont project was done in the town of Mid-desex by the Vermont Agency of Transportation (VAT) using state forces [Winters, 1991]. The objective of the project was to eliminate the need for guardrails by flattening the side slope from 1/1.5 to 1/3. In September 1990, 2738 cu yds (110,000 tires) of tire shred were placed as side slope fill at a height of 18 feet. The unit weight found in this study (47 to 56 pcf) is in the same range reported in the Oregon study. The specific gravity of the tire particles was 1.2 and the compacted void ratio was 0.45; all of these values should be of interest to designers of drainage layers and embankments using shredded tires.
Economics — The cost of the project and the influence of haul cost is interesting. The cost of the tire chips alone was $6,763 ($0.06/tire) including haul cost. However, the supply of chips had to come from two different sources due to the Vermont supplier being unable to maintain a continuous supply. (This problem will be discussed further under Barriers to Implementation). The cost of the chips from the Vermont supplier (Palmer Shredding, North Ferrisburg, Vt.) was $0.40/cu yd ($0.01/tire). The haul cost for this supply was $4.51/cu yd ($0.11/tire) for a total of $4.91/cu yd ($0.12/tire). As the report states, the Vermont supplier reduced the cost of the tire chips to generate a market. (In a telephone conversation with Mr. Palmer, a price of $5/cu yd ($0.13/tire) was mentioned as being typical for the shred [N. Palmer, personal communication, Aug. 26, 1992]). The alternate supplier was from New Hampshire and the cost of chips including hauling was $1.50/cu yd ($0.04/tire). If earth borrow had been used, the cost was estimated to have been $6.23/cu yd. Thus, depending on the cost of the chips and the hauling expense, the cost of tire chips could have been significantly lower or higher than the earth borrow cost. It is clear, however, that if an incentive can be provided to offset the cost of the tire shred, a short haul distance can result in a substantial economical advantage of tire shred over borrow and a much greater haul distance can be tolerated for the cost of tire shred not to exceed that of borrow.

Minnesota

Minnesota has been very active in the use of scrap tires in lightweight fills as well as research on the environmental effects of this usage. The Minnesota Pollution Control Agency (MPCA) has documented 23 sites (through February 1992) throughout the state which have used over 80,000 cu yds (approximately 3.2 million tires) of shredded tires [MNDOT, 1992].

Approximately 1,000,000 scrap tires were economically used as lightweight embankment fill for a ramp off Interstate I-35 in Minnesota.

One of the first applications involved experimental test sections near Floodwood, Minn. in 1986. Nine experimental sections were placed to upgrade the roadway across a peat swamp. Some sections used tire mats and others used shredded tires. The scrap tires were placed on top of the peat and over the existing old road bed. Borrow was placed over the top of the tire mats and a gravel wearing surface completed the structural section. Mats conforming to different configurations and tire shred made up the different test sections. Test observations made after two years of service indicated that the settlement of 12 to 16 inches was significantly lower than that expected on conventional road sections over these soil types [Geisler, et al., 1989].

Another site was in a fill on a section of County State Aid Highway 21 north of Rice, Minn. [Public Works, 1990]. A 250 ft embankment failure over a swamp was corrected as follows:

- The entire embankment was excavated down to a level about six inches above the level of the marsh.
- A geofabric was installed and sewn on the floor of the excavation.
- The shredded tires (approximately 52,000 tires) were placed directly on the fabric in two feet lifts to a height within 3 1/2 feet of the top of subgrade elevation. The largest pieces allowed were eight inches square (or round) or twelve inches long.
- After the tires were compacted, an additional layer of fabric was installed on top of the tires.

The early reported performance was that the correction method was successful.

Based on the field projects in Minnesota, it has been suggested that the following roadway sections be utilized [Public Works, 1990]:
1. for geogrid-type applications, use half tires with cups down.
2. for applications utilizing shredded tires, use separation fabrics.
The shredded tires, placed to a maximum depth of 15 feet, were enclosed in a geotextile fabric to prevent migration of the fines. The tires were to be capped when the I-35 ramp is constructed in the spring of 1993.

The tire shreds used in the I-35 embankment passed an eight-inch screen. A standard pocket knife provides reference to show the size of the fill material.

The use of shredded tires as a lightweight fill appears promising for crossing swamps and other soft soils; however, the use of geogrid-type applications is labor intensive.

The most recent work in Minnesota has been done by the Minnesota Department of Transportation in constructing a ramp to Interstate I-35 in September 1992, using 30,000 cu yds of shredded tires. The project utilized approximately 1,000,000 tires based on Minnesota's calculation of 33 tires/cu yd. [B. Nelson, personal communication, Jan. 15, 1993].

The project involved the repair of an embankment failure underneath the northwest ramp. A plastic silty loam, trapped under 25 feet of embankment fill, was the likely cause for the deep seated rotational type failure. A lightweight fill design, consisting of shredded tires, was recommended to keep the embankment loading in the failed area at or below the existing load. The only other alternative included the removal of the unstable soil in the failure area which would have required an additional 33 feet of excavation. Hence, the lightweight fill design was selected because it was the safest, quickest, and most cost-effective solution available.

The existing embankment was excavated to within one foot of the ground water surface. The MPCA does not currently allow tires any closer to the ground water. Type 5 Geotextile Fabric was then placed and sewn together. The chips, 90 percent by weight must pass an eight inch screen, were placed in one foot lifts. The shredded tires were required to weigh less than 600 pounds per cubic yard, loose volume. Compaction was completed by a dozer moving in a zig-zag pattern. The entire mass was encapsulated with the Type 5 Geotextile Fabric when completed to prevent migration of fines. The maximum depth of the 30,000 cu yd of chips placed was approximately 15 feet. Settlement plates were placed for future analysis. The shredded tires will be capped and the roadway constructed in the spring of 1993 [R. Olsen, memorandum, Jan. 1, 1993].

Washington

Washington State Department of Transportation (WSDOT) has developed plans for correcting a lightweight wood fiber fill with shredded tires in 1993 [R. Finkle, personal communication, Sept. 15, 1992]. Decomposition of the wood fibers on the face of the embankment has resulted in roadway shoulder subsidence. The shredded tires have been delivered to the construction site at no cost to the WSDOT by an agreement with the Washington State Department of Ecology. The expected cost of placement and compaction for the 7,000 cu yd (280,000 tires) project is $4 to $5 per cu yd ($0.10 to $0.13/tire) and is anticipated to save
$64,000 over the comparable cost of using wood fiber. The specifications to be used, like those used in Oregon, are a modification of those developed by the Minnesota Department of Natural Resources.

Leachate

The Minnesota leachate report is a study from waste tires exposed to different environmental conditions. The study was conducted by the Twin City Testing Corporation for the Minnesota Pollution Control Agency [MPCA, 1990]. The report contains several technical conclusions concerning leachate levels. But of particular importance to the engineering application of waste tires in drainage layers and embankments are these two conclusions:

1. Field studies did not identify significant differences between waste tire areas and control areas for either the soil samples or for the biological survey, and
2. Potential environmental impacts from the use of waste tires can be minimized by placement of tire materials only in the unsaturated zone of the roadway subgrade.

This last conclusion has been followed closely in both the Vermont and Oregon installations.

Another leachate study done by the Radian Corporation for the Rubber Manufacturers Association (RMA) found that none of the (waste rubber) products tested, cured or uncured, exceeded proposed Toxicity Characterization Leaching Procedure (TCLP) regulatory levels [Radian Corp., 1989]. Quoting from the report, "The results inherent in ground and unground samples were comparable. Uncertainties in the TCLP procedure had a greater impact on the variability of the results than differences in ground and unground methods." In a follow-up discussion to the Radian Report, Dr. Joseph L. Zelibor writes, "Although the results of this (Radian Corp.) study should not be extrapolated to the environment, this study provides strong evidence that leachate from scrap tire shred/chips will not pose a threat to groundwater or surface water" [Zelibor, 1991]. This is an indication of the conservative nature of the Vermont and Oregon installations, which have purposefully been constructed to remain above the water table.

Drainage Layers

The use of shredded scrap tires for subbase drainage layers in highways is attractive from several standpoints. Of primary importance is the substantial quantity of scrap tires which can be disposed of in a mile of highway. It is also attractive technologically because, even without strict gradation limits, the tire chips have sufficient voids to be permeable, allowing free drainage. A 1984 report from California concludes:

"Used tires that are coarsely shredded or chopped can be used as an alternative permeable material. Two-inch shredded or chopped tire material has permeability values comparable to the permeability values of 1 1/2" x 3/4" coarse aggregate. Subdrainage material must also be durable and remain relatively free of fines over an extended period of time. The relatively inert nature of the elastomer in used tires precludes disintegration and, therefore, will guarantee the integrity of the permeable material throughout the design life. Wrapping drainage material in filter fabric provides the required filtering [Bressette, 1964]."

Furthermore, the low unit weight of the material allows the chips to be placed over marshy land where heavier materials tend to sink [Frascoia, 1991].

Vermont

The VAT reported on an application of shredded tires "to serve as both a drainage layer and barrier to prevent contamination between a wet silty sand subgrade and a gravel base" by the town of Georgia, Vt. The report states that a high water table commonly results in the area becoming impassable for other than four-wheel drive traffic during the spring thaw season. The traffic, although only in the range of several hundred cars per day, pumps the fine (24-43 percent passing the #200 sieve) subgrade into the gravel base contaminating the latter and resulting in the loss of strength.

The test section placed in 1990 was about 300 feet long, 20 feet wide, and when compacted was about six inches thick. Single shredded tires with some chips as large as six inches were used in a volume of about 50 cu yds. The double shredded tires, most of which are less than two inches in size, were used in a volume of 150 cu yds. On this small area of 6,000 sq ft (200 cu yds), about 8,000 shredded tires were consumed. The cost of the tire chips for the 1990 project was $1 per cu yd ($0.025/tire) or $200 for the 6,000 sq ft. (This cost is somewhat understated as it was used as an incentive to develop a market). This application of scrap tires has been so successful and economical that the town of Georgia has placed sections in 1991 and 1992 as a maintenance material in the same area [R. Frascoia, personal communication, Aug. 27, 1992].

Investigation of the 1990 project has revealed that the ground water table remains six to 12 inches below the bottom of the rubber drainage layer (and thus, leachate from the rubber is not a concern) and that the chips placed about nine inches thick have compacted to about six inches under the weight of the overlying gravel.

The town of Georgia has been concerned as to whether the tire chips create too much deflection to support an asphalt surface. To answer this question the town placed a chip seal surface treatment over the area containing the scrap tire drainage layer in September 1992. The application was successful, and the real test will come in the spring when thawing occurs. Logically, the deflections can be reduced to an acceptable level if sufficient...
Use of Discarded Tires in Highway Maintenance

**BENEFITS:**

- **SALVAGED MATERIALS**
  May be obtained from maintenance operations.
- **DISCARDED TIRES**
  Can be obtained from various sources.
- **EQUIPMENT**
  No special equipment necessary.
- **PERSONNEL**
  Work performed by maintenance personnel.
- **COST**
  More economical than many alternative materials.

**SHOULDER REINFORCEMENT**

Before - ![Image](image1)

After - ![Image](image2)

**CHANNEL SLOPE PROTECTION**

Before - ![Image](image3)

After - ![Image](image4)

(Courtesy of California Department of Transportation)

Gravel is used between the rubber drainage layer and the surface treatment.

While researching the project discussed above, a telephone conversation with Nathan Palmer, who supplied the tires on this project, revealed that his company located in Vermont typically disposes of 400,000 tires annually as backfill for houses as well as for road projects. These uses consume essentially all the scrap tires generated annually in Vermont (N. Palmer, personal communication, Aug. 26, 1992).

**Slope Stability/Retaining Walls**

Most of the work in this area has been done by the California Department of Transportation (Caltrans) [Caltrans, 1990; Nguyen and Williams, 1989], although one project recently completed in North Carolina used waste tires in a retaining wall (J. Parker, personal communication, Sept. 3, 1992; NCDOT, 1991).

**California**

Caltrans developed installation specifications for shoulder stabilization which served as a retaining wall using whole tires. The installation used engineering fabric behind, under and over the tires to prevent soil erosion. The tires were placed in parallel rows and backfilled with permeable material. The tires were connected using clips fabricated from 1/2 inch steel reinforcing bars. A six inch layer of permeable material was placed on the first layer of tires and the second layer of tires was placed and backfilled. To provide an unpaved shoulder, an 18 inch layer of native soil was placed on top of the last layer of engineering fabric and compacted. Woody plants...
were recommended to be placed on the slope below the tire installation to accelerate the reestablishment of vegetation.

**Economics**

Typical cost in 1988 for scrap tires as shoulder stabilization was about $80 per linear foot for a five-foot high wall. A gabion wall costs about twice as much as the scrap tire wall and a concrete crib wall was about three times the cost of the same scrap tire wall [Nyugen and Williams, 1989].

Caltrans has used this same type of installation for channel slope protection [Nyugen and Williams, 1989]. Some of the more pertinent requirements of this installation are:

1. Scrap tires shall be in such condition as they will retain original manufactured shape when stacked.
2. Sidewalls of tires should be spread during backfilling operations to facilitate adequate compaction of the backfill.
3. Tires shall be used on lower slopes and in locations not visible to the motorist.
4. Painting the tires to blend with the surrounding terrain will improve the aesthetics of the installation.

**Whole scrap truck tires were used as a retaining wall in a North Carolina road project that used several recycled materials.**

(Photos courtesy of Charles S. Hughes.)

Approximately 25 percent of the embankment fill behind the scrap-tire retaining wall consists of scrap tire shreds.

Typical costs for channel slope protection are $50 to $80 per linear foot for a five-foot high wall. This compares to about $125 per foot for rock slope protection, $150 per foot for broken concrete slope protection, and $165 per foot for a gabion wall, all five feet high.

**North Carolina**

The 2.2 mile long project in North Carolina, constructed in 1992, is different from other projects in that it used several recycled materials, such as recycled plastic delineator and fence posts, in addition to the scrap tires [J. Parker, personal communication. Sept. 3, 1992]. Shredded scrap tire rubber was used in the asphalt cement binder in the base, intermediate, and surface courses. Scrap tires shredded into one- to three-inch strips were layered in the embankment, covered with soil, and mixed to provide a lightweight fill. The specifications called for the shredded tires to constitute between ten to 40 percent of the volume of the embankment with a goal of an average of 25 percent. Scrap tires were also used as a 2,000 sq ft retaining wall. The specifications for this item required 42 inch scrap truck tires, and was expected to use approximately 1,500 tires. Steel clips, 1/2 inch in diameter, were used to tie the tires together [NCDOT, 1991]. The cost data for this project were not available.
Barriers to Implementation

There are several barriers to increased use of scrap tires in all of the applications discussed in this synthesis [Keamey, 1991].

1. Source of supply.
For any use of scrap tires, the location of the nearest source(s) is extremely important in determining haul costs which play a large role in establishing the economic viability of using scrap tires. Reliable supply source of processed tires becomes a larger problem as the needs for the rubber become more restrictive; e.g., from chopped to dewired to ground.

2. Consistency of supply.
In any use of scrap tires, the process is established to use a certain percentage of rubber. Any disruption to this amount of rubber also disrupts the process, requires alternative materials, presents operational problems, and does not help solve the scrap tire problem.

3. High capital or initial costs.
While often these cannot be overcome, incentives can be provided to help overcome their effects.

4. Conservative nature of user industries.
Economics aside, it is human nature to abhor change; this is exacerbated when change costs money.

5. Nonstandardization of air permit modifications.
This is particularly troublesome to industries working in more than one state, but also is a problem in that some states have much more restrictive permit modification requirements than others.

Often when the subject of tire burning is raised, a public outcry is heard. The public must be educated to the high level of emission controls that reduce the emissions to or below levels of alternative fuels, and to the advantages associated with burning tires as TDF and dedicated tires-to-energy.

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico
Conclusions and Recommendations

Conclusions

1. The profit-per-tire equation indicates that both TDF and dedicated tires-to-energy uses of scrap tires can be cost effective.

2. The generation of electricity at dedicated tires-to-energy facilities appears to be very promising.

3. The use of economic incentives can change a negative or marginal economic analysis to a positive one.

4. Some areas of the country—e.g., Vermont, Connecticut, Minnesota, and Wisconsin—have reportedly developed uses of scrap tires that consume the majority of the scrap tires generated.

5. Both dedicated tires-to-energy and TDF have the potential for consuming large quantities of scrap tires.

6. For uses within civil engineering, both lightweight fills and drainage layers have the potential for consuming large quantities of scrap tires in a technically feasible and cost-effective manner.

7. On a cost-per-tire basis, both TDF and dedicated tires-to-energy uses have a positive value of $0.15 to $1.25/tire; lightweight fills and drainage layers cost about $0.20/tire (which is often less than alternative materials); whereas for CRM, a negative value of $5 to $10/tire exists.

Recommendations

1. Economic analysis must be a major factor that is used to determine the best solution(s) to the waste tire problem. The profit-per-tire equation can be a useful analysis tool.

2. The development and use of various incentives to promote scrap tire usage is needed.

3. Standardization of air permitting regulations is needed to minimize bureaucracy and help industries obtain the necessary permits.

4. Public education addressing the advantages of TDF and dedicated tires-to-energy must be increased.
General Bibliography


Velar-Prieto, Jorge F. *Los neumáticos descartados y sus usos como aditivoificador del cemento asfáltico.* Term project report, Civil Engineering 6995, UPR Mayagüez, November 16, 1992.

References


9 Heitzman, Michael A. State of the Practice.


15 Heitzman, *State of the Practice*.


23 Heitzman, Michael A. *State of the Practice*.


26 Heitzman, Michael A. *State of the Practice*.


29 Heitzman, Michael A. *State of the Practice*.

30 FHWA-RD-93-147, EPA/600/R-93/095, June 1993.


32 Heitzman, Michael A. *State of the Practice*. 

---

*Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico*

Heitzman, Michael A. State of the Practice.

Heitzman, Michael A. State of the Practice.

Heitzman, Michael A. State of the Practice.

Heitzman, Michael A. State of the Practice.

Heitzman, Michael A. State of the Practice.

Fidalgo, José, laboratory technician, Betteroads Asphalt, Inc.; personal communication to Eng. Jorge Velar, research assistant.


Heitzman, Michael A. State of the Practice.


Takallou, H. Barry, and Alain Sainton.

Musselman, James A., Bituminous Materials Engineer; personal communication to Eng. Jorge Velar, research assistant.

Heitzman, Michael A. State of the Practice.


France, Al.
Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico

52 France, Al.

53 Charania, Equbalali, et al.


---

Feasibility of Using Crumb Rubber Modifier in Hot-Mix Asphalt Pavement Applications in Puerto Rico  Page 172


70 Heitzman, Michael A. State of the Practice.

71 Amirkhanian, Serji N.


73 Chávez, Ottmar. Testimony before the Committee on Planning and Socioeconomic Development of the Puerto Rico House of Representatives, July 29, 1993.

74 Stroup-Gardiner, Mary.

75 Stroup-Gardiner, Mary.


77 ASTM D 2172-88, Standard Test for Quantitative Extraction of Bituminous Paving Mixtures.

78 Fidalgo. Personal communication to Eng. Jorge Velar, research assistant.


80 FHWA-RD-93-147, EPA/600/R-93/095, June 1993.

81 FHWA-RD-93-147, EPA/600/R-93/095, June 1993.

82 FHWA-RD-93-147, EPA/600/R-93/095, June 1993.


89 Wolfgang, Henry. Vice President of ATSI-PR. Personal communication to Eng. Jorge Velar, research assistant.

90 Quiñones, Andy. Engineer, PRHTA. Personal communication to Dr. Benjamín Colucci, principal investigator.


92 Sikora, Mary.


97 Hughes, Charles S.


100 Hughes, Charles S.

101 Hughes, Charles S.


107 Baker, Timothy. President of Baker Rubber, Inc. Personal communication to Dr. B. Colucci.