The Road to Reuse

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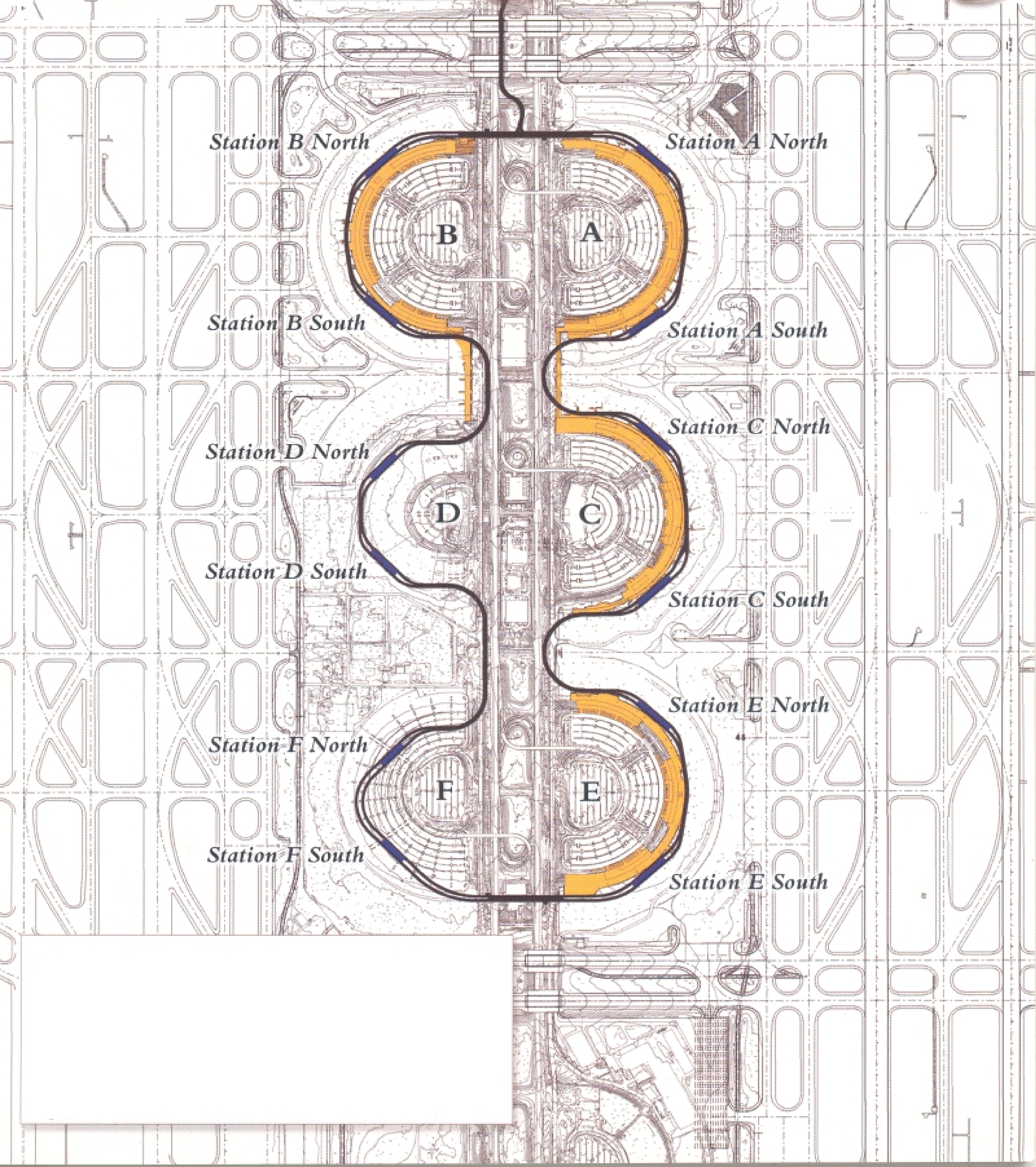

THE ROAD TO REUSE

A wealth of information is available both in the United States and abroad regarding the use of recycled materials in highway construction, and several states have active recycling programs. New partnerships may help the private sector, universities, research institutions, government bodies, environmental groups, and the public to coordinate their efforts. **By T. Taylor Eighmy and Bryan J. Magee**

Why should we as a society continue to dispose of materials that may have inherent engineering value and suitable environmental properties and continue to rely on nonrenewable natural resources in constructing the U.S. infrastructure? Shouldn't we be making a concerted effort to use recycled materials as substitutes for natural aggregates or materials in the construction of highway infrastructure? Indeed, these materials may become increasingly deserving of consideration as we tackle deteriorating infrastructure problems in the United States. And the use of recycled materials in lieu of natural materials may provide additional environmental benefits through better performance and lower cost because there would be less need to mine, process, and transport traditional materials.

There are many types of wastes and by-product materials with potential uses in the highway environment. Ground recycled asphalt pavement, crushed reclaimed concrete, foundry sands, coal bottom ash, blast furnace slags, nonferrous slags, steel slags, quarry by-products, shredded tires, and glass cullet can all serve as aggregate substitutes. Cement kiln dusts, silica fume, ground-granulated blast furnace slag, class F coal fly ash, and class C coal fly ash can serve as alternative cementitious materials. Ground recycled asphalt pavement, roofing shingle scraps, and ground rubber can serve as sources of asphalt cement or asphalt modifiers. And coal combustion by-products, wood ash, sludge ash, composted biomass, and ground wood wastes can serve as soil amendments, soil cover, mulch, and erosion control materials.

Applications for recycled materials within the highway environment include both bound and unbound uses: asphalt pavement, portland cement concrete pavement, granular bases and subbases, stabilized bases, embankments, structural fills, flowable fills, soil cover and erosion control, and appurtenances. Materials such as reclaimed asphalt pavement (RAP) are widely recycled using both in-place and off-site recycling methods. More than 45 states use RAP. The National Asphalt Paving Association reported in April 2000 that RAP has one of the highest recycling rates in the United States—close to 80 percent. About 73 million tons (66 million Mg) are recycled each year, saving taxpayers almost $300 million annually.

A recent, but incomplete, compilation of materials recycled in the highway environment in the United States shows that other materials are recycled annually at reasonable rates. These annual usage and recycling rates are worth noting: blast furnace slag—24 million tons (12.6 million Mg), 90 percent recycling rate; coal fly ash—16 million tons (14.6 million Mg), 27 percent; coal bottom ash—4.8 million tons (4.4 million Mg), 30 percent; coal boiler slag—2.3 million tons (2.1 million Mg), 91 percent; cement kiln dust and lime kiln dust—9.1 million tons (8.3 million Mg), 31 percent; and steel slag—8.3 million tons (7.5 million Mg), percentage unknown. However, the number of states that use recycled materials varies significantly, as do the approaches states take in conducting beneficial use determinations, particularly on less traditional materials. There is a general sense that states with higher industrial activity use more of the resulting by-products—foundry sands and slags, for example. There also appears to be a relation between a state's commitment to recycling and the maturity of the beneficial use program in that state.

A number of European countries have routinely used recycled materials since the 1970s with a high degree of success. What is remarkable about the European story is the

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recycling rate of materials used (material used/material produced) in the highway environment, with rates of 100 percent frequently noted. The Netherlands, a populous country with more limited aggregate resources and a high degree of industrialization and interest in land reclamation, is the best example. The annual reported totals of metric tons used, together with the recycling rates, are as follows: steel slag—0.5 million, 100 percent; blast furnace slag—1.2 million, 100 percent; coal bottom ash—0.08 million, 100 percent; coal fly ash—0.85 million, 100 percent; construction and demolition aggregates—9.2 million, 100 percent; municipal solid waste combustion bottom ash—0.8 million, 100 percent; and RAP—10.7 million, 100 percent.

Data from a variety of sources suggest potential sources of recycled materials for use in the highway environment. In their paper "Utilization of Waste Materials in Civil Engineering," R.J. Collins and S.K. Ciesielski cited four major sources of waste and by-product materials for highway use: agriculture (2,100 million tons [1,905 million Mg] per year), domestic (200 million tons [181 million Mg] per year), industrial (400 million tons [363 million Mg] per year), and mineral (1,800 million tons [1,633 million Mg] per year). Combined, these account for about 4.5 billion tons per year.

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Recent data from the Federal Highway Administration (FHWA) indicate that in 1997 there were almost 4 million mi (6.4 million km) of roads in the United States—4 percent under federal jurisdiction, 21 percent under state jurisdiction, and 75 percent under local jurisdiction. Data from 1992 on material uses in the highway environment from the National Research Council show that the construction, rehabilitation, and maintenance of U.S. highways require about 350 million tons (318 million Mg) of natural and manufactured materials, including 20 million tons (18 million Mg) per year of asphalt, 10 million tons (9 million Mg) per year of portland cement, and 320 million tons (290 million Mg) per year of natural aggregates, paving mixtures, and synthetic surfacing and coating materials. It is interesting to contrast these numbers with the data presented on waste and by-product production. Undoubtedly, these numbers have increased.

ASCE's *2001 Report Card for America's Infrastructure* indicates that one-third of the nation's roads are in poor or mediocre condition, costing American drivers an estimated $5.8 billion and contributing to as many as 13,800 highway fatalities each year. Additionally, the assessment quotes FHWA findings that 29 percent of the nation's bridges are structurally deficient or functionally obsolete and its estimate that eliminating all bridge deficiencies would cost $10.6 billion over the course of 20 years. There is a critical need for a significant investment of money and material to help alleviate these conditions and for changes in transportation behavior, transportation investment, and the application of innovative technologies. How much of this necessary rehabilitation can make appropriate use—both economically and from long-term engineering and environmental performance perspectives—of the materials already present in pavements, base courses, subbases, embankments, bridge decks, and bridge abutments? What other waste or by-product material might be used?

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) gave high priority to research on recycling. Largely as a result of this focus, the FHWA and the National Cooperative Highway Research Program (NCHRP) sponsored several projects related to recycling, all of them national in scope. Other federal agencies have developed guidelines or programs that in some way relate to the use of recycled materials. For example, the publication *User Guidelines for Waste and By-Product Materials in Pavement Construction* was developed to assist those who have an interest in using or increasing their understanding of the types of waste and by-product materials that may be recovered and used in pavement construction applications. By documenting the potential use of 19 recycled materials in six construction applications, these guidelines, which were produced by the FHWA and published in 1997, are intended to describe the nature of each material, suggest sources for obtaining additional information, and outline the issues that need to be evaluated when considering the use of a particular material. The guidelines are also intended to provide general information on engineering evaluation requirements, environmental issues, and economic considerations in determining the suitability of particular recovered materials in pavement applications. (An electronic version of the guidelines is available at the Web site of the Recycled Materials Resource Center *[www.rmrc.unh.edu/Partners/UserGuide/begin.htm]*.)

Funded by the NCHRP and completed in 1998, the Recycled Materials Information Database was created as a tool that can be used to review and store data on the properties and applications of recycled material and on testing procedures. Reference information is also included. With information on 21 materials, the database is divided into nine main categories and provides the user with both general and detailed engineering and environmental information on each material. Recommended laboratory engineering tests that can be used to assess the suitability of each waste and recycled material for transportation applications are included, along with recommendations for monitoring in-field trials. (Copies of the database may be downloaded from the Recycled Materials Resource Center Web site *[www.rmrc.unh.edu/Resources/UsefulDocuments&Programs/NCHRP/NCHRP.asp]*.)

The *Framework for Evaluating Use of Recycled Materials in the Highway Environment* was recently published by the FHWA to establish a logical and hierarchical evaluation process that all states can use either to develop a beneficial use determination process or to refine an existing process of this type. The purpose of this document is to help reduce barriers to the use of recycled materials and to facilitate the migration of successful practices across state boundaries. Additionally, because the management and regulation of recycled materials use in the highway environment are jurisdictionally the responsibility of a state's department of transportation (DOT) and its environmental protection agency (EPA), a major goal was to work with state DOTs and EPAs to develop a consensus-based approach that would encourage the two agencies to work together in the evaluation process. The process uses a series of stages that can each lead to approval or a beneficial use application from both an engineering and an environmental perspective. It comprises issue definition, data evaluation, laboratory testing, and field tests. The project used an expert technical group to help develop the framework. DOTs and EPAs from Florida, Minnesota, New Hampshire, New Jersey, and New York were involved. (An electronic version of the guidelines is available on the Web site of the Recycled Materials Resource Center *[www.rmrc.unh.edu/Partners/Framework/Start/start.htm]*.)

The report *Environmental Impact of Construction and Repair Materials on Surface and Ground Waters* (NCHRP 25-9) was prepared by the NCHRP after determining whether commonly used construction and repair materials might affect—through the persistence of any toxic leachates—the quality of surface water or groundwater adjacent to highways. A number of widely used waste and by-product materials were included in this evaluation. By developing a model that can be applied to any medium through which the leachates might pass, the report provides users with a tool capable of predicting the potential environmental harm of various waste and by-product materials. (Copies of the report can be obtained from the Transportation Research Board's bookstore *[http://nationalacademies.org/trb/bookstore]* by searching book code NR448.)

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Established in 1998 in close coordination with the FHWA's Pavement Management Coordination Group, the Recycled Materials Resource Center (RMRC) works on the national level to promote the appropriate use of recycled materials in the highway environment. The RMRC forms part of the Environmental Research Group at the University of New Hampshire. It has a unique role in the growing application of recycled materials to highway construction—namely to serve as a catalyst to reduce barriers to the appropriate use of these materials. The center is a culmination of a number of diverse but integrated efforts on the part of the FHWA, other federal and state agencies, and academia to provide a cohesive approach to the complex engineering and environmental issues surrounding the use of recycled materials. The RMRC focuses on both research and outreach activities in carrying out its mission, and its principal clients are state DOTs and EPAs.

In terms of research, the RMRC channels approximately half of its overall budget to a diverse range of projects related to recycling. At present 2 projects have been completed and 11 are in progress nationwide at a number of academic institutions and consulting companies. In addition, with the request for proposals issued by the center in February, three are slated to commence in September. The projects address a range of engineering and environmental issues related to recycling, among them the mitigation of alkali silicate reactions in recycled concrete; environmental weathering of granular waste materials; concrete mixtures with inclusions to improve the sound-absorbing capacity of portland cement concrete pavements; and the development of a risk analysis framework for the beneficial use of secondary materials. Attention is also given to leaching from granular materials used in highway construction during intermittent wetting; the development and preparation of specifications for recycled materials in transportation applications; the determination of the number of revolutions needed for cold-in-place Superpave mixture design using the sequential gyratory compactor; the development of a rational and practical mix design system for full depth reclamation; the fatigue durability of stabilized recycled aggregate base course containing coal fly ash and waste-plastic strip reinforcement; and the development of lightweight synthetic aggregate from coal fly ash and waste plastics.

The RMRC orchestrates numerous activities, the principal and most accessible of which is its Web site *(www.rmrc.unh.edu)*. The site provides a variety of tools, including a client registration feature; an information request feature; virtual demonstration sites; updates on all RMRC-funded research projects; numerous documents and programs; links to pertinent specifications, state DOT programs, literature search engines, and national and international entities; lists of scheduled events; information on funding opportunities; and access to libraries and databases. In addition the center sends out a quarterly electronic newsletter to its clients, keeping them abreast of ongoing and upcoming events related to recycling.

Of particular interest is the center's first specification to be adopted by the American Association of State Highway and Transportation Officials (AASHTO). In December 2000 AASHTO voted to adopt "Glass Cullet Use for Soil Aggregate Base Course" as a new national specification (M-318-01). While currently recognized as a national specification, the document will first appear in the 21st edition of the AASHTO specifications, which is slated for publication this year. This recycling specification was developed by Warren Chesner of Chesner Engineering, in Commack, New York, in conjunction with the AASHTO subcommittee on materials as part of a research project funded by the RMRC. The project is looking at the properties of selected recycled materials and is developing—with the assistance of a technical advisory group made up of representatives of 15 state DOTs—specifications in an AASHTO format for the use of these materials in highway construction.

An upcoming outreach event of note is the international conference Beneficial Use of Recycled Materials in Transportation Applications, which the center is helping to organize. All told, 163 abstracts have been submitted from engineers and researches from 23 different countries. The event will be held in Washington, D.C., November 13–15 (see *[www.rmrc.unh.edu/2001Conf/overview.asp]*).

In September 1999 an FHWA delegation visited Sweden, Denmark, Germany, the Netherlands, and France to review and document innovative policies, programs, and techniques that would help to reduce barriers to the use of recycled materials in U.S. highways. The delegation met with more than 100 representatives from transportation and environment ministries, research organizations, contractors, and material producers involved with recycled materials in those countries. The U.S. delegation discerned a number of factors that have played a role in the success of recycling on highways in Europe, particularly in the Netherlands. The factors fall under the general concept of sustainability within the highway environment. The major components of the sustainability initiatives are the three Es: economics, engineering, and environment. (The final report is available online at *[www.international.fhwa.dot.gov/Pdfs/recycolor.pdf]*.)

The FHWA has established a team to provide leadership, direction, and technical guidance to the transportation community to promote the use of recycled materials in highway environments and to provide technical support and assistance.

As a follow-on to the European visit, a workshop—Partnerships for Sustainability: A New Approach to Highway Materials—was developed to share European advances in recycling in the highway environment with a targeted audience of state DOT materials engineers, state DOT environmental staff members, and state EPA staff members who work on beneficial use. Fifteen states were invited to send representatives to the workshop, and more than 100 people attended. The goals were to showcase recent developments, introduce the Dutch sustainability concept, and encourage state agency personnel to work together on all aspects of using recycled materials on highways. (The workshop is highlighted on the RMRC Web page *[www.rmrc.unh.edu/partner.asp]*, and the final report can be accessed at *[www.rmrc.unh.edu/Partners/finalreport.asp]*.)

The FHWA has established a team to provide leadership, direction, and technical guidance to the transportation community to promote the use of recycled materials in highway environments and to provide technical support and assistance. The team is preparing a white paper that will set forth priority initiatives for recycling, and it is forming partnerships with AASHTO's subcommittees on materials and construction, with the RMRC, and with industry. Members of the team—their FHWA division given in parentheses—include Jason Harrington and Michael Rafalowski (Infrastructure Core Business Unit), Connie Hill (Planning and Environment Core Business Unit), Terry Mitchell and Jack Youtcheff (Research and Development Support Business Unit), Michael Smith (Southern Resource Center), Walter Waidlich (New Hampshire Division), Bryan Cawley (North Dakota Division), and Jim Travis (Texas Division).

A number of state DOTs have established recycling coordinator positions. These positions frequently figure prominently in technology transfer, research coordination, and informational outreach. The DOTs of California, Massachusetts, North Carolina, Pennsylvania, and Texas all have active programs.

MassHighway

Over the past few years, the Massachusetts DOT, MassHighway, has made significant progress on the recycling front. Steps have been taken throughout the department to increase the use of waste and recycled materials in construction projects and everyday activities; to focus on recycled, remanufactured, and environmentally beneficial materials in procurement decisions for offices, stockrooms, facilities, and construction sites; and to promote the recycling of various waste streams. Recycling and environmentally beneficial procurement are becoming part of the routine way of doing business at MassHighway. Although highway performance, safety, and cost are of primary importance, as long as recycled and environmentally beneficial materials and products can fill this bill, they will be considered comparable, if not superior, to virgin alternatives.

Recent projects in Massachusetts include the procurement of recycled antifreeze, re-refined oils, and safety vests manufactured from soft drink bottles that are fully recycled; the acceptance of specifications allowing for the use of recycled plastic offset blocks as a substitute for pressure-treated lumber blocks; and the commencement of a research project to investigate the use of tire shreds beneath a roadway embankment. In addition there are plans to set up trial and demonstration projects involving bio-based lubricants, recycled street sweepings, and noise barriers made of recycled plastic.

In 1999 alone MassHighway was able to recycle more than 10,000 tons (9,000 Mg) of waste, use more than 138,000 tons (125,000 Mg) of reclaimed or recycled materials in construction projects, and spend more than $33 million on materials and products that had a high recycled content or were environmentally beneficial. There is still much to be done. MassHighway will continue to evaluate its many procurement procedures and specifications to remove unnecessary barriers and find new applications for recycled materials and materials that are environmentally beneficial. It will also continue to examine its construction and maintenance operations to find areas where waste can be reduced. Additionally, it will continue to work in coordination with local, state, and national environmental and public works entities to share its experiences and to learn more about the use of recycled and environmentally beneficial materials in highway and roadway construction.

Pennsylvania DOT

PennDOT has developed a strategic recycling program (SRP) as a tool for systematically identifying, evaluating, and implementing opportunities to use recycled materials in transportation and civil engineering work throughout the state. The ultimate objective of the SRP is to realize economic savings and environmental benefits for both PennDOT and the state by recycling, limiting pollution, and continuing various other environmental initiatives.

Five key areas have been targeted by the state to help PennDOT achieve and sustain its mission to increase the use of recycled materials:

1) Research: Continue to evaluate the existing uses of recycled materials and products and conduct research into new uses of recycled materials in transportation and civil engineering work.
2) Specifications: Develop and approve material and use specifications, bidding specifications, and guidelines for the use of recycled materials that confer significant environmental, engineering, or economic benefits.
3) Project development: Identify, promote, and plan projects that use recycled materials that conform to approved or provisional specifications.
4) Communication: Provide information via various media to PennDOT, government agencies, and the public on the performance and applicability of recycled materials in transportation and civil engineering work.
5) Contract bidding: Evaluate construction contract legal bidding requirements and develop innovative ways to enable PennDOT to specify the use of recycled materials in transportation construction and maintenance projects.

North Carolina DOT

Last year NCDOT recycled 2.4 million lb (1.1 million kg) of metal, 1 million lb (450,000 kg) of paper products, and more than 30,000 lb (14,000 kg) of glass and plastic as part of their daily operations. In addition to these efforts, the department continues to seek applications for recycled products in highway construction. Since 1989 the NCDOT has used more than 7 million tires, 50,000 tons (45,000 kg) of glass beads, and 14,000 tons (13,000 kg) of asphalt shingles.

Lyndo Tippett, the state's secretary of transportation, has indicated he will expand the department's environmental efforts. "As a native of rural North Carolina, I know firsthand the value of our state's natural resources," he said. "We must be proactive about finding opportunities that not only protect our environment but also improve it."

One such opportunity is the department's partnership with Habitat for Humanity of Wake County, which won an environmental excellence award from the FHWA this year. In this program, Habitat helps raze houses within the department's rights-of-way that are scheduled for demolition.

Prospective homeowners help demolish the houses, earning credit toward the construction of their new homes. Materials are then stored in Habitat's reuse center and sold to the general public at reduced prices. The department is currently working to develop partnerships with other Habitat chapters throughout the state.

Another initiative is a pilot project with Bion Technologies, of Clayton, North Carolina. Last year the company donated 900 lb (410 kg) of swine waste for use as an alternative to commercial fertilizer. NCDOT roadside environmental engineers are currently working with the company to monitor the effectiveness of this product in test plots of wildflower beds along U.S. 117 south of Goldsboro to see if more widespread use is warranted.

"Our partnerships with Habitat for Humanity and Bion Technologies demonstrate to the public the positive effect that recycling has on our culture as well as our environment," said Tippett. "These efforts also prove that it is possible to have a quality transportation system and a beautiful environment at the same time."

Texas DOT

TxDOT's Road to Recycling initiative represents a mammoth endeavor to use recycled materials in road construction and maintenance projects. The goal of this initiative is to increase the use of recycled materials in road construction when they confer environmental benefits and economic or engineering advantages.

Since 1995 TxDOT has coordinated more than $1 million worth of research to investigate the use of a broad array of recycled materials in road construction, including glass cullet, scrap tires, fly and bottom ash, crushed porcelain toilets, shredded brush, compost, roofing shingles, plastics, RAP, crushed concrete, and industrial wastes. The research has been equally broad in the scope of roadway construction applications studied and has examined road signs, roadway safety devices, embankments, asphalt and concrete pavements, soil erosion control, drainage, vertical moisture barriers, and road bases.

Information on the merits of recycled roadway materials has been disseminated around the world through information showcases, press releases, a video, a Web site, two conferences, and a yearlong publicity campaign.

Since the inception of its recycling program in 1994, TxDOT has spent more than $506 million on "green" products and diverted more than 13 million tons (12 million Mg) of materials from landfills—a diversion equivalent to more than 1,300 lb (590 kg) for every man, woman, and child in Texas. These staggering numbers are for the most part directly attributable to the use of recycled materials in road construction applications.

As part of its continuing efforts to promote the use of materials recovered from solid waste, the U.S. EPA has developed the Comprehensive Procurement Guideline (CPG) program. The institutional purchase of recycled products by government ensures that the materials collected in recycling programs will be used again in the manufacture of new products. Congress authorizes the CPG program under section 6002 of the Resource Conservation and Recovery Act (RCRA). The CPG process designates products that are or can be made with recycled materials. At present for construction products, coal fly ash and ground granulated blast furnace slag are listed for cement and concrete materials, and coal fly ash and foundry sands are listed for flowable fill. Materials are also listed for transportation and landscaping categories. (Additional information is available at *[www.epa.gov/cpg/]*.)

Other Initiatives

Established in the 1990s by the U.S. Department of Energy (DOE), the Industries for the Future Program creates partnerships linking industry, government, and supporting laboratories and institutions to accelerate technology research, development, and deployment. The DOE's Office of Industrial Technologies is implementing the program for nine energy- and waste-intensive industries, namely agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. The program's goal of increasing competitiveness and reducing energy consumption waste involves recycling by-products from these industries. A recent conference hosted by the DOE and the Civil Engineering Research Foundation explored recycling opportunities for these industries and in formulating plans for the future looked at perceived barriers, market needs, and collaborative relationships. (For additional information about the Industries for the Future Program, see *[www.oit.doe.gov/industries.shtml]*.)

Life-cycle analysis (LCA) has become increasingly common in civil engineering construction applications. Indeed, its use is being widely encouraged in addressing America's infrastructure problems. An excellent example of this application is the model BridgeLCC, developed by the National Institute for Standards and Technology for use evaluating high-performance bridges. BridgeLCC (see *[www.bfrl.nist.gov/bridgelcc/]*) is geared toward helping design engineers estimate and compare the life-cycle costs of a new technology—for example, high-performance concrete or fiber-reinforced-polymer (FRP) composites—with those of a conventional technology made with conventional materials. The FHWA has instituted similar models for highway design (see *[www.fhwa.dot.gov/resourcecenters/southern/msmith.htm]*).

There is less experience here in the United States with the application of LCA in deciding whether to use recycled materials or traditional materials in highway work, and this is even more pronounced when environmental burdens or emissions are included in the model. Recent work by the Finnish National Road Administration has resulted in the development of a comprehensive LCA and inventory analysis program. In Finland the production and transport of materials produce the most significant environmental burdens; the activities that consume the most energy are the production of bituminous asphalt and cement and the crushing and transport of materials. The consumption of raw materials and the leaching behavior of recycled materials there were also regarded as being of great significance. A weighted environmental loading assessment for three scenarios (coal fly ash in subbase and stabilized subbase; crushed concrete in base and subbase; and blast furnace slags in base, subbase, and lower subbase) and a traditional construction scenario were conducted in the Finnish study. The use of blast furnace slag, crushed concrete, and coal fly ash in road bases was seen as imposing a lower total environmental loading than the use of coal fly ash in stabilized subbases or the use of traditional pavements using crushed rock. *(continued on page 80)*

The Road to Reuse

(continued from page 71) Obviously, such analytical tools and case studies need to be developed and applied to scenarios here in the United States. However, the Finnish National Road Administration data suggest that in a broader sense there may be additional benefits to using recycled materials when life-cycle material costs are considered in conjunction with the harm to the environment caused by energy production and the processing and transport of materials.

In refining their strategic plans, state DOTs may find it advantageous to consider the role of recycling. In addition, as studies are carried out on proposed transportation projects under the auspices of the National Environmental Policy Act, is it possible that credit might be given for the use of recycled materials, particularly if LCA shows that the materials convey environmental benefits?

The Netherlands probably best typifies the concept of sustainability, and it offers a suitable model for certain states and metropolitan areas here in the United States. The recycling or reuse of secondary materials within the Dutch building industry is commonplace—more than 10 percent of all granular materials used in the building industry are recycled.

The Netherlands is an affluent country with high population densities and limited land resources. The public has elected not to set aside areas for landfills or aggregate mining. This has led to the practice of sustainable development within the building industry, as well as to a subset of that industry: the highway construction industry. The basic premise of the sustainability concept is that material cycles should be closed (recycling involving use, reuse, re-reuse, et cetera) so that there is less outright disposal and less consumption of nonrenewable natural materials. A number of legislative initiatives, including the National Environmental Policy Plan, the Waste Materials Policy, the Soil Protection Policy, the Surface Minerals Policy, and the Construction Industry Policy Declaration, provide the underpinning for sustainable construction.

The Dutch have adopted a market philosophy that regards recycled materials as products rather than waste. This means that the product will exhibit a typical product life cycle in the marketplace. Recycled materials first undergo development before coming into widespread use and maturing. Government and private-sector publicity campaigns and policies support the market. This concept might prove applicable in the United States in states or geographic regions where population densities are high, natural aggregates are scarce, and sources of suitable recycled materials are plentiful.

The Dutch government provides clear and unequivocal engineering and environmental standards for all recycled materials. This is usually achieved through governmental research in support of the standards. Further, public or industry working groups (including contractors) work together to achieve these standards. The producers of recycled materials use certified quality assurance and quality control programs so that their goods can compete against natural materials. The policy is clear, as is the planning and implementation, which enables the producers and contractors to prepare for this new market. The government provides certain economic incentives, such as hefty landfill disposal taxes on materials that can be recycled and modest taxes on the use of natural aggregates. If these aspects are combined, then a mature recycling market can develop over time.

There is a clear need for partnerships linking the private sector, universities, research institutions, government bodies, environmental groups, and the public. This relates to the formulation and coordination of policy, the transfer of information, and making resources available for additional research and development (R&D).

The private sector can play a variety of roles. Those interested in having their by-products considered can make use of the document *Framework for Evaluating Use of Recycled Materials in the Highway Environment* so that they can work with state DOTs and EPAs to develop the necessary data for evaluation. Contractors can explore the use of recycled materials to help meet the requirements of performance bonds. Equipment manufacturers can also play a role by developing technologies that would make it possible to recycle materials on-site for pavements, bridges, and other civil infrastructure, thereby reducing transport costs and associated environmental burdens.

At the state level, it may be appropriate for the DOTs to consider recycling as stand-alone policy or as part and parcel of their strategic plans. PennDOT's SRP may be a starting point in efforts to systematically find, evaluate, and apply recycled materials in transportation and civil engineering work (see *[www.dot.state.pa.us/penndot/bureaus/beq.nsf/srp?OpenPage]*). State DOTs may wish to give credit to recycling strategies during the planning stage of transportation projects, as well as in analyzing alternatives and mitigation measures. In planning transportation projects states could develop checklists that ask questions about recycling choices or options for use, with the responses used in analyzing alternatives and evaluating secondary and cumulative effects. States could use information derived from LCAs as part of their benefits analysis and in information packages prepared for public hearings and for obtaining permits.

A more formal relationship between AASHTO and the Association of State and Territorial Solid Waste Management Officials is definitely worth exploring as this can help pave the way for relationships at the state level. State DOTs and EPAs might consider adopting beneficial use evaluation frameworks similar to successful ones already in place or to the generic one offered by the *Framework for Evaluating Use of Recycled Materials in the Highway Environment*.

A lowering of the barriers encountered in transferring technologies from one jurisdiction to another across state lines would be a great benefit. Fortunately, the Environmental Council of States (see *[www.sso.org/ecos/]*) has two programs related to reciprocity. The group called Interstate Technology Regulatory Cooperation (ITRC) is a state-led national coalition dedicated to achieving better environmental protection through the use of innovative technologies. The ITRC *(www.itrcweb.org/)* is exploring general reciprocity arrangements involving 37 state members. Six states (California, Illinois, Massachusetts, New Jersey, Pennsylvania, and Virginia), under the Environmental Technology Acceptance and Reciprocity Partnership (e.TARP) are exploring reciprocity arrangements of a more formal type, including one for beneficial use determinations.

One recommendation that was strongly emphasized in the final report on the workshop Partnerships for Sustainability: A New Approach to Highway Materials Partnerships for Sustainability is that state DOTs establish recycling coordinator positions for the purposes of technology transfer, research coordination, and outreach.

At the federal level, partnerships linking the private sector, the FHWA, the U.S. EPA, the DOE, and other competent agencies are encouraged. Two obvious examples might be coordinating the U.S. EPA's CPG program with the DOE's Industries for the Future Program. Funneling beneficial use applications and adopted specifications to the CPG program also makes sense. There may be an opportunity to establish a leadership council that could coordinate communication and policy and improve intergovernmental approaches. Shared funding should be considered for lowering barriers between jurisdictions, demonstrating the use of innovative materials, and applying LCA analysis. A recent report on the role to be played by the National Science Foundation in meeting environmental science and engineering needs in the 21st century named industrial ecology (including product and process LCA) as a program needing enhancement. This topic should include recycling for infrastructure improvement.

Congress is considering a number of bills that could serve as vehicles in promoting recycling. The reauthorization of the next highway bill in 2003 provides an excellent opportunity to further promote appropriate recycling, partnerships, technology transfer, and R&D. Making funds available to allow two or more states to carry out joint demonstration projects would go a long way toward reducing barriers. Congress can also examine the information recently provided by the U.S. EPA's Science Advisory Board on overcoming barriers to waste utilization (see *[www.epa.gov/science1/eeccm06.pdf]*). One of the board's most important recommendations—interpreting key definitions so that wastes could be beneficially used and not be inappropriately labeled as hazardous—would help with the confusion at the federal level about the need for a third category of by-product. Material that qualifies for inclusion in this category would not be labeled as solid waste or as hazardous waste; rather it would be suitable for beneficial reuse in an open market. The reauthorization of the RCRA may provide a suitable opportunity for this change. ■

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