Greening Roadway Infrastructure Initiative

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Executive Summary

This document presents the compilation of research and findings associated with the use of recycled materials in the Greening Roadway Infrastructure Initiative associated with the Guam Environmental Protection Agency (Guam EPA) Zero Waste Plan. As part of the Zero Waste Plan, the greening of Guam’s roadway infrastructure is an initiative that encourages the use of recycled materials in roadway construction. The use of these recycled materials will not only reduce waste in landfills and those being shipped off-island, but will also conserve Guam’s natural resources that are currently being used for construction.

The use of different types of waste materials generated from construction and industry has been tested and evaluated throughout the United States (U.S.) for decades. Recycled materials have been used with varying degrees in fill and backfill, base and subbase, and paving mixes. This document summarizes advantages and disadvantages of these materials and various initiatives being undertaken by American states.

Stakeholders from federal and local government and industry leaders provided information on current practices, ideas, and changes that may need to be made to implement the Greening Roadway Infrastructure Initiative. Stakeholder input identified the following target list of recycled materials that can be used in roadway construction on Guam: recycled asphalt pavement (RAP), recycled concrete aggregate (RCA), recycled glass, waste tires, and compost. Plastics are another potentially suitable material for roadway construction use, although they are not specifically targeted at this time. Development of plastics use in roadways will continue to be monitored.

An economic evaluation was conducted with the five target materials. Unit prices provided by material suppliers on Guam were compared with unit prices for virgin or conventional materials.

Conclusions from this research and economic evaluation for the five target recycled materials are as follows:

- **RAP:** RAP is already being milled and recycled for use in roadway construction and resurfacing on Guam. However, the exact volume of RAP being diverted for reuse versus being disposed of in Guam’s hardfills is not being measured or monitored at this time. Guam’s current roadway construction specifications allow up to 15 percent RAP in asphalt base course mix. RAP that is not directly reused in pavement construction is made available for resurfacing of dirt roads in villages. The unit cost for RAP is less than the cost for virgin aggregate on Guam; therefore, it is appropriate that all available RAP be reused for roadway construction. To ensure that the diversion of RAP is maximized for reuse in the greening of roadway infrastructure, it is recommended that Guam ban the disposal of RAP in hardfills.

- **RCA:** RCA can be processed to equivalent road construction specifications as virgin aggregate. The unit cost of RCA is less than virgin aggregate on Guam, even with the required processing. There is enough concrete to source the RCA on Guam. However, before mandating the use of RCA, additional research, studies, or both should be conducted to evaluate concerns about elevated alkalinity in surface water runoff through RCA. If such research and studies confirm that RCA is safe for the environment, then use of RCA should be mandated to replace virgin aggregate for Guam’s roadway construction projects.

- **Glass:** The volume of glass that could be reused on Guam is not known at this time, as the only glass currently being recycled is that which residents voluntarily bring to one of five recycling collection points located throughout the island. All of the currently available recycled glass on the island could be immediately used in roadway embankment construction or utility bedding or construction. For use in further roadway applications, the probable volume of glass available for recycling if glass were to be diverted from disposal should be calculated and developed. Additional processing and testing of recycled glass purity will likely be required to meet Federal Highway Administration requirements. If Guam decides to pursue the use of glass in roadways, ongoing supply and future construction needs (that is, trench backfill, subbase, base aggregate, and utility bedding needs) should be assessed. To ensure that the diversion of glass is maximized for recycling and reuse, consideration must be given to enacting a ban on landfill or hardfill disposal of glass, setting up a collection system, and specifying recycled glass as a given preference in roadway and utility construction.
- **Tires**: Currently, the best use for recycled tires on Guam is to use shredded tires within roadway embankments. Shredded tires can be immediately used in roadway construction in embankments, if appropriate performance specifications are met. Waste tires can also be crumbled for use in roadway construction; however, this is not currently economical given the significant investment required for specialized equipment and the limited supply of tires. The available amount of waste tires on Guam is not currently known. If Guam decides to use waste tires in roadways, ongoing supply of suitably processed tires and future construction needs should be assessed. Costs for additional equipment could be offset by obtaining grants.

- **Compost**: Over the last decade, several private companies on Guam have developed operations to recycle green waste into mulch and compost that can be used in roadway erosion control applications. To sustain these local operations, on-island markets for Guam’s mulch and compost must be created to provide demand. Therefore, Guam should mandate, via roadway project specifications, that locally produced mulch, compost, or both be used for erosion control and site restoration in roadway infrastructure construction projects. Prior to such mandate, capacity of these operations should be confirmed to ensure they can meet the demand. Outreach should be conducted to address supplier processes and public and agency perception issues related to the rhino beetle infestation. Composting of green waste, food waste, and biosolids should be considered during maturation of composting programs, as should the feasibility of on-island manufacturing of compost filter socks for erosion control.

Roadway construction represents an immediate opportunity to recycle materials that would otherwise be disposed in Guam’s landfill or hardfills. A limited volume of RAP and mulch/compost is already being used in roadway infrastructure projects on Guam. The use of these two recycled materials to green roadway infrastructure can be increased and maximized by taking the steps recommended in this report to decrease disposal, increase diversion, and create local on-island markets for RAP and mulch/compost by stating a preference for the use of these materials in applicable design manuals/documents and construction specifications. Additional study, testing, or consensus is required before RCA, glass, and tires can be added to the list of recycled materials available to green roadway infrastructure on Guam. The research conducted in this report documents that RCA, glass, and tires are already being reused or recycled for roadway infrastructure construction applications in other states. The next step for Guam is to form a Greening Roadway Infrastructure Initiative Working Group to gain consensus and make this happen.
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<th>Description</th>
</tr>
</thead>
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<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>AC</td>
<td>asphalt concrete</td>
</tr>
<tr>
<td>ASTSWMO</td>
<td>Association of State and Territorial Solid Waste Management Officials</td>
</tr>
<tr>
<td>BMP</td>
<td>best management practice</td>
</tr>
<tr>
<td>C&amp;D</td>
<td>construction and demolition</td>
</tr>
<tr>
<td>CalRecycle</td>
<td>California Department of Resources Recycling and Recovery</td>
</tr>
<tr>
<td>Caltrans</td>
<td>California Department of Transportation</td>
</tr>
<tr>
<td>CKD</td>
<td>cement kiln dust</td>
</tr>
<tr>
<td>CR</td>
<td>crumb rubber</td>
</tr>
<tr>
<td>CWC</td>
<td>Clean Washington Center</td>
</tr>
<tr>
<td>DoD</td>
<td>U.S. Department of Defense</td>
</tr>
<tr>
<td>DOT</td>
<td>department of transportation</td>
</tr>
<tr>
<td>DPW</td>
<td>Department of Public Works</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>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>GovGuam</td>
<td>Government of Guam</td>
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<tr>
<td>GSWA</td>
<td>Guam Solid Waste Authority</td>
</tr>
<tr>
<td>GWA</td>
<td>Guam Water Authority</td>
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<tr>
<td>HDOT</td>
<td>Hawaii Department of Transportation</td>
</tr>
<tr>
<td>HMA</td>
<td>hot mix asphalt</td>
</tr>
<tr>
<td>HPM</td>
<td>hot plant mix</td>
</tr>
<tr>
<td>INDOT</td>
<td>Indiana Department of Transportation</td>
</tr>
<tr>
<td>K</td>
<td>thousand [dollars]</td>
</tr>
<tr>
<td>LKD</td>
<td>lime kiln dust</td>
</tr>
<tr>
<td>MDOT</td>
<td>Michigan Department of Transportation</td>
</tr>
<tr>
<td>MnDOT</td>
<td>Minnesota Department of Transportation</td>
</tr>
<tr>
<td>MDT</td>
<td>Montana Department of Transportation</td>
</tr>
<tr>
<td>MRF</td>
<td>material recycling facility</td>
</tr>
<tr>
<td>NAPA</td>
<td>National Asphalt Pavement Association</td>
</tr>
<tr>
<td>NAVFAC</td>
<td>Naval Facilities Engineering Command</td>
</tr>
<tr>
<td>NJDOT</td>
<td>New Jersey Department of Transportation</td>
</tr>
<tr>
<td>ODOT</td>
<td>Oregon Department of Transportation</td>
</tr>
<tr>
<td>PCC</td>
<td>Portland cement concrete</td>
</tr>
<tr>
<td>QC</td>
<td>quality control</td>
</tr>
<tr>
<td>RAC</td>
<td>rubberized asphalt concrete</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>RAP</td>
<td>reclaimed asphalt pavement</td>
</tr>
<tr>
<td>RAS</td>
<td>recycled asphalt shingles</td>
</tr>
<tr>
<td>RCA</td>
<td>recycled concrete aggregate</td>
</tr>
<tr>
<td>RHPM</td>
<td>recycled hot plant mix</td>
</tr>
<tr>
<td>SWA</td>
<td>Solid Waste Authority</td>
</tr>
<tr>
<td>TRB</td>
<td>Transportation Research Board</td>
</tr>
<tr>
<td>TxDOT</td>
<td>Texas Department of Transportation</td>
</tr>
<tr>
<td>U.S.</td>
<td>United States</td>
</tr>
<tr>
<td>USEPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>w/c</td>
<td>water to cement</td>
</tr>
<tr>
<td>WSDOT</td>
<td>Washington Department of Transportation</td>
</tr>
<tr>
<td>WisDOT</td>
<td>Wisconsin Department of Transportation</td>
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<tr>
<td>VDOT</td>
<td>Virginia Department of Transportation</td>
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1. Introduction

In June 2013, the Government of Guam (GovGuam) commissioned the Matrix Design Group to publish the Guam Zero Waste Plan—Reaching for Zero: A Blueprint for Zero Waste in Guam (Guam Zero Waste Plan), a 20-year blueprint for the government and people of Guam to realize a vision of Zero Waste and preserve the environment. The Guam Zero Waste Plan includes a detailed analysis and evaluation of 15 Zero Waste Initiatives comprising upstream, midstream, and downstream source diversion and global program options.

The intent of one of those initiatives, originally referred to in the Guam Zero Waste Plan as the Greening Roadway Pavement Systems Initiative and referred to here as the Greening Roadway Infrastructure Initiative, is to develop the policies and procedures necessary to advance Guam’s Zero Waste Goals by encouraging the use of recycled materials in lieu of conventional, nonrenewable resources (that is, virgin materials) in the construction and maintenance of roadway infrastructure. This report serves to advance the initiative by evaluating current industry practices and how those practices may be adapted and implemented on Guam.

1.1 Guam’s Zero Waste Plan

The Guam Zero Waste Plan sets the stage for reaching Zero Waste on Guam (Matrix Design Group, 2013). Zero Waste is an approach to address the problem of unsustainable resource flows with the goal of reducing waste generated and materials discarded by managing resources before they become waste. It involves elimination of waste at the source through product design and producer responsibility and reduction strategies down the supply chain such as recycling, reuse and composting. Zero Waste is a principle that uses a wholistic approach that goes beyond recycling to provide sustainable alternatives to waste disposal (Matrix Design Group, 2013).

This approach to Zero Waste creates the design of a full-cycle system as shown in Figure 1-1, which looks at both upstream and downstream solutions and the interaction between them. This broadens the responsibility of different solutions involving industry, retail, consumers, producers, and policy makers to act interactively to achieve the goal of Zero Waste.

The Guam Zero Waste Plan includes a detailed analysis and evaluation of the fifteen upstream, midstream, and downstream source diversion and global program Zero Waste Initiatives shown in Table 1-1.

<table>
<thead>
<tr>
<th>Table 1-1. Guam Zero Waste Plan Initiatives</th>
</tr>
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<tbody>
<tr>
<td><strong>Upstream</strong></td>
</tr>
<tr>
<td>• Green/Environmentally Preferable Purchasing (EPP)</td>
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<tr>
<td>• Extended Producer Responsibility</td>
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<tr>
<td>• Pay-As-You-Throw (PAYT)</td>
</tr>
<tr>
<td>• Plastic Bag Disposal Ban</td>
</tr>
<tr>
<td><strong>Midstream</strong></td>
</tr>
<tr>
<td>• Used Building Material Facility</td>
</tr>
<tr>
<td>• 3R Requirements for Public Buildings</td>
</tr>
<tr>
<td>• Greening Roadway Pavement Systems (that is, Greening Roadway Infrastructure)</td>
</tr>
<tr>
<td><strong>Downstream</strong></td>
</tr>
<tr>
<td>• Illegal Dumping &amp; Litter Control Enforcement</td>
</tr>
<tr>
<td>• Composting/Organics Processing Facility</td>
</tr>
<tr>
<td>• Construction &amp; Demolition (C&amp;D) Debris Processing Facility</td>
</tr>
<tr>
<td>• C&amp;D Diversion Policy</td>
</tr>
<tr>
<td><strong>Global Program Options</strong></td>
</tr>
<tr>
<td>• Zero Waste Association of Guam</td>
</tr>
<tr>
<td>• Zero Waste Grant Program</td>
</tr>
<tr>
<td>• Education &amp; Outreach Program</td>
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<tr>
<td>• Evaluation of Funding Sources</td>
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</tbody>
</table>

Implementation of the Zero Waste Plan presented in the document is intended to occur over a 20-year period, in four distinct phases. Phase I involves implementation initiatives, including legislation and policy that will allow GovGuam and industry stakeholders to build a strong foundation for Zero Waste. The Phase II initiatives include partnerships between public and private entities to raise funds and allocation of staff in support of additional initiatives. Phase III will involve initiatives requiring additional legislation or extensive research. The final phase is a long-term strategy to include the expansion of existing policy and programs to broaden the scope of Zero Waste practices and move Guam toward its ultimate Zero Waste Goals.
1.2 Greening Roadway Infrastructure Initiative Overview

The purpose of the Greening Roadway Infrastructure Initiative is to research and develop the policies and procedures necessary to advance Guam's Zero Waste Goals by encouraging the use of recycled materials to replace conventional, nonrenewable resources in the construction and maintenance of roadway infrastructure. As of 2018, Guam's Roadway Network includes 155 miles of routed roads and 860 miles of village streets, with the length of village streets continuing to grow (Guam Department of Public Works [DPW], 2018). Implementation of this Zero Waste Initiative is intended to conserve landfill and hardfill space on Guam by reducing waste disposal, reducing potential additional air and water pollution sources, developing on-island markets for recycled materials, creating green jobs, and conserving nonrenewable natural resources.

The initiative is being advanced, at a minimum, by completion of the following activities:

- Convening stakeholders to kick off the initiative
- Researching and identifying recycled materials feasible for use in the construction of roadway infrastructure
- Quantifying the opportunities and constraints of using various recycled materials
• Screening, evaluating and recommending a short-list of recycled materials feasible for use on Guam
• Conducting an economic evaluation
• Developing supplemental roadway infrastructure requirements that encourage the use of recycled materials and meet technical design and construction standards for roadway infrastructure
• Changing policies and legislation to encourage the use of recycled materials

1.3 Organization of this Document

To better inform stakeholders in the Greening Roadway Infrastructure Initiative and explain the actions identified in Section 1.2, this document is divided into the following seven sections:

• Section 1 provides a background and history of the Guam Zero Waste Plan, presents Guam’s Greening Roadway Infrastructure Initiative, and explains how the document is organized.
• Section 2 introduces the concept of building sustainable roadway infrastructure, presents an overview of roadway infrastructure components, summarizes the life cycle of a roadway, and introduces the best management practice (BMP) of incorporating recycled materials into the construction of roadway infrastructure to produce a more sustainable roadway infrastructure.
• Section 3 presents an overview of recycled materials suitable for use in roadway infrastructure, followed by a summary of recycled material applications in roadway infrastructure and green roadway construction.
• Section 4 provides a summary of federal and prominent state agency initiatives to green roadway infrastructure.
• Section 5 presents a case study for the Guam Greening Roadway Infrastructure Initiative from the start-up of the initiative through a series of recent analyses that have been undertaken to determine how to best implement the initiative, as well as an overview of future activities to be undertaken.
• Section 6 provides resources and references used in the development of this document.

Appendixes presented after the main text provide the following supplemental information:

• Appendix A provides a more detailed description of documents and projects summarized in Section 4.
• Appendix B presents example specifications incorporating recycled materials.
2. Building Sustainable Roadway Infrastructure

The construction of roadway infrastructure worldwide consumes vast quantities of conventional, nonrenewable resources (that is, virgin materials). Greening roadway infrastructure is a sustainability BMP that integrates the functionality of transportation engineering requirements with ecological sustainability principles. This practice is gaining momentum around the globe and has the potential to shift resource flow dynamics in the transportation industry from the use of nonrenewable, virgin materials to recycled materials, resulting in the preservation and restoration of surrounding ecosystems while constructing roads that meet industry standards (FHWA, 2006). Section 2 of this document provides a brief discussion of green roadway infrastructure characteristics and an introduction to the various design and construction components present in roadway infrastructure, recycled materials that can be used in roadway infrastructure applications, and the benefits of building more sustainable roadway infrastructure.

2.1 Green Roadway Infrastructure

Green roadway infrastructure integrates transportation functionality and ecological sustainability by using an environmental approach throughout the planning, design, and construction of a road. The result is a roadway or highway that benefits transportation, the ecosystem, urban growth, public health, and the surrounding communities (FHWA, 2006). A green road can have many different design features, but typically includes at least one of the following characteristics:

1) Is built with permeable materials that provide superior watershed-driven stormwater management, preventing contaminants from leaching into streams and rivers and improving water quality.
2) Is designed using cutting-edge technologies to protect critical habitats and ecosystems from the encroachment of roadway infrastructure.
3) Incorporates sustainability measures during the design, construction, and long-term operations and maintenance activities, all of which are aimed at reducing the overall life-cycle material needs, energy needs, and emissions.
4) Is constructed (in part) with recycled materials, so that waste materials are beneficially reused rather than being disposed of in a landfill.

The remainder of this document is dedicated to discussing Characteristic #4: the beneficial reuse of waste materials and the opportunities to use recycled materials instead of nonrenewable, virgin materials in the construction of roadway infrastructure.

2.2 Roadway Infrastructure Components

Historically, the construction of roadway infrastructure has used conventional, nonrenewable resources (for example, virgin materials such as sand, gravel, or coral), typically mined from sources in close proximity to the infrastructure project, to construct the various roadway infrastructure components shown in Figure 2-1. In addition to those components, the figure shows potential recycled materials that can be combined with the virgin materials to construct the following roadway infrastructure components:

- Embankment or excavation – Creating or building the grade at which the roadway is to be constructed by removing or placing and compacting the existing ground, including ditches and slopes.
- Subgrade – The compaction and preparation of the existing ground to which the road itself will be constructed on.
- Subbase – The layer above the prepared subgrade, consisting of stabilized or unstabilized materials, typically native soils and aggregates. This layer may or may not be part of the roadway and is sometimes omitted.
- Base – The layer above the subbase or subgrade, consisting of stabilized or unstabilized materials, typically consisting of native aggregate, and sometimes stabilized with cement or asphalt.
• Surfacing – The top layers of roadway construction, consisting of various types of asphalt and Portland cement concrete (PCC).

• Roadside development/erosion control – The restoration and development of slopes outside the road itself, which includes both temporary and permanent erosion control and planting of vegetation.

Figure 2-1. Roadway Infrastructure Components

2.3 Life Cycle of a Road

The life cycle of a roadway begins with the collection of materials with which to construct it. These typically consist of raw materials such as soil, aggregate, cement, and refined petroleum (asphalt), but may also include materials recycled from either the demolition of an existing road at the end of its lifecycle or the partial removal of a roadway during its lifecycle.

Roadways are engineered and designed to a specific usable lifespan. That lifespan, or design life, is dependent on the roadway classification, surfacing type, traffic, and governing agency policies responsible for the maintenance of the roadway. The design life may vary, but it is typically 20 years for lower volume roads and up to 50 years for high volume interstate roadways.

As no pavement is maintenance-free, certain activities must be done to preserve the pavement during its lifespan. These would include, but not be limited to, crack sealing, surface sealing, and resurfacing. Before the end of its design life, a roadway will require replacement of a portion of the top surfacing that has degraded from weathering and traffic. While a new surface or seal can be placed directly over the existing pavement, more typically, the top surface is milled first before a new surface is placed. A portion of the entire pavement structure may require complete reconstruction because of localized failures. These millings or portions of removed pavement, performed during or at the end of the pavement life cycle, can then be recycled back into the production of the paving and reused at the start of a new pavement lifecycle. Figure 2-2 illustrates the life cycle of an asphalt road as presented by and with permission from the Hawaii Asphalt Paving Industry.
Figure 2-2. Lifecycle of an Asphalt Pavement (Hawaii Asphalt Paving Industry, n.d.)
2.4  **Sustainability Best Management Practice Benefits**

Greening roadway infrastructure through the beneficial reuse of recycled materials instead of conventional, nonrenewable resources in roadway construction can lead to considerable social and financial benefits. Engaging in this sustainability BMP provides both direct and indirect benefits, including the following:

- **Short-term (Capital) Cost Savings.** Recycled materials have the potential to provide a best value solution on many types of new construction projects. Some recycled materials, such as reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA), are excellent examples of recycled materials that can be beneficially used in roadways but that are unlikely to be reused in other construction applications. Recycled materials are often less expensive than the virgin materials they replace, and recycling or reusing materials onsite can reduce material hauling and disposal costs (USEPA, 2009). Their best use is in roadway construction, where they originated. Recycling these materials can reduce the cost of improvements and have an indirect savings on other costs, such as labor, and on nonmonetary savings such as reduced greenhouse gas (GHG) emissions.

- **Life-cycle Cost Savings.** Savings can also be realized throughout the life cycle of a roadway through the use of recycled materials in lieu of virgin, nonrenewable resources. If recycled material use is planned from the beginning, total project costs can be lower, allowing more work to be accomplished within the same budget. For example, by incorporating recycled materials for improvements and maintenance for the entire pavement life cycle compared to improvements and maintenance using virgin materials, the overall life-cycle costs can be less. These savings are realized throughout the pavement life cycle for a period ranging from 20 to 50 years versus the cost of new reconstruction.

- **Landfill Space Conservation.** The use of recycled materials as a roadway construction material helps conserve landfill space by reducing disposal of wastes into landfills and hardfills. Beneficial reuse of waste, which normally would go to landfills, results in direct cost savings on land acquisition fees, associated haul costs, and fuel and disposal fees. In addition, indirect and nonmonetary cost savings on other costs including the conservation of land, a reduction in GHG emissions, and a reduction in additional potential air and water pollution sources is realized. The conservation of landfill space also will help to extend existing landfill life-expectancies and preserve habitat that may otherwise be appropriated for landfill expansion.

- **Creation of New Markets for Recycled Materials.** As the demand for recycled materials increases, either through the establishment of a new market for an existing commodity or an increased demand in an existing commodity, jobs and small business opportunities can be generated. Glass, scrap tires, compost, construction waste, and industry waste could all see new market demands in collection, processing, and supplying of these materials for additional use in roadway infrastructure construction. A new demand for recycled materials can lead to further research and development into additional areas for recycled materials to be incorporated in roadway infrastructure.

- **GHG Emissions Reduction.** Using recycled materials in lieu of conventional, nonrenewable resources saves energy that would otherwise be required to produce virgin materials. Recycling and reducing waste are critical for climate protection by keeping waste out of incinerators and landfills, where it produces GHG emissions. Actual energy savings and GHG emissions reductions are material, volume, and quantity dependent. Credit for these savings should be calculated and taken at every opportunity when using recycled materials.

- **Natural Resources Conservation.** The use of recycled materials conserves nonrenewable natural resources. Materials sourced directly from nature in their virgin form, such as from the mining of aggregate, requires the use of much more energy and depletes more natural resources, as opposed to beneficially reusing using recycled materials.
3. Building Roadway Infrastructure with Recycled Materials

Section 3.1 presents an overview of recycled materials potentially suitable for use in roadway infrastructure. Section 3.2 follows that by summarizing recycled material applications in roadway infrastructure/green roadway construction.

3.1 Recycled Materials Suitable for Use in Roadway Infrastructure

Numerous waste materials and recycled materials have been tried and tested for various uses within roadway infrastructure components (for example, in embankments and subgrade, subbase, base, and surface layers) in the U.S. and throughout the world. The inert and non-decomposing waste materials and products from industry, construction, and consumer goods presented in the following sections have been used with varying degrees of success in roadway infrastructure components.

3.1.1 Construction Debris

3.1.1.1 Reclaimed Asphalt Pavement

RAP refers to removed or reprocessed pavement materials containing asphalt and aggregates that are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. Reclaiming the bituminous concrete may involve either cold milling a portion of the existing bituminous concrete pavement or full depth removal and crushing (Illinois Department of Transportation, 2002).

RAP is the most recycled material in the U.S. The latest survey of asphalt mix producers indicates that more than 99 percent of asphalt pavement reclaimed from roads and parking lots was reclaimed for use in new pavements instead of going into landfills. In the survey, 98 percent of producers reported using RAP in their mixes for new construction, pavement preservation, rehabilitation, and other projects (NAPA, 2019). Because RAP originates from asphalt pavement, it has the same characteristics as new aggregate and can be blended with virgin aggregate.

RAP contains aged asphalt cement that has oxidized over time and has lost some of the elasticity from the original binder. This results in a harder cement and more brittle pavement that increases the likelihood of cracking. To compensate for the aged asphalt cement in RAP, mix designs may require adjustments in new asphalt binder to account for the stiffness and still meet physical requirements for a new asphalt mix. Specifications for asphalt pavement allow for certain percentages of RAP in new asphalt mixes without adjustments. Testing continues to evaluate larger percentages of RAP in asphalt mixes and their effect on the performance of the asphalt pavement.

3.1.1.2 Recycled Concrete Aggregate

RCA, also known as recycled concrete material or reclaimed concrete aggregate, is reclaimed PCC from roadway or building demolition materials. Primary sources of RCA are demolition of existing concrete pavement, bridge structures, curb, and gutter, as well as central recyclers, who obtain raw feed from commercial and private facilities. This material is often crushed by mechanical means into manageable fragments and reinforcing steel is removed through magnetization. The concrete is then crushed down to the size of the largest aggregate in the concrete. Depending on its intended use, the aggregate can be washed or screened, segregated, and stockpiled for use separately or blending with other aggregates. Whether put back into the concrete paving mixture as aggregate or used in other applications, RCA is often selected over virgin material as an economical alternative to natural aggregate while offering comparable or better performance in many applications.

In 2016, the National Concrete Pavement Technology Center performed a study that surveyed state highway agencies and paving contractors on their practices of and experiences in using RCA. The study
found that the primary uses of RCA were as granular subbase (40 percent), crushed products for other markets (18 percent), and embankment (12 percent). Other uses included coarse concrete aggregate (9 percent), shoulder material, haul roads, and stabilized base. Per the study, some of the barriers of using RCA included lack of quantity, inconsistency of quality, water quality (pH and tufa/calcium carbonate precipitate), lack of technical guidance in concrete mix design, and uncertainty of economic benefits (National Concrete Pavement Technology Center, 2018).

3.1.2 Demolition Debris

3.1.2.1 Gypsum and Drywall

Drywall is a construction material derived from the mineral gypsum (or calcium sulfur dihydrate) used for interior walls and ceilings. Drywall and construction gypsum board can be crushed or ground and may be used as a soil additive to improve drainage and the structure of heavy clay soils, adjust pH, and act as a fertilizer. They can also be used as a fly ash additive to slow the setting of stabilized base courses for increased workability.

Gypsum and drywall have not historically been widely used; the Federal Highway Administration’s (FHWA’s) Autumn 1994 edition of Public Roads magazine, “The Use of Recycled Materials in Highway Construction” doesn’t list current or past uses for the materials (Schroeder, 1994). Experiments have taken place with mixing gypsum and drywall with native soil as fill material. Because it is inert and dry, it mixes well with fine-grained soils to help with the plasticity, acting similar to a lime stabilized soil to aid in the workability of wet soils.

3.1.2.2 Brick and Block

Ceramics such as brick and block can be broken and crushed into smaller pieces. These pieces can then be blended with native soils and used as fill material or subbase. These materials tend to be brittle in nature and do not have the same soundness and durability as native aggregate. They can also be more porous and have a much higher absorption rate than hard durable aggregate and are not used in surface mixes or base courses. Similar to gypsum and drywall, the FHWA does not list any current or past uses for brick and block.

3.1.3 Consumer Byproducts

3.1.3.1 Recycled Glass

Glass is formed by supercooling a molten mixture of sand (silicon dioxide), soda ash (sodium carbonate), limestone, or a mix thereof, to form a rigid physical state. Glass aggregate is a product of recycled mixed glass from manufacturing and post-consumer waste. When glass is properly crushed, this material exhibits a coefficient of permeability similar to coarse sand. Crushed glass or recycled glass is clean consumer glass that is crushed and polished into small particles. The high angularity of this material, compared to rounded sand, may enhance the stability of asphalt mixes. In general, glass is known for its heat retention properties, which can help decrease the depth of frost penetration (Illinois Department of Transportation, 2002). These particles can be substituted as aggregate and blended with aggregate in fill, backfill and paving applications. Other uses include reflective beads in pavement markings and roadway infrastructure landscaping. The amount of recycled glass allowed varies from state to state, depending on testing application and historical uses, but is usually small in paving applications. When used in an asphalt mix, an anti-stripping additive such as lime must be added to allow the asphalt binder to adhere to the glass particles.

3.1.3.2 Waste Tires

According to The Use of Recycled Tire Rubber to Modify Asphalt Binder and Mixtures, rubber from waste tires has been used as an asphalt binder modifier since the 1960s (FHWA, 2014a). Depending on their use, waste tires can be used whole, shredded, chipped, or ground. Although not aesthetically pleasing, whole tires are sometimes used as barriers or short retaining walls in isolated cases. Tires can also be
shredded into smaller sizes and used as fill with or without blending with native soils. Care must be taken when using in fill to make sure tires do not contain petroleum products or combustible materials and that enough soil is placed over any fill containing waste tires.

Tires can also be processed into crumb rubber through grinding then freezing and fracturing to achieve small cubes in the 4- to 5-millimeter size range. The crumb rubber can then be mixed with asphalt binder to provide elasticity to the paving mix. According to the Rubber Pavements Association, “between 500 and 2,000 scrap tires can be used per lane mile of pavement.” A further benefit of rubber-modified pavement is that it can be further recycled as RAP without issue.

3.1.3.3 Asphalt Shingles

Asphalt shingles are composed of asphalt cement, small aggregate, and fiber and are common construction waste. Approximately 11 million tons of shingles are disposed of each year in the United States (McGraw et al., 2007). Asphalt shingles may be blended with base course material or used with asphalt patching or as dust control. Because asphalt cement and aggregate are natural components of an asphalt pavement mix, one of the better uses for asphalt shingles is as an additive in new asphalt pavement.

To be incorporated into asphalt paving, asphalt shingles must be ground to fine aggregate size and stockpiled to control the gradation and the amount introduced into the asphalt mix.

Because asphalt shingles already contain binder, less binder is required for the mix design. Some of the asphalt binder in shingles is polymer-modified or rubberized, leading to improved elasticity and additional benefits as described in Section 3.1.3.4. These benefits are not as prominent with the addition of asphalt shingles, as the modifications can vary with shingle source.

3.1.3.4 Plastics

Recycled low density polyethylene from plastics has been pelletized and used as an asphalt cement modifier creating a polymer-modified asphalt. Adding a polymer to an asphalt pavement essentially enhances the properties that make asphalt cement desirable. Pavements created using polymer modified asphalt cements experience reduced rutting due to higher stability at high temperatures as well as reduced thermal cracking due to increased flexibility at low temperatures and reduced load-induced cracking because of the combination of the two.

Most state departments of transportation (DOTs) in areas of high temperature extremes (that is, the midwest, southcentral, and mountain regions) require the use of polymer-modified asphalts for their standard road mixes. The Federal Aviation Administration has also adopted the widespread use of polymer-modified asphalt because of the increased longevity of the pavement.

3.1.3.5 Carpet-fiber Waste

Both commercially available and waste fibers from carpet have been tried to increase concrete toughness, resistance to shrinkage, energy absorption, and asphalt strain resistance. Experimental results were mixed in finding that concrete strength was reduced and asphalt cement content increased, with no appreciable difference in strength.

Since the introduction of synthetic fibers of polyolefin and aramid fibers to the market, the use of carpet-fiber waste has decreased. Synthetic engineered fibers add strength and toughness to asphalt mixes, increasing tensile strength and durability, outperforming and adding more benefit than carpet-waste fibers.

3.1.4 Green Waste

Green waste is typically included incorporated into compost and mulch products. In roadway construction, compost and mulch can be used only for erosion control, site restoration, and revegetation.
3.1.4.1 Compost

Compost is defined as the product resulting from the controlled biological decomposition of organic material under aerobic conditions, which has been sanitized through the generation of heat and stabilized to the point that it is appropriate for its application. Compostable raw materials are produced at almost every home and business, and can consist of food waste, grass clippings, manure, leaves, straw, and wood chips (BARC, 2019; Compost Guide, 2019; Sherman, 2018). Through the process of composting, microorganisms break down organic matter into a nutrient-rich material that can be used to enrich soils and encourage plant growth. The heat generated during the composting process generally eliminates pathogens that may be associated with the raw materials. For large scale applications such as roadway infrastructure projects, where compost can be used to promote revegetation of the project staging or access paths, and right-of-way areas (including shoulders, embankments, along sidewalks, etc.) compost is generally obtained from large scale composting operations at landfills or independent businesses.

3.1.4.2 Mulch

Mulch can be any number of a variety of materials that are applied to the soil surface to suppress weeds, retain moisture, stabilize or enrich soil, or provide aesthetic value (Iannotti, 2019; McLeod, 2019). Mulch material can include a wide range of materials, including shredded tires, wood chips, paper products, lava rock, dried leaves, or even glass. Not all mulch materials provide the same benefits, so the objective must be considered before selecting an appropriate material. Roadway infrastructure projects generally use mulch to help stabilize soils and provide some weed control. Materials such as wood chips and other local plant material can be generated and re-used on site. Natural materials can provide some benefits to adding nutrients to soil as they break down, but man-made materials such as tires may leach undesirable chemicals to soil.

3.1.5 Coal Combustion Byproducts

Coal combustion byproducts are readily available in most of the contiguous U.S., and more than half of the energy created in the U.S. is through the burning of coal. The U.S. produces over 50 metric tons of fly ash per year and consumes just over 30 percent of that produced material for various uses.

Fly ash is a commonly used PCC additive, and is used as a component of flowable fill. As a PCC additive, it can improve workability, reduce permeability, improve sulfate resistance, reduce segregation, lower water to cement ratio, and yield higher strength. It is common to see fly ash as a requirement of a PCC mix design in state or federal standard specifications.

Boiler slag, desulfurized material, and bottom ash are other inert non-decomposing materials from coal combustion that have been used for other purposes, though not as frequently as fly ash. They are typically used as an additive in road base and structural fill (TxDOT, 1999).

3.1.6 Foundry Sand

Foundry sands are silica or lake sands that are bonded to form molds for metal castings. Foundry sand is used in the same manner as silica or lake sands however additional processing and testing are required.

After casting, these sands may contain iron or steel. Spent foundry sand may also contain leachable heavy metals. Foundry sand must be crushed, screened, and stockpiled to a uniform size. It has the same characteristics of natural sand for soundness, durability, and stability.

Because of the contaminants that can be seen in foundry sand, it is rarely used as asphalt aggregate. The potential for contamination also raises concern when leaching of heavy metals into water supplies is possible (FHWA, 2016b).
3.1.7 Steel and Iron Production

Steel and iron production produce electric arc and blast furnace slags, which are byproducts of the production processes. Steel slag contains fused mixtures of oxides and silicates and significant quantities of iron. Its highly compressed void structure results in a very dense, hard material.

Slag must be crushed, washed, and screened prior to use. Quality control (QC) testing is required, as undesirable material from steelworks processing can be incorporated into the slag if not separated. A major concern with slag is the potential inclusion of unreacted lime and dolime, which can contribute to volume instability (FHWA, 2016b).

Blast furnace slag used in cement can provide equal or improved performance over conventional Portland cement concrete. Slag cement has low heat hydration, good long-term strength gain, and high chemical resistance. Use of slag cement containing more than 80 percent granulated blast furnace slag can, however, increase the time needed to attain design strength (Schroeder, 1994).

Steel has been used as an aggregate in hot mix asphalt (HMA). Bituminous mixtures containing steel slag exhibited high stability, high skid resistance, and longer heat retention, resulting in easier compaction. Because slag has a high absorption rate, it will increase the cost of asphalt by requiring more binder.

3.1.8 Municipal Waste

Sewage sludge ash is a byproduct resulting from the burning of solid waste, producing fly ash and bottom ash. Because these recycled materials may contain elevated concentrations of copper, lead, and cadmium, the usage of sewage sludge ash has led to increased environmental concern and can be difficult to obtain environmental regulatory agency concurrence or approval to use. Because of these environmental concerns and technological advances in municipal waste treatment, municipal waste ash is rarely used.

3.1.9 Lime/Cement Production

Lime kiln dust (LKD) and cement kiln dust (CKD) is collected during lime and cement production and is a material similar to fly ash and Portland cement. LKD and CKD are best used as part of stabilized bases or, in the case of CKD, it may be used as the only cementitious material in the stabilized base.

LKD and CKD are best used when fresh. Stockpiled and aged, LKD and CKD lose their reactivity and must be conditioned with lime prior to use. It is best to keep fresh LKD and CKD in enclosed bins to keep out moisture. Kiln dusts are typically mixed and placed using standard construction equipment and procedures contributing to their ease of use.

CKD and LKD exhibit properties similar to stone dust and hydrated lime when used as a stabilizer and additive in asphalt concrete mixes. When added to stabilized base mixes, kiln dusts can create a higher strength mixture.
### 3.2 Recycled Materials Applications

Table 3-1 provides a summary of recycled materials applications in roadway infrastructure/green roadway construction, based on “The Use of Recycled Materials in Highway Construction” (Schroeder, 1994).

**Table 3-1. Summary of Potential Uses of Recycled Materials in Roadway Infrastructure Components and Construction Materials**

<table>
<thead>
<tr>
<th>Origin</th>
<th>Recycled Material</th>
<th>Potential Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Debris</td>
<td>RAP</td>
<td>Asphalt concrete pavement, base, subbase and fill</td>
</tr>
<tr>
<td></td>
<td>RCA</td>
<td>New PCC paving, minor concrete structures, base and subbase</td>
</tr>
<tr>
<td>Demolition Debris</td>
<td>Gypsum and Drywall</td>
<td>Fill material</td>
</tr>
<tr>
<td></td>
<td>Brick and Block</td>
<td>Subbase, fill</td>
</tr>
<tr>
<td>Consumer Byproducts</td>
<td>Recycled Glass (crushed and cullet)</td>
<td>Base, subbase, asphalt concrete, fill</td>
</tr>
<tr>
<td></td>
<td>Waste Tires (shredded and crumb)</td>
<td>Asphalt concrete mixes, fill, subbase and base (blended with native material), retaining walls and crash cushions</td>
</tr>
<tr>
<td></td>
<td>Asphalt Shingles</td>
<td>Asphalt concrete</td>
</tr>
<tr>
<td></td>
<td>Ceramic waste</td>
<td>Subbase, fill, PCC</td>
</tr>
<tr>
<td></td>
<td>Plastics</td>
<td>Asphalt concrete additive, PCC additive, poles, posts, barriers</td>
</tr>
<tr>
<td></td>
<td>Carpet Fibers</td>
<td>PCC additive</td>
</tr>
<tr>
<td>Coal Combustion Byproducts</td>
<td>Fly Ash, Boiler Slag, Desulfurization Material, Bottom Ash</td>
<td>PCC, flowable fill, soil stabilization</td>
</tr>
<tr>
<td>Foundry Sand</td>
<td>Spent Sand (from metal casting)</td>
<td>Embankments, manufactured soils, flowable fill, structural fill, road base and subbase</td>
</tr>
<tr>
<td>Steel and Iron Production</td>
<td>Electric Arc and Blast Furnace Slag</td>
<td>Base and subbase, PCC, bioretention and infiltration aggregate</td>
</tr>
<tr>
<td>Municipal Waste</td>
<td>Sewage Sludge Ash</td>
<td>Base and subbase aggregate additive</td>
</tr>
<tr>
<td>Lime/Cement Production</td>
<td>Kiln Dust</td>
<td>Asphalt concrete mineral filler, Asphalt concrete cement modifier, soil stabilization</td>
</tr>
</tbody>
</table>
4. Federal and State Agency Initiatives to Green Roadway Infrastructure

Greening roadway infrastructure has been gaining momentum since circa 2005, supported by policies, requirements, and initiatives at both a federal and state level.

4.1 Federal Initiatives to Green Roadway Infrastructure

In the U.S., two federal agencies are primarily responsible for the policies and requirements related to greening roadway infrastructure: the U.S. Environmental Protection Agency (USEPA) and the FHWA division of the U.S. Department of Transportation (USDOT), as discussed in Sections 4.1 and 4.2. The efforts of these two agencies and a collaboration effort known as the Green Highway Partnership initiated by these two agencies and industry in 2005 (see Section 4.1.1) have resulted in an increased use of recycled materials in roadway infrastructure projects in the U.S. in recent years.

4.1.1 Environmental Protection Agency

The primary mission of the USEPA is to protect human health and the environment. The USEPA’s responsibilities associated with carrying out this mission are vast and include, but are not limited to, working to ensure that environmental stewardship is incorporated into U.S. policies and other U.S. federal agency practices concerning natural resources, human health, economic growth, energy, transportation, agriculture, industry, and international trade.

For decades, the USEPA has worked and continues to work at a national level to develop policy related to the building of green infrastructure, including green roadway infrastructure, and to provide funds (that is, grants and low-cost financing in the form of revolving funds) to state, territory and local governments for green infrastructure projects (USEPA, 2018a). The USEPA also works at a national level to develop policy related to sustainable materials management (USEPA, 2019) and the beneficial reuse of recycled materials (USEPA, 2018b).

In 2005, the USEPA, FHWA, and American Association of State Highway and Transportation Officials (AASHTO) launched the Green Highways Partnership. The Green Highways Partnership’s goal was to combine safe and efficient transportation systems with environmental stewardship and sustainability. The partnership formed teams to focus on environmental stewardship, storm water management and recycling with the intent to identify best management practices, develop fact sheets, identify case studies highlighting “green” transportation projects with a sustainability focus, and hold workshops to disseminate information to states, territories and local governmental agencies responsible for roadway infrastructure design, construction, and maintenance (Osterhues, 2006).

4.1.2 Federal Highway Administration

The FHWA is tasked with supporting state and local governments in the design, construction, and maintenance of the U.S. highway system and roadways on various federally and tribally owned lands. The FHWA provides federally appropriated funds to state, territorial, and local governments for construction of roadway infrastructure. As a condition of funding, the governments must meet or exceed the FHWA’s design, construction, and maintenance standards (FHWA, 2012).

Recognizing the importance moving toward more sustainable practices in transportation projects, in 2002 the FHWA established a Recycled Materials Policy to encourage the use of recycled materials in roadway infrastructure projects funded with federal transportation money (FHWA, 2015). Key points of FHWA’s Recycled Materials Policy include the following:

- Recycling can offer engineering, economic, and environmental benefits.
- Recycled materials should get first consideration in overall materials selection.
- Engineering and environmental properties are important.
• Life-cycle cost benefits assessment is warranted.
• Restrictions prohibiting recycled material that are without technical basis should be removed.

In 2010, the FHWA launched the Sustainable Pavements Program to further advance the knowledge and practice of sustainability as related to pavements. This program has taken on much of the work initially started by the Green Highways Partnership discussed in Section 4.3, has accomplished an impressive amount of work in less than a decade, and has published a number of guidance and technical documents for use related to sustainable pavements and greening roadway infrastructure (FHWA, 2018c), including specifications that allow for the use of recycled materials in roadway infrastructure.

From the work of the FHWA’s Recyclable Materials Policy and Sustainable Pavements Program, the FHWA has published numerous documents and guidelines on its research and findings. Among these are:

• State of the Knowledge for Use of Asphalt Mixtures with Reclaimed Binder Content (FHWA, 2018d)
• FHWA Division Office Survey on State Highway Agency Usage of Reclaimed Asphalt Shingles: Quantities, Trends, Requirements and Direction – Results from May 2017 (FHWA, 2018a)
• Overview of Project Selection Guidelines for Cold In-place and Cold Central Plant Pavement Recycling (FHWA, 2018b)
• Supplementary Cementitious Materials – Best Practices for Concrete Pavements (FHWA, 2016a)
• “Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement” (FHWA, 2007)
• “Highway Materials Recycling: Partnering for Sustainability” (FHWA, 2001a)
• “Tools and Resources for Using Industrial By-Product Materials in Road Construction” (FHWA, 2008)
• User Guidelines for Waste and Byproduct Material in Pavement Construction (FHWA, 2016b)
• “Recycle Texas: A Success Story” (FHWA, 2001b)

Pavement recycling practices have been adopted by the FHWA and are included as part of their Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-14 (FHWA, 2014b). Recycling practices adopted and their relevant sections include the following:

• Section 304 – Full Depth Reclamation. This section covers the practice of pulverizing an existing paved road and reshaping and recompacting the existing material to form a new roadbed.
• Section 305 – Full Depth Reclamation with Cement. This section adds cement to a pulverized roadway to create a stabilized base.
• Section 306 – Full Depth Reclamation with Asphalt. This section adds asphalt to a pulverized roadway to create a stabilized base.
• Section 310 – Cold-in-Place Recycled Asphalt Base Course. This section involves milling an existing asphalt pavement, mixing the millings with lime and emulsified asphalt, and replacing and recompacting to form a new asphalt base.
• Section 713 – Roadside Improvement Material. In this section, provisions are given for the use of mature organic compost and recycled pulp fiber manufactured from natural material diverted from the waste-stream of manufacturing processes or produced from recycled material such as newsprint, chipboard, corrugated cardboard, wood chips, and similar material.

4.2 State Initiatives to Green Roadway Infrastructure

With the FHWA leading the way, multiple states have begun using recycled materials in their roadway infrastructure and have developed design and construction specifications that allow for and sometimes even encourage the use of recycled materials in roadway infrastructure construction projects. The states with the most and longest experience include California, Florida, Hawaii, Michigan, Minnesota, Montana,
Greening Roadway Infrastructure Initiative on Guam

New Jersey, Ohio, Oregon, Texas, Washington, and Wisconsin. This section highlights state policies, guidelines, standards, projects, and initiatives that support and promote safe, beneficial use of recycled materials in roadway infrastructure. A more detailed description of the highlighted guidance, standard specifications, and other publications listed here can be found in Appendix A.

California

Guidance Documents and Associated Publications

- **Asphalt Rubber Usage Guide** (California Department of Transportation [Caltrans], 2003)
  - Material addressed – crumb rubber
  - Summary - This guidance covers BMPs, possible applications, benefits and drawbacks, cost considerations, design procedures and considerations, preparation methods and equipment, construction, and inspections.

Standard Specifications

- **Standard Specifications** (Section 39 Caltrans Standard Specifications for Hot Mix Asphalt) (Caltrans, 2018)
  - Material addressed – crumb rubber, asphalt rubber, RAP
  - Summary – These specifications include AASHTO testing, gradation, quality characteristics, general requirements, and application.

Florida

Guidance Documents and Associated Publications

- **Developing Improved Opportunities for the Recycling and Reuse of Materials in Road, Bridge, and Construction Projects** research project (University of Florida, 2014)
  - Materials addressed – RAP, RCA, waste tires, recycled glass
  - Summary – Through focus groups and interviews with industry professionals, strategies for recycled material use in roadways were recommended to the Florida Department of Transportation (FDOT). Recommendations included developing guidance documents and standards specifications as well as holding educational seminars and providing contractual incentives for use of the recycled materials.

Standard Specifications

- **Standard Specifications for Road and Bridge Construction** (FDOT, 2019)
  - Materials addressed – RCA, RAP, recycled glass
  - Summary - As of 2019, FDOT has RCA, RAP, and recycled glass implemented into their Standard Specifications.

Hawaii

Guidance Documents and Associated Publications

- **Sustainable Pavement Solutions for O’ahu** (Muench and Muramoto, 2011)
  - Materials addressed – common recycled materials in the Hawaiian Islands
  - Summary – This report explored the use of recycled materials in pavement construction projects.
Standard Specifications

- **2005 Standard Specifications for Road and Bridge Construction** (HDOT, 2005)
  - Materials addressed – recycled glass, RAP
  - Summary – Recycled glass use is required for road base construction and certain percentages of recycled glass and RAP are required to be used in glassphalt. Some exclusions apply for cost considerations.

**Michigan**

Guidance Documents and Associated Publications

- **Using Recycled Concrete in MDOT’s Transportation Infrastructure – Manual of Practice** (Applied Pavement Technology, Inc., 2011)
  - Material addressed – RCA
  - Summary – This document introduces the benefits and limitations, potential uses and applications, and the Michigan Department of Transportation’s (MDOT’s) experience with this recycled material.

- **Study/Pilot Project: Use of waste rubber in roadways study/pilot project** (Lombardo, 2013)
  - Material addressed - crumb rubber
  - Summary – Research and testing (including a 3.2-mile roadway pilot project) was undertaken to explore how to successfully incorporate crumb rubber into roadway construction.

**Standard Specifications**

- **Standard Specifications for Construction** (MDOT, 2012)
  - Materials addressed – RAP, RCA
  - Summary – These specifications allow for use of RAP in HMA mixtures and RCA in various applications (gutters, concrete barriers, sidewalks, driveways, and more), as long as the mixtures meet all applicable performance criteria.

**Minnesota**

Guidance Documents and Associated Publications

- **Using Recycled Concrete Aggregate in New Concrete Pavement Mixes** (MnDOT, 2017)
  - Material addressed – RCA
  - Summary – This document provides guidance for successfully using RCA in pavement mixes, including specifying appropriate applications.

- **Publication: Use of Crushed Concrete Products in Minnesota Pavement Foundations** (MnDOT, 1995)
  - Material addressed - RCA
  - Summary – This document summarizes the findings of studies examining the effects of RCA use in roadway infrastructure on the environment; the findings resulted in revisions to the Minnesota Department of Transportation (MnDOT) Standard Specifications for use of the material.

- **Publication: Reclaimed Glass: Information Kit** (Minnesota Local Road Research Board, 2001)
  - Material addressed: recycled glass
  - Summary – After MnDOT and Sibley County, Minnesota launched an initiative to decrease the volume of glass being disposed of in landfills, and conducted research and development regarding the use of recycled glass in pavement, the Information Kit was produced to guide
usage in roadway construction. MnDOT also revised their Standard Specifications to include recycled glass in pavement mixes.

Standard Specifications

- **Standard Specifications for Construction** (MnDOT, 2018)
  - Material addressed – Class 7 Aggregate (includes salvaged or recycled aggregates)
  - Summary – In 2018, the MnDOT Standard Specifications were revised to include Class 7 Aggregate, which is broadly defined to allow use of a variety of recycled materials, as long as they meet performance requirements set forth in the specifications.

**Montana**

Guidance Documents and Associated Publications

- **Guide to Beneficial Use Determinations of Waste Industrial and Manufacturing Byproducts** (Montana Department of Environmental Quality, 2010)
  - Materials addressed – industrial and manufacturing byproducts
  - Summary – This guidance provides in-depth information regarding which industrial and manufacturing byproducts are eligible for beneficial reuse and the type(s) of license(s) needed.
- **Pavement Design Manual** (MDT, 2018)
  - Material addressed – RAP
  - Summary – This manual provides guidelines and details about how and when to apply RAP to pavement design.

Standard Specifications

- **Standard Specifications for Road and Bridge Construction** (MDT, 2014)
  - Materials addressed – RAP, recycled glass
  - Summary – The Montana Department of Transportation (MDT) Standard Specifications provide maximum percentages and permissible usage for RAP and recycled glass in blended aggregates for roadway construction.

**New Jersey**

Standard Specifications

- **Standard Specifications for Road and Bridge Construction** (NJDOT, 2007)
  - Material addressed – RAP, RCA, recycled glass, recycled asphalt shingles (RAS), remediated petroleum-contaminated soil aggregate
  - Summary – The New Jersey Department of Transportation (NJDOT) Standard Specifications provide maximum percentages for recycled materials, potential applications, and specific QC requirements that must be met when the materials are used.

**Ohio**

Guidance Documents and Associated Publications

- **Use of Crushed Recycled Glass in Construction of Local Roadways** Feasibility Study Report (Tao, 2017)
  - Material addressed – recycled glass
  - Summary – The study evaluated recycled glass relative to the demand of potential projects that could benefit and concluded supply more than met demand.
Standard Specifications

- *Construction and Maintenance Specifications* (Ohio DOT, 2016)
  - Materials addressed – RAP, RCA, steel slag aggregate, granulated slag, blast furnace slag
  - Summary – Ohio DOT Standard Specifications provide blend requirements and possible usage for these materials.

**Oregon**

Guidance Documents and Associated Publications

- *Beneficial Use of Reclaimed Asphalt Grindings* Fact Sheet (Barrows, 2015)
  - Material addressed – reclaimed asphalt grindings
  - Summary – This fact sheet provided BMPs for use of reclaimed asphalt grindings.

Standard Specifications

- *Standard Specifications for Construction* (ODOT, 2018)
  - Materials addressed – RAP, recycled glass, compost
  - Summary – Oregon Department of Transportation (ODOT) Standard Specifications require the use of recycled materials to the maximum extent practical while still being economically feasible. The standards provide percentages allowable for RAP in paving material and describe potential usage applications for recycled glass and compost.

**Texas**

Guidance Documents and Associated Publications

- *Roadway Recycled Materials Summaries* Information Packets (TxDOT, n.d.)
  - Materials addressed – asphalt shingles, coal combustion by-products, compost and mulch, glass, industrial sands, metals, plastics, RCA, slags, soils, tires and tire rubber
  - Summary – Materials identified as part of the Road to Recycling Initiative (detailed in Appendix A) have information packets that provide guidelines, demonstration projects, research, reports, specifications, and availability.

- *Using Scrap Tires and Crumb Rubber in Texas Highway Construction Projects* (TxDOT, 2007)
  - Material addressed – crumb rubber
  - Summary – This report explored the past, present, and future of waste tire usage in transportation-related tire-rubber products, including benefits, opportunities, results of research, identified issues (and solutions), and alignment with the Texas Department of Transportation’s (TxDOT’s) goals and strategic plan.

Standard Specifications

- *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (TxDOT, 2014)
  - Materials addressed – RAP, RCA, crumb rubber, compost
  - Summary – TxDOT Standard Specifications provide allowable percentages for recycled materials in roadway infrastructure applications and dictate allowable usage strategies.
Washington

Guidance Documents and Associated Publications

- **WSDOT Standard Practice QC-9 and QC-10** (WSDOT, 2018a and 2018b)
  - Material addressed – RCA
  - Summary – These documents identify the standard practice for certifying concrete for consistent quality from both known and unknown sources.

Standard Specifications

- **Standard Specifications for Road, Bridge, and Municipal Construction** (WSDOT, 2018c)
  - Material addressed – RAP
  - Summary – The Washington Department of Transportation (WSDOT) Standard Specifications outline storage; incorporation processes; evaluation of quality, minimum and maximum allowable percentages (for various applications); and usage requirements.

Wisconsin

Standard Specifications

- **Standard Specifications for Construction** (WisDOT, 2019)
  - Materials addressed – RAP, RCA, RAS, recycled glass
  - Summary – The Wisconsin Department of Transportation (WisDOT) Standard Specifications allow the use of the listed materials in a variety of roadway infrastructure component applications if all performance requirements are met and provide percentages for maximum content.
5. Guam’s Greening Roadway Infrastructure Initiative

With 155 miles of routed roads and 860 miles of village streets, Guam could realize significant cost savings as well as conservation of landfill space through the use of recycled materials during reconstruction (as well as new construction). The following sections examine the current efforts of stakeholders to collaborate on recycled material use, evaluations of available materials, potential applications of those materials, advantages and disadvantages of each material, economic impacts, and past projects involving the use of recycled materials. Recommendations at the end of the section summarize the overall suitability of various types and uses of recycled materials to green roadway infrastructure on Guam.

5.1 Stakeholder Kick-off Meeting

On October 9, 2018, public-sector stakeholders from Guam EPA, Guam DPW, Guam Solid Waste Authority (GSWA), Naval Facilities Engineering Command, Marianas (NAVFAC Marianas), and private-sector industry representatives and consultants met at the Guam Power Authority Building to kick off Guam’s Greening Roadway Infrastructure Initiative. The goals of this Stakeholder Meeting were to do the following:

1) Identify recycled materials viable for use in this initiative.
2) Identify the opportunities and constraints of using these recycled materials through a highly interactive process with a multi-disciplinary group of stakeholders.
3) Identify reasons not to proceed with various recycled materials.
4) Identify quantities of recycled materials available and needed for use in roadway infrastructure.
5) Identify equipment on island that is available to process recycled materials for this initiative.
6) Determine what equipment is still needed to process recycled materials for this initiative.
7) Suggest a narrowed number of opportunities to investigate further.
8) Enhance the probability of success by identifying, addressing, and mitigating factors early on that could affect the viability of the Greening Roadway Infrastructure Initiative Implementation.
9) Provide quality information for decision making and next-steps.

The following activities occurred in the first half of the Stakeholder Meeting:

- Presentations to provide context for subsequent stakeholder discussions, including a summary of the Zero Waste Plan, Zero Waste Plan history, and an update on Guam EPA’s current activities and successes in implementing the Zero Waste Plan.
- An overview of Guam’s Greening Roadway Infrastructure Initiative, along with the goals of the initiative and the benefits implementing the initiative would provide to Guam.
- An overview of Guam’s roadway network system (provided by Guam DPW), along with a summary of Guam DPW’s roadway design, construction, and maintenance policies and practices.
- Discussion of recycled materials generally suitable for use in roadway construction projects and an identification of the specific recycled materials proposed for use in roadway infrastructure on Guam: RAP, RCA, recycled glass, waste tires, and compost.
- Discussion of the equipment needed for processing recycled materials in roadway construction.

In the afternoon, two groups were formed to discuss the information presented in the first half of the Stakeholder Meeting. For each of the five recycled materials proposed for use to green roadway infrastructure on Guam, participants were asked to identify constraints in implementation, equipment available or needed on the island, and ways to overcome constraints. The findings from the groups are presented in Tables 5-1 and 5-2.

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<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Constraints</th>
<th>Equipment on Island</th>
<th>Equipment Needed</th>
<th>Ways to Overcome Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recycled Glass, Group 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decorative concrete</td>
<td>Need to source separate</td>
<td>Crusher</td>
<td>Cost to implement in Base:</td>
<td></td>
</tr>
<tr>
<td>(sidewalks and similar)</td>
<td></td>
<td>Drum</td>
<td>• Flow control law to push to crusher</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Add into specifications</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>• Educate designers</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>• Provide to contractors for free</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Incentives</td>
<td></td>
</tr>
<tr>
<td>Filter media/utility bedding</td>
<td>Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>Only residential glass waste accepted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbase</td>
<td>Limited technical qualities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily cover at landfill</td>
<td>Storage areas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RAP, Group 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reuse in village roads, asphalt</td>
<td>Funding</td>
<td>Basic equipment here</td>
<td>Need more</td>
<td>Village roads – funding to do more, HMA</td>
</tr>
<tr>
<td>pavement</td>
<td></td>
<td></td>
<td></td>
<td>• More equipment to do more</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Training of workers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Better planning/phasing of construction and schedules</td>
</tr>
<tr>
<td>Mud control on unpaved roads/lots</td>
<td>Not enough? More specialized contractors</td>
<td>DPW, Hawaiian Rock,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(hot mix plant)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compost/Mulch, Group 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion control</td>
<td>Cost</td>
<td>Windrow turner</td>
<td>• Educate designers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>for large quantity</td>
<td>• Develop/introduce into specs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and demand</td>
<td>• Tax/non-native material fine</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Revise current specifications</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bid preferences and % - incentives to use local</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Educate procurement and suppliers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Enforcement of Guam Code Annotated with respect to compost/mulch – not subject to lowest price</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Tax breaks</td>
<td></td>
</tr>
<tr>
<td>Weed control</td>
<td>Rhino Beetle</td>
<td>Extensive collection system for restaurants and food waste (trucks) specialized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscaping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5-1. Breakout Session Notes, Group 1

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Constraints</th>
<th>Equipment on Island</th>
<th>Equipment Needed</th>
<th>Ways to Overcome Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stormwater water quality/biofiltration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medians, shoulders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RCA, Group 1</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Demo bldgs.</td>
<td>Potential contaminated/needs to be cleaned</td>
<td>Crusher</td>
<td>None</td>
<td>• Use on village streets as preference over RAP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• ‘Certified Clean’ only</td>
</tr>
<tr>
<td>Aggregate base</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fill</td>
<td>Limited source</td>
<td>Rebar puller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbase</td>
<td>Inconsistent resource flows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Village streets/parking lots</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Waste Tires, Group 1</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Embankment fill</td>
<td>Cost to obtain equipment</td>
<td>Shredder to 1 inch</td>
<td>Grinder $$$$</td>
<td>• Educating designers, utility companies, contractors on usage – bedding and backfill, septic system filter, concrete pole buffer, substations</td>
</tr>
<tr>
<td>Tire planters</td>
<td>Facilities to process</td>
<td></td>
<td></td>
<td>• Introduce into specifications</td>
</tr>
<tr>
<td>Crumb rubber added to asphalt binder</td>
<td>Crumb rubber $$$$</td>
<td></td>
<td></td>
<td>• Modify requirements for filtration rock</td>
</tr>
<tr>
<td>Pipe bedding</td>
<td>Volume + resource flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filtration rock</td>
<td>• Septic systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Utilities</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• Impact supports</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:

% = percent

$ = cost [Note that all specific costs provided in this document are presented in U.S. dollars.]

Table 5-2. Breakout Session Notes, Group 2

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Constraints</th>
<th>Equipment on Island</th>
<th>Equipment Needed</th>
<th>Ways to Overcome Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recycled Glass, Group 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road base (100 tons/hour road base)</td>
<td>More processing/washing</td>
<td>Crushers/screens</td>
<td>Sanitize equipment</td>
<td>Local/federal specs</td>
</tr>
<tr>
<td></td>
<td>Limited volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local use requirement not recognized</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot mix</td>
<td>Cost for anti-strip agent</td>
<td>Crushers/screens</td>
<td>None</td>
<td>Local/federal specs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Require</td>
</tr>
<tr>
<td>Opportunity</td>
<td>Constraints</td>
<td>Equipment on Island</td>
<td>Equipment Needed</td>
<td>Ways to Overcome Constraints</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------------</td>
<td>---------------------</td>
<td>------------------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>Landscaping</td>
<td>Processing cost/cheaper sources</td>
<td>Crushers/screens</td>
<td>Tumblers</td>
<td>Education to counter liability concerns</td>
</tr>
<tr>
<td></td>
<td>Liability for hotel use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cottage industry (counter tops, blowing, stained glass)</td>
<td>Lack of Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Training marketing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadway marking (local only)</td>
<td>Not allowed for federal</td>
<td>Department of Defense (DoD) has pulverizer</td>
<td>Locally available pulverizer</td>
<td>Local/federal specs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RAP, Group 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road base (processed)</td>
<td></td>
<td>Yes</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Hot mix</td>
<td>Project</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specs do not allow use (typically) FHWA/DoD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>None</td>
<td>Work with FHWA and DoD to get RAP into specs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No state-developed specs</td>
</tr>
<tr>
<td>Gravel base (processed)</td>
<td>Rollers would be needed, but Rollers are limited to the Mayors use on village roads</td>
<td></td>
<td>Rollers would be needed, but Rollers are limited to the Mayors use on Village roads</td>
<td>Share DPW equipment</td>
</tr>
<tr>
<td><strong>Compost/Mulch, Group 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion control socks</td>
<td>• Socks imported</td>
<td>Yes, on-island fab of sock mesh?</td>
<td>More machine to fill socks</td>
<td>Better marketing/education Require use, local specs</td>
</tr>
<tr>
<td></td>
<td>• Rhino Beetle (keep sm. Mesh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Not made on island</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control overgrowth</td>
<td>Rhino Beetle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Rhino Beetle</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Cannot compete with Home Depot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust control/desiccation</td>
<td>Rhino Beetle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biosolids/food</td>
<td>Public support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Testing, odor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RCA, Group 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General fill (used now)</td>
<td>Processing cost</td>
<td>Crushers</td>
<td>More…</td>
<td>Legislation requiring reuse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jack hammers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road base (not used now)</td>
<td>Project specs do not allow use</td>
<td>Same</td>
<td>None</td>
<td>Need local specs</td>
</tr>
<tr>
<td>Drain rock media (used now)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 5-2. Breakout Session Notes, Group 2

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Constraints</th>
<th>Equipment on Island</th>
<th>Equipment Needed</th>
<th>Ways to Overcome Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Waste Tires, Group 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crumb in hot mix</td>
<td>High cost for equip/low output. $180K to start up</td>
<td>No</td>
<td>Crumb processing machine ($3-5 million)</td>
<td>No Go!</td>
</tr>
<tr>
<td>Ship off (pavements, energy, playgrounds)</td>
<td>Too expensive</td>
<td>Baling machines (more, larger, higher capacity)</td>
<td>More baling machines (more, larger, higher capacity)</td>
<td>Shipping subsidy ($1,000/container) + Charge fees on tire sales for disposal/recycle</td>
</tr>
<tr>
<td>Recreation (whole tires)</td>
<td>Small # tires used Mosquito/vector control</td>
<td></td>
<td></td>
<td>Education on opportunities Drill/cut so they do not hold water</td>
</tr>
<tr>
<td>Construction applications (embankment/walls)</td>
<td>Limited use (height restriction)</td>
<td>Balers</td>
<td>Local standards/specs Education, market analysis</td>
<td></td>
</tr>
<tr>
<td>Safety applications</td>
<td>Limited use</td>
<td></td>
<td></td>
<td>Education, standards/specs</td>
</tr>
<tr>
<td>Cottage industry marking other items</td>
<td>Available expertise</td>
<td>Vary</td>
<td>Vary</td>
<td>Training, create market</td>
</tr>
</tbody>
</table>

### 5.2 Summary of Recycled Materials Suitable for Use in Guam

Section 3.1 identified various recycled materials that have been used globally and throughout the U.S. in roadway infrastructure. As an initial screening step, the recycled materials listed in Section 3.1 were evaluated to determine if the following criteria were met:

1) The recycled material is/was produced on the island – certain industries (that is, foundries) do not exist on Guam.

2) Sufficient quantity exists – that is, that there are enough recycled material and sources on the island for roadway infrastructure project(s).

3) Recycled materials are readily available today.

4) Recycled materials have had past success in roadway construction off-island.

Recycled materials meeting these criteria were RAP, RCA, waste tires, recycled glass, and compost/mulch.

### 5.3 Summary of Recycled Material Applications in Guam

Sections 3.2 and 5 provide a summary of where and how recycled materials have been tried and used in roadway infrastructure construction. Table 5-3 shows where the suitable recycled materials identified in Section 6.2 would apply to roadway infrastructure in Guam.
### Table 5-3. Potential Recycled Material Applications in Guam Roadways

<table>
<thead>
<tr>
<th>Roadway Construction Component</th>
<th>Potential Recycled Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>Recycled glass</td>
</tr>
<tr>
<td></td>
<td>RAP</td>
</tr>
<tr>
<td></td>
<td>RCA</td>
</tr>
<tr>
<td></td>
<td>Crumb rubber from waste tires</td>
</tr>
<tr>
<td>PCC</td>
<td>RCA</td>
</tr>
<tr>
<td></td>
<td>Crumb rubber from waste tires</td>
</tr>
<tr>
<td>Base and subbase</td>
<td>Recycled glass</td>
</tr>
<tr>
<td></td>
<td>RAP</td>
</tr>
<tr>
<td></td>
<td>RCA</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Recycled glass</td>
</tr>
<tr>
<td></td>
<td>RAP</td>
</tr>
<tr>
<td></td>
<td>RCA</td>
</tr>
<tr>
<td>Embankment</td>
<td>Recycled glass</td>
</tr>
<tr>
<td></td>
<td>Shredded waste tires</td>
</tr>
<tr>
<td>Trench Bedding and Backfill</td>
<td>RAP</td>
</tr>
<tr>
<td></td>
<td>RCA</td>
</tr>
<tr>
<td></td>
<td>Recycled Glass</td>
</tr>
<tr>
<td></td>
<td>Shredded tires</td>
</tr>
<tr>
<td>Roadside development (site restoration/revegetation/erosion control)</td>
<td>Compost (including kitchen, yard, and larger-scale cleared vegetation)</td>
</tr>
</tbody>
</table>

Note: Although asphalt shingles are an ideal material for use in asphalt pavement, supply is limited on Guam because the shingles do not withstand high wind (typhoon) conditions.

### 5.4 Advantages and Disadvantages of Using Recycled Materials in Roadway Infrastructure

The following sections present advantages and disadvantages of using RAP, RCA, recycled glass, waste tires, and compost to construct more sustainable roadway infrastructure.

#### 5.4.1 Recycled Asphalt Pavement

While RAP may be used in both aggregate bases and new asphalt pavement, blending for aggregate use is well documented and poses little issue. The advantages and disadvantages outlined in this section pertain mainly to using RAP in new asphalt pavement.

#### 5.4.1.1 Advantages of Using Reclaimed Asphalt Pavement

- **Cost Savings**: Potential onsite production resulting in minimized transportation costs, reuse of demolished asphalt reducing or eliminating disposal fees, and a reduction in required quantity of higher priced virgin aggregate all contribute to cost savings. Examples of cost savings that have been achieved by using RAP in roadway infrastructure projects include the following:
  - The FDOT estimates $224 million in savings from the use of RAP since 1979, the equivalent of two thirds of their annual resurfacing budget ([South Carolina Department of Transportation, 2014](#)).
  - A Minnesota study estimated an 18 percent savings when 40 percent RAP was used in HMA production ([South Carolina Department of Transportation, 2014](#)).

Further discussion regarding RAP costs can be found in Section 6.5.

- **Environmental Benefits**: Reusing asphalt contributes to the conservation of nonrenewable resources (that is, virgin aggregate) and a reduction in environmental impacts including GHG
emissions through production and transportation of new hot-mix asphalt. An additional benefit is reduction of potential air and water pollution sources by minimizing the placement of additional waste in landfills.

- **Established Design and Construction Requirements:** One of the biggest advantages that RAP offers over other recycled materials is that it has been studied and used so extensively in roadway construction projects and its use is endorsed by FHWA. FHWA (2011) states “RAP has successfully been used for more than 30 years. Based on previously documented experience, recycled asphalt mixtures designed under established mixture design procedures and produced under appropriate quality control/quality assurance measures perform comparably to conventional asphalt mixtures.”

5.4.1.2 Disadvantages of Using Reclaimed Asphalt Pavement

- **Variability in RAP Quality:** A major disadvantage of using RAP as material in pavement mix design is RAP quality. RAP from two different pavement sections may have multiple asphalt binder types or ages, leading to difficulty in producing a mix design that meets desired performance standards. Differing manufacturing processes (pulverizing versus milling) yield differing aggregate sizes, which could impact supply of properly sized material. According to FHWA (2011), “The most common challenges to increasing the use of RAP are State transportation department specification limits, lack of processing (that is, variability of RAP), lack of RAP availability, and past experiences.”

- **Performance:** Introduction of RAP into an asphalt mix at improper percentages can cause issues with stiffening of the final product, which leads to poor cold-weather performance. Older, oxidized RAP and varied gradations of RAP from differing sources will also negatively affect performance. According to FHWA (2011), “One of the most common disadvantages of using RAP is the quality of the blended virgin and RAP binders, especially for high RAP mixes, and the stiffening of the mix from high RAP quantities and resulting cracking performance.”

- **Quality Control Requirements:** Incorporating RAP into an asphalt pavement mix design is not as predictable as non-RAP-containing mixes because of the variability of the RAP sources as described above, as well as the multitude of processing options that each yield their own advantages and disadvantages. When using a mix with RAP, additional performance testing is required in addition to the typical laboratory and field testing that is completed with non-RAP mixes to demonstrate the final product conforms to design criteria. Per FHWA (2011), “Evaluating mixture performance of the designed asphalt mixture containing RAP, especially high RAP, is recommended. There are a variety of performance tests available for evaluating the probable permanent deformation, fatigue, and thermal cracking performance of compacted asphalt mixtures.”

5.4.2 Recycled Concrete Aggregate

The following sections describe advantages and disadvantages of using RCA in roadway infrastructure, from a design and construction perspective.

5.4.2.1 Advantages of Using Recycled Concrete Aggregate

The advantages of using RCA in roadway infrastructure include the following:

- **Cost Savings:** Savings resulting from minimized transportation and disposal fees and the need to purchase a reduced volume of higher priced virgin aggregate because the overall aggregate mix requirements can be supplemented with the addition of lower cost RCA. Another economic benefit that can lead to cost savings associated with the use of RCA in roadway infrastructure projects is the recovery of steel from the recycling process. This material usually becomes property of the contractor, who can sell it as scrap metal. Examples of cost savings that have been achieved by using RCA in roadway infrastructure projects include a project in Michigan which reaped the cost savings benefits by using RCA. According to Transportation Applications Of Recycled Concrete Aggregate, “A recent value-engineering proposal for using RCA in the pavement base structure on US-41 resulted in savings of $114,000 on a $3 million-dollar project. The Contractor and the State shared this savings equally” (FHWA, 2004). If the cost savings of transportation and disposal fees for disposing of the RCA at landfill were calculated, the cost savings would have been even greater.
• **Ease of Use:** Many agencies allow a 100 percent replacement rate of RCA for various aggregates, including subbase and base as well as coarse and fine concrete aggregate. The processing that is required for use is minimal and uses common equipment in rock crushers and screens combined with electromagnets common to salvage yards. A further benefit is seen in new PCC mixes, where a proper mix design results in an increased ease of finishing. Again according to *Transportation Applications Of Recycled Concrete Aggregate*, “The use of RCA in new concrete initially created problems with mix workability. The problem was associated with the high absorbency of water of aggregate and the difficulty in maintaining a consistent and uniform saturated surface dry condition of RCA aggregate. The Contractors overcame this hurdle by improving their process control program. Their process control program heightened their awareness of the need to water stockpiles and to conduct frequent testing of aggregate for moisture content.” From FHWA research and testing, it was determined that this could be mitigated by ensuring that the stockpile is saturated. From this, there have been some DOTs that have provided construction recommendations while working with RCA, which has ultimately improved the workability of the RCA and the product that comes from using this material. Specifically, the Virginia Department of Transportation (VDOT) has made recommendations for working with RCA: “VDOT has provided construction recommendations for compacting RCA when it is used in base and sub-base. These recommendations include compacting the RCA in a saturated state to aid in the migration of fines throughout the mix” (*FHWA, 2004*). These recommendations in turn increase how the RCA reacts and improves the quality of the product.

• **Environmental Benefits:** Benefits may occur through the conservation of nonrenewable resources (that is, virgin aggregate) and a reduction in environmental impacts (including GHG emissions and other potential air and water pollution sources) by minimizing the placement of additional waste in landfills and hardfills.

• **Established Design and Construction Requirements:** Like RAP, one of the biggest advantages that RCA offers over other recycled materials is that it has been studied and used extensively in roadway construction projects and the FHWA endorses the use of RCA. As of 2004, 38 states used RCA as a base course and 11 states used RCA in new concrete mixes (*FHWA, 2004*).

### 5.4.2.2 Disadvantages of Using Recycled Concrete Aggregate

• **Performance:** RCA contains existing concrete dust which causes complications in mix design. The existing concrete dust demands a modified water to cement (w/c) ratio that is typically higher than non-RCA inclusive mixes. If the w/c ratio is assumed at a non-RCA inclusive level, it could be too low adding complications with premature cracking, and lower strength due to incomplete hydration.

• **Quality Control Requirements:** Similar to using RAP in new pavement designs, incorporating RCA into a new PCC mix design is not as predictable as non-RCA containing mixes. When using a mix with RCA, additional performance testing is required in addition to the typical laboratory and field testing that is completed with non-RAP mixes, to demonstrate the final product conforms to design criteria.

• **Potential Environmental Hazard:** Because of the possibility of tufa-like precipitates from the cement in RCA, there have been concerns over leachates into groundwater and corrosion of aluminum or galvanized steel piping. WSDOT has added the requirement that RCA not be placed below the ordinary high water mark of any surface water nor used for erosion control or water pollution control (*WSDOT, 2018a*). The FHWA *User Guidelines for Waste and Byproduct Materials in Pavement Construction* identify special considerations where some jurisdictions may require stockpiles to be separated a minimum distance from water courses because of the alkaline nature of RCA leachate (*FHWA, 2016b*). This same document recommends that RCA should not be placed in contact with aluminum or galvanized steel pipes and that it not be used in wet conditions, as its high alkalinity can result in corrosivity when combined with water.

### 5.4.3 Recycled Glass

#### 5.4.3.1 Advantages of Using Recycled Glass

• **Cost Savings:** With the rising cost of dumping in landfills, using recycled glass in any application saves municipalities money through waste reduction. Reduction of cost is one of the larger benefits of
using recycled glass in roadway construction; recycled glass can often be implemented into a project with little to no extra cost while also decreasing landfill disposal fee. Ramsey County, Minnesota, was able to obtain recycled glass from a local glass supplier for $1 a ton; it was implemented into their road construction with no extra charge, and there was no negative change in roadway performance (Dan Krivit and Associates, 1999).

- **Performance**: In some instances when Ramsey County used recycled glass as an aggregate base, they found better performance and slightly longer road lifespan. It has been concluded by many states that incorporating a specific amount of recycled glass into the wearing surface of a mix can help recycle the material and not negatively affect the roads performance. TxDOT has implemented recycled glass in roadway construction several times and has shown in their specs they will allow up to 20 percent recycled glass in the wearing surface mix (TxDOT, 2014). The department is confident that this amount of recycled glass or less in the mix will not adversely affect the engineering properties of the mixture. Several states have concluded that using recycled glass as a replacement for natural aggregate rarely has drawbacks to it and further decreases project cost.

### 5.4.3.2 Disadvantages of Using Recycled Glass

- **Supply**: Obtaining the needed recycled glass is easier in larger cities, but sometimes is not beneficial to go out of the way to obtain the glass in smaller cities or towns. To be recycled in roadway construction, the glass needs to be crushed, screened, and mixed with the base course. These processes can sometimes be an extra cost to the project if the recycling facility does not already implement these processes.

- **Potential Performance Issues**: In some cases when too much recycled glass was used as a replacement for a current material, there were undesirable performance results. FHWA has implemented a 15 percent limitation when adding recycled glass to asphalt mixes, because in the past stripping of the asphalt cement binder from the recycled glass has occurred. (FHWA, 2016b). In some cases when more than 15 percent recycled glass was used in asphalt mixes, there has been pavement raveling and poor skid resistance, and tire punctures have been reported. If the glass is not cleaned or not cleaned properly, then biochemical oxygen demand levels of nearby water have the possibility to increase (Dan Krivit and Associates, 1999).

### 5.4.4 Waste Tires

#### 5.4.4.1 Advantages of Using Waste Tires

- **Availability**: Waste tires have a great deal of availability as tire stockpiles are common, take up a good deal of space, and are a problematic source of mosquito breeding. Because of the availability of waste tires, the recycling and reuse of these should be understood and performed.

- **Cost Savings**: Section 6.6.4 describes the cost savings of using waste tires and includes example projects that show the savings of using waste tires.

- **Landfill Reduction**: According to the Arizona Department of Transportation, paving with rubberized asphalt recycles approximately 10,000 tires per mile (Harrington, 2005). If one considers the fact that 10,000 tires can be used in one mile, then it is apparent how quickly a paving project of any size will quickly begin to lower the number of tires that are otherwise disposed of in landfills. Because waste tires can be incorporated in asphalt paving in multiple ways, both in the actual asphalt mix by being a portion of the liquid asphalt, and the availability of the rubber to be an aggregate, the savings of virgin materials can basically come from multiple areas in the cross section of a paving project.

#### 5.4.4.2 Disadvantages of Using Waste Tires

- **Processing**: Specialized processing equipment for waste tires can be expensive. If the equipment is not readily available, cost savings cannot be realized, and a useful material cannot be made.

- **Quality Control**: QC checks are needed to ensure there is no foreign material that makes its way into the mix and it is only the crumb rubber. This is typically done though a visual inspection.
5.4.5 Compost

5.4.5.1 Advantages of Using Compost

- **Availability:** Compost can be generated by every household and many businesses. For minimal sunk cost, composting facilities can be created and a collection program can be implemented.

- **Ease of Use:** Compost can be used at a 100 percent application or a 50 percent blend in topsoil. Existing methods for blending and placing soil are used for placement and do not require specialization.

- **Landfill Reduction:** While compost, by nature, degrades more rapidly than other generated waste, it still uses space within landfills. Using compost in construction projects frees up space in a beneficial manner. It should be noted that other organic material generated during land clearing for construction projects is already banned from landfill disposal and must be taken to composting facilities, composted on site, or chipped to use onsite as mulch for erosion and dust control.

5.4.5.2 Disadvantages of Using Compost

- **Aesthetics:** Compost processing facilities can create a nuisance smell. There may not be ample space on Guam to place a facility sufficiently removed from residences to avoid the nuisance.

- **Sorting:** Compost must be sorted to contain a minimal amount of trash and undesirable contamination. Separation requires a carefully crafted collection program and is contingent on the adherence to the process by the residents.

5.5 Economic Evaluation

This section provides an evaluation on cost of material purchase and private sector availability for each of the five recycled materials. The unit costs provided in this section are mostly based on information collected from foreign markets, mainly the U.S. The unit costs reported for the Guam market are mostly based on personal communications with local contractors. Note that not all the unit cost information for the Guam market is available. The private sector availability of each recycled material is discussed based on the available information provided by GovGuam and other information collected through personal communications.

5.5.1 Reclaimed Asphalt Pavement

The “Markets for Recovered Material” memorandum contained in Volume II of the [Guam Zero Waste Plan](#) (Matrix Design Group, 2013) does not directly provide information regarding the price of RAP in Guam. However, it estimates a market price of $3 to $4 per ton for a broad range of aggregates including RAP and indicates on-island market use for these aggregates (Matrix Design Group, 2013). These aggregates are banned from Layon Landfill, which is a Subtitle D landfill permitted under the Resource Conservation and Recovery Act.

5.5.1.1 Raw Material Cost

According to the FHWA [User Guidelines for Waste and Byproduct Materials in Pavement Construction](#), milled or crushed RAP can be used in pavement construction in five main forms: (1) aggregate substitute, (2) asphalt cement supplement in recycled asphalt paving (hot mix or cold mix), (3) granular base or subbase, (4) stabilized base aggregate, and (5) embankment or field material (FHWA, 2016b).

The properties of RAP can vary significantly because of its dependence on the materials and asphalt concrete type used in the original pavement. The raw material cost of RAP is typically low as it is mostly readily available from construction projects. Therefore, processing and hauling and stockpiling are controlling factors of the raw material cost for RAP (Table 5-4).

In the mainland U.S., milling, hauling, and stockpiling of RAP costs approximately $6.50 per ton. Alternatively, excavating, hauling, and stockpiling RAP costs around $7 per ton and requires additional
reprocessing that costs approximately $5 per ton of RAP. The raw material cost of RAP is significantly lower than the cost of virgin aggregate. Therefore, the higher the percentage of RAP used in pavement construction, typically the greater the cost benefit for the project (Bonte and McDaniel, 2009).

According to Peter Errett of Hawaiian Rock Products on Guam, the milling cost of RAP on Guam is around $11 per ton. Hawaiian Rock Products offers recycled asphalt mix that consists of 25 percent RAP and 75 percent virgin aggregate, which costs around $165 per ton. The recycled asphalt mix is approximately 20 percent cheaper than use of asphalt mix made out of 100 percent virgin aggregate, which costs around $197 per ton in Guam. This cost does not include hauling or placing of RAP, but includes the operating and processing cost to produce the asphalt mix.

5.5.1.2 Private Sector Availability

RAP is currently being produced in Guam and used in asphalt mix for pavement construction. However, it should be noted that if a requirement to use RAP is added to technical specifications for roadway infrastructure projects in Guam, demand may exceed available supply unless investment in additional equipment (that is, milling machinery or RAP crushers) sufficient to satisfy the demand for additional RAP is made.

Discussions during the October 2018 Stakeholder Meeting revealed that the biggest demand for RAP comes from the mayors of villages on the island, for use as surfacing on local gravel and dirt roads. Currently, there is more demand for RAP that can be produced. Guam DPW has begun to incorporate milling specifications as a preferred means of pavement removal to produce more RAP.

Milling produces the largest quantity of RAP and is the preferred method of obtaining it, because it keeps material of differing qualities separate and improves the surface smoothness of the milled pavement. Milling machine costs range from $200,000 to more than $300,000 (Bennink, 2005).

According to the National Asphalt Pavement Association (NAPA) Best Practices for RAP and RAS Management, many contractors have found that the best type of RAP crusher is a horizontal-shaft impactor. The average price of a mobile impact crusher ranges between $450,000 and $550,000, depending on the capabilities and capacity.

5.5.2 Recycled Concrete Aggregate

The “Markets for Recovered Material” memorandum does not provide a discussion on the local price of RCA in Guam. However, it estimates a market price of $3 to $4 per ton for a broad range of aggregates including RAP and indicates on-island market use for these aggregates (Matrix Design Group, 2013). These aggregates are banned from Layon Landfill, similar to RAP. According to personal communications with Karen Storts of Ian Construction, RCA is readily available in Guam.

5.5.2.1 Raw Material Cost

As with RAP, according to the FHWA User Guidelines for Waste and Byproduct Materials in Pavement Construction, RCA can be used in pavement construction in five main forms: (1) aggregate for cement-treated or lean concrete bases, (2) concrete aggregate, (3) aggregate or flowable fill, or (4) asphalt concrete aggregate, and (5) embankment, fill, or trench backfill material (FHWA, 2016b).

RCA is usually obtained from central processing plants where the processed material is stockpiled and sold. Well-processed RCA normally has consistent physical properties; however, a variation in properties might be observed based on the quality of the recovered concrete.

On the U.S. mainland, recycling concrete from demolition projects can result in considerable savings in transportation costs (approximately $0.25 per ton per mile) and in disposal costs (approximately $100 per ton for demolished concrete in the U.S. market) (Concrete Network, 2014). The processed material cost of RCA in the U.S. ranges between $3 and $10 per ton depending on the maximum particle size and the amount purchased (Auburn Aggregates, n.d.).
In Guam, the raw material cost of RCA is around $16 per ton, including hauling to the central part of the island (note that cost might increase for hauling to the northern part of the island), based on personal communications with Karen Storts of Ian Construction. The raw material cost of virgin aggregate in Guam can range between $18 to $25 per ton, which does not include hauling. Therefore, when compared to the use of virgin aggregate, the use of RCA in pavement construction can result in substantial savings in depending on haul distances.

5.5.2.2 Private Sector Availability

The aggregate recycling business typically requires a capital investment between $4.40 and $8.80 per ton of annual capacity depending on the size of the processing facility (USGS, 2000). If use of RCA is going to be required in roadway infrastructure projects on Guam, a capital investment in additional equipment may be needed to keep pace with the demand for RCA. A variety of crusher types (similar to the ones used for crushing RAP) can be used to process RCA. Therefore, similarly, the average price of a mobile impact crusher ranges between $450,000 and $550,000 depending on the capabilities and capacity of the crusher.

5.5.3 Recycled Glass

The “Markets for Recovered Material” memorandum provides a summary of available information on 2012 market conditions and revenues (costs) for waste materials. According to the memorandum, the local price of recycled glass was reported to be $0 with a local market destination (Matrix Design Group, 2013).

Based on personal communications, currently recycled glass in Guam is self-hauled to transfer stations then collected at the Layon Landfill, where it is crushed using heavy equipment and used as alternative cover material at the landfill. The Layon Landfill does not charge a disposal fee to accept waste glass. There are no other identified recycling markets for recycled glass on Guam.

5.5.3.1 Raw Material Cost

According to the FHWA User Guidelines for Waste and Byproduct Materials in Pavement Construction, recycled glass has two main uses in pavement construction as (1) asphalt concrete aggregate and (2) granular base or fill (FHWA, 2016b). For both uses, the recycled glass needs to be free of ferrous and nonferrous metal, plastic, and paper. Use as granular base or fill requires a recycled glass purity of approximately 95 percent; higher purity is required for the use of recycled glass as asphalt concrete aggregate.

In the mainland U.S. market, material recycling facilities (MRFs) typically receive $21 per ton for flint glasses and $11 to $15 per ton for brown glasses (Tao, 2017). For green glass, the MRFs either ship for free or pay the processors approximately $6 per ton. Alternatively, the processors pay a lump sum of $15 per ton for unsorted (all color) glass. Shipping costs for recycled glass can range between $10 and $40 per ton across the country (Rogoff et al., 2016). At 80 percent purity, the raw material cost of the recycled glass can range between negative $38 and $55 per ton. However, as the purity of the recycled glass increases, the raw material cost might increase to positive $77 to $110 per ton at 99.8 percent purity (Recycling Product News, 2017). The average cost for recycled glass product is around $24 per ton in the mainland U.S.

In Guam, recycled glass delivered to and crushed at the Layon Landfill is currently available at no cost.

5.5.3.2 Private Sector Availability

For the reuse of recycled glass, an adequate supply of waste or recycled glass and proper glass pulverization equipment is essential. From September 2017 to September 2018, 63 tons of recycled glass were crushed and used as alternative daily cover at Layon Landfill on Guam. This glass was collected at three residential transfer stations at which private citizens can drop off glass for recycling at no charge. Glass that is not separated and self-hauled to the transfer stations is currently disposed of as municipal
solid waste at a cost of $172 per ton. To ensure a more reliable and adequate supply of recycled glass, discussions would need to be held with GSWA to discuss the feasibility of adding glass to their recycling program, both residential and commercial. Capital and long-term operations and maintenance costs to add glass to the recycling program would then need to be calculated with input from GSWA to determine life-cycle costs.

With respect to glass pulverization equipment, there are various stationary and mobile machinery that screens and scrubs material to ensure effective removal of contaminants. The mobile processors are preassembled, ensuring rapid installation and deployment as well as easy transportation of the processor to alternative sites if needed. As cited in The use of Crushed Glass as both an Aggregate Substitute in Road Base and in Asphalt in Australia Business Case [Australian Food and Grocery Council, 2008], Berger et al. (2004) recommends a mix of multiple stationary pulverizers or a few medium-sized mobile pulverizers as the optimal approach for more efficient, economically feasible, and standardized end-product. The average cost of a typical pulverizer starts at $75,000, which excludes delivery and additional operational costs such as electricity, maintenance, and labor.

If the use of recycled glass is going to be required in roadway infrastructure projects, a capital investment in glass pulverization equipment is necessary. The capital cost of effective clean-up systems for a mid-size MRF handling more than 10,000-tons of recycled glass per year can range from $350,000 to $1,000,000. Potential use of recycled glass in Guam for roadway infrastructure projects would therefore need a significant capital investment.

5.5.4 Waste Tires

The “Markets for Recovered Material” memorandum provides a summary of available information on 2012 market conditions and revenues (costs) for waste materials. In the memorandum, the local price of tires was reported to range between $1 to $12 per tire, with a Southeast Asian market destination (Matrix Design Group, 2013). Tires are currently banned from Layon Landfill.

Currently, waste tires collected in Guam are shredded to 2-inch pieces at Guahan Waste Control, which can process approximately 100 tons of waste tires per month. However, the shredded tires are not used in the local market. According to recent reports from industry, waste tires are now either stockpiled on the island or are sent off-island in bulk shipping containers to East Asian markets for use as fuel in waste to energy facilities.

5.5.4.1 Raw Material Cost

According to the FHWA User Guidelines for Waste and Byproduct Materials in Pavement Construction, waste tires have four main uses in pavement construction: (1) embankment construction, (2) aggregate substitute, (3) asphalt modifier, and (4) retaining walls (FHWA, 2016b). Shredded or chipped tires can be used as lightweight fill material for embankment construction, ground rubber can be used as a fine aggregate substitute in asphalt pavements, and crumb rubber can be used to produce asphalt-rubber binder. Although not directly related to pavement construction, whole waste tires can also be used in retaining wall construction to stabilize roadside shoulder area.

The waste tire collection fee collected by American states ranges from $0.5 to $2.5 per tire in the mainland U.S. for a passenger car tire, depending on the state. The collection fee can go up to $10 per tire for large (off-road) tires (Tirebuyer, 2013). The raw material cost of a passenger tire can be up to $1 per tire and $5 per tire for heavy-truck tires (Recycler’s World, 2019). According to the Rubber Manufacturers Association, there are approximately 100 tires in a ton of waste tire. Therefore, the raw material cost of a passenger tire can be assumed to be approximately $75 per ton of waste tire. Loading and hauling of waste tires cost around $100 per ton of waste tire. Special permits from the states are required for the stockpiling of waste tires. The stockpiling fees for waste tires range between $15 and $25 per ton of waste tire. The processing fees to obtain shredded, ground, crumb rubber from the waste tires range from $10 to $55 per ton of waste tires depending on the size of the processed tire (RMA, 2004).
According to Bob Perron of Guahan Waste Control, in Guam the raw material cost (the cost of procuring waste tires) is $0 per ton. (The private Mr. Rubbishman service charges a collection fee of $4.25 per passenger tire and $14.25 per truck tire self-hauled to their transfer station). Guahan Waste Control is currently capable of producing 2-inch shreds from waste tires, which can be used for roadway construction in embankments. However, the 2-inch shredded tires are not suitable for use as aggregate in pavement construction. Bob Perron indicated waste tires are not currently used in Guam to produce the crumb rubber that can be used in pavement construction.

5.5.4.2 Private Sector Availability

If shredded tires are to be used in the form of crumb rubber in roadway projects, a capital investment in tire shredders with secondary processors that can generate finer byproducts is necessary. A basic tire shredder that can cut tires into roughly 2-inch by 2-inch particles costs approximately $130,000 to $150,000, but shredded tires for use in roadway products should be more finely processed and wire-free. The initial cost of such secondary processors can be an additional $250,000 to $500,000, while the approximate operating cost for the equipment is $9 to $15 per ton.

The typical size of the end product from secondary processors ranges from 5/8 inch to 1 inch. The wire derived through this processing step can be valued at $40 to $120 per ton, depending on the market, quality, and customer demand. If the construction application requires a smaller product, a granulator can provide the third processing step. The cost for a granulator, which generates a typical product size of 1/4 inch to 1/2 inch, can range from $350,000 to $500,000.

Note that these costs do not include shipment of the equipment; when shipping is included, actual costs may be significantly greater.

5.5.5 Compost

Compost is defined as the product resulting from the controlled biological decomposition of organic material under aerobic conditions, which has been sanitized through the generation of heat and stabilized to the point that it is appropriate for its application. Roadway applications for compost and mulch typically occur at the end of the rehabilitation or reconstruction process and include both soil amendments (especially where organic content in the natural soil is low) and erosion control. These benefits are both temporary (helping establish vegetation and mitigate storm impacts immediately post-construction) and permanent (supporting long-term plant health). Compost, which is often applied as filter berms, socks, or compost blankets, improves sandy soils by increasing water retention and improves clay soils by adding porosity. It also adds microbes to the soil that extract nutrients and improve plant health. Mulch also increases waste retention, reduces soil temperature extremes, and minimizes erosion.

In the U.S., most states use compost derived from yard waste. According to the Guam Zero Waste Plan Five Year Review Site Visit Findings prepared by Jacobs in June 2018, composted and green waste was 30.5 percent of Guam’s total municipal solid waste stream in 2016.

5.5.5.1 Raw Material Cost

Compost applications in roadway constructions can take various forms to control erosion and retain sediment in disturbed areas, including as a (1) compost blanket, where a layer of loosely applied compost or composted material is placed on the soil, (2) compost filter berm, where a dike of compost or a compost product, trapezoidal in cross section, is placed perpendicular to sheet-flow runoff, and (3) compost filter sock, where essentially a contained compost filter berm (that is, a tubular filtration device, oval to round in cross section, and filled with composted material) is placed perpendicular to sheet-flow runoff. More than 30 state DOTs currently have specifications that address the use of compost product materials in roadway applications. Mulch application is straightforward and typically requires only grinding equipment.

Table 5-5 presents the unit costs of the compostable materials on Guam as provided in personal communication with Pacific Unlimited, Inc.
### Table 5-5. Compost and Select Organic Material Unit Costs on Guam

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit</th>
<th>Unit Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Cuttings, Clippings, Banana and Papaya Leaves/Trees</td>
<td>Cubic Yard</td>
<td>Free</td>
</tr>
<tr>
<td>Chipped Woods or Ground Green Waste</td>
<td>Cubic Yard</td>
<td>$6.00</td>
</tr>
<tr>
<td>Wood Pallets</td>
<td>Cubic Yard</td>
<td>$9.00</td>
</tr>
<tr>
<td>Non-fibrous Green Waste</td>
<td>Cubic Yard</td>
<td>$9.00</td>
</tr>
<tr>
<td>Mixed Construction Wood Waste</td>
<td>Cubic Yard</td>
<td>$11.00</td>
</tr>
<tr>
<td>Fibrous (palms, coconuts, bamboo, coconut tree trunks)</td>
<td>Cubic Yard</td>
<td>$12.00</td>
</tr>
<tr>
<td>Compost (unscreened)</td>
<td>Cubic Yard</td>
<td>$19.00</td>
</tr>
<tr>
<td>Compost (3.8-inch screened)</td>
<td>Cubic Yard</td>
<td>$26.00</td>
</tr>
<tr>
<td>Colored Mulch - Red/Dark Brown</td>
<td>Cubic Yard</td>
<td>$60.00</td>
</tr>
<tr>
<td>Mulch - Organic</td>
<td>Cubic Yard</td>
<td>$15.00</td>
</tr>
<tr>
<td>Mulch - Wood (2- to 4-inch screened)</td>
<td>Cubic Yard</td>
<td>$5.00</td>
</tr>
<tr>
<td>Mulch - Wood (2-inch Screened)</td>
<td>Cubic Yard</td>
<td>$10.00</td>
</tr>
</tbody>
</table>

If compost or mulch can be used for vegetation and erosion control on Guam roadway rights-of-way, a reasonable amount of this waste could be diverted from disposal. If only 5 percent of Guam's total highways (about 27 miles) underwent rehabilitation or reconstruction each year, approximately 1,000 tons of compost and 200 tons of wood mulch would be diverted. This equates to more than 10 percent of the yard and green wastes generated by Guam's businesses and residents annually. Compost typically reduces feedstock volume by 50 percent; therefore, 2,000 tons of yard waste is needed to produce 1,000 tons of compost. This diversion estimate assumes a 30-foot right-of-way on each roadside and applications rates for compost and mulch of 5 tons per acre and 1 ton per acre, respectively. The tipping fee of yard waste at GSWA's transferring platform was $35 per cubic yard in 2015.

Although full-scale composting has not matured on Guam to a point that capital or operating costs are known, the composting process can be a relatively cost-intensive process (requiring debagging, grinding, turning, hydration, screening, hauling, and monitoring equipment). However, it is expected to be less expensive than disposal via landfill even when all regulatory requirements are established, and it allows the materials to be used to enrich the land rather than paying to bury them in hardfills.

### 5.5.5.2 Private Sector Availability

Organic waste generated during construction vegetation clearance is banned from disposal in landfills. Chipping or grinding brush, pruning waste, and landscaping debris for mulch is generally a low-cost operation using mobile equipment and can be especially cost-effective when debris generated from clearing and grubbing operations is generated onsite. The Eddie Cruz Hardfill, South Pacific Environmental, Pacific Unlimited (John Limtiaco), the University of Guam, and the Coconut Rhinoceros Beetle Eradication Project all operate mobile grinders. Sufficient equipment and expertise exists on Guam to provide mulch and compost for roadway construction. Larger tub-grinders would allow processing of even more materials like logs, whole trees, and similar.

### 5.6 Past Projects with Recycled Materials

#### 5.6.1 Reclaimed Asphalt Pavement

A report submitted at the 2012 Transportation Research Board (TRB) annual meeting (Andreen et al., 2012) looked at the cost benefits of using RAP in roadway projects. The 2012 report provided an in-depth breakdown of the cost savings of using RAP instead of virgin mix, broken down to show the savings of
each material. The report compared the cost per ton to produce asphalt using all virgin aggregate vs. RAP, including milling and hauling. The comparison showed a savings of $8.20 per ton in 1997 values. From this, it is apparent that a savings of $8.20 per ton would quickly add up to a large savings over the duration of a project. Because the raw material costs use 1997 numbers and liquid asphalt process costs have risen, we can assume that the savings demonstrated in the report would be higher under current market value (Andreen et al., 2012).

The Andreen report includes a chart that symbolizes the cost savings of using different percentages of RAP in an AC mix. These savings varied from 14 percent for 20 percent RAP to 34 percent for 50 percent RAP in asphalt mixes. However, if the RAP percentage goes too high, the performance and life cycle of the pavement can be impacted adversely.

The 2012 TRB report also discusses some cost savings some states have attained by incorporating RAP (Andreen et al., 2012). The FDOT estimates $224 million in savings as a result of RAP use since 1979, the equivalent of two thirds of their annual resurfacing budget. A Minnesota study estimated 18 percent savings if 40 percent RAP were used in HMA production. The Indiana Department of Transportation (INDOT) conducted a cost–benefit analysis of a research project [Designing Superpave Mixes with Locally RAP] as part of an independent review of the cost-effectiveness of the department’s research program. According to the conservative estimate of the cost-effectiveness review, INDOT’s savings in materials were nearly $330,000 per year when adding only 5 percent RAP to more than 5 million tons of base and intermediate mixes; RAP contents of 15 percent to 20 percent are more typical, and would lead to higher savings. The review did not assess the environmental benefits of reusing RAP. The study yielded a conservative benefit-to-cost ratio of 220 to 1 for Indiana in material cost savings alone (Bonte and McDaniel, 2009). These findings show how beneficial the use of RAP can be in lowering construction costs, even when only using a small percentage of RAP.

Another cost comparison chart from the 2012 TRB report (Andreen et al., 2012) provides a breakdown of not only the unit costs of raw materials, but also the cost to produce these materials into an actual mix that can be placed. The cost comparison shows the cost to place a ton of recycled hot plant mix (RHPM) versus typical hot plant mix (HPM). The study showed a cost of $58.24 per ton of RHPM vs. $64.37 for HPM, or a 9.5 percent savings, which over the life cycle of a project could lead to substantial savings.

5.6.2 Recycled Concrete Aggregate

RCA is a material that can be recycled into transportation practices in different ways, ranging from being an aggregate for pavement, mixed into PCC, as HMA aggregate, and various other ways. According to TxDOT (2008), “TxDOT has researched and used RCA with good success for about 15 years. In just the last two years alone, TxDOT saved approximately 1.8 million tons of virgin aggregates by incorporating RCA in cement treated base, flexible base, continuously reinforced concrete pavement, filter dams, gabion walls, concrete traffic barriers, flowable fill and select backfill for mechanically stabilized earth walls. This equates to an estimated savings of $12.6 million from reduced or eliminated landfill and virgin aggregate associated costs. Savings from using RCA has the potential to increase tenfold based on current availability of RCA.” In 15 years, Texas has saved nearly $13 million, and the DOT has said that the savings could be even higher if enough RCA is stockpiled for use.

In July 2013, the Nebraska Department of Roads completed The Use of Recycled Concrete Aggregates (RCA) for Temporary Pavements (Nebraska Department of Roads, 2013), an investigation on using temporary pavement that uses crushed concrete obtained from removing old Portland Cement pavements. This investigation looked at a specific use of recycled concrete, but the cost savings of using recycled concrete remain.

The investigation assumed that crushed concrete was already available on the site and cost $5.00 per ton and the cost for stone, delivered to the site was $20.00 per ton. The resultant cost savings per cubic yard were determined to be $7.00, $9.50 and $12.50 for 30 percent, 40 percent and 50 percent replacement, respectively. This shows that as the amount of crushed concrete increases, so do the cost savings. However, in this investigation it was found that RCA in concrete has some workability issues due to the high absorbency of water and other issues in the characteristics of this material. Therefore, the study...
states that RCA would be great for temporary pavements but is not suggested for long term pavements. However, there are still many other uses for RCA that would lead to quality long term products and allow for cost savings by using this material.

5.6.3 Recycled Glass

Recycled glass is a material that takes up a great deal of space in landfills around the globe; according to Schroeder (1994) “Glass makes up approximately 7 percent - approximately 12 million tons of the total weight of US Municipal solid waste discarded annually.” One way to minimize this waste is to reuse the resource in other ways, such as is in the construction of roadways. To date, glass has been recycled for roadway construction either as an aggregate for asphalt concrete or as an aggregate for subbase. A study completed by Ramsey County in Minnesota found that, “Reclaimed glass can be used either directly (as 100 percent glass) into the first lift of subgrade as demonstrated in 1998 or as a pre-blended mixture (as 10 percent glass) into the aggregate base as demonstrated in 1997” (Dan Krivit and Associates, 1999). The study included various example projects where recycled glass was used in the construction of paved areas. The six example projects show that the use of recycled glass varied from aggregate base to glassphalt (a type of asphalt cement concrete that uses some recycled glass in the mix) and subgrade. Although there were no significant cost benefits to the contractor in any of the six projects, the raw material cost for the recycled glass was either $0 per ton or $1 per ton, which is substantially less than normal virgin aggregate. Therefore, if recycled glass is readily available to use, there might not be a huge cost savings in installation cost but the benefits of reducing the amount of waste in the landfill could be substantial.

Raintree County in New Mexico conducted research on the use of recycled materials in roadways that refers to a recycling center in Seattle, Washington, the Clean Washington Center (CWC). According to CWC, the cost-effectiveness of substituting glass for conventional aggregate is highly dependent on the location and the quality and cost of local aggregates, in addition to any credits available for using recycled materials in beneficial reuse applications. CWC notes that the economic benefits of glassphalt generally rely on the recognition of the value of waste diversion in the local market (McEntire, 2004). Therefore, the cost benefits from use of recycled glass mostly depend on the availability and the quality of glass to be used in addition to the support of the local agency (in this case, GovGuam) in providing credits to contractors for using recycled materials.

The University of Florida conducted a research project focusing on advanced use of recycled materials in projects. This study showed that there is a significant non-construction industry demand for recycled glass and consequently, collected glass waste is essentially all reused for non-construction purposes at a relatively high market value of approximately $110 per ton. However, there is a significant cost involved in shipping collected glass from local collection centers to regional processing centers (University of Florida, 2014). The off-construction-market use of recycled glass in Florida results in high raw material costs. However, the study notes that hauling of recycled glass is a large cost, mostly due to the weight of the recycled glass and fewer stockpiling options. For Guam to reap the cost savings of using recycled glass in roadway construction, there would need to be easy access to a large amount of recycled glass, stockpiling options, and recycled glass processors that were in close proximity to recycling facilities.

5.6.4 Waste Tires

California is a leading state in recycling and using recycled materials for practical uses, such as using waste tires in asphalt concrete. According to the California Department of Resources Recycling and Recovery (CalRecycle) webpage, use of rubberized asphalt concrete (RAC) may not be cost-effective for smaller projects considering the initial cost. Implementation of RAC is generally cost-effective when used as thin (1.2- to 2.4-inch) gap- or open-graded surface courses or overlays, or in chip seals and interlayer applications. Therefore, to maximize the cost savings of using RAC, the type and size of the projects should be evaluated carefully. CalRecycle provides a few cost comparisons demonstrating the differences in using RCA instead of conventional asphalt concrete (AC) mixes.
CalRecycle has illustrated two example roadway construction situations provided by Caltrans. One example shows a two-to-one equivalency factor of using RAC compared to AC resurfacing projects when using a minimum thickness of 1.5 inches of RAC in pavement construction (CalRecycle, 2018).

The example compares the use of a 4-inch overlay of conventional asphalt cement with a 2-inch RAC overlay. The cost comparison breaks the cost down into a resultant cost per lane for 1 mile when using each type of pavement material. Based on this information, using a 2-inch RAC mix results in cost savings of greater than $76,000 per lane mile, which would quickly add up for a project. The example is based on a cost of $100 per ton of conventional asphalt pavement, and a cost of $125 per ton for RAC, but only needing 2 inches of RAC as compared to 4 inches of conventional asphalt (CalRecycle, 2018).

A second example presented by CalRecycle provided three different engineering solutions for paving a roadway that has a gravel equivalent of 26 or greater. In California, the gravel equivalent is a predetermined number that must be attained to achieve no deformation of an underlying layer from the suspected traffic loading. The second example presented the following solutions:

1) Reconstruct the entire roadway, including excavation, aggregate base, and a 4-inch AC overlay
2) Overlay 4-inch AC (conventional approach, discussed in the previous example)
3) Cold mill 1 inch deep and add 2.5 inches of RAC

From the cost comparison perspective, Solution 3 above would be the most cost-efficient way to obtain the specific gravel equivalent. This example assumed costs of $40 per cubic yard for excavation, $30 per cubic yard for aggregate base, $100 per ton for asphalt, $0.40 per square foot for milling, and $125 per ton for RAC. These costs resulted in costs per lane mile of $422,400, $170,400, and $143,013 for Solutions 1, 2 and 3, respectively. Solution 3 (which uses RAC in the pavement construction) can result in savings of $30,000 per lane mile; the project has two 10-mile lanes, so using waste tires in the pavement design could result in a savings of greater than $500,000 (CalRecycle, 2018).

According to Rubber Pavements, the cost of asphalt has risen over 250 percent in the last 20 years: the raw material cost of asphalt was around $140 per ton in the 1990s, while it currently costs over $500 per ton of liquid. Recycled tire rubber has held steady between 12 to 17 cents a pound ($240 to $340 per ton) within the same period (Rubber Pavements Association, 2016). The cost savings of using even a percentage of recycled rubber compared to paying $500 a ton for liquid asphalt would quickly add up over the span of any roadway project, in addition to the savings of using recycled rubber as an aggregate. Another CalRecycle study, “Green Roads: Paving the Way with Recycled Tires” (CalRecycle, 2019), provides a cost comparison that outlines the cost savings of using either a RAC pavement (where rubber is used in the actual AC mix) or a recycled tire rubber aggregate in a roadway project. The comparison, which was developed for two projects completed in the state of California, showed that the cost savings are much higher when using rubber as an aggregate. However, there still is a sustainable saving in using rubber in the AC mix, and this option could grow even more popular as oil becomes scarcer.

5.6.5 Compost Filter Berms and Socks

Compost filter berms and compost filter socks are environmentally preferable erosion control methods for roadway construction and maintenance. Using compost for this purpose has several health and safety benefits, which also can offer cost savings over time, including:

- Fossil Fuel Reduction: eliminates the petroleum needed to manufacture silt fences
- Water Usage Reduction: reduced the irrigation required due to compost’s natural water retention properties and recharges the water table with excess surface water
- Waste Reduction: unlike traditional methods, compost erosion controls do not need to be removed and disposed of after use
- Improved Erosion Control: compost erosion control methods are more effective because they can absorb more water than silt fences

The capital and operational cost of using compost for erosion control is typically lower than synthetic alternatives. To assist projects in conducting a comparison of the compost-based erosion solutions, the
USEPA released a Cost Calculator Tool (USEPA, 2016). The calculator inputs the project’s size and duration to directly compare the cost of using compost berms, compost filter socks and silt fencing for project parameters. The calculator used the following factors to develop low and high cost estimates for each method of erosion control:

- Materials and install costs
- Inspection and sediment removal costs
- Repair costs

To illustrate the cost effectiveness of using compost erosion control methods, three sample projects were using the calculator with different lengths of erosion control and project durations. Table 5-6 shows the compost-based methods for erosion control are consistently lower cost than traditional silt fencing.

<table>
<thead>
<tr>
<th>Project Parameters</th>
<th>100 linear feet, 6 months duration</th>
<th>500 linear feet, 12 months duration</th>
<th>1,000 linear feet, 24 months duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- x 2-foot Compost Berms</td>
<td>$2,131</td>
<td>$5,472</td>
<td>$11,808</td>
</tr>
<tr>
<td>12-inch-diameter Compost Filter Socks</td>
<td>$2,143</td>
<td>$5,380</td>
<td>$11,030</td>
</tr>
<tr>
<td>3-inch Silt Fencing</td>
<td>$2,232</td>
<td>$6,381</td>
<td>$15,251</td>
</tr>
</tbody>
</table>

The percent cost savings of using a compost-based method for erosion control over silt fencing is shown graphically in Figure 5-1.

Figure 5-1. Savings of Compost Methods Over Silt Fencing

In 2015, the state DOTs and the U.S. Composting Council put together a collection of 10 case studies to investigate the current use of compost products for roadway applications, success stories, usage experience, and specification tables. The case studies revealed overall positive results for the projects using compost and reported the following benefits:

- Survival rates for plants planted in compost of 100 percent compared to mortalities averaging 40 percent in control groups
- Improved plant available water
- Better vegetative growth with an estimated 30 to 40 percent better coverage
- Decreased erosion
5.7 Recommendations

5.7.1 Suitability of Use in Guam Roadway Infrastructure

The Greening Roadway Infrastructure Initiative is intended to conserve landfill and hardfill space on Guam by reducing waste disposal, reducing potential additional air and water pollution sources, developing on-island markets for recycled materials, creating green jobs, and conserving nonrenewable natural resources. Considering these objectives and the results of the case study analysis, Table 5-7 provides a summary of advantages and disadvantages of as well as recommendations for each potentially suitable recycled material. Because a key aspect of implementing the use of these materials is adapting current specifications to allow or require them, suggested modifications to specific sections are included in Appendix B.
## Greening Roadway Infrastructure Initiative on Guam

### Table 5-7. Summary of Use of Recycled Materials in Guam Roadway Infrastructure

<table>
<thead>
<tr>
<th>Recycled Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Conclusion</th>
</tr>
</thead>
</table>
| RAP               | - Already being used on Guam and basic equipment is available  
- Material costs for a RAP and virgin aggregate mixture are less than material costs for a pure virgin aggregate mixture  
- Onsite production and use can result in minimized transportation and disposal costs  
-Reuse of asphalt conserves nonrenewable resources used to make virgin aggregate  
-Decreases production of GHG because production and transportation of new HMA is reduced  
-Proven material that has been studied and extensively used in construction roadway projects  
-FHWA endorses RAP use  
-RAP quality can vary and may not meet desired performance standards and specifications (for example, aggregate sizing, poor cold-weather performance, and similar)  
-RAP reuse can increase difficulty of QC in design and construction compared to virgin material  
-Capital investment in machinery and equipment will be required should RAP use significantly increase | - RAP has been successfully used in roadway projects in the U.S. and on Guam and construction trends are leaning towards use of non-virgin materials.  
-Guam DPW has recently added milling to their specifications for asphalt removal and roadway construction specifications allow for up to 15% RAP in asphalt base course mix. The current demand for RAP is to use as dirt road resurfacing in the villages, which is not its highest beneficial reuse. The better use for RAP is to recycle for use in new asphalt pavement and other roadway construction applications.  
The unit cost for RAP is less than the cost for virgin aggregate on Guam; therefore, it is appropriate that all available RAP be reused for roadway construction (an example supplementary specification is provided in Appendix B). It is therefore recommended that Guam ban the disposal of RAP in hardfills. | |
| RCA               | - Various aggregates can be 100% replaced by RCA  
- Material costs for RCA are less than material costs for pure virgin aggregate  
- Onsite production and use can result in minimized transportation and disposal costs  
- Use of RCA can increase steel recovery and recycling  
- Reuse of concrete conserves nonrenewable resources used to make virgin aggregate  
- Decreases production of GHG because production and transportation of virgin aggregate is reduced  
- Proven material that has been studied and extensively used in construction roadway projects  
- FHWA endorses RCA use  
- Use of RCA typically requires a larger amount of water in mix design  
- RCA reuse can increase difficulty of QC in design and construction, compared to virgin material  
- Capital investment in machinery and equipment will be required should RCA use significantly increase  
- RCA has the potential to be hazardous, depending on the source (for example, demolished building, sidewalk, and similar) | - RCA has been successfully used in roadway projects in the U.S. and construction trends are leaning towards use of non-virgin materials. RCA can be processed to equivalent road construction specifications as virgin aggregate (an example supplementary specification is provided in Appendix B). However, before mandating the use of RCA, additional research and/or studies should be conducted to evaluate concerns about elevated alkalinity in surface water runoff through RCA. If such research and studies confirm that RCA is safe for the environment, then use of RCA should be mandated to replace virgin aggregate for Guam’s roadway construction projects.  
- Capital investment in machinery and equipment will be required | |
| Recycled glass    | - Glass can be diverted from landfills, conserving landfill capacity  
- Significant cost savings by offsetting landfill disposal costs  
- Recycled glass in roadways can increase roadway performance and lifespan  
- Recycled glass can be used in many roadway applications, including asphalt concrete, PCC, base and subbase, embankments, and reflective paint striping  
- Current recycled glass on Guam does not meet purity requirements specified by FHWA  
- Mix design with glass must be tested and optimized to ensure adequate performance  
- Glass is not currently collected for residential or commercial recycling on Guam; implementing residential and commercial pickup programs will incur costs  
- Glass supply on Guam may be limited  
- Capital investment in machinery and equipment will be required should recycled glass be used in roadway construction  
- The glass supply on Guam may be limited; however, available glass can be incorporated into roadway construction to improve waste diversion and conserve landfill capacity.  
- All of the available recycled glass on Guam could be immediately used in roadway construction by incorporating crushed glass into the roadway embankment prism below the surface. An example of an appropriate specification for this use would be to crush the glass to a size of 3 inches or less in its largest dimension, scarsey the glass layer 6 inches deep into the existing embankment, and recompact to the specified embankment density.  
- To use additional quantities of recycled glass, additional processing and testing of recycled glass purity will be required to meet FHWA requirements. If Guam decides to pursue the use of glass in roadways, ongoing supply and future construction needs (that is, trench backfill, subbase, base aggregate, and utility bedding) should be assessed.  
- If Guam wants to remove glass from the waste stream, consideration must be given to enacting a ban on landfill or hardfill disposal of glass, setup of a collection system, and required use in roadway and utility construction, pending available volumes. | - The unit cost for recycled glass is less than the cost for virgin aggregate on Guam; therefore, it is appropriate that all available recycled glass be reused for roadway construction (an example specification is provided in Appendix B). It is therefore recommended that Guam ban the disposal of recycled glass in hardfills.  
- Additional research and/or studies should be conducted to evaluate concerns about elevated alkalinity in surface water runoff through recycled glass. The impacts of stormwater leachate through the recycled glass should be evaluated.  
- The better use for recycled glass is to use as embankment materials. Recycled glass can be immediately used in roadway construction in embankments, if appropriate performance specifications are met. The impacts of stormwater leachate through the recycled glass should be evaluated.  
-Waste tires can be crumbled for use in roadway construction; however, this is not currently economical given the significant investment required for specialized equipment and the potentially limited supply of tires. The available recycled glass on Guam is unknown and may vary from year to year. The sustainability of this new market may not be favorable given the anticipated supply and demand. If Guam decides to use waste tires in roadways, ongoing supply of suitable processed tires and future construction needs should be assessed.  
-Costs for additional equipment could be offset by obtaining grants. | |
| Waste tires       | - Use of waste tires on-island will reduce current costs to dispose of/recycle off-island  
- Supply is readily available  
- Significant investment in specialized equipment will be required should tires be used in roadway construction (it is not currently economical, and many stakeholders are opposed)  
- Use of tires will require increased quality control effort to screen foreign material  
- Although supply is readily available, it may be limited depending on construction needs and may not be worth the investment | - The best use of shredded tires is to use them in embankments. Shredded tires can be immediately used in roadway construction in embankments, if appropriate performance specifications are met. The impacts of stormwater leachate through the shredded tires should be evaluated.  
-Waste tires can be crumbled for use in roadway construction; however, this is not currently economical given the significant investment required for specialized equipment and the potentially limited supply of tires. The available recycled glass on Guam is unknown and may vary from year to year. The sustainability of this new market may not be favorable given the anticipated supply and demand. If Guam decides to use waste tires in roadways, ongoing supply of suitable processed tires and future construction needs should be assessed.  
-Costs for additional equipment could be offset by obtaining grants. | |
### Table 5-7. Summary of Use of Recycled Materials in Guam Roadway Infrastructure

<table>
<thead>
<tr>
<th>Recycled Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Conclusion</th>
</tr>
</thead>
</table>
| Compost           | • Supply is readily available  
• Application in roadside development/erosion control is not difficult and placement methods do not require specialization  
• Compost can be diverted from landfills, conserving landfill capacity  
• Compost can be used beneficially in other applications outside of roadway construction | • Compost facilities are not popular with the public due to odors and vectors; there may not be enough space on Guam to site a facility sufficiently distant from residences  
• Compost must be sorted to reduce contamination and requires a robust curbside collection program and compliance by the public  
• Composting processes can be cost-intensive  
• Relatively limited use in roadway construction; can only be used for roadside development/erosion control | Over the last decade, several private companies on Guam have developed operations to recycle green waste into mulch and compost that can be used in roadway erosion control applications. To sustain these local operations, on-island markets for Guam’s mulch and compost must be created in order to provide demand. Therefore, Guam should mandate, via roadway project specifications, that locally produced mulch/compost be used for erosion control in roadway construction projects. Prior to such mandate, capacity of these operations should be confirmed to ensure they can meet the demand. Outreach should be conducted to address perception issues related to rhino beetle infestation.  
Composting of green waste, food waste, and biosolids should be added to composting programs as the programs mature.  
Investigate the feasibility of manufacturing filter socks for compost on Guam for use in erosion control. |

Over the last decade, several private companies on Guam have developed operations to recycle green waste into mulch and compost that can be used in roadway erosion control applications. To sustain these local operations, on-island markets for Guam’s mulch and compost must be created in order to provide demand. Therefore, Guam should mandate, via roadway project specifications, that locally produced mulch/compost be used for erosion control in roadway construction projects. Prior to such mandate, capacity of these operations should be confirmed to ensure they can meet the demand. Outreach should be conducted to address perception issues related to rhino beetle infestation. Composting of green waste, food waste, and biosolids should be added to composting programs as the programs mature. Investigate the feasibility of manufacturing filter socks for compost on Guam for use in erosion control.
5.7.2 Implementation

The following short-term actions are recommended to continue moving Guam’s Greening Roadway Infrastructure Initiative forward:

1) Establish a “One Guam” Greening Roadway Infrastructure Initiative Working Group to facilitate the roll-out and implementation of this initiative. This group should meet a minimum of once every other month and report to the Governor’s office on progress every 180 days. This group should be chaired by the Guam EPA and include the following members: Guam EPA, Guam DPW, Guam Water Authority (GWA), Guam Power Authority, Mayors Council, USEPA, and FHWA. Discussions may need to be facilitated to keep the group on course and moving in a positive direction. Action items for the group include the following:
   - Gain consensus on what recycled materials will be accepted for use in paving course, base course, and subbase course for primary and secondary roads.
   - Agree on recycled materials to promote in other roadway infrastructure applications, such as glass beading in roadway paint, shredded tires in embankment, compost for revegetation after roadway construction, trench bedding and backfill, drainage aggregate, septic fields, and similar.
   - Leverage group to explore/initiate use in other utility applications of recycled materials that did not make the cut for the Greening Roadway Infrastructure Initiative.
   - Establish a reporting structure for use of recycled materials in roadway infrastructure on primary and secondary roadway infrastructure projects and other applications.
   - Determine if the Guam Airport and Port Authorities might be viable partners in this initiative (that is, can they use recycled materials in infrastructure associated with airport runways, aprons, and airport and port maintenance roads).
   - Begin tracking use of recycled materials in roadway infrastructure projects on Guam; report use to USEPA, FHWA, and the Association of State and Territorial Solid Waste Management Officials (ASTSWMO); and provide recognition rewards for use of recycled materials in roadway infrastructure.
   - Determine if there is interest and support for investment of needed equipment and machinery.
   - Evaluate group involvement with industry leaders in various recycling applications.

2) At the ASTSWMO 2019 Midyear Meeting in May, find out the status of new and current state initiatives regarding recycled materials in roadway infrastructure and determine if any actions being implemented by the states would be of benefit to Guam.

3) Once specific recycled materials are picked for primary and secondary roads (paving course, base course and subbase course), establish an Ad-Hoc Committee of Guam EPA, Guam DPW, and FHWA; agree on percentage range of recycled materials allowed in each application, performance requirements, monitoring, and QC testing requirements; and recommend existing specifications that can be used or tailor existing Guam DPW specifications (example supplemental specifications are provided in Appendix B).

Follow-up and ongoing actions recommended to move toward full-scale implementation of Guam’s Greening Roadway Infrastructure Initiative include, but are not limited to, the following:

1) Have a dedicated Guam webpage for the Greening Roadway Infrastructure Initiative (to possibly be co-maintained by Guam EPA and Guam DPW) where engineers or contractors can go to obtain information specific to the Greening Roadway Infrastructure Initiative; the page should include a list of allowable recycled materials in roadway infrastructure with picture icons (asphalt, concrete, aggregate, base/subbase, embankment), links to suppliers of recycled materials, and links to approved specifications.

2) Provide outreach to various communities potentially affected by the initiative to let them know about the push to use recycled materials: architects and engineers, construction contractors, and material suppliers.
3) Implement ongoing tracking of use of recycled materials in roadway infrastructure projects on Guam; track metrics over time; report use to USEPA, FHWA, and ASTSWMO; and provide recognition rewards for use of recycled materials in roadway infrastructure.

4) Research grants that are available for recycled materials in roadway infrastructure pilot/demonstration projects with the federal government (USEPA and FHWA) and non-governmental organizations and provide recommendations for applying.

5) In conjunction with GSWA, determine the viability of adding glass to Guam’s residential and commercial recycling programs.

6) In conjunction with Guam DPW, determine the volume of RAP and RCA likely to be available from primary and secondary road construction/reconstruction projects over the next 10 years.

7) Develop business pro formas for investment in various recycling equipment (RAP, RCA, recycled glass, waste tires, and compost) to determine actual equipment cost basis and equipment amortization schedules.

8) Determine if incentives in the form of tax breaks, low-cost loans, and grants are needed to attract industry to invest in this initiative.

9) Determine if legislative changes are needed to move this initiative forward.
6. References


Bay Area Recycling for Charities (BARC). 2019. *Spring Into Composting | Everything you Need to Know.* May 1. https://mybarc.org/composting-101/?gclid=EAIaIQobChMI0siBk7-y4lVDMZkCh3rwqIeAYASAAEgKDk_D_BwE.


Greening Roadway Infrastructure Initiative on Guam

Closed Loop Foundation. 2017 Glass Clean-up Systems in MRFs. April. 


www.pca.state.mn.us/sites/default/files/ramsey.pdf.


Greening Roadway Infrastructure Initiative on Guam


Greening Roadway Infrastructure Initiative on Guam


Appendix A

State Highlights: Use of Recycled Materials in Roadway Infrastructure by State
Appendix A: State Highlights: Use of Recycled Materials in Roadway Infrastructure by State

A.1 Introduction

Appendix A provides a more detailed description of documents and projects summarized in Section 4.2. These initiatives, organized by state, provide an overview of what is being done on the state level in the U.S. to develop and promote the use of recycled materials in roadway infrastructure.

A.2 California

In 2003, the California Department of Transportation (Caltrans) published their Asphalt Rubber Usage Guide (Usage Guide). This guide covers the proper use of crumb rubber modifiers in roadway construction in California roadways. The purpose of the guide is to provide best management practices (BMPs) to help engineers, construction contractors, and material suppliers obtain the advertised benefits of using waste tire in roadway construction projects. The Usage Guide covers the different applications that asphalt rubber can be used for, the benefits and drawbacks of using the material, and cost considerations. Design procedures are thoroughly discussed in the Usage Guide, including requirements for crumb rubber modifier and use of supplemental specifications, design considerations, and proper design procedures. In addition to design considerations, the guide presents methods for rubber preparation, including the specific types of equipment needed. Proper construction and inspection is also covered at the end of the guide, making this a beginning-to-end guide (Caltrans, 2003).


Section 39 of the Caltrans Standard Specifications for Hot Mix Asphalt (Caltrans, 2018) covers testing, gradation, quality characteristics, general requirements, and applications and also includes requirements for crumb-rubber-modified binder and asphalt-rubber binder. The Caltrans Standard Specifications allow for the use of 100 percent reclaimed asphalt pavement (RAP) in shoulder backing; if 100 percent RAP is used, then the shoulder backing must be graded to meet certain requirements laid out by the specifications. Also allowed is the use of up to 25 percent RAP in the production of new asphalt concrete; the asphalt concrete must pass all applicable and specified American Association of State Highway and Transportation Officials (AASHTO) tests. Crumb-rubber modifier may be used in bituminous seals, asphalt concrete, and asphalt binders. Quality characteristics, gradation, testing methods, and maximum percentage of material allowed are all given per application. Caltrans also lists many of its own testing methods in the Usage Guide, along with acceptable AASHTO testing methods.


A.3 Florida

The Florida Department of Transportation (FDOT) follows and adheres to both AASHTO and Federal Highway Administration (FHWA) recycled materials policies and standards. FDOT states that they will accept data from other states, when appropriate, to help develop a new specification. The data that they are pulling from needs to meet FDOT specific needs, material properties, and environmental requirements as mentioned in the Frequently Asked Questions section of the FDOT State Materials Office website (FDOT, n.d.).


In December 2014, the University of Florida completed a research project regarding development strategies for improving the use of recycled materials in FDOT projects. This research project covered the use of RAP, recycled concrete aggregate (RCA), waste tires, and recycled glass. Each of the recycled
materials physical properties were discussed, and experienced industry professionals were brought in to discuss results of using the recycled materials, barriers, and how to improve the use of the recycled material. Focus groups were also brought in for the project. The focus groups developed recommendations for each recycled material including preliminary ideas, recommended strategies for each recycled material, and a list of sample contract specifications from different states to help FDOT incorporate these materials into their specifications (University of Florida, 2014).

Link: rosap.ntl.bts.gov/view/dot/28433

Based on interviews with industry professionals, the physical and chemical aspects, availability, and feasibility of using each recycled material was discussed (University of Florida, 2014). Demand for RCA is higher than the supply; many projects in Florida use this recycled material as much as possible already. Recycled glass is a costlier recycled material for FDOT; however, the state has successfully used ground recycled glass as a fine aggregate component. RAP stockpiles currently exceed the need for the material. RAP is being used as much as possible in projects, but the amount generated from roadway resurfacing exceeds the amount needed. Because of this, it was determined that FDOT needs to come up with alternative uses for RAP. Findings from this project included the following:

1) Recycled materials work very well in roadway infrastructure projects; however, most contractors do not know how and to what extent recycled materials can be used in lieu of or as a supplement to virgin aggregate materials. Guidance is needed on acceptance testing and protocol for implementation.

2) FDOT should consider awarding technical points to contractors and consultants for using recycled materials.

3) FDOT should develop standard specifications that incorporate recycled materials for pavement and other roadway infrastructure components.

4) FDOT should hold educational seminars regarding the acceptability of recycled materials to get the word to the design and construction community as soon as possible.

As of 2019, FDOT has RCA, RAP, and recycled glass implemented into their Standard Specifications. The specifications allow for the use of RCA and RAP as base course, an optional base course, and as a granular subbase. RCA is also allowed for use as a base and stabilized base material. The specifications allow RAP to replace up to 20 percent of the aggregate in PCC. Recycled crushed glass, if all requirements are met, can be used up to a maximum of 15 percent by weight of total aggregate in an asphalt mixture. Along with all the allowable uses, the specifications give specific requirements that each recycled material needs to meet and what tests can be performed on these materials (FDOT, 2019).

Link: https://www.fdot.gov/programmanagement/specs.shtm

A.4 Hawaii

The state of Hawaii commissioned a report in 2011 entitled Sustainable Pavement Solutions for O‘ahu that explored the use of recycled materials in pavement construction projects (Muench and Muramoto, 2011). The report explored uses for common recycled materials on the Hawaiian islands and determined what and how each could be used. Construction specifications were developed based on recommendations contained in the report.


The Hawaii Department of Transportation (HDOT) not only allows but requires the use of recycled glass cullet in roadway construction in roadway base and subbase courses, as well as in embankment. An exclusion can be applied if the cost of the recycled glass cullet exceeds virgin aggregate or if cullet is not produced locally. Cullet is also used in utility and drainage operations at a maximum content of 100 percent by weight reducing the need for blending (HDOT, 2005).

Recycled glass is also used in a glassphalt base course that can also use RAP. HDOT glassphalt uses up to 10 percent recycled glass cullet and 20 percent RAP by weight. Similar to recycled glass cullet use, glassphalt may be replaced with traditional hot mix asphalt (HMA) if the cost of its use exceeds the cost of HMA. Notably, HDOT does not allow use of recycled glass cullet in HMA base or wear courses. This is because of the poor performance of asphalt mixes when recycled glass cullet was incorporated. HDOT does allow the use of RAP in HMA (HDOT, 2005).

A.5 Michigan

The Michigan Department of Transportation (MDOT) has used RCA in transportation-related construction projects since the 1980s. To decrease the environmental impact and increase the use of recycled materials in transportation-related construction projects, in 2011, MDOT commissioned the Using Recycled Concrete in MDOT’s Transportation Infrastructure – Manual of Practice report, which is limited to the subject of RCA and introduces the benefits and limitations, potential uses and applications, and MDOT’s experience with this recycled material. The process and production of RCA is broken down into steps to help show how to manage the material, and the physical and chemical properties of RCA are discussed to prove why this recycled material can be beneficially reused in certain applications. Finally, the manual details the procedure of using RCA in base layers, asphalt paving layers, and concrete pavement mixtures. Each process has different requirements; checklists for those requirements are included in the manual. Because of the research that went into developing the manual, RCA is now incorporated into MDOT’s Standard Specifications and special provisions for aggregate uses in dense graded aggregate, earthwork, shoulders, HMA, and concrete mixes (Applied Pavement Technology, Inc., 2011).


Since the early 1990s, MDOT has also conducted research and testing related to the use of crumb rubber from waste tires to determine how to successfully incorporate this recycled material into roadway infrastructure construction. In 2014 the Michigan Department of Environmental Quality awarded several grants to study rubberized asphalt. A pilot project was conducted in which 6,000 tons of crumb rubber modified HMA was used to construct a new, 3.2-mile-long road. As a result of the various studies and the success of this pilot project, crumb rubber has been implemented into the MDOT Standard Specifications (Applied Pavement Technology, Inc., 2011).

According to the MDOT Standard Specifications, RAP may be substituted for a portion of new material required to produce an HMA mixture. Limitations on the percentage of RAP that may be incorporated into the mix are not specified, only that the mix must meet all performance criteria in the specification. MDOT Standard Specifications also allow the use of RCA in various applications, including curb and gutter, valley gutter, sidewalk, concrete barriers, and driveways. Similar to RAP, limitations on the percentage of RCA that may be incorporated into the mix are not specified, only that the mix must meet all performance criteria in the specification (MDOT, 2012).

Link: https://mdotboss.state.mi.us/SpecProv/specBookHome.htm

A.6 Minnesota

In the 1980s, the Minnesota Department of Transportation (MnDOT) began research and development work related to the use of RCA in pavement mixes. Years later, they found that using RCA throughout the entire slab could cause cracking in the middle of the slab. MnDOT now only uses RCA in base and subbase courses. This ensures longevity of the road while still promoting environmental sustainability (MnDOT, 2017). Over the years, MnDOT has had several environmental concerns regarding the use of RCA in roadway infrastructure applications. Because of these concerns, MnDOT has conducted various field and laboratory studies, which have found that crushed concrete can produce various precipitates that are harmful to the environment. The specification that allowed the use of RCA in several applications was subsequently revised and now only allows the use of RCA in specific applications, suggests washing of the material prior to use, and sets out other performance standards that must be met if RCA is used (MnDOT, 1995).

Link: dotapp7.dot.state.mn.us/research/pdf/199612.pdf
In the early 1990s, the MnDOT and Sibley County, Minnesota, initiated a project to decrease the volume of glass being disposed of in local landfills and to beneficially reuse recycled glass in an aggregate mix used for roadway construction (Minnesota Local Road Research Board, 2001). MnDOT subsequently conducted a significant amount of research and development regarding the use of recycled glass in pavement mixes and in 1999 included recycled glass in their Standard Specifications for construction.

Link: [www.pca.state.mn.us/sites/default/files/glasstoolkit.pdf](http://www.pca.state.mn.us/sites/default/files/glasstoolkit.pdf)

With more research being done over the years, the MnDOT Aggregate for Surface and Base Courses Standard Specifications (2018) have been updated to include a Class 7 aggregate, which includes salvaged or recycled aggregate materials. Wherever possible, the state attempts to include recycled material into an aggregate mix. If salvaged or recycled material is used in Class 7 aggregates, MnDOT requires a minimum of 10 percent usage up to a maximum of 100 percent use if certain conditions are met. Class 7 remains broad in definition to encourage contractors to use different recycled materials that they see fit for the project, not just recycled glass, as long as the recycled materials meet the performance requirements set forth in the specifications.

Link: [http://www.dot.state.mn.us/pre-letting/spec/](http://www.dot.state.mn.us/pre-letting/spec/)

### A.7 Montana

The 2006 State of Montana Integrated Waste Management Plan declared that the state will be steadily reducing the amount of non-hazardous industrial waste that may be disposed of into their landfills and has developed a series of document and specifications to meet that goal. In 2010, the Montana Department of Environmental Quality published the *Guide to Beneficial Use Determinations of Waste Industrial and Manufacturing Byproducts*, which provides in-depth information regarding which industrial and manufacturing byproducts may be eligible for beneficial reuse. For a byproduct to be eligible for beneficial reuse, it must be able to be used in its original form without need for treatment or reprocessing. The criteria used to evaluate eligibility include, but are not limited to, its protectiveness of human health and the environment, diversion of waste from a disposal facility, resource or energy conservation potential, and other requirements. The guide also includes a Beneficial Use Determination Application Form that requires supplemental information be provided. The more supplemental information provided with the application, the better the chance that the state will license the byproduct for beneficial reuse. While this guide is a beneficial tool in determining usefulness of industrial byproducts, currently the only two materials eligible for a beneficial use determination as outlined by the guide are coal combustion residue and lime kiln dust (Montana Department of Environmental Quality, 2010).


The Montana Department of Transportation (MDT) allows the use of several recycled materials in roadway infrastructure construction, including RAP and recycled glass. Specifically, the MDT Standard Specifications allow up to 15 percent RAP by weight to be incorporated into the top 0.15-foot layer of warm mix surfacing. They also allow up to 30 percent RAP by weight to be incorporated into the lower lifts of the warm mix surfacing.


The MDT 2016 *Pavement Design Manual* provides guidelines and details about how and when to apply RAP to pavement design. Recycled glass may also be used as an aggregate blending material if approved by MDT. It must adhere to the requirements in the MDT standards and the AASHTO standards referenced in the MDT specifications. Recycled glass can be up to a maximum of 10 percent of the total blended aggregate filler product.

Link: [https://www.mdt.mt.gov/other/webdata/external/pavementanalysis/pavementdesignmanual.pdf](https://www.mdt.mt.gov/other/webdata/external/pavementanalysis/pavementdesignmanual.pdf)

### A.8 New Jersey

New Jersey Department of Transportation (NJDOT) Standard Specifications allow for the use of several different recycled materials in an HMA base or intermediate course, including RAP, recycled glass,
Appendix A: State Highlights: Use of Recycled Materials in Roadway Infrastructure by State

recycled asphalt shingles (RAS), and remediated petroleum-contaminated soil aggregate. The HMA base or intermediate courses may contain up to 35 percent recycled materials. The specification includes individual maximum percentages for each recycled material: for example, up to 25 percent RAP and up to 10 percent recycled glass can be used (NJDOT, 2007). When RAP is used, it needs to conform to certain quality control (QC) requirements. These requirements are clearly outlined in the specifications and are no different than the standard requirements when standard materials are used. When recycled glass is used, 100 percent of the material needs to pass a 3/8-inch sieve. Recycled glass has an additional requirement, the material has a maximum allowable percentage of foreign materials. This state is also one of the many states that have included glass beads in their traffic control devices, permanent traffic striping, and marking standard specifications (NJDOT, 2007).


For RCA in aggregate base course, sidewalks, islands, and driveways, the NJDOT Standard Specifications allow the use of both RCA and RAP. RCA can be 100 percent comprised of RCA if it meets the composition, and percentage of wear requirements. RAP can be no more than a maximum of 50 percent of the RCA mix; the rest must be virgin RCA.

A.9 Ohio

In May 2017, a study was conducted that assessed the feasibility of using recycled glass as an aggregate in Ohio roadway construction applications. The study investigated the supply of recycled glass and compared it to potential project demand. It was concluded that supply more than met demand and that the state had many applications that could use this material. Glass processors and recycling facilities around the state showed strong interest in participating in projects to help eliminate glass waste in landfills (Tao, 2017).

Link: www.dot.state.oh.us/groups/oril/Documents/Projects/Reports/135329FinalReport.pdf

The Ohio DOT recently issued an update to their Standard Specifications. Specification 703, Aggregates, allows for the use of RCA and RAP for embankment construction. When using either material, the specification requires they be blended with at least 30 percent natural soil or natural granular material. Ohio DOT Standard Specifications 410, 411, and 617 all allow materials conforming to Standard Specification 703. This means that RAP or RCA can both be used in traffic compacted surfaces, stabilized crushed aggregate, or reconditioning shoulders. Currently, the state works with several different RAP and RCA recycling centers to provide the material to their contractors. The most recent update to Standard Specification 703 includes guidance on usage of steel slag aggregate, granulated slag, and blast furnace slag in coarse and fine aggregate, structural backfill, and embankment. The specification also describes handling and usage of slag in embankments to minimize environmental impacts.


A.10 Oregon

Oregon Department of Transportation (ODOT) Standard Specifications state that the contractor shall use recycled materials to the maximum extent practical while still being economically feasible. Currently RAP, recycled glass, and compost are all incorporated into ODOT Standard Specifications. Up to 30 percent RAP may be used in the production of new porous asphalt concrete or in the production of asphalt concrete pavement. With either application, the rest of the product must be virgin aggregate material. RAP is allowed in all levels of the asphalt concrete pavement at 30 percent maximum, except for a 20 percent maximum allowed in the Level 4 wearing course. When it comes to RAP usage, ODOT relies heavily on the AASHTO standards. Whenever RAP usage is called out in the ODOT Standard Specifications, AASHTO standards are referenced. The ODOT Standard Specifications allow for the use of recycled glass as selected granular backfill, selected stone backfill, and drainage blankets. There is a specific section dedicated to recycled glass, which covers the applications, hauling and placement, compaction, and testing of this recycled material in roadway infrastructure components. ODOT has also been using compost as an erosion control material for many years. Compost is commonly used in many
Appendix A: State Highlights: Use of Recycled Materials in Roadway Infrastructure by State

Oregon projects; the state allows for the use of compost in many applications including erosion control blankets, sediment barriers, and filter berms and has Standard Specifications for these applications (ODOT, 2018).


In 2015, The Oregon Department of Environmental Quality released a fact sheet about the beneficial use of reclaimed asphalt grindings. The factsheet addressed BMPs for this recycled material and its benefits (Barrows, 2015).

Link: https://www.oregon.gov/deq/FilterDocs/benuse-asphalt.pdf

A.11 Texas

The Texas Department of Transportation’s (TxDOT) Road to Recycling Initiative identifies a wide variety of recycled materials and provides information regarding potential recycled materials applications in roadway construction. TxDOT has identified 12 recycled materials with a high probability for successful use in roadway infrastructure construction projects, with compost, recycled glass, RCA, and waste rubber included as 4 of the 12 identified materials. Each of the 12 materials has a packet of information pulled together by the state; these packets include guidelines, demonstration projects, research, reports, specifications, and availability. Not all the information in these packets originated within TxDOT; rather the packets contain a compendium of information from TxDOT and other state and federal agencies with relevant information.

Link: www.txdot.gov/inside-txdot/division/support/recycling/materials.html

The TxDOT Standard Specifications allow for the use of RAP in a variety of applications, including base course with a flexible base, cement treatment, asphalt treatment, dense-graded HMA, and permeable friction course. For base course asphalt treatment, RAP is allowed up to a maximum of 30 percent by weight. The state has their own readily available stockpile of RAP; if a contractor wants to use RAP from a different stockpile, they must submit information to the state and meet certain requirements. This state has a wide variety of allowed applications for RAP as well as many requirements that they have standardized (TxDOT, 2014).


Texas is a major user of RCA; as stated in TxDOT’s online “Roadway Recycled Materials Summaries,” around one million tons of RCA are reclaimed and reused annually by TxDOT. The TxDOT Standard Specifications allow for the use of RCA in a variety of applications, including asphalt treated base course, fine aggregate for concrete, and base aggregate. No limits were listed for asphalt treated base course and base aggregate. If RCA is used for fine concrete aggregate, it is limited to a 20 percent usage.

Similar to other states, TxDOT has implemented compost into their Standard Specifications as compost manufactured topsoil, erosion control compost, or general use compost (TxDOT, 2014). Compost manufactured topsoil is a blend of 25 percent compost with 75 percent topsoil either blended in place, blended onsite, or plant blended. Erosion control compost consists of 50 percent compost and 50 percent wood chips. General use compost is compost used for plant bed preparation or as a top dressing.

In 2007, TxDOT and the Texas Commission on Environmental Quality released the Using Scrap Tires and Crumb Rubber in Texas Highway Construction Projects report, which explores the opportunities, benefits, and research progress of using waste tires. The report also discussed previous issues in using waste tires for which TxDOT had come up with solutions. Based on this progress report, TxDOT has made significant progress: they have made sure that their goals align with their strategic plan, they had new contracts that require the use of several thousand tons of scrap tire in paving applications, and they continue to evaluate other innovative uses for transportation-related tire-rubber products. The report focused on new or previously unresolved issues, such as illegal scrap tire dumping, demand for scrap tire not being high enough, and funding for clean-up not being high enough. Even with the persisting issues, this progress report shows that TxDOT is pursuing new applications for scrap tire use and is working to encourage the existing markets to grow as well (TxDOT, 2007). Currently, TxDOT has incorporated
crumb rubber into the TxDOT Standard Specifications. Crumb rubber may be used in asphalt-rubber binders at a minimum of 15 percent by weight.


### A.12 Washington

The Washington Department of Transportation (WSDOT) Standard Specifications allow for the inclusion of RAP in HMA mixes. The specifications have two HMA mix designs classified by the amount of RAP content; based on the classification, there are different design submittals, ways to stockpile, and testing frequencies. Currently the Standard Specification allows for up to 40 percent RAP in the HMA mix. The Standard Specifications include details about the mixing process, RAP quality (that is, what must be removed from the RAP prior to use), when to add RAP to the mixer, and maximum water content in the mix. The WSDOT Standard Specifications also require that contractors use a minimum of 25 percent of RCA for the total quantity of aggregate incorporated into a contract that uses WSDOT Standard Specifications. This usage is verified through a contractor-supplied utilization plan that is required prior to construction, with actual usage reported at construction completion. The specifications also include a table that provides different applications that specific recycled materials can be used for, with each application having a different maximum allowable percentage of recycled material. Each application has different general requirements that the recycled material must meet (WSDOT, 2018c).

Link: [https://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/SS.pdf](https://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/SS.pdf)

Chapter 9 of WSDOT’s *Construction Manual* goes over how the quality of a material can be evaluated and accepted (WSDOT, 2019). WSDOT also has a standard practice for certifying sources of RCA to maintain consistent quality of the product. There is a standard practice for both known and unknown concrete sources (WSDOT Standard Practice QC-9 [WSDOT, 2018a] and QC-10 [WSDOT, 2018b]).


### A.13 Wisconsin

The Wisconsin Department of Transportation (WisDOT) allows the use of RAP, RCA, RAS, and recycled glass in a variety of roadway infrastructure component applications if all required performance requirements are met (WisDOT, 2019). Prior to 2012, the WisDOT allowed the use of RAP in HMA mixes following AASHTO’s Superpave Specifications (Specification M 323), allowing up to 25 percent RAP in surface courses and 35 percent in lower courses as a binder replacement (WisDOT, 2012). As of the 2019 WisDOT *Standard Specifications for Construction*, the maximum amount of RAP allowed for binder replacement in surface courses was decreased to 20 percent and the maximum amount of RAP allowed for binder replacement in all lower courses was decreased to 25 percent. These maximums may be exceeded on a case-by-case basis. Recycled glass may be used up to a maximum of 12 percent by weight in most base courses.


WisDOT allows RCA use in base and subbase aggregates. Aggregates using RCA are classified as crushed concrete if the material consists of greater than 90 percent concrete, blended material if it consists of less than 90 percent concrete, or reprocessed material if it consists of between 80 percent and 90 percent crushed concrete as well as containing crushed asphalt. WisDOT allows the use of RCA as dense graded base and both coarse and fine aggregate for new concrete so long as it meets a specific gradation.
Appendix B

Example Supplemental Specifications
Incorporating Recycled Materials
Section 204 – Excavation and Embankment

Description

204.02 Definition. This subsection is amended as follows:

(a) Excavation

(1) Roadway excavation. The definition of this item shall include sub-excavation of material below sub-grade as shown on the plans. All sub-excavated material suitable for embankment may be reused.

204.03 Materials. The following is added to this subsection:

| Glass Cullet       | 704.14 |

Construction Requirements

204.06 Roadway Excavation.

(a) General. The following is added to this subsection:

Excavation: Where clayey silty soils exist within the upper 1.5 feet of the final roadway subgrade elevation, including the road shoulders, these soils shall be excavated for replacement with well compacted, non-expansive limestone fill meeting the requirements of Section 704.10.

Re-compaction and proof rolling: After stripping and required excavation are completed, the exposed surface shall be scarified to a depth of approximately 6 to 8 inches, moisture conditioned as necessary and compacted with a heavy vibratory roller, until it is dense and unyielding with at least 95 percent of its maximum dry density (per ASTM D1557). The compacted surface should be relatively uniform, dense, and non-yielding.

Spot Repairs: Where the stripped or excavated ground surface is soft and yielding, and where soft and yielding spots are detected during the above re-compaction and proof rolling, the soft or yielding soils should be excavated entirely and replaced with limestone sand/gravel fill compacted to at least 95 percent of its maximum dry density. The Project Engineer shall inspect, evaluate, and determine the need for spot repairs.

(b) Rock Cuts. This item is revised as follows:

Blasting is not permitted. Excavate rock cuts to 6 inches below subgrade within the roadbed limits. Backfill to subgrade with non-expansive limestone fill meeting the requirements of Section 704.10.

Add the following Subsection:

204.09 Preparing Foundation for Embankment Construction. This subsection is revised as follows:

After stripping and required excavation are completed, the exposed surface shall be scarified to a depth of approximately 6 to 8 inches, moisture conditioned as necessary and compacted with a heavy vibratory roller, until it is dense and unyielding with at least 95 percent of its maximum dry density for cohesionless soils and 90 percent for cohesive soils (per ASTM D1577). The compacted surface shall be relatively uniform, dense, and non-yielding.
204.10 Embankment Construction. This subsection is modified as follows:

All fill materials should be free of organic matter, debris and rock fragments or silt/clay lumps larger than 4 inches, or one-half the compacted layer thickness, in greatest dimension. The upper 12 inches of the roadway final subgrade should consist of non-expansive, select or subbase limestone sand and gravel meeting Subsection 703.05.

Onsite excavated silty sandy limestone gravel fill (existing road base/subbase) meeting the above requirements may be reused as select or subbase fill as well as general fill. Onsite excavated silty or clay soils may be reused as general fill outside roadway and shoulder limits.

Approved fill materials shall be placed in loose layers 8 inches or less, moisture conditioned as necessary and compacted to at least 90 percent maximum dry density for cohesive silt or clay soils and 95 percent for limestone fill including select or subbase fill.

204.14 Disposal of Unsuitable or Excess Material. This subsection is amended as follows:

Dispose of unsuitable or excess material according to Subsection 203.05.

*** END OF SECTION 204 ***
Section 209 – Structure Excavation and Backfill

Description

209.02 Materials. The following is added to this subsection:

- Recycled Concrete Aggregate 704.13
- Glass Cullet 704.14

*** END OF SECTION 209 ***
Section 254 – Crib Walls

254.02 Material. The following is added to this subsection:

Recycled Concrete Aggregate 704.13

*** END OF SECTION 254 ***
Section 301 – Untreated Aggregate Courses

301.02 Material. The following is added to this subsection:

Recycled Concrete Aggregate 703.20
Glass Cullet 703.21

*** END OF SECTION 301 ***
Section 308 – Minor Crushed Aggregate

308.02 Material. The following is added to this subsection:

- Recycled Concrete Aggregate
  - 703.20
- Glass Cullet
  - 703.21

*** END OF SECTION 308 ***
Section 501 – Rigid Pavement

501.02 Material. The following is added to this subsection:

Recycled Concrete Aggregate 703.20

*** END OF SECTION 501 ***
Section 601 – Minor Concrete Structures

601.02 Material. The following is added to this subsection:

Recycled Concrete Aggregate 703.20

*** END OF SECTION 601 ***
Section 614 – Lean Concrete Backfill

614.02 Material. The following is added to this subsection:

Recycled Concrete Aggregate 703.20

*** END OF SECTION 614 ***
Section 615 – Sidewalks, Drivepads, and Paved Medians

Description

615.01. Revise this subsection to read as follows:

This work consists of constructing sidewalks, drive pads, paved medians, and detectable warning pads.

Sidewalks, drive pads, and paved medians are designated as concrete, asphalt, or concrete brick.

Material

615.02. Revise this subsection to read as follows:

- Untreated Aggregate Courses 301
- Hot Mix Asphalt (HMA) Concrete Pavement by Marshall Mix Design Method (AASHTO T 245) 402
- Reinforcing Steel 554
- Minor Concrete Structures 601
- Recycled Concrete Aggregate 704.13
- Glass Cullet 704.14

Detectable Warning Materials. Detectable warning surfaces comprised of truncated domes will be supplied on pedestrian ramps as specified in the plans. All detectable warning surfaces shall meet the requirements of the Americans with Disabilities Act (ADA). Surface-applied truncated domes, field-applied surface coatings/paint, stamped concrete, imprint plastic and/or asphalt shall not be accepted. Acceptable panels shall be precast, modular, and prefabricated only. Panels shall have homogenous coloring. Field applied surface coatings to the panel shall not be permitted.

Detectable warning surfaces using modular brick pavers shall comply with the requirements of ASTM C 902, Class SX, Type I.

Panel color shall be Federal Yellow #33538.

Submit 1-foot-square samples for evaluation to the Project Engineer for acceptance.

Construction Requirements

615.03 General. Revise this Subsection to read as follows:

Excavate and backfill according to Section 204 Excavation and Embankment. Place aggregate base in layers not exceeding 6 inches in compacted thickness. Compact each layer according to Section 204.10(b) Embankment within the roadway prism.

- 615.04(a)(1) Expansion joints - Delete this subsection.
- 615.04(a)(2) Contraction joints - Add the following section to the end of this subsection.
All formed joints shall be a tooled joint using a standard ½” concrete groove tool with 3/8” rounded edges.

615.04 Concrete Sidewalks, Drive Pads, and Medians. Revise this subsection to read as follows:

(b) Finishes. Add the following:

(2) Patterned Concrete Median Surface. The patterning for the concrete median surface shall be stamped into the concrete. The proposed pattern shall be selected by the Contractor and drawings showing the proposed pattern shall be submitted with the bid documents. Final approval of the selected pattern shall be made by the Project Engineer. Application of the pattern shall be done in accordance with the manufacturer’s recommendations.

The concrete shall be placed and finished in accordance with Subsection 552.14(c)(2) except the area to be stamped shall not be broomed. When the bleed water has been absorbed, stamping shall begin. The entire width of the concrete median surface shall be stamped at the same time. A single stamp or a combination of stamps may be used.

Prior to placing the stamp on the concrete, the stamp shall be coated with the release agent. When recommended by the manufacturer, the release agent may also be applied to the concrete surface. Once the stamp has been placed on the concrete median surface, it shall remain down until the stamping is complete.

The entire area of the stamp shall be tamped with a short, slow, repetitive action such that the depth of stamping is as recommended by the manufacturer. Stepping or walking on the stamp will not be allowed.

When stamping is complete, the stamp shall be removed and the concrete cured.

Add the following:

(c) Detectable Warning Surfaces. Construct detectable warning surfaces per plan while constructing the curb ramp. Surfaces of the detectable warning panel shall be constructed flush with the curb ramp surface. Detectable warning panels are to be installed in strict accordance with the manufacturer’s instructions. Improper installation shall result in the removal of the panel and associated curb ramp work without payment from or penalty to the Department.

• 615.04(a)(3) Contraction joints - Delete the last sentence of the first paragraph requiring preformed expansion joint filler. Delete the last paragraph of this subsection.

• 615.05 Asphalt Concrete Sidewalks, Drive Pads, and Medians. Revise the subsection to read as follows:

Perform the work according to Section 402 Hot Asphalt Concrete Pavement by Hveem or Marshall Mix Design Method.

615.07 Acceptance. Revise this subsection to read as follows and delete Table 615-1:

Concrete brick, curing material, joint fillers, and reinforcing steel will be evaluated under Subsections 106.02 and 106.03.

Aggregate base material will be evaluated under Subsections 106.02 and 106.04.
Construction of sidewalks, drive pads, and medians will be evaluated under Subsections 106.02 and 106.04.

Excavation and backfill will be evaluated under Section 209.

Hot Asphalt Concrete will be evaluated under Section 402.

Concrete will be evaluated under Section 601.

Detectable Warning Panels will be evaluated under this Section 106.02, 106.03, and 106.04.

*** END OF SECTION 615 ***
Section 703 – Aggregate

703.01 Fine Aggregate for Concrete. Revise the first sentence to read:

Furnish sand conforming to AASHTO M 6, class B. except as amended or supplemented by the following:

Add the following sentence at the bottom of the section:

Testing requirements for alkali silica reactivity are provided in 703.02.

703.02 Coarse Aggregate for Concrete. Add the following requirements at the bottom of the section:

Fine and Coarse Aggregate for Concrete testing for alkali silica reactivity

The following testing will be conducted on the aggregates and the results provided with the concrete mix design. Testing of all aggregates will be done on an annual basis.

Alkali reactivity of aggregates (Mortar bar method), ASTM C 1260 0.10% max.

Aggregates tested by ASTM C 1260 that exhibit mortar bar expansions less than 0.10 % at 16 days after casting are considered innocuous and may be used.

Aggregates tested by ASTM C 1260 that exhibit mortar bar expansions between 0.10 and 0.20 % at 16 days after casting may be used if acceptable supplemental information is submitted that confirms that mortar bar expansions are not caused by alkali-silica reactions. Acceptable supplemental information includes:

- A report of petrographic examination of the aggregate by ASTM C 295 performed within 1 year from the time of submittal that contains quantifiable data and conclusions verifying that the aggregate is not potentially deleteriously reactive with cement

or

- A report of petrographic examination of the ASTM C 1260 mortar bar samples by ASTM C 856 that contains quantifiable data and conclusions verifying that the aggregate is not potentially deleteriously reactive with cement and that the mortar bar reaction products are not due to alkali-silica reaction.

Aggregates tested by ASTM C 1260 that exhibit mortar bar expansions more than 0.20 % at 16 days after casting or aggregates exhibiting expansions between 0.10 and 0.20 % at 16 days after casting that have been found to be potentially deleteriously reactive by acceptable supplemental information may be used if additional supplemental information is submitted that confirms that effective mitigation measures using supplementary cementitious materials have been used in the concrete mix design. Acceptable supplemental information includes:

- Data and test results by ASTM C 1567 that confirm that concrete mix design combinations of cement, fly ash, silica fume and/or ground iron blast furnace slag exhibit expansions less than 0.10 % at 16 days after casting. Lithium compounds shall not be used.

Testing of the reactivity of aggregates by ASTM C 1293 may be substituted for ASTM C 1260. In such a case, the average concrete prism expansion must be less than 0.04 % at 1 year. Aggregates exhibiting mortar bar expansions more than 0.04 % at 1 year may be used if additional supplemental information is submitted that confirms that effective mitigation measures using supplementary cementitious materials have been used in the concrete mix design. Acceptable supplemental information includes:
• Data and test results by ASTM C 1567 that confirm that concrete mix design combinations of cement, fly ash, silica fume and/or ground iron blast furnace slag exhibit expansions less than 0.10 % at 16 days after casting. Lithium compounds shall not be used.

703.04 Permeable Backfill. Delete the text and substitute the following:

Furnish either sand conforming to Subsection 703.15, glass cullet conforming to Section 703.21, or coarse aggregate consisting of sound, durable particles of gravel, slag, or crushed stone conforming to Table 703-1.

703.07 Hot Asphalt Concrete Pavement Aggregate. Add the following sentence to the start of the subsection:

The aggregate sources to be used must be approved by the Project Engineer.

703.08 Open-Graded Asphalt Friction Course Aggregate. Delete this subsection in total;

703.17 Superpave Asphalt Concrete Pavement Aggregate. Delete this subsection in total.

Table 703-10. Delete
Table 703-11. Delete
Table 703-12. Delete
Table 703-13. Delete
Table 703-14. Delete

703.19 Recycled Asphalt Pavement. Delete the text and substitute the following:

703.19 Recycled Asphalt Pavement. Furnish recycled asphalt pavement that is processed in some form (by crushing and screening) to produce a well-graded gradation and asphalt content. Process recycled asphalt pavement so that no particle in the mixture made with recycled asphalt pavement will exceed the mixture maximum aggregate size at the time of production. Size and grade the material so that it can be blended with aggregates to meet gradation requirements of the mix design. Millings will be considered processed provided they have a uniform gradation and asphalt content. Provide recycled asphalt pavement material with a maximum of 2 % deleterious materials.

703.20 Recycled Concrete Aggregate. New section:

703.20 Recycled Concrete Aggregate. Furnish recycled concrete aggregate that is processed in some form (by crushing and screening) to produce a well-graded aggregate. Contaminants including reinforcing steel, dowel bars/baskets, joint sealant, soil/base course material, etc. shall be removed prior to processing existing concrete into recycled concrete aggregate. Process recycled concrete aggregate so that no particle in the mixture made with recycled concrete aggregate will exceed the maximum aggregate size at the time of production.

Recycled concrete aggregate may be used in lieu of or blended with the following aggregates:

(a) Granular Backfill with geotextile 703.03 (a)
(b) Permeable Backfill 703.04
(c) Subbase, Base, and Surface Course 703.05
(d) Crushed Aggregate 703.06
Recycled concrete aggregate may be used as coarse or fine aggregate for concrete. Recycled concrete aggregate shall meet all requirements for coarse or fine aggregate for concrete contained in Sections 703.01 and 703.02. In addition,

(e) Recycled concrete aggregate shall contain less than 1% by weight of contaminants including metals, wood, paper, fabrics, building materials, or other deleterious materials.

(f) Recycled concrete aggregate susceptible to ASR shall not be allowed for use as aggregate for concrete.

(g) Recycled concrete aggregate shall have an absorption of less than 10% when tested in accordance with AASHTO T 85.

(h) The total fracture calculation shall include recycled concrete aggregate.

703.21 Glass Cullet. New Section

703.21 Glass Cullet.

Unless otherwise prohibited in the plans and/or special provisions, glass cullet may be blended with aggregates according to Table 703-16. Blending shall occur during the crushing and production of the mixture and prior to delivery to the job site.

Glass cullet shall consist of consumer glass from food or beverage containers, plain or ceramic dinnerware, building glass, or other glass that can be certified as free of contaminants. Prohibited glass includes automobile windshields, light bulbs, porcelain products, laboratory glass, cathode ray monitors, or materials containing hazardous substance as listed in 40 CFR, table 302.4.

Glass cullet shall be uniformly graded with a maximum material size of 3/8-inch and shall conform to AASHTO M 318. Deleterious material including plastic, papers, trash, etc. shall be limited to 2% by weight of any blended material. Hazardous material shall not be allowed in cullet.

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<td>Subbase Course</td>
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<td>Crushed Aggregate</td>
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*** END OF SECTION 703 ***
Section 704 – Soil

704.13 Recycled Concrete Aggregate. New section.

704.13 Recycled Concrete Aggregate. Furnish recycled concrete aggregate that is processed in some form (by crushing and screening) to produce a well graded aggregate. Contaminants including reinforcing steel, dowel bars/baskets, joint sealant, soil/base course material, etc. shall be removed prior to processing existing concrete into recycled concrete aggregate. Process recycled concrete aggregate so that no particle in the mixture made with recycled concrete aggregate will exceed the maximum aggregate size at the time of production.

Recycled concrete aggregate shall not be used when the material or blended material is in direct contact with underdrains. Underdrains shall be protected with a geotextile sock or shall be separated from the course containing recycled concrete aggregate by a 12-inch permeable aggregate layer.

Recycled concrete aggregate may be used in lieu of or blended with the following aggregates:

(a) Foundation Fill 704.01
(b) Bedding Material 704.02
(c) Backfill Material 704.03
(d) Unclassified Borrow 704.06
(e) Select Borrow 704.07
(f) Select Granular Backfill 704.10
(g) Crib Wall Backfill 704.11

704.14 Glass Cullet. Glass cullet shall be uniformly graded with a maximum material size of 3/8-inch and shall conform to AASHTO M 318. Deleterious material including plastic, papers, trash, etc. shall be limited to 2% by weight of any blended material. Hazardous material shall not be allowed in cullet.

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