United States Department of Agriculture
Forest Service

RECLAIMED MATERIALS AND THEIR APPLICATIONS IN ROAD CONSTRUCTION: A CONDENSED GUIDE FOR ROAD MANAGERS

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Abstract

Federal land management agencies recently received instruction and direction through Executive Order 13423 "Strengthening Federal Environmental, Energy, and Transportation Management" that required Federal agencies to reduce greenhouse gas emissions and develop programs to become more sustainable. Executive Order 13423 identified six areas for lessening environmental impacts; one was waste prevention and recycling of materials. In an attempt to address this Executive order, this document provides a variety of tables, references, links, and case studies to assist in developing a program to recycle industrial byproduct materials, such as crushed concrete, asphalt, and shingles.

Currently, information is available regarding the use of industrial byproduct materials in construction applications, particularly pavement construction and maintenance. This document provides road managers with an easy-to-use toolbox with the basics on using recycled materials in construction projects, particularly road construction and maintenance. Also, it provides information on where to find guidance to verify that recycled materials are used correctly.

This document provides information on materials if you have a recycling application, or provides information on applications if you have a material to use. Table 1-3 provides additional information (references, links, and case studies) for materials or applications.

The primary audience is road managers for the Forest Service, an agency of the U.S. Department of Agriculture, and other Federal land management agencies. The document may be applicable to counties and towns or any agency that manages rural and low-volume roads.

Keywords:

Recycled asphalt, recycled asphalt pavement, reclaimed asphalt pavement, RAP, full depth reclamation, stabilization, reclaimed concrete aggregate, glass cullet, roofing shingles, wood chips, scrap tires, coal fly ash, blast furnace slag

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Reclaimed Materials and Their Applications in Road Construction: A Condensed Guide for Road Managers

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Introduction

Executive Order 13423 "Strengthening Federal Environmental, Energy, and Transportation Management" requires Federal agencies to reduce greenhouse gas emissions and develop programs to become more sustainable. The subsequent Executive Order 13514 "Federal Leadership in Environmental, Energy and Economic Performance" also requires agencies to reduce waste, conserve water and fuel, and to develop a greenhouse gas emissions reduction target for 2020.

Executive Order 13423 identified six areas for lessening environmental impacts. One area was waste prevention and recycling. Federal land management agencies and other agencies that manage low-volume roads have already made strides in waste prevention and recycling of paper, plastic, glass, and aluminum. The focus of this project is to provide information on developing a program to recycle industrial byproduct materials, such as crushed concrete, asphalt, and shingles.

Considering that the Federal land management agencies own and manage hundreds of thousands of miles of roads and tens of thousands of buildings, the maintenance and decommissioning of these assets will produce a significant volume of material, much of it recyclable or reusable. Using recycled materials in road construction and maintenance is important because the agencies have an extensive road network to manage, and road construction and maintenance require significant volumes of construction materials.

Much information is available regarding the use of industrial byproduct materials in construction applications, particularly pertaining to pavement construction and maintenance. This project developed a very basic, easy-to-use toolbox that provides road managers with the basics of recycled materials used in construction projects, particularly road construction and maintenance. While geared toward the Forest Service and the other Federal land management agencies, it also is applicable to counties, towns, and any agencies that manage rural and low-volume roads.

Scope

At least 20 industrial byproduct material streams are used or have been used as material for road construction projects. Discussing all of the byproduct material streams and all of the possible applications is beyond the scope of this project, so only those materials that might reasonably be used by Federal land management agency personnel will be discussed. Also, this is not a design manual. The design of roadways and other infrastructure is very site specific, and it is beyond the scope of this project. Ultimately, it is the responsibility of the road manger to ensure that the design is done correctly. Therefore, this toolbox only provides information on where to get guidance to verify that recycled materials are used correctly.

Outline of the Guide

- ❑ Introduction.
- ❑ Chapter 1 discusses combinations of materials and applications.
- ❑ Chapter 2 provides information and tables from an applications perspective.
- ❑ Chapter 3 provides information and tables from a materials perspective.
- ❑ Conclusions.
- ❑ Appendixes
    - ▼ Survey responses.
    - ▼ Glossary of recycled material terms.
    - ▼ References and links.
    - ▼ Selected case studies.

Much of the documentation in this report was drawn from public domain materials developed by the U.S. Department of Transportation, Federal Highway Administration (FHWA); the Recycled Materials Resource Center (a partner laboratory of FHWA); and the U.S. Environmental Protection Agency (EPA). The information can be downloaded and distributed. Care has been taken to limit the use of documents that are not in the public domain to encourage the dissemination of information.

How To Use This Guide

If you know the material or the application you want to use, refer to the tables and figures in chapter 1 (figure 1-3 and table 1-3 focus on Federal land management agencies). After you select the material or application from table 1-3, go to chapters 2 and 3 to obtain details on the materials or applications. Web sites and references are provided for further guidance. Case studies are provided in the appendixes.

Materials and Applications Covered In This Guide

This section describes the process to select the recycled materials and applications for inclusion in the guide, based on potential use by Federal land management agency personnel. The selection process was based on the assumption that Federal lands generally are farther from urban centers and heavy industry, or at least far enough that the transportation of materials from those locations would be cost prohibitive.

Initial Survey and Introduction of Full-Depth Reclamation

During the summer of 2010, the National Technology and Development Center of the Forest Service, an agency of the U.S. Department of Agriculture, distributed an informal survey on recycled materials to Forest Service representatives. The survey had three goals:

1. To determine what byproduct materials Forest Service representatives were aware of, or at least thinking about.
2. To determine how they wanted to use the materials.
3. To provide a minimum list of questions and issues that could be covered if possible in this publication.

Specific survey responses are available in appendix A. Most responses referenced reuse of hot-mix asphalt and the use of in-place recycling through full-depth reclamation. While individual materials and applications for full-depth reclamation will be addressed, it should be noted that in 2005, the U.S. Department of Transportation, Federal Highways Administration, Federal Lands Highway Division published the "Context Sensitive Roadway Surfacing Selection Guide" <http://www.cflhd.gov/programs/techDevelopment/pavement/context-roadway-surfacing/>, which includes detailed information about full-depth reclamation applications on Federal lands. A summary is included in chapter 3 with links to relevant document sections.

Combinations of Applications and Materials

Table 1-1 provides a general list of potential applications for recycled materials. While it is easy to come up with more than 40 specific applications, table 1-1 is limited to only 10 applications that provide value in terms of sustainable practices.

Table 1-1. Basic list of potential uses for recycled industrial materials. Where possible, the materials are linked to the "Recycled Materials Resource Center Beneficial User Guidelines" or other sources for application descriptions

Application	Links
Bituminous asphalt pavement	http://www.recycledmaterials.org/tools/uguidelines/app.asp#asp
Portland cement concrete pavement	http://www.recycledmaterials.org/tools/uguidelines/app2.asp
Portland cement concrete products	http://www.industrialresourcescouncil.org/Applications/PortlandCementConcrete/tabid/381/Default.aspx
Portland cement manufacturing/ additives	http://www.industrialresourcescouncil.org/Applications/PortlandCementManufacturing/tabid/384/Default.aspx
Granular base/subbase	http://www.recycledmaterials.org/tools/uguidelines/app3.asp
Embankment or fill	http://www.recycledmaterials.org/tools/uguidelines/app4.asp
Stabilized base/subbase	http://www.recycledmaterials.org/tools/uguidelines/app5.asp
Flowable fill	http://www.recycledmaterials.org/tools/uguidelines/app6.asp
Erosion control	http://www.caes.uga.edu/publications/pubDetail.cfm?pk_id=6296
Agricultural land application	http://www.industrialresourcescouncil.org/Applications/AgriculturalLandApplication/tabid/421/Default.aspx

Table 1-2 lists 20 common industrial byproduct and coproduct materials that have been used in construction projects.

Table 1-2. Industrial byproduct and coproduct materials that have been used in construction projects. Where possible, the materials are linked to the "Recycled Materials Resource Center Beneficial User Guidelines" or other sources for material properties

Materials	Links
Reclaimed asphalt pavement	http://www.recycledmaterials.org/tools/uguidelines/rap131.asp
Reclaimed concrete aggregate	http://www.recycledmaterials.org/tools/uguidelines/rcc1.asp
Waste glass	http://www.recycledmaterials.org/tools/uguidelines/wg1.asp
Roofing shingles	http://www.recycledmaterials.org/tools/uguidelines/rss1.asp
Compost/wood chips	
Scrap tires	http://www.recycledmaterials.org/tools/uguidelines/st1.asp
Blast-furnace slag	http://www.recycledmaterials.org/tools/uguidelines/bfs1.asp
Coal-fly ash	http://www.recycledmaterials.org/tools/uguidelines/cfa51.asp
Coal-bottom ash/boiler slag	http://www.recycledmaterials.org/tools/uguidelines/cbabs1.asp
Foundry sand	http://www.recycledmaterials.org/tools/uguidelines/fs1.asp
Steel slag	http://www.recycledmaterials.org/tools/uguidelines/ssa1.asp
Kiln dusts	http://www.recycledmaterials.org/tools/uguidelines/kd1.asp
Flue gas desulfurization material	http://www.recycledmaterials.org/tools/uguidelines/fgd1.asp
Baghouse fines	http://www.recycledmaterials.org/tools/uguidelines/bd.asp
Mineral processing byproducts	http://www.recycledmaterials.org/tools/uguidelines/mwst1.asp
Quarry byproducts	http://www.recycledmaterials.org/tools/uguidelines/qbp121.asp
Wastewater treatment plant residuals (paper sludge)	http://www.industrialresourcescouncil.org/Materials/PulpandPaperIndustryMaterials/tabid/368/Default.aspx
Solid waste combustor ash	http://www.recycledmaterials.org/tools/uguidelines/mswca1.asp
Sewage sludge ash	http://www.recycledmaterials.org/tools/uguidelines/ss1.asp
Nonferrous slags	http://www.recycledmaterials.org/tools/uguidelines/nfs1.asp

Matrices

Figure 1-1 shows a basic application/material matrix from the "Recycled Materials Resource Center Beneficial User Guidelines" <http://www.recycledmaterials.org/tools/uguidelines/index.asp> (Used with permission of the Recycled Materials Resource Center). Figure 1-2 shows a similar matrix developed by the Industrial Resources Council <http://www.industrialresourcescouncil.org> that contains additional materials and applications. Potential applications are listed across the top, while potential materials are listed down the left-hand side. The basic idea is that someone with surplus asphalt or crushed concrete could read across to see how this material could be used, or someone looking for sustainable fill material could read down and see what materials could be used.

	Asphalt concrete pavement	Portland cement concrete pavement	Granular base	Embankment or fill	Stabilized base	Flowable fill
Baghouse fines	x					
Blast furnace slag	x	x	x	x		
Coal bottom ash/boiler slag	x		x	x	x	
Coal fly ash	x	x		x	x	x
Flue gas desulfurization scrubber material					x	x
Foundry sand	x	x		x		x
Kiln dusts	x				x	
Mineral processing wastes	x		x	x		
Municipal solid waste combustor ash	x		x			
Nonferrous slags	x		x	x		

	Asphalt concrete pavement	Portland cement concrete pavement	Granular base	Embankment or fill	Stabilized base	Flowable fill
Quarry byproducts						x
Reclaimed asphalt pavement	x (hot and cold)		x	x		
Reclaimed concrete material			x	x		
Roofing shingle scrap	x					
Scrap tires	x (wet and dry)			x		
Sewage sludge ash	x					
Steel slag	x		x			
Sulfate wastes					x	
Waste glass	x		x			

Figure 1-1. Matrix of recycled materials and their potential uses. The x represents a potentially successful material/application combination. This matrix is hyperlinked to the original matrix on the Recycled Materials Resource Center Web site at <http://www.recycledmaterials.org/tools/uguidelines/index.asp#matrix>. (Used with permission of the Recycled Materials Resource Center.)

MATERIAL \ APPLICATION	Structural fill	Embankments	Granular base/subbase	Stabilizaed base/subbase	PCC pavement	Hot mix asphalt	Flowable fill	Portland cement manufacturing	PCC products	Soil stabilization	Building products	Agricultural land applications	Manufactured soils	Soils-based applications, other	Landfill cover/construction	Brownfield remediation	Mine reclamation	Other
Fly ash					X				X									
FDG gypsum												X						
Bottom ash	X																	
Foundry sands	X		X			X	X											
Iron foundary slags																		
Blast furnace slag						X												
Slag cement							X			X								X
Steel furnace slag																		
Reclaimed concrete aggregate	X		X															

Figure 1-2. A matrix by the Industrial Resources Council <http://www.industrialresourcescouncil.org> that shows additional materials and applications. The colors indicate materials that are produced by different industries. Used with permission of Elizabeth Olenbush of the Industrial Resources Council. The original matrix can be found at: <http://www.industrialresourcescouncil.org/Applications/IndustrialMaterialsMatrix/EMatrix/tabid/409/Default.aspx>.

MATERIAL / APPLICATION	Structural fill	Embankments	Granular base/subbase	Stabilizaed base/subbase	PCC pavement	Hot mix asphalt	Flowable fill	Portland cement manufacturing	PCC products	Soil stabilization	Building products	Agricultural land applications	Manufactured soils	Soils-based applications, other	Landfill cover/construction	Brownfield remediation	Mine reclamation	Other
Scrap wood																		
Dry wall																		
Asphalt shingles						x												
Tire derived fuel		x																
Ground rubber																		
Waste water treatment residual												x					x	
Causticizing residues												x						
Boiler ash																		

Figure 1-2. A matrix by the Industrial Resources Council <http://www.industrialresourcescouncil.org> that shows additional materials and applications. The colors indicate materials that are produced by different industries. Used with permission of Elizabeth Olenbush of the Industrial Resources Council. The original matrix can be found at: <http://www.industrialresourcescouncil.org/Applications/IndustrialMaterialsMatrix/EMatrix/tabid/409/Default.aspx>. continued

The challenge is to reduce these matrices to just applications and materials of interest to the Forest Service and other Federal land management agencies.

To arrive at such a matrix, first consider the potential applications based on Federal land management agencies' activities. This thought process reduces the list of potential applications to:

- ❏ Hot-mix asphalt.
- ❏ Structural fill/embankments.
- ❏ Granular base/subbase layers, stabilized base/subbase layers.
- ❏ Portland cement concrete.
- ❏ Full-depth reclamation.

In addition, erosion control is not shown in figures 1-1 or 1-2, but is a growing application and might be of interest to road managers who need to protect new slopes from erosion.

A similar thought experiment can be applied to the recycled materials. Realistically, the materials most likely to be generated by Federal land management agency activities are reduced to:

- ❏ Reclaimed hot-mix asphalt.
- ❏ Reclaimed concrete.
- ❏ Shingles.
- ❏ Tires.
- ❏ Scrap wood and brush.
- ❏ Waste glass.

Slag cement is not generated by these agencies, but it could be used in new concrete construction as part of their sustainability program. Slag cement has a fraction (or all) of the Portland cement replaced by ground granulated blast-furnace slag. This cement is supported by the Environmental Protection Agency as a sustainable building material.

Table 1-3 presents a simplified applications/materials matrix specific to Federal land management agency needs. Table 1-3 is the basis on which the recycled materials toolbox is built.

Table 1-3. Applications and recycled materials matrix for use by Federal land management agencies. These materials and applications were chosen based on activities most pertinent to the agencies

MATERIALS	APPLICATIONS: Hot-mix asphalt	Concrete construction	Structural fill / embankments	Granular base / subbase	Stabilized base / subbase	Full-depth reclamation	Erosion control
Reclaimed asphalt pavement	●		●	●	●	●	
Reclaimed concrete		●	●	●	●		
Reclaimed shingles	●		●	●	●		
Scrap tires			●				
Scrap wood/ brush							●
Waste glass			●	●			
Slag cement		●					

With the information obtained from table 1-3, the user can proceed to chapters 2 and 3 for general information about material descriptions and properties, environmental and safety issues, case studies, and references and Web sites with further details and guidance.

Recycled Material Applications

Each application has a separate table. The applications are described, and the materials used for each application are discussed.

Table 2-1. Hot-mix asphalt pavement

Description
The Forest Service and other Federal land management agencies tend to use flexible pavement designs, which usually include an asphalt surface layer constructed over a compacted granular base and subbase. The subbase sits on top of the subgrade, the native soil of the area. Asphalt pavements can be constructed using hot-mix or cold-mix asphalt. This summary however focuses on hot-mix placement. Hot-mix asphalt is a mixture of fine and coarse aggregate with asphalt cement binder that is mixed, placed, and compacted in a heated condition. The components are heated and mixed at a central plant and placed on the road using an asphalt spreader. After placement, it is compacted using rollers or similar equipment.
Materials in Hot-Mix Asphalt
The use of recycled asphalt products (RAP) in hot-mix asphalt is a generally accepted practice, with roughly 90 percent of the hot-mix asphalt placed in the United States containing some amount of RAP. Using RAP in new hot-mix asphalt takes advantage of the aggregate and bituminous binder already in the RAP, reducing the need for new asphalt binder and aggregates. The challenge for many Federal land management agencies would seem to be finding hot-mix plants near enough to units to make hot-mix asphalt recycling cost effective. If asphalt pavement is being milled as part of rehabilitation effort, then the milled asphalt can go back to the plant in the trucks that brought the new hot-mix asphalt, and it is straightforward to add the millings into new asphalt. It is more challenging to use stockpiled RAP sections. The RAP must be free of soil and debris, and then it must be crushed and screened before being added to new hot mix. All of these extra steps add to the cost of reusing the RAP, and if the hot-mix plant is far away, the transportation costs, fuel burned, and emissions produced offset the sustainable benefits of reusing the RAP in hot-mix asphalt. However, if there is a hot-mix plant nearby, then putting the old RAP into new hot-mix asphalt is the best use of the material. Much of the same reasoning applies to shingles from decommissioned buildings or roof repairs. Like RAP stockpiles, the shingles need to be free of nails, tar paper, wood, and other debris. The shingles then need to be ground small enough (0.5 inches or less) to be used in new hot-mix asphalt. Again, these steps add cost to reusing the shingles in asphalt, and if the processor and hot-mix plant are far away, the environmental benefit is reduced as well. However, if a processer and hot-mix plant are nearby, then using shingles in new hot-mix asphalt is the best reuse option.

Table 2-2. Concrete construction

Description
Concrete is almost ubiquitous in modern life, found in everything from sidewalks and post anchors to bridges to building foundations. Concrete is made by combining coarse and fine aggregates, water, and a cement binder. The water hydrates the cement to form a gel that holds the aggregate together. The most common type of cement is Portland cement, which is made by mixing lime with silica, iron, and aluminum minerals in a very hot kiln. Most of the lime comes from calcination of limestone, which involves applying tremendous heat to the limestone to convert it from calcium carbonate ($CaCO_3$) to lime (CaO). The calcination process is very energy intensive and produces about one ton of calcium dioxide (CaO_2) gas for each ton of cement produced. Concrete can be made more sustainable by using recycled materials, such as aggregate, or by using non-Portland type cements as a binder.
Materials in Concrete Construction
The Forest Service does not produce many materials that would be good aggregate for new concrete construction. However, there is growing experience showing that old concrete can be crushed and reused in new concrete. The old crushed concrete must be free of soil and debris, and also be free of distress from alkali-silica reactions to prevent premature failure of the concrete. The crushed concrete also has a higher water demand than regular aggregates, so the mix design must be changed accordingly. The biggest challenge would seem to be getting the concrete crushed and screened so that it meets the size requirements for new concrete aggregate. Another option for more sustainable concrete is to use slag cement. Slag cement uses ground blast-furnace slag as a substitute for Portland cement, reducing the carbon footprint of the new concrete structure. Assuming the agency does not produce slag or slag cement, it could put a notice about the use of slag cement in bid documents.

Table 2-3. Structural fills and embankments

Description
Structural fills and embankments often are used interchangeably. Typically, a structural fill describes the use of quality granular materials to fill in a hole or depression to raise the grade, or to create a strong, stable base. Structural fills also include backfill behind retaining walls. An embankment usually refers to an earthen structure that is used to raise the elevation of a roadway or railway above the surrounding area. An example of an embankment is the approach to a bridge, where the embankment raises the road to the level of the bridge deck. The structures are usually built by compacting sand, gravel, or other earthen materials to some unit weight near the maximum dry unit weight in order to achieve certain levels of compressibility and shear strength. An increase in unit weight and loss of shear strength due to saturation also are important considerations, so structural fills and embankments usually are built with materials that have good drainage properties.
Materials in Structural Fills and Embankments
Structural fills and embankments are good applications for the materials generated by the Forest Service and other Federal land management agencies, especially when taking cost and equipment requirements into account. Generally, it is argued that placing crushed concrete in embankments and fills is not the best use of the material and that it should be used for higher-value applications, such as granular-base aggregate. While this is a reasonable argument, it does not take into account the specific issues faced by the Federal land management agencies. Aggregate for base layers needs to meet specific gradation requirements, so the concrete would need to be crushed and screened. For many sites, this would entail transporting crushing and screening equipment some distance to the site at significant cost or perhaps transporting the concrete to a crusher and then to the construction site at significant cost. In the end, the transportation and processing costs would make using the crushed concrete in base applications unfeasible. However, crushed concrete makes a good embankment and fill material. Generally, the gradation requirements for these applications are better suited for larger aggregate, so the concrete can be crushed with regular construction equipment and used without expensive processing. A similar situation exists for recycled asphalt products and shingles. Using RAP and shingles in embankment and fill applications does not make use of the asphalt binder in these materials. However, the cost incurred, energy used, and greenhouse gases produced by transporting RAP and shingles from a remote site often outweigh the benefits of processing it and reusing it in hot-mix asphalt. In general, the RAP and shingles are broken up and mixed with aggregate and soil to meet the gradation requirements of the project. The mixture behaves like a natural granular material with the same gradation. Crushed glass also is an excellent aggregate. It has excellent permeability and has been used as aggregate where drainage is very important, such as stormwater control structures. While crushed glass can be used by itself as aggregate, it often is difficult to get sufficient volumes of the material, so usually it is mixed with other aggregate.

Table 2-3 continued on next page

Table 2-3 continued from previous page

Old tires can be used in fill and embankments either as whole tires or tire shreds. Tire shreds provide an excellent low-density material, typically one-third the weight of gravel, and provide good drainage. Usually, the tire shreds are mixed with other materials, or placed in layers separated by aggregate to prevent self-ignition of the rubber. It may be difficult and expensive for Forest Service sites to obtain a tire shredder, so using whole tires is another option. Typically, the tires are placed on their side in flat layers, or tied together in columns, and then filled with compacted soil. In general, the use of recycled materials for structural fill for embankments is relatively straightforward from an engineering point of view, and some materials have guidance documents and best practices for their use. However, different sites will have different issues (seismic activity, fire danger, nearby surface water, and so forth), and the individual properties of the respective recycled materials must be taken into consideration.

Table 2-4. Road base and subbase layers

Description
The Forest Service and other Federal land management agencies typically use flexible pavement structures composed of a layer or layers of hot-mix asphalt over unbound layers of granular material. The base layer is the load-bearing layer immediately below the asphalt layers and provides strength and support to the overlying pavement. The subbase serves as the foundation for the overall pavement structure, transmitting traffic loads to the subgrade while providing drainage and frost protection. The base and subbase layers are formed by spreading relatively thin layers (about 1-foot thick) of aggregate and then compacting it with heavy equipment until the material forms a dense layer of interlocking aggregate. Typically, base and subbase materials should last for 20 years or more, so they must be strong and durable, and must meet specific gradation requirements. Base and subbase materials traditionally are sand, gravel, crushed rock, quarry stone, and other natural mineral materials that provide the necessary strength and durability. Some areas of the country are beginning to suffer from aggregate shortages, or sources of aggregate are now so far from construction sites that hauling costs are becoming a significant expense. These factors are causing many transportation agencies to use recycled materials as a source of quality aggregate while reducing costs. This application deals with stockpiles of RECYCLED ASPHALT PRODUCTS, concrete, and other materials that are crushed, screened, and used as aggregate. This is a different approach than in situ recycling of an asphalt pavement through full-depth reclamation, which is discussed in a following section.
Materials in Road Base and Subbase Layers
While plenty of materials would serve as suitable aggregate for base and subbase layers, the increased processing costs may make this application unsuitable except for specific situations. The costs of crushing and screening stockpiles of material to obtain the required gradation must be balanced against using the materials as structural fill. When the economics work, concrete, recycled asphalt products, shingle, and glass stockpiles can be used in base and subbase layers. When stockpiles of old concrete are crushed, a range of material sizes is produced, which allows the concrete to be used as coarse and fine aggregate in base and subbase layers. In general, the crushed concrete is mixed with natural aggregates, and is not used as the sole aggregate source. In some areas, the best aggregate was used in making old concrete, so recycling the concrete has the added benefit of keeping high-quality natural aggregates in use. Similarly, recycled asphalt products and shingles contain high-quality aggregates. Recycled asphalt product millings, the small pieces of asphalt pavement ground up during resurfacing, can be mixed with natural aggregates and used as base material as long as the gradation is met. Shingles and chunks of recycled asphalt products must be ground or crushed first, and then mixed with other aggregates to meet the gradation requirements.

Table 2-4 continued on next page

Table 2-4 continued from previous page

Crushed glass also has been used in subbase applications, mixed with natural aggregates. One issue with crushed glass is that it can be difficult to obtain enough material to meet the job requirements, so glass is often used on small projects. In general, the construction practices are the same when using recycled materials in base and subbase applications, though adjustments may be needed. For instance, the presence of crushed concrete will usually increase the amount of water needed to compact the aggregate. However, a number of guidance documents are available that discuss these issues.

Table 2-5. Stabilized road base and subbase layers

Description
Usually, the base and subbase layers of flexible pavement systems the Forest Service uses are made of compacted granular material. However, the properties of these pavement layers can be improved by adding a binder, such as lime, cement, Class C coal fly ash, or Class F coal fly ash and lime. The increased construction cost from using the binder is offset by reduced maintenance costs, and possibly a reduced need for hot-mix asphalt. Stabilized layers describe layers built during new construction or complete reconstruction. In such cases the materials are mixed with the binder (and water if needed) and then placed, graded, and compacted. Stabilized base layers also can be formed through full-depth reclamation when binder is added to the reclaimed pavement material; however this technique is described in a later section. Stabilizing the base and subbase layers is not an inherently sustainable practice, but there are methods that can be used to improve its sustainability.
Materials in Stabilized Road Base and Subbase Layers
Recycled asphalt pavement (RAP), concrete, and shingles can be used for regular granular base and subbase layers, though this is not really an improvement over the unbound layers in terms of sustainability. However, some sites may be near a coal burning power plant, then use coal-fly ash as a binder. Class C coal-fly ash, typically found in the Western United States, can be used by itself as the binder because of its cementitious properties. Class F coal-fly ash (typically Eastern United States) can be used as a pozzolanic admixture in combination with lime or with cement as the binder. Using coal-fly ash in this way has fairly broad support as a beneficial use of the material and it does not seem that it will be affected by upcoming changes in Environmental Protection Agency (EPA) policy. In addition, slag cement can be used as the binder for stabilized base and subbase layers. Slag cement substitutes some or all of the Portland cement with blast-furnace slag. The use of slag cement is supported by the EPA as a way to reduce greenhouse gas levels. Again, using fly ash or slag cement is very site specific, and lands far from sources of ash and slag cement will not see a benefit from using them because of the transportation costs and emissions.

Table 2-6. Erosion control

Description
Road construction or rehabilitation often can result in the creation of new earthen slopes on the construction site. Typically, these slopes are seeded to promote plant growth, which stabilizes the slope and prevents erosion during rain events. However, seeding often is one of the last things done during construction, so until seeding, the new slopes are at risk of erosion. One successful technique for preventing erosion during construction is to use shredded brush and trees as mulch on the slope. This mulch is not meant to be a decorative final product, like uniform colored bark mulch, but is rather simply an erosion control treatment. It is spread on the slope to protect the slope from rain and to minimize the formation of preferential flow pathways across the slope. As the project finishes up, the shredded brush is mixed into the slope soil as an organic amendment, and the final seeding takes place.
Materials in Erosion Control
As a result of maintenance operations, the Forest Service and other Federal land management agencies have access to brush, limbs, trees, and other woody material. Shredding woody material and using it for erosion and sedimentation control is a very sustainable practice because it prevents erosion of earthen structures and adverse impacts on surface waters due to sedimentation, and it is a source of nutrients for newly seeded areas.

Table 2-7. Full-depth reclamation (with stabilization)

General Information

Full-depth reclamation (FDR) is a rehabilitation technique in which the full thickness of the asphalt pavement and predetermined portion of the underlying materials (base and, sometimes, subbase) are uniformly pulverized and blended to provide an upgraded, homogenous base material. The reclaimed layer is then compacted to provide a uniform platform for the asphalt base course or surface course. FDR is an in situ process without heat. Stabilizing additives can be applied to enhance the properties of the reclaimed layer.

Three different types of stabilization can be used: bituminous (using emulsified asphalt or foamed asphalt); chemical (using Portland cement, hydrated lime, cement kiln dust, or lime kiln dust); and mechanical (using new granular material, recycled asphalt pavement, or crushed Portland cement concrete). FDR with mechanical, bituminous, and foamed asphalt stabilizations are covered in detail in separate product summaries.

Full-depth stabilized layers commonly are overlaid with hot asphalt concrete pavement or covered with chip seals.

FDR material has been used as a temporary road surfacing, but generally is not used as a permanent surfacing.

NOTE: This text was modified from the section on FDR in the Federal Highways Administration Federal Lands Highway Division publication “Context Sensitive Roadway Surfacing Selection Guide” <http://www.cflhd.gov/programs/techDevelopment/pavement/context-roadway-surfacing/>. The section on FDR can be found at <http://www.cflhd.gov/programs/techDevelopment/pavement/context-roadway-surfacing/documents/context5-append-a8.pdf>.

Modified and used with permission of Mike Voth, pavement and materials technical leader, Federal Lands Highway Division.

Materials in Full-Depth Reclamation

Many of the survey responses were related to the reuse of old asphalt pavement in base and subbase applications. FDR is a potentially cost-effective way to reuse asphalt pavement. Recycled asphalt pavement is often taken back to a central hot-mix asphalt plant where it is added in to new hot-mix asphalt. However, the hot-mix plant has to be relatively close to make the process cost effective. The Forest Service has the challenge of its units often being at some distance from a hot-mix plant, so trucking old recycled asphalt products back and forth becomes expensive. The same may apply for other Federal land management agencies. When using FDR, the old asphalt is put directly into the base, reducing the need for new aggregate while at the same time providing a good foundation for the new hot-mix asphalt. In addition, using an asphalt emulsion as the binder will take advantage of the binder in the recycled asphalt pavement to provide better performance. It can be expensive to mobilize an FDR train if the unit is remote, so the technology is best used on big projects, on the order of miles, to make it cost effective.

Descriptions of Recycled Materials with Potential Use to Federal Land Management Agencies

A separate table is provided for each material. Materials are described and applications are discussed.

Table 3-1. Reclaimed (or recycled) asphalt pavement

General Information
Material Name(s): Reclaimed Asphalt Pavement (RAP), Recycled Asphalt Pavement, Recycled Asphalt Concrete **Description:** Reclaimed asphalt pavement (RAP) is the material removed from bound bituminous pavement layers. RAP is generated when asphalt pavements are removed for reconstruction, resurfacing, or utility work. Asphalt pavement generally is removed either by milling or full-depth removal. Milling uses grinders to remove the upper layers of the asphalt pavement and typically is done prior to rehabilitation work on the asphalt part of the pavement structure. Full-depth removal describes removal of the whole asphalt pavement down to the base course. Bulldozers or front-end loaders break the pavement structure into manageable slabs and then load them into trucks, which transport the pavement to a reprocessing site for crushing and sizing. RAP may be stockpiled by millings or slabs, or may be stockpiled by project. Large quantities of RAP from single projects are kept separate because once the RAP is processed it will provide consistent stone gradation, quality, asphalt content, and asphalt characteristics. However, it is more common that smaller amounts of RAP from various sites are stored in common piles before crushing and blending. The RAP is then crushed down to the largest aggregate size. This allows for the creation of a consistent product from various sources. Experience has demonstrated that with thorough blending and crushing, RAP with a consistent stone gradation and asphalt content can be manufactured from multiple-source stockpiles. Care should be taken when stockpiling RAP as it can “reaggomerate,” forming large chunks that are hard to process. Although the majority of old asphalt pavements are recycled at central processing plants, asphalt pavements may be pulverized in place using a self-propelled pulverizing machine. This is known as full-depth reclamation. The pulverized material can be compacted as is, or it can be mixed with cement, lime, or asphalt emulsions as a stabilization agent prior to compaction.

National Asphalt Pavement Association
5100 Forbes Boulevard
Lanham, MD 20706-4413
<http://www.hotmix.org/>

Asphalt Recycling and Reclaiming Association
3 Church Circle, Suite 250
Annapolis, MD 21401
<http://www.arra.org/>

Table 3-1 continued on next page

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Applications
Milled or crushed RAP can be used in many highway construction applications. These include its use as an aggregate substitute and asphalt cement supplement in recycled asphalt paving (hot-mix recycling), as a granular base or subbase, stabilized base aggregate, or as an embankment or fill material. ***Hot-Mix Asphalt Aggregate and Asphalt Cement Supplement***
Recycled asphalt pavement can be used as an aggregate substitute material in new hot-mix asphalt. However, in this application it provides an additional asphalt cement binder, thereby reducing the demand for asphalt binder in the mix. In hot-mix recycling, the RAP usually is processed at a central facility where crushers, screening units, conveyors, and stackers produce and stockpile a finished granular RAP product processed to the desired gradation. This product is then added to hot-mix asphalt paving mixtures as an aggregate substitute. Batch plants and drum-mix plants can incorporate RAP into hot-mix asphalt and deliver it to the site. ***Granular Base Aggregate***
To produce a granular base or subbase aggregate, RAP must be crushed, screened, and blended with conventional granular aggregate, or reclaimed concrete material. Blending granular RAP is necessary to attain the bearing strengths needed for most load-bearing unbound granular applications. RAP by itself may exhibit a somewhat lower bearing capacity than conventional granular aggregate bases. ***Embankment or Fill***
Stockpiled RAP material (figure 3-1) also may be used as a granular fill or base for embankment or backfill construction, although it is not the most suitable use. However, it may be an alternative for material that has been stockpiled for a considerable time period, or commingled from several different project sources, or used as an embankment base or fill material within the same right of way.

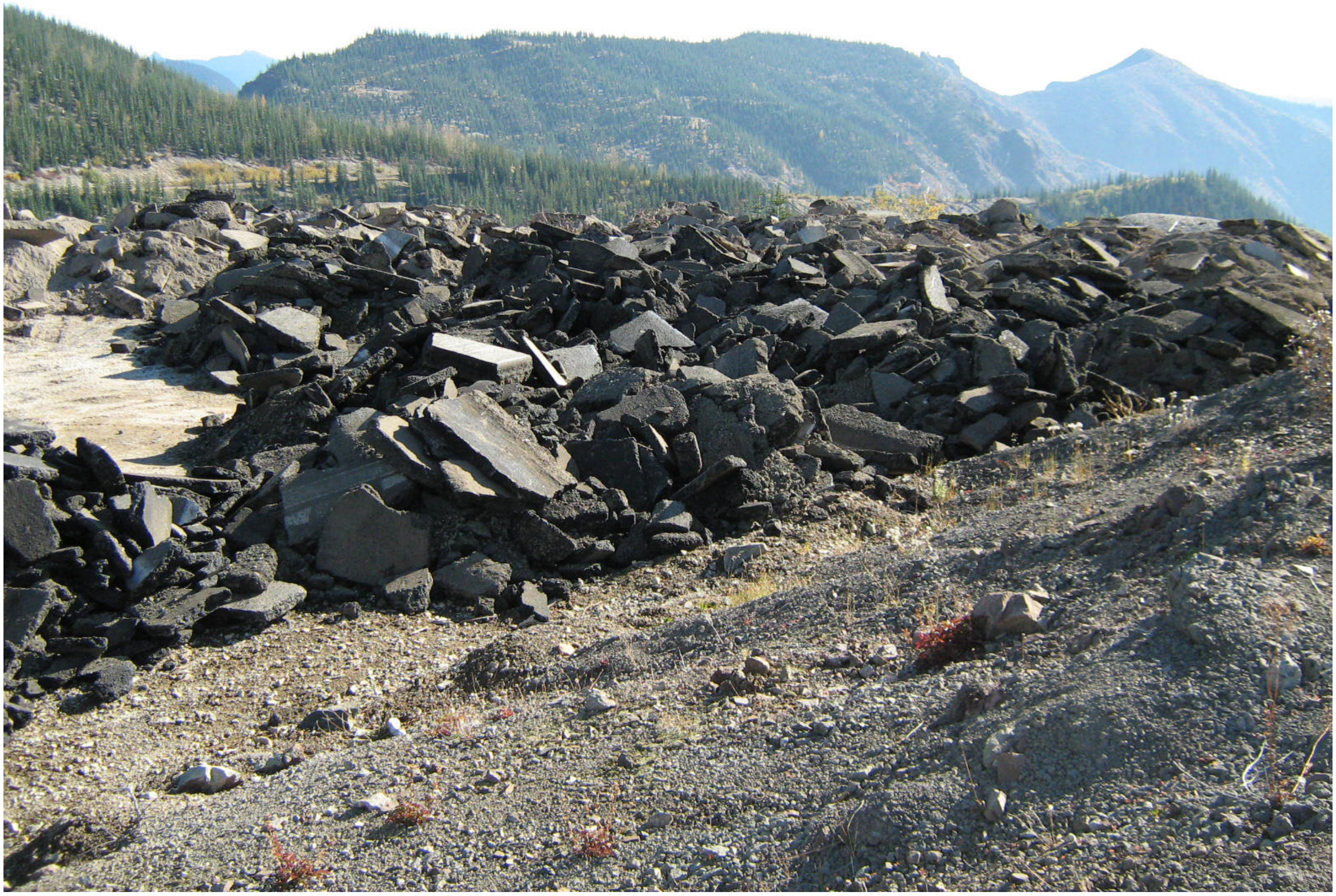

Figure 3-1. Ripped-up asphalt stockpiled in a quarry (Al Watson, Sequoia National Forest).

Stabilized Base Aggregate

To produce a stabilized base or subbase aggregate, RAP also must be crushed and screened, then blended with one or more stabilization reagents so that the blended material, when compacted, will gain strength.

Relevant Physical Properties

Type of Property	RAP Property	Typical Range of Values
Physical properties	Unit weight	1,940-2,300 kg/m^3 (120-140 lb/ft^3)
Moisture content	Normal: up to 5% Maximum: 7-8%	
Asphalt content	Normal: 4.5-6% Maximum Range: 3-7%	
Asphalt penetration	Normal: 10-80 at 25 °C (77 °F)	
Absolute viscosity or recovered asphalt cement	Normal: 4,000-25,000 poises at 60 °C (140 °F)	
Mechanical properties	Compacted unit weight	1,600-2,000 kg/m^3 (100-125 lb/ft^3)
California bearing ratio (CBR)	100% RAP: 20-25% 40% RAP and 60% Natural Aggregate: 150% or higher	

Environmental and Safety Information
Asphalt pavement consists of aggregate- and petroleum-derived asphalt binder containing volatile and semivolatile constituents (e.g., polycyclic aromatic hydrocarbons (PAHs)). Additionally, the asphalt pavement roadway may contain surface treatments, rubberized materials, or contaminants from vehicles or other emissions (e.g., historically lead). The environmental issues are different for RAP based upon various beneficial uses. For bound applications, such as RAP in hot-mix asphalt, research into the difference in emissions has not been conducted. For unbound applications, leachability from the RAP also may be a concern. This same leachability would be a concern if RAP was stockpiled or stored and exposed to precipitation. A project in Florida tested the leaching volatile organic compounds (VOCs), PAHs, and heavy metals; results were below the detection limit and below the applicable State regulatory groundwater guidance concentrations. This indicates that all RAP samples tested pose minimal risk under current waste policy in Florida. Other batch and column leaching tests were completed on RAP, which also found constituents leached were low and generally below European drinking water standards (The Drinking Water Directive, Council Directive 98/83/EC) (14). Additionally, the University of Minnesota completed a review of current literature on PAHs in asphalt pavement concluding that PAH concentrations depend on the type of pavement (coal-tar versus petroleum based). Petroleum-based asphalt pavement contained PAHs at concentrations below Minnesota Pollution Control Agency human health risk clean-up levels (15). The only exceedance was when PAHs were converted to benzo(a)pyrene equivalents, they could exceed the lowest limit (Tier I). The report further concluded that when RAP is used as subbase aggregate, it is mixed with soils or other aggregates that do not contain PAH, so this mixture would not likely exceed applicable limits.

Table 3-2. Reclaimed concrete aggregate (RCA)

General Information

Material Name(s): Reclaimed Concrete Aggregate, Recycled Concrete Aggregate (RCA)

Description: RCA is generated through the demolition of concrete elements, such as roads, runways, and structures during road reconstruction, utility excavations, or demolition operations. The Forest Service does not have many concrete roads and runways, but concrete also can come from foundations, footings, sidewalks, curbing, and so forth. Concrete sidewalks and driveway sections may have steel reinforcements, while heavy concrete elements like roads or foundations usually will have steel. Usually, the RCA is removed with a backhoe or payloader and is loaded into dump trucks for removal. The concrete may need to be broken into manageable sizes with a hammer before loading. The RCM excavation may include 10 to 30 percent subbase soil material and asphalt pavement. Therefore, the RCA is not concrete, but a mixture of concrete, soil, rock, and perhaps brick and bituminous concrete.

The excavated concrete that will be recycled may be hauled to a central facility for stockpiling and processing or processed onsite using a mobile plant. During crushing and screening, ferrous metal recovery operations occur. Present crushing systems, with magnetic separators, are capable of removing reinforcing steel without much difficulty. However, welded wire mesh reinforcement may be difficult to remove.

Construction Materials Recycling Association
P.O. Box 122
Eola, IL 60519
<http://www.cdrecycling.org>.
<http://www.concreterecycling.org>.

Applications

The use of RCM as an aggregate substitute in pavement construction is well established and includes its use in granular and stabilized base, engineered fill, and Portland cement concrete pavement applications. Since the volume of material is expected to be somewhat limited, it most likely that Forest Service concrete will be used in fill applications.

Although the use of RCA in embankments or fills may not make the best use of the high-quality aggregates associated with RCA, where no other applications are readily available, RCA can be used satisfactorily. RCA aggregates are considered by many specifying agencies to be conventional aggregate. It requires minimal processing to satisfy the conventional soil and aggregate physical requirements for embankment or fill material. The lower compacted unit weight of RCA aggregates compared with conventional mineral aggregates results in higher yield (greater volume for the same weight), and is therefore economically attractive to contractors. In addition, for large reconstruction projects, onsite processing and recycling of RCA is likely to result in economic benefits through reduced aggregate hauling costs.

Physical and Mechanical Properties

Property	Value
Los Angeles abrasion loss (ASTM C131), (%) — Coarse particles	 20-45 [6,1]
Magnesium sulfate soundness loss ASTM C88), (%) — Coarse particles — Fine particles	 4 or less [6,1,8] less than 9 [9]
California bearing ratio (CBR), (%)*	94 to 148 [1,8]

** Typical CBR value for crushed limestone is 100 percent.*

Environmental and Safety Information

For RCA, environmental considerations have focused on the leaching of high pH changes from porewater from concrete. Ohio Department of Transportation research concluded that using RCA as an aggregate base in low lying or wet areas where alkaline runoff likely would occur could have an adverse effect on the environment (1). An Iowa report found that the high pH of the drainage water from RCA use can kill or impede grass growth at a drain outlet (2). Texas also has completed research in using RCA in mechanically stabilized earth (MSE) berms that involved thorough material characterization, pH measurements, and an evaluation of use (3,4). They concluded that pH and resistivity specifications for MSE wall backfill materials should be waived for crushed concrete, concrete structures that have suffered sulfate attack should not be crushed and used as backfill in MSE walls, and MSE walls with crushed concrete backfill should include adequate drains and high permittivity filter fabrics behind the wall to avoid drainage problems (4). The potential for pH and drainage issues leads some jurisdictions to require that RCA stockpiles be separated (a minimum distance) from water courses.

References

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3. Rathje, E.M.; Rauch, A.F.; Folliard, K.J.; Trejo, D.; Little, D.; Viyanant, C.; Ogalla, M.; Esfelle, M. 2001. Recycled asphalt pavement and crushed concrete backfill: state-of-the-art review and material characterization. Austin, TX: Texas Department of Transportation, Center for Transportation Research, University of Texas, Austin. <http://www.utexas.edu/research/ctr/pdf_reports/4177_1.pdf>

4. Rathje, E.; Rauch, A.; Trejo, D.; Folliard, K.; Viyanant, C.; Esfellar, M.; Jain, A.; Ogalla, M. 2006. Evaluation of crushed concrete and recycled asphalt pavement as backfill for mechanically stabilized earth walls. Austin, TX: Texas Department of Transportation, Center for Transportation Research, University of Texas, Austin. <http://www.utexas.edu/research/ctr/pdf_reports/0_4177_3.pdf>.

Table 3-3. Glass cullet (waste glass)

General Information
Material Name(s): Glass Cullet, Cullet, Waste Glass, Glass Sand, Glass Gravel **Description:** Glass is a product of the supercooling of a melted liquid mixture of sand (silicon dioxide) and soda ash (sodium carbonate) to a rigid condition in which the supercooled material does not crystallize and retains the organization and internal structure of the melted liquid. When waste glass is crushed to sand-like particle sizes, similar to those of natural sand, it exhibits properties of an aggregate material. In many localities, it is not cost effective to separate glass containers by color to make new glass, so all of the glass is stockpiled together. Furthermore, the glass usually contains plastic, metal, paper, and dirt contaminants. Crushing and screening the stockpiled glass removes many contaminants and provides a useful construction material. Glass gradation can vary widely depending on the crushing and screening process. It ranges in size from fine sand to inches. It is often difficult to get enough crushed glass to use as aggregate in a fill application, so it is usually mixed with natural aggregates to meet the gradation and volume requirements of the project.
Applications
Glass containers collected from Forest Service visitor centers or administrative buildings could be stockpiled until the volume is large enough to justify hiring a contractor to crush and screen the material. Once the material is crushed, it could be used as fill material, or mixed with natural aggregate and used as base-course material. See American Association of State Highway and Transportation Officials M318 for guidance on using glass in base applications.
Environmental and Safety Information
Most hazards arising from the use of glass result from what was in the container, not the glass itself. Clean crushed glass is essentially colored sand and is safe.
References
1. American Association of State Highway and Transportation Officials. 2009. Standard specification for materials: M 318-01, “Standard specification for glass cullet use for soil-aggregate base course.” (2002), Part 2 Specifications, 14th Edition. Washington, DC: American Association of State Highway and Transportation Officials.

Table 3-4. Roofing shingles

General Information
Material Name(s): Scrap Shingles, Post-Consumer Shingles, Torn-Off Scrap Shingles (TOSS), Recycled Asphalt Shingles (RAS) **Description:** Approximately 11 million tons of asphalt roofing shingle scrap is generated each year in the United States. The scrap shingle can be divided into two groups: tear-off roofing shingles (TOSS) and roofing shingle tabs, also called manufacturer shingle scrap. TOSS is generated during the demolition or replacement of existing roofs, while roofing shingle tabs are generated when new asphalt shingles fail quality control specifications. Because Forest Service units are far from most shingle manufacturers, it would not be cost effective to use manufacturer-scrap shingles. However, shingles could be collected from Forest Service buildings that are being reroofed or decommissioned. The quality of tear-off roofing shingles can vary. Tear-off roofing shingles may contain debris, such as nails, wood, paper, and plastic, that is removed through processing. The aggregate in scrap shingles can be lost in the weathering process that occurs during the service period. As a result, tear-off scrap may contain more than 30 percent asphalt by weight. The aged binder in tear-off roofing scrap also may be hard or even brittle, but a tear-off shingle is easier to shred than factory scrap. Shingles can be recycled in hot-mix asphalt because of the asphalt binder; the shingles also can be used as fill material.
Construction Materials Recycling Association P.O. Box 122 Eola, IL 60519 <http://www.shinglerecycling.org>.
Applications
The best use of old shingles is to mix them into new hot-mix asphalt (figure 3-2). In many ways, shingles have the same effect on hot-mix asphalt as RAP. The use of recycled shingles in hot-mix asphalt typically will improve rutting resistance, but may cause lower fatigue resistance and a lower low-temperature cracking resistance. Using a softer virgin binder, the fatigue and low-temperature performance challenges of the mix can be improved. TOSS is easier to shred than factory scrap because the binder has aged and become brittle. Early recyclers used wood chippers to shred the shingles, but the hard aggregate quickly wore out the teeth. However, there are now a number of specialized shingle shredders that will quickly break up the shingles into a useful size. Also, because the TOSS has hardened with age, it is unlikely to agglomerate during processing. The debris that contaminates tear-off roofing shingle scrap can be removed effectively. Nails are removed with magnets; paper and other lightweight contaminants are removed with blowers or vacuums. The shingle chips can then be added to hot-mix asphalt. However, the Forest Service unit should consider whether grinding the shingles and sending them to a hot-mix plant is the most cost-effective option.

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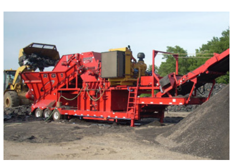
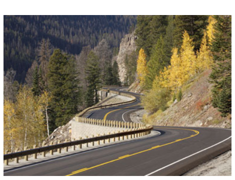
The cost of transporting and processing shingles can be prohibitive, so there is an increasing amount of work focusing on shingles as fill material. In this application, it is treated much like RAP, breaking it down to a manageable size and mixing it with natural materials to form a fill material with the appropriate gradation.
Environmental and Safety Concerns
Asbestos content in tear-off roofing shingles continues to be a concern for regulators. The California Integrated Waste Management Board reported that the total asbestos content in asphalt shingles manufactured in 1963 was 0.02 percent and in 1977 it had dropped to 0.00016 percent. However, the Georgia Department of Transportation reported that asbestos was used in roofing shingles as late as the 1980s. The Iowa Department of Transportation states that the use of asbestos in roofing shingles was discontinued after 1973. The Iowa Department of Transportation also conducted a study on the asbestos content of roofing shingles. From 368 shingle samples analyzed, only 3 contained asbestos, 0.8 percent. One issue often overlooked with grinding the shingles is that the aggregate dust also can be harmful, even without the asbestos, so workers need to use appropriate safety equipment to avoid silicosis.

1. **Receiving**
We receive tear-off shingle material from roofers and contractors. Asphalt shingle waste contains roughly 20% - 30% asphalt cement (asphalt binder). The material must be free of contaminants such as flashing, wood and plastic wrappers to ensure a high quality end product. For an additional charge, we will clean up any contaminated loads on site to ensure everything we receive will be recycled.



2. **Processing**
With the exclusive rights to the most technologically advanced shingle grinding equipment available, we have the ability to grind shingles faster and cleaner, without any waste byproduct. This means that unlike every other processor, 100% of the shingle material that we receive will be recycled. The nails are also automatically removed utilizing a built in magnetized separator. The nails collected are also recycled. We have the ability to process at rates exceeding 60 metric tons per hour.

3. **Raw Product**
Shingle waste is ground into clean 1/2” minus crumble ready for recycling. We adhere to strict guidelines for cleanliness to ensure a superior product to the end user. The clean crumble is then shipped to asphalt manufacturers to be used in their hot mix production.



4. **End Result**
Clean crumble is added to the asphalt hot mix which is used in paving roads. As much as 5% can be used to produce high quality asphalt for highways and high-traffic public roadways. Higher percentages can be used for private paving projects such as parking lots or driveways. Utilizing asphalt crumble not only reduces production costs, but also reduces the quantity of virgin resources that would otherwise be used in the production process. Adding crumble to the asphalt creates a superior product that is more durable and has a longer lifespan.

Figure 3-2. Recycled shingles. (Shane Ducholke, Environmental Processors) <http://www.environmentalprocessors.com>.

Table 3-5. Wood chips

General Information
Material Name(s): wood chips, mulch, shredded brush **Description:** Maintenance operations near roadways often result in brush being cut. Brush has to be kept clear of fire stands, signs, and stormwater structures. In addition, storms can bring down trees and tree limbs, which must be cleared. The brush and limbs are often fed through a chipper to make the material manageable. There is new interest in using shredded or chipped brush as erosion control. To be clear, the shredded brush, sometime called mulch, is not the same as the decorative bark mulch used for landscaping. Shredded brush is not particularly attractive, and is not to be used as a permanent landscaping feature.
Applications
When a new soil slope is created, or a new cut is exposed, these structures are at risk for erosion until they can be seeded. One option for preventing erosion during construction is to use shredded brush and trees as mulch on the slope. The shredded brush is simply spread on the slope to protect it from rain and to minimize the formation of preferential flowpaths across the slope. When the project is finished, the shredded brush is mixed into the slope soil as an organic amendment, and the final seeding takes place. So the wood chips serve two purposes, erosion control and nutrition for future plants.
Environmental and Safety Concerns
Studies have found no adverse effects on the soil or subsequent plants when the wood chips are tilled into the ground.

Table 3-6. Scrap tires

General Information
Material Name(s): Chipped Tires, Shredded Tires, Ground Tire Rubber, Crumb Tire Rubber, Tire-Derived Aggregate (TDA) **Description:** A typical scrapped automobile tire weighs 9.1 kilograms (kg) (20 pounds (lb)). Roughly 5.4 kg (12 lb) to 5.9 kg (13 lb) consists of recoverable rubber, composed of 35 percent natural rubber and 65 percent synthetic rubber. A typical truck tire weighs 18.2 kg (40 lb) and contains from 60 to 70 percent recoverable rubber. Rubber, and rubber tires, have very unique civil engineering properties and can be used safely in civil engineering applications. The tires can be utilized whole, slit in half, shredded, or reduced to a powder as crumb rubber. Given the number of tires generated by the Forest Service, it is likely that whole tires would be the most practical.
Rubber Manufacturers Association 1400 K Street, NW, Suite 900 Washington, DC 20005 <http://www.rma.org/scrap_tires/>
Applications
Whole tires have been used to construct retaining walls. They also have been used to stabilize roadside shoulder areas and provide channel slope protection. For each application, whole tires are stacked vertically. Adjacent tires are then clipped together horizontally, and metal posts are driven vertically through the tire openings and anchored into the underlying earth as necessary to provide lateral support and prevent later displacement. Each tire layer is filled with compacted earth backfill. This construction technique was first used in California.
Environmental and Safety Information
Early on, there were some instances where buried shredded tires caught fire. This was due to self-ignition because of the thickness of the layer. Another fire was caused by spilled fuel on the tires. Spreading the tires out and filling them with soil will prevent self-ignition.

Table 3-7. Coal fly ash

General Information
Material Name(s): Coal Fly Ash (CFA) **Description:** Usually, fly ash is derived from burning pulverized coal in a coal-fired boiler to generate electricity. It gets its name from the fact that it is a powdery ash that "flies away" in the exhaust gases, where it is captured using electrostatic precipitators, baghouses, or mechanical collection devices, such as cyclones. Fly ash that is produced from burning older, harder anthracite or bituminous coal typically is pozzolanic and is referred to as a Class F fly ash if the ash meets the chemical composition and physical requirements specified in American Society for Testing and Materials C618 (1, 2). Class F fly ash generally contains less than 10 percent material reported as lime (CaO). Although possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash require a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water to react and produce calcium silicate hydrates (cementitious compounds). Fly ash that is produced from the burning of younger lignite or subbituminous coal, in addition to having pozzolanic properties, also has self-cementing properties (ability to harden and gain strength in the presence of water) (2). When this fly ash meets the chemical composition and physical requirements outlined in ASTM C618, it is referred to as a Class C fly ash. Class C fly ash typically contains between 15 and 35 percent material reported as lime (CaO) (1). Most Class C fly ashes have self-cementing properties.

American Coal Ash Association (ACAA) 15200 E. Girard Avenue, Suite 3050 Aurora, CO 80014-3955 <http://www.acaa-usa.org/>	Coal Combustion Products Partnership (C2P2) Office of Solid Waste (5305P) 1200 Pennsylvania Avenue, NW Washington, DC 20460 http://www.epa.gov/epaoswer/osw/conserve/c2p2/index.asp>

AASHTO Center for Environmental Excellence 444 North Capitol Street, Suite 249, NW Washington, DC 20001 202-624-5800 <http://environment.transportation.org/>	Electric Power Research Institute (EPRI) 3412 Hillview Road Palo Alto, CA 94304 <http://my.epri.com/>

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Applications
It is unlikely that a Forest Service unit will be sufficiently close to a coal-burning power plant that produces enough CFA to justify transporting the material and using it as bulk fill. However, lesser quantities of CFA can be used as a soil stabilizer or as an amendment for Portland cement. Fly ash has been used as a cement and mineral admixture in Portland cement concrete (PCC) for nearly 70 years. Approximately 50 percent of recycled fly ash is used in the production of concrete and concrete products, making it the largest single use of fly ash (3). Adding CFA to cement generally results in a denser, more durable concrete, and the pozzolanic effect leads to enhanced long-term strength. In addition, like blast-furnace slag, using CFA as a cement admixture reduces the carbon footprint of the project. Note: It is important to know which class of CFA is available, since Class C and Class F have very different properties. See FHWA's booklet "Fly Ash Facts for Highway Engineers" at <http://www.fhwa.dot.gov/PAVEMENT/recycling/fatoc.cfm>. (2) Stabilized bases or subbases are mixtures of aggregates and binders, such as Portland cement, which increase the strength, bearing capacity, and durability of a pavement substructure. Because fly ash may exhibit pozzolanic properties or self-cementing properties; fly ash can be part of the binder in stabilized base construction applications. Results from laboratory and field studies have shown that fly ash can be used in stabilized bases or subbases, and those stabilized layers can be included in flexible pavement designs. Again, it is important to know what type of CFA is being used, since Class F CFA requires the addition of lime for the solidification process to take place.
Environmental and Safety Information
A concern with fly-ash use is the possibility of groundwater contamination by trace elements that are associated with coal-combustion byproducts. The possibility for trace elements to dissolve in rainwater that percolates through fly ash has caused restrictions on fly ash use by State environmental regulations. When fly ash is used in concrete, the potential for leaching of trace elements is very low. This is due to the constituents of fly ash being encapsulated in the matrix of the concrete. It is less clear about CFA used for stabilization. While soil stabilization is a bound application, it also is subjected to rainwater and occasional flooding, which is a concern for leaching. The Environmental Protection Agency is currently reworking their rule on the use of CFA in different applications, which should provide more guidance on the use of CFA for soil stabilization. Fly ash can cause a dust problem during placement. Workers involved with dry-ash handling should take precautions by wearing safety goggles to protect their eyes from dust, and by wearing a suitable particulate respirator (i.e., approved by the National Institute for Occupational Safety and Health for particulates). Dust problems can be partially alleviated by compaction and covering of the fly ash, moistening fly ash during placement, and using mechanical ventilation or extraction in areas where dust could escape into the workplace. Special lay-down trucks exist that reduce dusting issues.

Table 3-7 continued on next page

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References
1. ASTM C618-05. 2005. Standard specification for fly ash and raw or calcined natural pozzolan for use as mineral admixture in Portland cement concrete. In: Annual book of ASTM standards. West Conshohocken, PA: ASTM. 2. U.S. Department of Transportation, Federal Highway Administration. 2003. Fly ash facts for highway engineers. FHWA-IF-03-019. Washington, DC: U.S. Department of Transportation, Federal Highway Administration. 3. American Coal Ash Association. 2007. Coal combustion product (CCP) production and use. Aurora, CO: American Coal Ash Association.

Table 3-8. Blast furnace slag

General Information
Material Name(s): Blast-Furnace Slag (BFS), Ground Granulated Blast-Furnace Slag (GGBFS) **Description:** Blast-furnace slag is a coproduct from the blast-furnace production of iron. A coproduct is a material that is required for the production of another material (iron), while having its own intrinsic values. This is different than a byproduct material, which is an undesirable material with no intrinsic value. Iron is produced by heating iron, iron ore, iron scrap, and fluxes (limestone and/or dolomite) in a blast furnace along with coke for fuel. The coke is combusted to produce carbon monoxide, which reduces the iron ore to a molten-iron product. This molten-iron product can be cast into iron products, but is most often used as a feedstock for steel production. The fluxes capture noniron components of the feedstock, resulting in blast-furnace slag. The slag consists primarily of silicates, aluminosilicates, and calcium-alumina-silicates. Different forms of slag product are produced depending on the method used to cool the molten slag. If the liquid slag is poured into beds and slowly cooled under ambient conditions, a hard, durable crystalline material called air-cooled blast-furnace slag (ACBFS) is formed. This slag can be crushed, screened, and used as a mineral aggregate. If the molten slag is cooled and solidified by rapid water quenching to a glassy state, little or no crystallization occurs. This is called granulated blast-furnace slag. When crushed or milled to very fine cement-sized particles, ground granulated blast-furnace slag (GGBFS) has cementitious properties, which make a suitable partial replacement for or additive to Portland cement.
National Slag Association P.O. Box 1197 Pleasant Grove, UT 84062 <http://www.nationalslag.org/>

Table 3-8 continued on next page

Table 3-8 continued from previous page

Applications
Conceivably, the Forest Service could use ACBFS as an aggregate substitute. State transportation agencies have standards which consider ACBFS to be a conventional aggregate. It is used extensively in granular base, hot-mix asphalt, Portland cement concrete, and embankments or fill applications. The material can be crushed and screened to meet specified gradation requirements using conventional aggregate-processing equipment. Realistically however, most Forest Service units will be located at a significant distance from an iron foundry, and it is unlikely that transporting ACBFS to a Forest Service site would be cost effective. On the other hand, GGBFS is increasingly being used in the production of blended hydraulic cements (AASHTO M240) (1). When used in blended cements, granulated blast-furnace slag is too fine a particle size in accordance with AASHTO M302 (2) requirements. The ground slag can be introduced and milled with the cement feedstock or blended separately after the cement is ground to its required fineness.

The Environmental Protection Agency has recommended that effective May 1, 1995, procuring agencies specifically include provision in all construction contracts for the use of GGBFS in Portland cement concrete contracts (3). Cements containing GGBFS are now available from many producers of Portland cement, so the Forest Service can use slag cements or blended slag/Portland cements to lower their carbon footprint.
Environmental and Safety Information
Blast-furnace slag is primarily composed of calcium oxide, silicon dioxide, aluminum oxide, and magnesium oxide. It is not inherently dangerous, though the slag often contains some sulfur, which can leach out in certain conditions. In slag cement applications, the slag cement is handled and treated like Portland cement.
References
1. American Association of State Highway and Transportation Officials (AASHTO). 1986. Standard Specification for Materials, “Blended Hydraulic Cements.” AASHTO Designation: M240-85, Part I Specifications, 14th Edition. Washington, DC: AASHTO. 2. AASHTO. 1986. Standard Specification for Materials, “Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars.” AASHTO Designation: M302-86, Part I Specification, 14th Edition. Washington, DC: AASHTO. 3. U.S. Environmental Protection Agency. 1995. Recovered Materials Advisory Notice. Environmental Protection Agency. Federal Register; May 1, 1995.

Conclusions

Federal land management agencies have long been sensitive to the need for sustainable practices in order to maintain the forests and grasslands for future generations, while also providing recreation opportunities to the public. However, Federal agencies have been tasked to show more leadership in sustainable practices by reducing energy and water usage, reducing waste, and reducing greenhouse gas emissions. All of this is occurring at a time when agencies are being asked to conserve. One way for these agencies to show leadership in sustainable practices while reducing costs is to incorporate more recycled industrial byproduct materials into their construction and maintenance activities, particularly road construction and maintenance.

Road construction and maintenance was targeted in this project because the activities require significant volumes of fine and course aggregate, hot-mix asphalt, and possibly Portland cement. Mining and transporting the aggregates disrupts the environment around the mine, burns fuel, and releases greenhouse gases into the air. Asphalt binder is expensive; the cement in concrete requires significant energy during its production; and calcining the limestone releases carbon dioxide (CO_2) into the atmosphere (calcining uses high heat to convert limestone ($CaCO_3$) to lime (CaO) with CO_2 as a byproduct). The agencies need to address these issues in their respective sustainability plans.

However, using the materials in the applications shown in table 1-3 provides a way forward to reduce material and fuel demands while maintaining a satisfactory road system. Full depth reclamation provides a cost-effective way to recycle asphalt pavement and aggregates, reducing the demand for new materials. Using crushed concrete, asphalt, and glass as aggregate in fills and embankments also reduces the need for virgin aggregate. Shingles and old asphalt pavement also can be ground up and put back into new asphalt pavement, reducing the need for asphalt binder. And using slag cement instead of regular Portland cement reduces the carbon footprint of new concrete construction while providing a comparable product.

While this document provides only an introduction to recycling industrial materials, it provides the basis for road managers, engineers, and contractors to begin making more sustainable construction choices.

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APPENDIX A

Survey responses

The National Technology and Development Center sent out an informal survey on recycled materials to Forest Service representatives. Forest Service representatives were queried as to what topics they would like to see covered. The survey had three goals:

1. To determine what byproduct materials Forest Service representatives were aware of, or at least thinking about.
2. To determine how they wanted to use the materials.
3. To provide a minimum list of questions and issues that could be covered if possible.

The following is a list of excerpts from email responses from Forest Service personnel:

1. A "how to" guide [on hot-mix asphalt] to identify methods to pick it up, mixing methods, laying it back down, how much and what kind of asphalt to add to reuse it, etc.
2. Contacts on forests, and possibly State highway departments, or local road agencies.
3. Can you recycle any asphalt material or does it get unusable over time?
4. What "admixtures" are popular and for what reason?
5. In an effort to promote reuse/recycle and sustainability, what options do we have?
6. Information on asphalt millings applications on forest roads.
7. What about using recycled pavement as an aggregate course. Have been seeing roads where we've pulled up the asphalt...are we using it for aggregate? I've also been reading about alternatives to aggregate in the asphalt.
8. What about grinding up the existing asphalt pavement and reusing it in the sub-grade below the new asphalt?
9. Where is it appropriate to use recycled asphalt as "fill" material? The answer to this question probably varies by State. To be on the safe side, we've decided not to use the ground-up asphalt as fill in waterways or ditches that we're filling as part of a restoration project, and we only use it in "dry sites." This might be a point to cover: the appropriate use of recycled asphalt as fill in places other than road beds.
10. Where to place RAP so it is not an environmental hazard (i.e., roadway prism only)?
11. Maximum percent weight allowed in aggregate base or hot mix?
12. Size of the RAP in order to get a good compaction?
13. Where to place excess RAP (i.e., environmental issues)?
14. I would like to see some cost analysis… when we do asphalt work we store the used asphalt in our quarries, hoping to one day use the material. So could you address the following concerns:
    - What to do with wasted AC material?
    - What options are there to use material that has been stockpiled over the years?
    - Cost and value analysis. (Recycled product versus new.)

Out of the 14 responses received, 12 were specifically related to the reuse of hot-mix asphalt, primarily as fill material or as aggregate in base/subbase road construction. Question 8 "What about grinding up the existing asphalt pavement and reusing it in the subgrade below the new asphalt?" and related questions are essentially asking about the use of in-place recycling through full-depth reclamation (FDR).

There were a limited number of applications (fill and base/subbase uses) and no other recycled materials in the responses, though this is likely due to bias in the responses because of the survey format and who responded.

APPENDIX B
Glossary

Aggregate: Granular material that can be used in unbound applications, such as embankments and structural fill, or used in bound applications, such Portland cement and asphalt concretes. Aggregate materials include, but are not limited to, sand, gravel, crushed stone, rubber chips, crushed concrete, reclaimed asphalt pavement, foundry sand and slag, coal fly ash and bottom ash, blast-furnace slag and steel slag.

Aggregate gradation: See Gradation.

Agricultural land applications: Activities that focus on the application of materials on agricultural lands to modify soil conditions with the specific goal of improving crop health and yields. In this case, land application includes application directly to the surface as well as soil mixing. Agricultural land applications include the utilization of lime-bearing materials to change the soil pH; the utilization of materials to improve soil conditions, such as providing for better drainage or improved moisture retention, or the addition of mineral-bearing materials that provide nutrients to the soil.

Asphalt binder: A dark-brown to black cementitious material, in which the predominant constituents (+99 percent) are bitumens, which occur in nature or are obtained as residue in petroleum manufacturing, and are used as binder in asphalt-aggregate mixes.

Asphalt concrete: A mixture of asphalt binder and carefully graded coarse and fine aggregates.

Asphalt pavement: Pavement consisting of asphalt concrete layer(s) on supporting courses, such as concrete base, asphalt-treated base, cement-treated base, granular base, and/or granular subbase, placed over the subgrade.

Backfill: Material used to refill or backfill an excavated area. High quality, compacted backfill placed specifically to support a foundation or road is typically called structural fill.

Base: A layer of specified or selected material of planned thickness constructed on the subgrade or subbase to serve one or more functions, such as distributing load, providing drainage, minimizing frost action, and so forth. The base maybe placed in a granular or stabilized (bound) form.

Binder: A material or mixture of materials, which is primarily responsible for binding aggregate particles together in bound applications, such as Portland cement and asphalt concretes, as well as stabilized soils.

Bitumens: A class of black or dark-colored (solid, semisolid, or viscous) cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbons, of which asphalts, tars, and pitches are typical.

Bituminous: A material containing or treated with bitumen.

Blast-furnace slag: The nonmetallic components removed from iron ore during processing in a blast furnace. It consists essentially of silicates and aluminosilicates of calcium and other metals.

Boiler ash: General term to describe material produced by burning wood, coal, or other solid fuels to produce steam and electricity.

Byproduct: A secondary material that is produced as the result of some process. The production of the byproduct material is not the primary goal of the process. A byproduct also can be a product that has less value than the primary product. For instance, ash is a byproduct of the combustion process, though the primary product is heat.

Causticizing residues: Byproduct of the kraft pulping process, specifically from the recovery of energy and chemicals from spent pulping liquor. The most widely used of the causticizing residues is lime mud, which is essentially calcium carbonate (limestone) with a small amount of calcium hydroxide (lime).

Coal bottom ash: Granular, sandy residue generated by burning coal for electricity. The bottom ash falls out of the furnace into a collection hopper. Most bottom ash is predominantly silica, alumina, and iron.

Coal fly ash: A fine, powdery residue generated by burning coal used for electricity. The ash is captured from the flue gases using precipitators. Class F fly ash generally is generated by burning bituminous coal, while Class C fly ash is generated by burning lignite and subbituminous coal. Class F fly ash typically contains less lime than Class C ash and will act as a pozzolan in cementitous reactions, whereas Class C ash will form a cementitious compound when mixed with water.

Coarse aggregate: There is some variation in the definition of coarse aggregate between different industries, but it generally means the portion of aggregate retained on the No. 4 (4.75mm) sieve.

Construction and demolition debris: An aggregate material composed of crushed concrete, brick, stone, and other materials derived from construction and demolition processes. It also may contain shingles, reclaimed asphalt pavement, wood, and drywall.

Coproduct: A coproduct is a material that is produced as part of a process. Coproducts have equal value to the other products of the process.

Crumb rubber: see ground rubber.

Embankment: An embankment is a “built up” earthen structure used to raise the surface level. An embankment in a road is the layer of engineered material that raises the pavement structure to the appropriate grade. Embankments also describe the raised approach to bridges. Some geotechnical sites also include dams as embankments. There is somewhat of an overlap with structural fill because that term is used sometimes to describe the material that is used to construct an embankment.

Fine aggregate: In the construction industry, it is aggregate passing the No. 4 (4.75mm) sieve and predominantly retained on the No. 200 sieve (0.075mm) sieve.

Fines: In a general sense, the fines are the fraction of a soil in a batch of aggregate. It is usually more specifically taken to mean the material finer than the No. 200 (0.075mm) sieve.

Flowable fill: A self-compacting material typically composed of water, fine aggregate, a cementitious binder, and admixtures to control air and flowability. It is also called controlled low-strength material by the American Concrete Institute. Flowable fill is placed in a slurry form, usually to fill voids and trenches, after which it hardens into a strong, hard matrix.

Foundry sand: Foundry sand is byproduct material generated from the metal casting processes at metal foundries. Metal casting is a metal-forming technique used to produce metal parts ranging from automobile engine blocks and pistons, to plumbing fixtures to precision aircraft parts. Foundry sands are high-quality silica sands used to make the molds for casting the parts. The sand is reused until it is physically degraded, at which point it is removed from the sand supply.

Foundry slag: Foundry slag is similar to foundry sand. It is a byproduct material generated by metal casting processes at metal foundries. Foundry slag is composed of fluxing agents and impurities removed from the molten metal prior to casting.

Gradation: Usually, granular materials and soils are composed of particles with a range of sizes. The gradation describes the distribution of particles sizes. It is expressed in terms of the mass retained on or passing different sized sieves.

Granular base: In pavement design, the base course is the layer directly below the surface layer. The function of the base course is to support the asphalt and transmit traffic loads to the underlying layers. A granular base is composed of select aggregate materials that are chosen for superior strength and durability. The base is placed in layers called lifts and densified using heavy compaction equipment.

Granular subbase: The subbase is the layer between base course and the subgrade, which is a prepared soil layer. The function of the subbase is to transfer and disseminate the loads from the base course into the underlying material. Like the granular base, the subbase is composed of compacted aggregate material. The main difference is that the subbase tends to have a coarser gradation.

Ground rubber: Also called crumb rubber, it is a fine granular material composed of small rubber particles obtained from old tires. It can be used as a solid or mixed with asphalt binder as a polymer modifier.

Hot-mix asphalt: A form of asphalt concrete. The hot-mix asphalt is made by mixing heated asphalt binder and aggregate, and then placed and compacted while the mixture is still hot.

Landfill applications: Activities that utilize material in the construction and maintenance of landfills. Typically, the focus is on drainage applications, liner construction, and capping of the landfill, though alternate daily cover also is included.

Lignite coal: Also called brown coal, it is a soft, brownish-black coal in which the alteration of vegetable matter has proceeded further than in peat but not as far as in bituminous coal.

Other concrete uses: Application that focuses on the utilization of materials in concrete blocks, masonry units, and other types of concrete construction products. This application complements the use of materials in Portland cement concrete pavement and other massive concrete structures that people are more familiar with.

Permeability: The rate of flow of a liquid or gas through a porous material.

pH: A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14.

Portland cement: Hydraulic cement comprised of very fine grains produced by pulverizing clinkers consisting essentially of hydraulic calcium silicates and calcium sulfate.

Portland cement concrete: The product of mixing Portland cement, mineral aggregates, water, and in some cases additives, such as an air-entering agent, which result in a hardened structural material after hydration.

Portland cement concrete pavement: Also called rigid pavements. They are pavement structures in which the top or surface layer is made from Portland cement concrete.

Portland cement manufacturing: This application is focused on materials that can be used as feedstock for cement manufacturing, or can be used as a cement amendment.

Pozzolanic: A siliceous volcanic ash used to produce hydraulic cement.

Prompt roofing shingle scrap (roofing shingle tabs): Asphalt roofing shingles that are generated from "out-of-spec" shingles or when new asphalt shingles are trimmed during production to the required physical dimensions.

Reclaimed asphalt pavement (RAP): Asphalt pavement or paving mixture removed from its original location for use in another application.

Reclaimed concrete aggregate: An aggregate material obtained from crushing concrete structures. Reclaimed concrete aggregate includes the original aggregate from the concrete as well as parts of the hardened cement.

Recycle: To use a waste or byproduct as an input material in the construction or manufacture of another product (replacing virgin material).

Soil stabilization: Application that refers to modifying soils to provide better engineering properties. This is different than stabilized base because soil stabilization considers true soils, while base stabilization is focused on binding aggregates. In addition, the application does not include dynamic stabilization or purely mechanical means of stabilization, but is focused on chemical soil stabilization to reduce the plasticity of clayey soils and to improve the shear strength. Materials that are high in lime or have pozzolanic properties would be candidates for soil stabilization. Sandy materials that improve drainage also would be considered.

Stabilized base: The function of the base layer is the same as described above. The major difference is that a binding agent is added to the aggregate to stiffen and strengthen the layer.

Stabilized subbase: The function of the subbase layer is the same as described above. The major difference is that a binding agent is added to the aggregate to stiffen and strengthen the layer.

Steel furnace slag: The nonmetallic product that is developed simultaneously with steel in basic oxygen, electric, or open-hearth furnaces. It consists of calcium silicates and ferrites combined with fused and mineralogically combined oxides of iron, aluminum, manganese, calcium, and magnesium

Stiffness: The physical property of being inflexible and hard to bend.

Strength: The ability of a material to resist deformation when a stress is applied to it.

Structural fill: This term can be confusing. It commonly is used to describe an application and the material that is used in that application. In general terms, the structural fill application is the filling in of a depression with a material that meets specific engineering requirements. For example, if a building is to be constructed at a particular site that has poor soil, the native soil will be excavated and replaced with high-quality material. The new body of material is called a structural fill. Another example is the use of material to fill in a trench in roadway.

Subbase: The layer of select compacted granular material placed on the subgrade, which is overlain by the base of a flexible pavement structure or the Portland cement concrete slab of a rigid pavement structure. The subbase can be placed in stabilized or granular forms.

Subbituminous: Coal of lower rank than bituminous coal but higher than lignite.

Subgrade: The soil prepared and compacted to support a pavement structure. The subgrade is the layer below the subbase.

Tear-off roofing shingles: Asphalt roofing shingles that are generated during the demolition or replacement of existing roofs. They also are referred to as post-consumer shingles.

Tire-derived aggregate: Coarse aggregate material obtained by shedding old tires.

Unconfined compression strength: The load-per-unit-area at which soil will fail in compression.

Virgin aggregate: Aggregate that has been mined and not used in any prior applications.

Wastewater treatment plant residuals: Byproduct material of the pulp and paper industry composed of the solids removed from process water. They consist mostly of wood fibers and mineral materials, such as kaolin clay and calcium carbonate.

APPENDIX C
Web sites, References, Specifications

Toolbox

Table C-1. Primary recycled material tool box

NHI Module IV A - Recycling, February 25-27, 2009

1		DOCUMENTS	Web Site	PDF on CD
1.1		**Level 1 Sources**		
	1.	Federal Highway Administration User Guidelines, April 1998	http://www.recycledmaterials.org/tools/uguidelines/index.asp	
	2.	National Cooperative Highway Research Program (NCHRP) 4-21 Computerized Database, June 2000	http://www.recycledmaterials.org/Resources/CD/NCHRP/NCHRP.zip	
	3	Federal Highway Administration Evaluation Framework, October 2001	http://www.recycledmaterials.org/Resources/CD/Framework/Start/start.htm	
	4.	Recycled Materials Resource Center Project 23 PaLATE Life-Cycle Assessment Tool, December 2003	http://www.recycledmaterials.org/Resources/CD/PaLATE/PaLATE.htm	
1.2		**Level 2 Sources**		
	1.	NCHRP 25-25(04) Compendium of Environmental Stewardship Practices in Construction and Maintenance	http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/	✔
	2.	NCHRP 25-09 Environmental Impacts of Construction and Repair Materials on Surface and Ground Waters	http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_443.pdf	✔
	3.	Fly Ash Facts for Highway Engineers, 4th Edition, June 2003	http://www.fhwa.dot.gov/Pavement/recycling/fafacts.pdf	
	4.	Foundry Sand Facts Handbook	http://isddc.dot.gov/OLPFiles/FHWA/011435.pdf	

Table C-1. Primary recycled material tool box continued

1		DOCUMENTS	Web Site	PDF on CD
	5.	Asphalt Recycling and Reclaiming Association Basic Asphalt Recycling Manual	http://www.pavementpreservation.org/library/getfile.php?journal_id=635	
	6.	FHWA European Scanning Tour	http://www.international.fhwa.dot.gov/Pdfs/recycolor.pdf	✔
	7.	Association of State and Territorial Solid Waste Management Officials Beneficial Use Survey	http://www.astswmo.org/Publications/pdf/Benfuserpt.pdf	✔
	8.	“Road to Reuse” article from Civil Engineering Magazine		✔
	9.	“An Integrated Framework for Evaluating Leaching in Waste Management and Utilization of Secondary Materials,” a journal article from Environmental Engineering Science by Dr. David Kosson and colleagues	http://www.rmrc.unh.edu/Resources/PandD/kosson/Kossonetal.pdf	✔
	10.	“Use of a New Leaching Test Framework for Evaluating Alternative Treatment Processes for Mercury-Contaminated Soils,” a journal article from Environmental Engineering Science by Dr. Florence Sanchez and colleagues		✔
	11.	“A Probabilistic Source Assessment Framework for Leaching from Secondary Materials in Highway Applications,” a journal article from Clean Technologies & Environmental Policy by Dr. Defne Apul and colleagues		✔
	12.	“Transportation Applications of Recycled Concrete Aggregate”		✔
	13.	Materials from Dr. Dana Humphrey	http://useit.umaine.edu/case_studies/tires/case_studies.htm	

Table C-1. Primary recycled material tool box continued

2		WEB SITES	
	1.	Recycled Materials Resource Center (RMRC)	http://www.recycledmaterials.org/
	2.	Turner Fairbanks Highway Research Center (TFHRC)	http://www.tfhrc.gov/hnr20/recycle/wrc.htm
	3.	Asphalt Recycling and Reclaiming Association (ARRA)	http://www.arra.org/
	4.	American Coal Ash Association (ACAA)	http://www.acaa-usa.org/
	5.	National Slag Association (NSA)	http://www.nationalslagassoc.org/
	6.	Foundry Industry (AFS)	http://www.foundryrecycling.org/whatis.html
	7.	Rubber Pavements Association	http://www.rubberpavements.org/
	8.	Transportation Research Board – National Cooperative Highway Research Program	http://www4.trb.org/trb/crp.nsf/reference/appendices/NCHRP+Overview
	9.	U.S. Environmental Protection Agency – C&D Debris (USEPA C&D Debris)	http://www.epa.gov/epaoswer/non-hw/debris/about.htm
	10.	Texas Department of Transportation (DOT) – Road to Recycling	http://www.dot.state.tx.us/gsd/recycle/mat.htm
	11.	Combustion Byproducts Recycling Consortium	http://wvwri.nrcce.wvu.edu/programs/cbrc/index.cfm
	12.	**State DOT Recycling Program Web Sites**	
	12.1	California DOT (Caltrans)	http://www.dot.ca.gov/hq/oppd/rescons/rchomepg.htm
	12.2	Massachusetts DOT (MassHighway)	http://www.mass.gov/mhd/recycle/recycling.htm
	12.3	North Carolina DOT (NCDOT)	http://www.doh.dot.state.nc.us/preconstruct/highway/dsn_srvc/value/recycle/default.html
	12.4	Pennsylvania DOT (PennDOT)	http://www.dot.state.pa.us/penndot/bureaus/chiefeng.nsf/frmSEMPemsISO?openframeset&frame=contents&src=/penndot/bureaus/chiefeng.nsf/vSPL/inforecycling
	12.5	Texas DOT (TXDOT)	http://www.dot.state.tx.us/GSD/recycle/plan.htm
	12.6	Virginia DOT (VDOT)	http://www.virginiadot.org/infoservice/news/HRO4232002-Recycled.asp

Table C-1. Primary recycled material tool box continued

3		SPECIFICATIONS	PDF on CD
3.1		Various American Association of State Highway Transportation Officials (AASHTO) Recycled Material Specification from RMRC Projects	
	1.	Glass Cullet, Base Course Aggregate - AASHTO Designation: M 318-01	✔
	2.	Reclaimed Concrete in Portland Cement - Draft	✔
	3.	Reclaimed Concrete in Granular Base - AASHTO Designation: M 319-02	✔
	4.	Recycled Asphalt Shingle as an Additive in Hot Mix Asphalt – Draft	✔
	5.	Compost for Erosion Control (Compost Blanket) – AASHTO MP-10	✔
	6.	Compost for Erosion Control (Filter Berms) – AASHTO MP-9	✔

APPENDIX D

Case study—Cold Recycling Foam. Recycling in Estes National Park, Colorado (taken with permission from Wirtgen)

A section of highway in Estes Park, Colorado, recently underwent rehabilitation and recycling, using foamed bitumen. Details outlining the pavement structure, mix design, and recycling process are provided at: <http://www.wirtgen.de/media/redaktion/pdf-dokumente/03_kaltrecycling_stabilisierung/_allgemein_1/job-reports_kaltrecycling/jr_colorado_e.pdf>

Case study—Cold Recycling Foam. Recycling project, Canyon de Chelly, Arizona (taken with permission from Wirtgen)

Wirtgen and FHWA Central Federal Lands Highway Division recently rehabilitated 17.6 lane miles of road in Canyon De Chelly National Park using foam bitumen as the stabilization agent. The pavement sections that underwent rehabilitation consisted of a chip seal and bituminous base atop a sandy clay and silty sand subgrade. Details on the mix design, construction, and photos depicting the entire process are provided at:<http://www.wirtgen.de/media/redaktion/pdf-dokumente/03_kaltrecycling_stabilisierung/_allgemein_1/job-reports_kaltrecycling/jr_arizona_e.pdf>