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Where Ideas Become Reality

MATERIALS RECYCLING AND REUSE – FINDING OPPORTUNITIES IN COLORADO HIGHWAYS

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COLORADO DEPARTMENT OF TRANSPORTATION
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Prepared in cooperation with the Environmental Protection Agency

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16. Abstract

The Colorado Department of Transportation (CDOT) secured a Resource Conservation Grant provided by the U.S. EPA to determine a strategy to improve recycling on highway projects and reduce waste in landfills. The project focused primarily on five high-tonnage materials: asphalt, concrete, metal, wood, and tires. These materials can be reused, recycled, and replaced on highway projects in cost-effective ways. Recommendations include:

- Increase the percent of RAP allowed in highway asphalt pavement projects from 15% to 30%;
- Use crushed concrete for more project applications;
- Replace wood products with more recycle-friendly products such as steel and plastic;
- Replace raw materials with steel products made from recycled steel;
- Increase use of rubber tire products in engineering applications;
- Modify construction specifications and improve tracking to both increase and measure efforts; and
- Present findings to engineers and DOT designers responsible for materials selection in project design.

Implementation:

- Educate engineers and contractors about opportunities for replacing conventional highway materials with recycled materials;
- Remove recycling barriers inherent to current highway design plans;
- Revise construction specification language to encourage contractors to reuse and recycle;
- Improve tracking of reused and recycled material, starting with a baseline to compare future efforts; and
- Share research and recommendations from this project with CDOT staff, corporations, other government agencies, and the environmental community through an outreach program.

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EXECUTIVE SUMMARY

Environmental sustainability has evolved into a key concept that many states are adopting within the EPA Region 8 area. In Colorado, emphasis is placed on maximizing the amount of recyclable materials in new, widened, and rehabilitated highway applications to reduce solid waste, reduce costs of materials, and preserve natural resources. The Colorado Department of Transportation (CDOT) secured a Resource Conservation Grant provided by EPA to determine a strategy to improve recycling and reduce waste disposed in landfills. The grant was awarded to CDOT in May of 2006 and funding provided in October of 2006.

Four tasks were identified for this project to develop a strategy. These tasks involved:

1. **Research** - Conduct research to determine how various states and nations are tackling the ability to reduce waste through reusing and recycling materials for highway applications.
2. **Specifications** - Identify changes in the construction specifications to eliminate some barriers to recycling.
3. **Tracking** - Develop a tracking method strategy including establishment of a baseline to understand the current and future recycling efforts on CDOT highway projects.
4. **Presentation** - Present findings to CDOT staff and at the National Recycling Coalition conference in September of 2007.

CDOT and other Colorado agencies have successfully used recycled and reused materials on many of their roadway projects. Some of these specific projects that involved recycling are described within this report. Applying these recycling practices to other CDOT projects is a promising way to increase the recycling rate throughout the state.

To efficiently conduct the research, a specific list of highest-priority materials was required to focus the project. A survey of CDOT construction, maintenance, and design engineers was conducted to help determine this list. The following exported (leaving the site) and imported (brought to the site) items were identified as the initial focus of the research efforts. The imported materials are identified accordingly. Those materials in bold were selected as the areas of highest focus for this project based in part on the survey results:

1. **Asphalt** - Hot Mix Asphalt (HMA), Recycled Asphalt Pavement (RAP), Paving/Roadway Materials, Roof Shingles (import)
2. **Concrete** - Structural Concrete, Pre-cast concrete (PCCP), Flatwork Concrete (curb, gutter, etc), Bridge/Barrier Rail, Concrete Pavement, Recycled Concrete Aggregate (RCA)
3. **Wood** - Delineator Posts, Fence, Posts/Stakes, Construction Materials
4. **Metal** - Bridge Railing, Guard Rail, Metal Fence, Structural Steel, Corrugated Steel Pipe, Electrical Metal Conduit, Reinforcing Steel, Ductile Iron Pipe
5. **Scrap Tires** (import)
6. **Metal** - Bridge Railing, Guard Rail, Metal Fence, Structural Steel, Corrugated Steel Pipe, Electrical Metal Conduit, Re
7. Geotextiles - Silt Fence, Erosion Logs.
8. Plants/Organics - Trees, Branches, Grass, Compost.

9. Glass, Ceramics – Traffic Control Material, Glass (import), Ceramics (import)
10. Plastic - PVC/Pipe, HDPE, Electrical Plastic Conduit

The research findings for each of the above areas were documented including data, case studies and recycling companies in the Colorado area for each particular material category.

The multiple reuse opportunities for materials on highway construction and maintenance projects provide many opportunities for CDOT to dramatically increase their recycling rate. It is encouraging to learn that 100% of asphalt, concrete and metal could be recycled with minor changes to the design process, specifications, and/or construction methods, and with little to no adverse changes in performance expectations, overall cost, and structural longevity. Several changes could be made to significantly reduce waste on highway projects based on the research conducted. The following are a few examples:

- Increase the percent of RAP allowed in highway asphalt pavement projects from 15% to 30%;
- Use crushed concrete for more project applications;
- Replace wood products, which are difficult or impossible to recycle at the end of their useful lives, with more recycle-friendly products such as steel and plastic;
- Replace raw materials with steel products made from recycled steel; and
- Increase use of rubber tire products.

Additional recommendations of this research project include:

- **Educate, inform, and motivate** engineers and contractors about new, improved and proven opportunities for recyclable materials to replace conventional materials on highway projects.
- Remove the recycling barriers inherent to current **highway design plans** by including more information, design notes, and requirements or incentives to recycle in the special conditions.
- Revise **construction specification** language to provide clear direction to contractors, encouraging them to reuse and recycle. Areas of focus include materials removal, erosion control, and possibly an overall "greening" specification.
- **Improve tracking** of reused and recycled material, starting with a baseline to compare future efforts. By using the CDOT Cost Data Book, project specifications and pay item numbers would be developed for reuse and recycled materials. These items would be accounted for in the design and construction of a project using the same bid item process currently in use. Progress could then be tracked over time to track improvements and further analyze methods to increase recycling. Items could be tracked through CDOT's new Enterprise Resource Planning computerized database once it has this capacity.
- Share research and recommendations from this project with CDOT staff, corporations, other government agencies, and the environmental community through an **outreach**

program. Initial plans include presentations by Patricia Martinek, CDOT's Environmental and Planning Research Manager to CDOT staff, as well as the National Recycling Coalition 26th Annual Congress and Expo in Denver, Colorado in mid-September 2007, the National Asphalt Pavement Association annual meeting in February 2008, and the EPA-sponsored Industrial Byproducts Summit in April 2008.

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AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ADOT	Arizona Department of Transportation
AR	asphalt rubber
AR-AC	asphalt rubber asphalt concrete
AR-ACFC	asphalt rubber asphalt concrete friction course
ASR	alkali-silica reaction
ASTM	American Society for Testing and Materials
BMP	best management practice
Caltrans	California Department of Transportation
CAPA	Colorado Asphalt Pavement Association
CCA	Colorado Contractors' Association
C&D	construction and demolition
CDOT	Colorado Department of Transportation
CIPR	cold in-place recycling
CIWMB	California Integrated Waste Management Board
CP	composite of plastics
CPG	Comprehensive Procurement Guidelines
CRM	crumb rubber mixture
DMS	Department Material Specification
DOT	Department of Transportation
EPA	U.S. Environmental Protection Agency
FHU	Felsburg Holt & Ullevig
FHWA	Federal Highway Administration
GHG	greenhouse gas
HB	house bill
HDPE	high-density polyethylene
HMA	hot mix asphalt
ISTEA	Intermodal Surface Transportation Efficiency Act
KYTC	Kentucky Transportation Cabinet
LA abrasion	Los Angeles Abrasion Test (AASHTO T-96)
LDPE	low-density polyethylene
LL	liquid limit
LRA	limestone rock asphalt
LTAP	Local Technical Assistance Program
MDOT	Michigan Department of Transportation
MGPEC	Metropolitan Government Pavement Engineers Council
Mn/DOT	Minnesota Department of Transportation
M&S Standards	CDOT Standard Plans
MTCO2E	Metric Tons of Carbon Dioxide Equivalent
NCHRP	National Cooperative Highway Research Program
NRC	National Recycling Coalition
PCC	pre-cast concrete
PCCP	portland cement concrete pavement
PET	polyethylene terephthalate
PI	plasticity index

PVC	polyvinyl chloride
RAP	recycled asphalt pavement
RCA	recycled concrete aggregate
RCM	reclaimed concrete material
RMRC	Recycled Materials Resource Center
RPS	renewable portfolio standard
RRP	reinforced recycled plastic
SAM	stress absorbing membrane
SAMI	stress absorbing membrane interlayer
SB	senate bill
TCD	traffic control devices
TNRCC	Texas Natural Resource Conservation Commission
TRM	turf reinforcing matting
T-REX	Transportation Expansion of I-25 in Denver, CO
TERRA TACKTM SC	shredded wood with a polyacrylamide tackifier
TxDOT	Texas Department of Transportation
USDOT	United States Department of Transportation
UV	ultraviolet
WARM	WAste Reduction Model
WTE	waste to energy

1.0 INTRODUCTION

The Colorado Department of Transportation (CDOT) is the state agency responsible for Colorado's 9,156 mile highway system, which includes 3,714 bridges. Each year, this system handles over 26.1 billion vehicle miles of travel. Although the Interstate system accounts for only about 10 percent (915 miles) of the total mileage on the state system, 40 percent of all travel takes place on our Interstate highways. Nearly 75% of the interstate system was built before 1970.

Awareness of the human impact on the environment has been heightened by recent global conferences, state and federal legislation and initiatives, and scientific data presented daily in the media, addressing greenhouse gas emissions related to global warming and climate change, energy efficiency, pollution, and solid waste. Recycling is an important way to reduce solid waste and reduce the use of natural resources. Recycling can also contribute to a reduction of greenhouse gas emission and energy consumption. Recognizing the importance of recycling and promoting waste management, the U.S. Environmental Protection Agency (EPA) has set a goal to increase the national recycling rate from 30% to 35% by 2008. The other five goals set by EPA include the following, which are also of special interest to CDOT:

1. The reduction and recycling of industrial waste products including coal combustion byproducts, slag materials, and foundry sand—some of which could be incorporated into many of the roadway materials used on CDOT highway projects.
2. Minimizing and reusing the construction and demolition materials--such as those generated from highway projects.
3. Reducing priority chemical amounts found in waste streams.
4. Reducing waste electrical and electronic equipment (WEEE) sent to landfills to some extent—a waste stream which is not a high volume material in highway projects.
5. Using recycled tires through various end-use products--on highway and other projects.

CDOT also has an interest in reducing waste and increasing their rate of recycling. EPA's national recycling rate goal has motivated CDOT to conduct this research project and work towards increasing their rate of recycling by 10% over the next two years. CDOT has chosen to focus on their highway related waste generating projects in an effort to achieve their recycling goal. This research project was funded through a Resource Conservation Grant provided by EPA. This grant was awarded to CDOT in May of 2006 and funding provided in October of 2006.

This project has been divided into four parts:

Task 1: Conduct research

Task 2: Identify potential specification changes

Task 3: Develop tracking method strategies to meet the recycling goal

Task 4: Prepare a presentation to share the study findings

To focus research in this task, a Landfill Materials Survey was distributed to CDOT staff to identify waste materials that are sent to landfills instead of being reused or recycled on the project site. These results were cross-referenced with the CDOT Cost Data Bid Summaries to determine which materials would yield the most significant results by recycling and reuse during construction highway projects based on materials quantities, volumes, etc. A meeting with area contractors familiar with the CDOT process was also conducted to better understand their perspective and suggestions on methods to improve recycling and reuse on highway projects. Using available resources and the internet, research was then conducted to determine the best techniques to promote recycling and to identify case studies that exemplify recycling practices on highway projects around the world.

While the purpose of the survey for this project was to narrow the number of materials being researched, it also provided a subjective evaluation of which materials are generally not reused or recycled on CDOT construction projects.

CDOT specifications were reviewed to determine which sections that currently allow for reuse and recycling and which sections could be revised to improve reuse and recycling. Task 2 included providing specific recommendations for revising two sections of the CDOT specifications.

For CDOT to understand and track their performance for improving reuse and recycling on highway projects, a baseline needs to be established and tracked overtime. Task 3 provides a methodology for CDOT to track specific recycled materials over time using existing tools.

The information gathered as part of this research project will be distributed to others to build awareness. Task 4 included assembling a summary presentation to be given at the National Recycling Coalition (NRC) conference in Denver, Colorado in September 2007, as well as other upcoming events:

- National Asphalt Pavement Association annual meeting in February 2008
- EPA-sponsored Industrial Byproducts Summit in April 2008

2.0 COLORADO RECYCLING EFFORTS

2.1 Legislation

Within the state of Colorado, several measures have taken place to improve recycling. In 2005, former Governor Bill Owens issued executive orders for Greening Government and Energy Efficiency. Two Colorado Statutes have been revised to address energy efficiency and a Senate Joint Resolution was issued concerning the greening of state government buildings.[1] Likewise, the mayor of Denver has introduced Greenprint Denver, which is an action agenda for a more sustainable City and County of Denver.[2]

Colorado's new Governor Bill Ritter is also interested in improving the environment by reducing waste and conserving energy. He signed two bills since taking office in 2007 to implement his "New Energy Economy" pledge.[3] In April, 2007, Governor Ritter signed two Executive Orders towards Greening of State Government (D007 11 and D007 12) to reduce the environmental impact of all state agencies and to require them to meet quantifiable goals of reducing the consumption of energy, water, petroleum fuel, and paper by the year 2012. With regard to materials management, the Governor's Executive Orders require agencies to adopt a "zero waste" goal through re-use, reduction, recycling, and composting of waste streams.

These executive orders have a direct affect on CDOT projects by encouraging reuse and recycling strategies to the extent practicable. Research projects like this one are positive steps toward achieving the Governor's state-wide mandate. CDOT is one state agency where huge opportunities are possible to substantially increase the volume of recycling and reused materials because of the large material volumes handled and consumed in transportation projects.

Governor Ritter also is initiating efforts by state agencies to reduce ambient ozone concentrations and greenhouse gas emissions through interagency meetings and planning. An ozone reduction plan for the Denver Metropolitan area is due to the Governor from the Denver Regional Air Quality Council by summer of 2008. These efforts will require a reduction in transportation, construction, industrial, and other source emissions that increased recycling and reuse can help achieve.

Finally, Colorado's legislature recently passed House Bill 07-1220 which encourages the use of environmentally preferable products by state agencies. This bill also is tied to the concepts of purchasing more recycled content materials, generating more recyclable products, materials reuse, reduced consumption, increased recycling, consideration of life-cycle analysis, and others.

Other legislation that parallels Governor Ritters efforts towards greening state agencies include President George W. Bush's Executive Order 13423 on Greening of Federal Agencies, and the Federal Highway Administration's policy on recycling and reuse which recognizes engineering, economic, and environmental benefits.

The message from Colorado and federal leaders is clear. CDOT needs to continue and increase their efforts towards environmental stewardship and smart economically-sound green business practices. This research project provides background and means towards these goals.

2.2 Construction Project Examples

Many transportation agencies around the state of Colorado have been using and developing means to incorporate more recycling in their transportation projects. For example:

- The City of Pueblo 2007 Overlay Project, the City's asphalt mix design specification allows a maximum of 30% RAP in the total mix.
- CDOT uses and allows as much as 25% RAP in their new asphalt mix design specification for most asphalt, and up to 15% RAP in the top pavement lift. CDOT's Region 3 has used over 15,000 tons of RAP over the past 5 years, and Regions 3 and 4 have incorporated recycled in-place asphalt in their projects.

There have been some exemplary case studies of projects around the state of Colorado that have made great strides in the implementation of recycling within the project. The following are a few of the specific cases where detailed information is available. A brief description of each case is provided:

Transportation Expansion (T-REX) Project; Denver, CO[4]

The T-REX project in Denver, Colorado utilized all the old asphalt and concrete from the project. The asphalt rotomill tailings from the old roadway were utilized as subbase for the concrete pavement throughout the project. In addition, some were reused on-site in the asphalt product and on other nearby projects by the contractor. Therefore, none of the rotomill tailings left the site for disposal. Concrete from both the structure demolition and roadway removal was used both for tracking pad material and as fill on the project. Again, no concrete material left the project site for the landfill. Shredded tires were imported for use as ballast material beneath the T-REX project light rail corridor for vibration mitigation on the project. The contractor used low sulphur fuel in all project vehicles, although not required by their Contract. This type of fuel is cleaner than commercially available fuels. All of the waste oil from vehicle maintenance was also recycled.

Figure 1. Asphalt Paving Operations on the T-REX Project

Figure 2. Rails Made from Recycled Steel from Mile High Stadium

Steel imbedded within the concrete, steel sign structures, steel bridge girders, and old pedestrian railings were recycled. No significant steel products were landfilled. The steel used to manufacture the light rail tracks as part of the T-REX project was recycled from the former Mile High Stadium. The steel was stockpiled and then sent to the Rocky Mountain Steel Mill in Pueblo, CO, where it was melted down and formed into rail for the new light rail extension. The rail is inscribed "Mile High to T-REX" all along the tracks.[4]

The T-REX project was CDOT's first and largest design-build construction project to date. This contract was defined as one that allowed the contractor more latitude in the design and operations than is typical. It is believed that this latitude allowed the contractor to define the project in such a way that the high volume of on-site reuse and recycling both met construction specifications and helped the contractor win the contract because of the lowest cost proposal.

Belleview Avenue and Jordan Road; Arapahoe County, Colorado[5]

In 1994, Arapahoe County paved Belleview Avenue, west of Peoria Street and throughout the Cherry Creek State Park using reclaimed asphalt paving material. The pavement millings were crushed and treated with a specially developed asphalt emulsion. A five-inch thick layer of the recycled material were placed on the road, and then covered with a chip seal driving surface. These pavement sections have performed well with minimal visible surface distress.

Again in 1995, Arapahoe County paved Jordan Road with the same recycled asphalt concrete alternative. The present worth value of the recycled pavement was $302,828 while the virgin hot mix asphalt (HMA) alternative had a present worth value of $311,255. This translated into annual values of $17,513 vs. $18,000 for recycled and virgin HMA, respectively. The annual savings totaled approximately $1,500 per year.

US Highway 287; Longmont, Colorado[6]

CDOT approved the use of a lime/fly ash mix design for a project on US Highway 287 near Longmont, Colorado. Lime was mixed with soil and allowed to equilibrate for seven to ten days. Conditioned Class F fly ash was then delivered in live bottom trailers. A motor grader spread the ash evenly over the lime/soil mixture. A CMI roto-tiller connected to a water truck delivered and mixed a measured amount of water to the ash/soil/lime mixture. The water was mixed in such a way as to result in an approximately 9-inch layer after compaction. A sheep's-foot roller was used to compact the mix and then a layer of aggregate is placed prior to paving. This lime/ash mix was selected to achieve certain geotechnical properties at the project and to ensure uniformity in the engineered material.

Figure 3. Lime/Fly Ash Mix Design

U.S. 6 from Clifton to Palisade; Grand Junction, Colorado[7]

The project, U.S. 6 from Clifton to Palisade near Grand Junction for the Colorado DOT, won three awards from Colorado Asphalt Paving Association (CAPA) for use of a new technology that assisted in a hot in-place pavement recycling project in the mountains of west Colorado near Grand Junction. Using just one machine, the unique repaving process heats, scarifies and applies recycling agent to an existing, old pavement, and replaces that material as a new leveling course. Then the machine tops that leveling course with a virgin HMA overlay that is simultaneously fed into the repaver from the front. This overlay then bonds thermally with the recycled leveling course to form a monolithic pavement.

For this particular project, one inch of surface was hot in-place recycled, then topped with at least an inch of fresh hot mix asphalt. Because of the need to correct variances in cross slope, the actual overlay varied from 1 to 2 inches. The virgin mix was a Superpave design, a half-inch nominal aggregate size with PG 64-22 binder, appropriate for that climate and traffic load and readily available from area suppliers. The binder was not polymer-modified.

That one inch of recycling equates to 9,400 tons of asphalt pavement and construction aggregates that were kept in-place rather than landfilled, transported off-site, or stockpiled indefinitely. Because the asphalt pavement was used in-place, the state was able to eliminate a stream of dump trucks needed to haul out the old asphalt pavement thus decreasing fuel usage, diesel emissions, traffic congestion and highway wear and tear that those trucks would otherwise have created.

I-76/ Pecos Street Interchange; Denver, Colorado[8]

Portions of the proposed I-76 interchange with Pecos Street were constructed over an old landfill. Shredded tires were used as light-weight fill material beneath the highway where it crossed over the landfill, to minimize roadway settling due to landfill subsidence. This project was constructed between 1989 and 1993. The roadway and fill sections are holding up well over this extended time period.

Chelton Road, Union Boulevard and Briargate Parkway; Colorado Springs, CO[29]

The City of Colorado Springs is testing an asphalt-rubber mix on local streets for noise mitigation, sustainability and other long-term applications. Approximately 6,200 tons of rubberized asphalt were used this year at a cost of about $438,000. Rubberized asphalt costs approximately $70 a ton, compared with $43 a ton for nonrubberized asphalt. Although the rubberized asphalt was higher in price, the long-term benefits of less maintenance, less splash-back, better drainage and reduced noise justified the higher expense. The City reported a 3- to 4-decibel noise reduction, which compares to removing about half of the cars on the road and provided a discernable noise level difference for nearby residents. The reduced noise also eliminated the need for noise walls along the roadway. Current costs for noise walls are approximately $1 million per linear mile for each wall, or $2 million where two walls are needed.

The rubberized asphalt in Colorado Springs was applied on Chelton Road from Airport Road to Palmer Park Boulevard, on Union Boulevard north of Austin Bluffs Parkway to Academy Boulevard, and on the south side of Briargate Boulevard between Lexington Drive and Union. Next year, it will be applied to Union Boulevard between Constitution and Pikes Peak Avenues.

Glenwood Springs Municipal Airport

Another project combining the use of recycled tires in asphalt pavement was completed June 2003, in Glenwood Springs. Through a unique coordination of multiple organizations and funding sources, the Glenwood Springs Municipal Airport project utilized over 4,800 recycled tires in 30,000 square yards of asphalt tarmac on a runway, taxiways, and parking apron. This rubber-asphalt pavement contained 20-25% recycled waste rubber from Colorado tires. The objective of the project was to improve the usability of the airport while providing a test platform for the use of rubber-asphalt paving materials for general aviation airport maintenance.

While there are many other projects worthy of mention in a listing of reuse and recycling transportation projects, there is only sufficient space in this report to enumerate these few. Nonetheless, it is apparent that reuse and recycling strategies in the transportation industry is a growing and successful trend that is gaining acceptance nationally that will benefit society directly and indirectly on into the future.

3.0 METHODOLOGY

The research project identified a huge amount of information and resources currently available on all the materials used on highway construction projects. Therefore, it was important to develop an appropriate methodology to narrow the focus of the researched materials in order to stay within the limits of this project scope. The ultimate project goal is to increase the amount of materials that are reused and recycled on CDOT highway projects. Therefore, the research focused mostly on the materials that CDOT uses routinely in large quantities. For purposes of this project, recycling is defined as "reusing or making a substance available for reuse."

Commonly-used CDOT materials were identified by reviewing CDOT's Cost Data Book (bid summary list) used for projects. This analysis included data based on the past three years (2004-2006). The CDOT bid summary list identifies project materials that have either been exported from or imported to highway project sites. The list summarizes the items by category including the quantity used on CDOT projects. The best benefit could be realized by focusing on the larger quantity items exported and imported. If recycling even a small percentage of these large quantity materials could be achieved, the volume reduction of waste would be substantial.

3.1 Materials Landfill Survey

A survey was prepared to provide the research team information with regard to the percentage of materials generated on CDOT projects that are reused/recycled on site, sent to a recycle center, stockpiled off-site, or sent to a landfill. This feedback then allowed a better understanding of which materials have the greatest potential to improve the recycle rate goal at CDOT. The survey was then distributed by Email to 206 CDOT project engineers, resident engineers, materials engineers, and maintenance personnel, as well as a few contractors to gather feedback. A copy of the Survey is included in **Appendix A**.

3.2 Survey Responses

Out of the 206 staff who received the survey, 45 (almost 25 percent) responded. The results for each of the 45 surveys were tallied for each specific material under each main material heading (e.g. concrete) and then averaged based on the completed responses for each disposal method. See **Appendix A** for the compiled results of the survey. This was a highly subjective exercise and reflects perceptions and estimates of the respondents rather than measured percentages. One of the key aspects of this study was to help the committee to prepare a tracking method to more accurately account for the quantity and percentage of materials that are either being reused on the project, recycled, or made from recycled or waste material and imported to the site. The results of the survey are shown graphically for each material. These graphs are included in **Appendix A**. This survey information proved useful to concentrate our efforts.

Based upon the survey results, a review of the CDOT bid summaries list, and preliminary research on recycled materials that could be imported for use on highway projects, the following list was created which ranks the materials by potential for reuse and recycling. Imported items to the project as recycled materials from third party sources are identified in parentheses after the specific material:

1. Asphalt - Hot Mix Asphalt (HMA), Paving/Roadway Materials, Roof Shingles (import)
2. Concrete - Structural Concrete, Pre-cast concrete, Flatwork Concrete (curb, gutter, etc), Bridge/Barrier Rail, Concrete Pavement
3. Wood - Delineator Posts, Fence, Posts/Stakes, Construction Materials.
4. Metal - Bridge Railing, Guard Rail, Metal Fence, Structural Steel, Corrugated Steel Pipe, Electrical Metal Conduit, Reinforcing Steel, Ductile Iron Pipe
5. Scrap Tires (import)
6. Geotextiles - Silt Fence, Erosion Logs.
7. Plants/Organics - Trees, Branches, Grass, Compost.
8. Glass, Ceramics – Traffic Control Material, Glass (import), Ceramics (import)
9. Plastic - PVC/Pipe, HDPE, Electrical Plastic Conduit
10. Cool Fly Ash, Steel Slag and Quarry Waste Fines

Using the prioritized list (above), the next step for this task was to review references that cover specific cases where each of these materials have been used or reused on a project. Local, national, and international project references were used. Additionally, a review of CDOT, U.S. Departments of Transportation efforts on recycling, FHWA research, technical journals, and internet research on recycling was also conducted for these specific materials. This information and specific sources are included in Appendices B through M.

In January of 2006, CDOT completed a different survey detailing the recycled materials used on CDOT projects and submitted this form to the Recycled Materials Resource Center (RMRC). The RMRC was conducting a survey to determine the current state of recycled materials use in the highway environment. That survey stemmed from the National Cooperative Highway Research Program (NCHRP) Project 4-21 survey that was conducted in May 1996. The results of this survey were used to show how recycled materials use had changed over the past nine years.

As seen in **Table A-1** in **Appendix A,** the RMRC survey was used to estimate the volumes of materials used where specific data were not available, noting that the values were estimated. **Table A-1** is a matrix that lists a number of potential recycled materials (Column 1), a number of potential beneficial use applications (Columns 2-5), the extent of use (Column 6) and applicable specifications (Column 7). The table is a useful tool that provided a summary of different recycled material application combinations used in Colorado.

4.0 RESEARCH FINDINGS

Based on our research, the following findings were determined for each category:

4.1 Asphalt: RAP, HMA, Paving/Roadway Materials, Roof Shingles

4.1.1 Information and Data

Asphalt is 100% recyclable and can be reused on projects or recycled through a recycle facility. There are many uses for recycled asphalt on project sites including:

- Asphalt concrete aggregate and asphalt cement supplement
- Hot mix asphalt (central processing facility)
- Hot mix asphalt (in-place recycling)
- Cold mix asphalt (central processing facility)
- Cold mix asphalt (in-place recycling)
- Granular base aggregate
- Stabilized base aggregate
- Driveway and parking areas
- Bike and walking paths
- Embankment or fill

Asphalt is one of the largest quantities of construction materials typically used and disposed of on CDOT highway projects. From 2005 to March of 2007, CDOT used approximately 1,121,500 square yards of cold-in-place asphalt, 1,011,500 square yards of full depth replacement, and 1,855,000 square yards of hot mix asphalt. Region 3, in the western part of the state, has used approximately 441,000 square yards of cold-in-place asphalt from January 2007 through March 2007. Approximately 266,000 square yards of cold-in-place was used in Jackson County during the same 2007 time period for a 3.5 inch cold-in-place mix with a 2 inch overlay that included rock cuts for a project in Region 3. This information was based on the survey CDOT completed for RMRC.

Over the past 5 years, CDOT has removed over 22 million square yards of asphalt material and has placed over 13 million square yards of new asphalt pavement. If 25% of RAP was used in new asphalt over the past 5 years, a savings of 3.25 million square yards of virgin material could have been realized and 15% of the removed material could have been used. The remaining 85% of the removed asphalt material could have been used as aggregate base course, parking areas, and other uses. Efforts to provide 100% recycling of this material would significantly increase the amount of recycling conducted on CDOT projects. **By simply finding ways to recycle all removed asphalt material, CDOT would reach its goal of increasing its overall recycling rate by 10% over the next 2 years due to the high volume of material.**

Many European countries already successfully recycle 100% of their asphalt materials including Sweden, Germany, Denmark and the Netherlands. The US currently recycles about 80% of Recycled Asphalt Pavement (RAP).[9] California uses Recycled Asphalt Concrete (AC) with 15% to 50% of RAP as conditions warrant. Caltrans is working on specifications to use 25% to 50% RAP in hot-mix AC and 100% RAP in cold-in-place applications.[10] Recycling asphalt pavement is also a common practice in Texas. Under current Texas Department of Transportation (TxDOT) specifications, a maximum of 20 percent of the RAP is allowed in surface mixtures.[11]

Another potential source for recycled asphalt is roofing shingles. Each year, roofing manufacturers produce approximately 11 million tons of new waste roofing shingles and shingle trimmings (post-industrial) in the United States of America. In addition, residential and commercial roofing replacement activities generate 8 to 10 million tons of old roofing waste (post-consumer). More than 500 million tons of asphalt concrete are produced annually in the U.S., of which approximately 90% is hot mix asphalt. Therefore, using approximately 2% roofing shingle waste in all asphalt mixtures would consume all post-industrial and post-consumer roofing shingles generated each year.[12]

4.1.2 Case Studies

Several projects using RAP were highlighted in the Greater Iowa Asphalt Conference in March of 2007. In 1990, a 14-mile stretch of US 30 from Iowa 21 east to US 218 was resurfaced with a pavement mix that included 25% RAP. This pavement is still in service after 17 years. Also in 1990, I-80 west of County Road X40 to east of Cedar River in Cedar County was milled and overlayed with 3.5 inches of 20% RAP. This 6 mile section of highway is still in service after 17 years. I-35 from Clark County line north to Iowa 92 was resurfaced in 1991 using 40% RAP in the base material, 30% RAP in the intermediate material and 22% RAP in the surface material. This 13-mile length of roadway is still in service 16 years later. [13, 14]

For more research information on this material please refer to **Appendix B**.

4.1.3 Local Recycling Companies

Many local companies will accept recycled materials, will recycle on-site and can provide recycled materials in place of raw materials. A list of a few of these local companies follows:

- **ARS, Inc.:** ARS accepts clean concrete, clean asphalt and clean dirt. A large majority of their products are quickly sold including Class 6 recycled concrete, recycled asphalt, and fill dirt. Cobblestone is the only stagnant item due to a surplus in the market.

8505 W. Mountain View Lane
Littleton CO 80125
(303) 791-7404
http://arsdenver.com/

- **Recycled Materials Company, Inc. (RMCI):** RMCI currently operates six mobile plants and one stationary recycling plant which have provided millions of tons of on-site construction aggregates in Colorado and other Western states. Mobile recycle plants can process concrete, asphalt, block, brick, ceramic, or tile into sized or specification graded recycled aggregates at their source. This on-site processing eliminates expensive haul costs and provides contractors with specification aggregates of known substances made from on-site demolition materials. RMCI also owns and operates five concrete and asphalt recycling centers around the Denver metro area. RMCI produces 16 different specification aggregates for sale at their recycling centers.

  8200 East 56th Avenue
  Denver, CO 80216
  (303) 375-8959
  www.rmci-usa.com

- **Oxford Recycling, Inc.:** This company specializes in recycling concrete, asphalt and wood products. Products include RAP and Class 6 Aggregate Base Course. Their materials sell quickly, and the high demand for their concrete products currently exceeds their stockpiles.

  2400 West Oxford Avenue
  Englewood, CO 80110-4340
  (303) 762-1160
  www.oxfordrecycling.com

- **Allied Recycled Aggregates**: This company accepts asphalt and concrete which is clean and free of rebar, at no cost. They produce several recycled products including Class 6 aggregate base course, recycled asphalt, concrete crusher fines and 3” recycled concrete rock.

  7901 Hwy 85, P.O. Box 566
  Commerce City, CO
  80037-0566
  (303) 289-3366
  www.alliedrecycle.com

- **City of Fort Collins Streets Department:** The City accepts clean asphalt and concrete and produces recycled asphalt for road resurfacing, crushed concrete, structural fill and 6-inch concrete riprap.

  1380 Hoffman Road
  Fort Collins, CO 80522
  (970) 482-1249
  www.fcgov.com/streets/crushing.php

4.2 Concrete: Structural Concrete, Portland Cement Concrete, Flatwork Concrete (Curb, gutter, etc.)

4.2.1 Information and Data

Concrete is 100% recyclable and can be reused on projects or recycled through a recycle facility. Concrete can be recycled by concrete crushing plants to produce road base, aggregate, backfill and other materials. Additional applications of recycled concrete include erosion and off-site mud-tracking control, retaining walls and flood control projects as well as coarse aggregate in new cement mixes.

Existing concrete pavements can be incorporated into new pavement sections through the use of construction techniques such as “rubblization” and “crack/break and seat.” The use of these techniques helps diminish the amounts of old concrete pavements being landfilled and transported off-site.

Recycled concrete aggregate (RCA) can be used as coarse aggregate in Portland Cement Concrete for:

- Pavement for highways and interstates
- curbs and gutters
- sidewalks
- concrete barriers
- driveways
- temporary pavement interchange ramps and shoulders
- coarse aggregate in hot-mix asphalt
- dense-graded aggregate for base courses, surface courses, shoulders, approaches, and pavement patching

This is another one of the largest quantities of construction material typically processed on CDOT highway projects. Again, 100% recycling of this material would significantly increase the quantity percentages of materials recycled on CDOT projects. This amount would vary year to year depending on the construction projects; however, 35,000 to 200,000 tons could recycled compared to the 1,000 tons currently recycled which would be a significant increase. Many DOT's around the nation have been setting an example of how to incorporate recycled concrete into their projects, which include:

- Texas has used RCA in highway and street pavements and as a base material for the past 10 years.[15]
- Michigan has used RCA on such roads as M-10, US 41, I-75, I-94 and I-95 for the past 23 years, especially in the Detroit area with its large source of concrete rubble and experienced processing plants.[15]
- Minnesota uses 100% of the concrete removed from its pavements as dense-graded aggregates for base courses.[15]
- Virginia uses RCA and has developed standard specifications and recommendations for compaction.[15]
- California has a specification which allows use of any mixture of RCA and RAP for aggregate base providing contractors the ability to deliver the most economical material.[15]

4.2.2 Case Studies

- Michigan Department of Transportation (MDOT) uses recycled concrete aggregate (RCA) statewide as permitted in the Standard Specifications of Construction, 2003, Aggregate section 902.03 part B, 902.04, and 902.06. It allows the use of RCA as coarse aggregate for PCC for curb and gutter, valley gutter, sidewalk, concrete barriers, driveways, temporary pavement, interchange ramps, and shoulders. RCA is also allowed as coarse aggregate in hot mix asphalt and as dense-graded aggregate for base course, surface course, shoulders, approaches and patching. US-41 in the Upper Peninsula is currently being reconstructed using RCA as the base material with a mobile crushing operation. Cost savings of $114,000 were realized on a project on US-41 as a result of using RCA in the pavement base structure.[16]
- In California, much of the concrete from highway projects is salvaged for reused and made available for recycling, keeping it out of local landfills. Debris such as concrete, asphalt, and reclaimed glass can be crushed and re-used as base material. Using recycled rather than raw material also reduces the strain on California's dwindling aggregate supplies.[17]
- In Massachusetts, reclaimed pavement borrow material consists of crushed asphalt pavement and/or crushed cement concrete, and gravel borrow. The amount of combined crushed asphalt pavement and crushed cement concrete shall not exceed 50% by volume.[18]

For more research information on this material please refer to **Appendix C**.

4.2.3 Local Recycling Companies

Many local companies will accept recycled concrete materials, will recycle on site and can provide recycled materials in place of raw materials. See companies listed under asphalt for reference.

4.3 Wood: Delineator Posts, Fence, Posts/Stakes, and Construction Materials

4.3.1 Information and Data

Wood products are a significant material readily used on CDOT highway projects. Clean wood materials can be reused, recycled, and turned into mulch. Salvaged root wads can be placed along streambanks for stream restoration and fish habitat. Wood products require more frequent replacement than more durable materials such as concrete and plastic. Wood that is treated or painted usually cannot be recycled and must be disposed. Wood material products can be replaced with alternative materials that are more durable, contain more recycled content, and are less toxic. This replacement can reduce the amount of raw material used, reduce the amount of waste and maintenance, and could significantly increase the amount of recycling on CDOT projects. Replacement of wood by metal products could have the additional advantage of providing a revenue stream from salvaging the metal at the end of its use.

4.3.2 Case Study

California has been seeking substitutes for treated wood and is using reinforced recycled plastic (RRP) or composite of plastics (CP) and concrete polymer. RRP sheathing timbers have been installed on the Dumbarton Bridge, the San Mateo-Hayward Bridge and the San Francisco-Oakland Bay Bridge. Caltrans is also looking at using plastic lumber for guardrail offset blocks, which has been approved by FHWA, and for guardrail and sign posts.[10]

For more research information on this material please refer to **Appendix D**.

4.3.3 Local Recycling Companies

Many local companies accept recycled materials, recycle on site and provide recycled materials in place of raw materials. A partial list of these companies follows:

- **A1 Organics**: This company has been in the organic recycling business for over 30 years diverting over 8 million cubic yards of waste from Colorado landfills. They offer on-site grinding services. They provide high quality compost, mulch, and soils. Some of their soils incorporate not only recycled wood products, but also recycled fines from concrete crushing operations.

  16350 WCR 76
  Eaton, CO 80615
  (970) 454-3492
  www.a1organics.com

- **Tri City Truck & Equipment:** This company provides wood grinding service.

  Windsor, CO
  (303) 686-2110

- **Hageman Earth Cycle Inc.:** This company accepts clean construction wood waste. The demand for their products is high.

  3501 E. Prospect
  Fort Collins, CO
  (970) 221-7173
  www.hagemanearthcycle.com

- **Oxford Recycling, Inc.:** Oxford Recycling is a recycling company specializing in concrete, asphalt and wood products. Their primary product includes wood mulch of 100% post consumer wood waste, and it is a best seller. They only accept natural wood free of paint, preservatives and treatments.

  2400 West Oxford Avenue
  Englewood, CO 80110-4340
  (303) 762-1160
  www.oxfordrecycling.com

4.4 Metal: Bridge Railing, Guardrail, Metal Fence, Structural Steel, Corrugated Steel Pipe, Electrical Metal Conduit, Reinforcing Steel, and Ductile Iron Pipe

4.4.1 Information and Data

Metal is a highly recyclable and desired material and, therefore, has high potential of reuse. Most metal products contain reused metal or iron scraps and some contain 100% recycled material. For example, ductile iron pipe is made from 100% recycled iron. This material can be 100% recycled on highway projects and there are a number of local companies that accept and will collect metal from construction sites, including:

- steel
- iron
- aluminum
- copper
- lead
- tin
- iron

4.4.2 Case Studies

- The Kentucky Transportation Cabinet (KYTC) has formed a guardrail recycling program that reconditions damaged guardrail and redistributes them for needed highway projects around the state. This program has saved $1.26 million between July 2006 and January of 2007 by recycling guardrail and posts. The current program allows for damaged guardrail to be brought to a Frankfort work site, where inmate labor is used to sort and straighten reusable segments. Those pieces are then shipped to a contractor to be galvanized and then redistributed throughout the state. Since July, 2004 Kentucky has realized a savings of $3.6 million as a result of the guardrail recycling program.[19]
- California uses steel from rebar, sign posts, light posts, and metal beam guardrail for reuse and recycling. If these items are in good condition, they can be reused or stockpiled until needed. If items are damaged or found to be beyond repair, they can be recycled as scrap metal.[20]

For more research information on this material please refer to **Appendix E**.

4.4.3 Local Recycling Companies

Many local companies will accept recycled metal materials and can provide recycled materials in place of raw materials. A partial list of these companies follows:

- **Rocky Mountain Steel Mill:** Accepts scrap metal, and has scrap metal suppliers. Manufactures steel products. Their demand for metal is very high and the company has secured suppliers to continue to provide used materials.

  1612 E Abriendo Ave
  Pueblo, CO 81004
  (719) 561-6000

- **Atlas Metal and Iron Corporation:** Accepts non-ferrous metals for recycling, such as aluminum, copper, brass, and stainless steel. This is the parent company to Atlas Supply Division, which sells recycled and remilled steel and metal products. All their products sell quickly.

  318 Walnut Street
  Denver, CO 80204
  (303) 825-7166

- **Iron and Metals, Inc. (IMI):** Accepts all grades of steel, cast iron and aluminum. This company also provides and services containers at demolition and construction sites. All of their materials sell quickly.

  5555 Franklin Street
  Denver, CO 80216
  (303) 292-5555
  www.ironandmetals.com

- **Canland Recycling Center:** Accepts aluminum, copper, brass, insulated wire, magnesium, nickel, lead, and zinc. They do not accept iron or steel. The demand for lead has increased recently, both here and abroad.

  6141 N. Federal Blvd.
  Wheat Ridge, CO 80033
  (303) 426-4141
  www.canlandrecycling.com

- **Recycling Connections:** Accepts aluminum, copper, brass, copper cable, and electronic equipment.

  9985 East 104th Avenue, #B
  Henderson, CO 80640
  (303) 333-6363
  www.recyclingconnections.com

4.5 Scrap Tires

4.5.1 Information and Data

Recycled tires can replace a variety of raw materials on highway construction projects and reduce the amount of tires stockpiled or sent to the landfill each year. Tires can be recycled whole, by shredding them, or by creating crumb rubber, to produce a variety of engineering applications useful in transportation projects, including:

- asphalt binder
- asphalt aggregate
- erosion control material
- retaining and noise walls
- sidewalks
- subgrade fill
- lightweight embankment fills
- backfill behind retaining walls and bridge abutments
- vibration dampening under rail lines.

Waste tires are more expensive than soil or gravel, especially when they have been shredded. For that reason their use for backfill is limited to applications where the inherent properties of tire rubber are preferable to natural fill materials. These properties include excellent drainage, low weight, non-swelling and inert, predictable compaction, resilience (bounce), cracking resistance, insulating properties, coloring (materials can be painted), potential noise reduction in pavement, tax subsidies, local sources, and others. CDOT published a research report which discussed the engineering advantages of compressing whole tires into bales, and the costs and engineering applications of these bales are favorable compared to other competing materials.

When used properly, waste tire products do not catch fire due to lightning or spontaneous combustion as has occurred in previous years. Due to concerns from such events in Colorado and Washington, ASTM standards have been approved which help design rubber-containing embankments and other features which are not susceptible to fire.

Colorado has a state waste tire disposal and recycling program including end user and processor reimbursement program. The Colorado General Assembly passed legislation in 1998, HB 98-1176, creating the End User Program, C.R.S. 24-32-114 (1) (c), as amended. The General Assembly further amended the Waste Tire Statute in 2001, HB 1018. The intent of this program is to assist businesses that employ tire recycling and reuse technologies to become economically viable. Helping to sustain end user businesses through partial reimbursements reduces both the possibility of illegal tire dumping and increases the legal disposal of such tires in landfills. More information can be found at their website at http://www.dola.state.co.us/dlg/fa/wt/.

4.5.2 Case Study

Figure 4. Caltrans Uses Shredded Tires in Highway Embankments

- California's highway department Caltrans has used rubberized asphalt concrete with approximately 1 to 2% ground "crumb rubber" by weight of mix in over 130 projects using the wet process, which involves blending the rubber into the asphalt binder. The dry process involves blending into the aggregate.[10]

- One of Caltrans' most recent recycling efforts in highway development was the use of 660,000 shredded tires as lightweight fill at the 700-foot-long Dixon landing on-ramp on Interstate 880. The highway design substituted traditional aggregate with scrap tires, which not only diverted waste but also saved taxpayers an estimated $250,000 in material costs. Such developments represent some of the most innovative state projects designed to recycle waste materials.[21]

- Many communities are using rubberized sidewalks made of shredded tires to replace concrete sidewalks. These sidewalks are easier on knee joints of joggers, will not crack due to tree roots and freezing and are easier to install because they are a quarter of the weight of concrete. Over 60 cities are using them including Washington D.C., New Rochelle, New York, and Tallahassee, Florida.[22] Seattle, Washington installed a test area in their South Park neighborhood. Each rubber panel placed was made from 5 recycled tires. A total of 57 panels were used at a cost of about $8,000.[23]

For more research information on this material please refer to **Appendix F**.

4.5.3 *Local Recycling Companies*

Many local companies will accept recycled materials and can provide recycled materials in place of raw materials. A partial list of these companies follows:

- **Front Range Tire Recycle**: Accepts used tires for production of tire bales and shreds for subgrade, backfill behind retaining walls and bridge abutments. Demand for shredded tires to use in highway projects has been very low and is considered an untapped market. Most of their product is burned as Tire Derived Fuel due to its high BTU value; however, this demand has been tapering off. Recently, shredded tires have been used as landfill liners and alternative daily cover at solid waste landfills, but this may not be the best economical use for tires.

  5765 N. Peterson Road
  Sedalia, CO 80135
  (303) 660-0090
  www.frtirerecycle.com

- **Jaitire Industries, Inc.:** Accepts used tires up to 16 feet in diameter. They provide a variety of products including shredded tires for rubberized asphalt and decorative colored mulch. Highway rest areas are a possible location to use their products. Their products sell very well.

  4155 E. Jewell, Suite 616
  Denver, CO
  (303) 758-6781
  www.jaitire.com

- **Oxford Recycling, Inc.:** Accepts used tires and recycles tires. Their products resell quickly.

  2400 West Oxford Avenue
  Englewood, CO 80110-4340
  (303) 762-1160
  www.oxfordrecycling.com

4.6 Geotextiles: Silt Fence and Erosion Logs

4.6.1 *Information and Data*

Silt fence and erosion logs are used on almost every CDOT highway construction project. Recyclable materials such as compost berms can replace silt fence, and compost logs can replace erosion logs to further reduce waste on construction projects. The berms can be vegetated or unvegetated. Vegetated filter berms are normally left in place and provide long-term filtration of storm water as a post-construction Best Management Practice (BMP). Unvegetated berms are often disassembled once construction is complete and the compost is spread around the site as a soil amendment or mulch.[24]

4.6.2 Case Study

The Minnesota DOT erosion control compost specifications for "compost logs" recommend 30 to 40 percent weed-free compost and 60 to 70 percent partially decomposed wood chips. These specifications also require that 100 percent of the compost must pass the 2-inch (51 mm) sieve and 30 percent must pass the 3/8inch (10 mm) sieve.[24]

For more research information on this material please refer to **Appendix G.**

4.6.3 Local Recycling Companies

Many local companies accept recycled materials and can provide recycled materials in place of raw materials. A list of a few of these companies follows:

- **Hageman Earth Cycle Inc.:** Accepts clean construction wood and yard waste. Their products resell quickly.

  3501 E. Prospect
  Fort Collins, CO
  (970) 221-7173
  www.hagemanearthcycle.com

- **National Recycling, Inc.:** Accepts construction and demolition debris.

  2421 International Boulevard
  Fort Collins, CO
  (970) 493-7478

4.7 Plants and Organics: Trees, Branches, Grass and Compost

4.7.1 Information and Data

A majority of plants and organics are being disposed of in local landfills. All of this material could be recycled or reused on site as mulch, soil amendment, and erosion control.

4.7.2 Case Study

- Caltrans has recently begun using compost material for erosion control. They have also written new mulch specifications in November of 2006 to encourage the use of recycled materials in mulch. Caltrans uses mulch for weed control and water conservation. Most of their mulch is made from tree bark and clean wood chips often made from construction wood waste. Their current specifications also allow the use of compost as a soil amendment.[25]

- Composted manure makes up about half of the compost used in Texas road projects statewide, followed by composted yard trimmings and biosolids (sewage treated and processed for fertilizer). Projects in San Antonio use yard trimmings and composted biosolids produced by the city, while only yard trimmings are used in Houston. TxDOT's standards allow the use of Class A biosolids treated sewage but not Class B biosolids. TxDOT uses several compost applications. One is general-use compost, which is 100 percent compost. This is the compost specified by landscape architects for purposes such as amending soil for tree-planting. General-use compost is also the kind of compost that TxDOT's maintenance personnel sometimes uses to top dress a roadside park.[26]

For more research information on this material please refer to **Appendix H**.

4.7.3 Local Recycling Companies

Many local companies will accept clean construction wood and yard waste. A list of a few of these companies follows:

- **Hageman Earth Cycle Inc.:** Accepts clean construction wood and yard waste. Their Class 1 compost products sell quickly. Their dairy manure compost sells less successfully, because it is a lower quality Class 2 compost with a slightly higher pH compared to Class 1 compost. Dairy compost is great for sod and other planting areas, although it does not work well for flowerbeds or vineyards.

  3501 E. Prospect
  Fort Collins, CO
  (970) 221-7173
  www.hagemanearthcycle.com

- **Oxford Recycling, Inc.:** Major recycling operation specializing in concrete, asphalt and wood products. Products include wood mulch of 100% post-consumer wood waste.

  2400 West Oxford Avenue
  Englewood, CO 80110-4340
  (303) 762-1160
  www.oxfordrecycling.com

4.8 Glass and Ceramics: Traffic Control Material

4.8.1 Information and Data

Although glass and ceramics do not contribute largely to waste on a highway construction site, there are plenty of opportunities to recycle glass and ceramics there. Glass can be used to provide reflectivity to traffic-controlled material or sent offsite to recycling companies. Glass beads provide reflectivity to painted and thermoplastic traffic stripes as well as pavement markings by adding them to wet paint and molten thermoplastic. Other uses of recycled glass include:

- Utility trench backfill.
- Drainage trench backfill.
- Base course supplement.
- Embankment material.

- Substitute for free draining aggregates, e.g. drainage.
- Medium in trench drains.
- Cold patch aggregate
- Aggregate in "glassphalt".

4.8.2 Case Study

Brown County, Wisconsin, utilized post-consumer glass in two backfill applications on Hwy. J (Riverside Drive) in the Village of Howard. Thirty-four tons of three-color glass mix were used. In these projects, a two-foot wide storm sewer trench was excavated, and a storm sewer pipe was then connected to the main sewer line. The first project, which occurred in August, 1994, used a concrete storm sewer pipe. Broken glass was backfilled directly on the pipe in a 2 ½ foot layer.

The second project utilized PVC storm sewer pipe. Due to the potential abrasive damage of the broken glass on the PVC pipe, the pipe was first covered by 3/4 inch crushed stone to encapsulate the pipe surface before 2 feet of broken glass were backfilled into the trench. The glass was covered with more crushed stone and an asphalt mat. The size of the glass pieces was 3/8 inch or less, and compaction of the glass was not a concern. As of November, 1996, no problems had been reported including any unusual settlement or surface cracks. Brown County Solid Waste Department initiated the project by contacting Brown County Highway Department about projects where three-color mix glass could be utilized.[27]

For more research information on this material please refer to **Appendix I**.

4.8.3 Local Recycling Companies

Many local companies accept glass. A partial list of these companies follows:

- **Action Recycling:** Accepts non-ferrous and precious metals and ferrous metal, glass bottles, paper products and electronics.

  7610 W. 42nd Avenue
  Wheat Ridge, CO 80033
  (303) 424-1600
  www.actionrecyclingcenter.com

- **Optimum Art Glass**: Accepts glass.

  36471 Weld County Road 33
  Eaton, CO 80615
  (970) 454-2620

4.9 Plastics: PVC Pipe, HDPE Pipe, and Electrical Plastic Conduit

4.9.1 Information and Data

Recycling plastics is important because plastics make up 11 percent of our trash by volume and do not readily decompose in landfills. A 1997 American Plastics Council survey estimates that approximately half of U.S. communities collect plastics for recycling. In 1997, more than 600 million pounds each of Polyethylene Terephthalate (PET) and High Density Polyethylene (HDPE) were recycled. Recycled plastics can be blended with virgin plastic (plastic that has not been processed before) to reduce cost without sacrificing properties.[28] Products containing recycled plastic can replace wood products, are equally or more durable, are less toxic than treated wood, and do not need to be painted. Recycled plastic can be used in many transportation-related applications, including:

- traffic cones, barricades, channelizers
- flexible delineators
- safety fencing
- guardrail blockout posts
- manhole adjusting rings
- plastic lumber
- sound barriers

For more research information on this material please refer to **Appendix J**.

4.9.2 Local Recycling Companies

Many local companies will accept plastic. One of these companies is shown below:

- **National Recycling, Inc. Accepts Plastic.**

  2421 International Boulevard
  Fort Collins, CO
  (970) 493-7478

5.0 REUSE AND RECYCLING OPPORTUNITY COSTS

The retail prices paid by projects for their construction materials may not be the only consideration for decision-makers. The retail price of virgin construction materials is very similar to the retail price of recycled construction materials due to the competitive nature of the construction materials market. If prices were to be significantly lower for one type of material over the other, purchasing trends tend to shift toward the lower priced material. However, the actual price paid by a project is not always the entire consideration for design engineers when making construction material selections. Durability, ease of maintenance, and ease of handling are often variables considered by the design engineer. Beside these project considerations, there are yet other factors to be considered by the design engineers, including what are called "opportunity costs." These costs are frequently overlooked when engineers rely solely on raw material prices for decision-making rather than considering other factors.

Opportunity costs reflect the indirect costs of using a specific resource in terms of the opportunities forgone by not using an alternate resource. Site importation of materials has associated opportunity costs when on-site materials are available and suitable for reuse. Opportunity costs also are incurred when virgin materials are specified even though less expensive recycled materials are available and suitable. These opportunity costs are not reflected in the purchase price of the imported materials and should not be ignored. The potential opportunity costs can be attributed to: transportation, waste disposal, handling, and procurement.

Transportation opportunity costs refer to the cost of moving materials to and from construction sites. These costs include the direct cost of fuel consumption, vehicle use and maintenance, and human capital. They also include the less obvious indirect costs of additional air pollution, traffic congestion, roadway wear-and-tear, fossil fuel depletion, and accident potential. These transportation opportunity costs are avoided when site materials can be reused instead of importing off-site materials. Examples of reusable materials frequently found on construction sites include: concrete, asphalt, brick, and fabricated structures (wall materials, guardrails, piping and steel). Transportation opportunity costs are incurred when a material decision is made that does not take advantage of reusable on-site materials. The magnitude of these costs correlates to the volume of material in question and the distance materials must travel to and from the construction site. If site materials are reused to the extent possible, this transportation opportunity cost is avoided.

Disposal opportunity costs refer to the costs incurred by placing site materials into a landfill instead of reusing them at the construction site. The opportunity cost is born in part by avoiding payment of tipping fees for disposal, but also by society. Because this practice utilizes landfill space, it diminishes the capacity of the landfill for others. Since there is a finite amount of permitted landfill space, the appropriate use of this disposal space becomes a matter of societal concern. Colorado is more fortunate than other states because of the availability of landfill space with relatively low tipping fees, proximal to population centers. This good fortune is only temporary as landfill space is consumed and population centers expand. If landfills are used only for disposal of only those site materials with no other option, then disposal opportunity costs are optimized. The magnitude of the disposal opportunity cost correlates to the volume of material in question and the landfill disposal (tipping) fee.

Procurement opportunity costs refer to the cost of obtaining virgin material for construction use instead of specifying a reused or recycled material. The procurement opportunity cost is incurred when a resource is consumed for a purpose that could be adequately satisfied with a recycled or reused material. The limited supply of permitted well-graded aggregate deposits close to projects that need them in Colorado is leading to market conditions that are beginning to favor recycled or reused aggregate sources. Unnecessary consumption of virgin aggregate materials is accelerating the time when the direct economic forces will favor aggregate reuse and recycling.

An additional procurement opportunity cost is incurred by society when the current and potential land uses for areas mined for virgin aggregate resources are affected. Procurement of virgin material requires the dedication of land to a mining land use to supply the material in question. The opportunity cost is associated with the aesthetic, environmental, noise, traffic, and productivity change of land from one use to another. In some cases the productivity change can be significant and long-term when considering the change from agriculture, urban, recreational, or tourist-oriented to a mining land use. This opportunity cost is incurred when virgin materials are required to meet specifications for concrete and asphalt paving mixes, structural concrete mixes, pavement base materials, pipe bedding materials and road traction sand. The magnitude of this opportunity cost is dependent on the volume of the material required and the logistical considerations necessary for stockpile storage, loading and unloading. When a project can reclaim site material and re-install that material directly without stockpiling or transportation, the procurement opportunity cost is eliminated. This favorable situation can be encountered through roto-milling and direct overlay paving projects. Other ways to measure the opportunity costs include considering the magnitude of the mining reclamation bond, development restrictions, and tax base differential between a mining use and other desired uses. If recycled or reusable materials are consumed to the extent possible on a construction project, this opportunity cost is minimized.

Project management and/or design engineers making material selections must consider many factors. However, the actual price paid for the construction material may not be the only consideration when making these decisions. Projects supported by public funding could also consider the opportunity cost of project material selections in an effort to better consider societal benefits. **Table 1** provides estimates of the opportunity costs associated with the use of various materials at construction projects. Much of the information found in this table was obtained from an August 31, 2007, letter from Symbiotic Engineering to Recycled Materials Company, which is provided in **Appendix N**. No estimate of the procurement opportunity cost is made here, because no market conditions exist to make and estimate. However, this cost is understood to be greater than zero.

Table 1. Opportunity Cost Analysis

	Virgin Aggregate	Recycled Aggregate (imported to site)	Reused Aggregate (on-site material)
Actual Cost	$6.60/ton	$6.60/ton	$6.60/ton *
Additional Opportunity Costs			
Transportation Opportunity Cost	$0.15-$0.24 Per ton-mile	$0.15-$0.24 Per ton-mile	0
Disposal Opportunity Cost	$15.28/ton		0
Procurement Opportunity Cost	Cost > 0	0	0

* The actual cost for reused site material is not zero and is assumed to be equivalent to that of recycled material to account for the work required to transform raw site material to meet a project material specification. Examples of this work include the cost of roadway milling, concrete crushing, rebar removal, storage, or the cost to wash and size on-site aggregate.

In this table, notice that although the actual costs can be similar for each potential project material, the opportunity cost is dramatically different. The reused site aggregate has no additional opportunity cost (i.e. is the least expensive in all respects) because it is readily available at the construction site with no requirement for transportation, disposal, or procurement. If the existing on-site material is considered acceptable for project reuse, this is the ideal material choice from an economic standpoint. A second choice might include utilizing recycled aggregate brought on-site. This may have opportunity costs associated with transportation but avoids procurement opportunity costs. In this case, recycled material is obtained off-site icurring both a transportation and procurement opportunity cost. This option is more costly than the reuse of on-site aggregate option but still incurs less opportunity costs than the virgin aggregate option. Virgin material has the highest opportunity cost of the three options available. Along with transportation and disposal costs, there is also a procurement cost associated with using virgin materials. In the case of both the recyclable and reusable materials, procurement opportunity cost has already been fully incurred by initial construction project and should not apply to future reuses of the material.

Society is moving towards the concept of “Sustainability.” Transportation agencies and engineers need to understand that their activities can have a positive impact, and the underlying economics of “Opportunity Costs” presented in this section is a key factor in the analysis of this generation’s impacts on the costs which can be either avoided by or pushed upon future generations of Americans. As engineers make individual choices about specifying the use of recycled materials on their projects they need to understand that the results of their choices have impacts that extend far beyond their projects limits.

6.0 SPECIFICATIONS

The CDOT current Standard Specifications, Standard Special Provisions, Project Special Provision Worksheets, and Sample Construction Project Special Provisions were reviewed to determine recycling opportunities already allowed by CDOT and how the existing specifications could be modified to allow additional recycling opportunities and incentives on CDOT construction projects. Sample language was developed to include in Section 202 - Removal specifications to require recycling of designated salvaged materials at an authorized recycling facility and/or reused on the project.

A survey of Colorado contractors also was conducted to collect information on the contractor's opinions and experience with recycled materials on CDOT projects.

6.1 Summary of Current CDOT Specifications that Allow Reuse and/or Recycling

The main focus of the review of current CDOT specifications was to identify and improve opportunities already permitted for recycling and/or reuse of asphalt, concrete, wood, metal and tires on CDOT construction projects.

Reclaimed asphalt pavement (RAP) is currently allowed in roadway embankments, as roadway bed course material and on specific projects as a component of new hot mix asphalt. Reuse of existing asphalt pavement is also allowed in cold bituminous pavement recycling and with heating and scarifying of existing pavements.

Reclaimed concrete is currently allowed in roadway embankments, as roadway bed course material, and as an aggregate in new concrete mixes.

Unmerchantable timber is allowed for brush barriers or can be chipped for use as mulch. Recycling of steel is limited to the reuse of guardrail w-beam. No current CDOT specifications allow for use of recycled tires. Other recycled materials allowed on CDOT projects include recycled glass, furnace slag, cinders, and fly ash.

A summary of current CDOT specifications that allow for recycling or reuse of the above-mentioned materials is included in **Appendix O**.

6.2 Summary of Suggested Changes to Current CDOT Specifications to Allow Additional Reuse and/or Recycling

Slight changes to the wording of many current CDOT specifications could facilitate increased recycling and/or reuse of asphalt, concrete, wood, metal and tires on CDOT construction projects.

Suggested changes to specifications are summarized in a table in **Appendix P**. Many of the changes would require approval by CDOT's Materials Branch and Environmental Programs Branch.

6.2.1 Suggested Language for Section 202 – Removal Specifications

It is recommended that the following language be added to Section 202 – Removal Specifications to increase the use of recycled materials on CDOT construction projects:

"Materials removed and not designated in the Contract to be salvaged or incorporated into the work shall become the property of the Contractor. The Contractor shall transport designated salvable materials to an authorized recycling facility and/or reuse the designated removed materials on the project. The Contractor shall provide receipts provided by the recycling company documenting the weight of recycled product transported to the facility. Materials reused on the project shall meet all appropriate material specifications for the proposed use of that material."

If this language is incorporated into the CDOT Standard Specifications or a standard special provision, the Engineer will have to designate, in the plans or in a project special provision, the specific salvable materials within the project limits, list acceptable reuse of these items and/or list authorized recycling facilities for the materials listed.

6.2.2 Suggested Changes to Section 208 – Erosion Control Specifications

Based on discussions with Mike Banovich of the CDOT Environmental Programs Branch, the following revisions are recommended to be included to Section 208 – Erosion Control Specifications to increase the use of recycled materials on CDOT construction projects:

Add crushed recycled concrete as a construction material for check dams and outlet protection in Specification 208.02 (f) and (g), respectively. Include size restrictions as necessary.
Mandate recycled concrete as aggregate for stabilized construction entrances in CDOT Region 6 and allow for it in other regions in Specification 208.02 (l).

If this revision is incorporated into the CDOT Standard Specifications or a standard special provision, the Engineer will have to designate, in the plans or in a project special provision, the specific salvable materials within the project limits, list acceptable reuse of these items and/or list authorized recycling facilities for the materials listed.

6.2.3 Suggested Changes to Section 216 – Soil Retention Covering Specifications

Further discussions with Mike Banovich of the CDOT Environmental Programs Branch yielded the following recommended revisions to be included to Section 216 – Soil Retention Covering Specifications to increase the use of recycled materials on CDOT construction projects:

Add shredded soda bottles and other three-dimensional recycled polyester fibers as a construction material for soil retention blankets in Specification 216.02 (a).

See **Appendix Q** for a draft version of the potential revision to this specification as drafted by CDOT.

6.2.4 Suggested Changes to Section 506 –Riprap Specifications

Based on discussions with Mike Banovich of the CDOT Environmental Programs Branch, the following revisions are recommended to be included to Section 506 – Riprap Specifications to increase the use of recycled materials on CDOT construction projects:

Add crushed recycled concrete as a construction material for riprap in Specification 506.02. Include size restrictions as necessary.

If this revision is incorporated into the CDOT Standard Specifications or a standard special provision, the Engineer will have to designate, in the plans or in a project special provision, the specific salvable materials within the project limits, list acceptable reuse of these items and/or list authorized recycling facilities for the materials listed.

6.2.5 Other Departments of Transportation Specifications

Throughout the US, several states have been revising their specifications to encourage use of recycled materials. These following references include just a few of these DOT's:

- Texas
  http://www.dot.state.tx.us/business/specifications.htm
  Texas DOT has a website listing their recycled materials – by material within their specification for ease of use. See link below:
  http://www.dot.state.tx.us/services/general_services/recycling/speclist2.htm

- Minnesota
  http://www.dot.state.mn.us/tecsup/spec/
  Minnesota has a specific category for salvaged and recycled aggregate mixtures for pavement surfaces and base courses in their specifications under 3138.2 (A2).

- Wisconsin
  http://roadwaystandards.dot.wi.gov/standards/stndspec/index.htm
  Wisconsin has identified specific recycled by-product materials that the contractor may provide as an aggregate mixed with crushed gravel, crushed concrete, or crushed stone in their 301.2.3.4. By-Product Materials Specification. These include up to 12% glass, 7% foundry slag, 15% steel mill slag, 8% bottom ash and 7% pottery cull.

- Recycled Materials Resource Center
  The Recycled Materials Resource Center also has a wealth of information on other DOT specifications. Reference the link below for more information.
  http://www.rmrc.unh.edu/asp/url_specifications.asp

6.3 Contractor Survey

An Email survey was distributed to 1,700 Colorado Contractor's Association (CCA) members, soliciting their opinions and experience with recycled materials on CDOT projects. A total of 4 surveys were returned. This extremely low rate of return was of great concern to the project panel; however, the time constraints of this project did not allow any follow-up to generate increased interest in the survey. The lack of response indicates that there needs to be improved outreach from the recycling community to the general contracting community.

The following summarizes some of the trends and comments provided from the survey:

- All respondents had experience using asphalt, concrete, wood, and metal on their project. Two of the four did not have experience with scrap tires.
- The respondents were aware of a majority of the specific recycling applications listed in the survey (17 specific applications in 5 material categories).
- The respondents agreed that a majority of the recyclable materials are available for the listed applications.
- All responders indicated that the costs of recyclable materials are competitive with new or virgin materials.
- When asked whether the CDOT specifications allowed for each of the 17 specific applications, there were a few mixed opinions on a few items, such as:
    - Three out of four believe that reclaimed asphalt pavement (RAP) can be used in HMA.
    - Three out of four believe that concrete can be recycled as concrete aggregate.
- The respondents almost all replied "Don't Know" to whether CDOT allows the following applications:
    1. Wood - Reused as guardrail posts
    2. Metal - Reuse W-beam from guardrail
    3. Metal - Reuse steel guardrail posts
    4. Scrap Tires (Import) – All applications

- The respondents indicated that they had implemented approximately half of the 17 specific material applications on CDOT projects, whereas over three-quarters of the 17 had been applied to non-CDOT projects. One contractor had implemented all of the applications listed except for the scrap tire items, which they have no experience with.

- The following CDOT Specifications and specification items were identified to be preventing/discouraging the contractors from using recycled materials:

    1. Sections 203, 304, 501, 506, and 601
    2. Median Coverage
    3. Section 300 – Aggregate Base (no asphalt millings or RAP)
    4. Section 400 – No RAP in the top lift of asphalt

- The following recommendations were offered to encourage more use of recycled materials:

    5. "Require subs to submit a separate bid amount using recycled materials"
    6. "Edit spec book to make recycled materials the first choice or preferred material"
    7. "Provide a pay incentive for use of recycled materials"
    8. "Be open to recycled material proposals, even if it does not meet specs 100%"
    9. "Make it a topic at meetings and try to brainstorm ways to recycle job materials"
    10. "Get all CDOT Regions on the same page in regard to recycling. E.g., in some regions it is ok to use asphalt millings for base course, and in others it is not"

- Most respondents thought incentive payments for using recycled materials would encourage them to use more. One respondent felt that neither mandates nor incentives would be beneficial, but just providing the option of using them would be sufficient motivation to use recyclable materials.

- The most common construction items the contractors send to waste disposal sites included:

    1. Construction lumber and other wood
    2. Sod
    3. Waste excavation (earthwork)
    4. Asphalt
    5. Broken concrete

- All respondents noted they actively searched for recycling opportunities for the items commonly sent to waste disposal. One, however, noted they did so only for non-CDOT projects.

See **Appendix R** for a copy of the survey.

7.0 TRACKING

EPA has a recycling goal to increase the national recycling rate from 30% to 35% by 2008. EPA's national recycling rate goal has motivated CDOT towards increasing their rate of recycling by 10% over the next two years. CDOT, in concurrence with EPA, recognizes that recycling is an important means to reduce waste and improve the quality of the environment. In Task 3 (materials tracking), methods for tracking recycled materials on construction projects were established to measure CDOT's success in addressing this goal. Task 3 identifies waste management (reuse/recycling) options for CDOT management to consider. This task is focused on recycled materials in the construction bid process, because it is believed that this early phase is critical to keeping track of recycling efforts throughout the life of each project.

Project Task #3 provides recommendations that will facilitate CDOT in measuring the amount of materials reused and recycled on construction projects each year. These recommendations involve an integrated process, in effect using the existing CDOT bid summaries tracking system, to compile materials bid totals state-wide. This system would improve CDOT's ability to capture recycled rates data on construction projects and overcome the current lack of state-wide reporting and inconsistencies.

7.1 Tracking Constraints

There are over a hundred CDOT jobs that are bid and designed every year. In order to implement a recycled materials tracking program, CDOT will need to implement an efficient and automatic way to allow material (reused and recycled) types and quantities to be electronically totaled on an annual basis for all of CDOT's regions (Region 1-6). The goal for this project is first to develop a baseline of CDOT recycled materials use as soon as possible, and second to efficiently track and report future recycling quantities and trends.

7.2 Current Tracking

Currently CDOT does not have a system in place that readily and routinely allows identification or tracking of quantities of materials that are reused and recycled on construction projects. A review was conducted in order to determine whether or not CDOT had an existing tool in place that either could be modified or expanded to allow for reliable recycling materials tracking in the field.

In 2005, CDOT responded to a survey of recycled materials use in the highway environment that was conducted by The Recycled Materials Resource Center (RMRC). RMRC, located in Durham, New Hampshire, is a national center created to promote the use of recycled highway materials. This survey was requested by RMRC to determine the current state of recycled materials use in the highway environment and to demonstrate throughout the nation how recycled materials use has changed over the previous nine years. The survey stemmed from the National Cooperative Highway Research Program (NCHRP) Project 4-21 survey that was conducted in May 1996 and was used to estimate the volumes of materials used.
Upon completing this survey response, it was evident that no efficient system was in place for gathering recycle data from CDOT's construction projects. Since this time, CDOT has been working to identify a better method of tracking their recycling quantities.

As a first step, a thorough review was conducted of CDOT's entire list of more than 100 different construction forms which are completed during construction projects. The result of this review showed that little to no opportunity exists for modifying any of these forms to capture recycled material quantities and a new form may be needed.

7.3 Recycled Materials of Importance

In accordance with the materials reported to RMRC in August of 2005, CDOT is motivated to begin regularly tracking the primary recycled materials researched in Task 1 of this project and also reported in the RMRC survey. The primary recycled materials of interest for tracking implementation apply to the following:

1) Reclaimed Asphalt Pavement
2) Reclaimed Concrete Pavement
3) Coal Fly Ash
4) Quarry Waste Fines
5) Metals
6) Recycled rubber tires

These materials typically make up the largest (CDOT) quantity totals on an annual basis (see results from Task 1). There was also an interest in incorporating recycled tires on future projects and to track the increase in their use, to minimize the common practice of landfill disposal and indefinite stockpiling for future use. Other materials may be considered for tracking at a later time once tracking implementation proves acceptable.

7.4 Proposed Tracking Method

CDOT uses a bid summary form, during the design phase, to document the material quantities that will be used on and removed from a project. These plans provide contractors with project details to assist them in estimating and bidding project costs.

The quantities called out in the project summaries form have unique 8 digit item codes that all CDOT regions routinely use. The materials that are broken out during the design and bidding phases are categorized by an item code number and are tracked in a database. The data in this database can be sorted and totaled at the end of the year for reporting purposes. Currently, no bid summary codes exist for reused or recycled materials. New codes specifically listing those materials will allow CDOT to better track their use on construction projects. It is recommended that CDOT's list of bid summary codes be expanded to include the various materials that can be recycled.

Currently, two methods for developing specific bid items for tracking have been considered. The first method would include making modifications to existing removal numbers to track recycled materials. For example, the existing bid item number for Removal of Asphalt Material is 202-000220. A new bid item number 202-000221 Removal of Asphalt Material (Recycle) could be created to track the recycling of this material either on the project or taken to a recycling center. A technical specification would be written first to provide direction to the contractor on how to account for this bid item. A specification would be written first to address this specific item and then a bid item established.

A second method includes the development of an entire series of numbers dedicated to recycling. The Bid Item 202-09000 series is currently not used by CDOT, but it could be dedicated to recycled materials and used to track recycling. For example, bid item number 202-09001 could represent Recycling Removal of Asphalt Material.

More research is needed to determine the most effective and user-friendly method to use. Perhaps the first method could be used initially until a significant set of materials has been identified, and then the new series could be used. This methodology deserves further focus. To assist in tracking such items as steel and concrete for bridge removal projects, as-built plan information identifying the quantities of these items to be removed could be tabulated in the design plans “for information only”. This could assist the contractor with identifying a cost for the new bridge removal bid item 202-00402 Removal of Bridge (Recycle).

The process for developing and standardizing new bid items for recycling could take as long as 3 to 4 years. First, the specifications and applicable bid items numbers are developed and then reviewed by the Joint CDOT and CCA Specifications committee and other pertinent organizations for comment. Items are then used on a pilot project for testing. They then become a Project Special specification and bid item for a year. If that proves successful, the items could then become a standard specification and bid item.

7.5 Establishing a Baseline

After new bid codes are added, CDOT can begin using them during the design phase to assist contractors in identifying what costs are associated with recycling each specific material. At the end of the first year, CDOT can compile the quantities of recycled materials used on highway projects. That valued quantity would become the baseline scenario for measuring the following years’ change in recycling rates.

Importantly for CDOT, the units used for tracking recycled materials quantities should be consistent with units used for materials quantities that are currently used in the bidding process. This allows for apples-to-apples comparison of what has been used as virgin materials versus what has been used as recycled materials. For example, concrete which is currently removed from a project is measured in square yards. However, new concrete is measured and bid in tons (or by weight). All of the materials which will have new bid codes should be measured in similar units to those materials which are virgin materials in order to provide equal evaluation of quantities at the end of the project.

As more research is conducted in the development of recycled material specifications and corresponding bid item numbers, careful research on how these materials can best be measured will be an important component. This will be included as part of the short-term goals for CDOT to continue to develop as they pursue increasing their recycling efforts.

8.0 PRESENTATION

Dissemination of the project information to several targeted audiences is the culmination of this research project. A PowerPoint presentation was developed to highlight the results of this project and to facilitate increased reuse and recycling in Colorado's construction industry.

This presentation was presented at the National Recycling Coalition (NRC) Annual Conference in Denver, Colorado on September 17, 2007. This presentation will also be given to several key CDOT representatives, the Colorado Asphalt Pavement Association, and the EPA Industrial ByProducts Summit in Denver in April, 2008, to promote awareness of reuse and recycling on highway projects and highlight the next steps to reach CDOT goals for success.

A copy of the presentation is provided in **Appendix S**.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Research on materials, specifications, and tracking methods was conducted to determine the best combination to optimize reuse and recycling on highway projects. Research identified many large tonnage materials that are used and useable on highway projects, numerous agencies and projects that have used them successfully, the most promising materials that could be recycled in greater quantities, impediments and opportunities to further examine, and methods for improved tracking of recycling efforts. CDOT and other transportation agencies have a promising but limited track record, established protocol, research programs, and incentives towards the goals of increased recycling. This research project compiled an immense amount of information and tools to further enhance these goals.

However, more work is needed to implement the findings and recommendations of this project. Education of key staff directly involved in decision-making in the highway construction arena will be a key factor in implementation. The information gathered in this study needs to be shared with these strategic groups to continue progress toward more sustainable highways.

Projections on achieving CDOT's goal to increase recycling on highway projects based on the research project recommendations are included at the end of this section. Also, the potential savings of greenhouse gases based on concrete aggregate recycling were calculated. Tracking greenhouse gas (GHG) savings on this and many other materials could be accomplished in the future as the means to determine the amount of material that is removed from a site can be more easily quantified and as specific metrics for these materials become available.

The following conclusions and recommendations are a result of this study.

9.1 Material Research

The multiple reuse opportunities for materials related to highway construction provides a potential for CDOT to dramatically increase their recycle rate. The research shows that 100% of asphalt, concrete and metal could be recycled with minor changes within the design process, specifications, or construction methods. With just the few materials targeted in this project, several minor process changes could be made to significantly reduce waste on highway projects and preserve virgin resources. The following recommendations can be applied for the focused materials:

- **Asphalt:** Increase the percent of RAP allowed in highway asphalt pavement projects from 25% to 30% Also, increase the amount of hot in-place and cold in-place pavement recycling.
- **Concrete:** Use more crushed concrete products offered by a number of local recycling companies. Many of them will prepare the material according to the CDOT specification including pipe bedding material and riprap.   Also, provide excess used concrete to recycling companies who are able to process and resell it.
- **Wood:** Replace treated and painted wood products with more durable and recycle-friendly products such as steel and plastic.
- **Metal:** Replace raw materials with highly recyclable metal products containing steel, iron, lead, copper and aluminum.
- **Recycled Tires:** Utilize scrap tires for pavement additives, crack sealant, walls, mulch, sidewalks, permeable and lightweight fill, and many other applications where tires perform equally or better than other materials.

CDOT's engineers and contractors need to be made more aware and comfortable about the potential advantages and opportunities of utilizing recyclable materials on highway projects, through education, outreach, sharing, and possible research, especially as new advances emerge.

Another research finding was that the highway design plans present a barrier to recycling.   The plans need more information, design notes, and project special conditions, in order to provide contractors with a level playing field when bidding a project where recycling could be done.

9.2 Specifications Research

An inventory was compiled of existing specifications and special provisions that currently allow for reuse and recycling. Based on this, further evaluation was done to focus on areas that could be changed to increase the potential for reuse and recycling. The two most significant areas included material removal and erosion control. Recommended changes include adding language to the materials removal specifications contained in Section 202 to directly encourage reuse and recycling. Also, language is recommended in the erosion control of Section 208 to promote reusing site materials and taking advantage of available recycled materials for erosion control features. Specific examples include using crushed concrete for riprap to the extent possible and using recycled plastic in soil retention blankets.

9.3 Tracking Method Research

A practical and straight-forward tracking method is required for CDOT to measure their reuse and recycling efforts now and into the future. The best method capitalizes on the current material tracking system already used by CDOT and is accessible to everyone. This is the CDOT Cost Data Book, which is available on the CDOT website. Materials use could be measured best if specifications are developed for each material which is reused or recycled. This measurement would involve assigning specific pay item numbers to each material so all can be tracked using the current system. Minimal training would be required, as this builds on an existing tracking system that is already familiar to those in the industry and who use these tools. The process of initially setting up these new specifications and pay items will take time and staff resources. However, the ability to easily track these materials should make the effort worth the investment.

9.4 Information Dissemination

"Getting the word out" will be one of the ongoing items associated with this project for CDOT to succeed in increasing reuse and recycling on highway projects. A presentation was developed for the National Recycling Coalition conference. This presentation can be easily modified to address other specific audiences as needed.

9.5 Project Achievement Metrics

The initial goal set by CDOT at the outset of this project was to increase reuse and recycling on highway projects by 10 percent over 2 years. Based on available information and projections calculated with the measures taken as outlined in this project, this goal is attainable. **Table 2**, on the next page, shows the trends over the past two years for the focused materials identified on the project and the projected volumes for 2007. More accurate measures will be available once a baseline is established and these materials can be more readily tracked. With better awareness and appropriate tools, CDOT will be able to achieve this goal. In the process, reduction of GHG's that are effecting global warming can also be accomplished. As the metrics become available to better identify GHG emissions and other pollution prevention and social impacts for highway construction materials, more accurate data can also be tracked for determining the savings from improving reuse and recycling. Information was available to calculate the GHG savings for recycling more concrete aggregate and is provided in **Table 2**.

Table 2. Goal Achievement

Goal Acheivement Chart
for 10% Increase on CDOT Recycling on Highway Projects

Material	2005 Recycled [1]	2005 Virgin [2]	2005 Percent Recycled	2006 Recycled [1]	2006 Virgin [2]	2006 Percent Recycled	2007 [3] Recycled [1]	2007 [3] Virgin [2]	2007 [3] Percent Recycled
Asphalt (tons)	41,000	373,658	11%	30,000	347,942	9%	45,100	260,125	17%
Concrete (tons)	1,000	207,790	0%	1,000	592,893	0%	1,100	290,068	0%
Aggregate (tons)	100,000	206,966	48%	100,000	380,320	26%	110,000	254,674	43%

Material	2005 Recycled	2005 Virgin [2]	2005 Percent Recycled	2006 Recycled	2006 Virgin [2]	2006 Percent Change from Previous Year	2007 [3] Recycled	2007 [3] Virgin [2]	2007 [3] Percent Change from Previous Year
Wood (Mulch) (CF) [4]		1,298	0%		14,834	91%		837	-1672%
Wood (Fence Posts) (LF) [4]		36,236	0%		34,573	-5%		994	-3378%
Scrap Tires (import) (tons) [5]	0		0%	0		0%	20,000		100%
Metal (tons) [6]	0		0%	0		0%	50		100%

Greenhouse Gas Emission Calculations
for Concrete Aggregate

EPA created WAste Reduction Model (WARM) to help track greenhouse gas (GHG) emissions reductions and energy savings. The materials provided in this model were limited.

For this study we focused on the GHG emissions for concrete aggregate. Using this online model, the following conclusions were derived for recycling concrete.

Material	2005 Recycled [7]	2005 Landfilled [8]	2005 GHG (MTCO2E) [9]	2006 Recycled [7]	2006 Landfilled [8]	2006 GHG (MTCO2E) [9]	2007 [3] Recycled [7]	2007 [3] Landfilled [8]	2007 [3] GHG (MTCO2E) [9]
Concrete (tons) [10]	1,000	53,458	2024	1,000	139,355	5288	1,100	25,652	966
Concrete (tons) (10% recycled)	5,446	49,012	1820	14,036	126,319	4692	2,676	24,076	894
Change in GHG Emissions			-204			-596			-72

Notes:

1 The recycled information was obtained from the CDOT generated information for the Recycled Materials Resource Center (RMRC) on recycling. Recycled material for asphalt was RAP, concrete was crushed concrete, and aggregate was a combination of RAP and crushed concrete. The recycled quantities under 2007 were projected to increase by 10% above the highest amount previously recorded in 2005 or 2006.

2 The virgin material was obtained from the CDOT Cost Data. The asphalt included 25% of the hot mix asphalt pavement (the maximum amount allowed for RAP disregarding top lift limitations for this analysis), the concrete included concrete pavement, and the aggregate included asphalt base course class 6.

3 The Cost Data information for 2007 was through June 30, 2007; whereas, 2005 and 2006 quantities were for the entire year.

4 The objective for wood is to reduce the usage of virgin material and replace with more recycle friendly materials such as metal or plastic or other material in the case of mulch. This number should go to zero.

5 The objective for scrap tires is to increase the usage of material and replace it for other virgin materials such as asphalt or fill.

6 The objective for metal is to increase the amount of removed metal from the project to a recycling facility.

7 Used similar metrics as was determined with the RMRC survey.

8 Used concrete curb, gutter, sidewalks and pavement removals from CDOT Costs Data information for that year based on appropriate assumptions to convert to tons.

9 MTCO2E = Metric Tons of Carbon Dioxide Equivalent

10 Assumed a 10% increase in the amount of concrete recycled in 2007.

11 Examined the amount of GHG savings that could be generated by just recycling 10% of the total amount of concrete pavement.

10.0 NEXT STEPS

Additional efforts are recommended which extend beyond the limits of the scope of this project in order to fully explore and implement an improved construction materials recycling effort at CDOT. Short term and long term goals were developed focused on what was learned during the research project.

10.1 Short Term Goals

In the short term, it may be beneficial to identify how the different CDOT regions are currently recycling the high priority materials on their highway projects. The successful methods of recycling and reuse could be shared with the other regions at such venues as the Winter Conference or even a separate conference that is established to present reuse and recycling methods around the regions. This gathering would help create a methodology that ties CDOT's short-term goals to EPA's short-term goals.

At the end of Task 4, CDOT could consider a PowerPoint presentation of the research information gathered from this project and present the findings internally within CDOT to gather additional feedback from all the Colorado Regions.

CDOT should also identify a means to encourage recycling during project design, including development of a formal process to emphasize and encourage reuse and recycling. Project managers need to be informed about their role in supporting CDOT's and EPA's goal for recycling and waste reduction. They need to be empowered and encouraged to apply these concepts on their projects. They need to be assured that applications of unfamiliar materials are proven to be cost-effective and can meet specifications.

Further implementation of revisions suggested for the specifications should be conducted as a next step. Incorporating reuse and recycling into other appropriate specifications should be considered. Revisions to current specifications should be considered to allow and encourage use of more recycled material.

CDOT could include developing new specifications for materials identified in Section 6.0, including bid item numbers to use and track on projects. This would involve the use of consistent units of measurement for each item. The project would include obtaining approval from the specification committee and allowing trial use of these specifications and bid item numbers in order to develop a baseline. CDOT could also follow-up on the implementation of developing a special provision for tire bale embankments as part of Section 203 as suggested in the Tire Bales in Highway Applications: Feasibility and Properties Evaluation Report No. CDOT-DTD-R-2005-02.

CDOT participates in the Colorado Asphalt Pavement Association (CAPA) RAP Task Force meetings. Continuing efforts on this committee could bring CDOT closer to increasing RAP on CDOT highway projects.

10.2 Long Term Goals

A list of recommended long-term CDOT actions and goals include:

Research other materials which CDOT handles on highway construction projects that were not within this project scope. As new technological advances in recycling and reuse emerge, it will be important for CDOT to discover methods to include these technologies into their recycling efforts. CDOT should also continue to review techniques and strategies for reusing and recycling materials employed by other states, nations and agencies.

It was not possible to collect all state DOT reuse and recycling program information via the online web search. Therefore, a more in-depth follow-up of DOT programs is recommended to include other avenues, such as phone contacts, Email inquiries, and conference sharing. The research from this project has identified state DOT's who have progressed their recycling efforts over the years. More focused contact with those identified DOT's would be beneficial.

Additional follow-up contact could be aimed towards the Recycled Materials Resource Center in New Hampshire to identify additional states and projects that have been successful in reusing and recycling materials.

A valuable long-term consideration should be given to create a GIS-based Colorado map that geographically identifies all known materials stockpile locations, processed materials locations, and recycling business center locations in Colorado (several recycling centers have been identified in our research Task 1 report). This geographic information can help fuel the ability for many agencies and companies to find and connect with nearby recycling facilities and opportunities. Often, geographic and distance barriers drive the cost decisions for whether or not a material can cost-effectively be recycled off-site at a recycling center instead of disposed, based on hauling distance and cost. A map generated for this purpose would be a useful display tool to help contractors and engineers compare the cost of disposal versus recycling off-site. A potential partner or resource for this database would be the Solid Waste Unit of the Colorado Department of Public Health and Environment.

A web-based methodology could be prepared to link staff between CDOT Regions and projects in order for them to access each others' construction and demolition materials that may be available on adjacent projects. Such a tool could help staff recycle these materials instead of disposing them, and find reusable materials rather than purchase raw virgin ones. This system could help staff coordinate materials types, quantities, handling, timing, tracking, and other issues during all phases of project planning, demolition, and construction. This also would help sell the idea of recycling to those who may be new to it, by creating an easy path for them to see what other project engineers and contractors are doing, and are willing to help them on.

Metropolitan Government Pavement Engineers Council and the Colorado LTAP center are local industry governments already involved in a variety of recycling efforts for transportation-related materials. CDOT could strengthen their partnership efforts with local governments through these organizations to facilitate their recycling efforts. Doing so will help all involved to meet EPA's recycling goals, by connecting a cadre of well-informed and well-qualified staff that will assure the highest quality for recycled materials that are used in CDOT projects.

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APPENDIX A - MATERIALS LANDFILL SURVEY

The survey was distributed to 206 CDOT project engineers, resident engineers, materials engineers, and maintenance personnel, as well as a few contractors to gather feedback. Below is a list of the recipients of the survey:

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Materials Landfill Survey

Response Deadline 2/2/2007

Please take a moment to fill out this survey based on your working experience with CDOT projects.

CDOT's Applied Research and Innovation Branch is in the process of managing a study designed to help our agency reduce the generation of large-tonnage solid waste and to promote the recycling and reuse of industrial by-products. Our first step is to identify the large tonnage materials on CDOT construction projects which are reused, generated, recycled, and disposed. This survey has been constructed to give us a handle on where these construction/demolition materials from CDOT projects end up--whether they are used on-site or removed. We are eager to tap your experience as a CDOT project engineer or contractor who is familiar with these types of projects to complete this survey.

The following categories of materials are thought to be the primary list of large quantity materials of interest that we need to consider. Please add to this list of materials (next to other) if you have handled a large quantity material that does not appear on the list below.

This survey is a subjective estimate of the overall % of each material that ends up in 1 of the 4 final destinations.

Please contact Jordan Rudel 303-721-1440 with any questions or comments

Please place the estimated % out of 100% that each material most commonly fits in the below categories for CDOT projects.

Example – Each row should = 100% in column F

	Reused/ Recycled Onsite	Reused/ Recycled Offsite (Recycling Center)	Stockpiled For Later Use	Sent to Landfill	Total % should equal 100
Concrete					
Structural concrete					
Concrete pavement (PCCP)					
Flatwork concrete (curb, gutter, etc)					
Bridge/Barrier Rail					
Asbestos concrete pipe					
Pre-Cast concrete					
Other					
Asphalt					
Hot Mix Asphalt (HMA)					
Rotomillings					
Paving/Roadway materials					
Roof shingles					
Other					
Wood					
Delineator posts					
Fence					
Posts/Stakes					
Construction materials					
Other					
Metal					
Bridge railing					
Guard rail					
Fence					
Structural steel					
Corrugated steel pipe					
Electrical conduit					
Reinforcing steel					
Ductile iron pipe					
Aluminum					
Copper					
Lead					
Other					
Water					
Recycled water					
Other					
Excavation and Embankment Material					
Sandblasting					
Excavation material					
Top soil					

	Reused/ Recycled Onsite	Reused/ Recycled Offsite (Recycling Center)	Stockpiled For Later Use	Sent to Landfill	Total % should equal 100
Aggregate base course					
Riprap					
Other					
Plastic					
PVC/Pipe					
HDPE					
Electrical conduit					
Other					
Coal Fly Ash					
Coal fly ash C					
Coal fly ash F					
Pozzolan					
Blast furnace slag					
Other					
Oil					
Form					
Equipment					
Other					
Paper/Paperboard					
Paper					
Cardboard					
Other					
Plants/Organics					
Trees					
Branches					
Grass					
Compost					
Other					
Plant/Quarry Fines					
Baghouse fines					
Crusher waste fines					
Mineral filler					
Other					
Rubber*					
Scrap Tires					
Other					
Glass/Ceramics					
Traffic control material					
Glass					
Ceramics (tile or pipe, etc)					

	Reused/ Recycled Onsite	Reused/ Recycled Offsite (Recycling Center)	Stockpiled For Later Use	Sent to Landfill	Total % should equal 100
Scrap					
Other					
Geotextiles					
Silt fence					
Erosion logs					
Other					

Place an X Next To the Following Group That You Are Representing In This Survey

	X HERE
CDOT Project Engineer	
CDOT Resident Engineer	
CDOT Materials Engineer	
CDOT Maintenance	
Contractor	
Other ______________________	

Please email your completed survey to both Jordan.Rudel@FHUENG.com and Patricia.Martinek@dot.state.co.us. Thank you very much for sharing your expertise and completing this survey.

Comments from Survey Responders

1) The responses to this survey differ depending on the condition of the materials taken from the highway construction demolition.
2) Excavation and Embankment Materials often get sent to pit to be reclaimed.
3) Reinforcing steel is usually recycled or given to the contractor to crush.
4) Asphalt is usually given to producers or sold to landowners.
5) Most wood is either sent to dump, wasted on site if possible, or burned.
6) One project used water with poor quality for dust suppression but it was not recycled from the project.
7) Coal ash is sometimes used for soil stabilization and concrete(if meets certain criteria)
8) Coal ash is sometimes used in concrete (if it meets criteria). Some have attempted to use mixed with 50% clay.
9) Plants and Organics are sometimes placed in fills outside roadway or in topsoil piles.
10) Geo-textiles after use are in to bad of shape for reuse although they may be used multiple times on project.
11) Maintenance Section 2 recycles 5,000 to 10,000 ton of RAP (asphalt roto millings) per year. We machine patch with the RAP.
12) Regarding the use of fly ash in embankment, the contractor attempted to mix 50% F ash with 50% clay which created a varying material with moisture problems. They filed a claim which was settled by CDOT. They attempted to compare this process to some national research that showed F ash could be used to build embankments if they were specially designed and certain engineering considerations were accounted for.
13) We specify 20-30 lbs of silica fume per cubic yard of Class H Concrete.
14) Last year, we approved 269 concrete mix designs. Of those 50 had Class C fly ash, and 201 had Class F fly ash. 10 mixes used 25 lbs/cubic yard of silica fume.
15) On average last year, a concrete mix had 630 lbs/cubic yard of cementitious.
16) The average Class C fly ash replacement was 19.21%, 26 mixes used the maximum of 20%.
17) The average Class F fly ash replacement was 20.56%, 6 mixes used the maximum of 30%.
18) The specifications changed last year to allow up to 30% Class F instead of a maximum of 20%.
19) My recent experience/example is the I-25 over Broadway project. All the old steel from the old bridge superstructure was used twice... once for false work (construction support material for the new bridge construction) then was sold as scrap iron for steel industry. All HBP generated by the site was used as parking lot surfacing on the project or sold to recyclers. Steel reinforcing bars were collected in huge piles that looked like spaghetti and hauled off for steel recycling.

Materials Landfill Survey Results

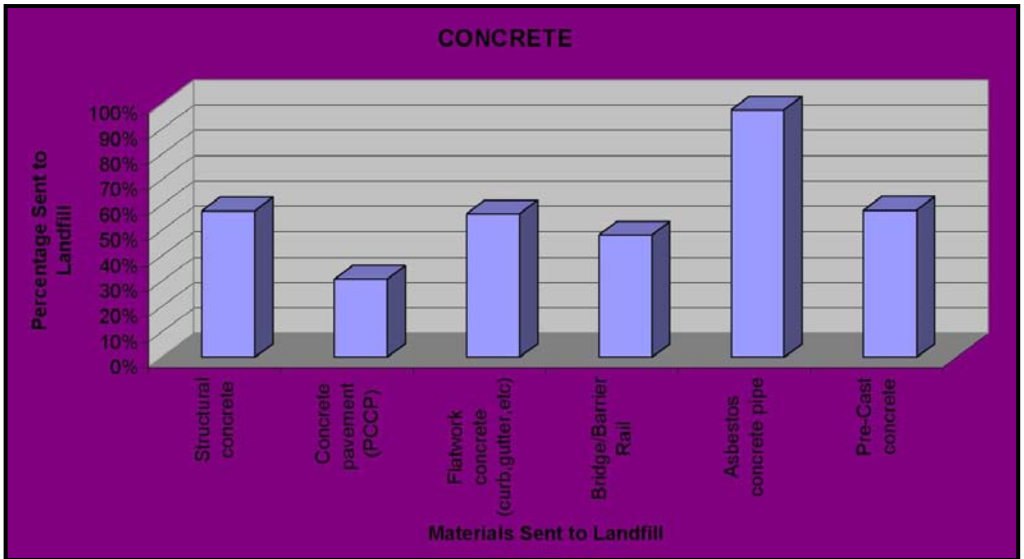
	Reused/ Recycled Onsite	Reused/ Recycled Offsite (Recycling Center)	Stockpiled For Later Use	Sent to Landfill	Total % should equal 100
Concrete					
Structural concrete	20%	18%	4%	58%	100%
Concrete pavement (PCCP)	34%	29%	7%	31%	100%
Flatwork concrete (curb, gutter, etc)	16%	24%	4%	57%	100%
Bridge/Barrier Rail	11%	24%	17%	48%	100%
Asbestos concrete pipe	0%	0%	3%	98%	100%
Pre-Cast concrete	18%	17%	7%	58%	100%
Asphalt					
Hot Mix Asphalt (HMA)	32%	31%	9%	28%	100%
Rotomillings	37%	17%	44%	2%	100%
Paving/Roadway materials	33%	23%	22%	23%	100%
Roof shingles	0%	11%	0%	90%	100%
Wood					
Delineator posts	9%	10%	8%	73%	100%
Fence	8%	10%	13%	69%	100%
Posts/Stakes	11%	12%	12%	65%	100%
Construction materials	11%	15%	15%	59%	100%
Metal					
Bridge railing	7%	43%	18%	32%	100%
Guard rail	5%	40%	34%	21%	100%
Fence	5%	25%	16%	55%	100%
Structural steel	3%	61%	10%	26%	100%
Corrugated steel pipe	6%	26%	12%	56%	100%
Electrical conduit	0%	14%	8%	77%	100%
Reinforcing steel	3%	34%	9%	54%	100%
Ductile iron pipe	0%	26%	10%	65%	100%
Aluminum	4%	62%	6%	28%	100%
Copper	4%	54%	4%	37%	100%
Lead	7%	21%	0%	73%	100%
Water *					
Recycled water	66%	17%	8%	10%	100%
Earthwork					
Sandblasting	16%	7%	3%	74%	100%
Excavation material	65%	13%	15%	8%	100%
Top soil	83%	2%	12%	3%	100%
Aggregate base course	70%	13%	11%	6%	100%
Riprap	67%	4%	21%	8%	100%
Plastic					
PVC/Pipe	7%	6%	9%	77%	100%

	Reused/ Recycled Onsite	Reused/ Recycled Offsite (Recycling Center)	Stockpiled For Later Use	Sent to Landfill	Total % should equal 100
HDPE	8%	4%	10%	79%	100%
Electrical conduit	5%	8%	4%	83%	100%
Coal Fly Ash**					
Coal fly ash C	0%	29%	5%	66%	100%
Coal fly ash F	0%	31%	6%	63%	100%
Pozzolan	0%	25%	8%	67%	100%
Blast furnace slag	0%	20%	7%	73%	100%
Oil					
Form	8%	28%	1%	63%	100%
Equipment	7%	63%	0%	29%	100%
Paper/Cardboard					
Paper	0%	26%	0%	74%	100%
Cardboard	0%	19%	0%	81%	100%
Plants/Organics					
Trees	17%	19%	5%	59%	100%
Branches	16%	13%	3%	68%	100%
Grass	29%	6%	0%	65%	100%
Compost	37%	9%	1%	53%	100%
Plant/Quarry Fines					
Baghouse fines	26%	5%	35%	35%	100%
Crusher waste fines	30%	8%	35%	27%	100%
Mineral filler	27%	7%	35%	31%	100%
Rubber*					
Scrap Tires	2%	19%	2%	78%	100%
Glass/Ceramics					
Traffic control material	26%	10%	11%	53%	100%
Glass	0%	9%	3%	88%	100%
Ceramics (tile or pipe, etc)	0%	6%	3%	90%	100%
Scrap	1%	7%	3%	91%	100%
Geotextiles					
Silt fence	3%	0%	3%	93%	100%
Erosion logs	10%	5%	2%	83%	100%

* Material is sometimes imported and not always generated from a CDOT project
** Material is solely imported and NOT generated from a CDOT project.

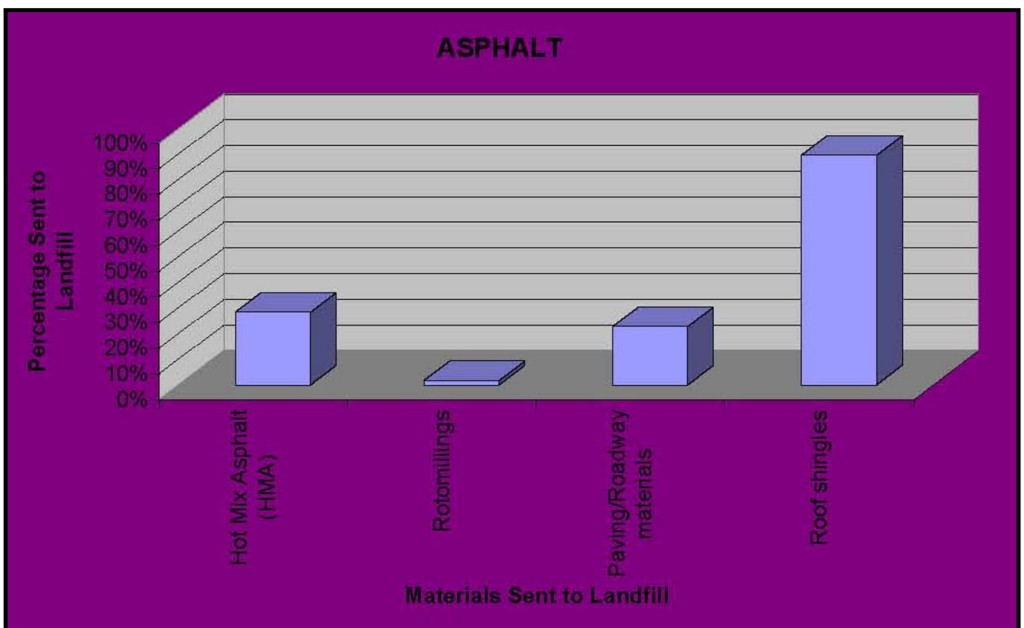
Each of the following graphs provides information on the percentage of each specific material currently sent to the landfill based on the Materials Landfill Survey conducted, separated by major category of material. Using these subjective percentages collected by CDOT and contractors and applying this information to quantity information provided in the 2006 CDOT Cost Data Book, the potential quantity of material that is sent to the landfill could be calculated and is presented in the table below each graph. The quantities presented are based specific pay items available; therefore, quantities are not provided for all materials.

Figure A-1. Concrete



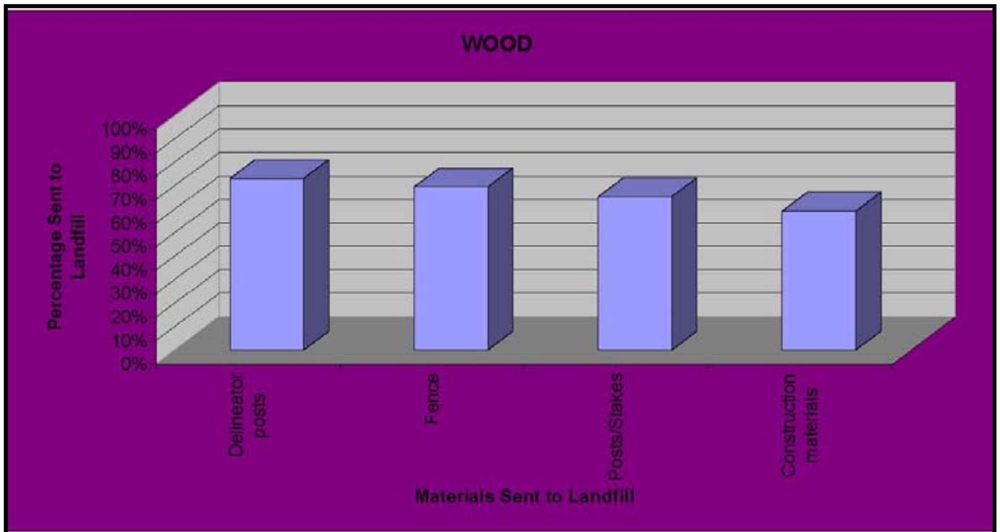
Concrete pavement (PCCP)	87,464	SY
Flatwork concrete (curb, gutter,etc)	36,516	SY

Figure A-2. Asphalt



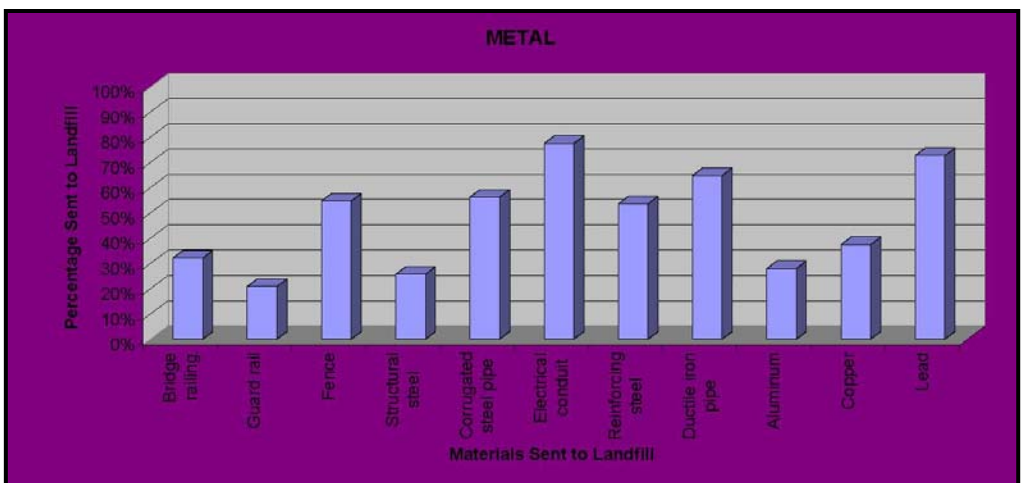
Hot Mix Asphalt (HMA)	130,450	SY
Rotomillings	66,158	SY
Paving/Roadway materials	970	SY

Figure A-3. Wood



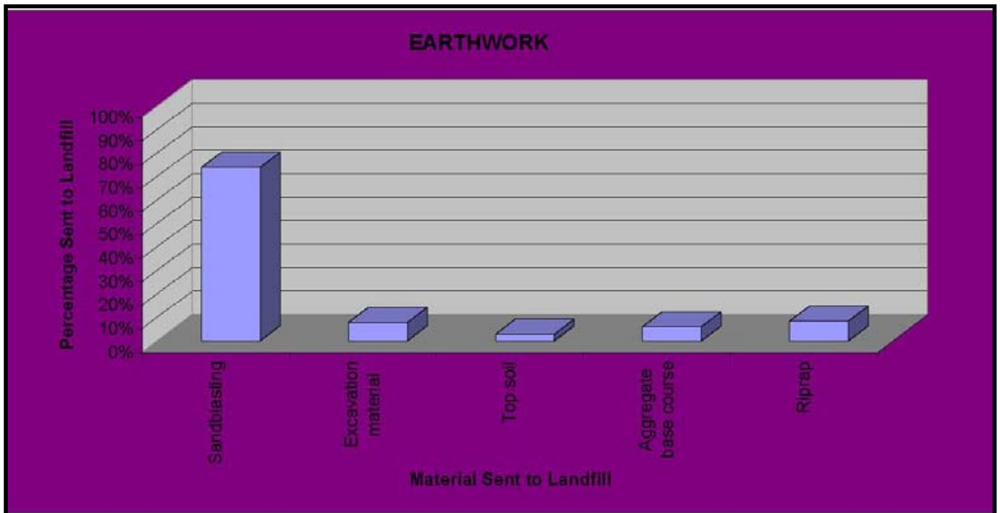
Delineator posts	3,503	EA
Fence	141,023	LF

Figure A-4. Metal



Bridge railing	2,822	LF
Guard rail	22,499	LF

Figure A-5. Earthwork



Sandblasting	61,104	SF
Excavation material	116,084	CY
Riprap	61	SY

Figure A-6. Plastic

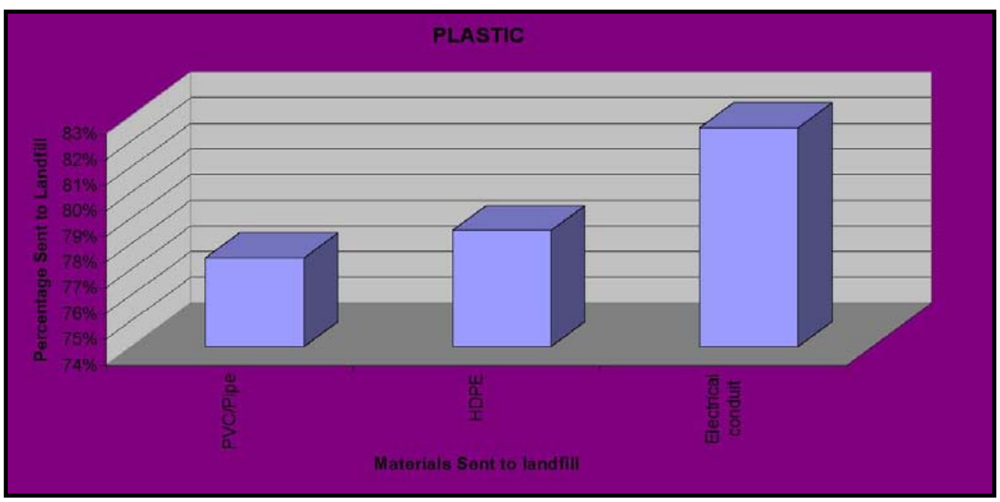


Figure A-7. Plastic/Cardboard

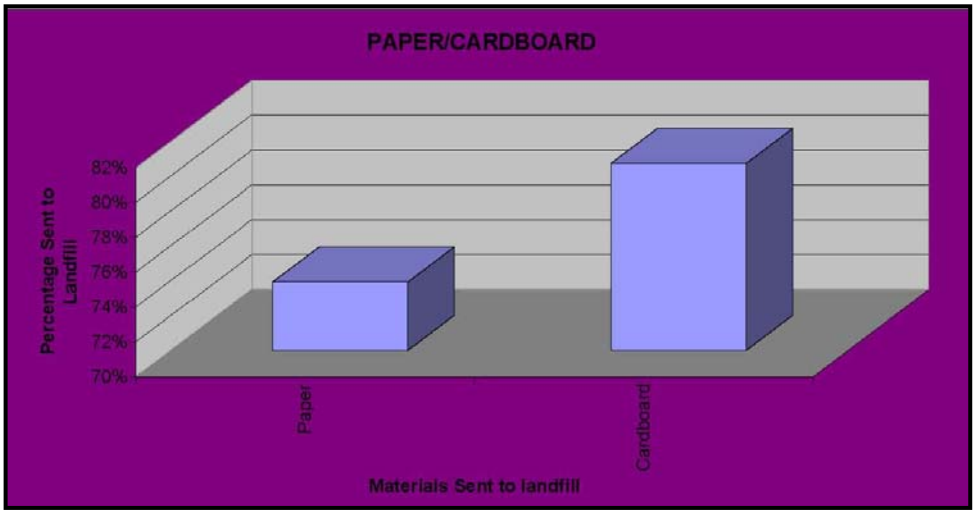
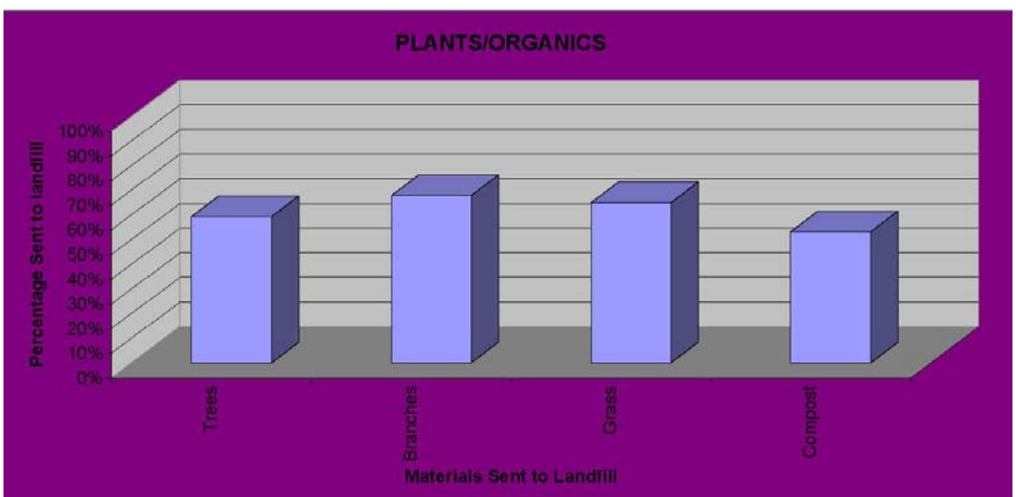


Figure A-8. Plants/Organics



Trees	421	EA

Figure A-9. Plant/Quary Fines

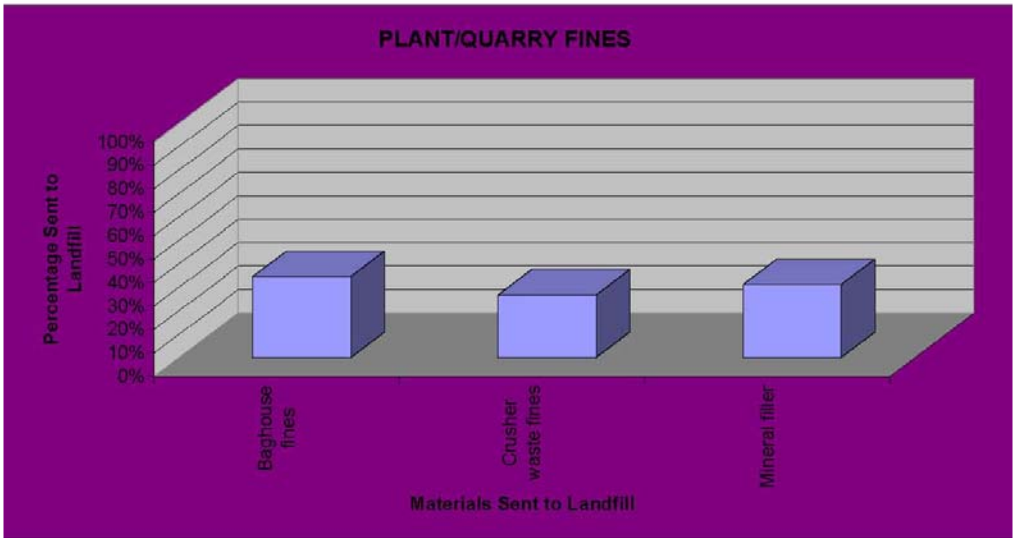


Figure A-10. Rubber

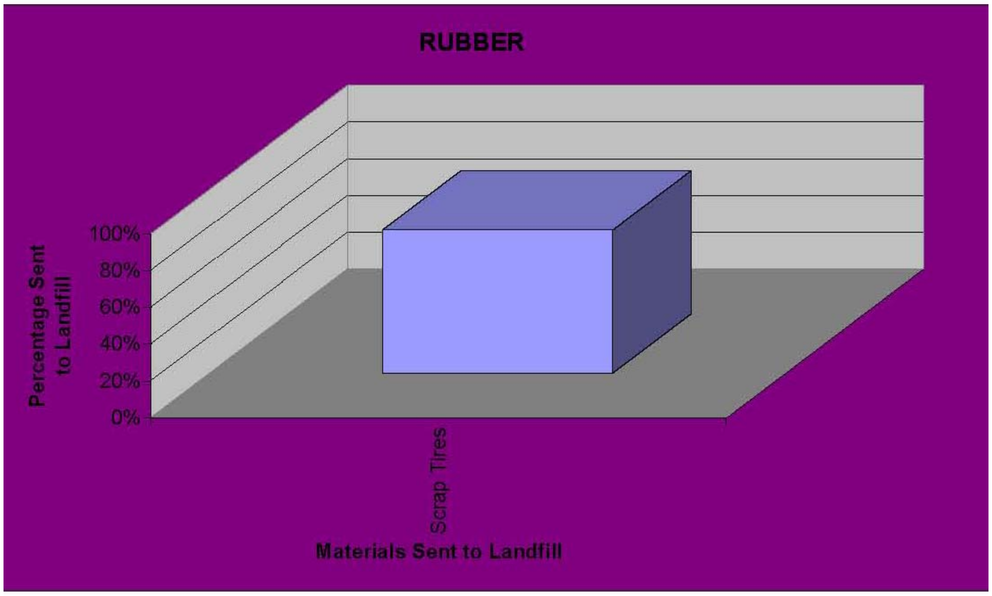
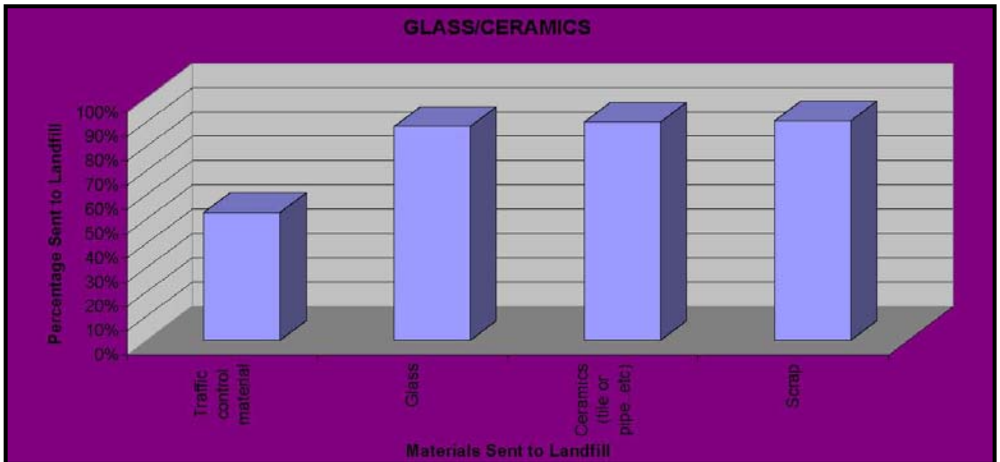


Figure A-11. Glass/Ceramics



Traffic control material	179,713	SF

Figure A-12. Geotextiles

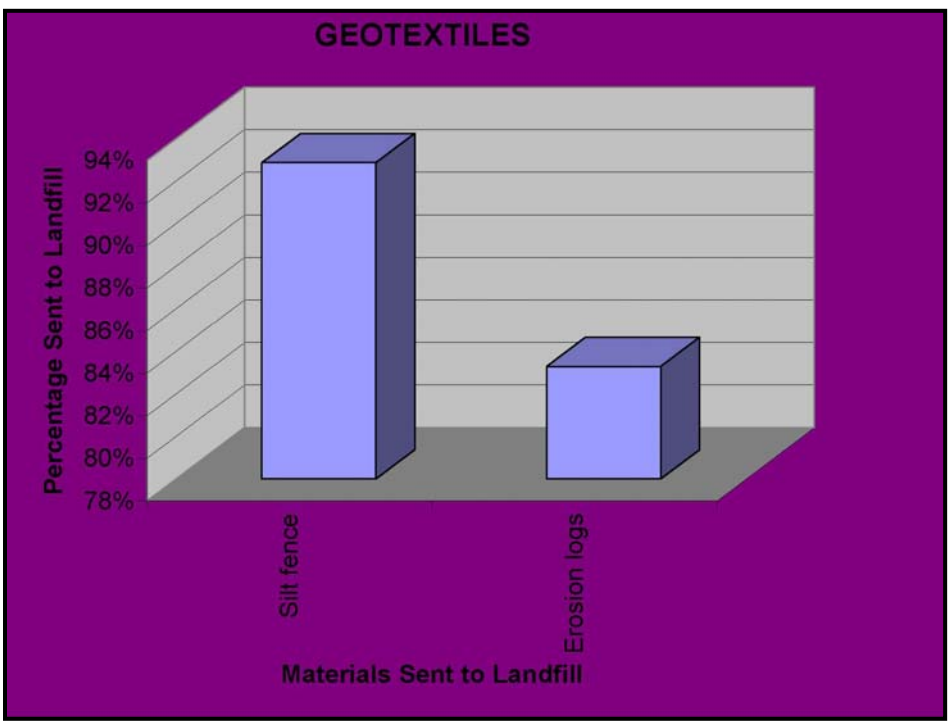


Table A-1 – Survey of Recycled Materials Use in the Highway Environment, 2005

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Material	**Bituminous Bound Applications (tons/yr)**	**Cement Bound Applications (tons/yr)**	**Unbound & Fill Applications (tons/yr)**	**Miscellaneous (tons/yr)**	**Extent of Use**	**Specifications**
EXAMPLE: Waste Glass	1 (10,000)		11 (1,000) 13 (10)		2 - Limited	AASHTO M-318-01
Reclaimed Asphalt Pavement	**1(41,000)**		**11 (60,000)**		**3**	**CDOT Spec**
Reclaimed Concrete Pavement		**6 (1,000)**	**11 (40,000)**		**3**	**CDOT Spec**
Roofing Shingle Waste					**0**	
Waste Glass (Cullet)					**0**	
Scrap Tires					**1**	
Coal Fly Ash		**8 (13,000)** **10 (300)**			**3**	
Coal Bottom Ash					**0**	
Coal Boiler Slag					**0**	
Cement Kiln Dust					**1**	
Lime Kiln Dust					**0**	
Spent Foundry Sand					**0**	
Blast Furnace Slag					**0**	
EXAMPLE: Waste Glass	1 (10,000)		11 (1,000) 13 (10)		2 - Limited	AASHTO M-318-01
Steel Slag					**1**	
Non Ferrous Slags					**0**	
Mill Tailings					**0**	
Phosphogypsum					**0**	
Quarry Waste Fines	**1 (140,000)**				**3**	**CDOT Spec**
Quarry Waste Rock					**0**	
Baghouse Fines	**5 (7,000)**				**3**	
Municipal Solid Waste Incinerator Ash					**0**	

Table A-1 – Survey of Recycled Materials Use in the Highway Environment, 2005

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Material	**Bituminous Bound Applications (tons/yr)**	**Cement Bound Applications (tons/yr)**	**Unbound & Fill Applications (tons/yr)**	**Miscellaneous (tons/yr)**	**Extent of Use**	**Specifications**
Flue Gas Desulfurization Sludge					**0**	
C & D Debris					**0**	
Sewage Sludge Ash					**0**	
Other: **Waste Glass**				**15 (7,000)**	**3**	**CDOT Spec**
Other:						

2006 SUMMARY OF RECYCLED MATERIALS USED BY THE COLORADO DEPARTMENT OF TRANSPORTATION

The following table is a matrix that lists a number of potential recycled materials (Column 1) that the Colorado Department of Transportation (CDOT) could use, a number of potential beneficial use applications (Columns 2-5), the extent of use (Column 6) and applicable specifications (Column 7). When finished, the table provides a summary of which different recycled material application combinations were used, or have been used, in CDOT for 2006. The following steps describe how the table was completed.

Step 1: For columns 2-5, we inserted the appropriate application number for the potential application(s) for each recycled material. The list of applications and application numbers is given below. We put the tonnage of material used in each application in parentheses after the application number.

Application	**Application Number**	**Application Description**
Bituminous Bound Applications (Column 2)	1 -------	Hot Mix Asphalt Aggregate
	2 -------	Cold Mix Asphalt Aggregate
	3 -------	Seal Coat or Surface Treatment Aggregate
	4 -------	Asphalt Cement Modifier
	5 -------	Mineral Filler
Cement Bound Applications (Column 3)	6 -------	Portland Cement Concrete Aggregate
	7 -------	Portland Cement Admixture or Modifier
	8 -------	Pozzolan
	9 -------	Stabilized Base or Subbase Aggregate
	10 -------	Flowable Fill Component
Unbound & Fill Applications (Column 4)	11 -------	Granular Base or Subbase Aggregates
	12 -------	Embankment or Engineered Fill
	13 -------	Drainage Material
	14 -------	Mulch or Topsoil Amendments
Miscellaneous (Column 5)	15 -------	Fencing or Traffic Control Material
	16 -------	Piping Material
	17 -------	Other

Step 2: In column 6, indicate the extent of use of each recycled material according to the rating system below:

3 Currently in general use.
2 Currently in limited use.
1 Used previously, not in current use.
0 Never used.

Step 3: In column 7, we indicate any CDOT or national specifications or practices used.

Table A-2 2006 Recycled Materials Used by CDOT in the Highway Environment

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Material	**Bituminous Bound Applications (tons/yr)**	**Cement Bound Applications (tons/yr)**	**Unbound & Fill Applications (tons/yr)**	**Miscellaneous (tons/yr)**	**Extent of Use**	**Specifications**
Reclaimed Asphalt Pavement	**1(30,000)**		**11 (54,000)**		**3**	**CDOT Spec**
Reclaimed Concrete Pavement		**6 (1,000)**	**11 (46,000)**		**3**	**CDOT Spec**
Roofing Shingle Waste					**0**	
Waste Glass (Cullet)				**15 (3,300)**	**3**	**CDOT Spec**
Scrap Tires					**1**	
Coal Fly Ash		**8 (10,500)** **10 (70)**			**3**	**CDOT Spec**
Coal Bottom Ash					**0**	
Coal Boiler Slag					**0**	
Cement Kiln Dust					**1**	
Lime Kiln Dust					**0**	
Blast Furnace Slag					**0**	
Steel Slag					**1**	
Mill Tailings					**0**	
Quarry Waste Fines	**1 (145,000)**				**3**	**CDOT Spec**
Quarry Waste Rock					**0**	

Table A-2 2006 Recycled Materials Used by CDOT in the Highway Environment

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Material	**Bituminous Bound Applications (tons/yr)**	**Cement Bound Applications (tons/yr)**	**Unbound & Fill Applications (tons/yr)**	**Miscellaneous (tons/yr)**	**Extent of Use**	**Specifications**
Baghouse Fines	**5 (7,500)**				**3**	**CDOT Spec**
Municipal Solid Waste Incinerator Ash					**0**	
Construction and Demolition Debris					**0**	
Sewage Sludge Ash					**0**	

APPENDIX B - ASPHALT

Material: Asphalt- Reclaimed Asphalt Pavement

One of the most commonly removed products from any transportation project is the asphalt pavement. As such, the quantity of this material available for reuse is substantial. Of all recycled construction/demolition materials, reclaimed asphalt pavement (RAP) is most commonly used. The following are several applications:

Cold mix reuse -

Reclaimed asphalt pavement (RAP) can be used as aggregate in the cold recycling of asphalt paving mixtures in two ways. The first method (cold mix plant recycling) involves a process in which RAP is combined with new emulsified or foamed asphalt, a recycling or rejuvenating agent, sometimes virgin aggregate. The mix can be made at a central plant or a mobile plant and produces cold mix base mixtures. The second, more common, method involves a process in which the asphalt pavement is recycled in-place (cold in-place recycling (CIPR) process). This process combines unheated RAP with new emulsified or foamed asphalt and/or a recycling or rejuvenating agent, sometimes with virgin aggregate. Mixing is done at the pavement site, at either partial depth or full depth, to produce a new cold mix end product. Most states have used cold in-place recycling in conjunction with a hot mix overlay or chip seal.

Hot mix reuse –

RAP is used as an aggregate in the hot recycling of asphalt paving mixtures in two ways. The most common method (conventional recycled hot mix) involves a process in which RAP is combined with virgin aggregate and new asphalt cement in a central mixing plant to produce new hot mix paving mixtures. A second method (hot in-place recycling) involves a process in which asphalt pavement surface distress is corrected by softening the existing surface with heat, mechanically removing the pavement surface, mixing it with a recycling or rejuvenating agent, possibly adding virgin asphalt and/or aggregate, and replacing it on the pavement without removing the recycled material from the pavement site.

Granular base –

Reclaimed asphalt pavement (RAP) can be used as granular base or subbase material in virtually all asphalt pavement types, including paved and unpaved roadways, parking areas, bicycle paths, gravel road rehabilitation, shoulders, residential driveways, trench backfill, engineered fill, pipe bedding, and culvert backfill.

The use of RAP in granular base applications is not considered the “highest best use” because it does not recover the asphalt cement potential in the old pavement, and typically does not allow it to be used again in pavement. However, it does provide an alternate application where no other markets (asphalt paving) are available or where unsuitable material (such as soil or mud) has been combined with the RAP so that it cannot be mixed into new recycled pavement

Material Properties

The properties of RAP are largely dependent on the properties of the constituent materials and the type of asphalt concrete mix (wearing surface, binder course, etc.). There can be substantial differences between asphalt concrete mixes in aggregate quality, size, and consistency. Aggregates in surface course (wearing course) asphalt concrete must have high resistance to wear/abrasion (polishing) in order to contribute to acceptable friction resistance properties. Therefore, these aggregates typically are of higher quality than the aggregates in binder course applications, where polishing resistance is not of concern.

Both milling and crushing can cause some aggregate degradation. The gradation of milled RAP is generally finer and denser than that of the virgin aggregates. Crushing does not cause as much degradation as milling; consequently, the gradation of crushed RAP is generally not as fine as milled RAP, but finer than virgin aggregates crushed with the same type of equipment.

The particle size distribution of milled or crushed RAP may vary to some extent, depending on the type of equipment used to produce the RAP, the type of aggregate in the pavement, and whether any underlying base or subbase aggregate has been mixed in with the reclaimed asphalt pavement material during the pavement removal.

During processing, virtually all RAP is milled or crushed down to a 38 mm (1.5 in) or smaller particle size, with a maximum allowable size of either 51 mm (2 in) or 63 mm (2.5 in). Table 13-1 lists the typical range of particle size distribution that normally results from the milling or crushing of RAP. Milled RAP is generally finer than crushed RAP. Studies on pavements in California, North Carolina, Utah and Virginia have shown that before and after milling, the pavement fraction passing a 2.36 mm (No. 8) sieve can be expected to increase from a premilled range of 41 to 69 percent to a postmilled range of 52 to 72 percent. The fraction passing a 0.075 mm (No. 200) sieve can be expected to increase from approximately 6 to 10 percent to a range of 8 to 12 percent.[(3)] Most sources of RAP will be a well-graded coarse aggregate, comparable to, or perhaps slightly finer and more variable than, crushed natural aggregates.

The unit weight of milled or processed RAP depends on the type of aggregate in the reclaimed pavement and the moisture content of the stockpiled material. Although available literature on RAP contains limited data pertaining to unit weight, the unit weight of milled or processed RAP has been found to range from 1940 to 2300 kg/m^3 (120 to 140 lb/ft^3), which is slightly lower than that of natural aggregates.

Information on the moisture content of RAP stockpiles is sparse, but indications are that the moisture content of the RAP increases while in storage. Crushed or milled RAP can absorb a considerable amount of water if exposed to rain. Moisture contents up to 5 percent or higher have been measured for stored crushed RAP.[(4)] As noted earlier, during periods of extensive precipitation, the moisture content of some RAP stockpiles may be as high as 7 to 8 percent.[(5)] Lengthy stockpiling of crushed or milled RAP should, therefore, be kept to a minimum. Alternatively, the piles should be covered.

The asphalt cement content of RAP typically ranges between 3 and 7 percent by weight. The asphalt cement adhering to the aggregate is somewhat harder than new asphalt cement. This is due primarily to exposure of the pavement to atmospheric oxygen (oxidation) during use and weathering. The degree of hardening depends on several factors, including the intrinsic properties of the asphalt cement, the mixing temperature/time (hardening increases with increasing temperature and exposure time), the degree of asphalt concrete compaction (hardening increases if asphalt is not well compacted), asphalt cement/air voids content (hardening increases with lower asphalt/higher air voids content), and age in service (hardening increases over time).

Local Projects

Colorado allows RAP to be incorporated in the products cited above. Performance-based criteria (i.e., gradation, Los Angeles abrasion, liquid limit, plasticity index, etc.) spell out abbreviations not used before dictate the extent to which it is allowed. RAP may only be used up to 25% in hot mix reuse and the particle size may not exceed 1 ½ inches prior to introduction to the mixer.

Reference- http://www.tfhrc.gov/hnr20/recycle/waste/index.htm Retrieved March, 2007.

Other States Projects

State/Location- California

How material is used- Much of the C & D debris from highway projects is salvaged for reuse or made available for recycling, keeping it out of local landfills. Debris such as concrete, asphalt, and reclaimed glass can be crushed and re-used as base material. Using recycled rather than new material also reduces the strain on California's dwindling aggregate supplies.

Reference - http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved March 9, 2007.

Other States Projects

State/Location- Massachusetts

How material is used- Placed on top of geotextile fabric under guardrail.

Specification-Recently milled asphalt concrete pavement (100 mm depth) shall be placed on top of a geotextile fabric under guardrail.

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

Other States Projects

State/Location- Massachusetts

How material is used- Used in Class I Bituminous Concrete.

Specification-The proportion of RAP to virgin aggregate shall be limited to a maximum of 40% for drum mix plans and 20% for modified batch plants. The maximum amount of RAP for surface courses shall be 10% (except in Open Graded Friction Course in which RAP is not allowed).

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

International Projects

Location – Sweden

How material is used – Old asphalt pavement is used "in new asphalt (cold and hot recycling)"; Annual Production of 0.8 million metric tons/0.76 million metric tons recycled

Specification – None found

Reference- Recycled Materials in European Highway Environments: Uses, Technologies, and Policies, USDOT/FHWA, International Technology Exchange Program, October 2000. pages 6-7.

Type of Project Case Study (Description)-
Case studies may be available at the Swedish National Road and Transport Research Institute website: http://www.vti.se/default2782.aspx or the Swedish Geotechnical Institute website. Retrieved March, 2007.

http://www.swedgeo.se/index-e.html which is referenced in the aforementioned document. Retrieved March, 2007.

Material: Asphalt - Roofing Shingles

There are two types of roofing shingle scraps. They include tear-off roofing shingles, and roofing shingle tabs also called prompt roofing shingle scrap. Tear-off roofing shingles are generated during the demolition or replacement of existing roofs. Roofing shingle tabs are generated when new asphalt shingles are trimmed during production to the required physical dimensions. The quality of tear-off roofing shingles can be quite variable.

Small quantities of prompt shingle scrap, typically shredded to 38 mm (1.5 in) and smaller, have been used as a gravel substitute for the wearing surface for rural roads and farm lanes. Increasing use of processed tabs or prompt roofing shingle scrap and, to a much lesser extent, tear-off roofing material is being made as a modifier to hot mix asphalt pavements, stone mastic asphalt pavements, and cold mix asphalt patching material.

Other States Projects

The following summaries from projects in Minnesota highlight the details of road projects that included shingle byproduct from the manufacturing process – such as the cuttings from shingles composed of paper or fiberglass mat, an asphalt binder, and ceramic aggregate – as part of the pavement mix. Minnesota Department of Transportation (Mn/DOT) specifications allow for the use of up to 5 percent of shingle byproduct in hot-mix asphalt. Please note that pavement performance testing is under way for many of these projects.

State/Location- Minnesota

How is material used- 5% prompt shingle scrap in HMA

Specification- Minnesota Department of Transportation (Mn/DOT) specifications allow for the use of up to 5 percent of shingle by-product in hot-mix asphalt.

Reference- http://www.pca.state.mn.us/oea/lc/purchasing/shinglestoolkit/shingles-casestudies.pdf Retrieved March, 2007.

Type of Project Case Study – Descriptive overview without technical information/documentation.

Other Research Findings from Associations- This site describes seven distinct projects.

Other States Projects

State/Location-Texas

How is material used- Post-consumer and post-industrial shingles used in HMA concrete surface

Specification-TXDOT Special Specification ITEM 3028 for HMAC Pavement Containing reclaimed roofing shingles

Reference- TxDOT Roofing Shingles Demonstration Project Final Report, http://www.rmrc.unh.edu/Resources/VDS/txdot-shingles/reports.asp Retrieved March, 2007.

Type of Project Case Study (Description)-

"Each year, roofing manufacturers produce approximately 11 million tons of new waste roofing shingles and shingle trimmings (post-industrial) in the United States of America (TxDOT, 1997). In addition, residential and commercial roofing replacement activities generate 8 to 10 million tons of old roofing waste (post-consumer). More than 500 million tons of asphalt concrete is produced annually in the U.S., and approximately 90% of which is hot mix asphalt. Therefore, using approximately 2% roofing shingle waste in all asphalt mixtures would consume all post-industrial and post-consumer roofing shingles generated each year.

In 1995, test sections were constructed by the Texas Department of Transportation using both post-consumer and post-industrial shingles in hot mix asphalt concrete surface. In addition, a control section was also constructed in order to monitor any significant deviation in performance from the conventional highway surface. The project site is located on WB SH 31 in Corsicana, Navarro County, Dallas District. It is a divided two-lane highway with a lane width of 12ft. Both post-consumer and post-industrial roofing shingles were used in the HMAC surface."

Reference- http://www.rmrc.unh.edu/Resources/VDS/txdot-shingles/shingles.asp, Accessed March 6, 2007

Other Research Findings from Associations-
Due to weight of shingles, transportation cost is an important consideration.

Other Notes/Photos
Cost of roofing shingles ~ $10/cubic yard. Disposal cost range $30/ton to $55/ton.

APPENDIX C - CONCRETE

Material: Concrete - Reclaimed Concrete Material

Reclaimed concrete material (RCM) is sometimes referred to as recycled concrete pavement (RCP), recycled concrete aggregate (RCA), or crushed concrete. It consists of high-quality, well-graded aggregates (usually mineral aggregates), bonded by a hardened cementitious paste. The aggregates comprise approximately 60 to 75 percent of the total volume of concrete.

RCM is generated through the demolition of Portland cement concrete elements of roads, runways, and structures during road reconstruction, utility excavations, or demolition operations.

The excavated concrete that will be recycled is typically hauled to a central facility for stockpiling and processing or, in some cases (such as large reconstruction projects), processed on site using a mobile plant. At the central processing facility, crushing, screening, and ferrous metal recovery operations occur. Crushing systems with magnetic separators are capable of removing reinforcing steel without much difficulty. Welded wire mesh reinforcement, however, may be difficult or impossible to remove effectively.

Reclaimed concrete material can be used as an aggregate for cement-treated or lean concrete bases, a concrete aggregate, an aggregate for flowable fill, or an asphalt concrete aggregate. It can also be used as a bulk fill material on land or water, as a shore line protection material (rip rap), a gabion basket fill, or a granular aggregate for base and trench backfill.

Use of RCM as Aggregate Substitute

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. Other potential applications include its use as an aggregate in flowable fill, hot mix asphalt concrete, and surface treatments.

To be used as an aggregate, RCM must be processed to remove as much foreign debris and reinforcing steel as possible. Reinforcing steel is sometimes removed before loading and hauling to a central processing plant. Most processing plants have a primary and secondary crusher. The primary crusher (e.g., jaw crusher) breaks the reinforcing steel from the concrete and reduces the concrete rubble to a maximum size of 75 mm (3 in) to 100 mm (4 in). As the material is conveyed to the secondary crusher, steel is typically removed by an electromagnetic separator. Secondary crushing further breaks down the RCM, which is then screened to the desired gradation. To avoid inadvertent segregation of particle sizes, coarse and fine RCM aggregates are typically stockpiled separately.

Mechanical Properties

Processed coarse RCM, which is greater than 4.75 mm in size (No. 4 sieve size), has favorable mechanical properties for aggregate use, including good abrasion resistance, good soundness characteristics, and bearing strength. Typical mechanical properties are given in Table 14-2. Los Angeles Abrasion loss values are somewhat higher than those of high-quality conventional aggregates. Magnesium sulfate soundness and California Bearing Ratio (CBR) values are comparable to conventional aggregates.

Areas of Concern When Using RCM

The cement paste component of RCM has a substantial influence on RCM alkalinity. Cement paste consists of a series of calcium-aluminum-silicate compounds, including calcium hydroxide, which is highly alkaline. The pH of RCM-water mixtures often exceeds 11.

RCM may be contaminated with chloride ions from the application of deicing salts to roadway surfaces or with sulfates from contact with sulfate-rich soils. Chloride ions are associated with corrosion of steel, while sulfate reactions lead to expansive disintegration of cement paste. RCM may also contain aggregate susceptible to alkali-silica reactions (ASR). When incorporated in concrete, ASR-susceptible aggregates may cause expansion and cracking.

The high alkalinity of RCM (pH greater than 11) can result in corrosion of aluminum or galvanized steel pipes in direct contact with RCM and in the presence of moisture. Similarly, RCM that is highly contaminated with chloride ions can lead to corrosion of steel. The high alkalinity of RCM can also be problematic when the material is proposed to be used as a filter media or as a subgrade stabilization material in the presence of groundwater.

Allowed Rates of Use of RCM in Transportation Projects

State specifications applicable to allowable usage percentages are not compiled in an accessible database that was available on the internet.

CDOT allows use of RCM in applications cited above using performance based criteria (i.e., gradation, LA abrasion, LL,PI, etc.).

Reference - http://www.tfhrc.gov/hnr20/recycle/waste/index.htm Retrieved March, 2007.

Other States Projects

State/Location- California

How material is used- Much of the C & D debris from highway projects is salvaged for reuse or made available for recycling, keeping it out of local landfills. Debris such as concrete, asphalt, and reclaimed glass can be crushed and reused as base material. Using recycled rather than new material also reduces the strain on California's dwindling aggregate supplies.

Reference - http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved March 9, 2007.

Other States Projects

State/Location- Massachusetts

How material is used- Produce a stabilized base and/or sub-base. Reclaimed pavement borrow material shall be used for base course and sub-base areas.

Specification-The existing pavement structure and a specified depth of acceptable sub-base material shall be recycled to produce a stabilized base and/or sub-base.

Reclaimed pavement borrow material shall consist of crushed asphalt pavement and/or crushed cement concrete, and gravel borrow. The amount of combined crushed asphalt pavement and crushed cement concrete shall not exceed 50% by volume.

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

Class 6 Aggregate Base Course

Class 6 Aggregate Base Course is 100% post consumer concrete and meets the Colorado Department of Transportation (CDOT) specifications. This product has reinforcing steel removed and pieces no larger than ¾ " down to dust. The most common usage is as a foundation for asphalt and concrete roadways. Compaction is obtained very easily because of the fractured faces created during the crushing process.

http://www.oxfordrecycling.com/product.html#1, Accessed March 1, 2007.

APPENDIX D - WOOD

Material: Wood- Aquatic Fenders

Other States Projects

State/Location- California

How material is used- Caltrans is seeking a substitute for creosote-treated wood timbers and pilings in aquatic fender applications, and is interested in using reinforced recycled plastic (RRP) or composites of plastic (CP) and concrete polymer in these applications. Fenders are "sacrificial" structures placed at the base of bridge piers as protection from shipping.

Reference - http://www.ciwmb.ca.gov/ConDemo/Roads/CalTrans.htm, Retrieved March 1, 2007.

Type of Project Case Study (Description)-

Present use of timbers. The Dumbarton Bridge, the San Mateo-Hayward Bridge, and the San Francisco-Oakland Bay Bridge each have had some RRP sheathing timbers installed. The fenders at these and other toll bridges in the San Francisco Bay Area will be rehabilitated with RRP or CP timbers in the near future.

APPENDIX E - METAL

Material: Metal- Light Rail, Guardrail

<u>Local Projects</u>

The steel used to manufacture the light rail tracks as part of the T-REX project was recycled from the former Mile High Stadium. The steel was stockpiled and then sent to the Rocky Mountain Steel Mill in Pueblo, CO, where it was melted down and formed into rail for the new light rail extension. The rail is inscribed "Mile High to T-REX" all along the tracks.

Reference- http://www.trexproject.com/ Retrieved March 1, 2007.

<u>Other States Projects</u>

State/Location- Kentucky

How material is used- Transportation Cabinet (KYTC) has developed a guard rail recycling program. Since July 2004 Kentucky has realized a savings of $3.6 million as a result of the guardrail recycling program and since July 2006 the KYTC has saved $1,260,000 by recycling guardrail and posts. The current program allows for damaged guardrail to be brought to a Frankfort work site, where inmate labor is used to sort and straighten reusable segments. Those pieces are then shipped to a contractor to be galvanized. It is then redistributed throughout the state.

Reference - http://kytcnewsroom.ky.gov/, January 29, 2007

Type of Project Case Study (Description)-

Material: Metal - Steel

<u>Other States Projects</u>

State/Location- California

How is material used- Steel from rebar, sign posts, light posts, and metal beam guardrail is reused or recycled. If these items are in good condition, they can be reused or stockpiled until needed. If items are damaged or found to be beyond repair, they can be recycled as scrap metal.

Reference- http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved on March 9, 2006.

Other Notes/Photos

Guardrail can be dismantled and used again.

Figure E-1 Guardrail

Reference- http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved on March 9, 2006.

Material: Metal - Aluminum

Other States Projects

State/Location-North Carolina

How material is used- Utilize signs made from at least 50% recycled aluminum. Once the signs are damaged or replaced, they are sent back to the manufacturer for recycling or sent to the NCDOT's sign refurbishing plant.

APPENDIX F - TIRES

Material: Scrap Tires - Used Tires

HIGHWAY USES AND PROCESSING REQUIREMENTS

Embankment Construction - Shredded or Chipped Tires

Shredded or chipped tires have been used as a lightweight fill material for construction of embankments. Combustion problems at three locations in the 1990's prompted a reevaluation of design techniques when shredded or chipped tires are used in embankment construction. ASTM standards were developed to alleviate this hazard.

Aggregate Substitute - Ground Rubber

Ground rubber has been used as a fine aggregate substitute in asphalt pavements. In this process, ground rubber particles are added into the hot mix as a fine aggregate in a gap-graded friction course type of mixture. This process, commonly referred to as the dry process, typically uses ground rubber particles ranging from approximately 6.4 mm (1/4 in) down to 0.85 mm (No. 20 sieve). Asphalt mixes in which ground rubber particles are added as a portion of the fine aggregate are referred to as rubberized asphalt.

Asphalt Modifier - Crumb Rubber

Crumb rubber can be used to modify the asphalt binder (e.g., increase its viscosity) in a process in which the rubber is blended with asphalt binder (usually in the range of 18 to 25 percent rubber). This process, commonly referred to as the wet process, blends and partially reacts crumb rubber with asphalt cement at high temperatures to produce a rubberized asphalt binder. Most of the wet processes require crumb rubber particles between 0.6 mm (No. 30 sieve) and 0.15 mm (No. 100 sieve) in size. The modified binder is commonly referred to as asphalt-rubber.

Asphalt-rubber binders are used primarily in hot mix asphalt paving, but are also used in seal coat applications as a stress absorbing membrane (SAM), a stress absorbing membrane interlayer (SAMI), or as a membrane sealant without any aggregate.

Retaining Walls - Whole and Slit Tires

Although not a direct highway application, whole tires have been used to construct retaining walls. They have also been used to stabilize roadside shoulder areas and provide channel slope protection. For each application, whole tires are stacked vertically on top of each other. 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 layer of tires is filled with compacted earth backfill.[(8)] This type of retaining wall construction was initially performed in California.

Slit scrap tires can be used as reinforcement in embankments and tied-back anchor retaining walls. By placing tire sidewalls in interconnected strips or mats and taking advantage of the extremely high tensile strength of the sidewalls, embankments can be stabilized in accordance with the reinforced earth principles. Sidewalls are held together by means of metal clips when reinforcing embankments, or by a cross-arm anchor bar assembly when used to anchor retaining walls.

Reference- http://www.tfhrc.gov/hnr20/recycle/waste/st1.htm Received March, 2007

Civil Engineering Applications

The use of shredded tires as fill in civil engineering applications is a major potential market for waste tires, but it is currently only in the demonstration phase in California. In 2001, the CIWMB sponsored a project in the San Francisco Bay area at a new interchange on Interstate 880. Six hundred thousand shredded tires were used as lightweight fill for a highway on-ramp built on unstable bay mud.

Shredded tires have an enormous potential to be used as lightweight fill in civil engineering applications, and they can replace other conventional lightweight fill such as expanded foam. Besides providing a major end use of tires, tires used as fill provide improved permeability and greater insulating properties than traditional fill materials.

Civil engineering fill has been limited to a few pilot projects in California (Humboldt County and Chico, in Butte County); however, the CIWMB is strongly supporting the development of this market. The State of Maine has been a major user of tires for civil engineering fill, making it the predominant use for its abatement piles.

This market can have a significant impact on discarded tire use. Individual projects can use several hundred thousand tires. Civil engineering applications require that tires are shredded, and minor adjustments to project designs may need to be made. The performance of the material can exceed current options available and can substantially reduce costs associated with lightweight fill.

Examples of civil engineering projects include the following:

- Overpass fill.
- Levee slurry wall (mix with concrete).
- Retaining wall fill.
- Roadway base fill.
- Bridge abutment fill.

In addition to fill applications developed by Maine, here are some other potential civil engineering applications:

- The CIWMB has guidelines regarding use of tire shreds in landfill applications. These uses include leachate drainage material, final cover foundation layer, operations cover, and gas collection layer. In Virginia, tire shreds have been used for septic tank bedding material. Specifications are available for septic tank leach fields in an average four-bedroom home using 1,350 tires per system.

- The usage of tires in Virginia presents a viable option for rural areas. Depending on the contamination limits and the ability to store a stockpile of shreds, a local government could make available the shreds as a subgrade fill for residential and commercial facilities.

The CIWMB is conducting a demonstration of tire shreds in leach fields at a highway rest stop along Interstate 5. The project was constructed in 1999-2000 and is currently being monitored. The project demonstrates efforts to replace playground equipment to achieve compliance with State and federal laws and to provide an opportunity to showcase new uses for recycled tires. (Source CIWMB)

Referencehttp://www.ciwmb.ca.gov/Publications/LocalAsst/31002010.pdf
Received March, 2007.

Considerable research on crumb-rubber-modified asphalt has been conducted since the 1991 passage of the Intermodal Surface Transportation Efficiency Act. This research has addressed both performance and environmental issues; additional research is examining the use of scrap tire rubber in other highway-related applications.

- A company in Carson City, Nevada is marketing a noise wall that contains recycled rubber tires and recycled plastics. This company is also researching the use of rubber tires in lightweight fill, subgrade insulation, and channel slope protection as well as an additive to Portland cement concrete pavement.

- The North Carolina Department of Transportation recently conducted a laboratory study on the use of ground scrap tires in Portland cement concrete. *(21)* After the scrap tires were processed to remove loose steel and fibers, they were finely ground. The ground rubber was then substituted for fine aggregate in the mix at increments of 10, 20, and 30 percent by volume of fine aggregate. Tests conducted to determine compressive and flexural strengths showed that these decreased with increasing amounts of rubber.

- A 1992 project in Richmond, Maine, assessed the effectiveness of using tire chips as an insulating layer in order to limit frost penetration beneath a gravel-surfaced road that experienced severe deterioration during spring thawing. *(22)* Thermocouples, resistivity gauges, groundwater monitoring wells, and a weather station were installed to monitor the project. After one year, results indicated that a 152-mm-thick tire chip layer can reduce frost penetration by up to 40 percent.

- A Mankato, Minn., company is marketing blocks made from recycled tires for a variety of uses, including landscaping and retaining walls.

- A company in Pittsburgh, Pa., has developed a process that can convert scrap tires into a form that can be used as poles or stakes. The process, which requires only that the tires be split and flattened, rolls the tires in a spiral fashion to form a nearly solid "log" of reinforced rubber material.

Reference- http://www.tfhrc.gov/pubrds/fall94/p94au32.htm Received March 2007.

Chip Seals

Chip seals, also known as seal coats, consist of a layer of asphalt, covered with a layer of rocks to provide either a new driving surface or a waterproof layer under the surface layer. Engineers choose chip seals with as much as 15 percent tire rubber in the asphalt to hold the rocks in place better and provide greater durability. TxDOT's FY '06 contracts call for using about 10,600 tons of tire rubber for chip seals – 19 percent less than in FY '05 due largely to rising petroleum prices.

Asphalt Pavement

Hot mix asphalt pavements are compacted mixtures of rock and asphalt. The asphalt ranges from five to eight percent of the mixture. Many TxDOT engineers choose asphalt mixtures with five to 15 percent rubber to increase pavement life. Through its FY '06 contracts, TxDOT will consume about 4,200 tons of rubber for hot mix asphalt pavement – about 32 percent more than in FY '05. TxDOT's use of rubber in asphalt paving will continue to grow for several reasons. TxDOT's 2004 standard specifications provide for expanded use of crumb-rubber modified asphalt over the 1993 specifications. In particular, crumb-rubber modified asphalt is an option in two relatively new hot-mix asphalt applications that districts are specifying increasingly – Item 342, Permeable Friction Course (PFC), and Item 346, Stone-Matrix Asphalt (SMA). TxDOT road designers choose PFC because it reduces traffic noise and improves skid resistance, visibility in wet weather, pavement durability and ride quality. They choose SMA because of its durability and improved ride quality. TxDOT engineers choose the rubber option for these two types of pavement because it adds even greater durability and ride quality – two of TxDOT's five goals.

Crack Sealer

To extend the life of existing pavements, TxDOT seals pavement cracks with asphalt-rubber products that contain 22 percent tire rubber. This application will account for an additional 500 tons of rubber used through FY '06 contracts. TxDOT's commitment and satisfaction with rubber in pavements is well known even outside the department. In the spring of 2006, the Rubber Pavements Association recognized the TxDOT Houston District for "Outstanding Contributions to the Expanded Use of Crumb Rubber in Asphalt in 2005." TxDOT is also pioneering and adopting many non-paving applications for tires and tire rubber such as tire bales and molded rubber products. CDOT also uses crack sealer with rubber content.

Embankment Construction or Repair with Tire Bales

TxDOT continues to develop innovative uses for tire bales. Comprised of about 100 passenger-car tires and weighing about one ton each, tire bales are about five feet square and 2 1/2 feet high. With a density between water and soil, designers consider them lightweight, permeable building blocks. As discussed in previous reports, in 2002, the TxDOT Fort Worth District experimented with repairing a failing embankment on I-30 by replacing poor quality soils with layers of tire bales. The success of that demonstration project led the TxDOT's Fort Worth District Materials Engineer to work with the Center for Transportation Research (CTR) at the University of Texas, Austin, to determine basic engineering properties of tire bales. In the summer of 2005, TxDOT's Fort Worth District used the results of CTR's work and input from other TxDOT engineers and consultants to develop an improved design for constructing or repairing embankments with tire bales.

The Fort Worth District used this new design to repair another problematic embankment adjacent to the previously repaired stretch on I-30 using 161 tire bales. Based in part on that work, TxDOT awarded a two-year research project to CTR in September 2006 to analyze further the engineering properties of tire bales, develop a computer model to examine various tire bale embankment designs, produce specifications and design guidelines and conduct an engineering workshop.

CDOT prepared a report entitled Tire Bales in Highway Applications: Feasibility and Properties Evaluation Report No. CDOT-DTD-R-2005-02 dated March 2005 which reviewed various applications of tire bales in highway construction with an emphasis on embankment applications. A special provision for tire bale embankments as part of the CDOT Section 203 “Embankments” should be developed as one implementation of this report.

Tire-Rubber Molded Products

The total quantity of rubber in the molded products TxDOT uses is small, especially when compared to the amount in roadway applications, but it continues to grow.

Vegetation-control mats. TxDOT continues to explore the use of mats comprised primarily of rubber from scrap tires to control vegetation along guardrails or around signposts to reduce herbicide use and string trimming. With safety always a top priority, TxDOT considered whether these mats could be a hazard. The Federal Highway Administration (FHWA) Office of Safety Design concluded that using these types of mats or poured-in-place rubber as mow strips under any type of post and beam traffic barrier (including a wire rope or cable design) would have no adverse affect on the crash performance of the barrier. The FHWA’s statement assumes that the barrier height remains within the manufacturer's specifications, the mats do not affect the performance of the posts, and that the mat itself does not create a hazard.

Delineator posts. Several years ago, TxDOT’s Traffic Operations Division, TxDOT’s Pharr District and CaminoVerde developed several recycled delineator post designs with 20 percent recycled tire rubber. This delineator post performs as well as, or better than, the designs it replaces. While the overall cost to install this product costs a little more than other designs, maintenance operations report that it lasts longer and that they can replace it more easily, saving money over the long term. Consequently, TxDOT maintenance sections are asking construction designers to specify this product on new construction projects instead of giving contractors the option to choose from among several approved designs.

Guardrail spacer blocks. TxDOT contractors can choose from several TxDOT-approved manufacturers’ composite spacer blocks with crumb rubber content. Many contractors chose composite blocks because they are lighter and easier to install than timber blocks.

Guardrail spacer blocks. TxDOT Department Material Specification 6310 (DMS-6310) presents the requirements for joint fillers used to fill concrete expansion joints. While this specification currently does not allow rubber products, TxDOT recognized that rubber expansion joint materials could meet the performance requirements of DMS-6310. Consequently, TxDOT is modifying this specification also to allow rubber products that meet other performance requirements. This action will allow rubber products to compete evenly with others not only for TxDOT projects, but also for projects engineered by local governments that use TxDOT's specifications.

Reference- ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/tirerpt.pdf Received March, 2007.

Desirable Properties

Tire chips (scrap tires cut into 1- to 12-inch pieces) have a number of qualities that makes them well-suited for use in road and bridge construction. Tire chips are:

- Lightweight
- low-pressure
- free-draining
- good thermal insulators
- durable
- low-price compared to some alternatives

Tire chips can help reduce fill weight and address slope stability, landslide, drainage, and embankment settlement problems. Tire chip unit weights (compacted in place) range from 40 pcf for a thin fill with no soil cover to 60 pcf for a thick fill covered with a thick soil cover. Gravel compares at 125 pcf. For retaining wall and bridge abutments, tire chips reduce wall pressure, which can save money. For example, using tire chips as backfill can lower pressure at the base of a 5-foot wall by 50%.

Tires chips are generally uniformly graded with specific gravities ranging from 1.02 to 1.27 depending on whether steel belted, glass belted, or a mixture were measured. Specific gravities for soils are typically 2.60 to 2.80, which is more than double that of tire chips. Water absorption capacities generally range from 2 to 4.3%. Unlike most soils, water content does not affect tire chip compaction. Compacted dry unit weights of tires range from 38 - 43 pcf, approximately 1/3 the unit weight of soils. However, the unit weight of tire chips does increase under the weight of overlying soils and tire chips.

Large volumes of tires can be used in civil engineering construction applications. As a guideline, 75 tires yield about 1 cubic yard of compacted tire chip fill, and 1,000 tires will fill a 14-cubic-yard dump truck.

Design Considerations - Paved Roads

Tire chips should be wrapped in an appropriate geotextile, with 18-inch overlaps at the seams, to prevent surrounding soil from being washed between the tire chips. The 3-inch nominal chips are easier to shape to the desired grade than 12-inch chips. To compensate for post construction compression, it is necessary to overbuild the tire chip layer so that the compressed elevation of the tire chips is at the desired level. Moist soils compact much more easily over tire chips. Final grading and paving should be delayed to allow for tire chip settlement.

Mixing soil with tire chips to minimize compression is not recommended. It is difficult to mix the soil and chips, which increases construction costs. Improper mixing may lead to long-term settlement problems. Also, soil decreases the benefits tire chips offer.

Design Considerations - Unpaved Roads

Soil cover on unpaved roads should be thick enough to prevent rutting and will depend on the thickness of the tire chip layer and on traffic loads. Use of geotextile may be unnecessary with 3-inch chips.

Design Considerations - Retaining Walls and Bridge Abutment Backfills

Because tire chips exert less than half the weight of gravel, retaining walls built with chips can be thinner and, therefore, cheaper. When using 3-inch chips, a reasonable coefficient of lateral earth pressure at rest is 0.40 for design. Geotextiles should be used to separate the tire chips from the surrounding soil using a "belt and suspenders" design at the contact between the geotextile and the back of the wall.

Design Considerations - To Limit Frost Penetration

Tire chips provide thermal insulation to reduce frost penetration depths. The chips have been shown to reduce penetration by up to 25%. The thermal conductivity of tire chips (0.1 to 0.2 Btu/hr-ft-E F) is eight times lower than that of typical soil.

Design Considerations - Drainage Layers

Tire chips have very high permeability and are an attractive substitute for granular soils in highway edge drains, French drains, and drainage layers at the bottom of subgrades. Tire chips need to be completely enclosed in geotextile to prevent fines from reducing permeability.

Exothermic Reactions in Tire Chip Fills

Of 70 installations of tire chip fill applications in the US, three have experienced exothermic, or heat-producing, reactions. These were all very large installations with a number of common features which should be avoided in the future including: free access to oxygen, thin soil cover, topsoil placed directly on tire chips, tire chips contaminated with liquid petroleum, abundant exposed steel, contact of tire chips with fertilizer, large areas of rubber materials uninterrupted by inert materials, and concentrations of crumb rubber.

TxDOT has adopted ASTM's "Standard Practice for Use of Scrap Tires in Civil Engineering Applications". The ASTM Subcommittee D-34.15, Construction and other Secondary Applications of Recovered Materials, has approved the Standard Practice as has ASTM Committee D-34 Waste Management. In general, recommended preliminary construction procedures are to: provide at least 4 feet of soil cover to reduce oxygen and water infiltration (soil should contain a minimum of 25% fines); prevent topsoil or fertilizer from coming in direct contact with tire shreds; use large tire shreds (8-inch nominal for fills of 10 feet or more); limit exposed steel belts; limit the amount of crumb rubber included with the shreds (no more than 1-2% passing #4 sieve); and place inert (non-combustible) blocks between rubber-containing areas such as soil or concrete.

Reference- ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/yrr_dec.pdf Received March, 2007.

Other States Projects

State/Location - Arizona

How material is used – Projects are constructed with either an asphalt rubber asphalt concrete(AR-AC) and/or asphalt rubber asphalt concrete friction course (AR-ACFC). An AR-AC is a gap graded hot mix constructed with about 7.5% asphalt rubber binder. The asphalt rubber (AR) binder contains about 20% ground tire rubber. The hot mixture of asphalt rubber is also referred to as crumb rubber mixture (CRM) or the MacDonald wet process.

Rubberized Asphalt Concrete is highly skid-resistant, quieter, and resists shoving and rutting if a gap-graded mix is used.

Specification - Typically the AR-AC is placed in one lift from 1.5 to 2 inches thick. Compaction and AR binder content are controlled with the appropriate nuclear testing equipment. The in-place density of the AR-AC is about 145 pounds per cubic foot.

Reference - http://www.azdot.gov/Highways/Materials/Pavement_Design/PDF/88-01rep.pdf. Retrieved on March 6, 2006.

Type of Project Case Study (Description, ex. Lessons Learned, Quantities, Goals etc.) – Arizona, a national pioneer in asphalt rubber projects, has recycled 13,000,000 tires and invested $200,000,000 in paving of Arizona Highways using Asphalt Rubber since 1988. From 1997 to 2001, ADOT recycled an average of 1.5 million tires in 400 miles of resurfacing projects each year. In 1998 alone, ADOT recycled some 2.5 million tires to finish 700 miles of resurfacing.

Scrap tires are ambiently reduced in size solely with the use of shredders, grinders, and cracker mills. All the steel and nylon fluff is removed with magnets and blowers at the appropriate stages of the production. As a result of this process, particles of rubber (Crumb Rubber) are produced. Crumb Rubber is little pieces of rubber in varied sizes from 3/8 inch to 100 mesh.

Rubberized asphalt concrete is environmentally friendly. A two-inch resurfacing project uses over 2,000 waste tires per lane mile. Rubberized asphalt concrete provides excellent long-lasting color contrast for striping and marking and provides a long-lasting, durable pavement that resists reflective cracking.

Other Notes/Photos – Arizona Department of Transportation Materials Group Pavement Design Section provided report listing asphalt rubber projects from 1988 to 2001.

Other States Projects

State/Location- California

How material is used- Caltrans has established a variety of uses for waste tire products. They include rubberized asphalt concrete as a pavement alternative and shredded waste tires, which are used as lightweight fill for embankments. When appropriate and cost-effective, rubberized asphalt concrete and aggregate made from tires are the Department's first choice.

Reference- http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved March 9, 2007.

http://www.ciwmb.ca.gov/StateAgency/STARR/Winners/2001/Innovation.htm Retrieved March 9, 2007.

Type of Project Case Study (Description)- One of Caltrans' most recent recycling efforts in highway development was the use of 660,000 shredded tires as lightweight fill at the 700-foot-long Dixon landing on-ramp on Interstate 880. The highway design substitutes traditional aggregate with scrapped tires, which not only diverted waste but also saved taxpayers an estimated $250,000 in material costs. Such developments represent some of the most innovative State projects designed to recycle waste materials.

Other Notes/Photos

Caltrans uses shredded tires in highway embankments

Figure F-1 Shredded Tire Use In Highway Embankments

Reference- http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved on March 9, 2006.

Other States Projects

State/Location- California

How material is used- Caltrans uses recycled offset blocks in metal beam guardrail and recycled rubber mats for weed control underneath guardrail.

Rubber mats are an adopted technology from the recreation industry where they are used primarily for playground safety surfacing. As with most structural treatments, the tiles prevent sunlight from reaching the ground surface, retarding seed germination and plant growth. The major component is recycled tire rubber bonded together with a resin into a mat.

Cut outs are molded or cut into the tile for post placement. The inherent weight of the tiles keeps them in place, and no staking is usually required. Mats are joined together with an overlap that is sealed with an asphalt crack filler or resin adhesive.

This product is used in urban, suburban and transitional areas under new and existing guardrail, around sign posts and under fences. Rubber mats are not recommended for large, non-linear areas or slopes.

Benefits

- The treatment is installed in sections and can be placed or repaired with no specialized equipment.
- Due to the weight of the mats, no staking is necessary.
- Since the product is flexible and not adhered or staked to the ground surface repairs after damage are more easily accomplished than with other surface treatments.
- The manufacturing process allows for specialized design for site-specific requirements.
- Integral color can be added in the manufacturing process.

Limitations

- Multiple joints in continuous runs may become unsightly over time.
- Installation can be slow and labor expenses may be cost-prohibitive for small installations.
- Exposure to high winds, or disturbance by mowing equipment may displace or lift mats, allowing weed growth.
- Joints have the potential for separation and vegetation growth if not sealed properly.
- Weeds may germinate on the surface of mats if not kept clean of debris.
- Long term degradation of the mats due to ultraviolet (UV) light and other factors is unknown at this time.

Reference- http://www.dot.ca.gov/hq/LandArch/roadside/specs/weed_control_mat_rubber.doc Retrieved March 9, 2007.

Reference- http://www.dot.ca.gov/hq/LandArch/roadside/detail-rwm.htm Retrieved March 9, 2007.

Other Notes/Photos

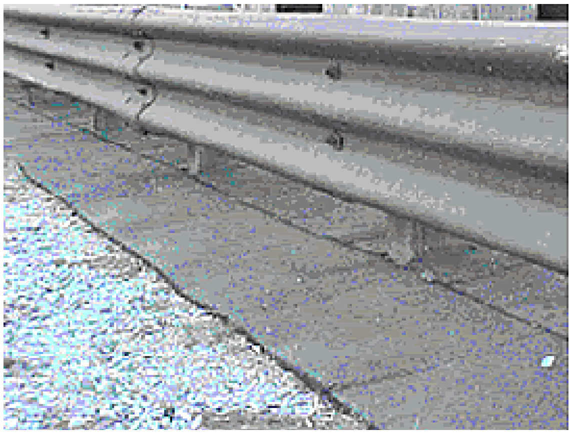
 

Figure F-2 and Figure F-3   Rubber Mats for Weed Control

Reference- http://www.dot.ca.gov/hq/LandArch/roadside/detail-rwm.htm Retrieved March 9, 2007.

<u>Other States Projects</u>

State/Location- Washington

How is material used- Seattle, Washington used rubberized sidewalks in its South Park neighborhood.

Benefits

- Easy on the joints of pedestrians and has more traction than concrete.
- Does not crack due to roots and freezing.
- Easy and cheap to maintain compared to concrete.

Limitations

- Original installation costs slightly more than concrete.

Reference- http://www.washingtonpost.com/wp-dyn/content/article/2006/07/25/AR2006072501073.html, July 26, 2006

Other Notes/Photos

Figure F-4 Rubber Sidewalk Installation

Reference- http://www.rubbersidewalks.com/pdf/seattlepi.pdf, October 5, 2005

APPENDIX G - GEOTEXTILES

Material: Geotextiles - Erosion Control Compost Filter Berm/Compost Logs

Other States Projects

State/Location- Minnesota

How is material used- A compost filter berm is a dike of compost or a compost product that is placed perpendicular to sheet flow runoff to control erosion in disturbed areas and retain sediment. It can be used in place of a traditional sediment and erosion control tool such as a silt fence or straw bale barrier. The compost filter berm, which is trapezoidal in cross-section, provides a three-dimensional filter that retains sediment and other pollutants (e.g., suspended solids, metals, oil and grease) while allowing the cleaned water to flow through the berm. Compost filter berms are generally placed along the perimeter of a site, or at intervals along a slope, to capture and treat storm water that runs off as sheet flow. The berms can be vegetated or unvegetated. Vegetated filter berms are normally left in place and provide long-term filtration of storm water as a post-construction BMP. Unvegetated berms are often broken down once construction is complete and the compost is spread around the site as a soil amendment or mulch. The Minnesota DOT erosion control compost specifications for “compost logs” recommend 30 to 40 percent weed-free compost and 60 to 70 percent partially decomposed wood chips, and that 100 percent of the compost passes the 2-inch (51 mm) sieve and 30 percent passes the 3/8-inch (10 mm) sieve.

Reference- http://www.jgpress.com/archives/_free/000765.html

APPENDIX H - PLANTS/ORGANICS

Material: Plants/Organics - Erosion Control Compost/Cover

Controlling erosion means stopping soil movement at its source. Rapid revegetation of disturbed ground has long been recognized as one of the best and most economical ways to minimize the loss of soil and the resulting pollution of water resources. This measure is especially important in highway construction, which historically has been viewed as a major contributor to nonpoint source pollution, or water runoff contaminated by multiple diffuse sources rather than a single pipe or industrial plant.

Planting quick-growing grasses from seed is the most common way to revegetate slopes in highway construction. This method frequently is accompanied by manual placement of harvested straw or erosion control blankets.

Texas DOT

Composted manure makes up about half of the compost used in Texas road projects statewide, followed by composted yard trimmings and biosolids (organic sewage matter treated and processed for fertilizer). Projects in San Antonio use yard trimmings and composted biosolids produced by the city, while only yard trimmings are used in Houston. TxDOT's standards allow the use of Class A biosolids treated sewage but not Class B biosolids. Class A biosolids contain no detectable levels of pathogens whereas Class B biosolids still contain detectible levels of pathogens.

TxDOT uses three compost applications. One is general-use compost, which is 100 percent compost. This is the compost specified by landscape architects for purposes such as amending soil for a tree-planting project. General-use compost is also the kind of compost that TxDOT's maintenance personnel might use to top dress a roadside park.

The second is compost-manufactured topsoil, used in fairly flat locations with poor soil quality and shallow slopes. "We can mix in about an inch of compost over the top and drag a till through it to kind of incorporate it lightly," says Cogburn. "And the third situation is where we have a steep slope, and we would traditionally have used a soil-retention blanket. In those areas, we're advocating what we call erosion control compost, which has a 50-50 blend with wood chips."

Use of Compost and Shredded Wood on Rights-of-Way

Highway construction has historically been viewed as a major contributor of nonpoint source pollution. Nonpoint source pollution or pollution such as surface runoff that cannot be linked to a particular source, is cited as being the most prevalent cause of contamination in receiving waters in the U.S. Damage control for erosion at construction sites can include erosion control nets, open-weave geotextiles, geosynthetic mattings, erosion control blankets, loose mulches, hydromulches and chemical soil binders. Most are designed to absorb the kinetic energy of rainfall by minimizing its contact with the soil and reducing water velocity. The performance of common sediment control methods such as fences, straw bales and sediment ponds depends on the quantity of site erosion and maintenance. State recycling legislation and the possible ban of vegetative materials from Texas landfills, combined with a nationwide expansion of waste-reduction mandates and controls on debris burning, prompted TxDOT to investigate the recycling of roadside refuse from right-of-way clearing operations.

Additionally, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 encourages the environmentally safe use of compost along the rights-of-way of federally funded highways.

Objectives - The TTI conducted project 0-1352, "The Use of Compost and Shredded Wood on Rights-of-Way," for TxDOT, TNRCC, and the Federal Highway Administration (FHWA). The purpose of the study was to determine the performance of compost and shredded wood as erosion-control materials for use on highway rights-of-way based on literature reviews and field tests.

Findings - The application of mulch—either compost or shredded wood—appears to be an effective erosion-control method, and the mulch does not need to be removed after construction. Left in place, the mulch can provide a soil amendment to encourage the establishment of vegetation. Compost may also chemically bind some toxic substances, which suggests that it may have some application in bio-remediation. The following are some potential advantages of using compost or shredded wood for erosion control:

- Compost may, if incorporated, beneficially alter the texture and structure of the soil in a manner that resists erosion.
- Compost and/or shredded wood can be left in place after construction.
- Using wood chips and compost uses debris that might otherwise be placed in landfills or burned.
- Use of wood chips and compost on rights-of-way provides additional environmental benefits as erosion control material including:
    - It does not have to be removed after construction.
    - It promotes the establishment of vegetation.
    - It chemically immobilizes toxic substances and can help them decompose.

Several research groups in the United States and worldwide have demonstrated the potential of compost as an erosion-control material. Compost in a sufficiently dense mat can provide a physical barrier between rainfall and surface soil, dissipating the impact energy of rainfall and minimizing erosive forces. TTI tested three materials in six test plots. The test materials included:

- compost, consisting of mixed yard debris and municipal sewage sludge;
- shredded wood with a polyacrylamide tackifier (TERRA TACKTM SC);
- shredded wood with a hydrophilic colloid tackifier containing germination stimulant (RMB Plus).

There were three sand plots and three clay plots on a 1:3 slope in a simulated highway environment. Rain simulations for one-year, two-year, and five-year storm events were tested for sediment loss on the plots. The percentage of vegetative cover was captured using the Vegetation Coverage Analysis Program. The compost produced 92 percent vegetation cover on sand and 99 percent vegetation cover on clay. The test plots lost 3.88 kg/10 m2 of sediment on the sand plots and 0.34 kg/10 m2 on the clay plots. Wood chips with TERRA TACKTM SC produced only 48 percent cover on sand while producing 95 percent vegetation cover on clay. These plots lost sediment at a rate of 11.27 kg/10 m2 on sand and 0.15 kg/10 m2 on clay. Wood chips with RMB Plus produced only a 57 percent vegetation cover on clay and a 50 percent vegetation cover on sand. The plots lost sediment at a rate of 10.97 kg/10 m2 on sand and 0.30 kg/10 m2 on clay. The results obtained for compost met the minimum performance standards required by TxDOT for soil retention blankets. Test results exceeded expectations and are encouraging.

The potential cost savings of using compost or wood chips with tackifier rather than rolled materials are significant. However, cost-effective application methods and quality-control issues must be resolved before recommendations can be made for general application such as reducing sediment loss. Debris from right-of-way clearing operations may provide a cost-effective source of wood chips. The contents of this summary are reported in detail in TTI Research Report 1352-2F, The Use of Compost and Shredded Wood on Rights-of-Way For Erosion Control, Beverly B. Storey, Jett A. McFalls and Sally H. Godfrey, preliminary report dated November 1995. This summary does not necessarily reflect the official views of the FHWA, TNRCC or TxDOT. Wood chips with TERRA TACKTM SC would qualify as a material for use on clay with slopes of 1:3 or less. The wood chips with RMB Plus did not meet any TxDOT standard. To obtain a copy of this report, please contact the TxDOT Construction Division Research Librarian at (512) 465-7644.

ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/yrr_march.pdf Received March, 2007.

Reference- http://www.tfhrc.gov/pubrds/04mar/03.htm Received March, 2007.

<u>Other States Projects</u>

State/Location- California

How material is used- Clearing away vegetation in preparation for a project, as well as routine landscape maintenance activities, generates green waste that is shredded for mulch in highway landscaping.

Caltrans routinely uses bark mulch and green plant material in highway planting and erosion control projects. Additionally, several Districts have tried recycling glass, in the form of pellets, as a mulch to control weeds. Caltrans is also researching the best ways to use compost to control erosion and improve storm water quality.

Reference-http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved on March 9, 2006.

<u>Other States Projects</u>

State/Location- TxDOT – Compost and Shredded Brush

According to the definition by Texas Senate Bill 1340, compost is ‘the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial top soil, growing medium amendment, or other similar uses.” Application of compost increases soil air space and drainage and moisture-holding capacity, releases nutrients over a long period of time, helps mitigate salt concentrations, buffers against heavy metals, encourages earthworms and other beneficial insects and microorganisms, and helps buffer against extremes in soil pH. The Texas Department of Transportation (TxDOT) owns more than 800,000 acres of land adjacent to the state's transportation corridors. The establishment of rights-of-way vegetation is frequently difficult because of overly compacted soils and soils with little or no nutritive value. A test project was located in Austin where several efforts had failed for establishment of vegetation. Compost, in the form of Dillo Dirt™, was applied and vegetation growth was seen within a few weeks. The grass was observed to grow quite rapidly in the area where the Dillo Dirt™ was placed. This project demonstrated that compost appears to offer the road construction industry a number of benefits such as rapid establishment of vegetative coverage, reduction of soil erosion, and of course, beneficial use of a recycled material.

Demonstration Project 1, Compost: The project site consisted of 9 acres of highway right-of-way located at the intersection of Ben White Blvd. and Lamar Blvd., in Southwest Austin. Commercial development (malls, restaurants, movie theaters, strip centers etc.),multifamily units, and undeveloped land surrounded the site. The average daily traffic at this section consisted of 60,000 cars. Compost, marketed as Dillo Dirt™, was applied on the project area.

Demonstration Project 2, Shredded Brush: TxDOT conducted a test study on shredded brush (wood chips) to evaluate its effectiveness as a erosion- control measure in San Augustine County, Lufkin District. The project site is located on SH103, 6.5 miles east of the intersection between SH103 and SH147 (see Figure 8.2). The total project area encompassed 9,104m^2. The average daily traffic at this section consisted of 1,900 vehicles per day. Shredded brush used as a mulch, was applied in October, 1997. The subgrade soil in the right-of-way was clayey. The local average annual rainfall is 40 - 49 inches. The wood chips were derived from pine and hardwood trees. The types of vegetation used in this project were Ryegrass and Bermuda.”

http://www.rmrc.unh.edu/Resources/VDS/txdot-compost/compost.asp, Accessed March 6, 2007

APPENDIX I - GLASS/CERAMICS

Material: Glass/Ceramics - Glass Cullet

Glass aggregate, also known as glass cullet, is 100 percent crushed material that is generally angular, flat and elongated in shape. This fragmented material comes in color or colorless forms. The size varies depending on the chemical composition and method of production.

Glass aggregate has been investigated by many state DOTs including New York, Washington, Pennsylvania, and Texas.

How material is used- New York DOT uses a limited amount of this material in embankments and bituminous concrete base and binder courses. This is a non-surface mix material because of concerns that it could result in injury claim liability. New York has experienced problems with stripping asphalt binder not adhering to aggregate that may be controlled by adding an anti-stripping agent, which in turn increases processing costs.

Since the 1960s, Washington DOT has used a portion of glass aggregate in bituminous concrete pavements. This aggregate material is also used in backfill for foundations, pipe bedding, and other applications not subject to heavy repeated loading. Washington State has not utilized this material on any recent projects.

Pennsylvania DOT also allows a portion of this material in nonstructural fills and drainage applications, while experimentation with this material in bituminous concrete has yielded results similar to New York's.

Minnesota's use of reclaimed glass in aggregate pavement began in 1991 when Mn/DOT, in cooperation with Sibley County, began a research effort to study the use of recycled glass in combination with virgin aggregate material to be used as a road base.
(http://www.mnltap.umn.edu/publications/exchange/2002-3/reclaimedglass.html)

The use of recycled materials in pavements has received a boost with the adoption of a new national specification for recycling glass in soil aggregate base courses. The specification, entitled "Glass Cullet Use for Soil Aggregate Base Course," was adopted by the American Association of State Highway and Transportation Officials (AASHTO) in December 2000 and will be published in the next edition of AASHTO's Standard Specifications for Transportation Materials of Sampling and Testing.

The specification notes that, "When properly processed and mixed with natural or crushed aggregate, hauled to, and properly spread and compacted on a prepared grade to appropriate density standards, glass cullet can be expected to provide adequate stability and load support for use as road or highway bases."
The new standard was developed as part of a research project conducted by the Recycled Materials Resource Center (RMRC) at the University of New Hampshire. This project is designed to investigate the properties of selected recycled materials and to develop guidance specifications for highway construction applications in an AASHTO format.

Overseeing the effort is a technical advisory group composed of representatives from 15 State departments of transportation (DOT). (http://www.tfhrc.gov/focus/aug01/recycledglass.htm)

Reference http://www.fhwa.dot.gov/pavement/recycling/recglass.cfm

Type of Project Case Study (Description)-No specific case studies cited.
Glass aggregate presents problems in both bituminous concrete and PCC pavements. In concrete pavements, this material is problematic because is increases the deleterious alkali-silica reaction with the cement paste. In bituminous pavements, this material bonds poorly to the asphalt, which results in stripping and raveling problems. In general, waste glass contains impurities such as ceramics, ferrous metal, paper, plastic, and mixed colored cullet; processing and specifications may limit associated problems. Use of glass cullet in flowable fill mix design as a substitution for the fine grades of aggregate has been noted in many areas.

Other States Projects

State/Location- TxDOT

Application, Percentage of Glass Cullet Permitted

- Embankments - Shall not exceed 20% by weight of the total mix.
- Flexible base (Type D) - Shall not exceed 20% by weight of the total mix.
- Asphalt anti-stripping agents - When cullet is used as an aggregate in asphalt-stabilized bases, lime and some liquid anti-stripping agents may not perform adequately.
- Asphalt-stabilized base - Shall not exceed 5% of the total weight of the aggregate.
- Excavation and backfill for structures:

    a.) Utility bedding material may comprise up to 100%.

    b.) Backfill that will support any portion of roadbed or embankment shall include less than 20%.

    c.) Backfill that does not support any portion of the roadbed or embankment may include up to 100%.

- Retaining wall - Structural backfill limited to maximum of 20%.
- Non-structural backfill up to 100%.
- Pipe underdrains - Up to 100%.
- Other open-graded base courses The use of cullet in this application shall be governed by, “Asphalt-stabilized base.” Not to exceed 5%.

http://www.dot.state.tx.us/services/general_services/recycling/recycleable.htm Retrieved March, 2007

TxDOT - Glass Cullet Research

As a part of a research study being conducted by TxDOT under the FHWA Priority Program (PTP), three test projects were constructed in Texas during 1996 and 1997. The performance of these recycled materials is being monitored by Texas Tech University. A brief description of these test projects is included in the case studies.

Demonstration Project # 1 The first test project involved the rehabilitation of Colonial Parkway and North Teal Drive in the City of Devine (Figure 5.1). Construction was done in July 1996 and involved reworking existing surface and base layers as the subbase for the new pavement. An 80/20 blend of crushed limestone and glass cullet was used to construct the flexible base and hot mix asphalt with limestone rock asphalt (LRA) aggregate was used in the surface layer. Vista Fibers of San Antonio supplied 440 tons of waste glass for the project and Vulcan Materials of San Antonio crushed it and blended with crushed limestone.

Demonstration Project # 2 The test project is on Antilley road, a city street in front of Wiley High school (Figure 5.2) Glass cullet was mixed with crushed limestone to form the flexible base. Construction involved spreading 12 inches of crushed limestone followed by glass cullet (Figure 5.3). A pavement material recycler mixed the two materials on the pavement and then the blend was compacted (Figures 5.4 & 5.5). A 1.5 inches thick hot mix asphalt concrete surface layer was placed on top of the flexible base layer containing glass. The eastern section of the road used a 10 percent glass cullet while the western section used 15 percent. Each section is 750 feet long and 12 feet wide and both sections are along the eastbound outside lane. This construction project used 240 tons of glass collected by the City of Abilene over a one-year period. Pine Street Salvage, a local salvage company, provided 75 percent of the glass while Dyess Air Force Base provided the remaining 25 percent. TxDOT collected and transported the glass from Pine Street Salvage to Dyess AFB where the glass was crushed into cullet.

Demonstration Project # 3 The project site is located in Beaumont District at the intersection of SH 62 and FM 105 in Orange County, near the Orange County Airport. In this project, glass cullet was used as the bedding material around two culvert pipes. Glass was crushed to quarter-inch pieces or smaller to be used as bedding material.

http://www.rmrc.unh.edu/Resources/VDS/txdot-GC/cullet.asp Accessed March 6, 2007

Other States Projects

State/Location- California

How material is used- Much of the construction and demolition (C & D) debris from highway projects is salvaged for reuse or made available for recycling, keeping it out of local landfills. Debris such as concrete, asphalt, and reclaimed glass can be crushed and re-used as base material. Using recycled rather than new material also reduces the strain on California’s dwindling aggregate supplies.

Reference - http://www.dot.ca.gov/ctnews/mar06/recycle.shtml Retrieved March 9, 2007.

Other States Projects

State/Location- Massachusetts

How is material used- Blend with borrow material for sub-base, etc.

Specification-This material shall consist of recycled glass food or beverage containers free of debris and manufactured from an approved supplier of crushed cullet.

- May be homogeneously blended with Ordinary Borrow material up to an addition rate of 10% by mass in unexposed areas.
- May be homogenously blended with Special Borrow material up to an addition rate of 10% by mass in unexposed areas.
- May be homogeneously blended with Gravel Borrow material up to an addition rate of 10% by mass in unexposed areas.
- May be homogeneously blended with Processed Gravel material for Subbase up to an addition rate of 10% by mass in unexposed areas.
- May be homogeneously blended with Sand Borrow material up to an addition rate of 10% by mass in unexposed areas.
- May be homogeneously blended with Sand Borrow material for Subdrains up to an addition rate of 10% by mass in unexposed areas.
- May be homogeneously blended with Dense Graded Crushed Stone material for Subbase up to an addition rate of 10% by mass in unexposed areas.
- May be used as Mineral Aggregate in Class I Bituminous Concrete at a maximum addition rate of 10% by mass (in place of RAP).

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

Material: Glass/Ceramics - Glass Beads

Other States Projects

State/Location- Illinois

How material is used- Virgin glass, in general, is a molten mixture of sand (silicon dioxide—a.k.a. silica), soda ash (sodium carbonate), and/or limestone supercooled to form a rigid solid (1). Glass beads, in particular, are a product of recycled soda-lime glass. This material's primary source is from manufacturing and post-consumer waste. At recycling centers, recovered glass is hand sorted by color (clear, amber, and green), and then crushed to customized sizes. The Illinois Department of Transportation uses two types of glass beads—Type A (uncoated) and Type B (silicone coated, moisture resistant)—depending on the method of application (drop-on or intermix) and the type of pavement-marking paint used (solvent-based, waterborne, or thermoplastic). Glass beads are utilized in many traffic control devices including reflective sheeting decals, pavement striping, and pavement marking tape. Essentially all traffic lines on highways contain glass beads, which improve the overall safety of night-time highway travel. Outside the Department, glass beads are utilized in license plates, movie screens, and reflective fabrics.

Reference - http://www.fhwa.dot.gov/pavement/recycling/recbead.cfm, Retrieved March, 2007.

State/Location- Wisconsin

How is material used-

- Utility trench backfill.
- Drainage trench backfill.
- Glass beads for pavement marking material.

Potential Accepted Uses:

- Base course supplement.
- Embankment material.
- Substitute for free-draining aggregates, e.g. drainage.
- Fill in trench drains.
    - Cold patch aggregate.

Restrictions:

- The recycled glass product must be recyclable.
- Do not use as aggregate in concrete masonry due to potential reaction problem.
- Do not use aggregate for asphaltic pavements due to potential stripping problem.
- Glass must not be left in an exposed condition due to potential human safety factor.
- In base courses, a maximum of ten percent of the total aggregate may be glass.

Type of Project Case Study (Description)-Brown County utilized post-consumer glass in two backfill applications on Hwy. J (Riverside Drive) in the Village of Howard. In all, 34 tons of three-color glass mix were used. In these projects, a two-foot wide storm sewer trench was excavated and a storm sewer pipe was then connected to the main sewer line. The first project, which occurred in August, 1994, used a concrete storm sewer pipe. Broken glass was backfilled directly on the pipe in a 2 ½ foot layer. The second project in August, 1994, used PVC storm sewer pipe. Due to the potential abrasive damage of the broken glass on the PVC pipe, the pipe was first covered by 3/4 inch crushed stone to encapsulate the pipe surface before 2 feet of broken glass were backfilled into the trench. The glass was covered with more crushed stone and an asphalt mat. The size of the glass used was 3/8 inch or less and compaction of the glass was not a problem. As of November 1996, no problems had been reported including any unusual settlement or surface cracks. Brown County Solid Waste Department initiated the project by contacting the Highway Department about projects where three-color mix glass could be utilized. Brown County has continued to use post-consumer glass in backfill applications. In June of 1997, 1412 tons of three color mix glass was utilized as backfill material for a landfill gas system at the Brown County West Landfill.

Reference - http://www.p2pays.org/ref/21/20303.pdf, 1997.

APPENDIX J - PLASTIC

Material: Plastic

Recycled Plastic - TXDOT

Recycling plastics is important because plastics make up 11 percent of our trash by volume and do not decompose in landfills. A 1997 American Plastics Council survey estimates that approximately half of U.S. communities collect plastics for recycling. In 1997, more than 600 million pounds each of PET and HDPE were recycled. Recycled plastics can be blended with virgin plastic (plastic that has not been processed before) to reduce cost without sacrificing properties. Recycled plastic can be used in many transportation-related applications, including

- traffic cones
- barricades
- channelizers
- delineators
- flexible delineators
- parking stops
- safety fencing;
- guardrail blockout posts;
- manhole adjusting rings;
- plastic lumber
- sound barriers.

Barricades, Traffic Control Devices (TCDs), Parking Stops, Safety Fencing and Traffic Cones

TCDs are frequently made using recycled materials, including plastics. The use of recycled plastics in these applications offers many benefits and, in fact, is required in certain circumstances. The U.S. Environmental Protection Agency (EPA), through its Comprehensive Procurement Guidelines (CPG), designates items that must contain recycled content when purchased by federal, state and local agencies or government contractors using appropriated federal funds. If TxDOT or contractors on TxDOT’s behalf spend more than $10,000 a year on a CPG-designated product, they are required to purchase the product with the highest recycled-content level practicable. TxDOT (or its contractors) may purchase designated items that do not contain recycled materials if:

- the price of a designated item made with recovered materials is unreasonably high,

- there are inadequate sources of supply,
- unusual and unreasonable delays would result from obtaining the item, or
- the item does not meet TxDOT's performance specifications.

Several TCDs are included on the CPG list of designated products with required levels of recycled content:

- traffic barricades, type I and II;
- channelizers, delineators and flexible delineators;
- parking stops;
- safety fencing; and
- traffic cones.

Guardrail Blockout Posts

The use of guardrail blockouts is expected to increase significantly because federal safety guideline NCHRP-350 requires that blockouts be used with every guardrail post. The Federal Highway Administration (FHWA) has approved two blockouts made of recycled plastic materials, which meet the NCHRP 350 requirements. The blockouts approved by FHWA are made by Mondo Polymer Technologies and Bryson Products. The Mondo polymer offset blocks for use with steel w-beam and the standard G4 (2W) wood guardrail post systems are made of 70 percent low-density polyethylene (LDPE) and 30 percent HDPE. The materials used to make this block include bubble wrap, shrinkwrap and stretch films. These blocks offer increased depth over the steel blockout, which FHWA says "should enhance small car performance by minimizing wheel-to-post contact." Other FHWA comments include, "Vehicular redirection was smooth, and there was less damage to the truck than has been seen in comparable tests with equivalent barriers. Occupant impact velocities and subsequent ridedown decelerations were significantly below the preferred limits." According to tests conducted by the Ohio Department of Transportation, the plastic guardrail block-out was "very capable of withstanding the extreme and cyclic temperatures which may be found in different climatic zones without material breakdown or any detrimental effect." The plastic experienced "minimal expansion and contraction of the recycled polymer material due to temperature change," which was "not sufficient to cause any problems in the guardrail system." In an installation test conducted by the West Virginia Division of Highways, Materials Control, Soil & Testing Division, they found that the Mondo recycled blocks were slightly heavier than wood blocks and slippery when wet. On the other hand, the bolt hole on the plastic block was drilled clean through and did not require the redrilling that wooden blocks frequently do. On the whole, installation crews were "quite willing to use this material exclusively," noting that "installing the recycled plastic blocks is somewhat easier than regular wood blocks." FHWA has also approved a recycled plastic blockout made by Bryson Products, Inc. The Bryson blockout is made from a blend of HDPE and polypropylene (PP). These blockouts are lightweight with void spaces that make them easy to handle. They are resistant to the weathering effects of sun and wind. They are environmentally friendly, not only because they are recycled but also because they do not pose the disposal challenges associated with treated wood.

Manhole Adjusting Rings

TxDOT's Product Evaluation Committee approved manhole adjustment rings made of HDPE by Ladtech, Inc. These manhole adjustment rings are lightweight (approximately 6 pounds each), watertight, noncorrosive, easy to handle, durable, interlocking and reusable. According to the manufacturer, the rings can withstand loading in excess of HS 25. They are made from 100 percent recycled HDPE plastic and come with a two-year material warranty.

Plastic Lumber

Plastic lumber is just what it sounds like: lumber made out of plastic. Recycled plastics can also be combined with fiberglass or wood fibers to enhance strength, and with plastic bags which are difficult to recycle in regular recycling facilities. Plastic lumber offers many benefits:

- It requires virtually no maintenance.
- It will not splinter, split or crack.
- It does not rot or decay.
- It does not have problems from termites and other insects.
- It resists damage from the sun's ultraviolet rays.
- It is not damaged by moisture.
- It is available in standard dimensional lumber sizes.
- It does not need to be sealed or painted, although it can be. (Some plastic lumbers are available in colors.)
- It can be cut with standard woodworking tools.
- It helps the environment by using recycled plastic.
- It does not leach wood-preserving chemicals into the ground.

Plastic lumber can be used in barricades, picnic benches, hand railings, sign and fence posts, and numerous other applications. It cannot, however, be used as a structural element in construction.

Sound Barriers Sources Sound barriers are built along roadsides to reduce the amount of traffic noise that reaches neighborhoods, and they can be built using recycled materials. Several such walls have been constructed in the U.S., including one built for a research project at Texas A&M University.

Reference- Horne, Dwight A. FHWA, HNG-14, March 11, 1997.
Jarvis, John. West Virginia Division of Highways, Materials Inspection Report #1296553, September 10, 1997.
Worster, Jenni. Ohio Department of Natural Resources correspondence, March 6, 1998.
www.ameriplas.org/benefits/about_plastics/primer.html
www.ameriplas.org/top_level/faqs.html#1wr
Yarbrough, Tom. TxDOT New Product Evaluation Committee–LAD Tech, January 22, 1999.

ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/yrr_oct.pdf Retrieved March, 2007.

Other States Projects

State/Location- Massachusetts

How material is used- Used for plastic offset blocks.

Specification-Shall be made with a minimum of 80% recycled polyethelyne plastic. Ultraviolet (UV) protection shall consist of at least 2.5% carbon black evenly dispersed throughout the block in accordance with ASTM D-1603 or an equivalent form of UV protection. Wood fillers will not be allowed. Each block shall be stamped at the factory with the Manufacturer's Identification and lot number and conform to the dimensions shown on the plans.

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

APPENDIX K - OIL

Material: Oil - Used Oil/Waste Oil

Other States Projects

State/Location – Alaska Ted Stevens Anchorage International Airport

How is material used – In 2006, the cost to recycle approximately 4,000 gallons of used oil cost the airport $135.00, which was greatly reduced than in years past.

Specification – None.

Reference - http://www.dot.state.ak.us/anc/business/environmental/2006envSummary.pdf Retrieved on March 6, 2006.

Type of Project Case Study (Description) – Environmental Section Summary Report.

APPENDIX L - BLAST FURNACE SLAG

Material: Blast Furnace Slag

Other States Projects

State/Location- Massachusetts

How is material used- Used to mitigate Alkali-Silica Reactivity (ASR) in Portland Cement Concrete.

Specification- Shall constitute 25 – 50% of the cementitious material by weight of cement plus pozzolan.

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

International Projects

Location-Sweden

How material is used – Used as "aggregate in unbound layers (crushed, air-cooled)"; Annual production is 1.0 million metric tons/0.7 million metric tons recycled.

Reference- Recycled Materials in European Highway Environments: Uses, Technologies, and Policies, USDOT/FHWA, International Technology Exchange Program, October 2000. pages 6-7.

Type of Project Case Study (Description)-

Case studies may be available at the Swedish National Road and Transport Research Institute website: http://www.vti.se/default____2782.aspx or the Swedish Geotechnical Institute website http://www.swedgeo.se/index-e.html, which is referenced in the aforementioned document.

International Projects

Location-France

How material is used – Aggregate/Granulated as a hydraulic binder.
Annual production of 5 million metric tons/3 million metric tons granulated/20 % used as aggregate/80% as hydraulic binder

Reference- Recycled Materials in European Highway Environments: Uses, Technologies, and Policies, USDOT/FHWA, International Technology Exchange Program, October 2000. page 65.

Material: Coal Fly Ash

Other States Projects

State/Location- Massachusetts

How is material used- Used to mitigate Alkali-Silica Reactivity (ASR) in Portland Cement Concrete.

Specification-Shall constitute 15 – 30% of the cementitious material (15% by weight of the design cement content, any additional fly ash will be considered as fine aggregate). Ingredient in very flowable Controlled Density Fill.

Reference-
http://www.mhd.state.ma.us/default.asp?pgid=environ/ContentSpec&sid=about#para8
Retrieved March 9, 2007.

International Projects

Location-Denmark

How material is used- Road Embankment; 1.060 million metric tons produced annually/0.556 million metric tons of unbound material is recycled/0.504 million metric tons of material goes to paving industry (Asphalt & Portland Cement)

Reference- Recycled Materials in European Highway Environments: Uses, Technologies, and Policies, USDOT/FHWA, International Technology Exchange Program, October 2000. pages 9, 52.

Type of Project Case Study (Description)-

- 212,000 metric tons of coal fly ash/density 1.1 – 1.2 metric tons/m^3 used for a road embankment with an asphalt bicycle and ped path on site.
- Ash 25-45% moisture
- Clay soil layer used to prevent water infiltration
- Construction in 1984 – no cracking to-date.

Material: WTE Bottom Ash

Location-Sweden

How is material used- Used as "subbase and base in roads within facility boundary; some in demonstrations". 0.34 million metric tons produced annually/all 0.34 million metric tons recycled.

Reference- Recycled Materials in European Highway Environments: Uses, Technologies, and Policies, USDOT/FHWA, International Technology Exchange Program, October 2000. pages 6-7.

Type of Project Case Study (Description)- Case studies may be available at the Swedish National Road and Transport Research Institute website: http://www.vti.se/default____2782.aspx or the Swedish Geotechnical Institute website http://www.swedgeo.se/index-e.html, which is referenced in the aforementioned document. Retrieved March, 2007.

Location-Netherlands

How material is used- Road Embankments

Reference- Recycled Materials in European Highway Environments: Uses, Technologies, and Policies, USDOT/FHWA, International Technology Exchange Program, October 2000. pages 61.

Type of Project Case Study (Description)- Insulinde Recycling BV WTE bottom ash recycling project. Bottom layer of sand/4-meter-thick layer of bottom ash at least 1 meter above groundwater table/bentonite clay soil and high-density polyethylene liner placed on top.

Material: Coal Bottom Ash and Boiler Slag

Coal bottom ash and boiler slag are the coarse, granular, incombustible by-products that are collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. The majority of these coal by-products are produced at coal-fired electric utility generating stations, although considerable bottom ash and/or boiler slag are also produced from many smaller industrial or institutional coal-fired boilers and from coal-burning independent power production facilities. The type of by-product (i.e., bottom ash or boiler slag) produced depends on the type of furnace used to burn the coal.

Bottom Ash

The most common type of coal-burning furnace in the electric utility industry is the dry, bottom pulverized coal boiler. When pulverized coal is burned in a dry, bottom boiler, about 80 percent of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining 20 percent of the ash is dry bottom ash, a dark gray, granular, porous, predominantly sand size minus 12.7mm (½ in) material that is collected in a water-filled hopper at the bottom of the furnace. When a sufficient amount of bottom ash drops into the hopper, it is removed by means of high-pressure water jets and conveyed by sluiceways either to a disposal pond or to a decant basin for dewatering, crushing, and stockpiling for disposal or use. During 1996, the utility industry generated 14.5 million metric tons (16.1 million tons) of bottom ash.

Boiler Slag

There are two types of wet-bottom boilers: the slag-tap boiler and the cyclone boiler. The slag-tap boiler burns pulverized coal and the cyclone boiler burns crushed coal. In each type, the bottom ash is kept in a molten state and tapped off as a liquid. Both boiler types have a solid base with an orifice that can be opened to permit the molten ash that has collected at the base to flow into the ash hopper below. The ash hopper in wet-bottom furnaces contains quenching water. When the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms pellets. The resulting boiler slag, often referred to as “black beauty,” is a coarse, hard, black, angular, glassy material.

When pulverized coal is burned in a slag-tap furnace, as much as 50 percent of the ash is retained in the furnace as boiler slag. In a cyclone furnace, which burns crushed coal, some 70 to 80 percent of the ash is retained as boiler slag, with only 20 to 30 percent leaving the furnace in the form of fly ash.

Wet-bottom boiler slag is a term that describes the molten condition of the ash as it is drawn from the bottom of the slag-tap or cyclone furnaces. At intervals, high-pressure water jets wash the boiler slag from the hopper pit into a sluiceway which is then conveys it to a collection basin for dewatering, possible crushing or screening, and either disposal or reuse. During 1995, the utility industry in the United States generated 2.3 million metric tons (2.6 million tons) of boiler slag.

HIGHWAY USES AND PROCESSING REQUIREMENTS

Asphalt Concrete Aggregate (Bottom Ash and Boiler Slag)

Both bottom ash and boiler slag have been used as fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, and emulsified asphalt cold mix wearing surfaces and base courses. Because of the “popcorn,” clinkerlike low durability nature of some bottom ash particles, bottom ash has been used more frequently in base courses than wearing surfaces. Boiler slag has been used in wearing surfaces, base courses and asphalt surface treatment or seal coat applications. There are no known uses of bottom ash in asphalt surface treatment or seal coat applications.

Screening of oversized particles and blending with other aggregates will typically be required to use bottom ash and boiler slag in paving applications. Pyrite (iron sulfide) that may be present in the bottom ash should also be removed (with electromagnets) prior to use. Pyrite is volumetrically unstable, expansive, and produces sulfuric acid and red iron oxide stains when exposed to water over an extended time period.

Granular Base (Bottom Ash and Boiler Slag)

Both bottom ash and boiler slag have occasionally been used as unbound aggregate or granular base material for pavement construction. Bottom ash and boiler slag are considered fine aggregates in this use. To meet required specifications, the bottom ash or slag may need to be blended with other natural aggregates prior to its use as a base or subbase material. Screening or grinding may also be necessary prior to use, particularly for the bottom ash, where large particle sizes, typically greater than 19 mm (3/4 in), are present in the ash.

Stabilized Base Aggregate (Bottom Ash and Boiler Slag)

Bottom ash and boiler slag have been used in stabilized base applications. Stabilized base or subbase mixtures contain a blend of aggregate and cementitious materials that bind the aggregates, providing the mixture with greater bearing strength. Types of cementitious materials typically used include Portland cement, cement kiln dust, or pozzolans with activators, such as lime, cement kiln dusts, and lime kiln dusts. When constructing a stabilized base using either bottom ash or boiler slag, both moisture control and proper sizing are required. Deleterious materials such as pyrite should also be removed.

Embankment or Backfill Material (Mainly Bottom Ash)

Bottom ash and ponded ash have been used as structural fill materials for the construction of highway embankments and backfilling of abutments, retaining walls, and trenches. These materials may also be used as pipe bedding in lieu of sand or pea gravel. In order to be suitable for these applications, the bottom ash or ponded ash must be at or reasonably close to its optimum moisture content, free of pyrite and/or “popcorn” like particles, and must be non-corrosive. Reclaimed ponded ash must be stockpiled and adequately dewatered prior to use. Bottom ash may require screening or grinding to remove or reduce oversize materials (greater than 19 mm (3/4 in) in size.

Flowable Fill Aggregate (Mainly Bottom Ash)

Bottom ash has been used as an aggregate material in flowable fill mixes. Ponded ash also has the potential for being reclaimed and used in flowable fill. Since most flowable fill mixes involve the development of comparatively low compressive strength (in order to be able to be excavated at a later time, if necessary), no advance processing of bottom ash or ponded ash is needed. Neither bottom ash nor ponded ash needs to be at any particular moisture content to be used in flowable fill mixes because the amount of water in the mix can be adjusted in order to provide the desired flowability.

Local Projects

Colorado allows the use of bottom ash and boiler slag for the production of the materials cited above. The Standard Specifications require the raw materials to meet performance standards (i.e., gradation, LA abrasion, LL, PI, etc). There are no specific maximum percentage allowances for using the raw materials, as the specification mandates only the performance based criteria cited above.

Fly ash that is produced from the burning of anthracite or bituminous coal is typically pozzolanic and is referred to as a Class F fly ash if it meets the chemical composition and physical requirements specified in ASTM C618. Materials with pozzolanic properties contain glassy silica and alumina that will, in the presence of water and free lime, react with the calcium in the lime to produce calcium silicate hydrates (cementitious compounds).

Fly ash that is produced from the burning of lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties (ability to harden and gain strength in the presence of water alone). 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. Most Class C fly ashes have self-cementing properties.

Reference- http://www.tfhrc.gov/hnr20/recycle/waste/index.htm Retrieved March, 2007.

Other States Projects

State/Location- New Hampshire

How is material used- “Aggregate Substitute in asphalt binder coarse pavement”

Other States Projects

State/Location- The Laconia, New Hampshire Bottom Ash Paving Project

“Grate ash from the Concord, N.H. waste-to-energy (WTE) facility was successfully used as an aggregate substitute in an asphalt binder course pavement. The grate ash was used in a New Hampshire Department of Transportation type B binder course as part of an ash utilization demonstration project during reconstruction of a section of Rt. 3 in Laconia, N.H. As part of the demonstration, a test section and a control section were built. The test section used a binder course containing 50% grate ash and 50% natural aggregate with 7% asphalt cement. The control section used a binder course containing 100% natural aggregate with 5 % asphalt cement. Both sections were placed above a stabilized base course containing soil and recycled asphalt pavement (RAP) from the road rehabilitation. Both sections were overlaid with a wearing course containing natural aggregate. The demonstration involved extensive field and laboratory testing for both physical and environmental performance. The physical performance of the test section over the 1.5 year study period was equal to that of the control section. No environmental impacts were observed over the 1.5 year study period.”

http://www.rmrc.unh.edu/Resources/VDS/Laconia/laconiamain.asp, Accessed March 6, 2007.

APPENDIX M - ADDITIONAL REFERENCES LIST

http://www.metrokc.gov/procure/green/bul65.htm

http://www.metrokc.gov/procure/green/concrete.htm

http://www.metrokc.gov/procure/green/asphalt.htm

http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/

http://faculty.washington.edu/cooperjs/Education/ME415/Project%20resources.htm

http://www.uctc.net/papers/final%20reports/year14/44%20-%20Horvath%20final%20report%20year%2014.htm

http://www.ncdot.org/doh/preconstruct/highway/geotech/trb/download/presentations/3a/02a%20---PaLATE.pdf

http://www.fhwa.dot.gov/Pavement/recycling/reccrumb.cfm

http://www.epa.gov/epaoswer/non-hw/muncpl/recycle.htm

http://www.cicacenter.org/cs2.cfm

Stabilization of Slopes Using Recycled Plastic Pins

http://www.fhwa.dot.gov/pavement/pub_listing.cfm?areas=Recycling

www.arra.org

www.acaa-usa.org

www.foundryrecycling.org

www.rubberpavements.org

http://www.epa.gov/epaoswer/osw/index.htm

http://www.epa.gov/epaoswer/osw/conserve/c2p2/cases/highway2.pdf

http://www.tfhrc.gov/hnr20/recycle/waste/index.htm

http://www.tfhrc.gov/pubrds/julaug00/recycnat.htm

http://www.tfhrc.gov/pubrds/fall94/p94au32.htm

http://www.mmsconferencing.com/nanoc/pdf/034-ID_193.pdf

http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_12.asp
x

Germany

http://wmr.sagepub.com/cgi/content/abstract/24/3/197
http://waste.eionet.europa.eu/publications

Europe
http://www.tfhrc.gov/pubrds/julaug00/recycscan.htm
http://waste.eionet.europa.eu/publications/factsheet
http://www.worldhighways.com/latest_issue/index.cfm?issue=78
http://www.tfhrc.gov/focus/jan01/highway_materials.htm
http://ntl.bts.gov/lib/9000/9800/9800/pdfs-recycolor.pdf
http://www.nbsgreenconstruction.com/bibliography/R3.asp
http://www.tfhrc.gov/pubrds/vol64.htm
http://www.fhwa.dot.gov/Pavement/recycling/houston.pdf

England
http://www.sustainablebuild.co.uk/ReducingManagingWaste.html

Brazil
http://www.brazzilmag.com/content/view/3098/54/

Belgium
http://www.brrc.be/brrc/e01-01.php
http://www.ecvm.org/code/page.cfm?id_page=425

California
http://www.ciwmb.ca.gov/LGLibrary/Innovations/Tires/PublicWorks.htm
http://www.ciwmb.ca.gov/ConDemo/Roads/CalTrans.htm
http://www.ciwmb.ca.gov/Pressroom/2002/June/042.htm
http://www.uctc.net/papers/683.pdf

Idaho
http://itd.idaho.gov/highways/ops/materials/download/lifecycle/lccamanual.pdf

Illinois
http://dot.state.il.us/press/r111306a.html

Indiana
http://www.in.gov/dot/div/communications/2002annualreport/Greening_the_Government.pdf

Massachusetts
http://www.mhd.state.ma.us/downloads/recycle/publications/newsletter1.pdf

Minnesota
http://www.pca.state.mn.us/oea/lc/purchasing/shinglestoolkit/shingles-casestudies.pdf

New Hampshire
Laconia New Hampshire MSW Bottom Ash Paving Project

North Carolina
http://www.tfhrc.gov/pubrds/julaug00/recycnc.htm

Texas
http://www.dot.state.tx.us/services/general_services/recycling/default.htm
ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/tirerpt.pdf
http://www.dot.state.tx.us/services/general_services/recycling/recycleable.htm
http://www.tfhrc.gov/focus/apr01/recycletexas.htm
TxDOT - Recycled Tires and Tire Rubber
TxDOT - Recycled Roofing Shingles
TxDOT - Glass Cullet Research
TxDOT - Compost and Shredded Brush

West Virginia
http://www.wvdot.com/tv/112002/november2002%5Fdmv%5Frecycling%5Fvehicle%5Fwaste.htm

Wisconsin
http://www.dot.wisconsin.gov/library/research/docs/finalreports/tau-finalreports/recycled.pdf

APPENDIX N - LETTER FROM SYMBIOTIC ENGINEERING

Heather Pettigrew
Recycled Materials Company, Inc
6425 W. 52nd Ave., Suite #1
Arvada, CO 80002

August 31, 2007

RE: Virgin vs Recycled Aggregate: Demand, Energy/Emissions, and Cost

Dear Ms. Pettigrew:

Thank you for your request for information concerning the demand of aggregates in Colorado, the energy needed and emissions released from producing virgin aggregates vs. producing recycled aggregates, and the avoided transport costs and landfilling differences between virgin and recycled aggregates.

The calculations in this letter consider the life-cycle energy involved in virgin and recycled aggregate processing. For example, the processing of virgin aggregates requires significant energy inputs to develop the quarry through the stripping of overburden or charges to blast mountain rock. This additional energy is not incorporated into recycled aggregate calculations as the source is demolished infrastructure debris that would otherwise be sent to disposal at a landfill. Because landfills represent large capital investments that require energy to receive, move and cover incoming debris, recycled aggregates could claim this avoided energy and emissions. In addition, as mountain and alluvial virgin aggregate quarries are spatially fixed and recycled aggregates can be processed at the site of demolition, the transportation cost of hauling aggregates to a site is also considered as a significant difference between virgin and recycled aggregate.

AGGREGATE DEMAND

The national apparent consumption of construction sand and gravel increased by 1.6% from 2005 with a total demand of 1.28 billion tonnes in 2006 and a national per capita annual consumption of 8.7 tonnes [USGS, 2006 and 1999]. The range of per capita annual consumption varies significantly by state. In 2005, California consumed about 235 million tons of construction aggregate, or about 6.6 tons per person. In Colorado, the per capita annual consumption of aggregates has remained at 9.5 tons for the last decade. As this is an average demand, the general economy, and certain large construction projects have created spikes and dips in this demand at their conclusion. This flux in demand is illustrated on Figure 1.

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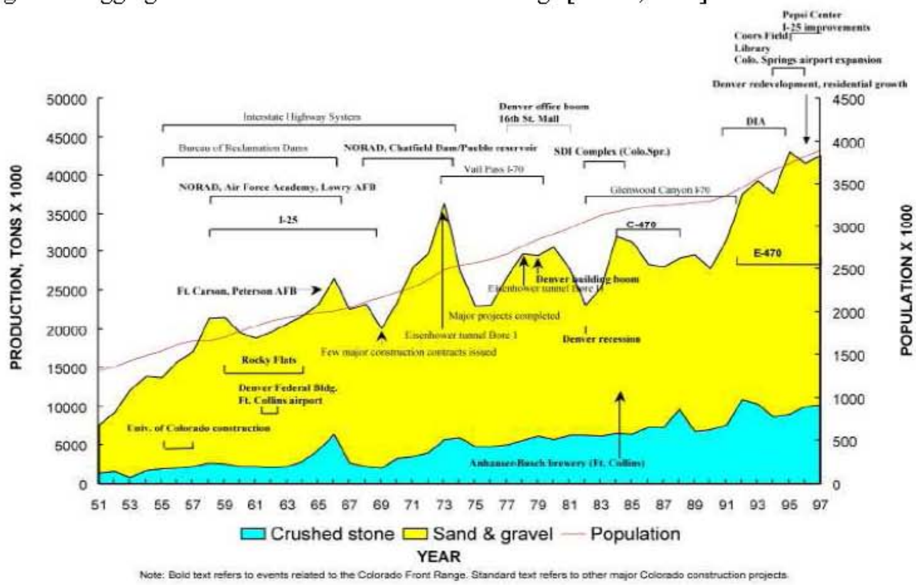
Figure 1: Aggregate Demand in the Colorado Front Range [USGS, 1999]



ENERGY and GHG EMISSIONS from AGGREGATE PROCESSING and TRANSPORT

Virgin Aggregates: The energy to produce concrete coarse and fine aggregate from virgin crushed rock (mountain quarry) is 81 kJ/kg (70,000 Btu/ton), and the energy to produce similar aggregate from virgin uncrushed (alluvial) is 17 kJ/kg (14,600 Btu/ton) [NIST/BEES, 2007]. Therefore, there is an approximate five-fold energy increase for crushed virgin aggregate compared to alluvial river aggregate.

Recycled Aggregates: The required processing energy for recycled aggregates is approximately 29% less than for processing virgin uncrushed (alluvial) at 12 kJ/kg (10,400 Btu/ton) [Reiner, 2007 – based on an actual RMCI project]. In addition, the life cycle energy of recycled aggregate can be further reduces by considering avoided energy and emissions savings that are realized by the following:

- Distance and mode of transport of the aggregate to the job site
- Avoided energy and emissions of <u>not</u> landfilling concrete debris.

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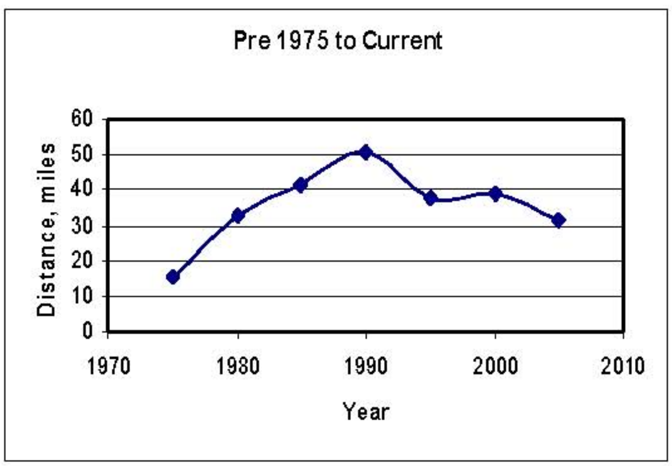
Transport: Further energy and emissions savings are realized for recycled aggregates by considering the distance and mode of transport of the aggregate to the job site, and the avoided energy and emissions avoiding landfilling of concrete debris. The approximate energy consumption for truck transport equals 3.7 MJ/ton-mi (8616 Btu/ton-mi) for truck transport and 0.6 MJ/ton-mi (1400 Btu/ton-mile) for transporting materials by rail [NIST/BEES, 2007].

Landfill: The avoided negative environmental impacts of landfilling concrete debris include space saved (in-place density of 1.2 tons/yd^3) and the energy and emissions needed to move, place and cover concrete debris. This life-cycle negative environmental impact was evaluated using the US EPA's WARM model which estimated -0.046 tons of greenhouse gas (GHG, or CO2e) per ton of concrete rubble diverted from landfill to replace virgin aggregate reserves and 53 MJ/ton (53,2300 Btu/ton) of embodied energy [Reiner, 2007].

COST of AGGREGATES and TRANSPORT

The cost of transport has the most significant impact for aggregates as aggregates are a low unit-cost item. The additional freight on-board (FOB) per ton transport cost can range from $0.15 per ton-mile to $0.24 per ton-mile, or on a 60 mile trip, add an additional $9/ton to $14.40/ton. The average distance of virgin coarse aggregates found along the riparian corridor of the South Platte River from downtown Denver is approximately 33 miles (as shown on Figure 2) which correlates to $6.60 FOB per ton.

Figure 2: Average Distance for Coarse Virgin Aggregate from Denver [Reiner, 2007]



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In addition, the life cycle costs for end-of-life infrastructure can be translated into economic savings. By recycling concrete debris into aggregate resources tipping fees, charged to dump material in landfills, are avoided. The average cost to dispose of 1-ton of concrete rubble at recycle center (assuming 40% non-reinforced, 40% reinforced, 20% heavily reinforced) is $5.95/ton compared to $15.28/ton at a landfill [Reiner, 2007].

SUMMARY

Considerations of the energy, emissions and source of recycled aggregates compared to virgin sources are summarized on Table 1. Also, to highlight the impact of avoided truck transport, an example is included to show the truck trips, cost, energy and emissions avoided by recycling on site rather than importing from a quarry. Other considerations such as performance, water demand and direct commodity costs are not included in this table as the evaluation of performance and water demand are dependent on aggregate source and direct commodity costs vary significantly by source and seasonally.

Table 1: Comparison of Energy, Emissions and Cost of Virgin vs Recycled Aggregates

Characteristic	Virgin Aggregate		Recycled Aggregate
	Crushed	Uncrushed	
Source Assumptions	Primarily from Mountain Quarry	Primarily Alluvial (riparian corridor)	On-site Production
Processing GHG Emissions per ton aggregates	3.22 lb	0.67 lb	0.47 lb
Processing Energy per ton aggregates	7000 Btu/ton	14,600 Btu/ton	10,400 Btu/ton
Avoided Landfilling GHG Emissions per ton, lb	Not Applicable	Not Applicable	92 lb
Avoided Landfilling Energy per ton	Not Applicable	Not Applicable	- 50,230 Btu
Example: Cost, energy and emissions with transporting 100-tons of aggregate by truck from a quarry (mountain or alluvial) 50 miles to project site compared to on-site recycling.			
FOB, $ ($0.20 per ton-mile)	$1,000	$1,000	$0
Avoided Truck Round-Trips	0	0	5
Emissions, lbs GHG	1,980 lb	1,980 lb	0
Energy, Btu	43 MBtu	43 MBtu	0

I would be happy to discuss this with you if you have any questions or comments.

Sincerely,

Symbiotic-Engineering, LLC

Mark Reiner

Mark Reiner, PhD, PE, PG.
Principal / LEED AP

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APPENDIX O - SUMMARY OF CURRENT CDOT SPECIFICATIONS THAT ALLOW REUSE AND/OR RECYCLING

EXAMINATION OF ALTERNATIVE MATERIALS REUSE IN HIGHWAY APPLICATIONS TO PROMOTE SOLID WASTE REDUCTION AND REUSE OF MATERIALS ON CDOT PROJECTS

TASK 2: SPECIFICATIONS
NOTES

1. Referenced Standard Specifications are from CDOT's 2005 Standard Specifications for Road and Bridge Construction.
2. Referenced Standard Special Provisions are as listed on CDOT's website at www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005index.htm.
3. Referenced Project Special Provision Worksheets are as listed on CDOT's website at www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/Work%20Sheets/2005ws.htm.
4. Referenced Sample Project Special Provisions are as listed on CDOT's website at www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005PSP/2005psp.htm.
5. There were no sample Traffic Project Special Provisions that specifically allow for recycling/reuse of materials. Sample Traffic Project Special Provisions are as listed on CDOT's website at www.dot.state.co.us/S_Standards/Project_Specials_2005/Special_Provisions_2005.html.
6. There were no M or S-Standards that specifically allow for recycling/reuse of materials, see CDOT's July 2006 Standard Plans.

EXAMINATION OF ALTERNATIVE MATERIALS REUSE IN HIGHWAY APPLICATIONS TO PROMOTE SOLID WASTE REDUCTION AND REUSE OF MATERIALS ON CDOT PROJECTS

TASK 2: SPECIFICATIONS
CDOT 2005 STANDARD SPECIFICATIONS THAT ALLOW RECYCLING/REUSE

CDOT Standard Specification	Allows Recycling/Reuse of:						Comment
	Asphalt	Concrete	Wood	Metal	Tires	Other	
Section 202 Removal of Structures and Obstructions							
202.02 General	x	x					Allows for concrete & asphalt removed from the project in the embankment.
202.03 Salvable Materials						x	Gives instructions on salvable material to become the property of CDOT or reused on project.
202.07 Pavements, Sidewalks, Curbs		x					Gives instructions on broken concrete pavement to be left in place.
Section 203 Excavation and Embankment							
203.06 Embankment	x	x				x	Allows for concrete, asphalt & other materials removed from the project in the embankment.
Section 206 Excavation and Backfill for Structures							
206.02 General - *(a) Structure Backfill*						x	Allows for recycled glass as aggregate in Structure Backfill (flow-fill)
206.02 General - *(b) Bed Course Material*	x	x				x	Allows for use of crushed asphalt, concrete, cinders and slag for bed course material.
206.02 General - *(c) Filter Material*						x	Allows for use of slag for filter material.
Section 207 Top Soil							
207.01 Description						x	Allows for salvage and reuse of on-site topsoil.
Section 208 Erosion Control							
208.02 Materials - *(e) Brush Barrier*			x				Allows for use of unmerchantable timber in brush barriers.
208.02 Materials - *(f) Check Dams*			x				Allows for use of logs in check dams.
208.02 Materials - *(l) Stabilized Const. Entrance*	x	x					Only calls for coarse material, could be crushed concrete or asphalt.
Section 210 Reset Structures						x	Allows for reuse of on-site existing materials, as specified by the Engineer.
Section 215 Transplanting						x	Allows for reuse of on-site existing vegetation, as specified by the Engineer.
Section 304 Aggregate Base Course							
304.02 Aggregate	x	x				x	Allows for use of crushed slag, reclaimed asphalt & concrete for aggregate base course.
Section 401 Plant Mix Pavements-General							
401.02 Composition of Materials	x						Allows for reclaimed asphalt pavement, if permitted by CDOT on a particular project.
401.03 Aggregates						x	Allows for crushed slag as HMA aggregate.
401.04 Mineral Filler						x	Allows for slag dust and fly ash for mineral filler.
Section 403 Hot Mix Asphalt	x					x	Allows materials conforming to Sections 401.02 thru 401.06, see above.
Section 405 Heating and Scarifying Treatment	x						Allows recycling the top portion of bituminous pavement, as specified by the Engineer.
Section 406 Cold Bituminous Pavement (Recycle)	x						Includes recycling a portion of bituminous surfacing, as specified by the Engineer.
Section 409 Sealcoat							
409.03 Cover Coat Material						x	Allows for use of crushed slag for aggregate.
Section 412 Portland Cement Concrete Pavement							
412.02 Materials		x				x	Referenced AASHTO M 80 allows for crushed concrete or slag as coarse aggregate.
Section 601 Structural Concrete							
601.03 Materials		x				x	Referenced AASHTO M 80 allows for crushed concrete or slag as coarse aggregate.
Section 608 Sidewalks and Bikeways							
608.02 Materials						x	Allows cinders and slag for bed course material.
Section 609 Curb & Gutter							
609.02 Materials						x	Allows cinders and slag for bed course material.
Section 703 Aggregates							
703.02 Coarse Aggregate for Concrete		x				x	Referenced AASHTO M 80 allows for crushed concrete or slag as coarse aggregate.
703.03 Aggregate for Bases	x	x				x	Allows for crushed slag or reclaimed concrete or asphalt in aggregate for bases.
703.04 Aggregates for HMA						x	Allows for crushed slag in aggregates for HMA.
703.05 Aggregates for Cover Coat Material						x	Allows for crushed slag in aggregates for cover coat material.
703.06 Mineral Filler						x	Allows for slag dust and fly ash for mineral filler.
703.07 Bed Course Material						x	Allows for slag and cinders as bed course material.
703.09 Filter Material						x	Allows for slag as filter material.

EXAMINATION OF ALTERNATIVE MATERIALS REUSE IN HIGHWAY APPLICATIONS TO PROMOTE SOLID WASTE REDUCTION AND REUSE OF MATERIALS ON CDOT PROJECTS

TASK 2: SPECIFICATIONS
CDOT STANDARD SPECIAL PROVISIONS THAT ALLOW RECYCLING/REUSE

CDOT Standard Special Provision	Allows Recycling/Reuse of:						Comment
	Asphalt	Concrete	Wood	Metal	Tires	Other	
Revision of Section 104							
Value Engineering Change Proposals						x	Allows for VE change proposal on alternative materials.
Revision of Section 410							
Reclaimed Asphalt Pavement	x						Allows for use of reclaimed asphalt pavement (RAP) in new HMA, up to 25%.

TASK 2: SPECIFICATIONS
CDOT PROJECT SPECIAL PROVISION WORKSHEETS THAT ALLOW RECYCLING/REUSE

CDOT Project Special Provision Worksheet	Allows Recycling/Reuse of:						Comment
	Asphalt	Concrete	Wood	Metal	Tires	Other	
Revision of Section 202							
Reclaimed Asphalt Pavement Millings	x						Calls for RAP to become property of CDOT + allows for use of RAP on the project.
Removal of Structure Coated with Heavy-Metal Based Paint						x	Gives instructions on salvable material to become the property of CDOT or reused on project.
Revision of Section 405							
Heating and Remixing Treatment	x						Mixes top layer of existing asphalt with new HMA, as specified by the Engineer.
Revision of Section 409							
Ultrathin Bonded Wearing Course						x	Allows for use of slag in coarse aggregate.

EXAMINATION OF ALTERNATIVE MATERIALS REUSE IN HIGHWAY APPLICATIONS TO PROMOTE SOLID WASTE REDUCTION AND REUSE OF MATERIALS ON CDOT PROJECTS

TASK 2: SPECIFICATIONS
CDOT SAMPLE PROJECT SPECIAL PROVISIONS THAT ALLOW RECYCLING/REUSE

CDOT Sample Project Special Provision	Allows Recycling/Reuse of:						Comment
	Asphalt	Concrete	Wood	Metal	Tires	Other	
Revision of Section 202							
Removal of Asphalt Mat	x						Allows for reuse of asphalt mat in embankment, bottom of fills, HMA and subgrade.
Removal of Bridge						x	Gives instructions on salvable material to become the property of CDOT or reused on project.
Removal of Guardrail Type 3				x			Allows salvage of W-beam for CDOT use.
Removal and Trimming of Trees			x				Requires branches and brush of less than 3-inch diameter to be chipped into mulch and stockpiled, not clear if to be reused on project.
Revision of Section 207							
Topsoil						x	Allows for reuse of on-site topsoil.
Revision of Section 210							
Modify Manhole						x	Allows for reuse of existing manholes, in current location, as specified by the Engineer.
Modify Structures						x	Allows for reuse of existing inlets & manholes, in current location, as specified by the Engineer.
Reset Impact Attenuator						x	Allows for reuse of existing impact attenuator, as specified by the Engineer.
Revision of Section 306							
Reconditioning	x						Allows for reuse existing asphalt as base material, as specified by the Engineer.
Revision of Section 310							
Full Depth Reclamation of HMA Pavement	x						Allows for reuse existing asphalt as base material, as specified by the Engineer.
Revision of Section 405							
Heating and Repaving Treatment	x						Allows rehabilitating the top layer of pavement, as specified by the Engineer.
Heating and Scarifying Treatment	x						Allows recycling the top portion of bituminous pavement, as specified by the Engineer.
Revision of Section 703							
Aggregate (Cover Coat Material)						x	Allows for use of slag in cover coat material.
Mineral Filler						x	Allows for use of slag dust as mineral filler.

APPENDIX P - SUMMARY OF SUGGESTED CHANGES TO CURRENT CDOT SPECIFICATIONS TO ALLOW ADDITIONAL RECYCLING AND/OR REUSE

EXAMINATION OF ALTERNATIVE MATERIALS REUSE IN HIGHWAY APPLICATIONS TO PROMOTE SOLID WASTE REDUCTION AND REUSE OF MATERIALS ON CDOT PROJECTS

TASK 2: SPECIFICATIONS
NOTES

1. Referenced Standard Specifications are from CDOT's 2005 Standard Specifications for Road and Bridge Construction.
2. Referenced Standard Special Provisions are as listed on CDOT's website at www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005index.htm.
3. Referenced Project Special Provision Worksheets are as listed on CDOT's website at www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/Work%20Sheets/2005ws.htm.
4. Referenced Sample Project Special Provisions are as listed on CDOT's website at www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005PSP/2005psp.htm.

EXAMINATION OF ALTERNATIVE MATERIALS REUSE IN HIGHWAY APPLICATIONS TO PROMOTE SOLID WASTE REDUCTION AND REUSE OF MATERIALS ON CDOT PROJECTS

TASK 2: SPECIFICATIONS
SUGGESTED CHANGES TO CDOT SPECIFICATIONS

CDOT Standard Specifications	Suggested Revision to Allow Additional Reuse/Recycling
Section 202 Removal of Structures and Obstructions	
202.01 Description	Consider adding language requiring the Contractor to make a good faith effort to dispose of removed materials at a recycling facility or reuse on the project.
202.02 General	Consider changing language requiring the Contractor to use removed asphalt/concrete in embankment on borrow projects; in lieu of saying "may be used" in the embankment.
202.12 Basis of Payment	Consider adding language that payment includes "disposal at a recycling facility as appropriate".
Section 203 Excavation and Embankment	
203.06 Embankment	Consider adding shredded rubber tires as allowable embankment material; need approval/research by CDOT Materials Branch.
Section 208 Erosion Control	
208.02 Materials - *(f) Check Dam*	Consider adding recycled concrete as material for a check dam; need approval/research by CDOT Materials Branch.
208.02 Materials - *(g) Outlet Protection*	Consider adding recycled concrete as material for outlet protection; need approval/research by CDOT Materials Branch.
208.02 Materials - *(l) Stabilized Const. Entrance*	Consider adding language that the stabilized construction entrance can be crushed asphalt or concrete; need approval/research by CDOT Materials Branch.
Section 401 Plant Mix Pavements-General	
401.02 Composition of Materials	Consider deleting "if permitted and used" from end of first sentence; in reference to reclaimed material.
Section 506 Riprap	
506.02 Materials	Consider allowing broken concrete for riprap; need approval/research by CDOT Materials Branch and CDOT Environmental.
Section 703 Aggregates	
703.02 Coarse Aggregate for Concrete	Consider adding language that AASHTO M 80 allows crushed concrete as an aggregate.
703.04 Aggregates for HMA	Consider adding crushed concrete as an aggregate for non-wear course; need approval/research by CDOT Materials Branch.
703.07 Bed Course Material	Consider adding crushed concrete and asphalt as allowable bed course material; requires approval/research by CDOT Materials Branch.
703.10 Aggregate for Median Cover	Consider adding crushed concrete and asphalt as allowable aggregate for median cover; requires approval/research by CDOT Materials Branch.
CDOT Standard Special Provisions	
Revision of Section 401	
Reclaimed Asphalt Pavement	Consider requiring this Standard Special Provision on all CDOT projects with HMA.
CDOT Project Special Provision Worksheets	
Revision of Section 202	
Reclaimed Asphalt Pavement Millings	Consider adding language to require the Contractor make a good faith effort to dispose of excess RAP at a recycling facility.
Removal of Bridge	Consider adding language to require the Contractor make a good faith effort to dispose of recyclable materials at a recycling facility, list which items may be recyclable.
CDOT Sample Project Special Provisions	
Revision of Section 202	
Removal of Asphalt Mat	Consider adding language to require the Contractor make a good faith effort to dispose of RAP not reused on the project at a recycling facility.
Revision of Section 250	
Solid Waste Disposal	Consider adding recycling facilities as options for disposal of solid waste.

APPENDIX Q - REVISION OF SECTION 216 – SOIL RETENTION BLANKET (PLASTIC)

Revision of Section 216
Soil Retention Blanket (Plastic)

Section 216 of the Standard Specification is hereby revised for this project as follows:

Subsection 216.02 (a) shall include the following:

5. Soil Retention Blanket (Plastic). Soil Retention Blanket (Plastic) shall be a dense mat consisting of three-dimensional recycled polyester fibers (soda bottles). The fibers are encased between two layers of UV-stabilized polypropylene netting and sewn together. The blanket or turf reinforcing matting (TRM) shall be capable of stabilizing soils and reinforcing vegetation in a channel application.

Material requirements:

Mass per Unit Area: 10.0 oz/sy
Thickness: 0.25-0.5 inches
Resiliency: 80%
Netting: Bottom dimension- 1 inch x ¾ inch. Top dimension-3/4 inch x ¾ inch

The Contractor shall submit a sample of the soil retention blanket (plastic) two weeks prior to installation for approval by the Engineer.

Delete subsection 216.02 (b) and replace with the following:

Ground Anchoring Devices. Ground Anchoring Devices shall include the following:

U-shaped wire staples, metal pins, or triangular wooden stakes.
(1) Wire staples: Minimum 8 gauge.
(2) Metal pins: Steel, minimum 0.20-inch diameter with 1.5-inch diameter steel washer.
(3) Triangular wooden stakes: 12 to 18 inch length with a 2-inch minimum base.

Subsection 216.03 shall include the following:

(d) Soil Retention Blanket (Plastic)

1. Preparation:

   Areas to be treated with blanket shall be graded and compacted as directed by the Engineer. The Contractor shall remove large rocks, soil clods, vegetation, and other sharp object that could keep the blanket from contact with the subgrade. The seedbed shall be prepared by loosening 2 to 3 inches of soil. Apply the required soil amendments, 75 percent of the topsoil, fertilizer, and seed at half the design rate to the scarified surface prior to installation of the bottom blanket (TRM).

   Construct 6 inch wide x 12-inch deep anchor trench at upgrade end of the installation to inhibit undermining from surface water. Excavate 6 inch x 6-inch check slots at 30-foot intervals along the length of the channel.

2. Installation:

   Install the blanket at the elevation and alignment shown on the plans. Beginning at the downstream end in the center of the channel, place the initial end of the first roll of the blanket in the anchor trench and secure with ground anchor devices a 12 inch intervals. Position adjacent rolls in the anchor trench in the same manner, overlapping the proceeding roll a minimum of 3 inches. Unroll the blanket upstream stopping at the next check slot or terminal anchor trench. Unroll the adjacent rolls (as required) upstream in a similar fashion maintaining a 3 inch overlap.

   Fold and secure the blankets snugly into transverse check slots. Lay the blanket in the bottom of the slot, and then fold back against itself. Anchor through both layers of blanket in trench at 12-inch intervals. Backfill the blankets with soil and compact by foot tamping. Continue unrolling blanket widths upstream loosely to avoid tension.

   Secure blanket to the channel bottom with ground anchoring devices at a frequency of 3 anchors per square yard or as recommended by the manufacture. The Engineer prior to execution must approve any alternate installation methods.

   Spread and rake the remaining 25 percent of the topsoil depth (2-inch maximum) over bottom blanket. Method of soil cover shall be performed in such a manner as to not disturb blanket or anchoring devices. Broadcast the remaining seed at half the rate and place soil retention blanket (straw/coconut) or approved equal above the soil filled blanket (TRM). Check slots for the top blanket will not be required.

Subsection 216.05 shall include the following:

Topsoil will be measured and paid for in accordance with Section 207. Soil retention blanket (straw/coconut) will **not be paid for separately** but include in the price of the soil retention blanket (plastic).

Pay Item	**Pay Unit**
Soil Retention Blanket (Plastic)	Square Yard

APPENDIX R - CONTRACTOR SURVEY

US EPA Research Grant Reuse and Recycling
Contractor Survey

Respondent Information: Contact Name:______________________________
Company:______________________________
Address:______________________________
Phone:______________________________
Email:______________________________

Return completed surveys via email (scanned), FAX, or mail to:
Bill Marcato
Felsburg Holt & Ullevig
6300 S. Syracuse Way, Ste. 600
Centennial, CO 80111
Phone: 303-721-1440
Fax: 303-721-0832
Email: Bill.Marcato@fhueng.com

DEPARTMENT OF TRANSPORTATION

FELSBURG HOLT & ULLEVIG
engineering paths to transportation solutions

1. Please circle your response to the following statements regarding the application of reusable and recyclable materials for roadway and bridge construction projects:
(Y = YES, N = NO, DK = DON'T KNOW)

	We are aware of this recycled material application	Material is readily available in Colorado	Cost of using this as a recycled material is competitive with new material	CDOT Specifications don't allow use of this material	Have you used this material on a CDOT project?	Have you used this material on a non-CDOT project?
Asphalt *[ ] – Check here if you work with this material*						
Recycled asphalt pavement (RAP) in HMA mix	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as embankment material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as pavement base course	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as shoulder material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Concrete *[ ] - Check here if you work with this material*						
Recycled as aggregate for concrete	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as embankment fill material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as pavement base course material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as riprap material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as pipe bedding material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as stabilized construction entrance	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Wood *[ ] - Check here if you work with this material*						
Recycled as mulch	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Reuse guardrail posts	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Metal *[ ] - Check here if you work with this material*						
Reuse w-beam from guardrail	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Reuse steel guardrail posts	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Scrap Tires (Import) *[ ] - Check here if you work with this material*						
Recycled as embankment fill	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as pavement subgrade fill	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK
Recycled as mulch or landscaping material	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK	Y N DK

2. List sections of the CDOT Specifications that prevent/discourage you from using recycled materials on your projects:
   a.________________________ d.________________________
   b.________________________ e.________________________
   c.________________________ f.________________________

3. What recommendations would you make to update the specifications to encourage more use of recycled materials?

4. If a project had mandatory recycled material requirements, how might it affect your bid?

5. Would mandatory recycled material requirements encourage or discourage your company from bidding?

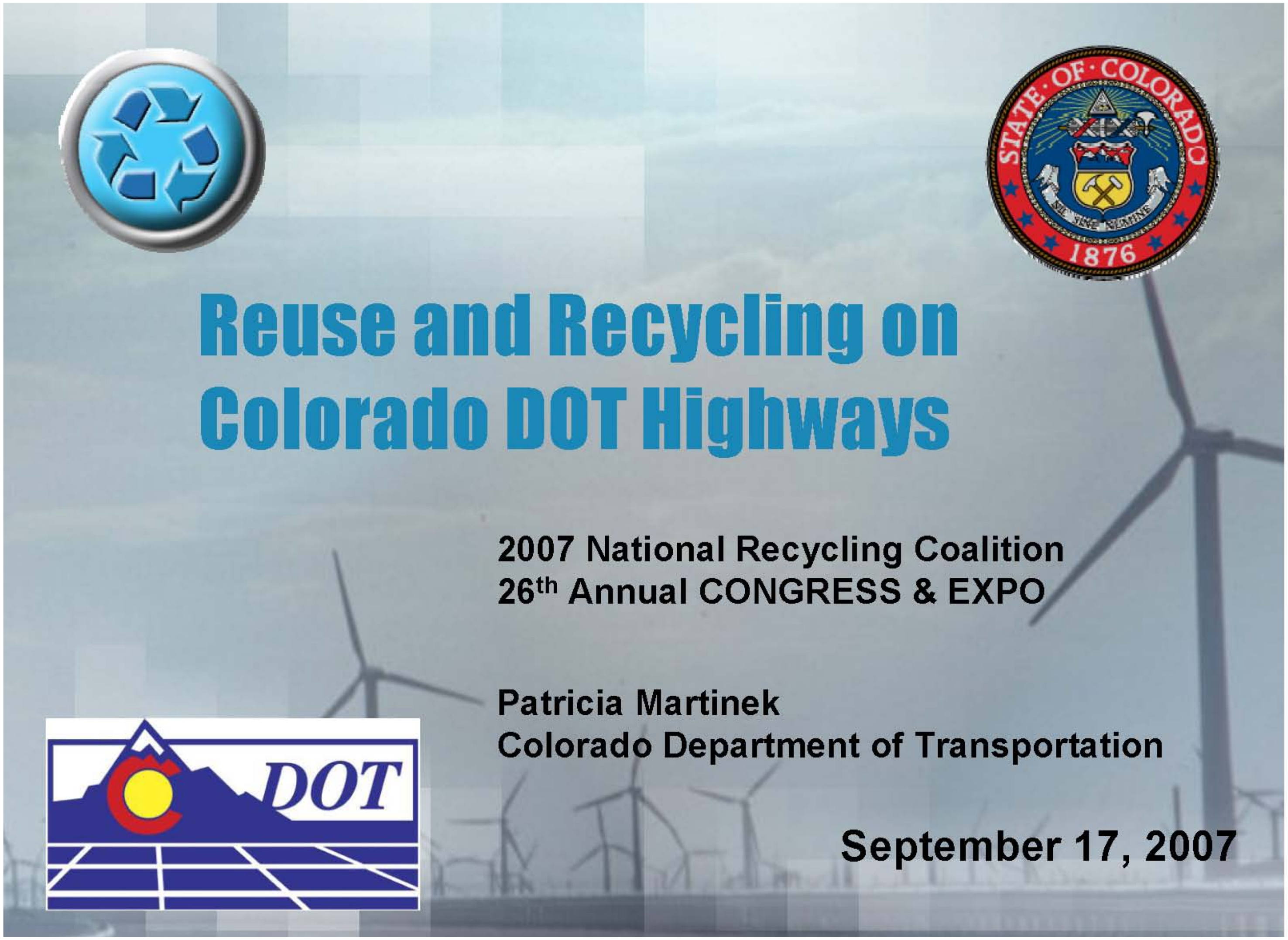
6. Do you think incentive payments for recycling would result in your company using more recycled materials (circle one)? Y N DN

7. Which project materials do you most often have to send to waste disposal sites?

8. Do you actively search for recycling opportunities for these materials?

Prepared by WJM 9/9/2007

APPENDIX S - PRESENTATION


Reuse and Recycling on
Colorado DOT Highways
2007 National Recycling Coalition
26th Annual CONGRESS & EXPO
Patricia Martinek
Colorado Department of Transportation
September 17, 2007
STATE OF COLORADO
1876
NIL SINE NUMINE
DOT

Appendix S-2

The Peer Pressure is on

New Initiatives – Governor Ritter

- Renewable energy
- Greening Government
  - Exec. Orders:
  - "Zero Waste Goal"
- Ozone and GHG Plans
- Environmentally Preferable Purchasing
  - – 5% premium

Federal Recycling Goals

- Federal Executive Order 13423 signed by G.W. Bush on 1/24/07 on Greening of Federal Agencies

- Federal Highway Administration (FHWA) policy on recycling*:
  - Recognizes engineering, economic and environmental benefits
  - Remove restrictions

*But no price premiums allowed!

EPA Goals

Target: Increase <u>national recycling rate</u> from 30% to 35% by 2008

- **Industrial byproducts**
- **Construction and demolition debris**
- **Tires**
- **Priority chemicals**
- **Electronic waste**

Region 8 Resource Conservation Grants

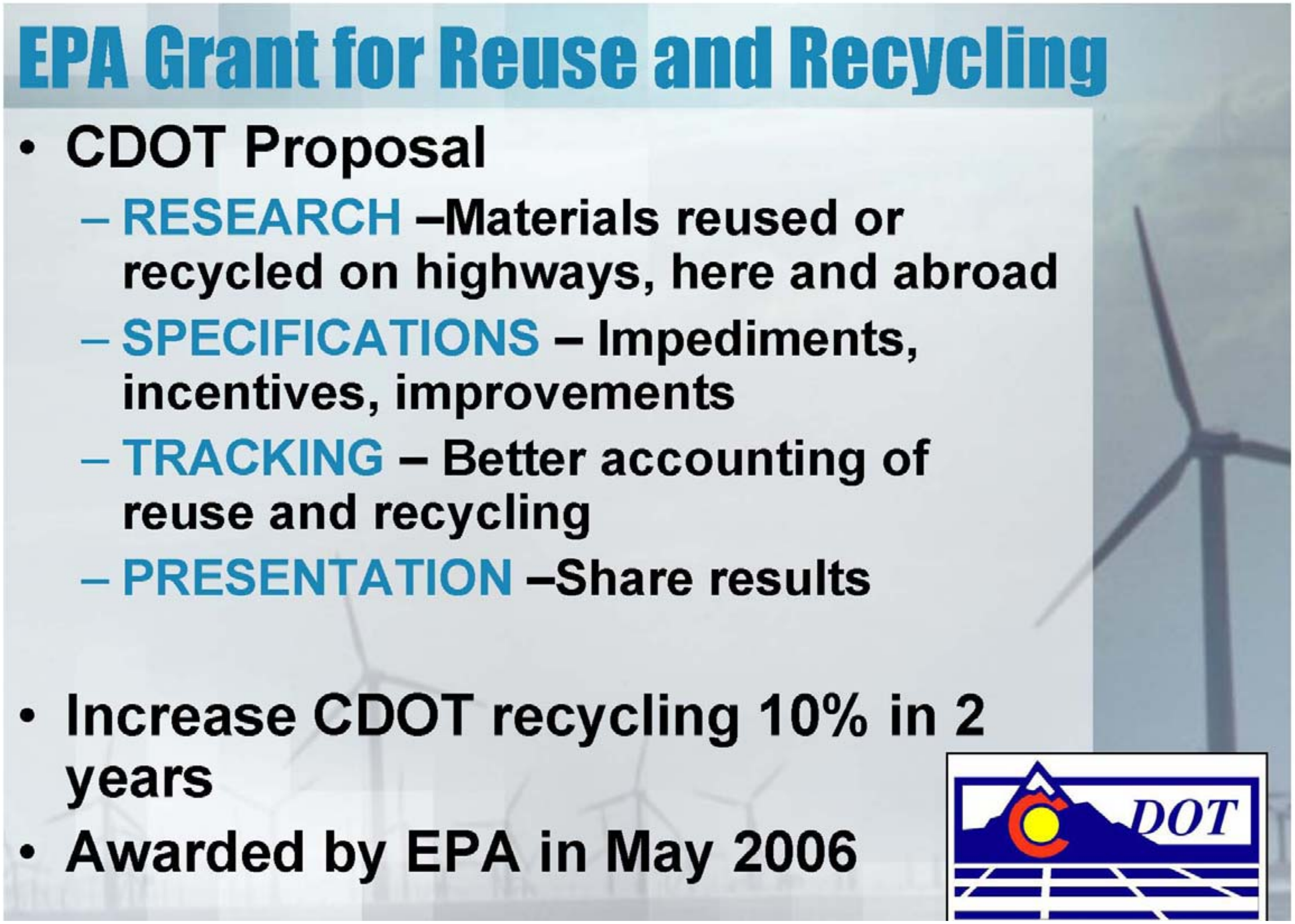
http://www.epa.gov/

CDOT 2007 Numbers

Concrete

- 290,068 tons used
- 1,100 tons recycled
- 0% recycle rate
- 894 tons CO2

- Asphalt
  - 260,125 tons used
  - 45,100 tons recycled
  - 17% recycled
  - 966 tons CO2


EPA Grant for Reuse and Recycling
• CDOT Proposal
– RESEARCH –Materials reused or recycled on highways, here and abroad
– SPECIFICATIONS – Impediments, incentives, improvements
– TRACKING – Better accounting of reuse and recycling
– PRESENTATION –Share results
• Increase CDOT recycling 10% in 2 years
• Awarded by EPA in May 2006
DOT

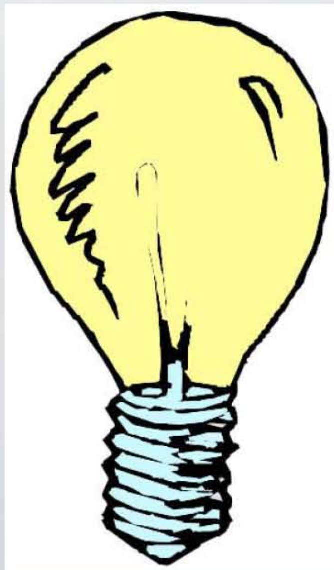
Research Project

- Research Contractor – Felsburg, Holt & Ullevig
- Research panel to oversee work
  - CDOT environmental, materials, specifications, landscape architect
  - FHWA
  - Industry
    - Front Range Tire
    - Recycled Materials Company, Inc.
    - Lawrence Construction Company

FELSBURG HOLT & ULLEVIG

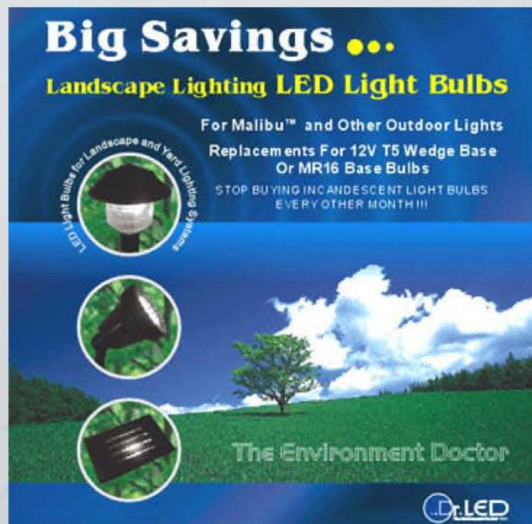
The Challenge

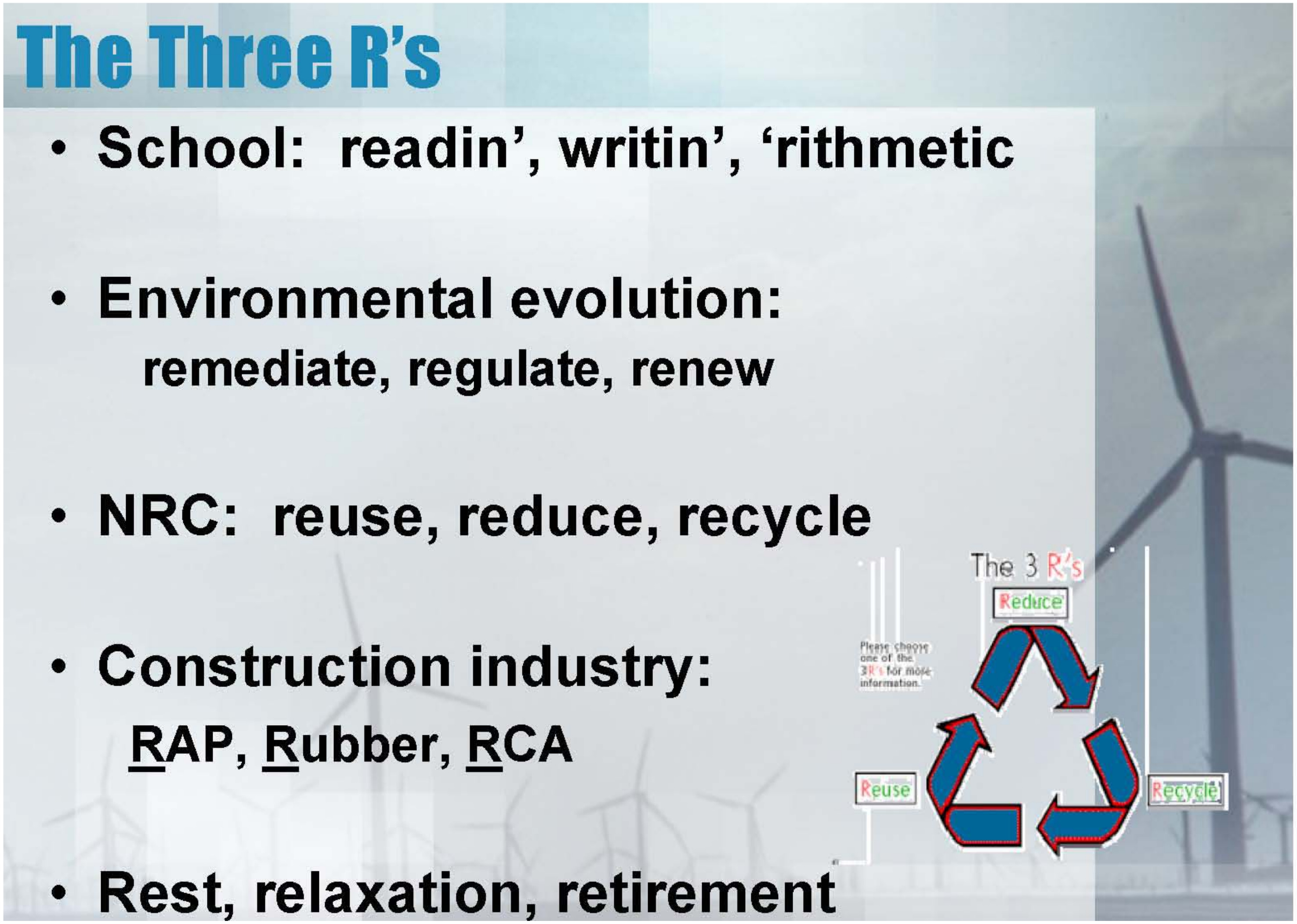
- How many engineers does it take to change a light bulb?



How to Speak Engineereeze?

How many light bulbs does it take to change an engineer?




The Three R's
• School: readin', writin', 'rithmetic
• Environmental evolution:
remediate, regulate, renew
• NRC: reuse, reduce, recycle
• Construction industry:
RAP, Rubber, RCA
• Rest, relaxation, retirement
The 3 R's
Reduce
Reuse
Recycle
Please choose one of the 3 R's for more information.

The 3R's of Engineereeze

***R**equirements*: Mission: what must we do?

***R**estrictions*: Do more with less:

***R**eplacements*: Performance:

What can we use instead?

How do we know it will work?

***R**esearch*!

Research – Let Them Speak

- **Landfill Materials Survey**
  - Ask for CDOT input about recycling and landfilling on projects
  - Over 200 CDOT engineers surveyed
  - Survey included 13 material categories including import and export materials
  - 25% response rate!

Research – What They Said

- Top materials for project focus:
  - Asphalt
  - Concrete
  - Wood
  - Metal
  - Scrap Tires (import)

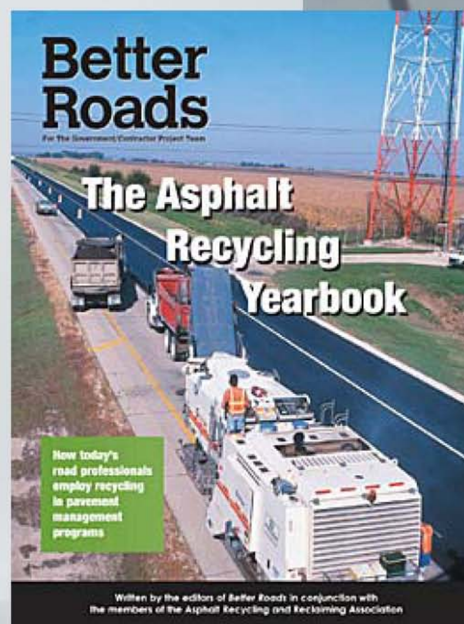
- Inconsistent, poorly tracked, unknown
- Some interested, some not
- Will do if saves money, tried and true

RAP Stars

- Asphalt
  - Reclaimed Asphalt Pavement (RAP) - 100% recyclable
  - Many European countries recycle about 100% asphalt materials
    - Sweden
    - Denmark
    - Netherlands
  - US recycles 80% of RAP (Reclaimed Asphalt Pavement)
  - Best highest use is pavement

RAP - all over the MAP

- Asphalt
  - Caltrans to allow 25 - 50% RAP in hot mix designs
  - TxDOT allows 20% RAP
  - City of Pueblo 2007 Overlay Project - allows 30% RAP
  - Iowa: 40% RAP on I-35



CDOT RAP Stars

CDOT and Asphalt

- Allows 25% RAP in hot mix designs, 15% RAP in top lift
- West Slope: >15,000 tons of RAP in past 5 years
- Pilot projects: hot in-place pavement recycling
    - Predictable
    - 3 + 1 > 4

Concrete Examples

- Concrete
  - Crushed concrete used on highway projects – mostly base course material
  - Other uses of crushed concrete:
    - Erosion control
    - Retaining walls
    - Flood control
    - Bedding material
    - Riprap
    - Recycled Concrete Aggregate (RCA) in concrete mixes

http://www.rmci-usa.com/stapletonpics.htm

Concrete Examples

- Concrete
  - Michigan DOT uses RCA statewide. US-41 reconstructed with RCA as base material in mobile crushing operation. Cost savings: $114,000
  - TREX Project (Denver) reused 100% of concrete from project
  - TxDOT saved 10 years' construction time building Houston beltways with RCA

Chuck the Wood

- **Wood**
  - **Much used on CDOT projects**
    - **Renewable, reusable**
    - **Untreated, trees, root wads =>**
      - **Mulch**
      - **Stream restoration**
    - **Treated, painted => waste**

  - **Replace treated wood products with more durable and recycled/recyclable substitutes (metal, plastic)**

Heavy Metal

- Metal
  - Sturdy, long-lasting
  - Products - 100% recycled
  - Money back
  - Lead-painted, corroded, damaged okay to recycle
  - Local steel mill
  - Metal - highly recyclable

TREX Project – I-25 in Denver

- Metal on TREX Project
  - Recycled steel used
  - Steel recycled from concrete, sign structures, bridge girders, and old pedestrian railings
  - No steel products sent to landfill
  - Steel light rail tracks recycled from former Mile High Stadium.

http://www.trexproject.com

ReTirement – 40 million bonanza!

- Recycled Tires - 6 million/year
- Can replace many raw materials on highway projects
    - Asphalt binder
    - Aggregate
    - Erosion control
    - Retaining and noise walls
    - Sidewalks
    - Subgrade fill
    - Lightweight embankment fills
    - Backfill for retaining walls and bridge abutments
    - Vibration dampening under rail lines (TREX)
    - Flexible crack sealant
    - Quiet asphalt

http://www.tireindustry.org/features/better_roads.asp

Rubber meets the Road

- Recycled Tires - CDOT
  - I-76 near Pecos Street on old landfill
    - Shredded tires - light-weight fill to minimize subsidence beneath roadway
    - Holding up well since built in 1989-'93
  - I-25 in City of Loveland
    - CSU and CDOT
    - Tire pieces for swelling soil reduction

  - I-25 in Denver (TREX)
    - Beneath light rail for vibration attenuation

Rubber Meets the Road

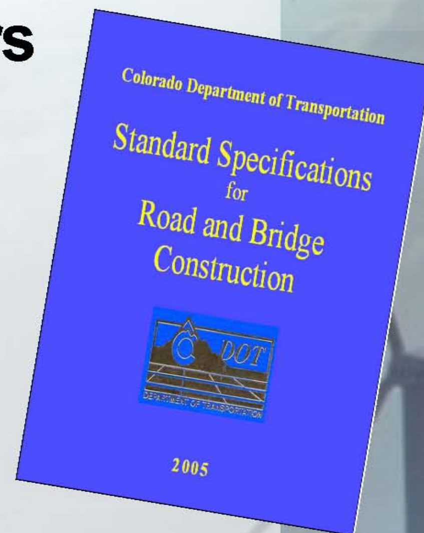
Recycled Tires

- **Colorado Springs testing asphalt-rubber mix on local streets**
  - 6,200 tons in 2006
  - Cost more: $438,000 at $70 a ton, compared with $43 a ton for non-rubberized
  - Savings in longevity, noise, sustainability

- **Cost barrier**

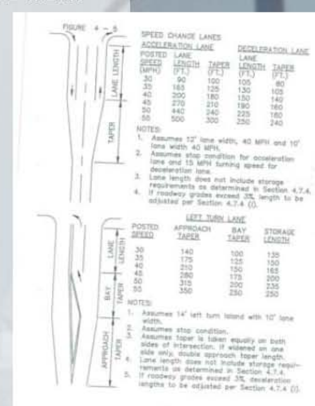
Specifications – the Engineereeze Book

- Review spec book for barriers
- Identifying specific areas for revisions
  - –Materials removal
  - –Erosion Control
  - –Possible Greening specification
- Researching other recycling specifications: DOTs, AASHTO



Tracking – How to Measure Success?

- Initial baseline – Recycled Materials Resource Center reporting
- More information on design plans
- Bid Item Numbers: Cost Data format
- Automatic input to computerized database



Tracking – The Numbers Speak

- **Metrics**
  - Quantities recycled/reused
  - Energy and water conservation
  - Pollution prevention
  - Greenhouse gas avoidance
  - Ozone reduction
  - Opportunity cost reductions

- Zero Waste Goal Credits!

Conclusion – Our Work is not Done

- Recycling: required, money talks!
- Target own reusable materials
- Recycle others' (ash, tires, metal)
- Specification updates and design plans
- Better track and report
- Improve through goal setting
- Spread the word, make it happen
- Follow through

Conclusion

- CDOT to improve recycling through future efforts
  - Presentation of research
  - Sharing successes
  - Reward the pioneers
  - Make sure it works
  - Make it:
    - Easy
    - Better
    - Cheaper
    - Automatic
    - Speak the language!

Project Report

Report Published by CDOT Research

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