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Research Report  
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**RECYCLED MATERIALS IN KENTUCKY  
HIGHWAY CONSTRUCTION**

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## EXECUTIVE SUMMARY

The objectives of this study were to identify and list waste materials which should be recycled to reduce solid waste disposal; report current and past efforts of the Kentucky Department of Highways to utilize recycled and waste materials; determine through a thorough literature search and review, the efforts of other local, state, national and international transportation agencies to utilize recycled materials; and, present preliminary recommendations listing areas where additional recycling efforts appear promising, feasible and needed.

Waste materials that were identified which could be recycled to reduce solid waste disposal included demolition waste (building rubble, recycled concrete pavement, recycled asphalt pavement), rubber tires, plastics, glass, and paper. It has been found that these materials contain recoverable fractions that are potentially useful in highway related applications. Examples of their use in highway construction and maintenance activities have been accentuated and discussed. Additionally, other reclaimed by-product materials have been identified that are effective in highway applications. Those include fly ash, bottom ash, scrubber sludge, AFBC residues, cement and lime kiln dust, and slag aggregates. A significant reduction in the extensive amount of land area required for waste disposal would be achieved through recycling only a portion of these materials.

The Kentucky Department of Highways has actively promoted research into the utilization of by-product materials in highway construction. The Department utilizes significant amounts of by-product materials as a result of the strong commitment to fund research in this area. However, recyclable materials such as rubber tires, plastics wastes, building rubble, waste glass, and waste paper have not been widely used.

Research is recommended relative to the use of recycled rubber in asphaltic concrete mixtures to determine whether any threat to human health or the environment exists, whether asphaltic concrete pavements containing rubber can be recycled, and whether those pavement types provide acceptable levels of performance. High volume uses of discarded tires should be investigated in other highway construction and maintenance applications such as light-weight embankments, retaining walls, and safety hardware. Recycled portland cement concrete as aggregate in paving applications appears feasible. The use of recycled plastic fibers in asphaltic and portland cement concrete mixtures should be evaluated. Innovative uses of recycled paper in highway applications should be studied. The Kentucky Department of Highways should increase high volume uses of fossil-fuel by-product materials that have been proven effective. High volume use of reclaimed asphaltic concrete materials should continue.

In order for the use of recycled and by-product materials to be feasible, a longer life, greatly improved performance, and reduced disposal costs must offset the higher initial costs related to their use.

## INTRODUCTION AND BACKGROUND

In an era when governmental agencies and the general public are demanding increased efforts to recycle materials, the objective of the Kentucky Department of Highways is to increase utilization of recycled and waste materials within the transportation area where it appears promising, feasible and needed. The Department already utilizes a significant number of waste materials in highway projects, including coal fly ash and bottom ash, boiler slag, blast furnace slag, steel slag, and reclaimed paving materials. Over 40,000 tons of blast-furnace slag are used annually as additives to bituminous surface wearing courses (1). During 1990, more than 130,000 tons of reclaimed asphaltic concrete paving materials were used throughout the state. Over the past five years, 1985 through 1990, an average of 160,000 tons per year of reclaimed asphaltic concrete paving materials were used.

According to recent information, the construction, rehabilitation, and maintenance of the nation's highways annually requires nearly 350 million tons of both natural and manufactured construction materials. This includes about 20 million tons of asphalt, 10 million tons of portland cement, and 320 million tons of natural aggregates, paving mixtures, and synthetic surfacing and coating materials (2). The availability of high quality aggregates in some areas is becoming critical. Escalating costs associated with the production of high quality aggregates warrant investigating usage of alternative materials such as recyclable materials, including glass, paper and plastic, and by-product materials including fly ash in highway applications. Current disposal practices encompass the potential for air and water pollution, health hazards, lack of suitable disposal sites, collection and disposal costs, and the loss of resources which may be economically and beneficially recovered through recycling. Many state agencies, including KDOH, have developed or are developing and implementing procedures to include a variety of waste and recycled materials in highway construction and rehabilitation in direct response to the increasing environmental concerns about waste disposal practices.

The Kentucky State Legislature directed that the Finance and Administrative Cabinet establish and promulgate regulations for minimum recycled material content for goods, supplies, equipment, materials and printing used in state agencies. The result of this action was Regulation 200 KAR 5:330, which took effect January 1, 1992. The regulation covers state agency contracts for construction, repair, renovation and demolition of public facilities and implements the provisions of KRS 45A.520. Every state agency must require, to the extent practicable, that every contractor use goods, supplies, equipment, materials, and printing which meet the requirements for the minimum recycled content indicated in the regulation. Furthermore, every state agency authorized to issue bonds

must require, to the extent practicable, that every project within the Commonwealth, 50 percent or more of the cost of which is financed with proceeds of bonds issued by the agency, be undertaken with goods, supplies, equipment, materials, and printing which meet the requirements for the minimum recycled content indicated in the regulation.

The regulation defines post-consumer waste as products or materials that have been discarded by a consumer. Recovered materials are those materials which have been separated, diverted, or removed from the solid waste stream after a manufacturing process. Recovered fly ash is defined as being the component of coal which results from the combustion of coal, and is typically the finely divided mineral residue which is usually collected from boiler stack gases by electrostatic precipitators or mechanical collection devices.

Several materials used in highway construction and maintenance are affected by the emergency regulation. For example, the regulation requires hot-mix asphalt products to contain ten percent post-consumer waste or recovered material. Cement, concrete cribbing, and ready-mix concrete products must contain five percent replacement of cement by weight with recovered fly ash. Gabions, sign brackets, metal bridge planks, metal pipe, steel cribbing, steel piling, steel post, sign and delineator, and open grid flooring made of steel are required to contain ten percent post-consumer waste or recovered material. Guardrail, guardrail posts and component parts are required to contain twenty percent post-consumer waste or recovered material. Glass beads and reflective powders must contain fifty percent post-consumer waste. Boiler slag and railroad rails must be one hundred percent post-consumer waste or recovered material.

Because the Kentucky Transportation Cabinet wishes to promote the utilization of recovered materials, as well as recycled materials within the Department of Highways to the fullest possible extent, the Cabinet requested the Kentucky Transportation Center to make an assessment of existing efforts within the Department of Highways to utilize recycled materials and provide recommendations indicating where improvements and increased utilization of those materials may be successfully implemented. The objectives of the Kentucky Transportation Center were to identify and list waste materials which should be recycled to reduce solid waste disposal; report current and prior efforts of the Kentucky Department of Highways to utilize recycled and waste materials; determine through a thorough literature search and review, the efforts of other local, state, national and international transportation agencies to utilize recycled materials; and, present preliminary recommendations listing areas where additional recycling efforts appear promising, feasible and needed.

## RECYCLABLES AND WASTE MATERIALS

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Demolition waste, rubber tires, plastic, glass, and paper are the most commonly identified waste materials which may be recycled to reduce the amount of solid waste being placed in landfills. It has been estimated that the total amount of waste aggregate resulting from the demolition of buildings and highways in the United States approaches nearly 40 million tons annually. There are three main categories of demolition waste: building rubble, recycled concrete pavement, and recycled asphalt pavement. Building rubble often consists of concrete, wood, iron and steel, bricks, gypsum, earth and mineral matter. Concrete constitutes the major proportion of building rubble. Concrete rubble has been crushed and used as coarse and fine aggregate in new concrete for several applications (3). Recycled pavement concrete has been successfully re-used as aggregate in cement-treated bases, unbound aggregate bases or subbases, concrete pavements, and bituminous pavements.

More than 250 million automobile and 25 million truck tires are disposed of annually in the United States. The total cumulative weight of these tires combine to amount to about 4.3 million tons of waste rubber disposed of per year. Further, an estimated three billion used tires are currently held in disposal piles. Reported uses of discarded rubber tires within the highway industry include; use as noise abatement systems; shoulder reinforcement on highway slopes; channel slope protection; use of granulated, or crumb, rubber as an asphalt additive; and, use of slitted tires as crash cushions.

Plastics constitute roughly six to seven percent of the daily municipal waste stream in the United States. Of that amount, only about one percent is being recycled each year. Commercial uses of recycled plastics within the transportation area include additives in asphaltic concrete wearing surfaces, safety barricades, curbstones, fence posts, and boards.

Approximately six to eight percent of all domestic refuse is glass, 80 percent of which is in the form of glass containers. Each year approximately 15 million tons are disposed of in urban landfills. Uses of waste glass in road construction include: aggregate substitute and mineral filler in bituminous paving mixtures and use as glass beads in reflective paints for pavements. However, there are apparently only limited quantities of glass being reclaimed each year (about one million tons).

Neither the amount of waste paper being placed in landfills nor the amount being recycled was determined. However, use of recycled paper is being investigated as an erosion control mat in Wisconsin. Reportedly, use of the waste paper for erosion control has been largely successful in protecting the bare ground and encouraging seed germination on open slopes. Researchers indicate that the five-ply mat is at least as effective as other erosion control blankets in aiding re-vegetation and will degrade in 6 to 12 months. Waste paper also has been used as a mulch.

It has been estimated that nearly 400 million tons of municipal solid waste are being generated each year within the United States, most of which is being dumped in landfills. Some waste materials, such as demolition debris, rubber tires, plastic, glass and paper, contain recoverable fractions which are potentially useful in highway related applications. There are numerous examples of successful applications in highway construction for each of these materials. By removing these materials from the solid waste stream and recycling them in highway applications, valuable landfill space will be conserved.

Several million tons of by-products, in the form of fly ash, bottom ash, flue gas desulfurization sludge (scrubber sludge), and boiler slag, are produced by coal-fired electric power generation plants each year. In Kentucky alone, more than three million tons of fly ash are produced annually. In 1984, some 51 million tons of fly ash were produced in the United States (4). Nearly 80 percent of this material was dumped into vast disposal ponds. The majority of reclaimed fly ash is used in cement and concrete products. Other uses of fly ash include: structural fills and embankments, road bases when combined with lime, grouting, and as a filler in asphalt mixtures.

## **RECYCLING EFFORTS IN TRANSPORTATION -- A LITERATURE REVIEW**

A search of the literature was conducted to identify articles and reports regarding recycling in the field of transportation. The primary search was on the computer database TRIS, which is the transportation database managed by the Transportation Research Board. A total of 287 abstracts, for the period 1986 to the present, were identified. The catalog of the library at the Kentucky Transportation Center was also searched for articles and journals. Many items dealt with the same topics so a limited number were selected for review to provide a sampling of the topics covered.



Recycling efforts in transportation are varied. Some have been in existence for a number of years while others have only recently been suggested. The various recycling efforts continue to be tested and evaluated. The literature review focuses on recycled asphalt and concrete pavements, recycled tires, paint removal wastes, fly ash, glass, and other miscellaneous recycled materials that relate to transportation. The economic, engineering, and environmental aspects of the recycling procedures reported will be discussed.

The Strategic Highway Research Program is providing funding for small research projects to study the use of different wastes in highway construction (5). The three types of waste materials being studied are used rubber tire products in asphalt mixes, recycled asphalt and concrete pavements, and incinerator residue.

### **Asphaltic Concrete Pavement**

Asphalt pavement recycling did not become practical until the 1970's (6). Today, 80% of the estimated two million miles of streets and highways in the United States are made of recycled asphaltic materials (7). Reclaimed asphalt pavement (RAP) is used to lower street and highway maintenance costs, reduce energy consumption, and conserve landfill space. Canessa also points out that recycling saves materials and speeds up the rehabilitation so the road is opened sooner to traffic (8).

Vollor has also identified cost, environmental and design incentives for recycling asphalt pavements (9). The cost of asphalt cement and aggregates that are used in asphalt pavements has risen dramatically in recent years. Transportation costs have also increased. Because of fuel costs, the further new materials must be hauled, the higher the cost. By recycling and reducing the amount of material being carried, the transportation costs can be lowered. Environmental considerations also had an impact on implementing recycling efforts according to Vollor (9). Proper disposal of old pavement is expensive. More importantly, there is a limited supply of natural resources needed for road construction (oil, good aggregate). The location of these materials is unevenly distributed, meaning the materials often are hauled long distances. The design advantages of recycling identified by Vollor include the following: reflective cracking is eliminated or retarded; dead loads on bridges can be maintained; clearances through tunnels and under bridges are unaffected; drainage patterns can be maintained; existing grades to adjoining surfaces can be met; only that area of pavement needing repair has to be repaired; and, base courses can be repaired. Other advantages include the

strengthening of pavements for increased loads or increased traffic, and improved surface conditions such as skid resistance, smoothness, and weather resistance.

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A number of processes exist for recycling asphalt and several publications give descriptions of these processes which are briefly described below.

### ***Cold Planing***

With cold planing, a certain depth of the asphalt pavement is removed with a milling machine. The RAP, with additional treatment, can be recycled into a smooth pavement with improved performance qualities. Advantages of cold planing include immediate use of the planed surface by traffic, little interruption to traffic flow, reclaimed material can be saved for future use, and the process can be applied to small or big projects. One disadvantage is that only surface distresses are corrected (10).

### ***Cold In-Place Recycling***

Cold in-place recycling uses a milling machine to pulverize the asphalt pavement and cut the roadway to a specified depth. An additive is mixed into the renewed surface. The new mixture is spread and compacted in a single operation (6, 7, and 11). Advantages of cold in-place recycling are that old pavements can be restored to the desired contour, troubled pavement can be eliminated, construction costs are lowered considerably, only a thin overlay of new asphalt is required, and the road can be strengthened. This method has gained wide acceptance in the United States (10).

An application of cold in-place recycling took place on low volume roads in Oregon (12). Scholz, Hicks, Frogge, and Allen report that Oregon has used cold in-place recycling since 1984 as an alternative to conventional operations for rehabilitating asphalt concrete pavements. The authors note that this procedure should not be performed in cold and damp conditions due to the possibility of breaking and constrain curing. The procedure, however, is recommended for rough pavements, cracked and broken pavements, and pavements that have raveled due to age. Cold in-place recycling can produce significant savings in energy and costly construction materials. Based on the studies conducted in Oregon, this process has proven to be a vital rehabilitation alternative for low volume roads and is proposed for use on higher volume roads.

### ***Hot In-Place Recycling***

Hot in-place recycling is a procedure where heaters raise the pavement temperature to 250 degrees F. The softened asphalt concrete is then loosened, mixed, and recompactd. The material does not have to be transported and less overlay material is required. Deformities in the surface are eliminated and a more flexible base is provided that adheres better to any new layers (11).

### ***Hot Mix Recycling***

In hot-mix recycling processes, the existing pavement can be recycled into asphalt hot mixes that perform as well as virgin mixes (7). The three types of asphalt hot-mix recycling are batch plant (30% RAP), drum-mix (50% RAP), and microwave (100% RAP). The mix may be a combination of RAP, reclaimed aggregate materials, new asphalt, new aggregate and recycling agents, which are used to restore the aged asphalt to current standards (10). Benefits of this method are that surface and base structural problems can be corrected, possible improvements in the structure can be obtained without significantly changing the thickness, and the pavement may not be as susceptible to frost.

Florida has saved a great deal of money by recycling asphalt pavements. Page and Murphy report that the Florida Department of Transportation (FDOT) has saved over \$38 million during the past 10 years by using hot-mix recycled asphalt (13). Hot-mix recycling, with a maximum of 60% RAP, became a standard design alternative on all reconstruction projects in 1980. FDOT found the cost of using hot-mix recycling was approximately 25% less than using virgin mixes and the overall energy demand was approximately 40% less. A major concern of FDOT is the property of the final asphalt concrete mix. By adding a rejuvenating agent, the quality, uniformity, and consistency of the asphalt concrete mix can be assured. The performance of hot-mix recycling asphalt concrete has been excellent for nine years in Florida.

### ***Full Depth Reclamation***

In full-depth reclamation, a roadway is turned into the base material for a new surface. The existing pavement and a portion of the underlying material are pulverized, blended, shaped, and compacted. This process is a cost-effective means of eliminating underlying defects in a multiple-layer roadway (11).

### *Foamed Bitumen Recycling*

A fairly new process is foamed bitumen road recycling, as reported by Maurice, Akeroyd and Hicks (14). This method employs the injection of cold water under controlled conditions and with certain additives into hot penetration grade bitumen before application through specially designed nozzles and spray bar. This process has been used for base stabilization (FOAMSTAB) in the United States, Australia, South Africa and Norway. Maurice, Akeroyd and Hicks note that FOAMSTAB recycling restores the structural integrity of road pavements, can be rapidly executed, conserves available resources, and is very efficient.

The process of cold in-place recycling using foamed bitumen has been tested in Dartford, Kent (England). One part of a road was recycled while the other part had conventional reconstruction. The compacted foamed bitumen had a uniform density and showed a high deformation resistance in universal creep stiffness tests. The recycled road was strong enough to withstand light traffic immediately after repair and interruptions to traffic was minimal. A big savings in energy usage was also realized (15).

Based on a survey reported in Better Roads, most states are using some form of recycling to improve pavement cost effectively (16). Recycling operations have been in use since the 1970's in Iowa, Illinois, North Dakota, New Jersey, and Nebraska. Quite a few other states started recycling asphalt pavements in the 1980's. The states that issue contracts with an option to use recycled material at a specified percentage include Maine, North Carolina, Maryland, Nevada, Virginia, Indiana, and Ohio. South Carolina at one time had the option but discontinued it because of problems with RAP stockpiles. Several states stipulate that the recycled material that is used must comply with the standard requirements of a virgin mix. These states are Colorado, New Jersey, Idaho, and Oklahoma. The processes used by the states include hot-mix, cold-mix, and milling.

Several states mentioned their satisfaction with recycling. The fact that it continues to be used is also an indication that recycling is worthwhile. Maryland mentioned a problem that was encountered with RAP. Whole sections of pavement were lifting from the surface and moving. This problem was attributed to inconsistent quality of the milled materials in the stockpiles. Research indicated that the problem could be resolved through improved quality control of the milled material. Tampa, Florida finds that single-pass, in-place surface recycling of asphalt pavement saves \$5,000 per day (17). This process has been used since 1984 but is limited to rehabilitation of the top inch of the

surface. It is inappropriate where pavement distresses are caused by traffic loads. Wallace reports that Tampa found this method to have great potential for conservation of energy and resources, and the reduction of traffic delays, material costs, and personnel.

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### **Cement Concrete Pavements**

Recycling portland cement concrete (PCC) pavement has become a cost-effective rehabilitation option. The recycled PCC pavement, through processing, is turned into aggregate and sand sizes that are used in constructing new PCC pavements or some element of the pavement structure (18, and 19). Yrjanson reports that several developments in the past decade have made recycling of PCC more economical (18). These developments are improved equipment for breaking PCC pavements before the crushing operations, new methods for the removal of steel, and modified crushing equipment that handles steel reinforcement.

The first use of recycled PCC pavements occurred in the mid 1940's. In Illinois during World War II, crushed pavement was used as an unstabilized base. After World War II, Europe used building rubble for new concrete construction. In the United States, recycled PCC was not used again until the 1960's. In 1964, at the Dallas - Fort Worth Airport, crushed concrete was used for a cement-treated subbase. Recycled PCC was used as an aggregate for asphalt concrete on a large-scale job in Texas in 1969. California, in 1975, had the first Econocrete or lean concrete section using recycled PCC. The first PCC pavement using crushed PCC was in Iowa in 1976. In the 1980's, the use of recycled PCC pavement became more common in a number of states (19).

Many of the reasons for recycling portland cement concrete pavement are the same as for recycling of asphalt concrete. Natural aggregate supplies are conserved, the aggregate to be used is at the job site, and disposal problems and costs are reduced. Cost savings are realized through savings in transportation costs, material costs, and energy conservation. Other advantages highlighted by Yrjanson include the possible improvement of substandard geometrics, strengthening or correction of subgrade conditions, maintenance of vertical clearances at bridges, and improvement of drainage (18). A couple of other advantages noted in another publication are that recycling reduces the need for disrupting the land for quarrying and it reduces haul road damage near the paving project (19).

Salvaged PCC pavement has a variety of applications. It can be used as aggregate for bases, surfaces, and chip seals. It can also be used as rip-rap and filter material, and as a supply source for independent commercial operations. Salvaged PCC pavement also has been used for shoulder concrete, porous granular fill, and open-graded drainage layers.

Yrjanson reported results of laboratory studies conducted on the suitability of recycled aggregate and the economic feasibility of recycling (18). Crushed concrete aggregate particles "have good particle shape, high absorptions, and low specific gravity compared with conventional mineral aggregates." There is no significant effect of recycled coarse aggregate on mixture proportions or mixture workability. Crushed concrete used as a fine aggregate make cement concrete mixtures less workable and more cement is needed because of water demand. Concrete made from recycled aggregate shows an increase in freeze-thaw resistance. Aggregate used from concrete pavement prone to D-cracking can improve the durability of new concrete. A D-cracked concrete pavement is characterized by a pattern of cracks running parallel and close to the pavement joint. The cracking is caused by the break down of larger aggregate particles from freeze and thaw action. Fly ash used in addition to the recycled D-cracked aggregate also reduces the potential for D-cracking. The compressive strength of concrete mixtures made with recycled aggregate from low-strength aggregate is not adversely affected.

The first PCC pavement recycling project in Oklahoma is described in a report by Hankins and Borg (20). The work was performed in 1983 on a section of concrete pavement on I-40 that had experienced moderate D-cracking failure in the joints. The contractor for the job chose to recycle the existing PCC pavement because the nearest source of virgin aggregate was more than 50 miles away. Engineers estimated that about \$800,000 were saved by recycling the old pavement rather than purchasing virgin aggregate. The recycling project was bid \$700,000 less than the alternative asphaltic concrete overlay. As a result of the project, recycling of PCC pavements was deemed to be practical. Sufficient coarse aggregate was produced by recycling. The recycled PCC also had the workability and met the strength requirements of virgin mix PCC. In addition, the D-cracking problem was reduced.

### **Used Rubber Tires**

Used tires are a major disposal problem in the United States. They are nearly indestructible and are possible fire, health, safety and environmental hazards. About 3 billion used tires are in various locations in the United States, with more than 240

million being discarded annually (5). Many states have passed legislation allowing a tax on new tires, vehicle title fees, or vehicle registration fees that are to specifically provide funds for the clean-up of old tires (21). One answer to this problem is to recycle the tires.

One way to recycle used tires is to use them in asphalt rubber. Asphalt rubber or rubber modified asphalt is a paving material composed of asphalt and ground recycled tire rubber that is then mixed with aggregate (22). One calculation made in Texas shows that if just 10% of the paving asphalt cement used each year by Texas was replaced with asphalt rubber, some 20% of the tires thrown away each year would be recycled. Asphalt rubber has been used in chip seals or stress absorbing membrane construction, stress absorbing membrane interlayer construction, crack and/or joint sealing, and hot-mix asphalt concrete (23).

Problems or disadvantages of asphalt rubber include higher initial costs of rubberized paving products, and possible health hazards when asphalt rubber pavements are themselves recycled. The health hazards arise because the temperature required for recycling pavement may emit toxic gases if the embedded rubber has degraded (5).

Advantages of asphalt rubber, as reported in two publications, include improved stability and durability, resistance to cracking, improvement in skid resistance under ice conditions, pavements are able to withstand studded tires or chains better, and reduced tire noise levels. In Alaska, asphalt rubber pavement was tested over three winters and there was an average 25% reduction in stopping distances and accidents due to surface frost being eliminated (22).

Florida, Wisconsin, and Arizona have used asphalt rubber in pavements in different ways. Busscher reports that Florida used ground rubber in the final layer of the asphalt surface (24). Asphalt rubber was used with the hope that pavement life would be extended and that pavement flexibility and durability would be increased. Wisconsin used asphalt rubber as a binder and as Stress Absorbing Membrane Interlayers (SAMIs). It was the first time it had ever been used as a binder in a recycling project (25). Wisconsin encountered several problems. After completion of cold rolling and being opened to traffic, the mix was very soft and tender. The lab densities that were required were not obtained either. A possible solution to the soft mix could have been a harder grade of asphalt cement. The densities could possibly have been improved by using a pneumatic-tired roller behind the cold roller. Asphalt rubber was used in Wisconsin because the engineers believed it was cost effective and the problems of potholes, wide spalling cracks, and an uncomfortable riding surface could be corrected by its use. Charania reports that Arizona

has used asphalt rubber in a chip seal (26). One of Arizona's first experiences with asphalt rubber was as a temporary measure to prevent complete pavement failure on a pavement that was in poor condition and badly cracked. The repaired pavement using asphalt rubber has lasted 19 years with very little maintenance. Asphalt rubber treatments prevent reflective cracking and greatly reduced, if not eliminated, surface maintenance for long periods of time. Asphalt rubber has been used successfully, but the author cautions that the pavement structural condition, size of the cracks, intended uses of asphalt rubber and its absorption properties must be carefully considered before using asphalt rubber in pavements.

Old tires can also be reused in other ways besides pavements. Berthelsen reports that Caltrans studied the use of old tires in several different erosion control measures because of legislative direction and the expense of new construction materials (27). The erosion control measures that were studied by Caltrans were shoulder stabilization, tire reinforced wall, and channel slope protection. The advantages of using old tires for shoulder reinforcement include their availability and relative low cost. The shoulders reinforced with tires should not, however, be open to traffic. The Tire Anchored Timber Wall was designed as an alternative to certain retaining walls in rural areas where the unit costs of conventional walls can be high. The tire sidewalls are attached to a metal rod which is attached to the face of the retaining wall that is made of timbers. Additional savings can be realized by reusing old guardrail posts for the timber facing. Channel slopes can be stabilized with discarded tires in low-velocity drainage areas.

Wilson (28) has proposed using old tires for noise barrier walls called Round Sound Rebound Walls (RSRWs). According to the author, such sound barrier walls are more sound absorptive, are aesthetically pleasing, cost less, are environmentally and ecologically appealing, and have impact resistance. Such walls can have the void space left empty or filled with soil for landscaping purposes. The surface of the walls could be covered with a plaster-type surfacing to make the surface fireproof and more aesthetically appealing. Research and refinement of this concept are still needed.

Old tires can also be used as a source of energy. Modesto, California has a new power plant that generates 14.4 MW of electricity by converting old tires to steam using a process developed in West Germany (29). This type of power plant can convert up to seven million tires a year. The whole tire is used so more energy is recovered per tire, and the problems and costs associated with conventional scrap tire processing technologies are avoided. The process is environmentally safe, and the power plant will generate local tax revenues and new jobs. According to Totten, New York is looking into



rubber pyrolysis that transforms old tires into gas (30). This process is expensive and requires a steady supply of tires. The author suggests that states unable to do this on their own because of costs or the lack of enough tires, can form a compact with other states and share the costs and have the necessary supply of tires.

## **Paint Wastes**

Thousands of bridges are coated with lead-based paint. During maintenance operations, removal of the paint along with the abrasive from blasting creates an enormous amount of waste. Health and environmental concerns accompany the lead-paint removal operations. The Environmental Protection Agency requires that paint removal wastes be treated before being disposed. Whatever the procedure used, costs have risen and maintenance has slowed down in many states (31).

An article in The Journal of Protective Coatings & Linings explains some of the ways paint removal wastes are handled (32). Three general strategies exist for dealing with wastes from lead paint removal operations: stabilization and disposal, incineration, and material reuse. In recycling paint removal waste, the waste may be unseparated or it may be minimized. Unseparated wastes consists of the abrasives, paint chips, corrosion by-products, and dust and could possibly be used in construction materials such as asphalt or brick. Techniques for waste minimization include use of recycling abrasives, cryogenic blasting materials, hand or power tool cleaning, ultra high pressure water jetting, and waste separation.

Because of the problems in disposing of blasting abrasive wastes from bridge maintenance operations, the Pennsylvania Department of Transportation (PennDOT) began a study in 1989 to identify and evaluate possible beneficial reuses of such wastes (33). The identified beneficial uses had to meet state and federal environmental regulations. Weyand and Sutton, who conducted the study, determined that recycling blasting abrasive is feasible, but it should be considered a supplementary rather than a primary operation. Whatever the application, the material being recycled will require some upgrading.

The beneficial reuse options considered in the study looked at the reuse of spent blasting abrasives in portland cement concrete, asphalt concrete mixes, cement kiln feeds, blasting abrasive reuse, polishing abrasives, airport anti-skid material, lead smelter feeds, structural clay products, and glass fiber/felt production. The process that met all the

criteria and holds the most promise for Pennsylvania is the use of abrasive wastes as a feed material replacement for structural clay products (bricks). Some of the improvements or advantages include improved performance and strength, similar appearance to bricks, less energy needed for firing the bricks, and the hazardous lead compounds are chemically altered and stabilized. Although PennDOT did not recommend the use of blasting waste in asphalt concrete pavement, North Carolina has reused blasting sand in an asphalt concrete pavement that had acceptable strength and lead leaching characteristics (34).

### **Glass Wastes**

Glass used in asphalt has potential if it is used precisely. The glass reused for asphalt must be only of glass that is not acceptable for higher levels of recycling, and the maximum percent of glass in the asphalt should not exceed 15 percent (35). One concern pointed out by Hughes is the resistance of the glass to moisture damage. Moisture damage tests must be conducted because of the tendency of glass to suffer moisture damage. Although economic benefits are minimal, reusing glass in asphalt pavements keeps the glass out of landfills and is therefore an environmental benefit. In June 1990 New Jersey used recycled crushed glass in bituminous concrete (glassphalt). The pavement made of glassphalt is currently being monitored for long-term skid resistance and stripping (36).

### **Fly Ash**

Fly ash and solid wastes from advanced coal combustion can be or has the potential to be recycled. New Jersey uses fly ash in bituminous concrete. Approximately 15,000 tons in 75,000 tons of mix are used each year. When combined with lime, water, and crushed stone, fly ash forms a base course which costs about 20% less than traditional bituminous bases (36). In Ohio, researchers are studying the potential use of coal combustion solid wastes in land reclamation, agricultural, and road construction applications. Tests will be conducted to see if the wastes are suited for neutralizing acidic soils around old coal mines, reducing acid drainage, stabilizing highway embankments, and use as an agricultural liming agent (37).

## Plastic Wastes

Plastics are beginning to be recycled and used in several transportation applications. In Austria and Italy, porous friction asphalt surfaces use recycled polymers as an additive. The roads have been resurfaced with a blended mix of paving grade asphalt and waste plastics, called Novophalt. This product was introduced and tested in the United States in 1988 and was reported to extend pavement life 50-100 percent. Other advantages include improved drainage, traction, and noise reduction (38). Australia has begun using curbstones made from recycled plastic waste. It is lighter than concrete, can be drilled, is flexible, is resistant to impact and is rot proof. Each eight-foot length is made of 3,200 recycled plastic two quart containers, yet is only 66 pounds. The only disadvantage mentioned is that it is 15% more expensive than concrete. The reduced landfill space is an environmental benefit that may make it worthwhile (39). The Illinois Department of Transportation has tested and approved for use recycled plastic for barricades. The highway barricades, called Safety Cades, are made from recycled high density polyethylene milk containers. Each barricade of Safety Cade is made from approximately 100 recycled plastic milk containers (40).

## Other Materials

Some wastes generated in a fleet maintenance shop can be recycled. An article in the Commercial Carrier Journal covers the reuse of drain oil, refrigerants, antifreeze, solvents, and batteries (21). Approximately 240 million gallons of diesel drain oil are generated each year. Drain oil has been used by many motor carriers as a furnace fuel or a furnace fuel supplement. It provides a cost savings for some fleets and is approved by the EPA if the drain oil is uncontaminated. Uncontaminated drain oil may also be mixed with diesel fuel as a fuel for trucks. The two are blended in either large storage tanks or directly in the truck fuel tank. This process keeps fueling costs down, and prevents the accumulation of water and sludge in saddle tanks.

Equipment for recycling refrigerants, antifreeze and solvents is available. The industry is complicated and fleets must be careful about the type of equipment they purchase or use. Three types of equipment exist that remove the refrigerant and make it available for reuse. Recovery equipment removes and stores the refrigerant from the system without any cleaning or reinstallation performed. Recycling equipment removes and cleans the refrigerant to a specified quality. Reclaiming equipment removes and processes the refrigerant until it is of pristine or virgin purity (21).

Used solvent (parts-cleaning fluid, paint thinner) can be replaced in its working container if it has been removed for on-site recycling using a filtration or distillation process and there has been no interim storage of the solvent. An antifreeze recycling system became available in 1987. To dispose of used antifreeze, the Philadelphia Electric Company's (PECO) fleet shop had been paying \$200 per drum. With the new antifreeze recycling system, the cost to PECO is about \$1.20 per gallon for ready-to-use, recycled coolant. Worn out automotive batteries can also be recycled. Several states have passed legislation to require the collection of battery cores, or to collect taxes or deposits to help fund battery recycling. To recycle a battery, the battery is broken up, the plastic case is shredded, the plates are converted to reusable lead, and the acids are neutralized or reclaimed (21).

Recycling has become an important issue in recent years. The options for recycling in the field of transportation are many and varied. Some are more developed than others. The most activity has been in the area of recycled pavements, primarily asphalt. The engineering, economical and environmental aspects are key to a recycling process being implemented.

### **KENTUCKY EFFORTS TO UTILIZE RECYCLABLE AND WASTE MATERIALS IN TRANSPORTATION**

Construction materials are becoming more difficult and expensive to produce. Costs of mining and processing crushed stone for aggregates has increased over the years. The same may be said of the production of gravels, cements used in concrete, and bituminous materials used for paving materials. Because Kentucky is one of the leading coal producers in the nation, there are abundant sources of by-product materials from mining processes and electrical power generation plants.

Nationwide efforts have been made for some time to find worthwhile uses for fly ash in order to convert a material, that might otherwise be an industrial waste, to a profitable product. Fly ash is the fine cinder collected from the flue gasses in force-draft combustion of powdered coal. During 1958, the Highway Materials Research Laboratory, predecessor of the Kentucky Transportation Center, reported on evaluations of fly ash in combination with lime as a soil modifier (41). Researchers determined that the fly ashes investigated would react hydraulically with lime, although to different degrees, which was essential prior to the evaluation of the materials as soil stabilizers. Fly ashes from different

sources reacted differently due to variations in fineness. The reactivity of coarser fly ashes was improved by grinding to finer sizes. The researchers concluded that various soils would respond similarly to lime-fly ash stabilization as they would to portland cement stabilization except that the rate of strength development would be drastically slower and comparable ultimate strengths might never be reached. Field evaluations were not conducted at that time because of economic considerations. The costs of lime, fly ash, and shipping would have far exceeded the cost of portland cement.

Concurrent with Hardyman's study on lime-fly ash stabilization, Whitney investigated the use of fly ash as a replacement in portland cement concrete (42). The pozzolanic nature of fly ash suggested not only of providing an inexpensive substitute for more expensive concrete mix ingredients, but possible enhancement of the desirable properties of concrete as well, including a reduction in mixing water. Chemical and physical properties of the fly ash were examined. Compressive and flexural strength, and durability tests were performed on eight different mixes. Results of tests on mortar cube and briquette specimens, wherein twenty percent of the sand was replaced with fly ash, completed after sixty days of curing indicated that the compressive strength values were almost double that of the control specimens. It was concluded that the fly ash tested could offer an effective and inexpensive substitute for at least some of the sand in air entrained concrete. Further, Whitney concluded that fly ash, as a replacement for up to twenty-five percent of the cement in air entrained concrete, could provide a material which would be perfectly acceptable for many uses if given curing periods of twenty-eight days or longer. If the use of the fly ash did not require high transportation costs, the fly ash could produce an improved concrete at a lower total expense.

In 1962, the Kentucky Department of Highways initiated a field trial to investigate the use and gain experience in the addition of fly ash to portland cement concrete for pavements (43). A 2.4-mile section of Poplar Level Road, a four-lane highway in Louisville, was selected for the project. The project was divided into three sections; a control section and two experimental sections, one containing 94 and the other 140 pounds of fly ash per cubic yard of pavement concrete. The Department of Highways developed special notes to cover the requirements for the experimental sections. The solid volume of fly ash in excess of that required to replace one bag of cement was considered as fine aggregate. Although not detailed in the report it is estimated, based on the structure's dimensions, that some 355 tons of fly ash, meeting the requirements of ASTM Designation C 350-60T, were utilized during this field trial. Apparently the only difficulty reported during construction of the pavement was in dispensing the correct amount of fly ash from the hopper, however, that problem was quickly remedied by installing new

rollers in the fly ash hopper. Finishers stated that the fly ash concrete had about the same finishing properties as the conventional portland concrete but occasional gumminess or stickiness was encountered when the concrete was not finished immediately after placement.

Researchers investigated both flexural and compressive strengths and freeze and thaw durability of the fly ash concrete and compared those results to those of the control section. Because a reduction in the water requirement could not be obtained as had been achieved in the laboratory, early compressive strengths of the fly ash concretes were somewhat lower than those of the control mix. However, after three months, the compressive strengths of the fly ash concretes exceeded those of the control mix. Freeze and thaw durability of the fly ash concretes was reported to be excellent after 300 cycles of rapid freezing and thawing. However, after 1,600 cycles, samples from experimental section B (140 pounds fly ash per cubic yard) exhibited poor performance. Five performance surveys, covering four years, were reported. Observations noted during the surveys were recorded on strip maps. Cracks, spalls and pop-outs were noted and summarized in tabular form. Cumulative totals given for cracking, spalls, and pop-outs indicated experimental sections A and B exhibited about 32 and 35 percent more lineal feet of cracking per foot of pavement, respectively, than the control section. Experimental section A exhibited six times the number of spalls and more than double the number of pop-outs than the control section. Experimental section B exhibited four times the number of spalls and only slightly more pop-outs than the control section.

In 1969, another experimental fly ash concrete pavement was placed on a section of the Outer Loop in Jefferson County apparently because performance surveys conducted in 1966 on Poplar Level Road were largely inconclusive (44). However, due to previously poorer freeze and thaw durability of the Experimental B mixtures used on the Poplar Level Road project, only Experimental A mixtures were used. Special Provision 70 was developed in 1969 to cover the requirements of the experimental concrete. The Special Provision required "1.25 barrels of cement and 94 pounds of fly ash per cubic yard." Similar evaluations were conducted, i.e. compressive and flexural strength, durability, etc., during the Outer Loop project. Also, the researcher reported on follow-up inspections of the Poplar Level Road project. Average strengths of specimens cast from mixtures placed at the Outer Loop project were somewhat lower than those obtained during the initial field trial but durability factors were similar. It was stated that the experimental sections of the Poplar Road project, inspected during 1970, contained an appreciably larger number of spalls and pop-outs than did the control section. Based on the two experimental projects, researchers concluded that fly ash may be used as a partial

cement replacement for paving concrete. However, no savings in costs were realized on either of the trial projects. Cost data given in the report indicated a unit bid price of \$6.45 per square yard for the fly ash concrete used in the Outer Loop project. During this same time, conventional cement concrete pavements placed within District 5 averaged only \$5.56 per square yard.

Currently, fly ash is being used successfully in Kentucky as an additive to subbase courses, soil subgrades, stabilized aggregate bases, and as cement replacement. Section 844 of the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction covers the general specifications for Class F and Class C fly ash. Requirements for fly ash used in portland cement concrete pavements are contained in Section 501 of the Standard Specifications. Class F fly ash and Class C fly ash may be used to reduce the quantity of cement, except Type 1P cement, up to a maximum of 20 percent and 30 percent, respectively, of the minimum cement content. Fly ash use in structural concretes is covered in Section 601. Use of fly ash in stabilized aggregate bases is detailed in Special Provision Number 70D [91]. The total amount of coal fly ash being utilized annually in Department of Highways' projects is estimated to be 25,000 tons.

Blast-furnace slag, a by-product of iron and steel making processes, has been an approved aggregate since the 1930's and approximately 40,000 tons are currently used annually. Another waste product evaluated in the early 1960's was wet-bottom boiler slag (45). Wet-bottom boiler slag is a furnace ash or cinder derived from coal-fired power plants. The main features of the slag aggregate were sharp edges, irregular shape, hardness, and glassy appearance; these being features which impart skid-resistance to a pavement surface. During 1961, the Division of Maintenance constructed a 1,000-foot test strip on Poplar Level Road for the purpose of evaluating a seal coat containing wet-bottom boiler slag. The aggregate used on the job was obtained from the Clifty Creek Power Plant in Madison, Indiana. Two mixtures were evaluated, the difference being the addition of neoprene rubber latex to the RS-2 emulsion binder. On the basis of the performance of the test section containing the neoprene rubber latex over about a one-week period, engineers with the Maintenance Division decided to seal the approaches and deck of the Clarke Memorial Bridge. The seal coat was placed in October 1961. The aggregate was applied at the rate of 24 pounds per square yard and the emulsion at the rate of 0.3 gallon per square yard. Approximately 300 tons of the wet-bottom boiler slag were used in the seal coat application. In October 1962, a slurry seal was placed on the southbound shoulder of the North-South Expressway in Louisville as a demonstration of wet-bottom boiler slag as a slurry aggregate (46).

In August 1964, wet-bottom boiler slag from the Tennessee Valley Authority's (TVA) Paradise Steam Generating Plant was used on an experimental basis in a 1.25-inch course of Class I, Type A bituminous concrete (47). A Special Note for the experimental use of wet-bottom boiler slag in Class I, Type A, bituminous concrete pavement was developed for the field trial. The Special Note required that 40 percent of the aggregate total, both fine and coarse, be slag aggregate from TVA's plant. A laboratory investigation into the feasibility of using the slag aggregate as a substitute for the natural sand normally required in high-type surface course mixtures preceded the field trial. The most significant hinderance to direct use of the slag aggregate was determined to be its gradation. Between 75 to 90 percent of the slag aggregate was found to exist within the No. 8 to No. 50 sieve range. The maximum amount of No. 8 to No. 50 material, allowed in a Type A surface by KDOH Specifications in force at that time, was 51 percent. In the experimental surface, the proportion of No. 8 to No. 50 material was about 50 percent, just at the upper limit of the specification. There were no reported production or placement difficulties. The average coefficient of friction was reported to be 0.50 approximately two weeks after placement of the experimental surface. Researchers were quite satisfied with the construction and initial performance of the experimental surface but concluded that should the slag aggregate be crushed to a more uniform gradation, its utilization in the transportation area would be greatly enhanced.

Special Provision Number 32 was approved in 1978 and covered the requirements of air-cooled blast furnace slag or other slag aggregate approved by the Bureau. As recently as 1988, more than 20,000 tons of wet-bottom boiler slag were utilized as an additive to surface wearing courses and shoulder seal coats. Unfortunately, the major supplier of this material has found that greater profits are realized when the material is marketed elsewhere as granular roofing materials.

Use of reclaimed materials in bituminous mixtures was approved by the Department in February 1981. Special Provision Number 55 covered the requirements for salvaging existing bituminous pavements. The Special Provision permits use of the salvaged materials in bituminous mixtures. Mixtures containing recycled materials are required to meet all requirements of the job-mix formula. The 1988 edition of the Standard Specifications for Road and Bridge Construction included for the first time a separate section, Section 414, detailing specifications for bituminous mixtures containing reclaimed materials. When the reclaimed material is salvaged from Department of Highways' projects; i.e., the material met Kentucky highway specifications when it was originally placed, the maximum amount that may be used in a bituminous mixture (by weight of the total mixture) is 30 percent. If the material was salvaged from other



sources, then only 20 percent is allowed to be used in a bituminous mixture. Reclaimed materials are not permitted in open-graded friction courses, sand asphalt surfaces, Class A bituminous concrete surfaces, other wearing courses intended to be highly skid resistant, unless it is documented to the Engineer's satisfaction that the material met the aggregate requirements when originally placed. During 1990, more than 130,000 tons of reclaimed asphaltic concrete paving materials were used throughout the state. Over the past five years, 1985 through 1990, an average of 160,000 tons per year of reclaimed asphaltic concrete paving materials were used.

The Highway Materials Research Laboratory did an extensive amount of research on synthetic rubberized asphalts and mixtures during the late 1950's and early 1960's. It was generally concluded that rubber was not beneficial under the conditions evaluated at that time. The rubber relaxed, offered only nominal tractive resistance, and mobilized only minor forces within the limits of strains within a pavement. It was thought that longer fibers might be more beneficial with respect to imparting tensile strength to the paving course. An experimental field trial was not executed due to the poor laboratory performance of the rubber asphalt mixture.

An experimental recycling demonstration project was conducted by TVA in Kentucky's Land Between the Lakes and completed during the summer of 1974. Some 300 old rubber tires were shredded and combined with regular liquid asphalt (two pounds of pulverized tire particles per gallon of liquid asphalt binder) to apply a chip seal to a 0.6-mile, heavily traveled, road leading to the Rushing Creek Campground. Engineers with TVA stated the chip seal was about 45 percent more expensive than using customary chip seal but thought that if the pavement proved to be more durable and more maintenance free, then it would be cheaper in the long run. After a 2-1/2-year evaluation, engineers reported negligible cracking and concluded the new surface was more durable than conventional asphalt sealing mixtures and recommended using reclaimed rubber for resurfacing roads in certain situations, especially where fatigue cracking had occurred. Neither the Kentucky Department of Highways nor the Highway Materials Research Laboratory were involved in this project.

More recently (1978-1979), various plans were made by the Department to participate in FHWA's Demonstration Project Number 37, "Discarded Tires in Highway Construction." It was planned to use crumb rubber from discarded tires for part of the asphalt binder. Asphalt-rubber projects were planned in Kentucky for I-65 in Warren County, I-71 in Carroll County, and U.S. 42 in Trimble County. However, in January 1980, the Department notified FHWA that it was no longer interested in constructing the

demonstration sections using discarded tires for part of the asphalt binder. The State Highway Engineer at that time cited higher initial costs of the material as the primary reason the Department chose not to participate.

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Presently, the Department has only one specification for the use of crumb rubber in asphalt. Special Provision Number 79 [88] covers the requirements for Stress Absorbing Membrane Interlayers (SAMI). This treatment is used over badly cracked pavements prior to resurfacing to reduce the occurrence of reflective cracking. A SAMI is also specified for use above stabilized aggregate bases to prevent development of a bond between the stabilized aggregate base and subsequent bituminous pavement layers. Applications of the SAMI have been very successful in minimizing reflective cracking of asphaltic concrete pavements. Under Special Provision Number 79, a contractor may use either asphalt-rubber or polymerized emulsion. Thus far, however, only the polymerized emulsion has been used because it is much less expensive than asphalt-rubber. Crumb rubber has also been used for some years in crack and joint sealers at the option of the manufacturer but is not specifically specified.

The Federal Highway Administration sponsored Demonstration Project Number 47 in the mid-70's which addressed recycling cement concrete pavements. Apparently, Kentucky did not participate in the demonstration project although Special Provision Number 52 [79], governing the requirements of recycled concrete pavement for use as a dense graded aggregate base, was developed for the project.

In May 1987, the Kentucky Transportation Center initiated a study to determine the feasibility of using fossil-fuel by-product materials in highway construction. Prior to that time, by-product materials had been used only on a limited basis in Kentucky. Research and evaluations had been largely conducted on a localized basis (48). Pavement bases had been constructed using a mixture of fly ash-lime kiln dust-aggregate for one arterial street and several residential streets in Fayette County (49). Approximately 1,114 tons of Class F fly ash and 1,114 tons lime kiln dust, a by-product from the production of lime, were utilized during construction of a 1.7-mile segment of Man O' War Boulevard in south Lexington during 1983 and 1984 (50). The performance of that material has been excellent thus far and future use was recommended.

In 1983, the Center conducted a laboratory analysis of flue gas desulfurization sludge (scrubber sludge) and pond ash for potential application as a highway subbase and/or embankment material (51). The laboratory study confirmed that scrubber sludge from the Big Rivers Power Plant in Seebree, in combination with pond ash from the same

plant, could be used for either application. During 1984, the optimum laboratory mix design of scrubber sludge and pond ash was used while constructing the subbase of Seebree Bypass, KY 494, in Webster County. The amount of waste material used could not be determined. The performance of the subbase has been excellent to date. The constructed base material apparently has had no adverse effects upon the environment and future use is recommended. However, for economical utilization, it is essential to have that project near the source of the waste material. Cost savings from the use of scrubber sludge mixtures result from a reduction in thicknesses of more expensive base and surface course materials. It is likely that the most economical use for scrubber sludge would be for low-fatigue roads.

Additional uses of fossil-fuel related by-product materials have resulted because of a strong commitment by the Kentucky Transportation Cabinet to identify uses for these materials in highway construction applications. Nearly 200 tons of wasted bottom ash from the Kentucky Power Company's Big Sandy Power Plant, near Louisa, were used in a one-mile section of the bituminous surface overlay placed on route KY 3 during September 1987. Based upon visual surveys and skid resistance measurements that have been taken, the performance of the bottom ash surface mixture has exceeded expectations. Because the bottom ash was made available to the contractor at no cost, a cost, economic comparisons to conventional bituminous mixtures could not be performed. The use of bottom ash in highly skid resistant bituminous surface courses may not be economical if one considers the higher bitumen content (about 8.5 percent for this project) and whether the aggregate has to be purchased and transported. Nevertheless, the apparent success of this field trial warrants further consideration of the use of bottom ash as a replacement for a portion of the conventional aggregates used in bituminous mixtures.

Two by-product materials were utilized in the modification of a soil subgrade of KY 11 (52). Materials used were multiclone kiln dust, a by-product from the production of lime, and spent lime, a by-product from an atmospheric fluidized bed combustion (AFBC) process used to crack crude oil. The multiclone kiln dust (MKD) was supplied cost free by Dravo Lime Company, Maysville. The spent lime was supplied cost free by Ashland Oil Company, Catlettsburg. A Special Note was developed for this project which detailed the use of the experimental materials and construction specifications. Approximately 580 tons of MKD and 2,000 tons of AFBC spent lime were utilized during the project. Because the materials were supplied at no cost, cost comparisons with more conventional soil modification admixtures (hydrated lime and Type 1P portland cement) were not performed.

The performance of the MKD section, compared to sections wherein hydrated lime or portland cement was used to modify the characteristics of the soil subgrade, has been excellent. The MKD appears to be an excellent soil modifier. The cost of the material would certainly influence future potential uses. However, transportation and other costs associated with the MKD should be similar to conventional soil modifiers. The initial performance of the AFBC spent lime sections however, was not satisfactory. The pavement surface in the two sections wherein AFBC spent lime had been incorporated in the soil exhibited noticeable signs of non-uniform heave or swelling. The humps generally formed perpendicular to the centerline of the roadway and caused a very uneven ride. The pavement swell appeared to be greater during the wet winter months, indicating the AFBC spent lime modified soil had a great affinity for water. Tests conducted on the modified soil indicated that although the moisture content had increased, there were no apparent reductions in the bearing capacity of the modified subgrade. The humps were later milled and the bituminous pavement was overlaid. Performance of the AFBC spent lime sections has been acceptable since that time. There have not been any apparent detrimental environmental effects due to the use of these materials. The AFBC spent lime obviously did not perform initially as expected and most likely should not be used as a soil modifier until additional research provides answers for its use.

Research Report UKTRP 87-15 describes the development and implementation of a no-cement concrete mixture containing pulverized fuel ash and atmospheric fluidized bed combustion residue (AFBC), (both from the Tennessee Valley Authority's Shawnee Power Plant, near Paducah), combined with conventional limestone aggregate to form a highway road base (53). The report presents a summary of laboratory evaluations and the application of those results to the design of a roadway base, construction, evaluation and performance of the pilot application of this material used as a base for a thin bituminous pavement. The total volume of AFBC residue utilized was approximately 32 cubic yards. Costs estimates were not available because the project was constructed using Tennessee Valley Authority (TVA) personnel and the construction materials were contributed by TVA for the pilot application. Staff members from TVA's Performance Evaluation Section assured UKTC staff personnel that the AFBC material was environmentally safe. The test section performed admirably with no cracking or deterioration observed. Deflection analyses indicated superior strength of the experimental base material relative to conventional, unbound, crushed stone, base materials. The mixture was recommended for further use.

The Kentucky Department of Highways permitted use of the AFBC concrete road base and an AFBC stabilized pond ash subbase as alternates to conventional materials for the 1.5-mile reconstruction of KY 3074 in central McCracken County. A Special Note was developed for this project which detailed the use of the materials and construction specifications. The mix design used for the AFBC concrete base pilot application described above was modified only slightly for this project. The AFBC stabilized pond ash mixture that was chosen for use had the most consistent strength gain characteristics of six different mixtures as determined through extensive laboratory testing.

Two 750-foot experimental sections were constructed during May and June 1988. One section contained the AFBC concrete base mixture and the other section contained the optimum AFBC stabilized pond ash mixture. Approximately 182 tons and 277 tons of AFBC residue were utilized constructing the AFBC concrete base and AFBC stabilized pond ash subbase sections, respectively. Additionally, about 591 tons of pond ash (bottom ash and fly ash) were utilized constructing the AFBC stabilized pond ash section. The AFBC residue and pond ash materials were made available to the contractor by TVA at no cost for this experimental project. The performance of these two experimental sections was greatly disappointing, primarily due to the considerable expansion of the base and subbase mixtures. It is highly probable that the AFBC residue was not fully pre-hydrated prior to its use, which is required to minimize the expansive effects of the AFBC residue. It was thought the pre-hydration step was accomplished satisfactorily and the performance of the material would imitate that of the pilot project. However, that was not the case. Expansion of the base and subbase materials proved detrimental to the performance of both sections. Deflection measurements taken during the study also indicated a weakening pavement structure.

Repeated maintenance expenditures on the two experimental sections and the overall deterioration of the AFBC concrete base section necessitated their removal in September, 1991, after a three-year trial. With respect to environmental concerns, personnel from TVA's Performance Evaluation Section installed lysimeters below and within the AFBC concrete base for leachate analyses. Also, wells were drilled to monitor groundwater. However, because TVA personnel suspended monitoring activities, results of these environmental monitoring actions are unknown. Because the AFBC residue was used successfully in the trial application at TVA's Shawnee Power Plant Reservation, this failed application should not discourage its future use. With proper construction controls, other successful applications similar to the pilot application should be possible.

Also included in the field trials at KY 3074 was a third experimental section which utilized ponded fly ash waste from the Shawnee Power Plant (54). Three stabilized aggregate base mixtures containing various proportions of dense graded aggregate, ponded fly ash, and hydrated lime were evaluated in the laboratory relative to maximum dry density, optimum moisture content, and unconfined compressive strength. An optimum mixture was chosen on the basis of strength development. A 750-foot section of the experimental roadway base was constructed in late May 1988. Approximately 80 tons of the ponded fly ash were utilized constructing the experimental base section. Performance of the bituminous layers above the experimental base course has been exceptional, especially when compared to the conventionally constructed control section. Rutting of the asphaltic concrete layers above the experimental base has been minimal. Rut depths obtained for the experimental section and the control section indicated the control section had nearly twice the magnitude of rutting. The ponded fly ash-hydrated lime-limestone aggregate base course enhanced the overall performance of the pavement. The constructed base material is environmentally acceptable and future use was recommended.

During the summer of 1990, the Tennessee Valley Authority was given permission by the Department of Highways to construct an embankment, or fill, on KY 176 near TVA's Paradise Steam Plant in Muhlenberg County using pure scrubber sludge (oxidized) from the power plant. Preliminary testing of the scrubber sludge was conducted by Transportation Center personnel. Construction of the 15-foot embankment and related construction detours utilized approximately 120,000 cubic yards of the scrubber sludge material from stockpiles on the reservation. The proximity of the stockpiles to the job site ensured the cost effectiveness of the operation and the performance of the fill has been excellent thus far. The constructed embankment is environmentally acceptable, according to staff members from TVA's Performance Evaluation Section, and future use is recommended.

The Department of Highways has long been a strong proponent of research to determine engineered uses of waste materials in highway applications. Based upon the experience and knowledge gained through research of these materials, it appears quite probable that extended pavement life may be obtained by using some of the abundant by-product materials located throughout Kentucky such as ponded fly ash, ponded bottom ash, scrubber sludge, and residue from AFBC processes, in constructing highway facilities. Increasing the utilization of these waste materials will decrease the vast amount of land area required for their disposal.

## SUMMARY

The objectives of this study were to identify and list waste materials which should be recycled to reduce solid waste disposal; report current and prior efforts of the Kentucky Department of Highways to utilize recycled and waste materials; determine through a thorough literature search and review, the efforts of other local, state, national and international transportation agencies to utilize recycled materials; and, present preliminary recommendations listing areas where additional recycling efforts appear promising, feasible and needed.

Waste materials which can be recycled to reduce solid waste disposal have been identified. They include, but are not limited to, demolition waste, automobile tires, plastics, glass, and paper. It has been found that these materials contain recoverable fractions that are potentially useful in highway related applications. There are numerous examples of their successful use in highway construction and maintenance practices. Recycling only a portion of these waste materials could significantly reduce the land area required for their disposal.

The Kentucky Transportation Cabinet has long been an active proponent of the engineered uses of waste materials in highway related construction and maintenance activities. Further, the Cabinet has sponsored significant research in this area. Foremost among fossil-fuel related by-product materials to be utilized in highway applications is fly ash. Beginning in the late 1950's, the Department initiated research through the Highway Materials Research Laboratory to investigate the use of waste fly ash as a soil modifier and as a partial replacement for cement in concrete pavements. Subsequently, fly ash was investigated for use as a component in stabilized aggregate road bases. Fly ash has been used effectively as a cement replacement, as an additive to subbase courses, in combination with lime or lime kiln dust in stabilized aggregate bases, and in soil subgrades. Wasted bottom ash also has been used quite successfully in a bituminous surface mix.

Other uses of fossil-fuel related by-product materials in highway applications have been demonstrated. Scrubber sludge has been used successfully as a subbase material and as embankment fill material. Scrubber sludge can be used economically and effectively for low-volume roads, provided the projects are near the source of the waste material. Highway embankments constructed of scrubber sludge appear to be promising and are very high volume usage of the waste material. Atmospheric fluidized-bed combustion

residue appears useable as a chemical modifier of highway subgrades and when used in combination with fly ash, it may be suitable in stabilized road base applications. However, very strict controls must be exercised when using these materials because of their intrinsic expansive properties. Multi-clone kiln dust and lime kiln dust, waste by-products from the production of lime, have been used successfully as subgrade modifiers and in combination with fly ash in stabilized aggregate bases.

The Department has experimented with the use of wet-bottom boiler slag in seal coats and in a bituminous concrete mixture. The use of wet-bottom boiler slag in seal coats was effective. However, use in a bituminous mixture did not prove to be as beneficial. The Department has utilized more than 20,000 tons annually of this waste material in shoulder seal coats. Unfortunately, the major supplier of the material has found that greater profits are realized when the material is marketed as granular roofing materials. Thus, the price of the material is beyond the Department's means. Over 40,000 tons of blast-furnace slag and 5,000 tons steel slag are used annually in Kentucky as additives to bituminous wearing courses.

Discarded tires have not been used in any way in Kentucky highway projects. An experimental project conducted by the Tennessee Valley Authority using rubber reclaimed from waste tires was constructed in the Land Between the Lakes. That experiment was purported to be successful. Various plans were made during the late 70's by the Department of Highways to participate in FHWA's Demonstration Project Number 37, but higher initial costs of the material were cited as the primary reason not to participate in the study. The Department does permit use of an asphalt-rubber, at the contractors option, in the construction of a SAMI. However, a polymerized emulsion, which is also an option specified in the Special Provision covering the requirements for a SAMI, has always been used by contractors. The reason an asphalt-rubber has not been used in a SAMI application is because it is much more expensive than the polymerized emulsion.

Reclaimed asphaltic concrete materials have been utilized in the Department's bituminous mixtures since the early 1980's. Use of reclaimed materials in bituminous mixtures was first approved by the Department of Highways in February 1981. Specifications for bituminous mixtures containing reclaimed materials are now contained in Section 414 of the Department's Standard Specifications for Road and Bridge Construction. The use of reclaimed materials in bituminous mixtures has increased over the years. During 1990, more than 130,000 tons of reclaimed paving materials were used.



The Department did not participate in a demonstration project sponsored by the Federal Highway Administration in the mid-70's. Demonstration Project Number 47 addressed recycling cement concrete pavements for use as aggregate elsewhere. A Special Provision governing the requirements of recycled concrete pavement for use as a dense graded aggregate base was developed for the project but never implemented.

Successful uses of recycled and waste materials have been documented through a literature review. Today, 80 percent of the estimated two million miles of streets and highways in the United States are comprised of recycled asphaltic materials. A number of asphalt recycling processes exist and several publications give descriptions of these processes. Lower street and highway maintenance costs, reduced energy consumption, and conservation of landfill space results when reclaimed asphalt pavement is used. Reportedly, many of the reasons for recycling portland cement concrete pavement are the same as those given for recycling asphalt concrete. Natural aggregate supplies are conserved, the aggregate to be used is at the job site, and disposal problems and costs are reduced. Cost savings are realized through savings in transportation costs, material costs, and energy conservation.

Used tires are a major problem in the United States. They are nearly indestructible and are possible fire, health, safety and environmental hazards. One way to recycle used tires is to use them in asphalt rubber. Asphalt rubber, or rubber modified asphalt, is a paving material composed of asphalt and ground recycled tire rubber that is then mixed with aggregate. Asphalt rubber has been used in chip seals or stress absorbing membrane construction, stress absorbing membrane interlayer construction, crack and/or joint sealing, and hot-mix asphalt concrete. Reported advantages of asphalt rubber include improved stability and durability, resistance to cracking, improvement in skid resistance under ice conditions, pavements are able to withstand studded tires or chains better, and reduced tire noise levels. Reported disadvantages of using asphalt rubber include higher initial costs of rubberized paving products, increased air pollution, and possible health hazards when asphalt rubber pavements are themselves recycled. It has been widely reported that the use of asphalt rubber applications increases the initial in-place construction costs by as much as 50 to 100 percent. Several states have reported that the production of rubberized mixtures noticeably increase the amount of air pollution. Visible emissions occur at the plant site. Health hazards arise due to the temperature required for recycling pavement. At elevated temperatures, toxic gases are emitted if the embedded rubber degrades. Old tires can also be reused in other ways. Reported uses include; noise abatement systems; shoulder reinforcement on highway slopes;

embankment construction; channel slope protection; and, use of slitted tires as crash cushions.

Abrasive paint removal wastes have been found to be quite acceptable as a feed material replacement for bricks in Pennsylvania but not for asphaltic concrete pavement. However, North Carolina has used blasting waste from removal of leaded bridge paint in an asphalt concrete pavement and found the pavement to have acceptable strength and lead leaching characteristics. Waste glass that cannot be used in higher levels of recycling has been used in asphaltic concrete pavements. The maximum percentage of waste glass should not exceed 15 percent. Moisture damage or stripping may be a problem if the waste glass is not used properly. Economic benefits reportedly are only minimal.

Plastics are beginning to be recycled and just beginning to be used in transportation applications. Recycled polymers have been used in combination with paving grade asphalt to construct porous friction courses. Reported advantages include extended pavement life of 50 to 100 percent, improved drainage, traction, and noise reduction. Safety barricades have been made from recycled plastic. Curbstones have also been manufactured using recycled plastic. Disadvantages were reported to be higher initial costs.

## CONCLUSIONS AND RECOMMENDATIONS

Waste materials that were identified which could be recycled to reduce solid waste disposal include, but are not limited to, demolition waste, (building rubble, recycled concrete pavement, recycled asphalt pavement) rubber tires, plastics, glass, and paper. It has been determined that these materials contain recoverable fractions that are potentially useful in highway related applications. Examples of their use in highway construction and maintenance have been discussed. Additionally, other reclaimed by-product materials have been identified that are effective in highway construction and maintenance activities. Those include fly ash, bottom ash, scrubber sludge, AFBC residues, lime kiln dust, boiler slags, blast furnace slags, and steel slags. Certainly, by recycling only a portion of these waste materials, a significant reduction in the amount of land area required for their disposal would be achieved.

The Kentucky Department of Highways has actively promoted research into the utilization of waste materials in highway construction although the State of Kentucky is blessed with an immense supply of high quality aggregate. Currently, the Department

utilizes significant amounts of coal fly ash, lime kiln dust, slag aggregates, and reclaimed asphaltic concrete materials in the construction and maintenance of the State's highways. Additionally, experimental uses of scrubber sludge, coal bottom ash, multi-clone kiln dust, and AFBC residue have been evaluated in the laboratory and in field trials. Scrubber sludge and coal bottom ash are recommended for increased usage based upon performance in the field.

Rubber tires, plastics wastes, building rubble, waste glass, and waste paper have not been used. Quite often, the primary reason for not using these material types are the higher initial costs associated with their use. In actuality, when the higher initial costs associated with the use of recycled materials are considered, it becomes readily apparent that less lane-miles can be built and, generally, that is the driving force behind decisions made not to use these materials. In order for the use of recycled and by-product materials to be feasible, a longer life, greatly improved performance, and reduced disposal costs must offset the higher initial costs related to their use.

It is recommended that the Department continue using those fossil-fuel by-product materials that have been proven with regard to engineering specifications, and environmental and economic considerations. Significant use of reclaimed asphaltic concrete materials should continue. Supplies of quality, natural aggregates are conserved, and lower street and highway maintenance costs are realized due to reduced energy consumption and transportation costs.

Research should be conducted to provide the necessary information needed to develop and implement specifications regarding the use of the other recycled products. Ground, or shredded, recycled rubber tires have been found to extend pavement life but the initial cost could be as much as 50 to 100 percent more than the cost of using virgin aggregates combined with asphalt cement. Other use options should be investigated. Uses such as noise abatement systems, embankment construction, channel slope protection, and as crash cushions should be investigated. Recycled tires used in these ways would largely eliminate the need for extensive processing of the tires prior to their use.

The Intermodal Surface Transportation Efficiency Act of 1991 requires that "beginning on an annual basis on July 1, 1995, each state must certify that it has satisfied a minimum utilization requirement for asphalt pavement containing recycled rubber .... 5 percent for 1994; 10 percent for 1995; 15 percent for 1996; and 20 percent for 1997 and each year thereafter." Only in the event that reliable evidence indicating the use of recycled rubber in asphalt pavements substantially increases the threat to human health or the environment, or that asphalt pavements containing recycled rubber cannot be

recycled, or that the asphalt pavement containing recycled rubber does not perform adequately, can the United States Secretary of Transportation set aside the provisions of the use of recycled rubber in asphaltic concrete pavements. Obviously, there are many unanswered questions with regard to the use of recycled rubber in asphaltic concrete pavements that can only be answered through extensive research.

The Kentucky Department of Highways should promote research to evaluate recycled portland cement concrete pavements. In some areas of the state, construction materials are becoming more difficult and expensive to produce. Regions within the state that are deficient in high quality aggregates should be targeted. In-place recycling of old portland cement concrete pavements could offset higher delivery costs associated with transporting aggregates into the region.

Waste glass should be used for glass beads and reflective powders for pavement demarkation. The use of waste glass in asphaltic concrete mixtures is not thought to be economically feasible within Kentucky due to a limited supply and problems associated with stripping. Recycled plastic fibers should be investigated for use asphaltic and portland cement concretes. If determined to be cost effective, the use of recycled waste plastics as curbstones, safety barricades, safety traffic cones, fence posts, park benches, and picnic tables could be implemented and increased throughout the state. Innovative uses of recycled paper should be investigated.

The Kentucky Department of Highways should increase high volume uses of fossil-fuel by-product materials that have been proven effective. High volume use of reclaimed asphaltic concrete materials should continue. Research must be performed relative to the use of recycled rubber in asphaltic concrete mixtures to determine whether any threat to human health or the environment exists, whether they can be recycled, and whether they provide acceptable performance. High volume uses of discarded tires should be investigated in other highway construction and maintenance applications. Recycled portland cement concrete as aggregate in paving applications appears feasible. The use of recycled plastic fibers in asphaltic and portland cement concrete mixtures should be evaluated. Innovative uses of recycled paper in highway applications should be studied.

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